MEEHANITE SPECIFICATION HANDBOOK 2013

ver: 09 07 2013

Meehanite Worldwide CORPORATION

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* This MEEHANITE Type was introduced in the UK to accommodate a grade found in the original British Standard.

Materials in blue represent the North American, Taiwan and sometimes South African MEEHANITE Types [in Imperial units]

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SYMBOLS, PROPERTIES AND THEIR UNITS

Symbols for mechanical and physical properties used in this handbook alongside the most commonly used units are given in the Table below.

Property	Symbol	Units	Units
Tensile strength [min]	R_m	N/mm^2	lbf/in^2
0.1% proof stress	$R_{p0.1}$	N/mm^2	lbf/in^2
0.2% proof stress	$R_{p0.2}$		
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	lbf/in^2
0.2% proof stress in compression	$\sigma_{c0.2}$	N/mm^2	lbf/in^2
Elongation	A_5	%	%
Tensile strength at -40°C[2]	$R_{m\ [-40]}$	N/mm^2	lbf/in^2
0.2% Proof stress at -40°C[2]	$R_{p0.2\ [-40]}$	N/mm^2	lbf/in^2
Elongation at -40°C[2]	$A_{5\ [-40]}$	%	%
Limit of proportionality	$R_{p0.01}$	N/mm^2	lbf/in^2
Bending strength	σ_B	N/mm^2	lbf/in^2
Torsional strength	T_B	N/mm^2	lbf/in^2
Modulus of elasticity[3]	E	kN/mm^2	lbf/in^2
Modulus of rigidity	G	N/mm^2	lbf/in^2
Modulus of rupture	R	N/mm^2	lbf/in^2
Poissons ratio	v		
Fatigue limit[4] – **Alternate bending**	σ_{bW}	N/mm^2	lbf/in^2
Push-pull	σ_{tcW}	N/mm^2	lbf/in^2
Fatigue strength	σ_D	N/mm^2	lbf/in^2
Impact strength [notched] +20°C	A_n	J	ft.lbf
Impact strength [unnotched] +20°C	A_{un}	J	ft.lbf
Impact strength [notched] -40°C	$A_{n\ [-40]}$	J	ft.lbf
Specific heat	c_p	J/g.K	cal/g.°C
Thermal expansion	α_l	1/10^6.K	1/10^6.°F
Thermal diffusivity	a	mm^2/s	in^2/s
Thermal conductivity	λ	W/m.K	cal/g.s.°C

INTRODUCTION

MEEHANITE METAL is the registered trademark of a range of cast irons produced under carefully controlled conditions to precise internationally recognised specifications. These cast irons can be classified into three broad categories:

- high duty flake [lamella] graphite or grey [gray] irons
- high duty “nodular”, SG or spheroidal graphite iron, or ductile iron, and
- a group consisting of special MEEHANITE Types for applications requiring resistance to heat, wear and corrosion.

Produced to MEEHANITE quality standards, such castings can only be supplied by foundries operating under MEEHANITE supervision. Buyers of MEEHANITE castings should ensure that they are purchasing from a licensed producer.

This Handbook has been prepared to assist designers, engineers and purchasing officers in choosing the most suitable Type of MEEHANITE for any particular application. Careful reference should be made to the physical and mechanical properties which are listed in order to ensure that the correct selection is made.

This new version of the MEEHANITE Specification Handbook is the first to incorporate both the International MEEHANITE [Europe and Asia] and MEEHANITE Worldwide [US] versions; consequently, both imperial and metric property values are included.

The actual values in previous International MEEHANITE Handbooks were expressed in imperial units so to clarify the situation in the present Handbook MEEHANITE Types have been provided with a numerical suffix, so MEEHANITE Type **GA** now reads MEEHANITE Type **GA350** [representing 350N/mm^2]. Correspondingly, MEEHANITE **GA** in the previous US Version was provided with the suffix 50 [representing 50000lb/in^2]. Both numbers indicate the minimum tensile strength specified for the particular MEEHANITE Type.

In addition, several extra MEEHANITE Types have been included in order to match the requirements of certain other international specifications. The user should understand that these property values have been obtained from properly prepared, fully representative, standard test specimens, taken from either separately cast test bars, cast-on test bars or from actual casting sections.

In the case of flake graphite irons the separately cast test bars are usually 30mm diameter. For nodular irons, it is usual to cast keel blocks from which a 25 mm diameter test bar is taken. Intended users are advised to utilise the combined experience of the MEEHANITE Organisation and consult on specification and casting design with a MEEHANITE foundry at the earliest possible stage in product development.

The metallurgy of MEEHANITE

There are two basic materials covered by the majority of MEEHANITE specifications, the flake [lamella] graphite or grey [gray] irons and the “nodular”, SG or spheroidal graphite iron, or ductile iron Types.

Flake [lamella] graphite or grey [gray] irons

The flake graphite Types were the result of the original MEEHANITE patents stretching back as far as the mid 1920’s. These are high duty cast irons produced by careful selection of the charge materials melted in a furnace to produce a liquid iron of a known constitutional value. This molten metal is subsequently processed by controlled inoculation; that is, the liquid iron with a known degree of undercooling is seeded with a predetermined amount of inoculating material to realise a definite structure, for any given MEEHANITE Type, related to cooling rate which is dependent upon casting section.

This means that the chemical composition of MEEHANITE metal is merely incidental to the cast structure. The object of such processing techniques is the production of microstructures in the material which generally consist of short, stubby graphite flakes in a solely pearlitic matrix and the absence of such undesirable micro-constituents such as iron phosphide and cementite. Although, the latter constituent will be found in certain heat and wear resisting Types so as to ensure a high degree of resistance to heat or abrasion.

In the higher strength flake iron graphite Types, ferrite, a soft, low strength constituent is absent; it is present, however, in the matrix, in relatively small amounts, in Types **GE200**/**GE30** and **GF150**/**GF20**.

As far as the castings are concerned, the result is a uniform, tight, close-grained structure throughout the cast section, absence of open grain in the centre of heavy sections and freedom from hard, chilled edges and corners. All these factors make for easy, consistent machining and ensure that the design parameters adopted by the designer are met in the casting.

“Nodular”, SG or spheroidal graphite iron, or ductile iron

The nodular graphite Types of MEEHANITE were developed in the 1950’s and a number of processes were patented for their manufacture. Again, careful material selection and process control are the keynotes for the production of the spectrum of MEEHANITE nodular iron castings to a range of specifications.

A low initial sulphur level in the molten metal combined with a well-proven nodularisation treatment provides the necessary assurance to designers and buyers of MEEHANITE nodular iron castings. In this regard, the MEEAHNITE Organisation developed, over the years, a number of extremely satisfactory patented processing techniques such as the “Trigger”, “Osmose”, “Inmold”, “Flotret” and “IMCONOD” Processes. Each technique has a place in the foundry and the use of any particular method depends essentially on the nature of the production being undertaken. As to the resultant material, with a purely ferritic matrix, elongation values of up to 25% can be obtained, with a tensile strength of 350N/mm^2 [~50000lbf/in^2].

If a proportion of the ferrite in the matrix is replaced by pearlite then the tensile strength increases and the ductility, as measured by the elongation, decreases. With only pearlite in the microstructure tensile strength values of up to 800N/mm^2 [115000lbf/in^2] are possible in the as-cast condition. In heat treated castings containing sorbo-pearlite strengths in excess of 800N/mm^2 [115000lbf/in^2] can be achieved. The material remains relatively tough at these tensile strength values with elongation levels of 2% to 3%. The pearlitic structure of the matrix can be converted further into bainite or martensite by more severe heat treatments, with a further increase in tensile strength or hardness.

The close metallurgical control exercised by MEEHANITE licensee foundries provides designers and engineers with a dependable and uniform material from which the maximum benefits of good casting design may be utilised in order to achieve adequate safety factors, the elimination of unnecessary weight and consistent machinability.

MEEHANITE development

MEEHANITE is unique amongst the foundry organisations in being able to conduct and co-ordinate development programmes within foundries in Europe, US and Asia. The objectives of this co-ordinated approach are to:

- promote scientific development and carry out organised investigations into foundry, metallurgical and engineering problems.
- improve the processes for the manufacture of castings.
- maintain a high standard of uniform quality and dependability of product.
- gather and disseminate information so that the progress made is cumulative.
- render an engineering service to the casting user.

Foundries throughout the world with well equipped laboratories and highly trained technicians work in collaboration with metallurgists and engineers from MEEHANITE to continue material development. This continuous group effort behind MEEHANITE castings eliminates guesswork and assures the casting buyer.

Many technical bulletins and articles on the use of MEEHANITE Metal are available, references to which will be made in the following pages.

THE MEEHANITE Process system of control

The MEEHANITE Process may be seen in operation throughout the world. Many aspects of the process remain protected by patents related, amongst others, to melting equipment and procedures which are the heart of the MEEHANITE Process.

The constitution of the molten iron in relation to the size and dimensions of the castings and the physical properties required is measurable, a factor which was formerly an impossibility for the foundryman.

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The application of statistical principles to test data places the MEEHANITE system on a quantitative basis and personal judgement in assessing the standard of process control is eliminated. Casting reliability is measured, not by the maximum tensile or other property test value the foundry can supply, but by how uniformly the strength values are maintained within set standards.

Standardisation of all foundry operations is the cornerstone of the MEEHANITE foundry. Standard methods are applied to pouring basins [bushes] and pouring practice, ingates, feeders [risers] and slag traps as well as to moulding sands and mould and core making practices.

Inspection is applied to all key operations and where possible instruments are used to check their accuracy. For example, thermal analysis and spectrographic analysis equipment as well as dip pyrometers for chemical analysis and temperature control; jigs for accurate core location leading to strict casting dimensional control.

Close inspection of the finished casting is the final link in the chain and MEEHANITE was the prime mover in using ultrasound for the non-destructive testing of nodular iron castings. This aids the foundry and assures the buyer by giving early warning of defects and assists in preventing the shipment of substandard castings to the customer. It is here that the casting buyer gains maximum benefit from the MEEHANITE Control System.

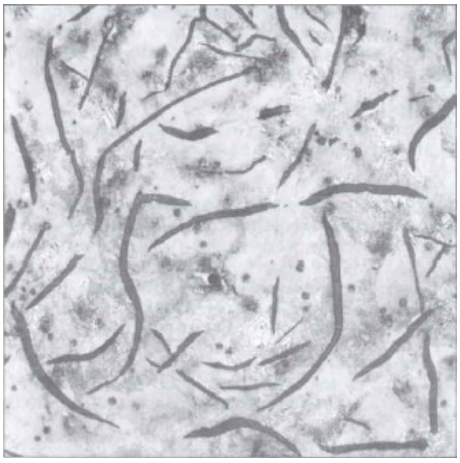
Material applications

More information on the application of the materials in this Handbook may be found by referring to the relevant MEEHANITE brochures on casting applications; namely:

MEEHANITE nodular iron
MEEHANITE ADI
MEEHANITE pumps & valves
MEEHANITE castings from polystyrene patterns
MEEHANITE castings replacing fabrications
ALMANITE New MEEHANITE abrasion-resistant metals

Post production treatments

Heat treatment of MEEHANITE castings
Welding of MEEHANITE castings



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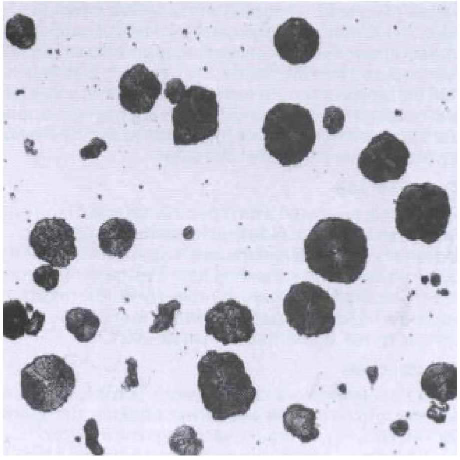

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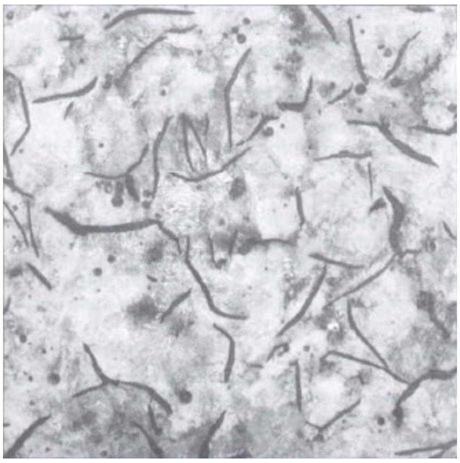

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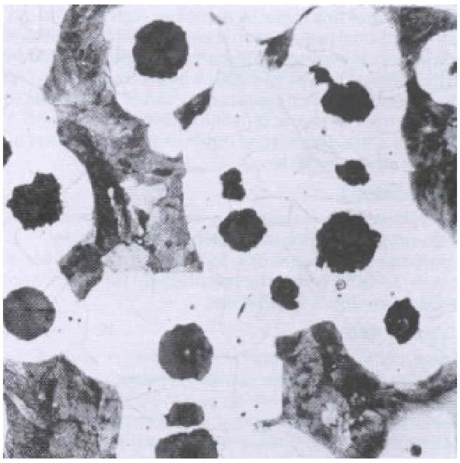
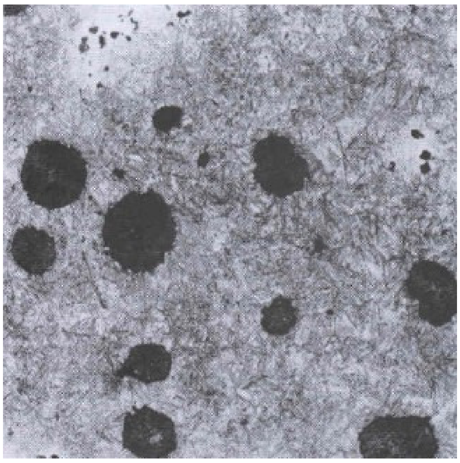


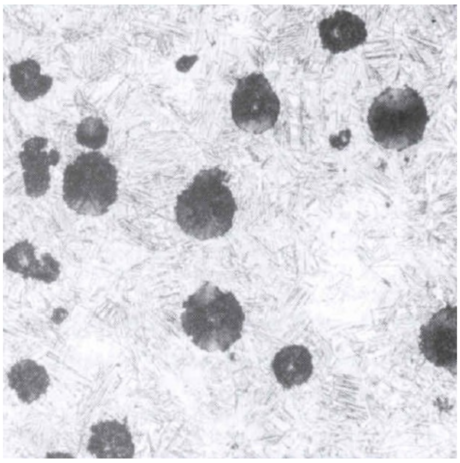
MEEHANITE Type SFP500

MEEHANITE Type GA350

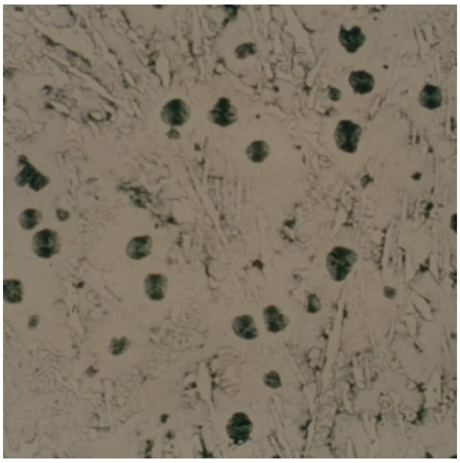


MEEHANITE Type SH1000

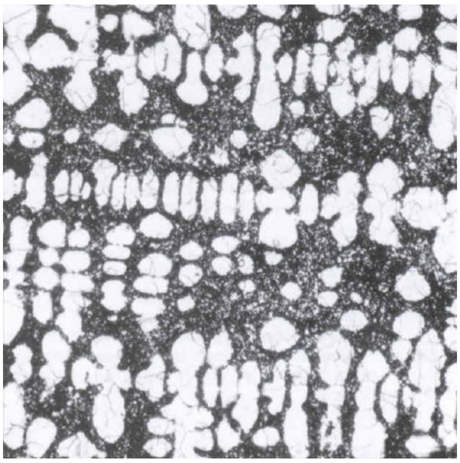
Magnification x100.



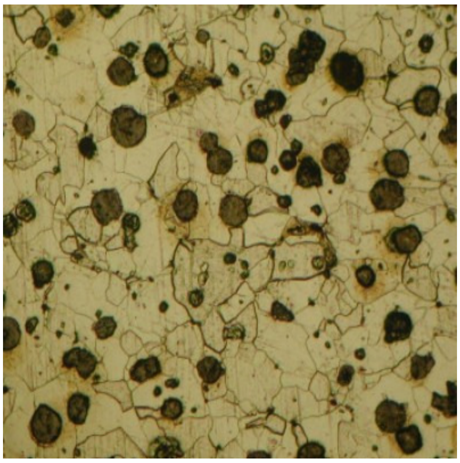
MEEHANITE Type ADI



MEEHANITE Type WSH_1



MEEHANITE Type UC



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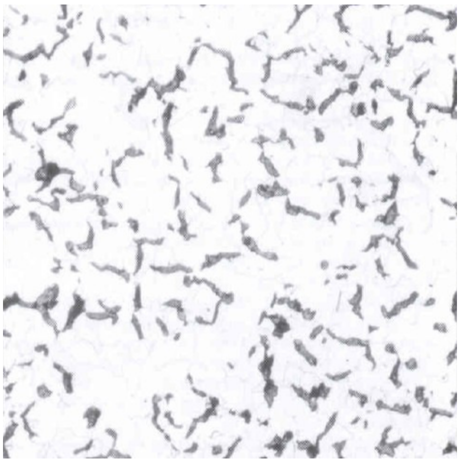

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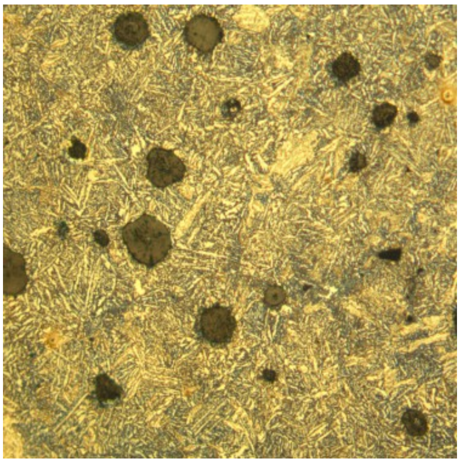


MEEHANITE Type SHBP1250

Magnification x100.

MEEHANITE FLAKE GRAPHITE IRON CASTINGS FOR GENERAL ENGINEERING

The general engineering Types of high duty flake iron [G] are subdivided according to the tensile strength because this is a convenient method for comparison with national and international standards. However, the engineer may be more interested in other specific properties other than tensile strength and they may be found in the subsidiary tables relating to each material.

The tensile strength values given are the minimum, but it should be realised that general engineering Types of MEEHANITE may be produced to any specific agreed minimum be it between two designated Types or not. In short, all properties show a gradual transition from high to low tensile strength values and are separated into various types solely for the purpose of writing a specification.

The first principle of production of high duty flake [lamella] graphite or grey [gray] MEEHANITE castings is that the chemical composition of the iron in only complementary to the achievement of a definite metal structure. The other more important factor is mass; that is, casting section thickness with its associated effect on cooling rate.

For a normal cast iron, slow cooling, as experienced in thick sections, produces a coarse open-grained, low strength structure, whereas fast cooling, as experienced in thin sections, results in a hard brittle, unmachinable structure. Thus, in MEEHANITE foundry practice great emphasis is placed upon the structure of the metal and the properties required are related to the thickness of the casting.

For any particular Type of MEEHANITE, a suitable charge mix is melted to obtain a base iron with a known constitution or chilling characteristic. In metallurgical terms, this material can be considered as undercooled; that is, it would solidify in the metastable condition as a hard white iron. While in the molten condition a calculated quantity of inoculant is added to this iron in order to modify or seed it to a predetermined degree. This inoculation process allows the metal to solidify in a grey, readily machinable form, possessing much enhanced mechanical and physical characteristics.

Outstanding among these physical characteristics is that MEEHANITE is much less sensitive to variations in casting section in comparison with normal grey iron. Open grain and chilled edges are avoided and soundness, solidity, ease and consistency of machining are achieved. It is these factors which make MEEHAITE superior to ordinary grey cast iron.

Material specification

This is the most versatile of all the MEEHANITE general engineering Type of flake irons. This low alloyed Type possesses a dense fine grained pearlitic structure and exhibits exceptionally high physical properties including good impact strength, shock resistance and pressure tightness. In certain cases the material can replace steel forgings and castings, high tensile bronzes and other non-ferrous metals.

Its machinability is good in casting sections over 40mm [1½"] but is a little more difficult with wall sections between 20mm [¾"] to 40mm [1½"].

Type **GM400/GM60** responds to heat treatment; its hardenability being excellent with little or no resultant distortion. The surface of **GM400/GM60** castings can be hardened by chilling, flame, induction or laser heat treatment.

Applications

Heavy service gears, sheaves, cable drums, crane wheels, kiln tyres and rollers, stamping, drawing, pressing, blanking and heading dies; lathe spindles, chucks, ball mill heads and gudgeons, hydraulic cylinders and rams; crankshafts, high pressure chambers, cylinder heads and valve bodies; straightening, bending and forming rolls.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1. All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2. Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3. The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4. Wöhler rotating bending fatigue test using an un-notched test bar
5. Un-notched Charpy test piece [10mm square]
6. Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7. Depends upon design, size of casting and heat treatment, if any, applied

MEEHANITE Types in blue represent material specifications in North America and Taiwan [in Imperial units].

MEEHANITE Type GM400/GM60

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	400N/mm^2	1380N/mm^2	0.30 – 0.80	210 – 280
Imperial equivalents	*25.9tonf/in^2*	*89.4tonf/in^2*		
	~58000lbf/in^2	*~200150lbf/in^2*		
US	60000lbf/in^2	200000lbf/in^2	0.30 – 0.80	210 – 280
Metric equivalents	*~414N/mm^2*	~1350N/mm^2		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

		Symbol	Units	Value	Units	Value
0.1% proof stress[1]		$R_{p0.1}$	N/mm^2	>260	lbf/in^2	>37700
0.1% proof stress in compression		$\sigma_{c0.1}$	N/mm^2	520	lbf/in^2	75400
Limit of proportionality[1]		$R_{p0.01}$	N/mm^2	170	lbf/in^2	24600
Bending strength		σ_B	N/mm^2	590	lbf/in^2	85500
Torsional strength		T_B	N/mm^2	460	lbf/in^2	66700
Modulus of elasticity[3]		E	kN/mm^2	145	lbf/in^2	21.03 x 10^6
Modulus of rigidity		G	N/mm^2	0.065 x 10^6	lbf/in^2	9.4 x 10^6
Modulus of rupture		R	N/mm^2	640	lbf/in^2	92800
Poisson's ratio		v		0.33		0.33
Fatigue limit[4]	Rotating bending	σ_{bW}	N/mm^2	150 - 170	lbf/in^2	21700 - 24600
	Push-pull	σ_{tcW}	N/mm^2	95	lbf/in^2	13800
Fatigue strength		σ_D	N/mm^2	170	lbf/in^2	24600
Impact strength, Charpy[5]		A_{un}	J	10.5	ft lbf	8
Fracture toughness		K_{1c}	N/mm$^{3/2}$	-	lbf/in$^{3/2}$	-
Damping capacity[6]			%	20	%	20
Density		ρ	kg/dm^3	7.34	lb/in^3	0.264
Specific heat	20 to 200°C 20 to 600°C	c	J/kg.K	-	cal/g.°C	-
Coefficient of thermal expansion -100 to +20°C 20 to 200°C 20 to 400°C		α_l	1/10^6.K	 9.54 11.52	1/10^6.°F	 5.30 6.40
Thermal conductivity	100°C 200°C 300°C 400°C 500°C	λ	W/m.K	44.0 43.0 42.0 41.0 40.0	Btu.in/ft^2.h.°F	323 316 308 301 294
Electrical resistivity		ε	Ω mm^2/m	0.64	Ω.in	25.2 x 10^{-6}
Coercive force		H_o	A/m	720	Oe	9.05
Maximum magnetic permeability		μ	μH/m	330		
Hysteresis loss [B=1T]			J/m^3	3000		
Machinability rating				50		50
Patternmaker's contraction[7]		s	%	1.1-1.5		1.1-1.5
Solid contraction			mm/m	13 - 16	in/ft	$^5/_{32}$ - $^6/_{32}$

MEEHANITE Type GM400/GM60

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	15 - 20	-	lbf/in^2	$^{5}/_{8}$" – $^{3}/_{4}$"	-
			20 - 40	370		**$^{3}/_{4}$" – $1^{5}/_{8}$"**	53660
			40 - 80	350		**$1^{5}/_{8}$" – $3^{1}/_{4}$"**	50760
			80 - 150	325		**$3^{1}/_{4}$" – $5^{7}/_{8}$"**	47140
			150 - 300	300		**$5^{7}/_{8}$" – $11^{3}/_{4}$"**	43510

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
15 - 20	390	285	$^{5}/_{8}$" – $^{3}/_{4}$"	56560	285
20 - 40	350	270	**$^{3}/_{4}$" – $1^{5}/_{8}$"**	50760	270
40 - 80	315	250	**$1^{5}/_{8}$" – $3^{1}/_{4}$"**	45680	250
80 - 150	280	235	**$3^{1}/_{4}$" – $5^{7}/_{8}$"**	40610	235
150 - 300	255	225	**$5^{7}/_{8}$" – $11^{3}/_{4}$"**	36980	225

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	20mm [$^{3}/_{4}$"]

MEEHANITE Type GA350/GA50

Material specification

This is a general utility iron combining high strength, toughness, wear resistance and machinability. The pearlitic matrix structure of this Type makes the material particularly suitable for heavy castings with wall sections up to 500mm [~20”]. Castings made from this grade of material machine to a very high finish.

The material responds well to heat treatment and has good hardenability and may be surface hardened or hardened locally using flame, induction or laser heat treatment.

Type **GA350**/**GA50** is used in a majority of cases where good, machinable, high strength iron is required, particularly in heavy sections where it provides soundness and solidity.

Applications

Heavy machine tool beds, saddles, racks and chucks, press and drawing cast to form dies, bolsters, compressor and diesel engine cylinders and liners, high speed gearing, flywheels, cam shafts, crank shafts

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type GA350/GA50

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	350N/mm^2	1240N/mm^2	0.30 – 0.80	210 – 250
Imperial equivalents	*22.7tonf/in^2*	*80.3tonf/in^2*		
	~50800lbf/in^2	*~180000lbf/in^2*		
US	50000lbf/in^2	180000lbf/in^2	0.30 – 0.80	210 – 250
Metric equivalents	*~345N/mm^2*	~1240N/mm^2		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
0.1% proof stress[1]	$R_{p0.1}$	N/mm^2	228-285	lbf/in^2	33000-41330
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	455	lbf/in^2	66000
Limit of proportionality[1]	$R_{p0.01}$	N/mm^2	140	lbf/in^2	20000
Bending strength	σ_B	N/mm^2	490	lbf/in^2	71000
Torsional strength	T_B	N/mm^2	400	lbf/in^2	58000
Modulus of elasticity[3]	E	kN/mm^2	140	lbf/in^2	20.30 x 10^6
Modulus of rigidity	G	N/mm^2	0.060 x 10^6	lbf/in^2	8.75 x 10^6
Modulus of rupture	R	N/mm^2	620	lbf/in^2	90000
Poisson's ratio	v		0.32		0.32
Fatigue limit[4] – **Rotating bending**	σ_{bW}	N/mm^2	145	lbf/in^2	21000
Fatigue limit[4] – **Push-pull**	σ_{tcW}	N/mm^2	85	lbf/in^2	12300
Fatigue strength	σ_D	N/mm^2	150	lbf/in^2	22000
Impact strength, Charpy[5]	A_{un}	J	9.5	ft lab	7.2
Fracture toughness	K_{1c}	N/mm$^{3/2}$	650	lbf/in$^{3/2}$	18700
Damping capacity[6]		%	22	%	22
Density	ρ	kg/dm^3	7.31	lb/in^3	0.264
Specific heat 20 to 200°C **20 to 600°C**	c	J/chg.	-	cal/go	-
Coefficient of thermal expansion **-100 to +20°C** **20 to 200°C** **20 to 400°C**	α_l	1/10^6.K	 9.63 11.70	1/10^6.°F	 5.35 6.50
Thermal conductivity 100°C **200°C** **300°C** **400°C** **500°C**	λ	W/m.K	45.5 44.5 43.5 42.0 41.5	Btu.in/ft^2.h.°F	334 327 319 308 305
Electrical resistivity	ε	Ω mm^2/m	0.67	Ω in^2/in	26.3 x 10^{-6}
Coercive force	H_o	A/m	700	Oe	8.80
Maximum magnetic permeability	μ	μH/m	316		
Hysteresis loss [B=1T]		J/m^3	2930		
Machinability rating			48		48
Patternmaker's contraction[7]	s	%	1.0-1.4		1.0-1.4
Solid contraction		mm/m	13 - 16	in/ft	$^1/_8$ - $^5/_{32}$

MEEHANITE Type GA350/GA50

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	10 - 20	-	lbf/in^2	3/8" – 3/4"	-
			20 - 40	320		**3/4" – 1 5/8"**	46410
			40 - 80	300		**1 5/8" – 3 1/4"**	43510
			80 - 150	275		**3 1/4" – 5 7/8"**	39880
			150 - 300	250		**5 7/8" – 11 3/4"**	36260

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
10 - 20	340	275	3/8" – 3/4"	49310	275
20 - 40	310	260	**3/4" – 1 5/8"**	44960	260
40 - 80	275	240	**1 5/8" – 3 1/4"**	39880	240
80 - 150	250	225	**3 1/4" – 5 7/8"**	36260	225
150 - 300	225	215	**5 7/8" – 11 3/4"**	32630	215

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	20mm [3/4"]

Material specification

This is another general utility iron combining good tensile, impact and wear resisting properties together with high damping capacity. The material provides good machinability in components with wall sections in excess of 10mm [~$^3/_8$"].

The pearlitic matrix guarantees excellent hardenability; for example, in machine tool slideways. Its low sensitivity to wall thickness makes it ideal for the production of pressure tight housings of complicated design.

Applications

Machine tool parts, drive housings, large pump and turbine housings, diesel engine parts, large gears and flywheels, hydraulic housings and valves, radiation shielding in nuclear reactors.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

MEEHANITE Type GB300

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	300N/mm^2	1100N/mm^2	0.30 – 0.80	200 – 240
Imperial equivalents	*19.4tonf/in^2*	*71.2tonf/in^2*		
	~43500lbf/in^2	*~160000lbf/in^2*		
US	-	-	-	-
Metric equivalents	-	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

		Symbol	Units	Value	Units	Value
0.1% proof stress[1]		$R_{p0.1}$	N/mm^2	195-260	lbf/in^2	28300-37700
0.1% proof stress in compression		$\sigma_{c0.1}$	N/mm^2	390	lbf/in^2	56560
Limit of proportionality[1]		$R_{p0.01}$	N/mm^2	115	lbf/in^2	16500
Bending strength		σ_B	N/mm^2	390	lbf/in^2	56560
Torsional strength		T_B	N/mm^2	345	lbf/in^2	50000
Modulus of elasticity[3]		E	kN/mm^2	135	lbf/in^2	19.58 x 10^6
Modulus of rigidity		G	N/mm^2	0.055 x 10^6	lbf/in^2	7.9 x 10^6
Modulus of rupture		R	N/mm^2	580	lbf/in^2	85000
Poissons ratio		v		0.31		0.31
Fatigue limit[4]	**Rotating bending**	σ_{bW}	N/mm^2	140	lbf/in^2	20300
	Push-pull	σ_{tcW}	N/mm^2	75	lbf/in^2	10900
Fatigue strength		σ_D	N/mm^2	130	lbf/in^2	19000
Impact strength, Charpy[5]		A_{un}	J	7.2	ft lbf	5.5
Fracture toughness		K_{1c}	N/mm$^{3/2}$	560	lbf/in$^{3/2}$	16100
Damping capacity[6]			%	22	%	22
Density		ρ	kg/dm^3	7.25	lb/in^3	0.261
Specific heat	**20 to 200°C** **20 to 600°C**	c	J/kg.K	-	cal/g.°C	-
Coefficient of thermal expansion	**-100 to +20°C**	α_l	1/10^6.K		1/10^6.°F	
	20 to 200°C			10.08		5.60
	20 to 400°C			12.00		6.67
Thermal conductivity	**100°C**	λ	W/m.K	47.5	Btu.in/ft^2.h.°F	349
	200°C			46.0		338
	300°C			45.0		330
	400°C			44.0		323
	500°C			43.0		316
Electrical resistivity		ε	Ω mm^2/m	0.70	Ω in^2/in	27.5 x 10^{-6}
Coercive force		H_o	A/m	675	Oe	8.48
Maximum magnetic permeability		μ	μH/m	300		
Hysteresis loss [B=1T]			J/m^3	2860		
Machinability rating				47.5		47.5
Patternmaker's contraction[7]		s	%	1.0-1.4		1.0-1.4
Solid contraction			mm/m	13 - 16	in/ft	$^1/_8$ - $^5/_{32}$

MEEHANITE Type GB300

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	10 - 20	-	lbf/in^2	$^{3}/_{8}$" – $^{3}/_{4}$"	-
			20 - 40	280		**$^{3}/_{4}$" – 1$^{5}/_{8}$"**	40610
			40 - 80	250		**1$^{5}/_{8}$" – 3$^{1}/_{4}$"**	36260
			80 - 150	230		**3$^{1}/_{4}$" – 5$^{7}/_{8}$"**	33360
			150 - 300	210		**5$^{7}/_{8}$" – 11$^{3}/_{4}$"**	30460

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
10 - 20	290	260	$^{3}/_{8}$" – $^{3}/_{4}$"	42060	260
20 - 40	265	240	**$^{3}/_{4}$" – 1$^{5}/_{8}$"**	38430	240
40 - 80	235	230	**1$^{5}/_{8}$" – 3$^{1}/_{4}$"**	34080	230
80 - 150	210	215	**3$^{1}/_{4}$" – 5$^{7}/_{8}$"**	30460	215
150 - 300	190	205	**5$^{7}/_{8}$" – 11$^{3}/_{4}$"**	27560	205

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	10mm [$^{3}/_{8}$"]

MEEHANITE Type GC275*/GC40

Material specification

A dense, easily machinable iron having a fine, close grained structure ideal for finishing cuts; this material is recommended for a wide variety of high quality castings and high pressure work.

This material finds general use on account of its useful combination of good all round properties with adaptability to large and small quantity production.

Applications

Excellent for use in machine tool beds, headstocks, tables, press frames, bedplates, crankcases, condenser bodies, cams, pistons, piston rings, cylinders, pulleys, propellers, hydraulic valves, etc.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

* This Type of MEEHANITE has been retained as it corresponds to a grade of iron which was very popular in Great Britain prior to metrication and features on many drawings produced during that period.

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type GC275*/GC40

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	275N/mm^2	1035N/mm^2	0.30 – 0.80	185 – 225
Imperial equivalents	*17.8tonf/in^2*	*67.0tonf/in^2*		
	~39900lbf/in^2	*~150000lbf/in^2*		
US	40000lbf/in^2	150000lbf/in^2	0.30 – 0.80	185 – 225
Metric equivalents	*~275N/mm^2*	~1035N/mm^2		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
0.1% proof stress[1]	$R_{p0.1}$	N/mm^2	180-244	lbf/in^2	26100-35300
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	358	lbf/in^2	51900
Limit of proportionality[1]	$R_{p0.01}$	N/mm^2	100	lbf/in^2	14500
Bending strength	σ_B	N/mm^2	365	lbf/in^2	52900
Torsional strength	T_B	N/mm^2	318	lbf/in^2	46100
Modulus of elasticity[3]	E	kN/mm^2	130	lbf/in^2	18 90 x 10^6
Modulus of rigidity	G	N/mm^2	0.050 x 10^6	lbf/in^2	7.25 x 10^6
Modulus of rupture	R	N/mm^2	550	lbf/in^2	80000
Poissons ratio	v		0.30		0.30
Fatigue limit[4] – **Rotating bending**	σ_{bW}	N/mm^2	130	lbf/in^2	18900
Fatigue limit[4] – **Push-pull**	σ_{tcW}	N/mm^2	67	lbf/in^2	9700
Fatigue strength	σ_D	N/mm^2	120	lbf/in^2	17400
Impact strength, Charpy[5]	A_{un}	J	5.9	ft lbf	4.5
Fracture toughness	K_{1c}	N/mm$^{3/2}$	520	lbf/in$^{3/2}$	14970
Damping capacity[6]		%	27	%	27
Density	ρ	kg/dm^3	7.25	lb/in^3	0.262
Specific heat **20 to 200°C** **20 to 600°C**	c	J/kg.K	-	cal/g.°C	-
Coefficient of thermal expansion	α_l	1/10^6.K		1/10^6.°F	
-100 to +20°C					
20 to 200°C			10.35		5.75
20 to 400°C			12.06		6.70
Thermal conductivity **100°C**	λ	W/m.K	48.0	Btu.in/ft^2.h.°F	352
200°C			46.5		341
300°C			45.5		334
400°C			44.5		327
500°C			43.5		319
Electrical resistivity	ε	Ω mm^2/m	0.72	Ω in^2/in	28.3 x 10^{-6}
Coercive force	H_o	A/m	650	Oe	8.17
Maximum magnetic permeability	μ	μH/m	283		
Hysteresis loss [B=1T]		J/m^3	2785		
Machinability rating			47		47
Patternmaker's contraction[7]	s	%	0.9-1.3		0.9-1.3
Solid contraction		mm/m	11 - 16	in/ft	$^7/_{64}$ - $^5/_{32}$

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	10 - 20	-	lbf/in^2	$^3/_8$" – $^3/_4$"	-
			20 - 40	280		**$^3/_4$" – 1$^5/_8$"**	40620
			40 - 80	250		**1$^5/_8$" – 3$^1/_4$"**	36260
			80 - 150	230		**3$^1/_4$" – 5$^7/_8$"**	33360
			150 - 300	210		**5$^7/_8$" – 11$^3/_4$"**	30460

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
10 - 20	290	260	$^3/_8$" – $^3/_4$"	42060	260
20 - 40	265	240	**$^3/_4$" – 1$^5/_8$"**	34810	240
40 - 80	235	230	**1$^5/_8$" – 3$^1/_4$"**	34080	230
80 - 150	210	215	**3$^1/_4$" – 5$^7/_8$"**	30460	215
150 - 300	190	205	**5$^7/_8$" – 11$^3/_4$"**	27560	205

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	8mm [$^5/_{16}$"]

Material specification

The best possible application for this Type of MEEHANITE is in the field of small to medium sized castings with wall thicknesses above 7mm [$^{9}/_{32}$"].Owing to its good machinability it is also very suitable for mass produced parts for automobiles as well as for small hydraulic bodies which require to be pressure tight.

Applications

Machine tool parts, drive housings, pump housings, hydraulic bodies, small gear wheels, clutch plates, brake drums, valves etc.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

MEEHANITE Type GD250

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	250N/mm^2	945N/mm^2	0.30 – 0.80	190 – 230
Imperial equivalents	*16.2tonf/in^2*	*61.2tonf/in^2*		
	~36200lbf/in^2	*~137000lbf/in^2*		
US	-	-	-	-
Metric equivalents	-	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
0.1% proof stress[1]	$R_{p0.1}$	N/mm^2	165-228	lbf/in^2	23900-33000
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	840	lbf/in^2	12180
Limit of proportionality[1]	$R_{p0.01}$	N/mm^2	90	lbf/in^2	13300
Bending strength	σ_B	N/mm^2	340	lbf/in^2	49300
Torsional strength	T_B	N/mm^2	290	lbf/in^2	42100
Modulus of elasticity[3]	E	kN/mm^2	125	lbf/in^2	18.13 x 10^6
Modulus of rigidity	G	N/mm^2	0.047 x 10^6	lbf/in^2	6.75 x 10^6
Modulus of rupture	R	N/mm^2	525	lbf/in^2	76000
Poissons ratio	ν		0.26		0.26
Fatigue limit[4] **Rotating bending**	σ_{bW}	N/mm^2	120	lbf/in^2	17400
Push-pull	σ_{tcW}	N/mm^2	60	lbf/in^2	8700
Fatigue strength	σ_D	N/mm^2	105	lbf/in^2	15000
Impact strength, Charpy[5]	A_{un}	J	4.9	ft lbf	3.7
Fracture toughness	K_{1c}	N/mm$^{3/2}$	480	lbf/in$^{3/2}$	13800
Damping capacity[6]		%	28	%	28
Density	ρ	kg/dm^3	7.2	lb/in^3	0.260
Specific heat 20 to 200°C 20 to 600°C	c	J/kg.K	460 535	cal/g.°C	0.16 0.27
Coefficient of thermal expansion -100 to +20°C 20 to 200°C 20 to 400°C	α_l	1/10^6.K	10.0 10.7 12.4	1/10^6.°F	5.56 5.95 6.90
Thermal conductivity 100°C 200°C 300°C 400°C 500°C	λ	W/m.K	48.5 47.5 46.5 45.0 44.5	Btu.in/ft^2.h.°F	356 349 341 330 327
Electrical resistivity	ε	Ω mm^2/m	0.73	Ω in^2/in	28.7 x 10^{-6}
Coercive force	H_o	A/m	625	Oe	7.86
Maximum magnetic permeability	μ	μH/m	267		
Hysteresis loss [B=1T]		J/m^3	2715		
Machinability rating			45		45
Patternmaker's contraction[7]	s	%	0.8-1.2		0.8-1.2
Solid contraction		mm/m	10 - 13	in/ft	$^1/_{10}$ - $^1/_8$

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	5 - 10	-	lbf/in^2	$^3/_{16}$" – $^3/_8$"	-
			10 - 20	-		**$^3/_8$" - $^3/_4$"**	-
			20 - 40	230		**$^3/_4$" – 1$^5/_8$"**	33360
			40 - 80	210		**1$^5/_8$" – 3$^1/_4$"**	30460

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
5 - 10	275	270	$^3/_{16}$" – $^3/_8$"	39880	270
10 - 20	240	250	**$^3/_8$" - $^3/_4$"**	34810	250
20 - 40	220	230	**$^3/_4$" – 1$^5/_8$"**	31910	230
40 - 80	200	215	**1$^5/_8$" – 3$^1/_4$"**	29010	215

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	7mm [$^9/_{32}$"]

MEEHANITE Type GE225*

Material specification

This MEEHANITE Type is manufactured under the same strict control as the other MEEHANITE Types and offers the benefits of structural uniformity and soundness in a softer type of iron.

It is available as an alternative and superior material for all applications of commonly available grey cast iron; in addition, to fulfilling many purposes for which the latter is unsuitable. It combines improved strength and density with better performance in the machine shop than common grey iron. This is due to its finer structure and the absence of hard spots.

Applications

It is suitable for the production of any size of casting from the lightest repetition item to the heaviest of individual jobs.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

* This Type of MEEHANITE has been retained as it corresponds to a grade of iron which was very popular in Great Britain prior to metrication and features on many drawings produced during that period.

MEEHANITE Type GE225*

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	225N/mm^2	860N/mm^2	0.30 – 0.80	185 – 225
Imperial equivalents	*14.6tonf/in^2*	*55.8tonf/in^2*		
	~32600lbf/in^2	*~125000lbf/in^2*		
US	-	-	-	-
Metric equivalents	-	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
0.1% proof stress[1]	$R_{p0.1}$	N/mm^2	147-212	lbf/in^2	21320-30750
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	292	lbf/in^2	42350
Limit of proportionality[1]	$R_{p0.01}$	N/mm^2	85	lbf/in^2	12200
Bending strength	σ_B	N/mm^2	315	lbf/in^2	45700
Torsional strength	T_B	N/mm^2	260	lbf/in^2	37700
Modulus of elasticity[3]	E	kN/mm^2	120	lbf/in^2	17.40 x 10^6
Modulus of rigidity	G	N/mm^2	0.043 x 10^6	lbf/in^2	6.20 x 10^6
Modulus of rupture	R	N/mm^2	480	lbf/in^2	70000
Poissons ratio	v		0.26		0.26
Fatigue limit[4] **Rotating bending**	σ_{bW}	N/mm^2	105	lbf/in^2	15220
Push-pull	σ_{tcW}	N/mm^2	55	lbf/in^2	8000
Fatigue strength	σ_D	N/mm^2	95	lbf/in^2	13500
Impact strength, Charpy[5]	A_{un}	J	3.8	ft lbf	2.9
Fracture toughness	K_{1c}	N/mm$^{3/2}$	440	lbf/in$^{3/2}$	12660
Damping capacity[6]		%	29	%	29
Density	ρ	kg/dm^3	7.15	lb/in^3	0.258
Specific heat 20 to 200°C **20 to 600°C**	c	J/kg.K	-	cal/g.°C	-
Coefficient of thermal expansion	α_l	1/10^6.K		1/10^6.°F	
-100 to +20°C					
20 to 200°C			10.55		5.86
20 to 400°C			12.42		6.90
Thermal conductivity 100°C	λ	W/m.K	49.5	Btu.in/ft^2.h.°F	363
200°C			48.5		356
300°C			47.5		349
400°C			46.5		341
500°C			45.5		334
Electrical resistivity	ε	Ω mm^2/m	0.75	Ω in^2/in	29.5 x 10^{-6}
Coercive force	H_o	A/m	610	Oe	7.67
Maximum magnetic permeability	μ	μH/m	253		
Hysteresis loss [B=1T]		J/m^3	2640		
Machinability rating			42		42
Patternmaker's contraction[7]	s	%	0.8-1.2		0.8-1.2
Solid contraction		mm/m	10 - 13	in/ft	$^1/_{10}$ - $^1/_8$

MEEHANITE Type GE225*

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	2.5 - 5	-	lbf/in^2	$^3/_{32}$" - $^3/_{16}$"	-
			5 - 10	-		**$^3/_{16}$" - $^3/_8$"**	-
			10 - 20	-		**$^3/_8$" – $^3/_4$"**	-
			20 - 40	180		**$^3/_4$" – 1$^5/_8$"**	26110

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
2.5 - 5	240	270	$^3/_{32}$" - $^3/_{16}$"	34810	270
5 - 10	220	245	**$^3/_{16}$" - $^3/_8$"**	31910	245
10 - 20	190	220	**$^3/_8$" – $^3/_4$"**	27560	220
20 - 40	170	200	**$^3/_4$" – 1$^5/_8$"**	24660	200

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	6mm [$^1/_4$"]

Material specification

This MEEHANITE Type is available as an alternative and superior material for all applications replacing ordinary flake cast iron. This material is generally used for smaller parts with wall thicknesses above 5mm [$^3/_{16}$"]. It has excellent fluidity, no tendency towards hard edges and a uniformly fine structure with small proportions of ferrite and is, therefore, readily machinable.

MEEHANITE Type **GE200**/**GE30** is manufactured under the same strict control as other MEEHANITE Types, therefore, offers the benefits of structural uniformity and soundness. The minimal differences in the structure, from one delivery to the next, is important for transfer machining [higher feeds and cutting speeds] in mass production.

MEEHANITE Type **GE200**/**GE30** combines improved strength and density and assures uniform dependable performance.

Applications

Electric motor housings, gear boxes, automobile drive housings, bearing plates, caps, exhaust manifolds, etc.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type GE200/GE30

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	200N/mm^2	840N/mm^2	0.30 – 0.80	180 – 220
Imperial equivalents	*13.0tonf/in^2*	*54.4tonf/in^2*		
	~29000lbf/in^2	*~121800lbf/in^2*		
US	30000lbf/in^2	120000lbf/in^2	0.30 – 0.80	180 – 220
Metric equivalents	*~207N/mm^2*	*~830N/mm^2*		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
0.1% proof stress[1]	$R_{p0.1}$	N/mm^2	130-195	lbf/in^2	18860-28280
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	260	lbf/in^2	37700
Limit of proportionality[1]	$R_{p0.01}$	N/mm^2	80	lbf/in^2	11500
Bending strength	σ_B	N/mm^2	290	lbf/in^2	42000
Torsional strength	T_B	N/mm^2	230	lbf/in^2	33360
Modulus of elasticity[3]	E	kN/mm^2	115	lbf/in^2	16.68 x 10^6
Modulus of rigidity	G	N/mm^2	0.038 x 10^6	lbf/in^2	5.5 x 10^6
Modulus of rupture	R	N/mm^2	420	lbf/in^2	61000
Poissons ratio	v		0.26		0.26
Fatigue limit[4] — **Rotating bending**	σ_{bW}	N/mm^2	90	lbf/in^2	13050
Fatigue limit[4] — **Push-pull**	σ_{tcW}	N/mm^2	50	lbf/in^2	7250
Fatigue strength	σ_D	N/mm^2	85	lbf/in^2	12200
Impact strength, Charpy[5]	A_{un}	J	2.8	ft lbf	2.1
Fracture toughness	K_{1c}	N/mm$^{3/2}$	400	lbf/in$^{3/2}$	11500
Damping capacity[6]		%	30	%	30
Density	ρ	kg/dm^3	7.10	lb/in^3	0.256
Specific heat **20 to 200°C** **20 to 600°C**	c	J/kg.K	-	cal/g.°C	-
Coefficient of thermal expansion **-100 to +20°C** **20 to 200°C** **20 to 400°C**	α_l	1/10^6.K	 10.71 12.24	1/10^6.°F	 5.95 6.80
Thermal conductivity **100°C** **200°C** **300°C** **400°C** **500°C**	λ	W/m.K	50.0 49.0 48.0 47.0 46.0	Btu.in/ft^2.h.°F	367 360 352 345 338
Electrical resistivity	ε	Ω mm^2/m	0.77	Ω in^2/in	30.2 x 10^{-6}
Coercive force	H_o	A/m	580	Oe	7.29
Maximum magnetic permeability	μ	μH/m	237		
Hysteresis loss [B=1T]		J/m^3	2570		
Machinability rating			38		38
Patternmaker's contraction[7]	s	%	0.8-1.2		0.8-1.2
Solid contraction		mm/m	10 - 13	in/ft	$^1/_{10}$ - $^1/_8$

MEEHANITE Type GE200/GE30

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm^2	2.5 - 5	-	lbf/in^2	3/32” - 3/16”	-
			5 - 10	-		**3/16” - 3/8”**	-
			10 - 20	-		**3/8” – 3/4”**	-
			20 - 40	180		**3/4” – 1 5/8”**	26110

[2] Recommended wall section ranges in **bold** figures

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting		Wall section in casting, in from to	Expected minimum values in the casting	
	Tensile strength N/mm^2	BHN		Tensile strength lbf/in^2	BHN
2.5 - 5	240	270	3/32” - 3/16”	34810	270
5 - 10	220	245	**3/16” - 3/8”**	31910	245
10 - 20	190	220	**3/8” – 3/4”**	27560	220
20 - 40	170	200	**3/4” – 1 5/8”**	26110	200

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	5mm [3/16”]

Material specification

This MEEHANITE Type possesses a mixed matrix of pearlite and ferrite, and there are no hard edges so that this Type of iron is especially useful where high machinability on high speed automatic machining lines is required and where ultimate tensile strength is a secondary consideration. Castings with wall sections as low as 3mm [$^1/_8$"] are easily machinable because of their low hardness.

Machinability can further be enhanced by an annealing treatment if it is considered necessary.

Applications

Small valves, bearing inserts, scale housings, printing and sewing machine parts etc.

The notes below apply to the numerical references in the material property tabulations for the flake graphite types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve
4 Wöhler rotating bending fatigue test using an un-notched test bar
5 Un-notched Charpy test piece [10mm square]
6 Percentage of 150N/mm^2 [22000lbf/in^2] torsional stress energy dissipated during first cycle.
7 Depends upon design, size of casting and heat treatment, if any, applied

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type GF150/GF30

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	150N/mm^2	600N/mm^2	0.30 – 0.80	160 – 190
Imperial equivalents	*10.0tonf/in^2*	*38.9tonf/in^2*		
	~21800lbf/in^2	*~87000lbf/in^2*		
US	20000lbf/in^2	90000lbf/in^2	0.30 – 0.80	160 – 190
Metric equivalents	*~138N/mm^2*	*~620N/mm^2*		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
0.1% proof stress[1]	$R_{p0.1}$	N/mm^2	98-165	lbf/in^2	14200-23900
0.1% proof stress in compression	$\sigma_{c0.1}$	N/mm^2	195	lbf/in^2	28280
Limit of proportionality[1]	$R_{p0.01}$	N/mm^2	80	lbf/in^2	11600
Bending strength	σ_B	N/mm^2	250	lbf/in^2	36260
Torsional strength	T_B	N/mm^2	170	lbf/in^2	24650
Modulus of elasticity[3]	E	kN/mm^2	100	lbf/in^2	14.50 x 10^6
Modulus of rigidity	G	N/mm^2	0.028 x 10^6	lbf/in^2	4.0 x 10^6
Modulus of rupture	R	N/mm^2	285	lbf/in^2	41000
Poissons ratio	v		0.26		0.26
Fatigue limit[4] **Rotating bending**	σ_{bW}	N/mm^2	70	lbf/in^2	10150
Fatigue limit[4] **Push-pull**	σ_{tcW}	N/mm^2	40	lbf/in^2	5800
Fatigue strength	σ_D	N/mm^2	80	lbf/in^2	11000
Impact strength, Charpy[5]	A_{un}	J	2.0	ft lbf	1.5
Fracture toughness	K_{1c}	N/mm$^{3/2}$	320	lbf/in$^{3/2}$	9200
Damping capacity[6]		%	30	%	30
Density	ρ	kg/dm^3	7.10	lb/in^3	0.256
Specific heat **20 to 200°C** **20 to 600°C**	c	J/kg.K	-	cal/g.°F	-
Coefficient of thermal expansion **-100 to +20°C** **20 to 200°C** **20 to 400°C**	α_l	1/10^6.K	 10.98 12.60	1/10^6.°F	 6.10 7.00
Thermal conductivity **100°C** **200°C** **300°C** **400°C** **500°C**	λ	W/m.K	52.5 51.0 50.0 49.0 48.5	Btu.in/ft^2.h.°F	385 374 367 360 356
Electrical resistivity	ε	Ω mm^2/m	0.77	Ω in^2/in	30.2 x 10^{-6}
Coercive force	H_o	A/m	580	Oe	7.29
Maximum magnetic permeability	μ	μH/m	237		
Hysteresis loss [B=1T]		J/m^3	2570		
Machinability rating			28		28
Patternmaker's contraction[7]	s	%	0.6-1.0		0.6-1.0
Solid contraction		mm/m	10 - 13	in/ft	$^1/_{10}$ - $^1/_8$

MEEHANITE Type GF150/GF20

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of flake cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength.

Casting specification: cast-on test bars

	Symbol	Units	Wall section in casting[2], mm from to	Value	Units	Wall section in casting[2], in from to	Value
Tensile strength [min]	R_m	N/mm²	2.5 - 5	nda	lbf/in²	3/32" - 3/16"	nda
			5 - 10	nda		**3/16" - 3/8"**	nda
			10 - 20	nda		**3/8" – 3/4"**	nda
			20 - 40	nda		**3/4" – 1 5/8"**	nda

[2] Recommended wall section ranges in **bold** figures
nda: no data available

Casting specification: guidance values for properties in castings

Wall section in casting[2], mm from to	Expected minimum values in the casting: Tensile strength N/mm²	BHN	Wall section in casting, in from to	Expected minimum values in the casting: Tensile strength lbf/in²	BHN
2.5 - 5	210	250	3/32" - 3/16"	30460	250
5 - 10	180	225	**3/16" - 3/8"**	26110	225
10 - 20	140	205	**3/8" – 3/4"**	20310	205
20 - 40	120	185	**3/4" – 1 5/8"**	17400	185

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	25% tensile strength
Direct compression	80% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit
Minimum casting section	3mm [1/8"]

MEEHANITE *FIRST GENERATION* NOUDUALR GRAPHITE IRON CASTINGS FOR GENERAL ENGINEERING

Introduction

This range of cast irons is known under a variety of names – “Nodular”, “SG” or “Spheroidal Graphite” iron, or “Ductile” iron.

These materials possess strength and ductility properties of a different order from those associated with flake [lamella] graphite grey [gray] cast irons although they still retain the comparable machining characteristics.

Whilst providing mechanical properties akin to cast steel or malleable iron, nodular iron presents few of the founding problems met with the former and little of the prolonged high temperature heat treatment and resultant distortion or the limitations on size and section associated with the latter.

As nodular iron can be poured at temperatures much less than those required for cast steel, both casting finish and dimensional accuracy are much improved; tensile strength and ductility levels are similar to those of cast steel, but proof stress values are considerably higher.

Although essentially the same material, a complete series of *first generation* MEEHANITE nodular irons is made available by suitable adjustments to the metal chemical composition, with or without subsequent heat treatment, in order to produce ferritic, pearlitic, bainitic, martensitic or other mixed matrix structures on which the mechanical properties of the material are basically dependent.

The presence of a source of carbon, in the form of graphite nodules in the matrix, allows for ease of heat treatment, for carbon can be introduced into, or abstracted from, the matrix by the graphite nodules through suitable heat treatment cycles.

MEEHANITE nodular irons are thus classified on the basis of microstructures into a series of Types which by strictly controlling foundry, melting and proprietary processing procedures, result in mechanical property levels often well in excess of the minima specified in national and international standards.

MEEHANITE Type SFF350

Material specification

This fully ferritic MEEHANITE Type is produced from specially selected high purity raw materials with the prime aim of reducing undesirable elements to an extremely low level. Even with these increasingly difficult to source, and costly, raw materials the castings are subjected to an extended heat treatment to fully develop the mechanical properties.

The extended annealing heat treatment results in a material possessing a completely ferritic matrix with excellent notched impact strength at sub-zero temperatures. Before embarking on sourcing castings in this material the customer is advised to liaise closely with the MEEHANITE licensee.

Applications

Parts for refrigerators, compressors, pumps, valves etc which are to be used in sub-zero conditions. Components for vehicles employed in the Artic and navel ship components where a high ductility and resistance to impact by explosion is mandatory.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.

MEEHANITE Type SFF350

Mechanical properties[1]

MEEHANITE Region	**Ultimate tensile strength R_m**	**0.2% Proof stress in tension* [min] ($R_{p0.2}$)**	**Compression Strength* [min]**	**% Elongation**	**BHN[2]**
Europe, Asia	350N/mm^2	220N/mm^2	600N/mm^2	24 [min]	130 – 160
Imperial equivalents	*22.7tonf/in^2*	*14.3tonf/in^2*	*~38.9tonf/in^2*		
	~50770lb/in^2	*~31900lb/in^2*	*~87000lb/in^2*		
US	50000lb/in^2	35000lb/in^2	85000lb/in^2	24 [min]	130 – 160
Metric equivalents	*~345N/mm^2*	*~240N/mm^2*	*~585N/mm^2*		

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	**Units**	**Value**	**Units**	**Value**	**Ref**
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	210	lb/in^2	30500	
Impact strength[3] [notched] at **-40°C [min]** **-20°C** **+20°C**	A_n	J	16	ft lbf	7.2	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	120	ft lbf	91.4	
Fatigue limit **Rotating bending [un-notched][5]** **Rotating bending [notched][6]** **Push - Pull**	 σ_{bw} σ_{bw} σ_{tcW}	 N/mm^2 N/mm^2 N/mm^2	 ± 180 ± 115 ± 100	 lbf/in^2 lbf/in^2 lbf/in^2	 ± 26100 ± 16800 ± 14500	a
Compression strength*	σ_c	N/mm^2	600	lbf/in^2	87100	
0.2% Proof stress in compression* **0.1% Proof stress in compression***	$\sigma_{c0.2}$ $\sigma_{c0.1}$	N/mm^2 N/mm^2	230 [300] 225 [295]	x 10^3 lbf/in^2 x 10^3 lbf/in^2	33.4 [43.5] 32.6 [42.8]	b
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	170	lbf/in^2	24.7 x 10^6	
Modulus of rigidity	G	N/mm^2	62000	lbf/in^2	8.99 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.90	d
Thermal conductivity @ 200°C	λ	W/m.K	39	Btu.in/ft^2.h.°F	286	d
Patternmakers contraction[7]		%	0.2 – 0.8	%	0.2 – 0.8	
Solid contraction		mm/m	0 – 0.5	in/ft	$^1/_{32}$ – $^3/_{32}$	
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	340	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	49300
			60 - 200	70	320		$1^3/_8$" – 8"	$2^{25}/_{32}$"	46400
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	230	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	33350
			60 - 200	70	220		$1^3/_8$" – 8"	$2^{25}/_{32}$"	31900
Elongation [min]	A_5	%	30 - 60	40	20	%	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	19
			60 - 200	70	16		$1^3/_8$" – 8"	$2^{25}/_{32}$"	16
Impact strength [notched] at -40°C	$A_{n\,[-40]}$	J	30 - 60	40	17	ft lbf	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	7.7
			60 - 200	70	15		$1^3/_8$" – 8"	$2^{25}/_{32}$"	6.8

Casting specification: guidance values for properties in castings

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	350	220	22		**2**	50760	31910	22
50	**80**	340	210	19	**2**	**$3^3/_{16}$**	49310	30460	19
80	**120**	330	200	16	**$3^3/_{16}$**	**4¾**	47860	29010	16
120	**200**	320	190	12	**4¾**	**8**	46410	27560	12

MEEHANITE Type SFF400

Material specification

Again, the matrix of this MEEHANITE Type is entirely ferritic although the compositional requirements are not quite so onerous and the impact transition temperature is slightly higher than is the case with MEEHANITE Type **SFF350**.

Originally, a high temperature annealing heat treatment formed part of the manufacturing procedure, however, with a careful selection of raw materials and a strict quality control procedure, such as that found in a MEEHANITE licensee, this material can be produced in the as-cast condition.

The characteristics of this Type of material are good ductility and a guaranteed notch impact strength down to -20°C.

Applications

For valves, brakes, couplings, brackets, pressure vessels, high pressure hydraulic housings, refrigeration components, wind and wave power generating equipment components.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	400N/mm^2	250N/mm^2	700N/mm^2	20 [min]	120 – 150
Imperial equivalents	*25.5tonf/in^2*	*16.2tonf/in^2*	*~45.3tonf/in^2*		
	~57100lb/in^2	*~36200lb/in^2*	*~101500lb/in^2*		
US	60000lb/in^2	42000lb/in^2	100000lb/in^2	20 [min]	120 – 150
Metric equivalents	*~414N/mm^2*	*~290N/mm^2*	*~690N/mm^2*		

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a) with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b) with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c) with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	240	lb/in^2	34800	
Impact strength[3] [notched] at **-40°C [min]** **-20°C** **+20°C**	A_n	J	 14 17	ft lbf	 6.3 7.7	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	100	ft lbf	76.1	
Fatigue limit **Rotating bending [un-notched][5]** **Rotating bending [notched][6]** **Push - Pull**	 σ_{bw} σ_{bw} σ_{tcW}	 N/mm^2 N/mm^2 N/mm^2	 ± 200 ± 120 ± 110	 lbf/in^2 lbf/in^2 lbf/in^2	 ± 29000 ± 17400 ± 15900	a
Compression strength*	σ_c	N/mm^2	700	lbf/in^2	101500	
0.2% Proof stress in compression* **0.1% Proof stress in compression***	$\sigma_{c0.2}$ $\sigma_{c0.1}$	N/mm^2 N/mm^2	275 [360] 270 [350]	x 10^3 lbf/in^2 x 10^3 lbf/in^2	39.9 [52.2] 39.2 [50.8]	b
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	170	lbf/in^2	24.7 x 10^6	
Modulus of rigidity	G	N/mm^2	62000	lbf/in^2	8.99 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.94	d
Thermal conductivity @ 200°C	λ	W/m.K	39	Btu.in/ft^2.h.°F	286	d
Patternmakers contraction[7]		%	0.2 – 0.8	in/ft	0.2 – 0.8	
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$	
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

MEEHANITE Type SFF400

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	390	lbf/in^2	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	56560
			60 - 200	70	370		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	53660
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	250	lbf/in^2	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	36260
			60 - 200	70	240		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	34810
Elongation [min]	A_5	%	30 - 60	40	18	%	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	18
			60 - 200	70	14		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	14
Impact strength [notched] at -40°C	$A_{n\,[-40]}$	J	30 - 60	40	14	ft lbf	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	6.2
			60 - 200	70	12		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	5.5

Casting specification: guidance values for properties in castings

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	400	250	20		**2**	58020	36260	20
50	**80**	380	240	17	**2**	**$3^{3}/_{16}$**	55110	34810	17
80	**120**	370	230	14	**$3^{3}/_{16}$**	**4¾**	53660	33360	14
120	**200**	360	220	10	**4¾**	**8**	52210	31910	10

Material specification

This material is for more general engineering applications where high ductility and exceptional resistance to impact is required. MEEHANITE Type **SF400/SF60** also provides maximum toughness at ambient temperatures. The matrix is entirely ferritic, therefore easily machinable, and is produced by either strict control of the raw materials during melting or by an annealing heat treatment to eliminate any pearlite formed during solidification.

Compared with cast steel of similar strength, it is possible to reduce machining times by up to 25%.

Applications

Replacement of fabricated, forged and malleable iron components in automobiles, commercial and agricultural vehicles; viz, wheel hubs, hydraulic levers, differential housings and carriers, bearing caps, disc brake calliper bodies, parking brake discs, rocker arms, etc.

Scraper teeth for refuse plants and agricultural machinery; high output, medium speed, ship's diesel engine frames, cylinder heads and flywheels; large thrust bearings for ship's propeller shafts, large variable pitch fan bodies and much more.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	400N/mm²	240N/mm²	800N/mm²	17 [min]	140 – 190
Imperial equivalents	*25.9tonf/in²*	*16.2tonf/in²*	*~51.8tonf/in²*		
	~58000lb/in²	*~35000lb/in²*	*~116000lb/in²*		
US	60000lb/in²	42000lb/in²	115000lb/in²	17 [min]	140 – 190
Metric equivalents	*~414N/mm²*	*~290N/mm²*	*~790N/mm²*		

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm²	240	lb/in²	34800	
Impact strength[3] [notched] at -40°C [min] -20°C +20°C	A_n	J	14	ft lbf	6.2	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	80	ft lbf	60.9	
Fatigue limit						a
Rotating bending [un-notched][5]	σ_{bw}	N/mm²	± 200	lbf/in²	± 29000	
Rotating bending [notched][6]	σ_{bw}	N/mm²	± 120	lbf/in²	± 17400	
Push - Pull	σ_{tcW}	N/mm²	± 110	lbf/in²	± 14500	
Compression strength*	σ_c	N/mm²	800	lbf/in²	116000	
0.2% Proof stress in compression*	$\sigma_{c0.2}$	N/mm²	275 [370]	x 10³ lbf/in²	39.9 [53.7]	b
0.1% Proof stress in compression*	$\sigma_{c0.1}$	N/mm²	270 [360]	x 10³ lbf/in²	39.2 [52.2]	
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm²	170	lbf/in²	24.6 x 10^6	
Modulus of rigidity	G	N/mm²	65000	lbf/in²	9.43 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10⁶.K	12.5	1/10⁶.°F	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	39	Btu.in/ft².h.°F	286	d
Patternmakers contraction[7]		%	0.2 – 0.8	in/ft	0.2 – 0.8	
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$	
Density at 20°C	ρ	kg/dm³	7.10	lb/in³	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

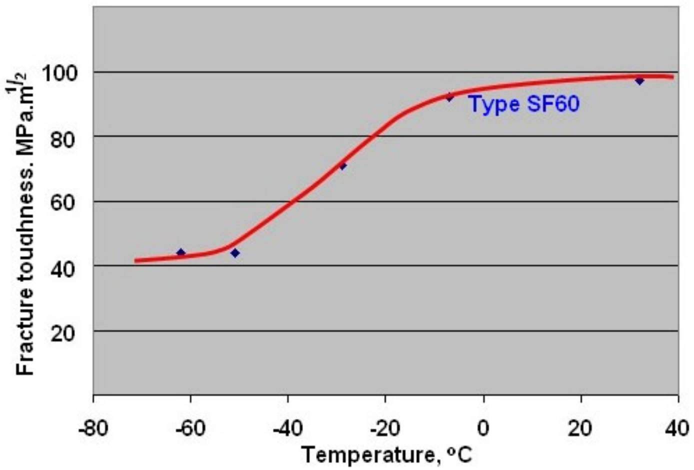
MEEHANITE Type SF400/SF60

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	390	lbf/in^2	1$^3/_{16}$" – 1$^3/_8$"	1$^5/_8$"	56560
			60 - 200	70	370		1$^3/_8$" – 8"	2$^{25}/_{32}$"	53660
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	250	lbf/in^2	1$^3/_{16}$" – 1$^3/_8$"	1$^5/_8$"	36260
			60 - 200	70	240		1$^3/_8$" – 8"	2$^{25}/_{32}$"	34810
Elongation [min]	A_5	%	30 - 60	40	17	%	1$^3/_{16}$" – 1$^3/_8$"	1$^5/_8$"	17
			60 - 200	70	14		1$^3/_8$" – 8"	2$^{25}/_{32}$"	14
Impact strength [notched] at +20^{o}C	A_n	J	30 - 60	40	-	ft lbf	1$^3/_{16}$" – 1$^3/_8$"	1$^5/_8$"	-
			60 - 200	70	-		1$^3/_8$" – 8"	2$^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	400	250	17		**2**	58020	36260	17
50	**80**	380	240	15	**2**	**3$^3/_{16}$**	55110	34810	15
80	**120**	370	230	12	**3$^3/_{16}$**	**4¾**	53660	33360	12
120	**200**	360	230	8	**4¾**	**8**	52210	33360	8



Fracture toughness of MEEHANITE Type SF400/SF60*

The figure on the left indicates the fracture toughness of a fully ferritic nodular iron over a range of temperatures. The material exhibits a transition from ductile to brittle fracture in the temperature range of -25^{o}C [~-15^{o}F] to -50^{o}C [~-80^{o}F].

*Variations in fracture toughness arise as a result of the nodularising treatment adopted in the geographical zone, see above.

MEEHANITE Type SF420.12*

Material specification

Used where a degree of shock resistance at ambient temperatures is important; possesses a predominantly ferritic matrix giving the material a good level of ductility. It is of particular interest to design engineers wishing to replace fabrications or malleable iron castings.

Good casting properties and easily machinable.

Applications

Suitable for use in levers, links, valves, housings. This particular material was produced to satisfy the specific requirements of the former British Standard BS 2789, Grade 420.12.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45^{o} V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.

* This Type of MEEHANITE has been retained as it corresponds to a grade of iron which was very popular in Great Britain prior to metrication and features on many drawings produced during that period.

MEEHANITE Type SF420.12*

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	420N/mm^2	260N/mm^2	800N/mm^2	12 [min]	150 – 200
Imperial equivalents	*27.2tonf/in^2*	*16.8tonf/in^2*	*~51.8tonf/in^2*		
	~61000lb/in^2	*~37700lb/in^2*	*~116000lb/in^2*		
US					
Metric equivalents					

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	250	lb/in^2	36300	
Impact strength[3] [notched] at -40°C [min] -20°C +20°C	A_n	J	8	ft lbf	3.6	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	75	ft lbf	57.1	
Fatigue limit						a
Rotating bending [un-notched][5]	σ_{bw}	N/mm^2	± 205	lbf/in^2	± 29700	
Rotating bending [notched][6]	σ_{bw}	N/mm^2	± 130	lbf/in^2	± 18900	
Push - Pull	σ_{tcW}	N/mm^2	± 120	lbf/in^2	± 17400	
Compression strength*	σ_c	N/mm^2	850	lbf/in^2	123280	
0.2% Proof stress in compression*	$\sigma_{c0.2}$	N/mm^2	295 [385]	x 10^3 lbf/in^2	42.8 [55.8]	b
0.1% Proof stress in compression*	$\sigma_{c0.1}$	N/mm^2	290 [380]	x 10^3 lbf/in^2	42.1 [55.1]	
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	171	lbf/in^2	24.8 x 10^6	
Modulus of rigidity	G	N/mm^2	65000	lbf/in^2	9.43 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.94	d
Thermal conductivity @ 200°C	λ	W/m.K	39	Btu.in/ft^2.h.°F	286	d
Patternmakers contraction[7]		%	0.2 – 0.8	in/ft	0.2 – 0.8	
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$	
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	410	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	59470
			60 - 200	70	390		$1^3/_8$" – 8"	$2^{25}/_{32}$"	56560
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	270	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	39160
			60 - 200	70	260		$1^3/_8$" – 8"	$2^{25}/_{32}$"	37710
Elongation [min]	A_5	%	30 - 60	40	12	%	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	12
			60 - 200	70	8		$1^3/_8$" – 8"	$2^{25}/_{32}$"	8
Impact strength [notched] at +20°C	A_n	J	30 - 60	40	-	ft lbf	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	-
			60 - 200	70	-		$1^3/_8$" – 8"	$2^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	**to**	**Tensile strength N/mm^2**	**0.2% Proof stress N/mm^2**	**Elongation %**	**from**	**to**	**Tensile strength lb/in^2**	**0.2% Proof stress lb/in^2**	**Elongation %**
	50	420	270	12		**2**	60920	39160	12
50	**80**	400	250	10	**2**	**$3^3/_{16}$**	58020	36260	10
80	**120**	370	240	7	**$3^3/_{16}$**	**4¾**	53660	34810	7
120	**200**	340	230	4	**4¾**	**8**	49310	33360	4

MEEHANITE Type SF450.15*

Material specification

This material is widely used. Like the old MEEHANITE Type **SF420.12** it is employed where a degree of shock resistance at ambient temperatures is important; the microstructure is predominantly ferritic giving it a good level of ductility. Again, it is of particular interest to design engineers wishing to replace fabrications or plain carbon castings.

Good casting properties and easily machinable.

Applications

Suitable for all general engineering applications, pumps, valves, housings, supports and brackets etc.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.

* This Type of MEEHANITE has been retained as it corresponds to a grade of iron which was very popular in Great Britain prior to metrication and features on many drawings produced during that period.

MEEHANITE Type SF450.15*

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	450N/mm^2	300N/mm^2	850N/mm^2	15 [min]	150 – 210
Imperial equivalents	*27.2tonf/in^2*	*16.8tonf/in^2*	*~55.0tonf/in^2*		
	~61000lb/in^2	*~37700lb/in^2*	*~123000lb/in^2*		
US					
Metric equivalents					

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	280	lb/in^2	40600	
Impact strength[3] [notched] at -40°C [min] -20°C +20°C	A_n	J	8	ft lbf	3.6	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	70	ft/lbf	53.3	
Fatigue limit						a
Rotating bending [un-notched][5]	σ_{bw}	N/mm^2	± 210	lbf/in^2	± 30500	
Rotating bending [notched][6]	σ_{bw}	N/mm^2	± 130	lbf/in^2	± 18900	
Push - Pull	σ_{tcW}	N/mm^2	± 130	lbf/in^2	± 18900	
Compression strength*	σ_c	N/mm^2	850	tonsf/in^2	55.0	
0.2% Proof stress in compression*	$\sigma_{c0.2}$	N/mm^2	305 [410]	x 10^3 lbf/in^2	44.2 [59.5]	b
0.1% Proof stress in compression*	$\sigma_{c0.1}$	N/mm^2	300 [400]	x 10^3 lbf/in^2	43.5 [58.0]	
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	172	lbf/in^2	24.8 x 10^6	
Modulus of rigidity	G	N/mm^2	65500	lbf/in^2	9.50 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	38	Btu.in/ft^2.h.°F	279	d
Patternmakers contraction[7]		%	0.2 – 0.8	in/ft	0.2 – 0.8	
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$	
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	440	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	63820
			60 - 200	70	400		$1^3/_8$" – 8"	$2^{25}/_{32}$"	58020
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	290	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	42060
			60 - 200	70	280		$1^3/_8$" – 8"	$2^{25}/_{32}$"	40610
Elongation [min]	A_5	%	30 - 60	40	15	%	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	15
			60 - 200	70	11		$1^3/_8$" – 8"	$2^{25}/_{32}$"	11
Impact strength [notched] at -20°C	A_n	J	30 - 60	40	-	ft lbf	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	-
			60 - 200	70	-		$1^3/_8$" – 8"	$2^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings

Wall section, mm from	to	Expected minimum values in the casting: Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	Wall section, in from	to	Expected minimum values in the casting: Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	450	290	13		**2**	65270	42060	13
50	**80**	410	270	11	**2**	**$3^3/_{16}$**	59470	39160	11
80	**120**	390	260	9	**$3^3/_{16}$**	**4¾**	56560	37710	9
120	**200**	370	250	6	**4¾**	**8**	53660	36260	6

Material specification

As the designation suggests, this material possesses a mixed matrix of ferrite and pearlite, with the ferrite predominating. This Type of MEEHANITE thus offers a compromise between the relatively soft, low tensile, high ductility ferritic types and the harder, higher tensile, lower ductility pearlitic grades.

It is a good all-round material providing a degree of toughness coupled with a higher tensile strength in the as-cast condition.

Applications

High pressure hydraulic valves, components for heavy commercial and earth-moving vehicles, components for large-bore diesel engines; viz, guideways for crosshead slides, rocker arm pedestals, fuel pump bodies, crosshead bearing caps, roller bearing housings for camshaft followers, etc.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45^{o} V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA, Alvechurch, England, 1986
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.
e Formerly DIN 1693, Part 2, Oct.1977

MEEHANITE Type SFP500

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	500N/mm^2	320N/mm^2	900N/mm^2	8 [min]	170 – 220
Imperial equivalents	*32.4tonf/in^2*	*20.7tonf/in^2*	*~58.3tonf/in^2*		
	~73500lb/in^2	*~46400lb/in^2*	*~130500lb/in^2*		
US					
Metric equivalents					

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	310	lb/in^2	36300	
Impact strength[3] [notched] at -40°C [min] -20°C +20°C	A_n	J	-	ft lbf	-	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	60	ft lbf	45.7	
Fatigue limit Rotating bending [un-notched][5] Rotating bending [notched][6] Push - Pull	 σ_{bw} σ_{bw} σ_{tcW}	 N/mm^2 N/mm^2 N/mm^2	 ± 225 ± 135 ± 150	 lbf/in^2 lbf/in^2 lbf/in^2	 ± 32600 ± 19600 ± 21800	a
Compression strength*	σ_c	N/mm^2	900	tonsf/in^2	58.3	
0.2% Proof stress in compression* 0.1% Proof stress in compression*	$\sigma_{c0.2}$ $\sigma_{c0.1}$	N/mm^2 N/mm^2	350 [455] 340 [440]	x 10^3 lbf/in^2 x 10^3 lbf/in^2	50.8 [66.0] 49.3 [63.8]	b
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	173	lbf/in^2	24.9 x 10^6	
Modulus of rigidity	G	N/mm^2	69000	lbf/in^2	10.0 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	35	Btu.in/ft^2.h.°F	257	d
Patternmakers contraction[7]		%	0.2 – 0.8	in/ft	0.2 – 0.8	
Solid contraction		mm/m	10-16	in/ft	$^1/_8$ – $^3/_{16}$	
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

MEEHANITE Type SFP500

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	450	lbf/in^2	$1\frac{3}{16}$” – $1\frac{3}{8}$”	$1\frac{5}{8}$”	65270
			60 - 200	70	420		$1\frac{3}{8}$” – 8”	$2\frac{25}{32}$”	60920
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	300	lbf/in^2	$1\frac{3}{16}$” – $1\frac{3}{8}$”	$1\frac{5}{8}$”	43510
			60 - 200	70	290		$1\frac{3}{8}$” – 8”	$2\frac{25}{32}$”	42060
Elongation [min]	A_5	%	30 - 60	40	8	%	$1\frac{3}{16}$” – $1\frac{3}{8}$”	$1\frac{5}{8}$”	8
			60 - 200	70	6		$1\frac{3}{8}$” – 8”	$2\frac{25}{32}$”	6
Impact strength [notched] at +20°C	A_n	J	30 - 60	40	-	ft lbf	$1\frac{3}{16}$” – $1\frac{3}{8}$”	$1\frac{5}{8}$”	-
			60 - 200	70	-		$1\frac{3}{8}$” – 8”	$2\frac{25}{32}$”	-

Casting specification: guidance values for properties in castings

Wall section, mm from	Wall section, mm to	Expected minimum values in the casting: Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	Wall section, in from	Wall section, in to	Expected minimum values in the casting: Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	500	320	8		**2**	72520	46410	8
50	**80**	450	300	7	**2**	**$3\frac{3}{16}$**	65270	43510	7
80	**120**	440	290	6	**$3\frac{3}{16}$**	**4¾**	63820	42060	6
120	**200**	430	280	5	**4¾**	**8**	62370	40610	5

Material specification

This MEEHANITE Type possesses, in the as-cast condition, more than twice the strength available in conventional flake iron.

Whilst this material has a mixed matrix; the matrix is predominantly pearlitic and provides a degree of ductility with a higher level of mechanical strength. The mix of good strength and acceptable ductility makes it a good general purpose material in the engineering field, suitable for specifying in place of carbon steels.

Applications

Recommended for use where severe stresses, shock or internal pressures are encountered such as high pressure pump bodies, clutch housings, yokes for power transmission universal joints, hydraulic motor bodies, turning gear pinions for super-tanker diesel engines, melting pots for zinc and lead alloys, gear blanks, hydraulic cylinders, pipe bending formers, compressor cylinders, differential housings and components for heavy machinery, diesel and automotive and related industries.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA, Alvechurch, England, 1986
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al*., Giesserei-Praxis, 1982, Nos.23/24, p380.
e Formerly DIN 1693, Part 2, Oct.1977

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type SPF600/SP80

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	600N/mm^2	380N/mm^2	1000N/mm^2	3 - 5[min]	200 – 260
Imperial equivalents	*32.4tonf/in^2*	*20.7tonf/in^2*	*~64.8tonf/in^2*		
	~73500lb/in^2	*~46400lb/in^2*	*~145000lb/in^2*		
US	80000lb/in^2	60000lb/in^2		3 - 5[min]	200 – 260
Metric equivalents	*~550N/mm^2*	*~410N/mm^2*			

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	360	lb/in^2	52200	
Impact strength[3] [notched] at **-40°C [min]** **-20°C** **+20°C**	A_n	J	-	ft lbf	-	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	40	ft lbf	30.6	
Fatigue limit **Rotating bending [un-notched][5]** **Rotating bending [notched][6]** **Push - Pull**	 σ_{bw} σ_{bw} σ_{tcW}	 N/mm^2 N/mm^2 N/mm^2	 ± 250 ± 150 ± 175	 lbf/in^2 lbf/in^2 lbf/in^2	 ± 32600 ± 19600 ± 21800	a
Compression strength*	σ_c	N/mm^2	1000	tonsf/in^2	64.8	
0.2% Proof stress in compression* **0.1% Proof stress in compression***	$\sigma_{c0.2}$ $\sigma_{c0.1}$	N/mm^2 N/mm^2	380 [500] 360 [475]	x 10^3 lbf/in^2 x 10^3 lbf/in^2	55.1 [72.5] 52.2 [68.9]	b
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	175	lbf/in^2	25.2 x 10^6	
Modulus of rigidity	G	N/mm^2	70000	lbf/in^2	10.15 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	32	Btu.in/ft^2.h.°F	235	d
Patternmakers contraction[7]		%	0.5 – 1.0	in/ft	0.5 – 1.0	
Solid contraction		mm/m	5-10	in/ft	$^1/_{16}$ – $^3/_8$	
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

MEEHANITE Type SPF600/SP80

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	600	lbf/in^2	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	87020
			60 - 200	70	550		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	79770
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	360	lbf/in^2	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	52210
			60 - 200	70	340		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	49310
Elongation [min]	A_5	%	30 - 60	40	3	%	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	3
			60 - 200	70	2		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	2
Impact strength [notched] at +20^{o}C	A_n	J	30 - 60	40	-	ft lbf	$1^{3}/_{16}$" – $1^{3}/_{8}$"	$1^{5}/_{8}$"	-
			60 - 200	70	-		$1^{3}/_{8}$" – 8"	$2^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	600	380	3		**2**	87020	55110	3
50	**80**	520	340	2	**2**	**$3^{3}/_{16}$**	75420	49310	2
80	**120**	470	320	2	**$3^{3}/_{16}$**	**4¾**	68170	46410	2
120	**200**	450	320	1	**4¾**	**8**	65270	46410	1

MEEHANITE Type SP700/SH100

Material specification

This Type of MEEHANITE is processed to ensure that matrix consists entirely of pearlite so as to provide high levels of strength and hardness with some degree of ductility. It is suitable for use in heavily stressed machine parts, particularly in diesel engines and machine tools.

The higher hardness levels combine wear resistance with reasonable machinability. In the finishing of machine tool slideways the material is ideal for hand scraping to very precise finished dimensions.

In addition, the pearlitic microstructure allows a very ready response to through hardening; as well, as surface hardening with either flame, or induction or laser heat treatment.

Applications

Pistons for medium speed diesels, crankshafts for automobiles, small and large medium speed diesel engines; medium speed diesel cylinder blocks, machine components and machine tools where high levels of dynamic and static loading are experienced.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA, Alvechurch, England, 1986
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.
e Formerly DIN 1693, Part 2, Oct.1977

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type SP700/SH100

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	700N/mm^2	440N/mm^2	1100N/mm^2	3 [min]	220 – 280
Imperial equivalents	*45.3tonf/in^2*	*28.5tonf/in^2*	*~71.2tonf/in^2*		
	~101500lb/in^2	*~63800lb/in^2*	*~160000lb/in^2*		
US	100000lb/in^2	70000lb/in^2		3 [min]	220 – 280
Metric equivalents	*~690N/mm^2*	*~480N/mm^2*			

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	410	lb/in^2	59500	
Impact strength[3] [notched] at -40°C [min] -20°C +20°C	A_n	J	-	ft lbf	-	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	30	ft lbf	23.0	
Fatigue limit						a
Rotating bending [un-notched][5]	σ_{bw}	N/mm^2	± 280	lbf/in^2	± 40600	
Rotating bending [notched][6]	σ_{bw}	N/mm^2	± 170	lbf/in^2	± 24700	
Push - Pull	σ_{tcW}	N/mm^2	± 200	lbf/in^2	± 29000	
Compression strength*	σ_c	N/mm^2	1100	tonsf/in^2	71.2	
0.2% Proof stress in compression*	$\sigma_{c0.2}$	N/mm^2	425 [550]	x 10^3 lbf/in^2	61.6 [79.8]	b
0.1% Proof stress in compression*	$\sigma_{c0.1}$	N/mm^2	390 [510]	x 10^3 lbf/in^2	56.6 [74.0]	
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	175	lbf/in^2	25.2 x 10^6	
Modulus of rigidity	G	N/mm^2	70000	lbf/in^2	10.15 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	31	Btu.in/ft^2.h.°F	228	d
Patternmakers contraction[7]		%	0.5 – 1.5	%	0.5 – 1.5	
Solid contraction		mm/m	10-16	in/ft	$^1/_8 – ^3/_{16}$	
Density at 20°C	ρ	kg/dm^3	7.2	lb/in^3	0.260	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	**Maximum allowable design stress**
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

MEEHANITE Type SP700/SH100

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	700	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	101530
			60 - 200	70	650		$1^3/_8$" – 8"	$2^{25}/_{32}$"	94280
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	400	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	58020
			60 - 200	70	380		$1^3/_8$" – 8"	$2^{25}/_{32}$"	55120
Elongation [min]	A_5	%	30 - 60	40	3	%	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	3
			60 - 200	70	2		$1^3/_8$" – 8"	$2^{25}/_{32}$"	2
Impact strength [notched] at +20°C	A_n	J	30 - 60	40	-	ft lbf	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	-
			60 - 200	70	-		$1^3/_8$" – 8"	$2^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings

Wall section, mm from	Wall section, mm to	Expected minimum values in the casting: Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	Wall section, in from	Wall section, in to	Expected minimum values in the casting: Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	700	400	2		**2**	101530	58020	2
50	**80**	600	380	1	**2**	**$3^3/_{16}$**	87020	55120	1
80	**120**	570	370	1	**$3^3/_{16}$**	**4¾**	82670	53660	1
120	**200**	520	360	1	**4¾**	**8**	75420	52210	1

Material specification

To meet this specification, castings would either have to be normalised or quenched and tempered. In the as-cast and normalised condition, the notched impact transition temperature is above ambient temperature, so that such material is utilised in applications requiring high hardness or high proof and tensile strength levels but with only limited ductility and toughness.

Quenching and tempering lowers the notched impact transition temperature although room temperature tests show noticeable improvement in the actual impact values.

Applications

Pressure housings for plastic moulding machines, crossheads for aluminium extrusion machines, mandrels for expanding steel pipes, guide rolls for rolling mills, wear resisting components for mills and crushers, heavy duty gears, pump liners.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA, Alvechurch, England, 1986
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.
e Formerly DIN 1693, Part 2, Oct.1977

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type SH800/SH100

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	$800N/mm^2$	$500N/mm^2$	$1200N/mm^2$	2 [min]	250 – 320
Imperial equivalents	*$51.8tonf/in^2$*	*$32.4tonf/in^2$*	*$\sim77.7tonf/in^2$*		
	$\sim116000lb/in^2$	*$\sim72500lb/in^2$*	*$\sim174000lb/in^2$*		
US	$100000lb/in^2$	$70000lb/in^2$		2 [min]	250 – 320
Metric equivalents	*$\sim690N/mm^2$*	*$\sim480N/mm^2$*			

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	470	lb/in^2	68200	
Impact strength[3] [notched] at **-40°C [min]** **-20°C** **+20°C**	A_n	J	≤ 5	ft lbf	≤ 3	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	20	ft lbf	≤ 15.2	
Fatigue limit **Rotating bending [un-notched][5]** **Rotating bending [notched][6]** **Push - Pull**	 σ_{bw} σ_{bw} σ_{tcW}	 N/mm^2 N/mm^2 N/mm^2	 ± 300 ± 180 ± 240	 lbf/in^2 lbf/in^2 lbf/in^2	 ± 43500 ± 26100 ± 34800	a
Compression strength*	σ_c	N/mm^2	1200	$tonsf/in^2$	77.7	
0.2% Proof stress in compression* **0.1% Proof stress in compression***	$\sigma_{c0.2}$ $\sigma_{c0.1}$	N/mm^2 N/mm^2	480 [630] 450 [590]	$x\ 10^3\ lbf/in^2$ $x\ 10^3\ lbf/in^2$	69.6 [91.4] 65.3 [85.6]	b
Poissons ratio			0.28		0.28	c
Modulus of elasticity	E	kN/mm^2	172	lbf/in^2	24.8×10^6	
Modulus of rigidity	G	N/mm^2	69000	lbf/in^2	10.00×10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	$1/10^6.K$	12.5	$1/10^6.°F$	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	31	$Btu.in/ft^2.h.°F$	228	d
Patternmakers contraction[7]		%	1.0 – 1.5	%	1.0 – 1.5	
Solid contraction		mm/m	10-16	in/ft	$^1/_8 - ^3/_{16}$	
Density at 20°C	ρ	kg/dm^3	7.2	lb/in^3	0.260	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Material specification

This MEEHANITE Type is produced by quenching an as-cast pearlitic material, so that the resulting matrix is martensitic, which on tempering can produce castings to whatever level of strength and hardness is required for applications involving high stresses and particularly abrasive wear.

Applications

Road ripper cylinders, dredger parts, liners, wear plates and impellers for pulverisers, sludge and ash pumps, crushing, mixing and extrusion parts for brick manufacture, elutriation plates for coal washeries, etc.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep U-notched Charpy test piece [10mm square], average of 3 tests
4 Un-notched Charpy test piece [10mm square]
5 Wöhler rotating bending fatigue test using an un-notched test bar
6 As for [5] but with a circumferential 45° V-notch having a root radius of 0.25mm
7 Depends upon design, size of casting and heat treatment, if any, applied

The references apply to the casting properties on the following page.

a R. Hänchen, Fatigue Limit Diagrams for Steel and Cast Iron, C. Hanser-Verlag, Munich, 1964
b Engineering Data on Nodular Cast irons, BCIRA, Alvechurch, England, 1986
c F. Richter, Giesserei Forschung, 37, 1985, no 3, pp97 - 102
d E. Nechtelberrger *et al.*, Giesserei-Praxis, 1982, Nos.23/24, p380.
e Formerly DIN 1693, Part 2, Oct.1977

MEEHANITE Type SH1000/SH100

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m	0.2% Proof stress in tension* [min] ($R_{p0.2}$)	Compression Strength* [min]	% Elongation	BHN[2]
Europe, Asia	1000 - 1400N/mm^2	600 - 800N/mm^2	1300N/mm^2	1 [min]	280 – 550
Imperial equivalents	*64.8 - 90.7tonf/in^2*	*38.9 - 51.8tonf/in^2*	*~84.2tonf/in^2*		
	~145000 - 203000 lb/in^2	*~87000 - 116000 lb/in^2*	*~188500lb/in^2*		
US	100000 - 170000 lb/in^2	70000 - 130000 lb/in^2		1 [min]	280 – 550
Metric equivalents	*~690 - 1175N/mm^2*	*~480 - 900N/mm^2*			

Values in italics represent imperial/metric conversions.

*Variations in the 0.2% Proof stress values in tension are as a result of the nodularising treatment adopted in the geographical zone:

a). with FeSiMg employed as the nodulariser the ratio of 0.2%PS/UTS ≈ 0.60-0.65,
b). with NiMg employed as the nodulariser the ratio of 0.2%PS [tension]/UTS ≈ 0.70 as a result of the nickel strengthening the ferritic matrix.
c). with NiMg employed as the nodulariser the ratio of 0.2%PS [compression]/UTS > 0.75 as a result of the nickel strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value	Ref
0.1% Proof stress in tension [min]*[1]	$R_{p0.1}$	N/mm^2	470	lb/in^2	68200	
Impact strength[3] [notched] at -40°C [min] -20°C +20°C	A_n	J	≤ 5	ft lbf	≤ 3	
Impact strength[4] [un-notched] at +20°C	A_{un}	J	-	ft lbf	-	
Fatigue limit Rotating bending [un-notched][5] Rotating bending [notched][6] Push - Pull	σ_{bw} σ_{bw} σ_{tcW}	N/mm^2 N/mm^2 N/mm^2	± 370 ± 220 ± 330	lbf/in^2 lbf/in^2 lbf/in^2	± 53700 ± 31900 ± 47900	a
Compression strength*	σ_c	N/mm^2	1300	tonsf/in^2	77.7	
0.2% Proof stress in compression* 0.1% Proof stress in compression*	$\sigma_{c0.2}$ $\sigma_{c0.1}$	N/mm^2 N/mm^2	720 [940] 690 [900]	x 10^3 lbf/in^2 x 10^3 lbf/in^2	104 [136] 100 [131]	b
Poissons ratio			0.29		0.29	c
Modulus of elasticity	E	kN/mm^2	172	lbf/in^2	24.8 x 10^6	
Modulus of rigidity	G	N/mm^2	69000	lbf/in^2	10.00 x 10^6	
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	12.5	1/10^6.°F	6.9	d
Thermal conductivity @ 200°C	λ	W/m.K	31	Btu.in/ft^2.h.°F	228	d
Patternmakers contraction[7]		%	1.0 – 1.5	%	1.0 – 1.5	
Solid contraction		mm/m	10-16	in/ft	$^1/_8 – ^3/_{16}$	
Density at 20°C	ρ	kg/dm^3	7.2	lb/in^3	0.260	

*Variations in the proof stress values in compression are as a result of the nodularising treatment adopted in the geographical zone, see above.

Casting specification

Castings manufactured in these MEEHANITE Types undergo either normalising or quenching and tempering heat treatments resulting in a range of mechanical property values which appear in the graph below. These values are based upon actual test results obtained in MEEHANITE licensed foundries and published data.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress.

The values shown in the graph for tensile strength only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress value remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve the property values shown in the graph.

Other design considerations

Practical design stress values for the mechanical properties tabulated below can be calculated from the given relationships.

Property	Maximum allowable design stress
Direct tension	55% of 0.1% proof stress in tension for ferritic types
	45% of 0.1% proof stress in tension for pearlitic types
Direct compression	60% of 0.1% proof stress in compression
Fatigue	33% of fatigue limit

Casting specification

The range mechanical properties achievable in nodular iron castings produced in MEEHANITE Types **SH800**/**SH100** & **SH1000**/**SH100** can be shown in the graph below, **Figure 1**.

A good combination of hardness, strength and toughness can be obtained by oil quenching from 900^{o}C [1650^{o}F] and tempering [drawing] at 400^{o}C [750^{o}F].

The tempering [drawing] temperature can vary from 200^{o}C [400^{o}F] to 600^{o}C [1100^{o}F]. The lower tempering temperature is sufficient to relieve hardening strains without reducing the maximum hardness value, while the maximum tempering temperature will result in hardness values of approximately BHN300, **Figure 2**.

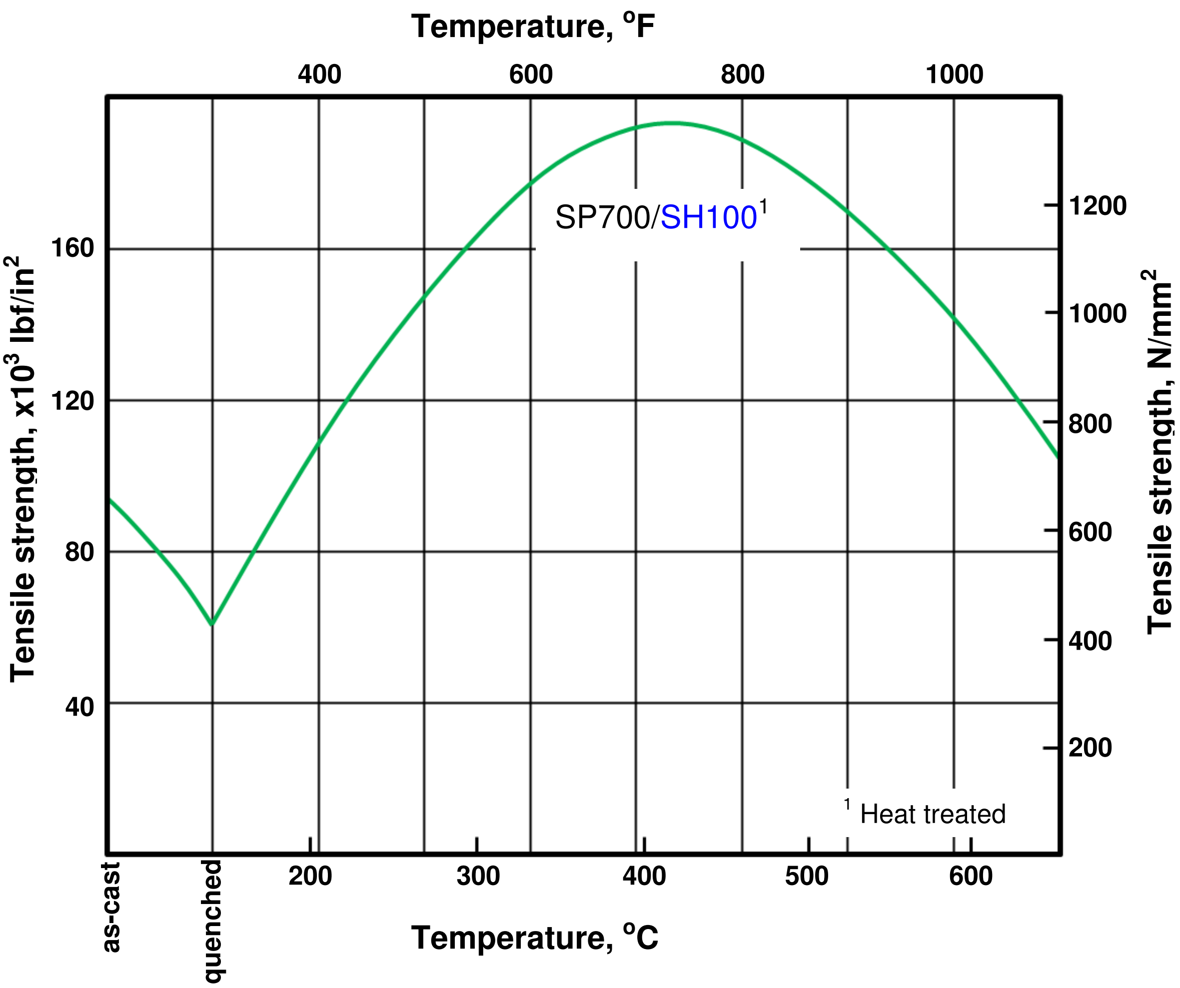


Figure 1 Tempering curve for MEEHANITE Types **SH800**/**SH100** & **SH1000**/**SH100**.

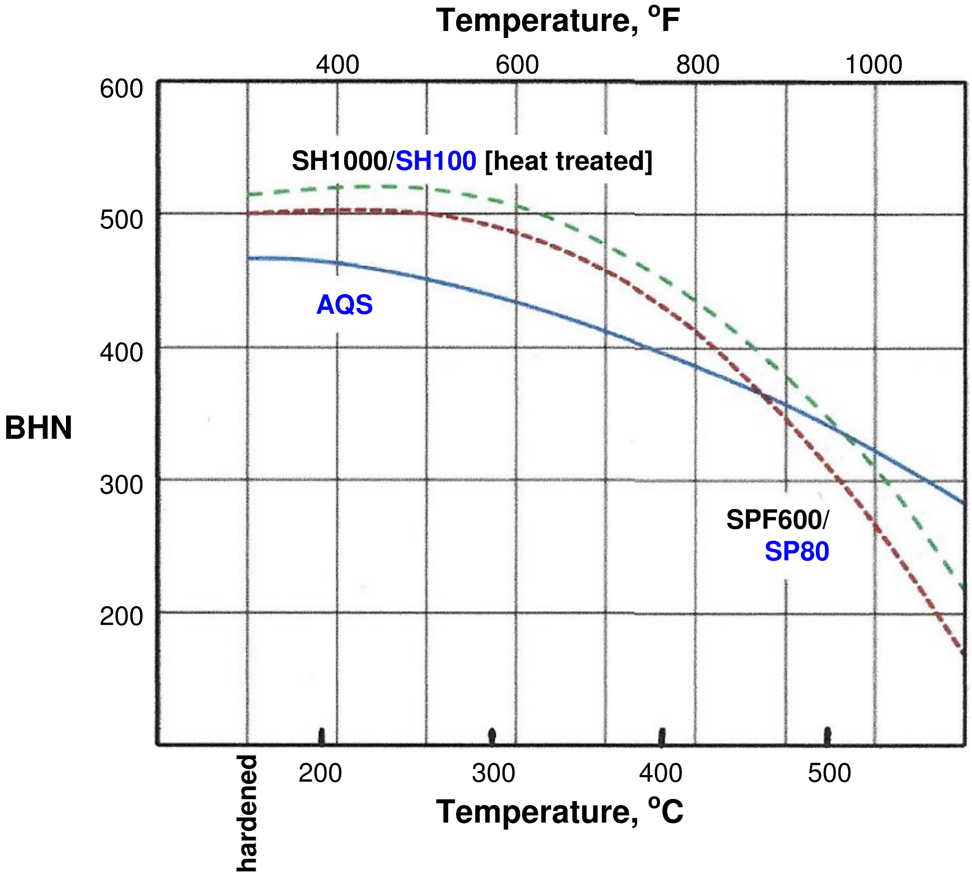
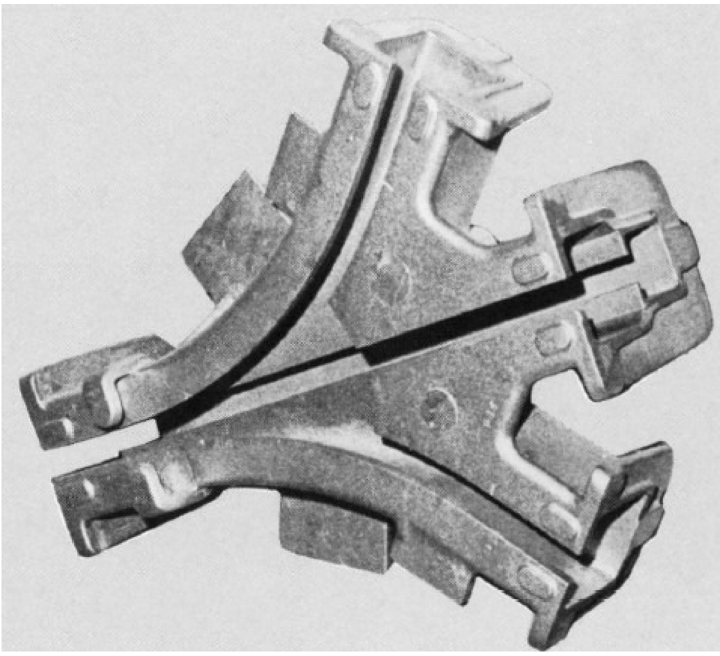


Figure 2 Effect of quenching and tempering on hardness; MEEHANITE Types **SH1000/SH100**, **AQS** and **SPF600/SP80**.



MEEHANITE Type **SH800/SH100** three-way switch casting for an overhead conveyor system requiring superior strength and wear resistance.

MEEHANITE *SECOND GENERATION* NOUDUALR GRAPHITE IRON CASTINGS FOR GENERAL ENGINEERING – Types SFF

Introduction

MEEHANITE Type **SFP500/7** has been a popular material amongst engineering designers for many years. The material is selected as it displays mechanical strengths higher than the predominantly ferritic MEEHANITE Type **SF400.18**.

However, this material does suffer from the problem that it displays section sensitivity. That is, the material contains varying amounts of pearlite depending upon the cooling rate in the casting section in question. This problem, section sensitivity, is amply displayed by the wide variations in tensile strength than can be found in castings made in this material.

More recently, an intermediate material MEEHANITE Type **SF450.10** has been produced to satisfy designer's requirements for a higher mechanical strength accompanied by improved ductility. Once again, improvements in the mechanical strength and ductility values are modest and again, show a degree of section sensitivity due to the amount of pearlite in the matrix.

As a result of further development work in the latter part of the twentieth century within one of the larger groups of European MEEHANITE foundries a family of irons was developed which may be described as silicon solution hardened ferritic nodular irons. With only a predominantly single phase in the matrix the materials display a much lower degree of section sensitivity in general engineering castings up to 30 – 80mm. The irons are not hardenable by heat treatment.

This work has led to the development of a family of fully ferritic second generation MEEHANITE nodular irons designated as follows:

Type **SFF450.18**
Type **SFF500.14**/**SFF70**
Type **SFF600.10**

Whilst there are three materials in this group is it only MEEHANITE Type **SFF500.14**/**SFF70** which has currently gained wide acceptance in the general engineering community. This acceptance is as a direct result of the material's excellent combination of strength, ductility and machinability over a range of service temperatures.

Over the normal range of casting sections encountered in general engineering castings the material **SFF500.14**/**SFF70** displays much lower section sensitivity allowing advantages to be gained during the design phase of any new component. The machinability of this material is said to be much better that the comparable **SFP500.7**.

Of particular interest to the designer is the high proof stress/ultimate tensile strength ratio [~0.75 to 0.80].

The benefits, comparing this new material to the original MEEHANITE Type **SFP500.7**, may be summarised as follows:

- less section sensitivity; that is, mechanical properties are less significantly influenced by casting section [refer to **Figure 3**].and hardness values are almost independent of casting section.
- the hardness distribution throughout a casting is remarkably consistent [**Figure 4**].
- good ductility in the 3.55% to 3.75% silicon range [**Figure 5**]
- no ferritic surface rim in greensand castings
- significantly improved machinability when compared with MEEHANITE SFP500.7 [**Figure 6**].
- increased 0.2% proof stress; up to 20% leading to casting weight reduction [**Figure 7**]
- up to double the elongation values
- higher fracture toughness [K_{1C}] values

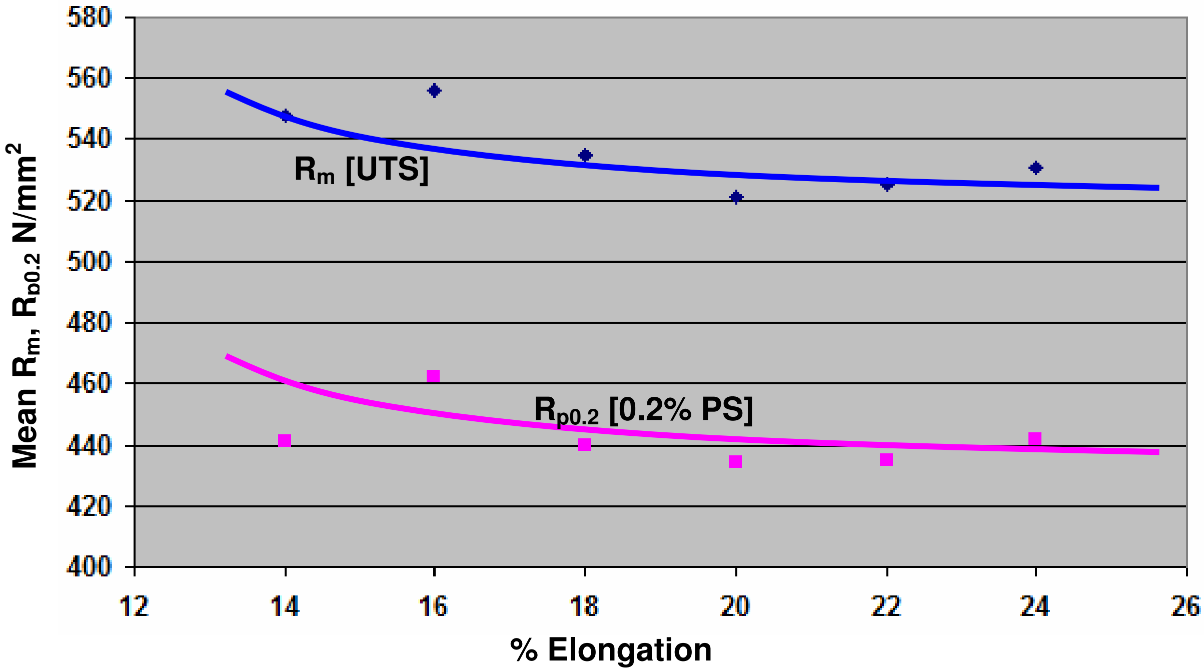
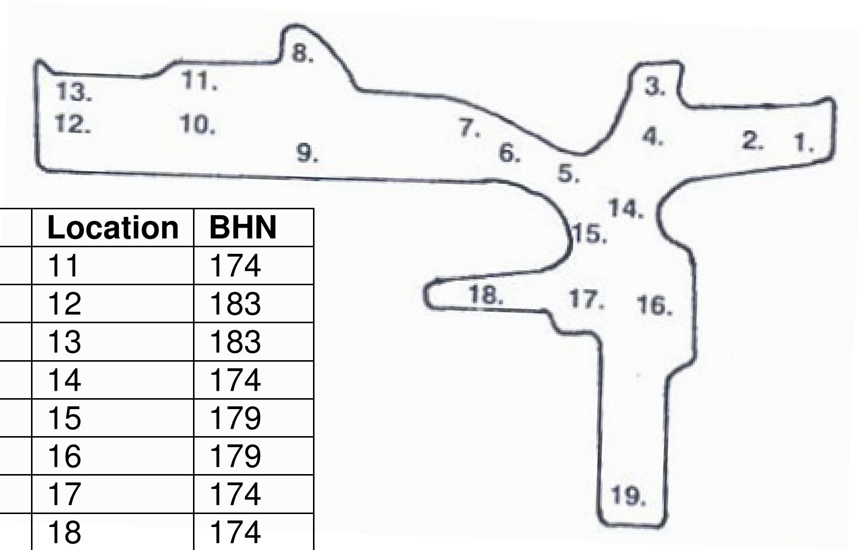


Figure 3 MEEHANITE Type **SFF500.14** showing reduced section sensitivity.



Location	BHN	Location	BHN
1	173	11	174
2	173	12	183
3	173	13	183
4	173	14	174
5	173	15	179
6	173	16	179
7	173	17	174
8	173	18	174
9	176	19	183
10	173		

Figure 4 Consistent hardness distribution in a MEEHANITE Type **SFF500.14** greensand hub casting as a result minimal casting section sensitivity and no ferrite rim.

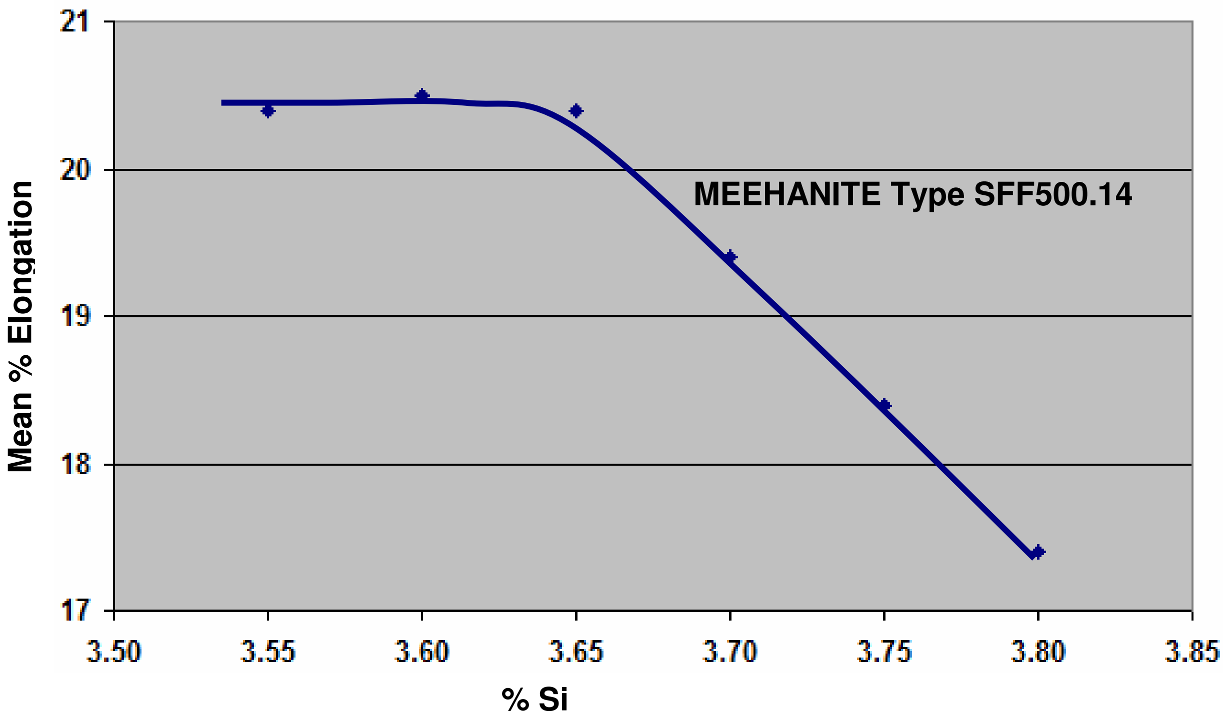


Figure 5 MEEHANITE Type **SFF500.14**: Ductility versus silicon content.

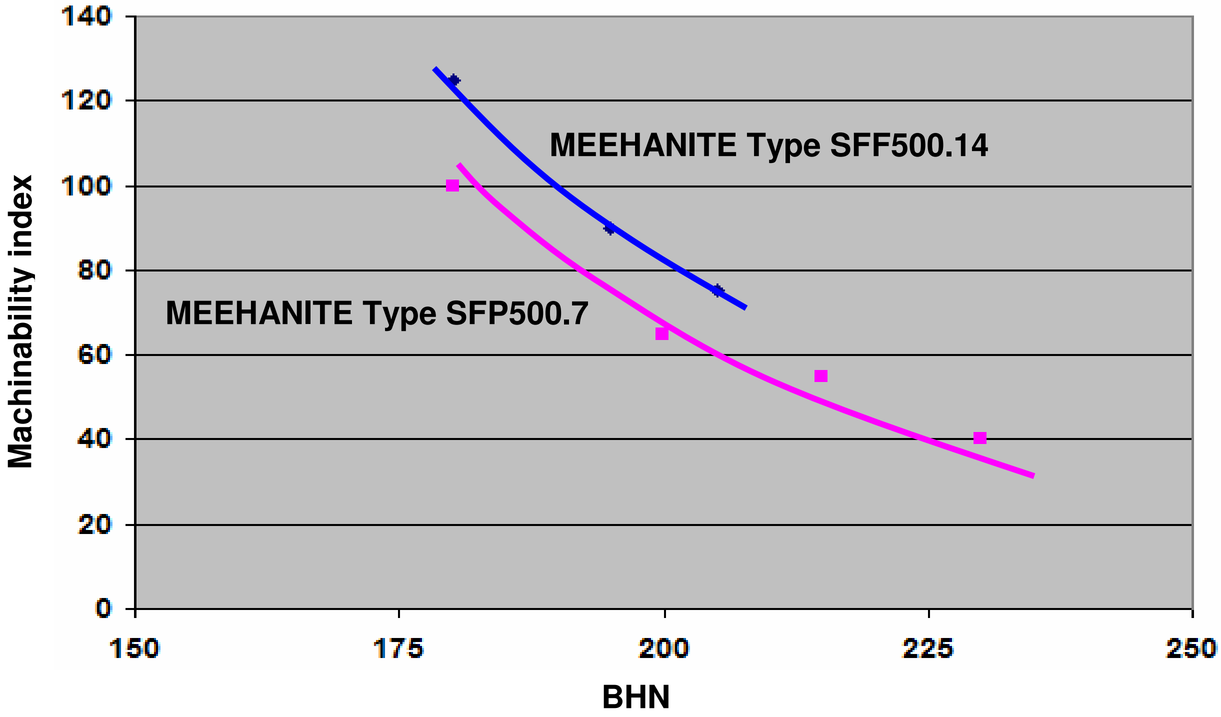


Figure 6 Much improved machinability when compared to MEEHANITE Type **SFP500.7**.

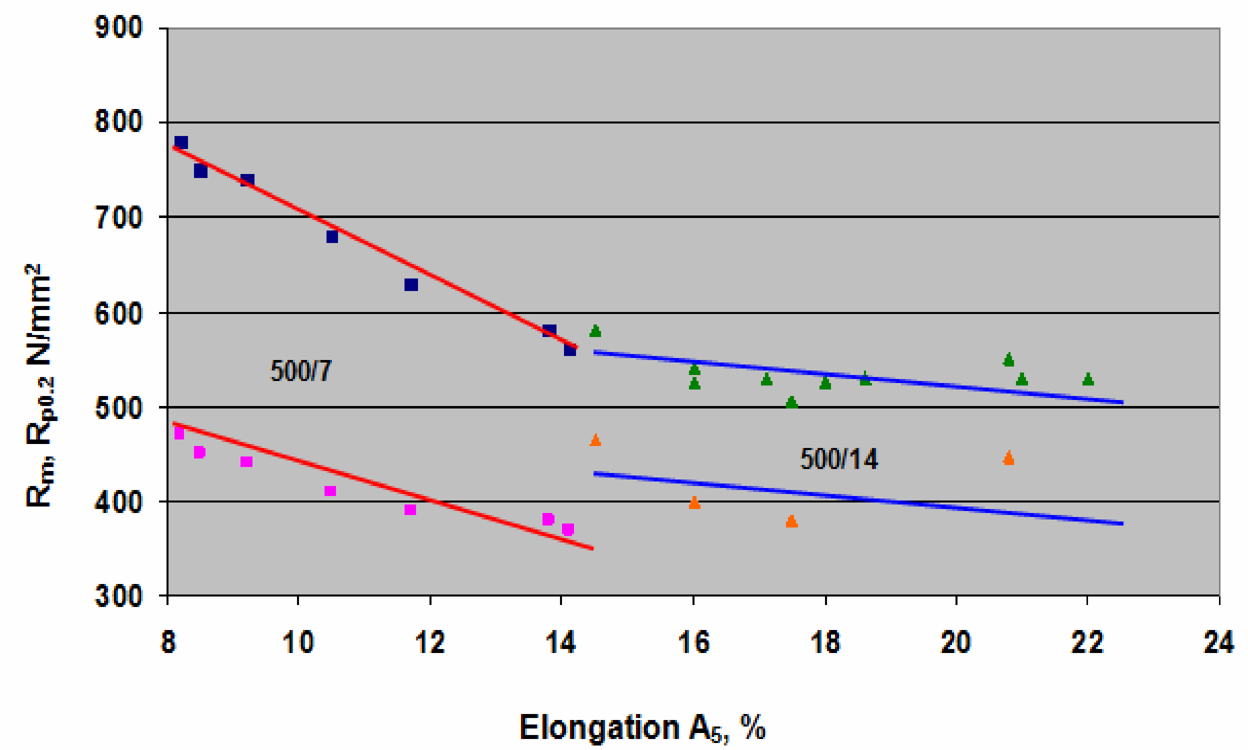


Figure 7 Relationship between ultimate tensile strength and proof stress versus elongation for both MEEHANITE **Type 500/7** and Type **500/14** [up to 60mm section].

MEEHANITE Type SFF450.18

Material specification

The matrix is entirely ferritic, therefore easily machinable, and is produced by either strict control of the raw materials during melting or by additions of silicon to the melt.

Compared with cast steel of similar strength, it is possible to reduce machining times by up to 30%.

As this is a new generation of materials there is still a paucity of information relating to their physical properties. As the information becomes available the following table will be updated.

Applications

Potentially suitable for all general engineering applications, pumps, valves, housings, supports and brackets etc. However, as there is little difference in the casting properties between this grade and MEEHANITE Type **SF450.15**, first generation nodular iron, this material has not yet gained wide acceptance.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep V-notched Charpy test piece [10mm square], average of 3 tests

MEEHANITE Type SFF450.18

Material specification[1]

MEEHANITE Region	Ultimate tensile strength[2] R_m	0.2% Proof stress in tension[2] [min] ($R_{p0.2}$)	% Elongation[2]	BHN[2]
Europe, Asia	450N/mm^2	350N/mm^2	18 [min]	150 – 200
Imperial equivalents	*29.1tonf/in^2*	*22.7tonf/in^2*		
	~65000lb/in^2	*~50700lb/in^2*		
US	65000lb/in^2	50000lb/in^2	18 [min]	150 – 200
Metric equivalents	*~450N/mm^2*	*~345N/mm^2*		

Values in italics represent imperial/metric conversions.

Proof stress:

a). with additional silicon being present in the matrix the ratio of 0.2%PS [tension]/UTS ≈ 0.80 as a result of the element strengthening the ferritic matrix.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Tensile strength at -40°C[2]	$R_{m\ [-40]}$	N/mm^2	-	ft lbf	-
0.2% Proof stress at -40°C[2]	$R_{p0.2\ [-40]}$	N/mm^2	-	ft lbf/in^2	-
Elongation at -40°C[2]	$A_{5\ [-40]}$	%	-	%	-
Impact strength[3] **[notched] at** **-40°C [min]** **-20°C** **0°C** **+20°C**	A_n	J	-	ft lbf	-
Fatigue limit **Push – Pull [10%]** **Push – Pull [90%]**	σ_{tcW}	N/mm^2	-	lbf/in^2	-
Poissons ratio			-		-
Modulus of elasticity	E	kN/mm^2	-	lbf/in^2	-
Modulus of rigidity	G	N/mm^2	-	lbf/in^2	-
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	-	1/10^6.°F	-
Specific heat	c_p	J/g.K	-	cal/g.°C	-
Thermal conductivity @ 200°C	λ	W/m.K	-	cal/g.s.°C	-
Thermal diffusivity	a	mm^2/s	-	in^2/s	-
Patternmakers contraction[7]		%	0.2 – 0.8	%	0.2 – 0.8
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress, however, the extent of this section sensitivity is less than that experienced with the *first* generation nodular irons.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress vale remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

Additionally, as this is a new material and not widely requested the pool of available data is limited with the result that it may well be beneficial for the casting buyer to investigate properties within a particular casting.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

MEEHANITE Type SFF450.18

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	460	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	66720
			60 - 200	70	440		$1^3/_8$" – 8"	$2^{25}/_{32}$"	63820
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	355	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	51490
			60 - 200	70	340		$1^3/_8$" – 8"	$2^{25}/_{32}$"	49310
Elongation [min]	A_5	%	30 - 60	40	18	%	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	18
			60 - 200	70	14		$1^3/_8$" – 8"	$2^{25}/_{32}$"	14
Impact strength [notched] at +20°C	A_n	J	30 - 60	40	-	ft lbf	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	-
			60 - 200	70	-		$1^3/_8$" – 8"	$2^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings @ +20°C

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	460	355	18		**2**	66720	51490	18
50	**80**	440	340	14	**2**	**$3^3/_{16}$**	63820	49310	14
80	**120**	420	320	12	**$3^3/_{16}$**	**4¾**	60920	46410	12
120	**200**	400	310	9	**4¾**	**8**	58020	44960	9

Material specification

This material is for more general engineering applications where components may be required to work under a wide range of temperatures. The material is highly ductile and this property extends well below 0^{o}C.

The matrix is entirely ferritic, therefore easily machinable, and is produced by either strict control of the raw materials during melting or by additions of silicon to the melt.

Compared with cast steel of similar strength, it is possible to reduce machining times by up to 30%.

Applications

Replacements for fabricated, forged and malleable iron components in automobiles, commercial and agricultural vehicles; viz, wheel hubs, differential housings and carriers, stator frames.

Bearing housings, hydraulic cylinders, cross beams and pulleys in marine environments.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep V-notched Charpy test piece [10mm square], average of 3 tests

MEEHANITE Type SFF500.14/SFF70

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength[2] R_m	0.2% Proof stress in tension[2] [min]* ($R_{p0.2}$)	% Elongation[2]	BHN[2]
Europe, Asia	500N/mm^2	400N/mm^2	14 [min]	180 – 210
Imperial equivalents	*32.4tonf/in^2*	*25.9tonf/in^2*		
	~72000lb/in^2	*~58000lb/in^2*		
US	72000lb/in^2	57600lb/in^2	14 [min]	180 – 210
Metric equivalents	*~500N/mm^2*	*~400N/mm^2*		

Values in italics represent imperial/metric conversions.

Proof stress:

a). with additional silicon being present in the matrix the ratio of 0.2%PS [tension]/UTS ≈ 0.80 as a result of the element strengthening the ferritic matrix.

Other mechanical and physical properties[1]

	Symbol	Units	Value	Units	Value
Tensile strength at -40°C[2]	$R_{m\ [-40]}$		520	ft lbf	75400
0.2% Proof stress at -40°C[2]	$R_{p0.2\ [-40]}$	N/mm^2	440	ft lbf/in^2	63800
Elongation at -40°C[2]	$A_{5\ [-40]}$	%	5.0	%	5.0
Impact strength[3] [notched] at -40°C [min] -20°C 0°C +20°C	A_n	J	4 4 5 5	ft lbf	1.7 1.7 2.2 2.2
Fatigue limit Push – Pull [10%] Push – Pull [90%]	σ_{tcW}	N/mm^2	± 320 ± 295	lbf/in^2	± 46400 ± 42800
Poissons ratio					
Modulus of elasticity	E	kN/mm^2	-	lbf/in^2	-
Modulus of rigidity	G	N/mm^2	-	lbf/in^2	-
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10^6.K	-	1/10^6.°F	-
Specific heat	c_p	J/g.K	0.50	cal/g.°C	0.12
Thermal conductivity @ 200°C	λ	W/m.K	23.5	cal/g.s.°C	0.054
Thermal diffusivity	a	mm^2/s	6.80	in^2/s	0.011
Patternmakers contraction[7]		%	0.2 – 0.8	%	0.2 – 0.8
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$
Density at 20°C	ρ	kg/dm^3	7.10	lb/in^3	0.256

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress, however, the extent of this section sensitivity is less than that experienced with the *first* generation nodular irons.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress vale remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

MEEHANITE Type SFF500.14/SFF70

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	540	lbf/in^2	1$^{3}/_{16}$" – 1$^{3}/_{8}$"	1$^{5}/_{8}$"	78320
			60 - 200	70	510		1$^{3}/_{8}$" – 8"	2$^{25}/_{32}$"	73970
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	430	lbf/in^2	1$^{3}/_{16}$" – 1$^{3}/_{8}$"	1$^{5}/_{8}$"	62370
			60 - 200	70	400		1$^{3}/_{8}$" – 8"	2$^{25}/_{32}$"	58020
Elongation [min]	A_5	%	30 - 60	40	16	%	1$^{3}/_{16}$" – 1$^{3}/_{8}$"	1$^{5}/_{8}$"	16
			60 - 200	70	14		1$^{3}/_{8}$" – 8"	2$^{25}/_{32}$"	14
Impact strength [notched] at +20°C	A_n	J	30 - 60	40	-	ft lbf	1$^{3}/_{16}$" – 1$^{3}/_{8}$"	1$^{5}/_{8}$"	-
			60 - 200	70	-		1$^{3}/_{8}$" – 8"	2$^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings @ +20°C

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	540	430	16		**2**	78320	62370	16
50	**80**	510	410	14	**2**	**3$^{3}/_{16}$**	73970	59470	14
80	**120**	490	390	10	**3$^{3}/_{16}$**	**4¾**	71070	56560	10
120	**200**	470	370	8	**4¾**	**8**	68170	53660	8

Casting specification: guidance values for properties in castings @ - 40°C

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	to	Tensile strength N/mm^2	0.2% Proof stress N/mm^2	Elongation %	from	to	Tensile strength lb/in^2	0.2% Proof stress lb/in^2	Elongation %
	50	550	440	6		**2**	79770	63820	6
50	**80**	540	430	5	**2**	**3$^{3}/_{16}$**	78320	62370	5

Material specification

This material can be used for general engineering applications where components have to display a good strength and ductility at ambient temperatures.

The matrix is entirely ferritic, therefore easily machinable, and is produced by either strict control of the raw materials during melting or by additions of silicon to the melt. As the matrix is fully ferritic the material cannot be hardened by heat treatment unlike MEEHANITE Type **SPF600**.

Compared with cast steel of similar strength, it is possible to reduce machining times by up to 30%.

As this is a new generation of materials there is still a paucity of information relating to their physical properties. As the information becomes available the following table will be updated.

Applications

The range of applications is limited as this material has yet to gain wide acceptance. Castings currently being made in this material are housings, and bearing frames.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 25mm diameter proportional test pieces taken from separately cast test samples
3 2mm deep V-notched Charpy test piece [10mm square], average of 3 tests

MEEHANITE Type SFF600.10

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength[2] R_m	0.2% Proof stress in tension[2] [min]* ($R_{p0.2}$)	% Elongation[2]	BHN[2]
Europe, Asia	600N/mm²	470N/mm²	10 [min]	210 – 250
Imperial equivalents	*38.9tonf/in²*	*30.4tonf/in²*		
	~87000lb/in²	*~68000lb/in²*		
US	90000lb/in²	70000lb/in²	10 [min]	210 – 250
Metric equivalents	*~620N/mm²*	*~480N/mm²*		

Values in italics represent imperial/metric conversions.

Proof stress:

a). with additional silicon being present in the matrix the ratio of 0.2%PS [tension]/UTS ≈ 0.80 as a result of the element strengthening the ferritic matrix.

Other mechanical and physical properties[1]

	Symbol	Units	Value	Units	Value
Tensile strength at -40°C[2]	$R_{m\ [-40]}$		-	ft lbf	-
0.2% Proof stress at -40°C[2]	$R_{p0.2\ [-40]}$	N/mm²	-	ft lbf/in²	-
Elongation at -40°C[2]	$A_{5\ [-40]}$	%	-	%	-
Impact strength[3] [notched] at -40°C [min] -20°C 0°C +20°C	A_n	J	-	ft lbf	-
Fatigue limit Push – Pull [10%] Push – Pull [90%]	σ_{tcW}	N/mm²	-	lbf/in²	-
Poissons ratio			-		-
Modulus of elasticity	E	kN/mm²	-	lbf/in²	-
Modulus of rigidity	G	N/mm²	-	lbf/in²	-
Coefficient of thermal expansion 20°C – 100°C	α_l	1/10⁶.K	-	1/10⁶.°F	-
Specific heat	c_p	J/g.K	-	cal/g.°C	-
Thermal conductivity @ 200°C	λ	W/m.K	-	cal/g.s.°C	-
Thermal diffusivity	a	mm²/s	-	in²/s	-
Patternmakers contraction[7]		%	0.2 – 0.8	%	0.2 – 0.8
Solid contraction		mm/m	8	in/ft	$^1/_{32}$ – $^3/_{32}$
Density at 20°C	ρ	kg/dm³	7.10	lb/in³	0.256

Casting specification

The mechanical property values which appear in the following tables are based upon actual test results obtained in MEEHANITE licensed foundries.

In common with other ferrous and non-ferrous materials, many of the properties of nodular cast iron are influenced by the cooling rate of the casting, which is proportional to wall section or casting modulus. This section sensitivity applies particularly to the values of tensile strength and elongation, but less so in the case of proof stress, however, the extent of this section sensitivity is less than that experienced with the *first* generation nodular irons.

The values quoted in the table for tensile strength and elongation only apply to sound castings. The presence of microporosity will adversely affect these values even when the proof stress vale remains relatively unaffected.

Equally, those properties, such as fatigue strength, which have a direct correlation with tensile strength will also suffer a corresponding reduction in values as a result of either section sensitivity or incidences of microporosity; whereas properties related to proof stress, such as Poisson's Ratio and the elastic moduli, are relatively unaffected.

Additionally, as this is a new material and not widely requested the pool of available data is limited with the result that it may well be beneficial for the casting buyer to investigate properties within a particular casting.

The actual property levels in any specific part of a casting can only be guaranteed by close liaison and agreement between the MEEHANITE casting supplier and purchaser. Through development programmes agreed between the foundry and customer it is possible to achieve property values well above those quoted in the table by adopting the most recent technical refinements to the casting process.

MEEHANITE Type SFF600.10

Casting specification: cast-on test bars

	Symbol	Units	Ruling wall section in casting, mm	Thickness of cast-on test piece, mm	Value	Units	Ruling wall section in casting, in	Thickness of cast-on test piece, in	Value
Tensile strength [min]	R_m	N/mm^2	30 - 60	40	610	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	88470
			60 - 200	70	590		$1^3/_8$" – 8"	$2^{25}/_{32}$"	85570
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	30 - 60	40	480	lbf/in^2	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	69620
			60 - 200	70	460		$1^3/_8$" – 8"	$2^{25}/_{32}$"	66720
Elongation [min]	A_5	%	30 - 60	40	11	%	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	11
			60 - 200	70	8		$1^3/_8$" – 8"	$2^{25}/_{32}$"	8
Impact strength [notched] at +20°C	A_n	J	30 - 60	40	-	ft lbf	$1^3/_{16}$" – $1^3/_8$"	$1^5/_8$"	-
			60 - 200	70	-		$1^3/_8$" – 8"	$2^{25}/_{32}$"	-

Casting specification: guidance values for properties in castings @ +20°C

Wall section, mm		Expected minimum values in the casting			Wall section, in		Expected minimum values in the casting		
from	**to**	**Tensile strength N/mm^2**	**0.2% Proof stress N/mm^2**	**Elongation %**	**from**	**to**	**Tensile strength lb/in^2**	**0.2% Proof stress lb/in^2**	**Elongation %**
	50	620	490	11		**2**	89920	71070	11
50	**80**	590	470	8	**2**	**$3^3/_{16}$**	85570	68170	8
80	**120**	570	450	6	**$3^3/_{16}$**	**4¾**	82670	65270	6
120	**200**	550	430	4	**4¾**	**8**	79770	62370	4

MEEHANITE Types SP750 – SHB1250

Introduction

This is a new range of materials developed to replace steel in medium sized castings [up to 5t] working under arduous conditions including high impact loading. This low alloy range of nodular irons, which responds to conventional heat treatment, was developed as an alternative to the MEEHANITE Type **ADI** castings which require more specialised less environmentally sound heat treatment procedures.

The safety critical nature of the castings developed using this material necessitated pairs of castings being produced at a time with test bars being cut from one of the twins. All properties quoted are, therefore, from castings rather than either separately cast or cast-on test bars.

The test bar results indicate that this material is strong yet reasonably ductile ensuring that it has good shock resistance.

Applications

Components for use in highly stressed manufacturing process equipment.

Casting specification: guidance values for properties in castings

MEEHANITE Type SP750 & SHPB750

	SP750 – as-cast	**SHPB750 – heat treated**
Wall thickness, mm [in]	**<100 [4]**	**<200 [8]**
Tensile strength, N/mm^2	760 - 780	700 - 800
0.2% Proof stress, N/mm^2	450 - 470	620 - 680
% Elongation	4.0 – 6.0	4.5 – 8.5
Impact strength,[notched], J	-	-
BHN	245 - 270	225 - 240

MEEHANITE Type SP850 & SHPB850

	SP850 – as-cast	**SHPB850 – heat treated**
Wall thickness, mm [in]	**<200 [4]**	**<100 [4]**
Tensile strength, N/mm^2	800 - 900	850 - 900
0.2% Proof stress, N/mm^2	490 - 560	490 - 580
% Elongation	4.0 – 8.5	4.5 – 7.5
Impact strength,[notched], J	-	4.0 – 9.0
BHN	215 - 230	220 - 240
Fracture toughness, K_{1c}, MPa m$^{1/2}$	-	55 - 65

MEEHANITE Type SHB950

		SHB950 – heat treated
Wall thickness, mm [in]		<200 [8]
Tensile strength, N/mm^2		925 - 950
0.2% Proof stress, N/mm^2		525 - 550
% Elongation		4.0 – 5.0
Impact strength,[notched], J		-
BHN		230 - 245

MEEHANITE Type SHB1250

		SHB1250 – heat treated
Wall thickness, mm [in]		<200 [8]
Tensile strength, N/mm^2		1250 - 1325
0.2% Proof stress, N/mm^2		840 - 900
% Elongation		5.0 – 6.0
Impact strength,[notched], J		-
BHN		280 - 550

Introduction

Austempered ductile iron [**ADI**] was developed and manufactured in a MEEHANITE foundry in the early 1970's as a high strength and hard wearing low alloyed material produced by a special isothermal heat treatment. The heat treatment requires an interrupted quench usually into a salt bath. The resulting material has a combination of exceptional strength and toughness, meeting and often exceeding those of alloy steels and the general engineering Types of nodular iron.

Austempered ductile iron can be made in sections up to about 150mm [6"] but to achieve fully austempered microstructures in sections over ~90mm [~3½"] requires a specialised and proprietary MEEHANITE heat treatment process along with carefully controlled alloying.

For applications where wear resistance is the major issue, it is a simple matter of adjusting the heat treatment to obtain higher hardness and strength values, but this is achieved with some sacrifice to toughness. It should also be remembered that this material will work harden on the surface, and so the material will, under the right circumstances, wear better than the quoted hardness values would suggest, and as a result MEEHANITE **ADI** will often out wear other materials of the same hardness.

Typical applications for MEEHANITE **ADI** are where high strength is needed and where excellent wear resistance and fatigue strength are required. Such an application is gears and MEEHANITE **ADI** has been used with great success. This tough work hardening material has proved to be an excellent replacement for hardened steels. The use of MEEHANITE **ADI** can result in less weight, reduced number of components, quieter running; because it has a lower modulus than steel, better face to face contact can be achieved which reduces the Hertzian or contact stress on the surfaces of the teeth.

Also MEEHANITE **ADI** will work harden which adds to the contact fatigue strength. As a result, gear face widths and diameters can be reduced which will enable the gear run better axially and also reduces weight, and at the same time provide better protection under overload conditions. The superior tribological properties of MEEHANITE **ADI** have resulted in the elimination of bronze bearing bushes, and will allow the gears to run temporarily without lubrication. Due to the type of matrix structure the softer grades of MEEHANITE **ADI** can be shot-peened to double the root fatigue strength. One caveat to be aware of is that MEEHANITE **ADI** is not suitable for applications where the service temperature reaches in excess of 350°C [660°F].

Another common application of MEEHANITE **ADI** has been crankshafts and axles. The majority of sealed-for-life refrigeration units are made with austempered crankshafts. Axle applications benefit from the material's lack of notch sensitivity, good fatigue strength and reasonable machinability.

The railroad industry makes extensive use of the material in retarders [brake blocks] and rolling stock. MEEHANITE **ADI** is commonly used in brake shoes where its superior quietness and wear resistance is appreciated in urban/semi-residential communities.

MEEHANITE **ADI** brake beams have also been shown to outlast steel beams, and withstand cold weather, with savings of more than 20%. Also steel forged track shoes are being replaced by MEEHANITE **ADI** shoes in all forms of tracked vehicles.

Typical applications for the material

Abrasive protection liners
Bearing sleeves
Brake shoes
Bushing sleeves
Cable drums
Camshafts
Chain sprockets
Connecting rods
Cultivating tools
Differential spiders
Drive shafts
Engine mounting brackets
Friction blocks
Ground engaging tools
Guide rolls
Hydraulic pump bodies
Piston sleeves
Pulleys
Pump impellers
Rack and pinion gearing
Railroad car wheels
Shredder knives
Steering knuckles
Shells and projectiles
Trolley wheels
Wear plated and guides
Wire guides

There are four specifications of MEEHANITE **ADI** and these are defined most conveniently by either their strength [Worldwide] or average hardness values [North America].

MEEHANITE Type ADI900/K300

This is the softest of the grades, with the highest elongation and exceptional impact values. Though the tensile strength is no higher than that which can be achieved with normal quenched and tempered nodular iron; the much higher impact and elongation values make this an attractive material for extreme applications. As the softest of the four grades with the highest percentage of retained austenite [30% to 40%] it is the grade most readily able to surface work harden and thus wear better than its hardness would suggest.

Though all nodular irons benefit from shot-peening to improve fatigue strength this material especially benefits from this treatment. Bending fatigue strength is almost doubled by shot-peening and, in fact, raised to the level found in MEEHANITE **ADI1600/K500**.

Applications

This is an ideal material for gears of all types, crankshafts, couplings or any application where high impact and fatigue strengths are required.

MEEHANITE Type ADI1000

This is the second softest grade having slightly higher tensile strength values and slightly lower elongations. It contains 20% to 30% retained austenite and may be shot-peened to improve its fatigue strength.

Applications

This material is used for similar general engineering applications to that of MEEHANITE Type **ADI900**/**K300**

MEEHANITE Type ADI1200/K400

This is one of the middle grades specified for high strength combined with moderate elongation and impact values. The ability to cast this material into complex shapes makes it a perfect replacement for many steels reducing casting volume and weight.

Applications

Often specific applications such as differential spiders, bearing rolls, annular type gears, structural suspension parts, disc brake rotors, retarder shoes and cast axe heads

MEEHANITE Type ADI1600/K500

This the hardest and strongest grade specified with a minimum tensile strength of 1600N/mm^2 [230,000lbf/in^2] whilst at the same time capable of reaching 1725N/mm^2 [250,000lbf/in^2] and still maintaining impact values typical of those found in regular pearlitic types of nodular iron.

Applications

This material is designed for severe wear applications such as crushing and grinding. It should be understood that this material at its highest hardness will probably contain some martensite which is ideal for crushing and grinding applications but not for impact.

To maximise impact resistance the material should be specified at the lower end of its hardness range; i.e. BHN450 – BHN500. In this form the material is even used for gears. Other applications include snowplough runners, coal mill hammers and muller wheels.

MEEHANITE ADI Types

Machining ADI

Machining of MEEHANITE **ADI** is generally speaking, possible, using normal machining techniques. Only tapping of small diameter holes [especially flat bottomed ones] and scraping of the softest Type is very difficult due to work hardening.

It is, however, common practice to machine near to final size and then heat treat. This is possible because the material before heat treatment is considered “soft” and the consequent volume changes during heat treatment are small and predictable with volume expansion of 0.2% to 0.4%.

MEEHANITE ADI Material specifications

MEEHANITE Type			**ADI900 /K300**	**ADI1000**	**ADI1200 /K400**	**ADI1600 /K500**
Property						
Tensile strength [min]		**N/mm^2**	900	1000	1200	1600
		$x\ 10^3\ lbf/in^2$	130	145	175	230
0.2% Proof stress [min]		**N/mm^2**	675	875	960	1275
		$x\ 10^3\ lbf/in^2$	98	127	140	185
% Elongation			8 - 14	5 - 8	2 - 8	<4
BHN			280 - 310	300 - 350	380 - 430	450 - 550
Endurance limit	**Un-notched**	**N/mm^2**	440	466	510	580
		$x\ 10^3\ lbf/in^2$	63	67	74	85
	Notched	**N/mm^2**	270	320	360	430
		$x\ 10^3\ lbf/in^2$	39	43	51	62
Endurance ratio			0.49	0.48	0.48	0.46
Charpy impact	**Un-notched**	**J**	100 - 120	80 - 100	60 - 90	<50
		ft.lbf	76 - 91	61 - 76	46 - 69	<38
	Notched	**J**	11 - 15	10 - 15	8 - 14	2 - 11
		ft.lbf	5 - 7	4 - 7	4 - 6	1 - 5
Retained austenite			30 - 40	20 - 30	10 - 20	<5

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

Introduction

It is as well to note that no one Type of MEEHANITE iron will successfully meet all the conditions where varying degrees of heat occur in service. Constant heating, intermittent heating and cooling, flame impingement, erosion, abrasion and complicated stress loadings whilst under heating or cooling conditions are some of the situations met in service.

A casting may thus have to resist growth, distortion, oxidation, cracking and frequently corrosive attack at one and the same time.

The selection of the correct Type of MEEHANITE, therefore, needs care. No cast iron can be guaranteed to resist heating conditions for long periods and maintain reasonable strength at temperatures approaching 900^{o}C [1650^{o}F].

The design of the component plays a very important part in castings used for heat resistance work. Whilst it is not intended to go into the matter in detail here the general rule is that uniform casting thickness should be adopted. The avoidance of light and heavy section junctions wherever possible will materially help to prolong the service life of the casting; particularly when under the influence of thermal stressing.

The designer is warned against blind acceptance of text book data from tests usually made solely under laboratory controlled conditions which, more often than not, are performed under constant temperature rarely obtained in service.

Usually it will be found that in service a compromise must be reached in order to meet the actual service conditions. It will be generally found more acceptable to make simulated service tests of the actual part rather than to rely upon the data obtained from laboratory testing.

To meet these varied conditions MEEHANITE has developed, over the years, a number of heat resisting irons each having a different combination of properties.

The heat resisting MEEHANITE Metals are designated: **HD**, **HE**/**HE**, **HR**/**HR**, **SC**, **HS**/**HS**, **HSV**/**HSV**, **PC400** and **FC300** and are divided into three main groups.

Group 1

Castings subjected to thermal shock [rapid heating and cooling] Types recommended for these service conditions are **HD** and **HE**/**HE**. For temperature conditions which are not severe but where a reasonable level of strength and machinability are important factors MEEHANITE Type **HE**/**HE** is the more suitable.

The individual characteristics and uses of each of these materials are dealt with separately, later.

Group 2

Castings subjected to continuous heating [scale and growth resistance]. Types recommended for such service are **HR**/**HR**, **SC, HS**/**HS** and **HSV**/**HSV**.

Group 3

Where heating is intermittent, conditions of thermal shock exist and crazing and cracking are problems then MEEHANITE Type **HE**/**HE** has been used traditionally. It is soft and easily machined but is unsuitable for constant high temperature conditions involving severe scaling and growth. Its role has been superseded, for example; in ingot moulds, by the recently developed compacted graphite irons which are available in two grades; the pearlitic MEEHANITE Type **PC400** and the ferritic MEEHANITE Type **FC275**.

There are of course certain conditions of service that overlap between each group. The final choice must be made only after full consideration of the actual service requirements.

Effect of operating temperature ranges on casting properties

The results of exhaustive tests on flake graphite Types of MEEHANITE show that the tensile strength and limit of proportionality increase on heating up to 320°C [610°F] and then return to ambient values at a temperature of approximately 390°C [735°F] after which there is a gradual loss of strength.

Modulus of elasticity values may also be taken as reasonably established and maintained up to a temperature of 300°C [570°F] after which there is a gradual fall.

Thus MEEHANITE will retain a high proportion of its strength over an important range of temperatures; namely, 0°C to 400°C [32°F to 750°F]; thereby, meeting the severe service requirements found in most installations involving the use of superheated steam and similar applications.

Tests on the effect of sub-zero temperatures have shown the tensile strength of the flake graphite Types of MEEHANITE is practically unaffected down to temperatures as low as -200°C [-330°F]. Some loss of impact strength occurs at low temperatures. At -60°C [-76°F] a reduction of some 5% to 10% has been found in un-notched bar impact values [see section on Additional Comparative MEEHANITE Engineering Data]. At the same temperature, notched bar values have shown a loss in the range 10% to 15% as compared with the corresponding room temperature values.

In the case of the nodular graphite range of MEEHANITE, notched impact strength values assume significance in the specifications. The impact values of the ferritic Types drop with fall in temperature in the sub-zero range, dramatically so, at the transition temperature. The minimum values for various sub-zero temperatures are specified under the appropriate Types.

Up to 400°C [750°F]

In this temperature range all Types of MEEHANITE will perform satisfactorily. It is customary to use the General Engineering Types of MEEHANITE rather than the special Heat Resistant Types. It is not particularly important whether heating conditions are steady or cyclic.

400°C to 675°C [750°F to 1250°F]

At temperatures above 400°C [750°F] the loss of hardness and mechanical strength in all materials is quite rapid, [see **Table I**]. As a result creep strength is considered more important in this temperature range and little emphasis is given to short time mechanical strength values.

Table I Typical BHN for MEEHANITE Types values at elevated temperatures.

MEEHANITE Type	Temperature, °C [°F]				
	400 [750]	480 [900]	540 [1000]	590 [1100]	675 [1250]
GA350/GA50	225	205	182	139	-
GC275/GC40	212	197	180	134	-
HR/HR	288	260	230	176	133

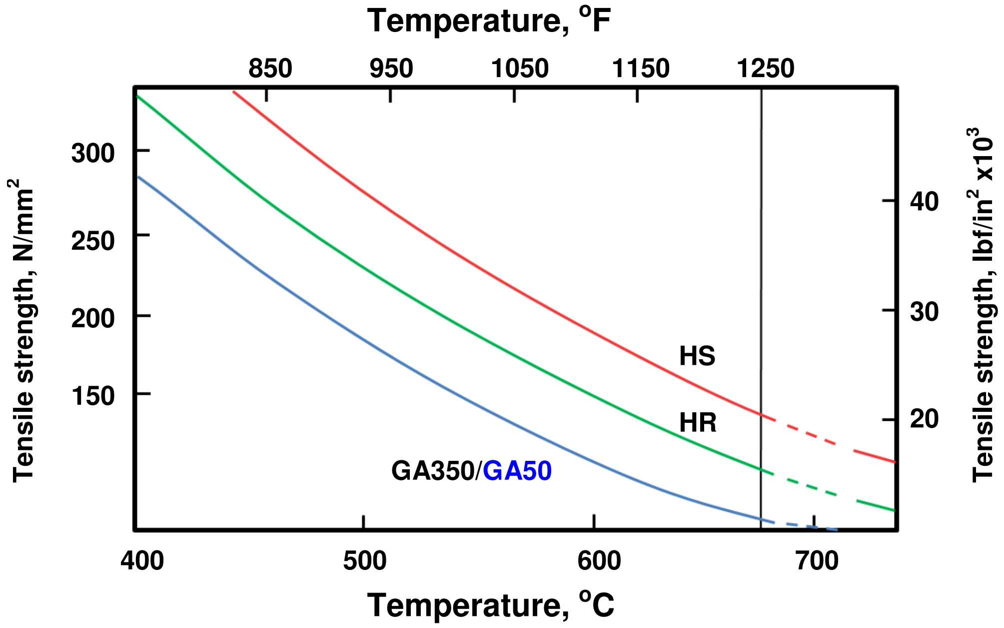


Figure 8 Tensile strength of some MEEHANITE flake irons from 400°C to 675°C [750°F to 1250°F].

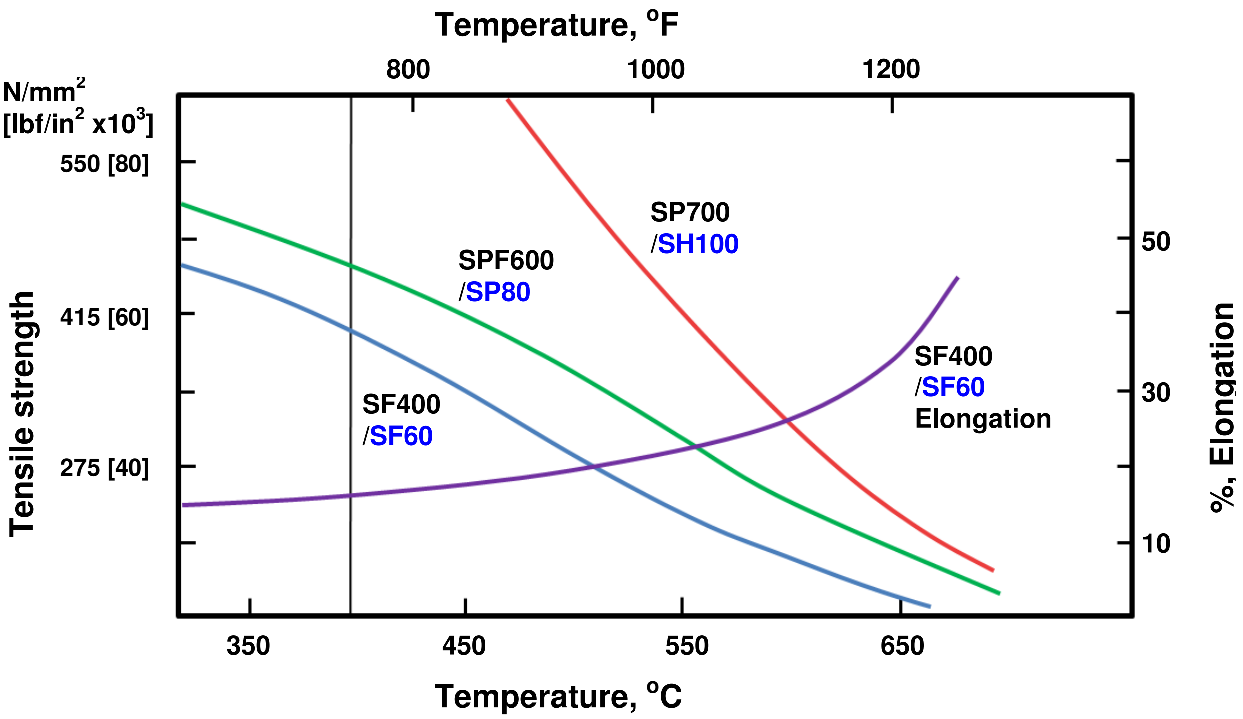


Figure 9 Tensile strength of some MEEHANITE nodular irons from 400°C to 675°C [750°F to 1250°F].

Resistance to plastic flow or creep is a major design consideration particularly in this temperature range. The General Engineering Types of flake graphite are not normally considered for use at the upper end of this range, **Figure 8**; the MEEHANITE nodular iron Types, however, have good tensile strengths and data on the short term tensile values are shown in **Figure 9**

The heat resistant Types **HR**/**HR** and **HS**/**HS** are recommended for use in the upper region of this temperature range [**Figure 8**] because of their overall heat resisting ability.

Creep is usually expressed as stress to rupture at various temperatures for specified times and is covered in a separate section.

675°C to 870°C [1250°F to 1600°F]

Loss of strength and hardness above 675°C [1250°F] is quite severe in all metals. In design involving load at these temperatures, allowance must be made for low load bearing capacities.

Despite low strength values MEEHANITE Types **HR**/**HR**, **HS**/**HS** and **HSV**/**HSV** are giving good service in the hot forming of titanium and other metals in this and higher temperature ranges.

Short term tensile strength values for **HS**/**HS** and **HSV**/**HSV** are shown in **Figure 10**.

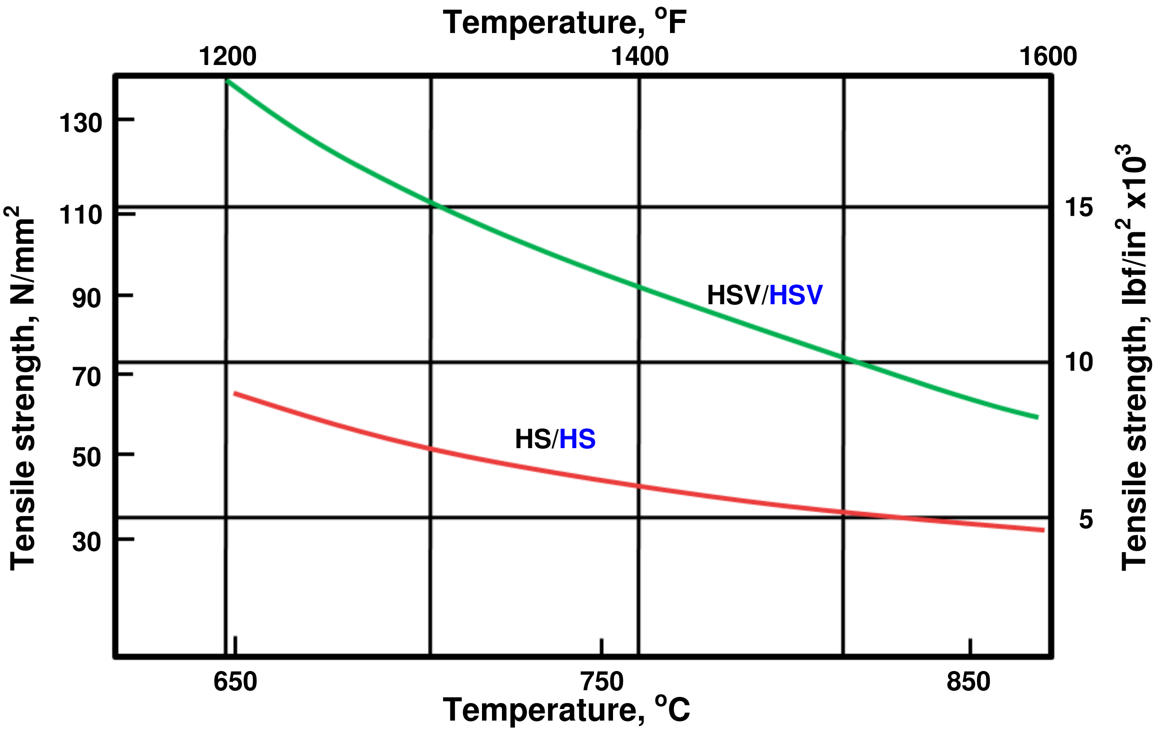
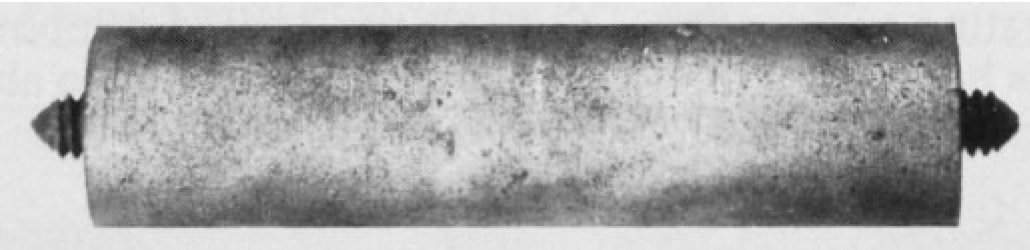


Figure 10 Short time high temperature strength of MEEHANITE Types **HS**/**HS** and **HSV**/**HSV**.



Type **HS**/**HS** MEEHANITE casting heated to and cooled from 870°C [1600°F] for a period of 300 hours showing no growth or scaling.

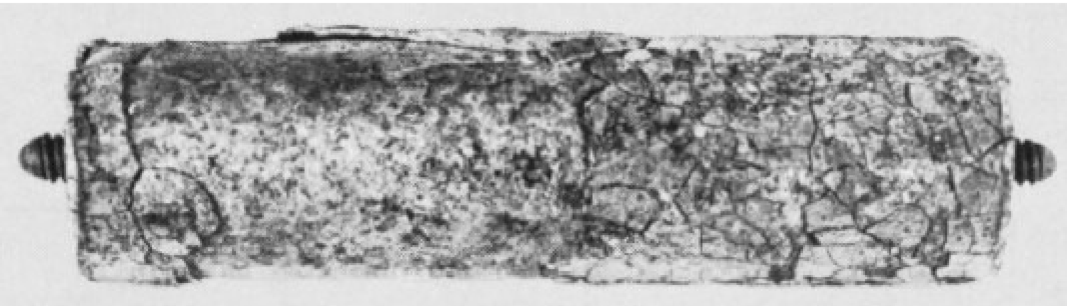


Figure 11 Alloy iron casting given the same test as above showing considerable growth and scaling.

Oxidation and scaling can become severe in the 675°C to 870°C [1250°F to 1600°F] temperature range. The scale resistant ability of Types **HS**/**HS**, **HSV**/**HSV**, **HR**/**HR** and **SC** is excellent under most conditions. The behaviour of Type **HS**/**HS** MEEHANITE is well illustrated in a special test conducted where a sample is repeatedly heated to and cooled from 870°C [1600°F] in an oxidising atmosphere, **Figure 11**.

MEEHANITE Type **HS**/**HS** forms a tight adhering oxide scale which effectively prevents further deterioration due to oxide penetration towards the centre of the sample.

870°C to 980°C [1600°F to 1800°F]

For the temperature range 870°C to 980°C [1600°F to 1800°F] mechanical properties fall off so rapidly that they become quite meaningless when considering them in the context of design. Selection of the right material for a given application becomes a matter of judgement based upon proven experience. For service in this temperature range only three Types of MEEHANITE are recommended.

MEEHANITE Type **HS**/**HS**, which compares very favourably from a strength standpoint with any heat resisting metal, is recommended for applications at temperatures above 900°C [1650°F], in a furnace gas atmosphere, and where either intermittent heating and cooling or continuous heating may be encountered without thermal shock. The yield stress in compression for MEEHANITE Type **HS**/**HS** over the temperature range of 850°C to 980°C [1560°F to 1800°F] is shown in **Figure 12**.

MEEHANITE Type **HE**/**HE** is recommended for cyclical heating applications involving severe shock. Large continuous graphite flakes contained in the metal structure dissipate heat stresses. Because of this the material has relatively moderate mechanical properties; tensile – ~210N/mm^2 [30000lbf/in^2] and compression ~900N/mm^2 [130000lbf/in^2].

Manufacturing procedures used give MEEHANITE Type **HE**/**HE** the optimum microstructure. it is particularly suited for applications such as ingot moulds, slag pots and bottle moulds. In bottle moulds it is customary to densen the working or machined surface of the mould by using chills. Type **HE**/**HE** when chilled will give the desired combination of metal density coupled with the ability to absorb heat stresses.

The use of MEEHANITE Type **SC** is also practical up to 900°C [1650°F]; it is recommended where temperatures remain fairly constant and thermal shock does not pose a problem. The microstructure consists of flake graphite in a matrix of silico-ferrite enabling the material to exhibit little or no growth up to 900°C [1650°F]. It also scales very slowly.

Creep characteristics

MEEHANITE possesses good creep resistance in the temperature range 350°C to 450°C [660°F to 840°F]. In the case of flake graphite Types of MEEHANITE, Type **GA350**/**GA50** has been found to withstand a stress of 155N/mm^2 [22480lbf/in^2] at 400°C [750°F] without exceeding the creep rate of 10^{-6} per hour.

As temperatures rise above 400°C [750°F], creep strength tends to fall rapidly and at 450°C [840°F], Type **GM400**/**GM60** is more suitable.

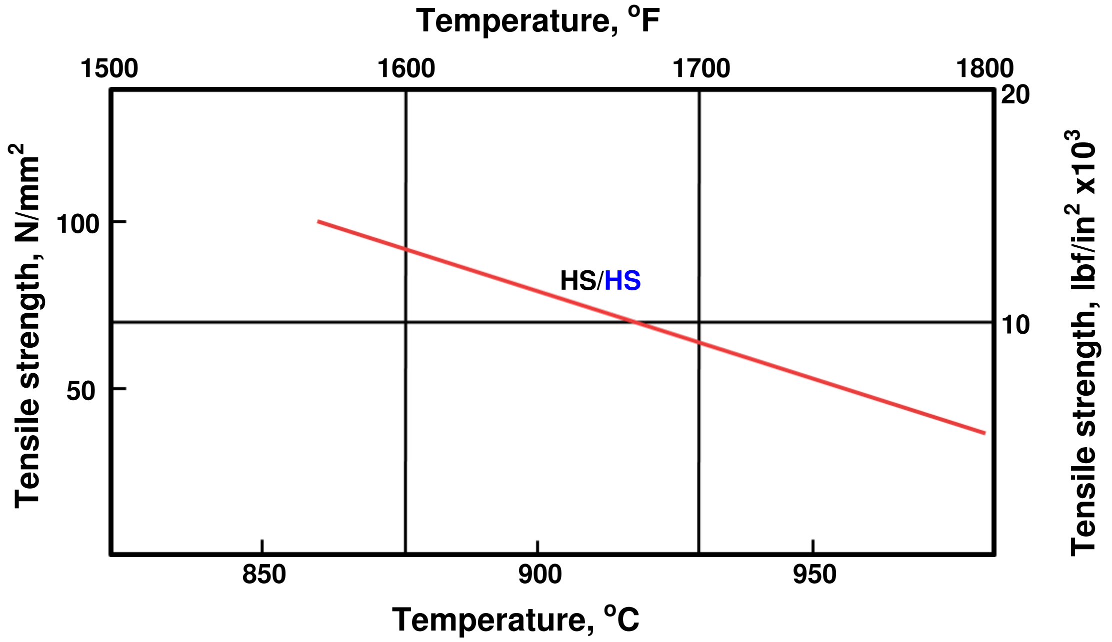


Figure 12 MEEHANITE Type **HS**/**HS** short term high temperature strength.

At 870°C [1600°F] most MEEHANITE Types are in the plastic range and flow under load becomes quite rapid. Creep [growth] data on Types **HR**/**HR** and **HS**/**HS** indicate that they are the only Types to be recommended for service involving mechanical loads, **Figure 13**.

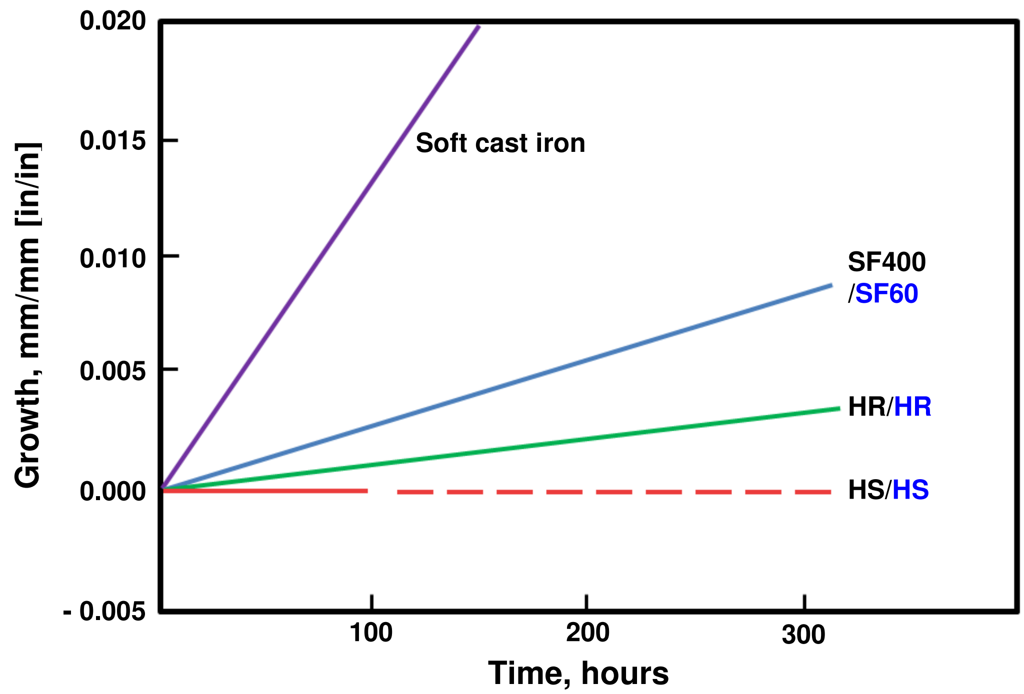


Figure 13 Growth data for MEEHANITE Types **HR**/**HR** and **HS**/**HS** at 870°C [1600°F].

In the case of nodular Types of MEEHANITE, ferritic nodular iron demonstrates creep properties barely distinguishable from those of aluminium killed mild steels of relatively high manganese content. Pearlitic nodular iron exhibits somewhat improved creep resistance, as may be expected from its pearlitic matrix and higher manganese content, so that its creep properties approach those of the best silicon killed carbon manganese steels. Pearlitic nodular irons with a molybdenum addition possess creep resistance which compare favourably with those of low allow steels.

Tests at the National Physical Laboratory [UK] and other institutions, have provided the following creep values for periods of 2500 hours, at temperatures of 400°C to 450°C [750°F to 840°F], **Table II**.

Table II Creep values for periods of 2500 hours at 400°C to 450°C [750°F to 840°F] for various Types of MEEHANITE.

MEEHANITE Type	Temperature °C [°F]		Stress, N/mm² [lbf/in²]			Creep rate, 10^{-6}/h
GM400/GM60	400 [750]				140 [20310]	0.110
	400 [750]			70 [10150]		0.013
		450 [840]		70 [10150]		0.100
		450 [840]	35 [5075]			0.040
GA350/GA50	400 [750]				140 [20310]	0.070
	400 [750]			70 [10150]		0.045
		450 [840]	35 [5075]			0.140
SF400/SF60	400 [750]				140 [20310]	0.690
	400 [750]			70 [10150]		0.020
	400 [750]		35 [5075]			0.010
SPF600/SP80	400 [750]				140 [20310]	0.240
	400 [750]			70 [10150]		0.010
	400 [750]		35 [5075]			0.010
SPF600/SP80 + Mo		450 [840]			140 [20310]	0.130
		450 [840]		70 [10150]		0.060

Stress to rupture properties

The following graphs, **Figures 14** and **15**, show typical stress to rupture curves for MEEHANITE nodular iron Types **SF400/SF60** and **SF400/SF60 with 0.8%Mo** under varying loads at different temperatures.

More general stress to rupture values for a number of MEEHANITE Types [**SF400/SF60**, **SPF600/SP80**, **SH/SH**, **HR/HR** and **HS/HS**] are shown on the Larsen-Miller nomogram, **Figure 16**, for periods ranging from 10^{-1} to 10^{5} hours.

Scaling and growth

Most Types of MEEHANITE Metal resist the penetration of steam and gases at relatively low temperatures. At higher temperatures, however, resistance to scaling, growth and surface crazing becomes a problem requiring the use of special Types of iron.

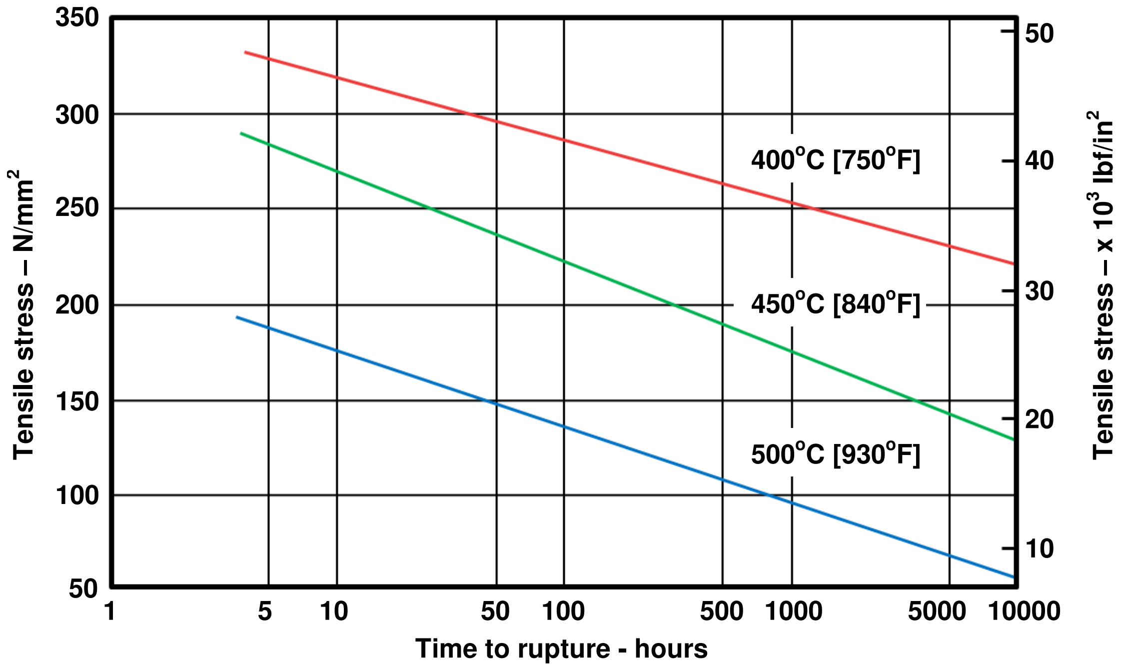


Figure 14 Stress to rupture values for MEEHANITE Type **SF400**/**SF60** at various temperatures.

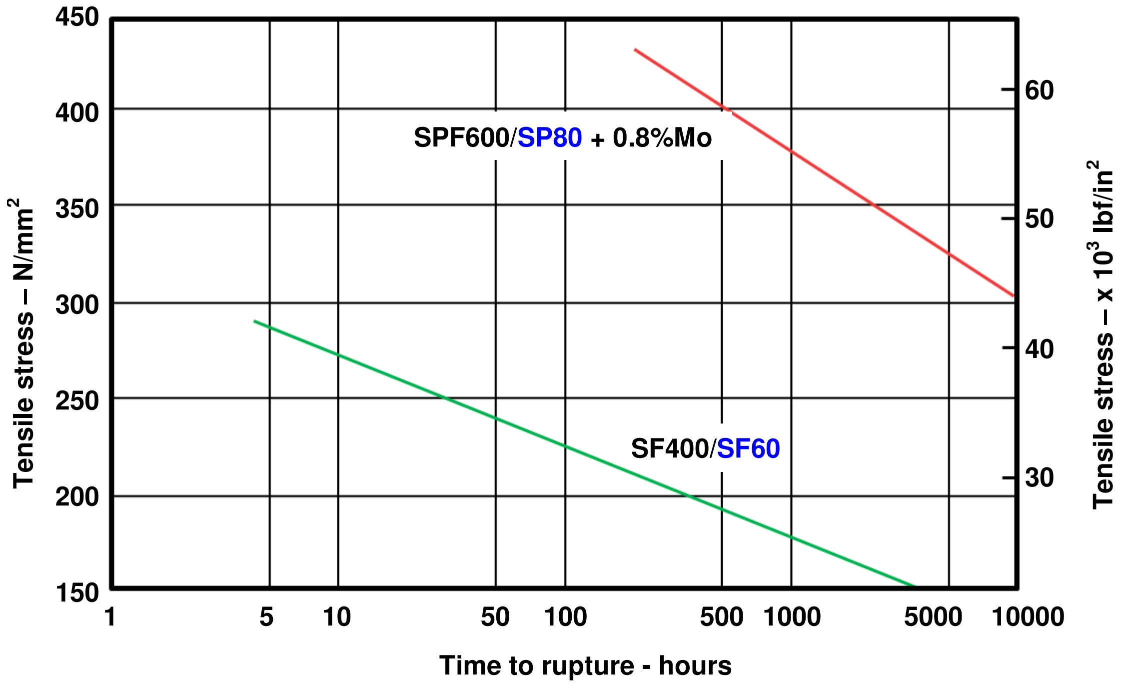


Figure 15 Stress to rupture values for MEEHANITE Types **SF400**/**SF60** and **SF400**/**SF60** **+ Mo** at 450°C [840°F].

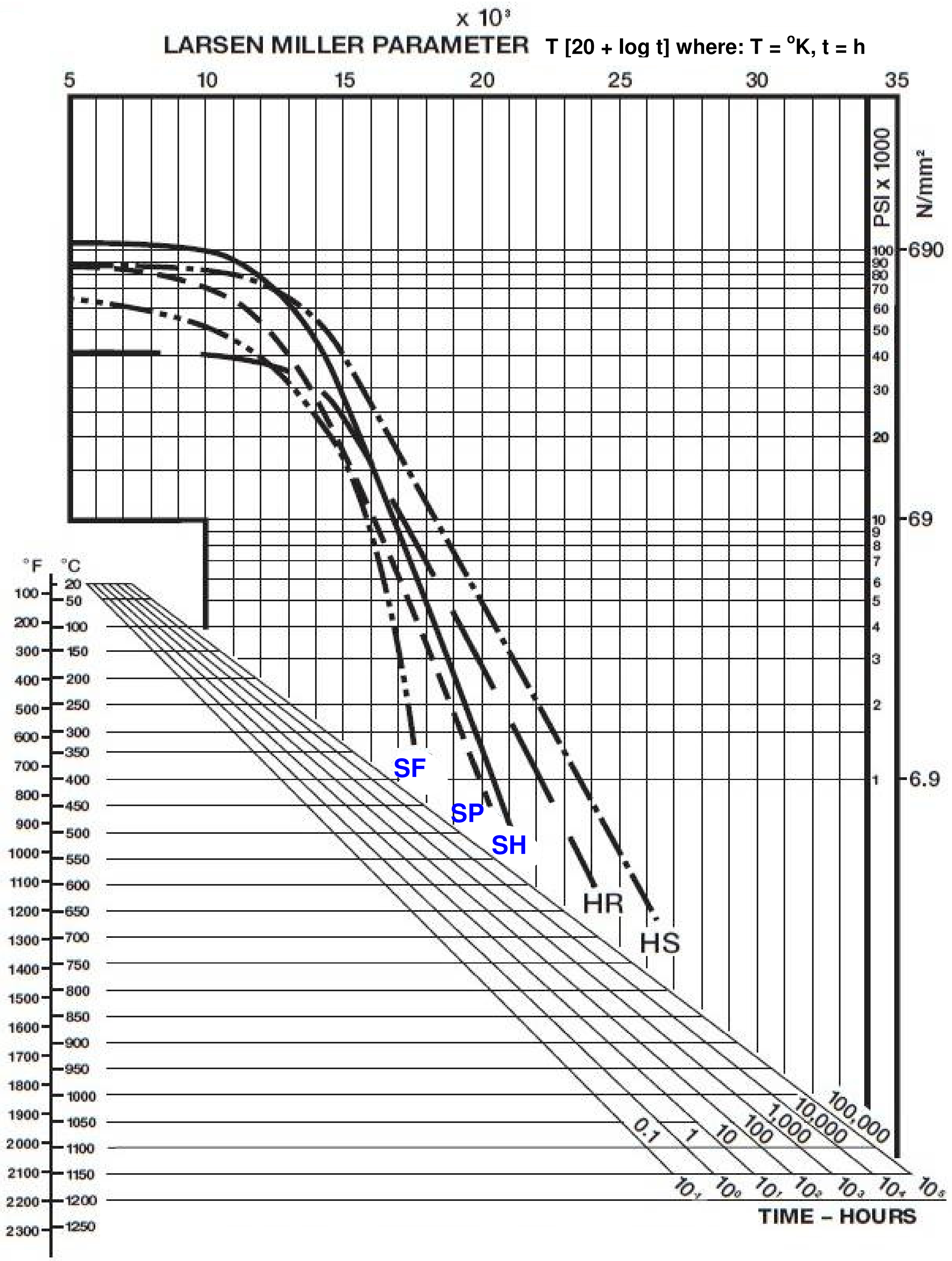


Figure 16 Stress to rupture values for MEEHANITE Types **SF400**/**SF60**, **SPF600**/**SP80**, **SP700**/**SH100**, **HR**/**HR** and **HS**/**HS**.

Excellent resistance to scaling and growth is provided by MEEHANITE Type **SC** but resistance to stress is lower than for other heat resisting Types. It is machinable but brittle, at ambient temperatures. However, for better strength levels, combined with good resistance to scaling and growth MEEHANITE Type **HS**/**HS** will be found to be most suitable replacing Type **SC**.

Good resistance to a combination of heat and abrasion is obtained from MEEHANITE Type **HR**/**HR** which is especially resistant to scaling and growth under conditions of continuous heating. It is, however, very hard and brittle and virtually unmachinable.

The maximum service temperatures quoted apply to relatively short term service.

Surface crazing

400°C to 675°C [750°F to 1250°F]

Some surface crazing may occur at the upper end of this temperature range, particularly if the rate of temperature change is severe.

In general the denser, higher strength engineering materials MEEHANITE Types **GM400**/**GM60**, **GA350**/**GA50**, **SPF600**/**SP80** and **SP700**/**SH100** are most resistant to surface crazing up to 675°C [1250°F].

Examples of Type **GA350**/**GA50** MEEHANITE compared to soft and chilled cast iron from a special trial at 650°C [1200°F] are shown in **Figure 17**. Surface oxidation at temperatures up to 675°C [1250°F] is not usually considered a serious problem with MEEHANITE flake irons.

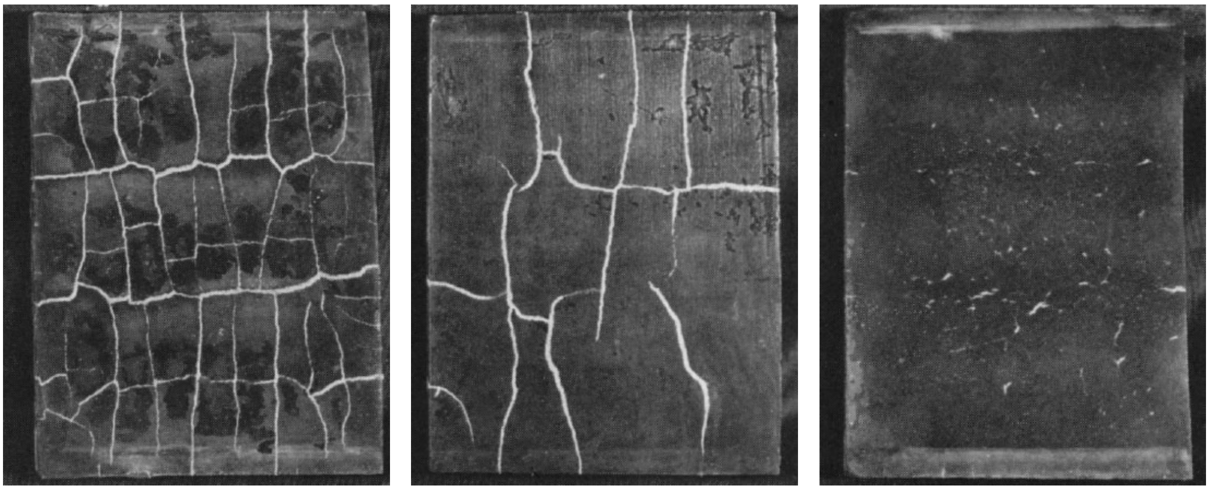
The MEEHANITE nodular irons are even more resistant to surface oxidation than the flake Types because the graphite exists in the form of nodules which impede oxide penetration from the surface.

675°C to 870°C [1250°F to 1600°F]

Surface crazing can occur more markedly in this temperature range particularly when temperatures are cyclic. It is recommended that castings operating in this temperature range are annealed before they are put into service.

Selection of casting materials must be based, therefore, often on a compromise, which is dependent upon:

1. Type of service, temperature cycle and rate of heating.
2. Conditions of stress, whether mechanical or thermal, including the effects of thermal expansion and thermal conductivity.
3. Resistance of the material to oxidation in terms of scaling and growth.
4. Machinability.



Soft cast iron | Chilled iron | MEEHANITE Type GA350/GA50

Figure 17 Surface crazing of different cast irons; including MEEHANITE Type **GA350**/**GA50**.

MEEHANITE Type HE/HE

Material specification

This Type of MEEHANITE is recommended for castings which either undergo alternative heating and cooling over a wide temperature range or experience intermittent temperature fluctuations in service or suffer thermal shock. The material is capable of withstanding rapid thermal cycling without premature failure.

MEEHANITE Type **HE**/**HE** is an all-round material for general use. It is also advantageous where either dimensional stability or a fine machined surface is required. The structure is soft and graphitic so permitting the absorption of alternating thermal expansion and contraction stresses which normally cause mechanical breakdown in the form of heat checking, cracking or crazing in the normal grades of cast iron. It is free machining.

Applications

Typical applications are ingot moulds and stools, parts which are directly heated by a naked flame such as salt baths, acid, lead, zinc and slog pots, hot plates, sintering grates, pig casting machine parts, furnace furniture and other castings, steam line fittings, blast furnace parts, coke oven doors and liners and evaporators.

For applications involving thermal shock.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve

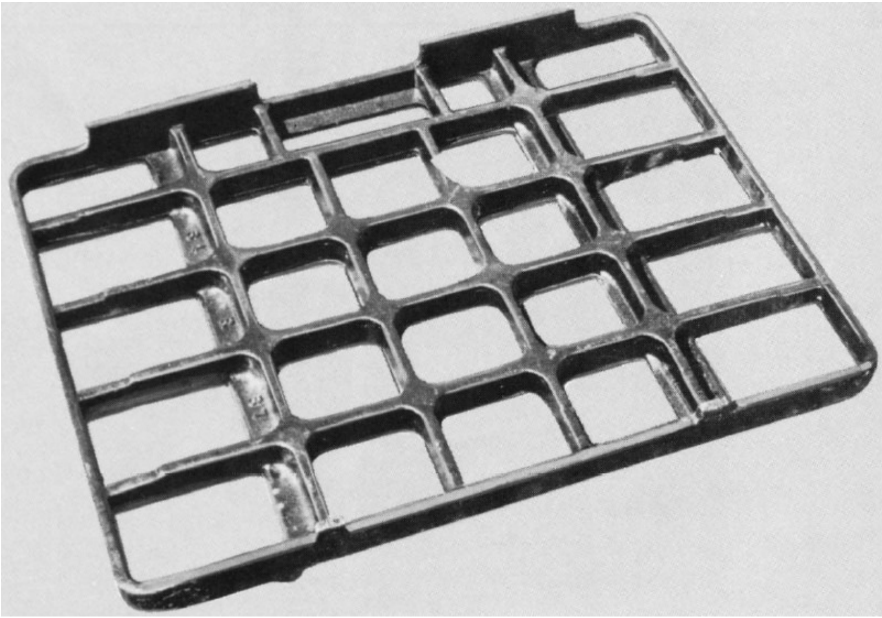
Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	200N/mm^2	800N/mm^2	<0.4	170 – 210
Imperial equivalents	*13.0tonf/in^2*	*51.8tonf/in^2*		
	~29000lbf/in^2	*~116000lbf/in^2*		
US	25000lbf/in^2	-	<0.4	170 – 210
Metric equivalents	*~170N/mm^2*	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity[3]	**E**	kN/mm^2	97	lbf/in^2	14.1×10^6
Coefficient of thermal expansion 20 to 500°C	α_l	$1/10^6.K$	13.0	$1/10^6.°F$	7.22
Thermal conductivity 20°C - 200°C	**λ**	W/m.K	55.0	$Btu.in/ft^2.h.°F$	351
Machinability			good		good



MEEHANITE Type **HS**/**HS** bracket provides good heat resistance and resists warping.

MEEHANITE Type HD

Material specification

A readily machinable Type of flake iron which can be used in light and medium weight castings up to a temperature of 620°C [1150°F].

Applications

Typical examples of its use are baffle plates and roof supports in oil refinery preheaters and drying ovens, bubble caps and trays, down flow pipes, exhaust valve boxes, hot plates and glass moulds.

For applications at temperatures up to 620°C [1150°F].

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve

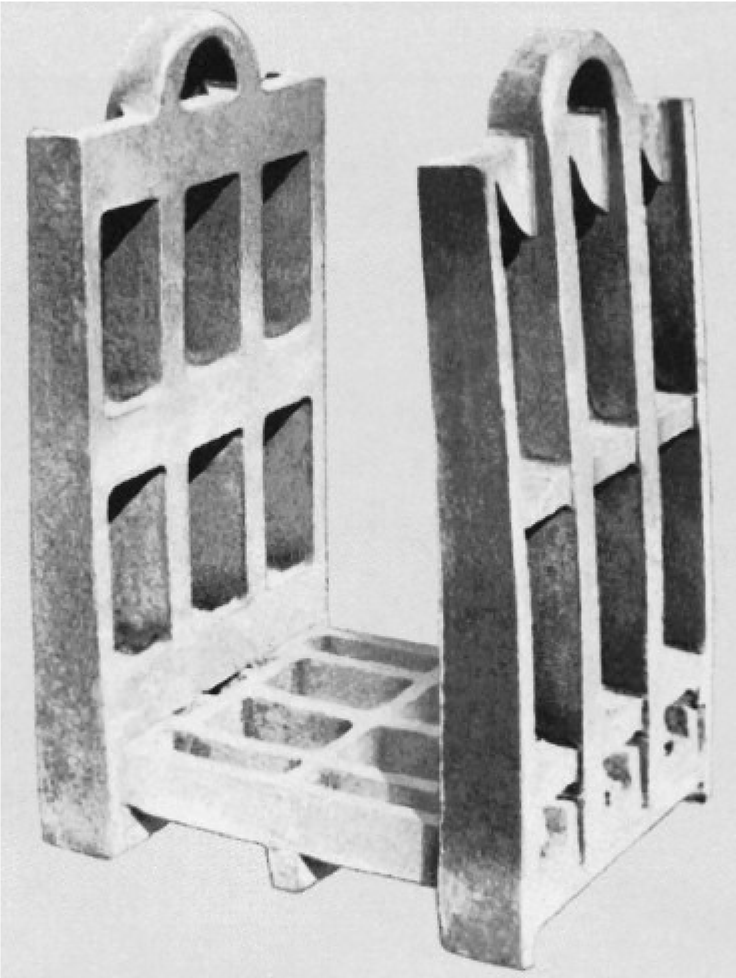
Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]*	% Elongation	BHN[2]
Europe, Asia	250N/mm^2	1000N/mm^2	<0.4	210 – 260
Imperial equivalents	*16.2tonf/in^2*	*64.8tonf/in^2*		
	~36000lbf/in^2	*~145000lbf/in^2*		
US	-	-	-	-
Metric equivalents	-	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity[3]	**E**	kN/mm^2	120	lbf/in^2	17.4 x 10^6
Coefficient of thermal expansion 20 to 500°C	**α_l**	1/10^6.K	13.0	1/10^6.°F	7.22
Thermal conductivity 20°C - 200°C	**λ**	W/m.K	47.0	Btu.in/ft^2.h.°F	300
Machinability			good		good



MEEHANITE Type **HS**/**HS** annealing basket used to support ~1000kg [>2000lb] of bar stock during heat treatment cycles at 790°C [1450°F]

MEEHANITE Type HR/HR

Material specification

MEEHANITE Type **HR**/**HR** is a strong dense cast iron with high rigidity with good creep properties. It possesses excellent resistance to scaling and growth up to 735°C [1355°F] under most service conditions. It is also resistant to corrosion in many environments. It displays good load bearing abilities. This material does not respond well to thermal shock.

Very difficult to machine as the matrix is essentially a mixture of carbides [cementite] and pearlite requiring the component to be cast to shape.

Applications

Mainly tube sheets, plates and supports on the low temperature side of pre-fired heaters for oil refineries, brick hangers for suspended furnace roofs in various industries; for example, brick making, glass manufacture, metal processing and heat treatment. Used also in furnace and burner parts, roasting furnace stirrer blades, retorts, annealing furnace rails, blast furnace pipes, grate bars and stoker links, oven furniture and muffle plates.

For temperatures in excess of 750°C [1380°F] MEEHANITE Type **HS**/**HS** should be used.

For applications at continuous temperatures up to 750°C [1380°F].

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.

2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve

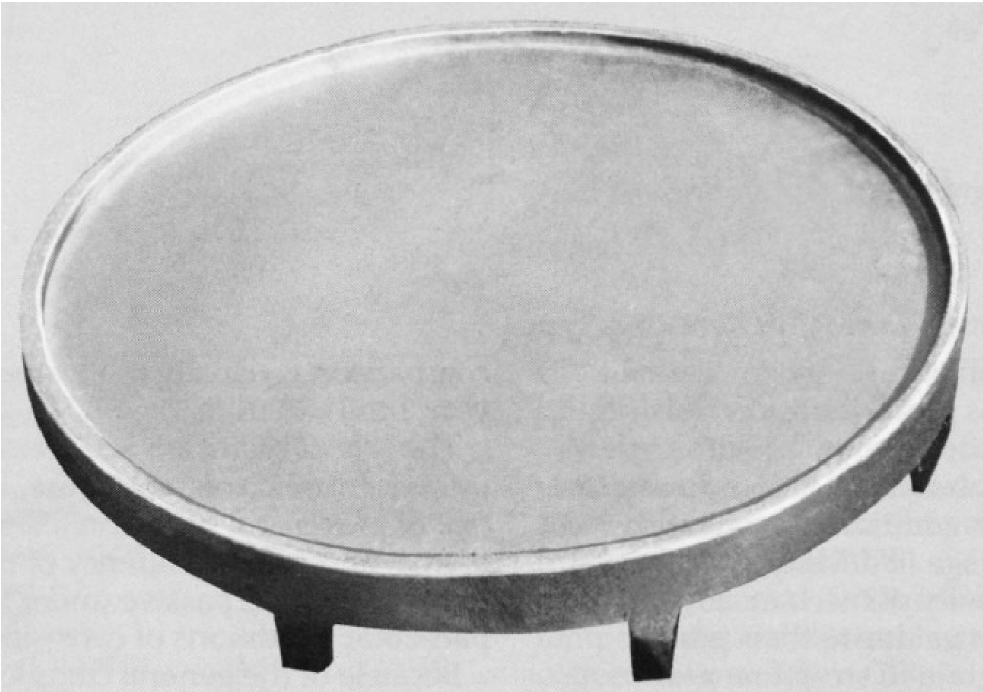
Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	300N/mm^2	1000N/mm^2	-	300 – 370
Imperial equivalents	*19.4tonf/in^2*	*64.8tonf/in^2*		
	~43500lbf/in^2	*~145000lbf/in^2*		
US	40000lbf/in^2	-	-	300 – 370
Metric equivalents	*~275N/mm^2*	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity[3]	**E**	kN/mm^2	135	lbf/in^2	$19.6x\ 10^6$
Coefficient of thermal expansion 20 to 500°C	α_l	$1/10^6.K$	13.0	$1/10^6.°F$	7.22
Thermal conductivity 20°C - 200°C	**λ**	W/m.K	33.0	$Btu.in/ft^2.h.°F$	211
Machinability			difficult		difficult



Sagger bottoms cast in MEEHANITE Type **HS**/**HS** to resist scaling and warping at 870°C [1600°F]

MEEHANITE Type SC

Material specification

For use at temperatures up to 900°C [1650°F] where the temperatures remain fairly constant and thermal shock does not present a problem; with a structure of flake graphite in a matrix of silico-ferrite, this material exhibits practically no growth at temperatures up to 900°C [1650°F]. It scales very slowly. Readily machinable but care must be taken when handling the castings as they may be brittle at ambient temperatures.

In furnace and other applications such castings should be heated up very slowly from room temperature.

Applications

Annealing boxes, carburising boxes and retorts, special fire grates and bars, heat treatment furnace parts.

For applications at continuous temperatures up to 900°C [1650°F].

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 25mm diameter proportional test pieces taken from separately cast test samples.
2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve

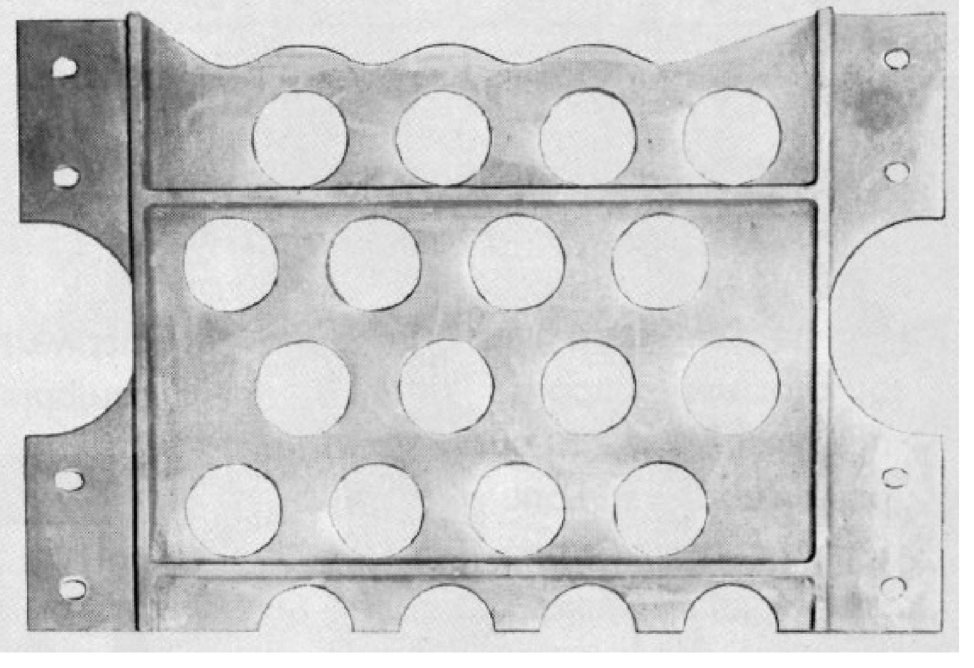
Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	200N/mm^2	900N/mm^2	-	200 – 300
Imperial equivalents	*13.0tonf/in^2*	*58.3tonf/in^2*		
	~29000lbf/in^2	*~130500lbf/in^2*		
US	25000lbf/in^2	-	-	200 – 300
Metric equivalents	*~170N/mm^2*	-		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity[3]	**E**	kN/mm^2	120	lbf/in^2	$17.4x\ 10^6$
Coefficient of thermal expansion 20 to 500°C	α_l	$1/10^6.K$	12.0	$1/10^6.°F$	6.67
Thermal conductivity 20°C - 200°C	**λ**	W/[m.K]	40.0	$Btu.in/ft^2.h.°F$	256
Machinability			good		good



Tube support plate in MEEHANITE Type **HS**/**HS** weighing 225kg [500lb]

MEEHANITE Type HS/HS [DuctIiron®]

Material specification

This MEEHANITE Type is a modified form of Type **SC**. The graphite is in the form of nodules in a silico-ferrite matrix. The result is a much higher strength material, **Figure 18**, with a rather better shock resistance at ambient temperature; in comparison with Type **SC**.

It is rather more resistant to growth and scaling up to 900°C [1650°F] under both conditions of cyclic and continuous heating without thermal shock. There are reports that it has been used successfully up to 980°C [1795°F].

Compositional changes can be made to suit the exact service conditions. It machines easily and provides maximum resistance to scaling and growth, **Figure 19**.

Applications

For blast furnace parts, boxes, trays, dampers, doors and frames, hot gas valves, rails and skids, reduction pots, glass moulds, annealing pots, drums, sagger bottoms for the pottery industry, retorts, floor castings, exhaust manifolds and turbocharger housings for diesel engines.

For cyclic and continuous heating up to 900°C [1650°F].

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 25mm diameter proportional test pieces taken from separately cast test samples.
2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.
3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength [min] R_m	Ultimate tensile strength [max] R_m	0.2% Proof stress in tension [min] ($R_{p0.2}$)	0.2% Proof stress in tension [max] ($R_{p0.2}$)	% Elong -ation	BHN[2]
Europe, Asia	400N/mm^2	650N/mm^2	300N/mm^2	500N/mm^2	2 0 – 10.0	200 – 280
Imperial equivalents	*25.9tonf/in^2*	*42.1tonf/in^2*	*19.4tonf/in^2*	*32.4tonf/in^2*		
	~58000lb/in^2	*94300lb/in^2*	*~43500lb/in^2*	*72500lb/in^2*		
US	60000lb/in^2	100000lb/in^2	45000lb/in^2	75000lb/in^2	2 0 – 10.0	200 – 280
Metric equivalents	*~415N/mm^2*	*~690N/mm^2*	*~310N/mm^2*	*~520N/mm^2*		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity[3]	**E**	kN/mm^2	160	lbf/in^2	$23.2x\ 10^6$
Coefficient of thermal expansion 20 to 500°C	α_l	$1/10^6.K$	13.0	$1/10^6.°F$	7.22
Thermal conductivity 20°C - 200°C	**λ**	W/m.K	-	$Btu.in/ft^2.h.°F$	-
Impact strength		J	2.0 – 15.5	ft.lbf	1 - 7
Machinability			good		good

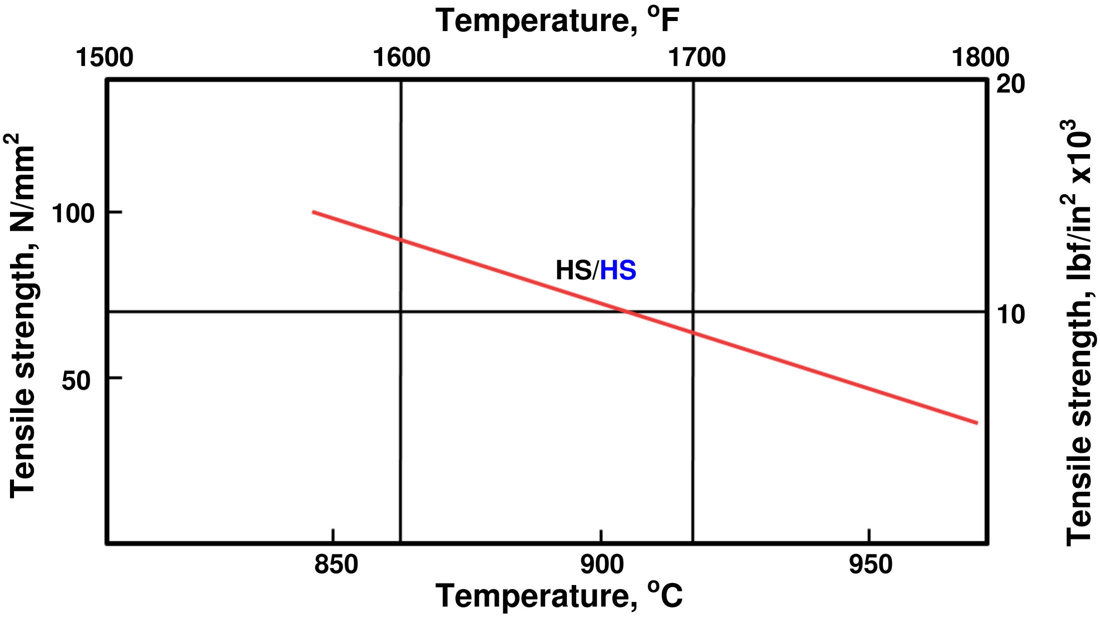


Figure 18 MEEHANITE Type **HS/HS** short term high temperature strength.

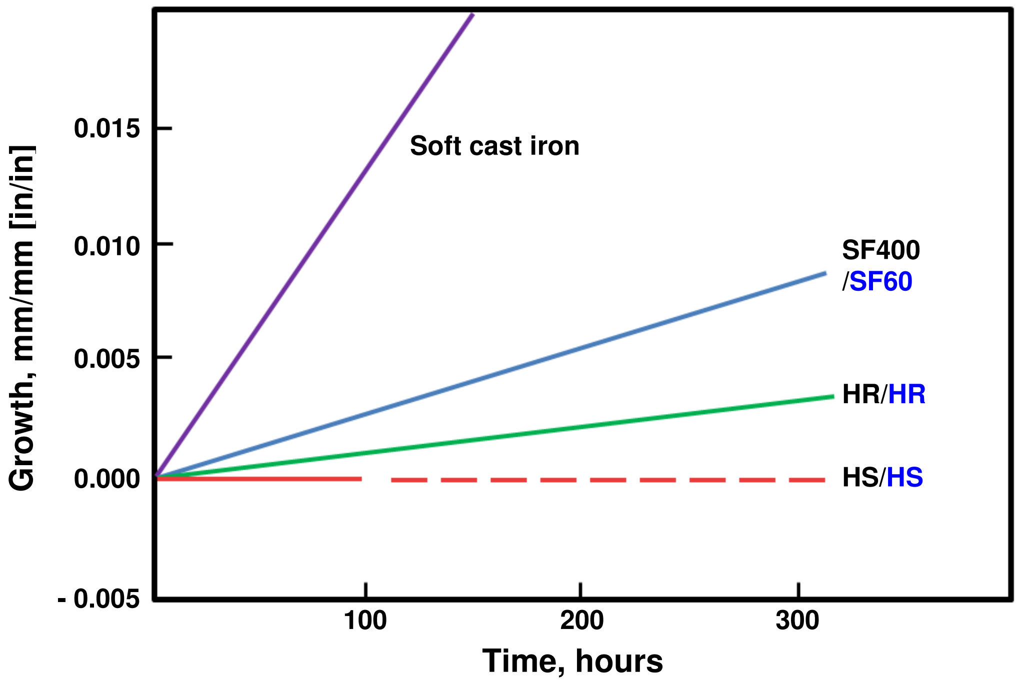


Figure 19 Growth as a result of time spent [in hours] at 870°C [1600°F]; MEEHANITE Types **SF400/SF60**, **SPF600/SP80**, **SP700/SH100**, **HR/HR** and **HS/HS**.

MEEHANITE Type HSV/HSV

Material specification

This iron is an improved version of MEEHANITE Type **HS**/**HS** alloyed with vanadium in order to withstand long periods of continuous heating at temperatures up to 870°C [1600°F] while maintaining the maximum load bearing capability.

The easy castability of MEEHANITE Type **HSV**/**HSV** permits castings of any shape to be produced reducing the amount of machining necessary. In some cases only simple hand grinding is required.

The material is readily machinable and possesses an excellent combination of properties at room temperature as well a good hardness and strength at elevated temperatures.

Applications

For high temperature tooling, especially dies used in the hot forming of titanium sheet, by press, hammer and stretching techniques; for turbocharger and supercharger castings and furnace parts.

For maximum load bearing up to 870°C [1600°F].

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 25mm diameter proportional test pieces taken from separately cast test samples.

2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

3 The modulus values quoted are the E_o values measured by the tangent through the origin of the stress/strain curve

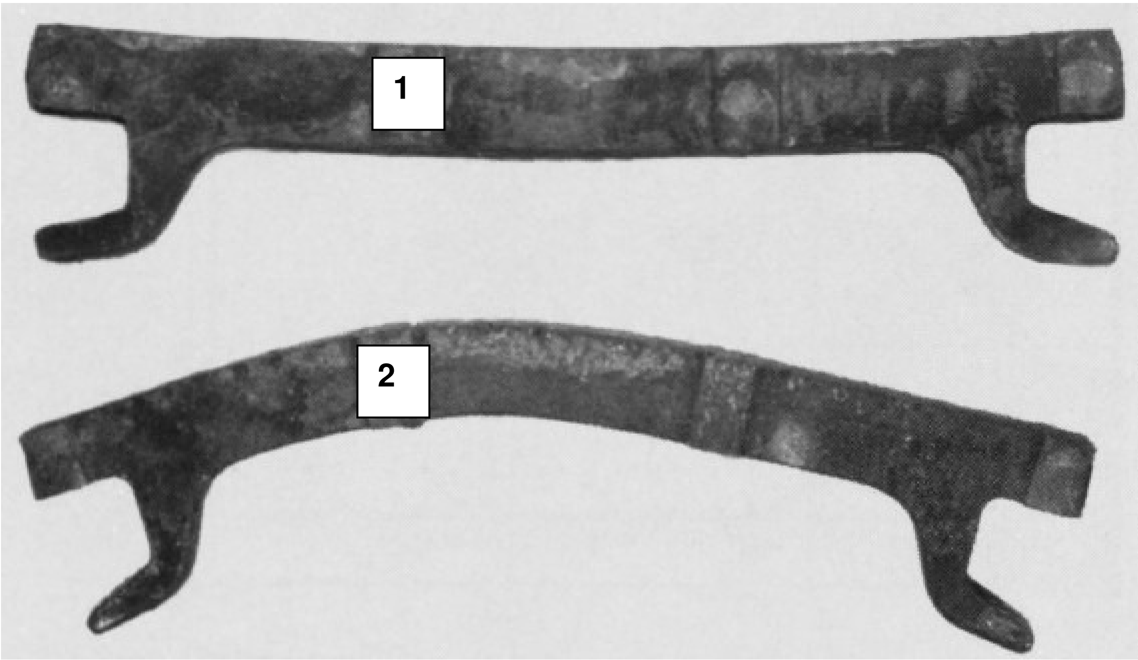
Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength [min] R_m	Ultimate tensile strength [max] R_m	0.2% Proof stress in tension [min] ($R_{p0.2}$)	0.2% Proof stress in tension [max] ($R_{p0.2}$)	% Elong -ation	BHN[2]
Europe, Asia	650N/mm^2	820N/mm^2	300N/mm^2	550N/mm^2	2 0 – 10.0	200 – 280
Imperial equivalents	*42.1tonf/in^2*	*53.1tonf/in^2*	*19.4tonf/in^2*	*35.6tonf/in^2*		
	~94300lb/in^2	*119000lb/in^2*	*~43500lb/in^2*	*80000lb/in^2*		
US	100000lb/in^2	120000lb/in^2	50000lb/in^2	80000lb/in^2	2 0 – 10.0	200 – 280
Metric equivalents	*~690N/mm^2*	*~825N/mm^2*	*~345N/mm^2*	*~550N/mm^2*		

Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity[3]	E	kN/mm^2	160	lbf/in^2	$23.2x\ 10^6$
Coefficient of thermal expansion 20 to 500°C	α_l	$1/10^6.K$	12.0	$1/10^6.{}^oF$	6.67
Thermal conductivity 20°C - 200°C	λ	W/m.K	43.5	$Btu.in/ft^2.h.{}^oF$	278
Machinability			good		good



Grate bars removed after service at temperatures above 650°C [1200°F].
Bar **1** is cast in MEEHANITE Type **HSV/HSV**. **Note:** freedom from growth and distortion.
Bar **2** is alloy steel [25%chromium and 12% nickel.

MEEHANITE Type UC

Material specification

MEEHANITE Type **UC** is a specially developed chilled as-cast ferritic iron with controlled undercooled flake graphite. The microstructure of the material contains high cell counts providing good machinability and leading to an exceptionally good machined surface finish. Ideally casting sections should be maintained between 25mm [1”] and 75mm [3”] to produce the optimum microstructure.

MEEHANITE Type **UC** displays good resistance to growth, oxidation and erosion. The material can be lightly alloyed to improve its resistance to thermal cycling still further whilst retaining its ferritic microstructure.

Applications

Glass bottle moulds, permanent moulds for zinc and aluminium castings. Tyre moulds and gravity die moulds for cast iron.

For applications where good resistance to growth, oxidation and erosion is required.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.

2 Depending upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

Mechanical properties[1]

<table>
<tr><th>MEEHANITE Region</th><th>Ultimate tensile strength [min] R_m</th><th>Ultimate tensile strength [max] R_m</th><th>0.2% Proof stress in tension [min] ($R_{p0.2}$)</th><th>0.2% Proof stress in tension [max] ($R_{p0.2}$)</th><th>% Elong -ation</th><th>BHN[2]</th></tr>
<tr><td>Europe, Asia</td><td>220N/mm^2</td><td>260N/mm^2</td><td>200N/mm^2</td><td>220N/mm^2</td><td rowspan="3">1 0 – 2.0</td><td rowspan="3">130 – 180</td></tr>
<tr><td rowspan="2">Imperial equivalents</td><td>14.2tonf/in^2</td><td>16.8tonf/in^2</td><td>19.4tonf/in^2</td><td>14.2tonf/in^2</td></tr>
<tr><td>~32000lb/in^2</td><td>38000lb/in^2</td><td>~43500lb/in^2</td><td>~32000lb/in^2</td></tr>
<tr><td>US</td><td>30000lb/in^2</td><td>38000lb/in^2</td><td>45000lb/in^2</td><td>30000lb/in^2</td><td rowspan="2">1 0 – 2.0</td><td rowspan="2">130 – 180</td></tr>
<tr><td>Metric equivalents</td><td>~210N/mm^2</td><td>~690N/mm^2</td><td>~260N/mm^2</td><td>~210N/mm^2</td></tr>
</table>

Values in italics represent imperial/metric conversions.

MEEHANITE Compacted Graphite Iron Types PC400 & FC275

Material specification

The compacted graphite iron Types of MEEHANITE have mechanical and physical properties intermediate between those of flake graphite and nodular graphite irons, thus, providing an interesting combination of tensile strength, especially hot tensile strength, and thermal conductivity.

Applications

For brake discs in automotive and particularly locomotive and railway rolling stock applications; for diesel engine cylinder heads, clutch plates, ingot moulds etc. In fact, in any service application where thermal crazing is a problem.

Typical thermal conductivity values

Temperature ^{o}C [^{o}F]	W/m.K [Btu.in/ft^2.h.^{o}F]				
	100 [212]	**200 [390]**	**300 [570]**	**400 [750]**	**500 [930]**
PC400	40 [256]	43 [275]	41 [262]	39 [249]	36 [230]
FC275	47 [301]	49 [313]	45 [288]	41 [262]	37 [237]

The optimum combination of thermal and mechanical properties is, to a great extent, a function of the predominant graphite shape in the microstructure and the incidence of either well formed graphite nodules or flake graphite must be kept to a minimum.

The notes below apply to the numerical references in the material property tabulations for the compacted graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Un-notched D V M test piece [10mm square].
4 Wöhler rotating bending fatigue test using an un-notched test bar.

MEEHANITE Compacted Graphite Iron Types PC400 & FC275

MEEHANITE Type PC400

Structure: Compacted graphite in a pearlitic matrix.

Mechanical and physical properties[1]

Property	Symbol	Units	Value	Units	Value
Tensile strength [min]	R_m	N/mm^2	400	lbf/in^2	58000
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	330	lbf/in^2	48000
Elongation [min]	A_5	%	1	%	1
BHN[2]			200 - 250		200 - 250
Impact strength[3]	A_n	J	-	ft lbf	-
Fatigue limit[4]	σ_{tcW}	N/mm^2	±200		±29000
Modulus of elasticity	E	kN/mm^2	165	lbf/in^2	23.9×10^6
Compression strength	σ_c	N/mm^2	600	lbf/in^2	87000
Poissons ratio	v		0.28		0.28
Thermal conductivity @ 200°C	λ	W/m.K	43	$Btu.in/ft^2.h.^\circ F$	316
Coefficient of thermal expansion [20°C – 500°C] (70°F – 930°F]	α_l	$1/10^6.K$	13.0	$1/10^6.^\circ F$	7.0
Density @ 20°C [70°F]	ρ	kg/dm^3	7.10	lb/in^3	0.256

MEEHANITE Type FC275

Structure: Compacted graphite in a ferritic matrix.

Mechanical and physical properties[1]

Property	Symbol	Units	Value	Units	Value
Tensile strength [min]	R_m	N/mm^2	275	lbf/in^2	40000
0.2% Proof stress [min]	$R_{p0.2}$	N/mm^2	220	lbf/in^2	32000
Elongation [min]	A_5	%	2	%	2
BHN[2]			130 - 180		130 - 180
Impact strength[3]	A_n	J	10	ft lbf	7.6
Fatigue limit[4]	σ_{tcW}	N/mm^2	±160	lbf/in^2	±23000
Modulus of elasticity	E	kN/mm^2	162	lbf/in^2	23.5×10^6
Compression strength	σ_c	N/mm^2	500	lbf/in^2	72500
Poissons ratio	v		0.28		0.28
Thermal conductivity @ 200°C	λ	W/m.K	49	$Btu.in/ft^2.h.^\circ F$	359
Coefficient of thermal expansion [20°C – 500°C] (70°F – 930°F]	α_l	$1/10^6.K$	11	$1/10^6.^\circ F$	5.9
Density @ 20°C [70°F]	ρ	kg/dm^3	7.00	lb/in^3	0.252

Introduction

Wear is a general term; wear is essentially a surface phenomenon. The process of wear involves many properties such as hardness, impact, fatigue under compression, friction, corrosion, thermal shock, grain structure, solidity and lubrication, which in themselves are not completely understood.

It follows, therefore, that every wear problem must be carefully considered on its own merits and the selection of any material must be made according to the conditions for any service operation.

Wear resistance is not a specific property of a material which can be expressed in absolute units. It does not exist apart from the conditions of service. This means that the precise conditions must be known before selecting the Type of MEEHANITE Metal which will give the maximum service possible. As a generalisation the wear resistance of a metal is associated with its hardness value; that is, the higher the hardness the better the wear resistance.

Broadly speaking abrasive wear conditions can be placed in three groups

- metal to metal, where lubrication is not involved,
- erosion where suspended solids are carried in either a gas or liquid,
- dry abrasion such as in the crushing of rocks.

Practically, improved wear resistance can be usually brought about through the increase in hardness by;

- increasing the proportion of carbides [cementite] and reducing the amount of free carbon [graphite] in the metal structure leading progressively though a mottled structure to a white structure which is extremely hard and difficult to machine; viz, MEEHANITE Types **W**, **WB** and **WH**.

- inducing the formation of a hard cementite layer on the surface of an otherwise grey machinable casting by the use of chills; viz, MEEHANITE Type **WEC**.

- heat treatment of the entire casting by either a quench and temper or the modification of the casting surface by using flame, laser or induction hardening. The maximum effect of this form of heat treatment is only achieved in castings possessing a dense fully pearlitic microstructure such as MEEHANITE Types **WA**, **GM3400**/**GM60**, **GA350**/**GA50**, **SP700** [leading to **SH800**/**SH100**], **SH1000**, **AQ** and **AQS**.

- producing castings with a series of austenitic-martensitic microstructures containing carbides and used in either the as-cast or heat treated conditions which provide abrasive resistance through their original martensitic content or as a result of the transformation of austenite into martensite; viz, MEEHANITE **Almanite® W** Types **W_1**, **W_2** and **W_4** and Types from the **WSH**/**WSH** group of irons and the MEEHANITE high chromium irons Types **W_{15}**, **W_{20}** and **W_{27}**.

With such a broad spectrum of wear resistant irons developed separately in North America and Europe the first step in the process of harmonisation is to classify the MEEHANITE Types available on a worldwide basis. The complete range of Types is listed in the **Table III** below.

Table III Classification of MEEHANITE Wear Resisting Types worldwide

MEEHANITE Type		As-cast			Heat treated		
		Tensile strength		BHN	Tensile strength		BHN
		N/mm^2	lbf/in^2		N/mm^2	lbf/in^2	
	AQ	350	50000	250 - 300	460	65000	<500
	AQS	690	100000	250 - 300	<1240	<180000	<500
	WA	340	50000	230 - 350	500	72500	<550
	WB	260	40000	350 - 500			350 - 500
	WEC	230	35000	200 - 250	220	35000	400 - 500[1]
	WH	200	30000				550 - 600
	WSH$_1$	<400	60000	250 - 300	600 - 1200		400 - 650
	WSH$_2$	<700	<100000	350 - 500	600 - 1200		650 - 700
ALMANITE®	W$_1$	345 - 415	<60000	200 - 300	345 - 415	<60000	500 - 600
ALMANITE®	W$_2$				<415	<60000	500 - 600
ALMANITE®	W$_4$				<550	<80000	400 - 700
ALMANITE®	WS				<450	<80000	400 - 525
ALMANITE®	WSH	<700	<100000	350 - 500			400 - 700
Hi Cr	W$_{15}$			500 - 550			>550
Hi Cr	W$_{20}$						>650
Hi Cr	W$_{27}$			550 - 650			~750[2]

[1] chilled face

[2] These values are at the limit of Brinell hardness testing. VP [Vickers Pyramid] hardness testing is required for more accurate values.

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type AQ

Material specification

This is a wear and abrasion resisting iron that is readily machinable in the as-cast condition but may be “air hardened” after machining with little or no risk of cracking or dimensional change.

Heat treatment is simple consisting of cooling in an air blast from a temperature of 900^{o}C [1650^{o}F].

Castings may also be locally hardened to improve the service life of working faces or edges on parts such as dies, punches, cams and rollers etc. Retention of a good hardness level up to operating temperatures of 540^{o}C [1000^{o}F], **Figure 20**, means this material is especially useful where abrasion resistance is required.

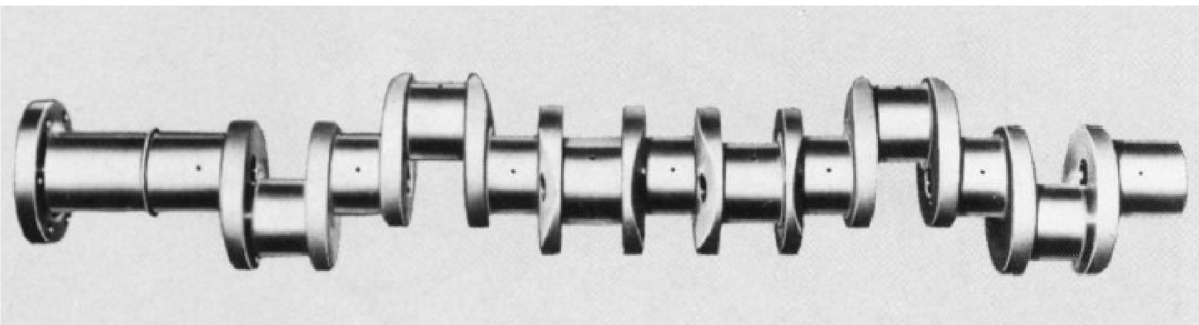
Typical applications

Components requiring good strength and abrasion resistance such as are used in conveyor and road making and agricultural equipment etc. MEEHANITE Type **AQ** is highly recommended for parts that must be machined and subsequently hardened without distortion such as cams, spinning mandrels, sheaves, wheels, dies, punches, rollers, engine liners and for equipment in service at elevated temperatures up to a dull red heat.

Mechanical and physical properties[1]

	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	345	lbf/in^2	50000	N/mm^2	450	lbf/in^2	65000
BHN[2]		<280		<280		<500		<500
Fatigue limit[3]					N/mm^2	±210		±30000
Thermal properties: see Table VIII – Thermal expansion.								

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Wöhler rotating bending fatigue test using an un-notched test bar.



Crankshaft in MEEHANITE Type AQS.

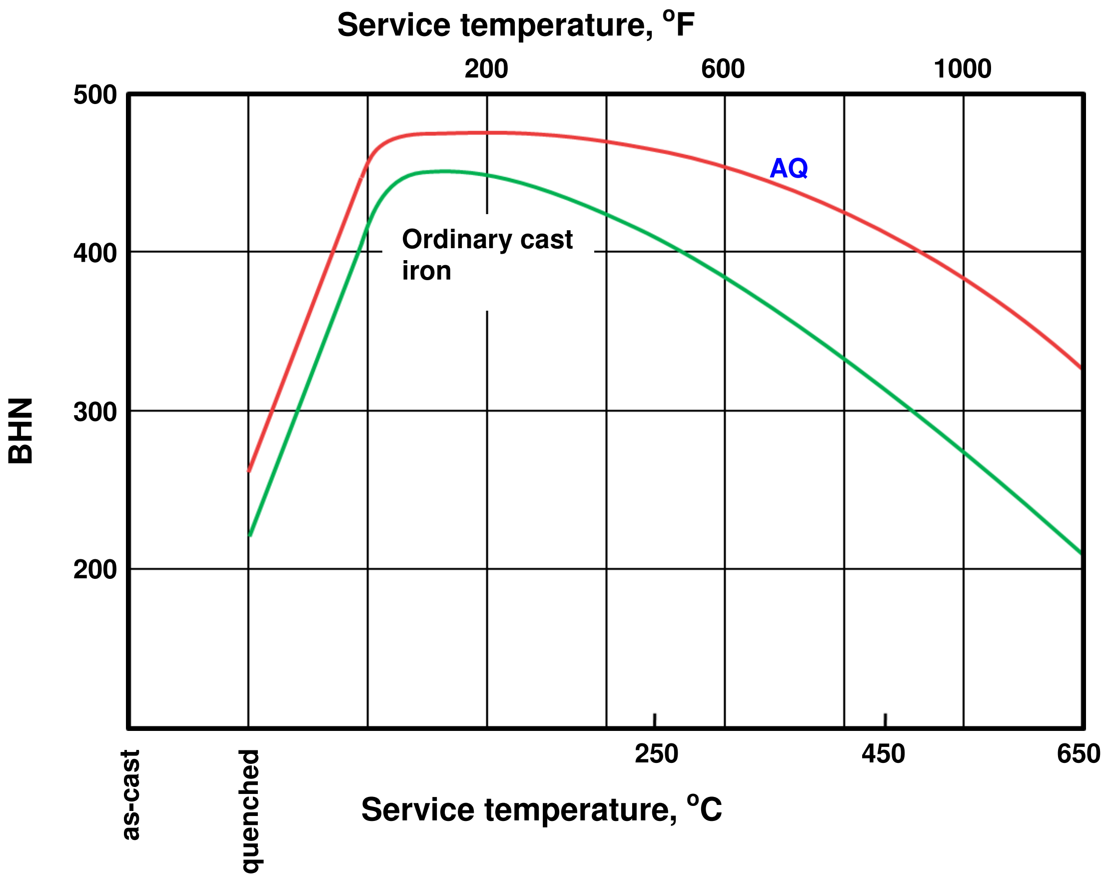


Figure 20 Retention of hardness values in MEEHANITE Type **AQ** at different operating temperatures.

MEEHANITE Type **AQS**

Material specification

This is an air-hardening material possessing high strength and hardness.

It may be fully through air quenched across the casting section after machining to a wide range of uniform strength and hardness values with little or no risk of cracking or distortion.

Its endurance strength is higher than most Types of MEEHANITE ductile iron and Type **AQS** also provides an excellent degree of abrasion resistance due in part to its work hardening characteristics.

Applications

For components subject to cycle stresses of a high order and requiring good wearing surfaces such as crankshafts, cams, gears and spinning mandrels or where resistance to abrasion by non-metallics is mandatory the high hardness and fatigue strength, **Figure 21**, of Type **AQS** is especially valuable.

Mechanical and physical properties[1]

	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	550	lbf/in^2	80000	N/mm^2	1240	lbf/in^2	180000
0.2% Proof stress [min]	N/mm^2	480	lbf/in^2	70000	N/mm^2	960	lbf/in^2	140000
Elongation[2]	%	1 - 3	%	1 - 3	%	1 - 3	%	1 - 3
BHN[2]		<225		<225		<500		<500
Impact strength[3] [un-notched]	J	1 - 3	ft lbf	0.8 – 2.3	J	-	ft lbf	-
Patternmakers shrinkage	%	1.0 – 1.5	%	1.0 - 1.5	%	1.0 – 1.5	%	1.0 - 1.5

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 2mm deep V-notched Charpy test piece [10mm square], average of 3 tests

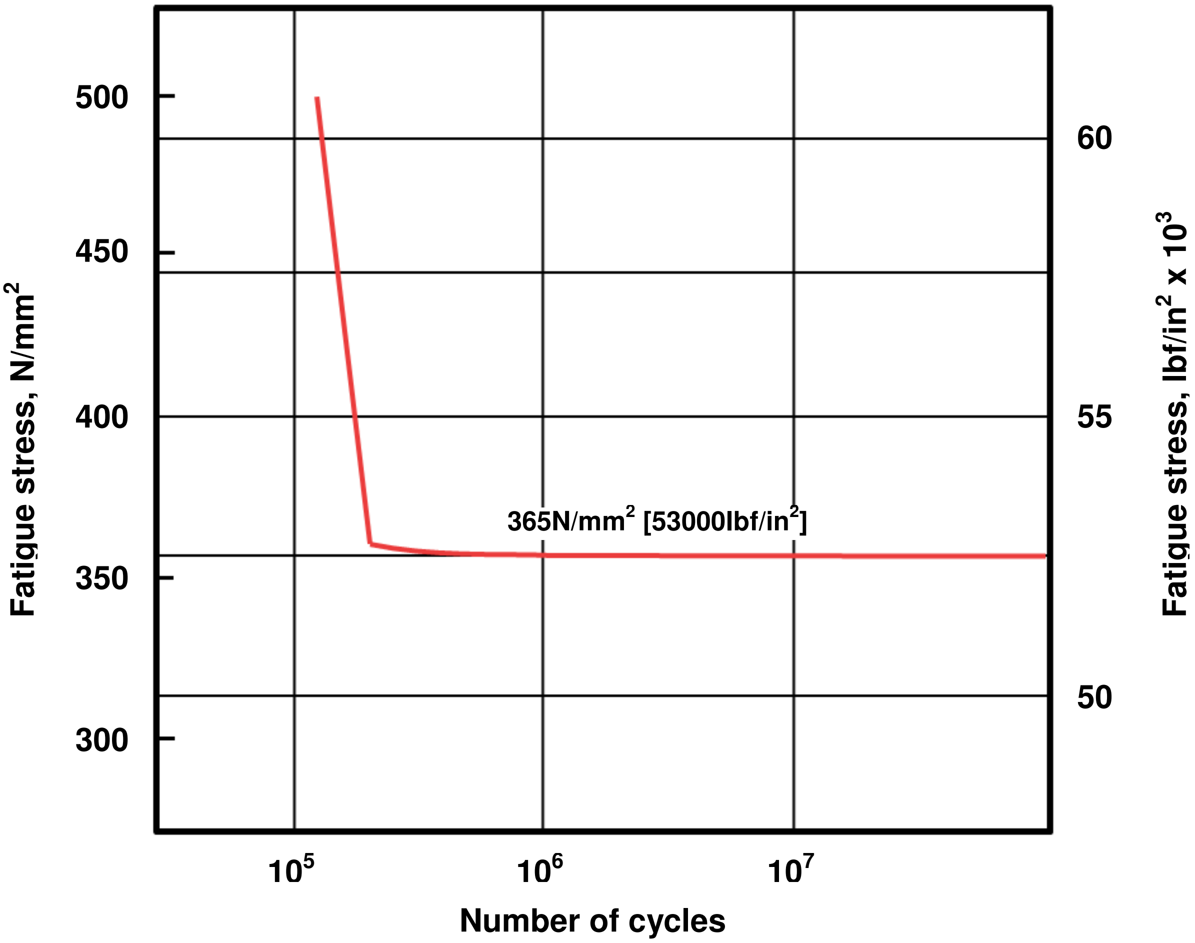


Figure 21 Un-notched fatigue limit of MEEHANITE Type **AQS**.

MEEHANITE Types W_1, W_2 & W_4

Material specification

This is a series of pearlitic/austenitic/martensitic white cast irons characterised by high hardness and relatively good impact strength.

Almanite® W has better wear resistance than chrome-nickel white irons and is a most economical material for general purpose abrasion resistance applications involving scratching with slight impact as encountered in end liners, wear shoes, sand pump impellers and similar parts.

Almanite® W is conveniently separated into Types **W_1**, **W_2** and **W_4**. All of these are white irons with excess carbon in the form of hard wearing carbides.

Type **W_1** has a pearlitic matrix, Type **W_2** has a martensitic matrix and Type **W_4** is highly alloyed to provide an austenitic matrix in the as-cast condition which may be further modified by heat treatment or freezing to give a martensitic matrix.

Hardness values in excess of BHN650 result from this treatment and, in the as-cast condition machining, whilst still difficult, is considered easier than in any other white iron. The carbides in Type **W_4** are of the trigonal and orthorhombic type giving it a toughness higher than usually associated with white iron.

Applications

Recommended for severe abrasion wear, either dry or wet, with moderate impact such as in liners, muller wheels, pan bottoms, pug-mill knife blades, wear shoes and sand pump impellers.

MEEHANITE **Type** W_{20} ore bin liners joined using a MEEHANITE Type **SF400** cap.

MEEHANITE Types W_1, W_2 & W_4

Mechanical and physical properties[1]

Type W_1								
	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	345 - 415	lbf/in^2	50000 - 60000	N/mm^2	-	lbf/in^2	-
BHN		500 - 600		500 - 600		-		-
Impact strength [un-notched][3]	J	0.8 – 1.3	ft lbf	0.6 – 1.0	J	-	ft lbf	-
Microstructure	Pearlitic				Bainitic/martensitic			

Type W_2								
	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	345 - 415	lbf/in^2	50000 - 60000	N/mm^2	-	lbf/in^2	-
BHN		500 - 600		500 - 600		-		-
Impact strength [un-notched][3]	J	1.1 – 1.6	ft lbf	0.8 – 1.2	J	-	ft lbf	-
Microstructure	Bainitic/martenstic				Bainitic/martenstic			

Type W_4								
	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	-	lbf/in^2	-	N/mm^2	415 - 550	lbf/in^2	60000 - 80000
BHN		-		-		400 - 700		400 - 700
Impact strength [un-notched][3]	J	-	ft lbf	-	J	1.0 – 2.0	ft lbf	0.8 – 1.5
Microstructure	Austenitic				Martensitic			

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Converted to 2mm deep V-notched Charpy test piece [10mm square] values, average of 3 tests

MEEHANITE Type WA

Material specification

This is a tough dense material with a high endurance limit offering a reasonable degree of machinability coupled with a desirable level of hardness. It is suited to applications involving a combination of wear and mechanical stress. It responds well to oil quenching and tempering heat treatment providing a tensile strength up to 500N/mm^2 [72500lbf/in^2] and a hardness of BHN550.

Applications

Typical applications include gears, heavy duty brake drums, cams, dies, sheaves, truck wheels, crane and winch drums, crane wheels, pinions, camshafts, clutch plates etc.

It can be machined before hardening for such applications as bearing bushes, cams, gears, liners, blanking and forming dies, valve guides etc.

Mechanical and physical properties[1]

Type WA								
	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	350	lbf/in^2	50000	N/mm^2	500	lbf/in^2	72500
BHN[3]		250 - 350		250 - 350		<550		<550
Microstructure	Flake graphite							
Machinability	Reasonable				Fair			

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry with the test location either being on the test bar or within a predetermined area on the casting.

MEEHANITE Type WB

Material specification

An abrasion resisting white iron for heavy wear conditions, the material is practically non-machinable and has wear resisting properties which compare favourably with those of many wear resisting steels. Does not warp, distort or flake [spall].

Applications

Recommended for applications such as mill liners, sand blast nozzles, crusher rings and segments, plug mill and sand mill knives and blades, roll guides, trough liners, pump impellers, coke and grizzly discs and chute wear plates, blast furnace hopper liner plates, gravel and concrete pipes, brick moulds, stamping dies etc.

Mechanical and physical properties[1]

Type WB								
	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	270	lbf/in^2	40000	N/mm^2		lbf/in^2	
BHN[3]		350 - 500		350 - 500				
Microstructure	White iron							
Machinability	Very difficult							

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry with the test location either being on the test bar or within a predetermined area on the casting.

Material specification

This material possesses an extremely hard working face, which does not spall or chip. The hard working surface is obtained by inserting chills in the mould. Chilling is not particularly deep but it is firmly locked to the base metal. The depth and hardness of the chill layer may be adjusted to specification.

The unchilled area of the casting away from the chilled faces is readily machinable. Generally, on the outside profiles of a casting can be chilled easily; nevertheless, specific internal regions can be chilled if the need arises.

Certain designs of castings are best stress-relieved immediately after manufacture.

Applications

Typical castings made in this Type of MEEHANITE are sheaves, rolls, small mine car wheels, road wheels, mill guides, small gears, clutches, rope guides etc.

Mechanical and physical properties[1]

Type WEC								
	Base metal				**Hardened surface**			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2	250	lbf/in^2	36000	N/mm^2		lbf/in^2	
BHN[3]		180 - 230		180 - 230		400 - 500		400 - 500
Microstructure	Flake graphite							
Machinability	Readily				Grinding only			

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry with the test location either within a predetermined area on the casting.

Material specification

A metal with extremely high hardness developed to withstand the action of the most severely abrasive materials such as; granite, carborundum, coke, concrete etc.

It is exceptionally difficult to machine so all holes for attachments, fittings etc, should be cored out.

Applications

It has been found to be a particularly useful material in cement plants, clay and brick plants, furnace sintering and roasting plants, dredging and pumping plants, ash disposal parts, gravel pipes, pump parts, sand blast machine tables and impellers, abrasive manufacture.

Mechanical and physical properties[1]

Type WH								
	As-cast				Heat treated			
Property	Units	Value	Units	Value	Units	Value	Units	Value
Tensile strength[2] [min]	N/mm^2	200	lbf/in^2	30000	N/mm^2		lbf/in^2	
BHN[3]		<600		<600				
Microstructure	Carbidic							
Machinability	Extremely difficult							

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry with the test location either within a predetermined area on the casting.

MEEHANITE Type WS

Material specification

MEEHANITE Type **WS [Almanite®]** is a martensitic iron with free carbon in the nodular form. The hardness value of Type **WS** is lower than that of Type **W**, but this is accompanied by a very high impact strength three to four times that shown by competitive materials with improved resistance to metal flow and wear.

MEEHANITE Type **WS [Almanite®]** is an ideal metal to use in service conditions involving high impact and abrasion. MEEHANITE Type **WS [Almanite®]** can be machined by conventional means, but with difficulty. It may be rendered more machinable after a soak at 870^{o}C [1600^{o}F] followed by a slow cool in the furnace. After machining, it is necessary to normalise or air harden to produce high hardness values.

Typical applications

Crusher jaws, crusher rings and rolls, liners of all types, hammers in impact pulverisers, slusher-scraper parts, etc.

MEEHANITE Type **WS [Almanite®]** coal pulveriser rings.

MEEHANITE Types WSH_1 & WSH_2/WSH

Material specification

These Types of MEEHANITE are produced from nodular iron base material and alloyed to permit improved hardenability so that through hardness levels can be achieved, in many cases, simply by air quenching.

Structural stabilisation treatments permit the retention of hardness values at operating temperatures up to 450°C [840°F].

In many wear-resisting applications MEEHANITE **Type WSH_2** has shown excellent service life.

Applications

For coke handling, brick manufacture, pumping of abrasive materials, refractory and ceramic production, shot blasting components such as impeller blades and wear plates etc.

Mechanical and physical properties[1]

Type WSH_1								
	As-cast				**Heat treated**			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2		lbf/in^2		N/mm^2	550 - 1200	lbf/in^2	80000 - 170000
BHN[3]						400 - 600		400 - 600
Microstructure	Austenitic nodular graphite iron							
Machinability	Easy				Difficult			

Type WSH_2								
	As-cast				**Heat treated**			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2		lbf/in^2		N/mm^2	250 - 400	lbf/in^2	36000 - 58000
BHN[3]						650 - 700		650 - 700
Microstructure	Martensitic nodular graphite iron							
Machinability	Difficult				Extremely difficult			

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry with the test location either within a predetermined area on the casting.

MEEHANITE Types W_{15}, W_{20} & W_{27}

Material specification

These three grades of MEEHANITE high chromium white irons, in the as-cast condition, contain primary carbides in a matrix of either austenite or martensite. The materials require heat treatment resulting in a microstructure consisting of primary orthorhombic carbides within a matrix of martensite embedded with fine secondary carbides.

As a family of irons, these materials are prone to cracking if residual austenite remains in the matrix. This is particularly pertinent if the castings in service are subject to some form of impact. Therefore, it is quite usual to heat treat these grades to eliminate any residual austenite. This treatment also increases the hardness.

All these grades of MEEHANITE should be stress relieved even if they are not heat treated to improve their hardness.

Applications

Recommended for severe abrasion wear, either dry or wet, with moderate impact such as in liners, muller wheels, pan bottoms, pug-mill knife blades, wear shoes and sand pump impellers.

Because of their high chromium contents MEEHANITE Types W_{15}, W_{20} & W_{27} show remarkably good corrosion resistance and could, therefore, be considered for use where a combination of both wear and corrosion exist.

MEEHANITE Type W_{27} lined feed chute.

MEEHANITE Types W_{15}, W_{20} & W_{27}

Mechanical and physical properties[1]

Type W_{15}

	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2		lbf/in^2		N/mm^2	350	lbf/in^2	50000
BHN		500 - 550		500 - 550		>550		>550
Impact strength [un-notched][3]	J		ft lbf		J	<1.8	ft lbf	<1.3
Modulus of elasticity	$170 N/mm^2$ [26×10^6 lbf/in^2]							
Microstructure	Primary and eutectic carbides in a martensitic matrix.							
Machinability[4]	Difficult				Grinding only			

Types W_{20}

	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2		lbf/in^2		N/mm^2	~400	lbf/in^2	~60000
BHN						>650		>650
Impact strength [un-notched][3]	J		ft lbf		J	<2.3	ft lbf	<1.7
Modulus of elasticity	$200 N/mm^2$ [28×10^6 lbf/in^2]							
Microstructure	Primary and eutectic carbides in a martensitic matrix.							
Machinability[4]	Difficult				Grinding only			

Types W_{27}

	As-cast				Heat treated			
Property	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**	**Value**
Tensile strength[2] [min]	N/mm^2		lbf/in^2		N/mm^2	~400	lbf/in^2	~60000
BHN		550 - 650		550 - 650		~750[5]		~750[5]
Impact strength [un-notched][3]	J		ft lbf		J	<2.0	ft lbf	<1.5
Modulus of elasticity	$200 N/mm^2$ [28×10^6 lbf/in^2]							
Microstructure	Primary and eutectic carbides in a martensitic matrix.							
Machinability[4]	Difficult				Grinding only			

1 All values are based upon testing in air at 20°C, unless otherwise stated.
2 Standard round 30mm diameter proportional test pieces taken from separately cast test samples.
3 Converted to 2mm deep V-notched Charpy test piece [10mm square] values, average of 3 tests
4 All these grades can be machined using inserts such as Arborite®, but it is preferable for the casting design to be such that final shapes can be achieved by grinding.
5 These values are at the limit of Brinell hardness testing. VP hardness testing is required for more accurate values.

Introduction

MEEHANITE castings in general possess good corrosion resisting properties compared with such materials as steel and ordinary cast iron due to their close grained microstructure, uniformly dispersed graphite and solidity; freedom from porosity. In addition, MEEHANITE metal castings have the advantage of close control in their manufacture. It is, therefore, possible to take advantage of their particular mechanical and other properties and at the same time to utilise their enhanced resistance to corrosion.

For mildly corrosive conditions MEEHANITE Type **CC**/**CC** is an all-round inexpensive pearlitic general engineering material. This material has, to all intents and purposes, replaced the older MEEHANITE Types **CB**, **KC** and **CB3**. However, many casting users still rely on these original materials as they have proved their worth in actual corrosive service conditions.

Specifically, MEEHANITE Type **CC** has been found to display good resistance to acids and general chemicals, whilst the newer Type **CB3** shows good resistance to concentrated sulphuric acid and Type **KC** similar resistance to alkalis.

MEEHANITE Type **CHS** is a higher strength nodular material recommended for use in acidic conditions at high temperatures.

For the more severe corrosive conditions, where none of the pearlitic grades are suitable, the austenitic ranges of corrosion resisting MEEHANITE Types **CR**/**CR** and **CRS**/**CRS** should be used. These austenitic series of irons are highly alloyed and provide a range of corrosion resistance and other useful properties. They are austenitic at ambient temperature due to the present of specific alloying elements. The carbon can be present as either flake graphite [Types **CR**/**CR**] or as nodular graphite [Types **CRS**/**CRS**]. The nodular Types generally have better levels of mechanical properties and superior resistance to heat and corrosion, when compared to the flake graphite Types of basically similar composition. Carbides are often present in the high chromium grades.

Corrosion is a complex phenomenon generally considered to be electro-chemical in nature, but being so dependent upon specific environmental conditions; corrosion resistance can only be expressed on a comparative basis. The unit of comparison is usually in mm per year [mils (0.001 inches) per year], **Table IV**. The rate of corrosion is affected by such factors as concentration, temperature, rate of movement of the corrosive media and by the tendency of the metal to become passive under particular conditions of corrosion.

Because of the general complexity of corrosive action it is recommended that specific cases be discussed with your casting supplier or with MEEHANITE who may have case histories corresponding to your application available in their extensive engineering library. The extent of corrosion may be best gauged from the test results on the behaviour of Type **CR**/**CR** [austenitic nickel] in various chemicals. Ranges given vary because of differences in concentration of the corrosive media and only provide the user with a broad guide.

A cautionary note; in many applications, the inclusion of steel chaplets in the mould to hold a core in position proves deleterious to the corrosion resistance of the casting. Thus, the customer should reach an agreement with the foundry as to the wisdom or otherwise of this practice, for any particular application.

In addition, surface rusting of the pearlitic MEEHANITE Types will occur on exposure to the atmosphere. To avoid this some form of protective coating should be applied.

Table IV Corrosion rates in various media.

Chemical		**Rate of corrosion**	
		mm/year	**mil/year**
Mineral acid	Hydrochloric	0.25 - 9.40	10 - 370
	Sulphuric	0.13 - 1.30	5 - 50
	Nitric	1.78 - 58.42	70 - 2300
	Phosphoric	0.51 - 2.50	20 - 100
Organic acids		0.03 - 3.05	1 - 120
Water	Fresh	0.001	0.06
	Salt	0.20 - 0.25	8 - 10
	Mine & industrial	0.13 - 1.02	5 - 40
Alkalis	Sodium hydroxide	0.003 - 2.29	0.10 - 90
	Ammonia	0.001 - 2.29	0.05 - 90
	Calcium hydroxide	0.006	0.20
Chlorides	Ammonium	0.08 - 0.25	3 - 10
	Barium	1.02	40
	Calcium	0.03 - 0.10	1 - 4
	Sodium	0.01 - 0.10	0.04 - 0.40
	Zinc	0.51 - 2.00	20 - 80
Sulphates	Aluminium	0.05 - 0.41	2 - 16
	Ammonium	0.002 - 0.15	35 - 490
	Copper	0.89 - 12.45	35 - 490
	Manganese	13.97	550
	Zinc	14.22	560
Paper chemicals		0.02 - 1.02	0.8 - 40
Petroleum chemicals		0.003 - 10.16	0.1 - 400

Note: 1 mil = 0.001”

Choice of MEEHANITE Types to suite corrosive conditions

Mineral acids: MEEHANITE Types **CC** and **CHS** have excellent corrosion resistance in 100% sulphuric acid at temperatures up to 120°C [250°F].

Corrosion increases with increasing temperature and decreasing acid concentration. Types **CR**/**CR** and **CRS**/**CRS** resist corrosion in dilute sulphuric acid.

Organic acids: MEEHANITE Types **CR**/**CR** and **CRS**/**CRS** resist corrosion by acids such as formic, acetic, oxalic, etc., better than low alloy grey irons.

Alkalis: MEEHANITE Type **CC**/**CC** is not corroded by dilute alkali solutions at any temperature. Hot solutions (above 65°C [150°F]) exceeding 30% concentration are mildly corrosive.

Industrial waters: For industrial waters of low acid concentration, MEEHANITE Type **CC**/**CC** is satisfactory. MEEHANITE Types **CR**/**CR** and **CRS**/**CRS** are used in applications where the pH is low, or in strongly acidic conditions. In applications where the component is subject to high velocity or abrasion MEEHANITE Types **CR**/**CR** and **CRS**/**CRS** should also be specified.

Many chemical plants castings require a combination of resistance to corrosion, heat, erosion, shock etc., and it is necessary to take these factors into consideration. Some examples of successful use are given in **Table V**.

Table V Metal selection for corrosion resistance.

Application	MEEHANITE Type used
Fusion pots for caustic soda	Type **HE**/**HE** for intermittent heating Type **KC** for continuous heating
Concentrators for alkalis, sulphides and ferrous salts	Type **HE**/**HE** for intermittent heating Types **CC**/**CC** or **KC** for continuous heating
Stills and pots for fatty acids	Type **HE**/**HE** for intermittent heating Type **CC**/**CC** for continuous heating
Valves, impellers, etc. for paper manufacture	Type **KC** for alkalis Type **CC**/**CC** for acids
Retorts for sulphur production	Type **HD**
Salt cake pots	Type **HE**/**HE**
Salt bath pots	Type **HD**
Pumps handling alkalis	Type **KC**
Pumps handling acids, oleum and other chemicals	Types **CC**/**CC** Type **CHS,** Type **CB$_3$**

MEEHANITE Types in blue represent material specifications in North America, Taiwan and sometimes South Africa [in Imperial units].

MEEHANITE Type CC/CC

Material specification

Whilst not considered corrosion resisting in the widest sense this MEEHANITE Type has been specially developed to resist corrosion to a somewhat greater extent than the general engineering Types of MEEHANITE while at the same time retaining good all-round mechanical properties and excellent machinability. However, where possible machining should be avoided as the as-cast surface appears to provide added protection against corrosion.

It can be used for slightly acid solutions, alkali solutions at 65^{o}C [150^{o}F] and concentrated sulphuric acid up to 120^{o}C [250^{o}F].

Applications

Acid pans, pots, pans, kettles, pumps, valves, fittings, evaporators, condensers, stills, retorts, filter presses, reaction vessels, etc., for handling chemicals, mine water and sea water, carbonators, causticisers and generally for solutions of less than pH2.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.

2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]*	% Elongation[1]	BHN[2]
Europe, Asia	300N/mm^2	1000N/mm^2	-	190 – 230
Imperial equivalents	*19.4tonf/in^2*	*64.8tonf/in^2*		
	~43500lbf/in^2	*~145000lbf/in^2*		
US	40000lbf/in^2	-	-	190 – 230
Metric equivalents	*~275N/mm^2*	-		
Microstructure	Flake graphite			
Machinability	Good			

Values in italics represent imperial/metric conversions.

MEEHANITE Type CB_3

Material specification

This MEEHANITE Type gives excellent service in plants producing and handling concentrated sulphuric acid and oleum, where the concentration exceeds 77% sulphuric acid.

At 77% concentration MEEHANITE Type **CB_3** can withstand temperatures up to 95°C [200°F], whilst at progressively higher concentrations, higher temperatures can be withstood up to around 200°C [390°F].

Applications

This Type is recommended for use in pumps, valves, fittings, pipes, stills, storage vessels etc., in contact with concentrated sulphuric acid.

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.

2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	300N/mm^2	1000N/mm^2	-	200 – 250
Imperial equivalents	*19.4tonf/in^2*	*64.8tonf/in^2*		
	~43500lbf/in^2	*~145000lbf/in^2*		
US	40000lbf/in^2	-	-	200 – 250
Metric equivalents	*~275N/mm^2*	-		
Microstructure	Flake graphite			
Machinability	Good			

Values in italics represent imperial/metric conversions.

MEEHANITE Type KC

Material specification

The general engineering Types of MEEHANITE offer good resistance to alkalis, but where more severe corrosion is experienced, MEEHANITE Type **KC** is recommended, say, for the handling of fused caustic.

Applications

The notes below apply to the numerical references in the material property tabulations for the flake graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20°C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.

2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength R_m [min]	Compressive Strength σ_B [min]	% Elongation	BHN[2]
Europe, Asia	250N/mm^2	945N/mm^2	-	170 – 210
Imperial equivalents	*16.2tonf/in^2*	*61.2tonf/in^2*		
	~36200lbf/in^2	*~137000lbf/in^2*		
US	36000lbf/in^2	-	-	170 – 210
Metric equivalents	*~250N/mm^2*	-		
Microstructure	Flake graphite			
Machinability	Good			

Values in italics represent imperial/metric conversions.

MEEHANITE Type CHS

Material specification

This corrosion resistant Type of MEEHANITE is a higher strength material with good shock resistance. Compositional adjustments are made to suit exact service conditions.

Applications

MEEHANITE Type **CHS** is recommended for use for components subjected to concentrated sulphuric acid or oleum.

The notes below apply to the numerical references in the material property tabulations for the nodular graphite Types of MEEHANITE that follow:

1 All values are based upon testing in air at 20^{o}C, unless otherwise stated. Standard round 30mm diameter proportional test pieces taken from separately cast test samples.

2 Depends upon section thickness of casting. For acceptance purposes, a hardness range may be agreed between the customer and foundry, the test taking place either on the test bar or at predetermined locations on the casting.

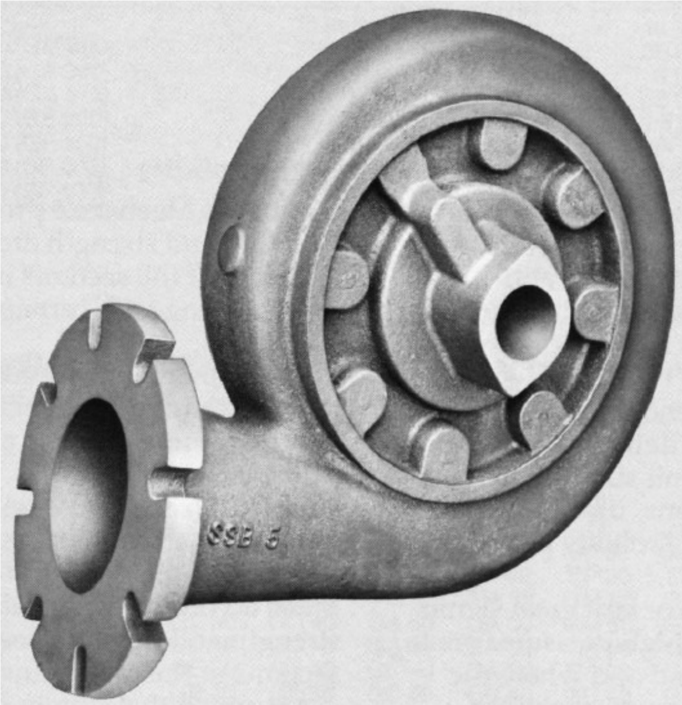
Mechanical properties[1]

MEEHANITE Region	Ultimate tensile strength [min] R_m	Ultimate tensile strength [max] R_m	0.2% Proof stress in tension [min] ($R_{p0.2}$)	0.2% Proof stress in tension [max] ($R_{p0.2}$)	% Elong -ation	BHN[2]
Europe, Asia	410N/mm^2	690N/mm^2	310N/mm^2	520N/mm^2	2 0 – 10.0	200 – 270
Imperial equivalents	*26.6tonf/in^2*	*44.7tonf/in^2*	*20.1tonf/in^2*	*33.7tonf/in^2*		
	~59500lb/in^2	*~100200lb/in^2*	*~45000lb/in^2*	*75400lb/in^2*		
US	60000lb/in^2	100000lb/in^2	45000lb/in^2	75000lb/in^2	2 0 – 10.0	200 – 270
Metric equivalents	*~415N/mm^2*	*~690N/mm^2*	*~310N/mm^2*	*~520N/mm^2*		
Microstructure	Nodular graphite					
Machinability	Good					

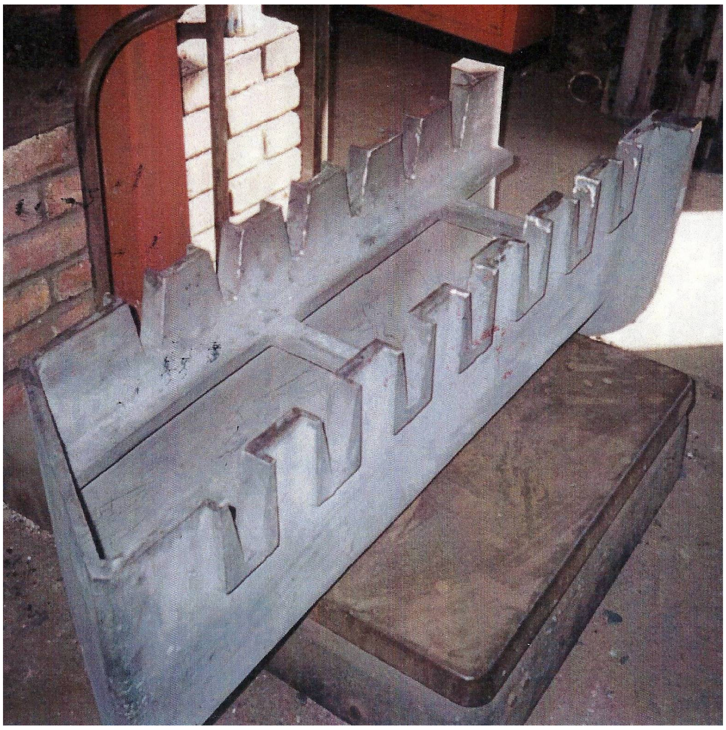
Values in italics represent imperial/metric conversions.

Other mechanical and physical properties

	Symbol	Units	Value	Units	Value
Modulus of elasticity	**E_o**	kN/mm^2	160	lbf/in^2	23.0x 10^6
Impact strength [V-notch]		J	2 - 12	ft.lbf	0.9 – 5.5



MEEHANITE Type **CHS** volute casting.



MEEHANITE Type **CB_3** acid plant trough.

MEEHANITE Type CR/CR

Material specification

MEEHANITE Metal Types **CR**/**CR** are austenitic materials especially designed to meet a wide variety of corrosion [and heat and wear] applications. The microstructures contain graphite in flake form and chemical analyses conforming to **EN 13835 (2012) [ASTM A436-84(2011) and ISO 2892 (2007)]**.

Because of the wide variations in the corrosive conditions encountered and the broad range of chemical analyses with this group of materials one has to have a close look at the exact service conditions before a selection is made.

Applications

In general MEEHANITE Types **CR**/**CR** are used for all applications, with modifications to the **CR**/**CR** Types being used for occasional special service applications such as copper sulphate or ammonia.

MEEHANITE Type **CR5**/**CR5** cover.

CR/CR Corrosion Types of MEEHANITE with flake graphite in an austenitic matrix

Conforming to ISO, ASTM and EN

MEEHANITE Type	Grade to: ISO 2892 (2007) [ASTM A436-84(2011)]	Properties[1] Tensile strength N/mm^2 [min]	Characteristics	Typical applications
CR1	L - Ni Mn 13 7	140	Non-magnetic.	Pressure covers for turbine generator sets, switchgear, housings, insulator flanges, terminals and ducts.
CR2	L - Ni Cu Cr 15 6 2	170	Good resistance to corrosion particularly in alkalis, dilute acids, sea water and salt solutions. Good heat resistance, good bearing properties, high thermal expansion, non-magnetic at low chromium contents.	Pumps, valves, furnace components, bushings, piston ring carriers for light alloy metal pistons.
CR3	L - Ni Cu Cr 15 6 3	190	Better corrosion and erosion resistance than CR2.	
CR4	L - Ni Cr 20 2	170	Like CR2 but more corrosion resistant to alkalis. High coefficient of thermal expansion.	Like CR2, but preferable for pumps handling alkalis, vessels for caustic alkalis, uses in the soap, food artificial silk and plastics industries. Suitable where copper-free materials are required.
CR5	L - Ni Cr 20 3	190	Like CR4, but more resistant to erosion, heat and growth.	Like CR4, but preferred also for high temperature applications.
CR6	L - Ni Si Cr 20 5 3	190	Good resistance to corrosion, even to dilute sulphuric acid. More heat resistant than CR4 and CR5. Unsuitable for use in the temperature range 500°C [930°F] to 600°C [1110°F].	Pump components, valve castings for induction furnaces.
CR7	L - Ni Cr 30 3	190	Resistant to heat and thermal shock up to 800°C [1470°F]. Good corrosion resistance at high temperatures; excellent erosion resistance in wet steam and salt slurry; average thermal expansion.	Pumps, pressure vessels, valves, filter parts, exhaust gas manifolds, turbocharger housings.
CR8	L - Ni Si Cr 30 5 5	170	Particularly resistant to corrosion, erosion and heat; average thermal expansion.	Pump components, valve castings for industrial furnaces.
CR9	L - Ni 35	120	Resistance to thermal shock, low thermal expansion.	Parts requiring dimensional stability e.g. machine tools, scientific instruments, glass moulds.

[1] All values based on testing standard round proportional test pieces, taken from separately cast test pieces, tested in air at 20°C, unless otherwise stated.

MEEHANITE Type CRS/CRS

Material specification

This is an austenitic material with graphite in the nodular form. Materials in this group conform to **EN 13835 (2012) [ASTM A439-83(2009) and ISO 2892 (2007)]** and provide much higher strengths than the MEEHANITE Types **CR**/**CR** with excellent resistance to corrosion and in many cases heat and wear resistance.

The MEEHANITE **CRS**/**CRS** Types are approximately the same as the **CR**/**CR** Types when it comes to corrosion resistance but they show excellent heat resistance and also have superior physical and mechanical properties.

Other properties, electrical characteristic and thermal properties are available from MEEHANITE on request.

Applications

MEEHANITE Types **CR**/**CR** and **CRS**/**CRS** are recommended for components which involve the handling of acid and alkali solutions at temperatures up to 705°C [1300°F], for abrasive slurries, salt water and other heat and wear applications with or without the presence of a corrosive media.

Turbocharger housing in MEEHANITE Type **CRS8**/**CRS8**.

CRS/CRS Corrosion Types of MEEHANITE with nodular graphite in an austenitic matrix

Conforming to ISO, ASTM and EN

MEEHANITE Type	Grade to: ISO 2892 (2007) [ASTM A439-83 (2009)]	Mechanical properties[1]				Characteristics	Typical applications
		Tensile strength N/mm^2 [min]	0.2% Proof stress N/mm^2 [min]	Elongation % [min]	Impact V-notch [Charpy], J		
CRS1	S - Ni Mn 13 7	390	210	15	16	Non-magnetic.	Pressure covers for turbine generator sets, housings for switchgear, insulator flanges, terminals and ducts.
CRS2	S - Ni Cr 20 2	370	210	7	13	Like CR4, in terms of corrosion and heat resistance.	Pumps, valves, compressors, bushings, turbocharger housings, exhaust gas manifolds.
CRS2W	S - Ni Cr Nb 20 2	370	210	7	13	Suitable for production welding using an approved technique, otherwise as for CRS2.	
CRS3	S - Ni Cr 20 3	390	210	7	-	Like CRS2, but better erosion and heat resistance.	
CRS4	S - Ni Si Cr 20 5 2	370	210	10	-	Good resistance to corrosion even to dilute sulphuric acid. Good heat resistance. Unsuitable for use in the temperature range 500°C [930°F] to 600°C [1110°F].	Pump components, valves, castings for industrial furnaces subject to high mechanical stress.
CRS5	S - Ni 22	370	170	20	20	High coefficient of thermal expansion; lower corrosion and heat resistance than CRS2. Good impact properties to -100°C [-150°F]. Non-magnetic.	Pumps, valves, compressors, bushings, turbocharger housings, exhaust gas manifolds.
CRS6	S - Ni Mn 23 4	440	210	25	24	Good impact properties down to -196°C [-320°F]. Non-magnetic.	Castings for refrigeration engineering for use down to -196°C [-320°F].
CRS7	S - Ni Cr 30 1	370	210	13	-	Similar to CR7, good bearing properties.	Pumps, boilers, filter parts, exhaust gas manifolds, valves, turbocharger housings
CRS8	S - Ni Cr 30 3	370	210	7	-	Similar to CR7	
CRS9	S - Ni Si Cr 30 5 5	390	240	-	-	Properties similar to CR8	Pump components, valves, castings for industrial furnaces subject to high mechanical stress.
CRS10	S - Ni 35	370	210	20	-	Low thermal expansion similar to CR9, but more resistant to thermal shock.	Parts requiring dimensional stability e.g. machine tools, scientific instruments, glass moulds.
CRS11	S - Ni Cr 35 3	370	210	7	-	Similar to CRS10.	Parts of gas turbine housings, glass moulds.
CRS12	S - Ni Si Cr 30 5 2	380	210	10	-	Particularly good corrosion, erosion and heat resistance. Better ductility and tougher than CRS9.	Pumps, fittings, exhaust manifolds, turbocharger housings, and industrial furnace furniture.
CRS13	S - Ni Si Cr 35 5 2	370	200	10	-	Excellent resistance to growth and scaling up to 850°C [1560°F]. Lower coefficient of expansion, higher ductility and better creep strength than other grades.	Gas turbine components, housings, support rings, exhaust manifolds and turbocharger housings, die blocks for hot pressing titanium sheet.

[1] All values based on testing standard round proportional test pieces, taken from separately cast test pieces, tested in air at 20°C, unless otherwise stated.

Effect of section thickness on strength and solidity

For every Type of MEEHANITE metal there is a maximum section thickness beyond which solidity and strength properties fall. In foundry parlance this is either called “mass affect” or “section sensitivity”.

“Mass affect” results in open grain, decrease in density and a drastic reduction in strength per unit of area in heavier sections, unless the metal has adequate “solidity penetration power”.

This property is of great significance where high pressures are to be encountered and where the design is to secure minimum weight with assured safety. With the MEEHANITE Process, the structure and strength are controlled to fit the sections involved in the casting with certain limitations.

Where uniformity of solidity [density] and machinability are required, these sections are given below in **Table VI**.

Table VI Recommended minimum and maximum casting section.

MEEHANITE Type	Minimum casting section		to	Maximum casting section	
GM400/GM60	$^{3}/_{4}$“	19mm		30”	760mm
GA350/GA50	$^{1}/_{2}$“	12mm		8”	200mm
GC275/GC40	$^{1}/_{4}$“	6mm		3”	75mm
GE200/GE30	$^{1}/_{8}$“	3mm		$1^{1}/_{2}$“	40mm
GF150/GF20	$^{3}/_{32}$“	2mm		$^{3}/_{4}$“	19mm
SPF600/SP80	$^{3}/_{8}$“	10mm		12”	305mm
SF400/SF60	$^{1}/_{4}$“	6mm		12”	305mm

Table VII displays a simple chart permitting the selection of the Type of MEEHANITE according to the tensile strength and the thickness of the sections of the casting involved.

Table VII Selection of Type of MEEHANITE according to casting thickness.

Ultimate tensile strength		Selection of Type of MEEHANITE according to casting thickness						
		$^{1}/_{4}$"	$^{1}/_{2}$"	1”	2”	3”	4”	6”
lbf/in^2	N/mm^2	6mm	13mm	25mm	50mm	75mm	100mm	150mm
75000	520	SF400/SF60	SFP600/SP80	SPF600/SP80	SPF600/SP80	SPF600/SP80	SP700/SH100	SP700/SH100
65000	450	SF400/SF60	SF400/SF60	SPF600/SP80	SPF600/SP80	SPF600/SP80	SPF600/SP80	SP700/SH100
55000	380	SF400/SF60	GA350/GA50	GM400/GM60	GM400/GM60	GM400/GM60	GM400/GM60	GM400/GM60
50000	350	GC275/GC40	GC275/GC40	GA350/GA50	GA350/GA50	GM400/GM60	GM400/GM60	GM400/GM60
45000	310	GC275/GC40	GC275/GC40	GA350/GA50	GA350/GA50	GA350/GA50	GA350/GA50	GA350/GA50
40000	275	GE200/GE30	GC275/GC40	GC275/GC40	GA350/GA50	GA350/GA50	GA350/GA50	GA350/GA50
35000	240	GE200/GE30	GE200/GE30	GC275/GC40	GC275/GC40	GC275/GC40	GA350/GA50	GA350/GA50
30000	210	GE200/GE30	GE200/GE30	GE200/GE30	GC275/GC40	GC275/GC40	GC275/GC40	GA350/GA50
20000	140	GF150/GF20	GF150/GF20	GE200/GE30	GE200/GE30	GE200/GE30	GE200/GE30	GC275/GC40

Assuming that certain service requirements indicate that the sections within a casting will vary considerably; for example, from 13mm [$^1/_2$”] to 75mm [3”] in section; reference to **Table VII** indicates the casting can readily be produced in **Type GC275**/**GC40** and uniformity will be obtained in the 75mm [3”] section, but the allowable stress value will be based on a 240N/mm^2 [35000 lbf/in^2] ultimate tensile value.

However, if the 75mm [3”] section could be reduced to 50mm [2”] then **Type GA350**/**GA50** can be used; the allowable stress would be based on a 275N/mm^2 [40000lbf/in^2]. Thus, by proper adjustment of the minimum casting section and/or consideration of the ultimate tensile value required in the heaviest section a decision can be made as to the Type of MEEHANITE Metal which is most economical and best to do the job.

From the information in **Table VII** one can select the Type of MEEHANITE Metal for a particular casting which will result in efficient use of both weight and the available characteristics.

Thermal conductivity

Thermal conductivity may be defined as the heat conducting power of a uniform, or homogenous, material per unit of its cross sectional area.

Values arrived at for thermal conductivity under controlled laboratory conditions may be used as a comparison between different materials, but they give little indication of how much heat the material can actually transfer in a particular service application. This is because the heat conductivity in service depends upon a number of factors such as:

- the rate of heat input.
- the temperature gradient between the two walls of the casting and the actual temperature of the metal.
- the shape of the casting.
- the condition of the surfaces of the casting.
- the type of gas, liquid or solid providing the thermal input to the casting.
- the thermal conductivity of the metal.

We see that in any heat conductivity consideration, thermal conductivity of the metal is only a relatively small factor.

In steam chests, for example, the importance of design, steam temperature and flow rate, and the condition of the casting surface are considered more important than the thermal conductivity of the metal comprising the chest.

In air-cooled engines, the design of the cooling fins is considered to be the most important factor.

The previous points have been made not to reduce the importance of the thermal conductivity of a metal but to illustrate that normally others factors may be more important to heat transfer than thermal conductivity alone.

With MEEHANITE Metal, both the chemistry and the microstructure of the material affect the thermal conductivity with graphite content, silicon content, and matrix structure the most important factors.

Graphite has the highest conductivity of any constituent in MEEHANITE and increasing the amount of graphite increases the thermal conductivity. Increases in carbon content will raise the thermal conductivity only if these increases enlarge the number and size of the graphite flakes. If the carbon changes results in an increase in the amount of pearlite in the matrix then the conductivity is decreased because the cementitic component of the pearlite has a much lower thermal conductivity than the ferrite.

Flake graphite irons have a greater thermal conductivity than nodular irons and a random graphite orientation conducts heat better than either undercooled or rosette type graphite.

The addition of almost all other alloying elements lowers thermal conductivity. These include silicon, manganese, phosphorus, aluminium, copper, nickel and chromium. Molybdenum and tungsten seem to give slight increases.

Effect of silicon and graphite content on thermal conductivity

When both the silicon content and the graphite are increased such as when going from **Type GA350/GA50** to **Type GE250/GE30** the effect of silicon lowering thermal conductivity over compensates for the increase due to more graphite being present [providing the matrix remains pearlitic] resulting in a fall in thermal conductivity. Ferritisation of the matrix will, however, increase the thermal conductivity.

For best thermal conductivity specify a high carbon fully ferritic flake iron such as **Type GF150/GF20** with low silicon and minimal alloy content. On the other hand, since thermal conductivity is usually a minor point in the overall heat transfer of a component, the Type of MEEHANITE is more frequently chosen for its other physical properties in preference to its thermal conductivity.

Ingot moulds are the exception to this; however, and a high carbon iron is chosen because of its high thermal conductivity.

Typical values for thermal conductivity for different Types of MEEHANITE Metal are given in **Table VIII**.

Annealing to produce a fully ferritic matrix from a fully pearlitic one increases the thermal conductivity by approximately 10%. Raising the mean temperature from 100°C to 400°C also lowers the thermal conductivity by approximately 10%.

Thermal expansion

When a solid material is subjected to a change in temperature, it undergoes a change in volume, which is directly related to the magnitude of the change in temperature. This expansion is usually expressed as mm/m of linear extension or [in/in].

Table VIII Thermal conductivity values for different MEEHANITE Types.

MEEHANITE Type	Thermal conductivity	
	Btu.in/ft^2.h.^{o}F	W/m.k
GM400/GM60	323	46.59
GA/350/GA50	290	41.83
GC40	325	46.87
GE200/GE30	365	52.64
GF150/GF20	365	52.64
HR	210	30.29
HE[1]	298	42.98
HE[2]	332	47.88
SF60	249	35.91
SP80	221	31.87
SH100	217	30.57
SFF500.14	146	21.09

[1] as-cast
[2] annealed
1Btu.in/ft^2.h.^{o}F = 0.144228W/m.K

The expansion mechanism of cast iron is quite complex. Irons may contain ferrite, carbides [either uncombined or in pearlite], free graphite and varying amounts of inclusions such as MnS. In addition, these irons may be heat treated or alloyed to produce ferritic, pearlitic, bainitic, martensitic, or even, austenitic, microstructures.

The behaviour of cast iron is further complicated by a magnetic change in cementite, which occurs at 200^{o}C [390^{o}F] and the changes in the crystalline structure which occur as heating progresses.

Several factors also contribute to volume changes which, unlike the reversible changes associated with expansion, result in permanent growth. Among them are microstructural changes such as decomposition of pearlite and internal oxidation.

As can be seen in the diagram on the following page all MEEHANITE Types [with the exception of austenitic **CR**] regardless of microstructure or composition initially expand at about the same rate. This rate will fall in the region identified as 1 on the graph [**Figure 22**] above 425^{o}C [800^{o}F], however, the expansion is not so regular.

The expansion curves for the flake-type of General Engineering irons **GA350/GA50**, **GC275/GC40** and **GE200/GE30** will fall in region 2. These materials undergo abrupt rate changes at the critical temperature above which they expand as indicated by region 3.

Above 425^{o}C [800^{o}F] increased alloy content decreases the rate of expansion, as does nodularity. Expansion curves for the following Types of MEEHANITE lie in region 4; **AQ**, **GM400/GM60**, **HS**, **SP700/SH100**.

It is interesting to note that quenching influences the rate of expansion only until the time at which the hardened structure has completely tempered, after which expansion is the same as in the as-cast condition. These rates also apply if the material undergoes a series of thermal cycles; the only change will be a vertical displacement of the curves arising after each cycle due to permanent growth during the cycle.

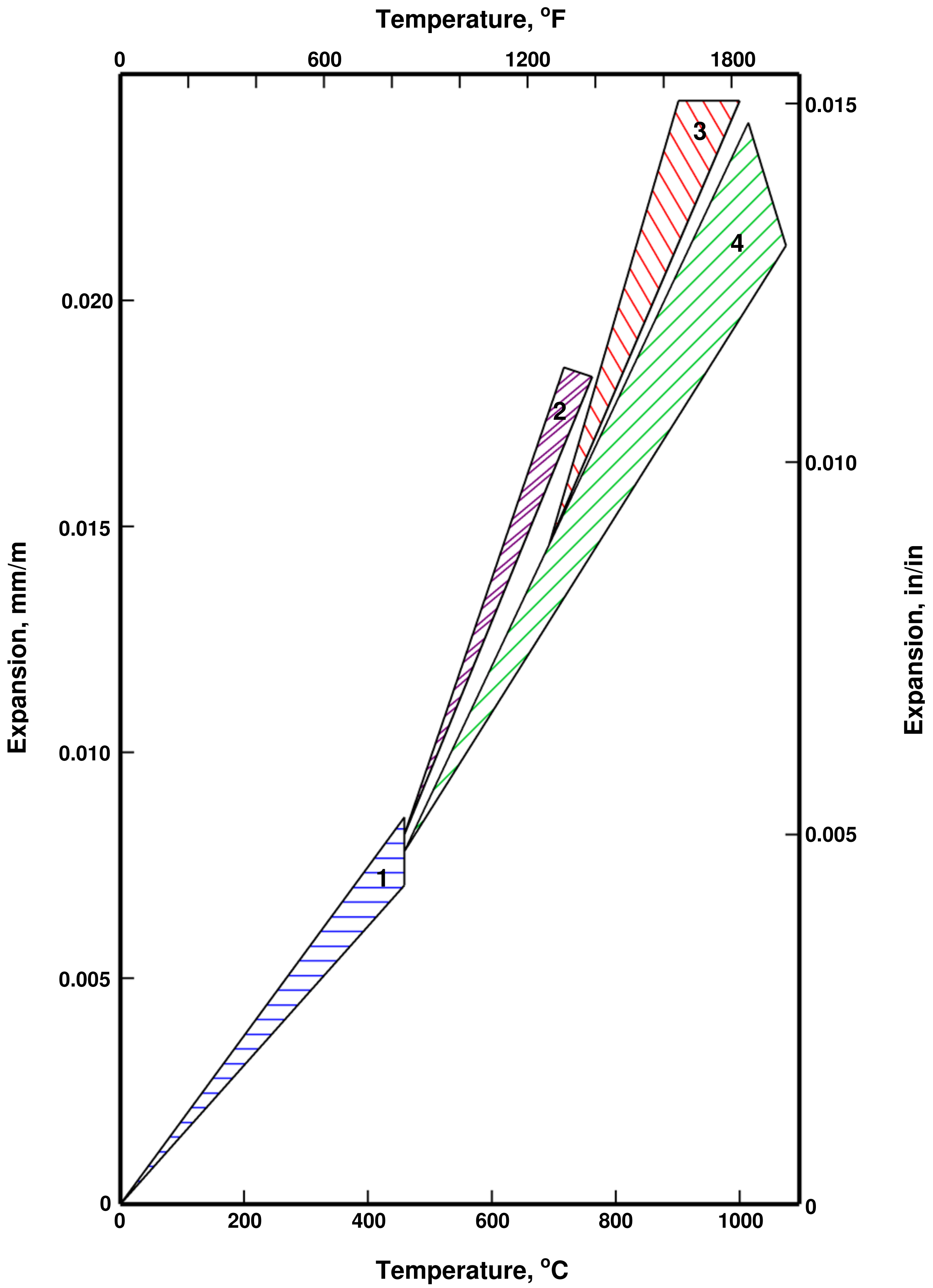


Figure 22 Changes in thermal expansion at different temperatures.

Table IX lists the approximate rates of expansion for some typical MEEHANITE Types. The following are some general observations which are applicable to MEEHANITE Metal:

- Increased carbon equivalents result in lower expansion in nodular irons.
- Nodularity results in a higher rate of expansion at low temperatures and a lower rate at high temperatures than that of a flake iron of similar composition.
- Alloying increases the rate of expansion to about 425°C [800°F] above which it degreases the rate.
- Manganese contents in excess of 0.8% have more effect on expansion than do copper and chromium. Copper has a greater the influence on expansion than chromium.

Table IX Approximate rates of thermal expansion for different MEEHANITE Types.

MEEHANITE Type	Approximate rates of thermal expansion from room temperature to °F [$1/10^6$.°F] °C [$1/10^6$.K]							
	200°F 93°C	400°F 204°C	600°F 315°C	800°F 426°C	1000°F 538°C	1200°F 648°C	1400°F 760°C	1600°F 871°C
GE200/GE30	5.85	5.95	6.35	6.80	7.90	9.05		
	10.53	10.71	11.43	12.24	14.22	16.29		
GC275/GC40	5.45	5.75	6.25	6.70	7.60	9.00		
	9.81	10.35	11.25	12.06	13.68	16.20		
GA/350/GA50	5.05	5.35	6.10	6.50	7.20	7.80		
	9.09	9.63	10.98	11.70	12.96	14.04		
GM400/GM60	5.00	5.30	6.00	6.40	7.05	7.50	7.80	8.30
	9.00	9.54	10.80	11.52	12.69	13.50	14.04	14.94
AQ	5.00	5.65	6.35	6.50	6.75	7.20	7.70	8.30
	9.00	10.17	11.43	11.70	12.15	12.96	13.86	14.94
AQ [as-cast]	6.65	9.40	10.95	9.75	8.15	8.20	8.40	9.10
	11.97	16.92	19.71	17.55	14.67	14.76	15.12	16.38
AQ [annealed]	5.85	5.95	7.70	7.75	7.05	7.20	7.55	8.20
	10.53	10.71	13.86	13.95	12.69	12.96	13.59	14.76
SF400/SF60	5.85	6.10	6.25	6.50	6.95	7.10	7.35	7.40
	10.53	10.98	11.25	11.70	12.51	12.78	13.23	13.32
SPF600/SP80	5.85	5.95	6.15	6.40	6.85	7.05	7.25	7.35
	10.53	10.71	11.07	11.52	12.33	12.69	13.05	13.23
SP700/SH100	6.55	6.65	6.75	6.80	7.40	7.80	8.25	8.50
	11.79	11.97	12.15	12.24	13.32	14.04	14.85	15.30
HR/HR	5.85	5.95	6.15	6.35	7.15	7.75	8.25	9.30
	10.53	10.71	11.07	11.43	12.87	13.95	14.85	16.74
HS/HS	5.85	6.25	6.35	6.50	7.00	7.20	7.40	7.50
	10.53	11.25	11.43	11.70	12.60	12.96	13.32	13.50
CR/CR	10.00	10.20	10.40	10.20	10.10	10.30	10.60	
	18.00	18.36	18.72	18.36	18.18	18.54	19.08	

Specific heat

The heat capacity of a material is defined as the amount of heat required to raise a unit mass of that material by one degree in temperature. The ratio of this amount of heat to that required to raise a unit mass of water one degree is the specific heat of the material.

For most engineering purposes, heat capacities may be assumed to be numerically equal to specific heats. In general, specific heat values vary with temperature but for moderate ranges, a mean value may be taken.

Specific heat may not be regarded as a primary consideration in many engineering applications when compared to the properties such as either thermal conductivity or thermal expansion; it is, nevertheless, a characteristic that must be given attention in certain engineering applications involving heat.

Any material with a high specific heat is capable of absorbing more units of heat before its temperature rises and, consequently, its properties would not be likely to change either as significantly or as soon as materials having a lower specific heat.

The differences may be appreciated by comparing widely different materials – **Table X**.

Table X Specific heats for different materials.

Material	Specific heat	
	J/g.K	cal/g.°C
Copper	0.389	0.093
Brass	0.385	0.092
Ni steel	0.456	0.109
Glass	0.837	0.200
Granite	0.796	0.190

The various constituents that go to make up the structure of cast iron have quite different specific heats – **Table XI**.

Table XI Specific heats of the constituents in cast iron.

Microstructural constituent	Specific heat			
	150°C [300°F]		850°C [1560°F]	
	J/g.K	cal/g.°C	J/g.K	cal/g.°C
Ferrite	0.507	0.121	0.812	0.194
Austenite	0.544	0.130	0.666	0.159
Cementite	0.624	0.149	0.921	0.220
Graphite	1.063	0.254	1.900	0.454

Actually, the specific heat of these constituents will vary more as the temperature changes than these figures would suggest. For example, ferrite [pure iron] will show a gradual increase to 750°C [1380°F] and then increase extremely rapidly to a peak in the range 750°C to 775°C [1380°F to 1425°C], dropping down again beyond 800°C [1470°F].

Similarly the specific heat of graphite changes quite rapidly as the temperature rises – **Table XII**.

Values given for specific heats of materials are usually the average values over a given temperature range.

Table XII Specific heat of graphite at different temperatures.

Temperature	Specific heat	
	J/g.K	cal/g.°C
20°C [70°F]	0.712	0.170
140°C [280°F]	1.063	0.254
640°C [1180°F]	1.905	0.455
900°C [1650°F]	1.901	0.454

As graphite has a different specific heat than ferrite [pure iron] or cementite, it follows that the amount of graphite in the matrix and also its distribution could have an effect on the overall specific heat value. One would, therefore, expect a high carbon cast iron to have a higher specific heat than a low carbon cast iron. actually, this is not the case and, in fact, a higher carbon cast iron usually has a lower specific heat than a low carbon cast iron. Some investigators claim that below 500°C [930°F] this trend is reversed.

Figure 23 shows the specific heat – temperature relationship for various Types of MEEHANITE.

It is also a fact that the amount of phosphorus has an influence on the specific heat of cast iron – **Table VI**. Phosphorus, therefore, lowers the specific heat.

Table XIII Specific heat values for various phosphorus contents in cast iron.

Phosphorus	Specific heat	
	J/g.K	cal/g.°C
0.15%	0.494	0.118
0.55%	0.435	0.104

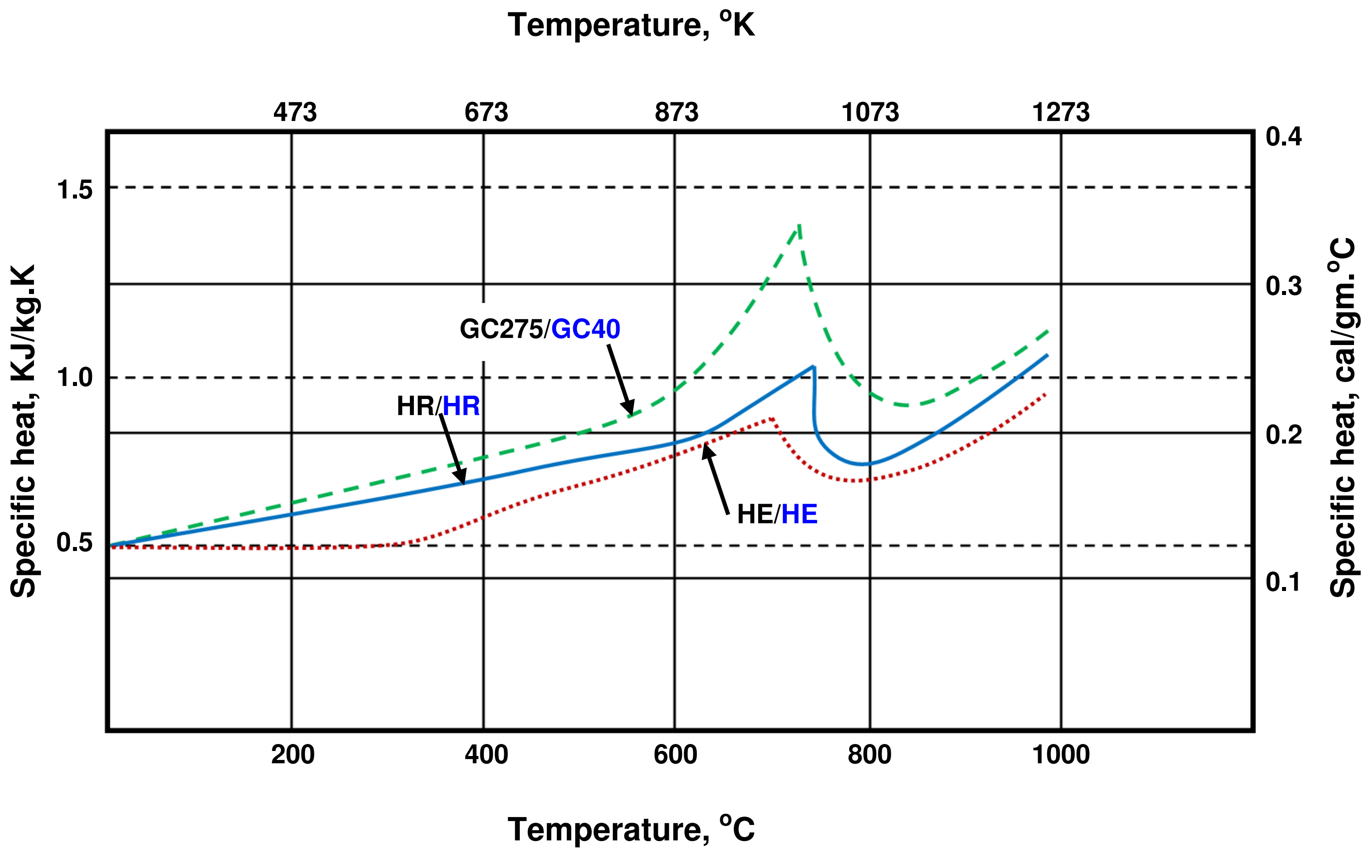


Figure 23 Specific heats at different temperatures for various Types of MEEHANITE.

Sub-zero impact properties

It is generally known that temperatures below freezing tend to lower the strength and impact resistance of most metals. The impact test per sé can be vague and misleading because of the many variables in the test itself. Factors such as the type of test bar, the temperature of testing and the method of applying the load are sometimes varied quite indiscriminately; this introduces an element of uncertainty when assessing test results.

Izod impact tests on a 20mm [0.798”] diameter unnotched test bars made from the flake graphite Types of MEEHANITE over a range of temperatures from room temperature to -196°C [320°F] are shown in **Figure 24.**

The toughness of MEEHANITE Types **GM400**/**GM60** and **GA350**/**GA50** actually increases as the temperature falls from room temperature to -196°C [320°F]. In design, however, it is usual for the room temperature impact values to be employed.

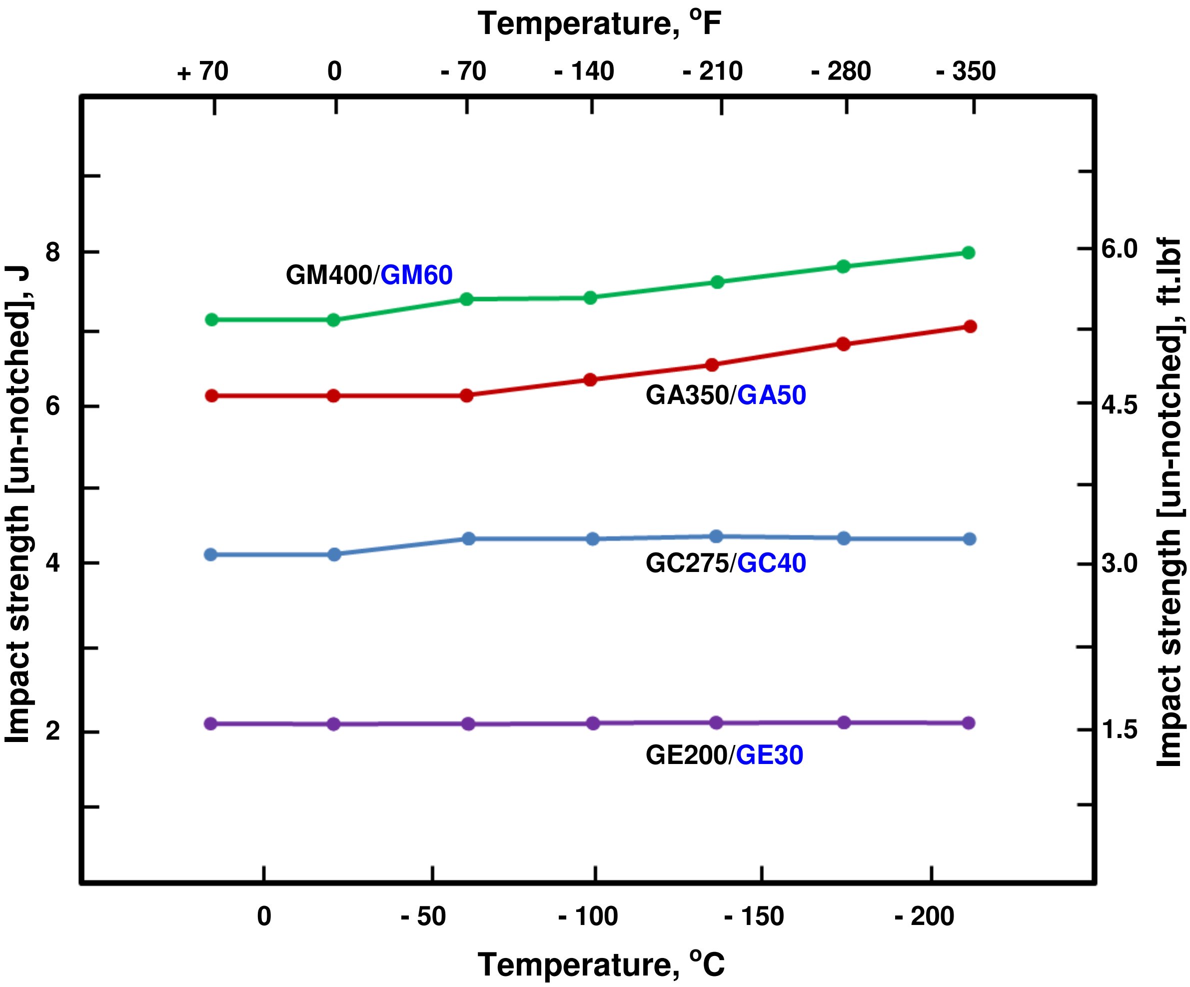


Figure 24 Impact values versus temperature for MEEHANITE Types **GA350/GA50**, **GC275/GC40** and **GE200/GE30**.

When designing castings in MEEHANITE nodular iron requiring ductility at sub-zero temperatures, it is necessary to consider factors affecting the “transition temperature” of the material. The transition temperature is the temperature below which the material behaves in a brittle way and exhibits a visually different fracture. Above this temperature the material behaves in a ductile manner.

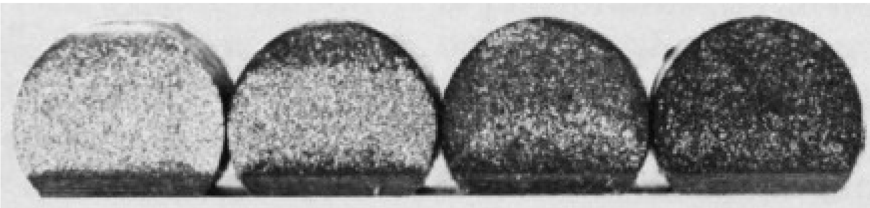


Figure 25 ductile [right] to brittle [left] fractures.

In **Figure 25**, the dark fractures are typically ductile whereas the lighter fractures which have been tested at a lower temperature exhibit the typical appearance of a brittle fracture.

In dealing with the more ductile materials, the chemistry as well as the metallurgical structure becomes important in determining the impact strength and the transition temperature. Therefore, in applications where toughness is a factor, a material is chosen whose transition temperature occurs below its normal operating temperature.

In the MEEHANITE nodular iron, Type **SF400**/**SF60** is designated to maintain its toughness even down to sub-zero temperatures. Types **SPF600**/**SP80** are primarily designated for high strength, and their toughness characteristics do not suit them for sub-zero applications with high shock loadings; however, they can be used in sub-zero applications where high strength is required but there is no shock loading.

Figure 26 shows the transition temperature tests for Type **SF400**/**SF60**. Impact tests were conducted on notched bars. With the typical composition for normal use [curve 3] the transition temperature occurs at approximately 4°C [40°F]. When the chemistry is suitably altered, as in curve 2, the transition temperature can be lowered to about -35°C [30°F].

Special heat treatments can also be used to further lower the transition temperature of Type **SF400**/**SF60** to about -60°C [-80°F] as in curve 1. The heat treatment in this case consisted of heating to 700°C [1300°F] holding for ½ hour and water quenching, then reheating to 200°C [400°F] and holding at this temperature for 24 hours. This heat treatment not only lowers the transition temperature but also raises the impact strength.

The lesson to be learnt from these comparisons is that materials, such as nodular iron, which are supposed to have good toughness, may exhibit severe brittleness if their composition is not related to service temperature. Nodular iron castings having silicon contents significantly higher than would have been expected have been known to fracture when dropped on a particularly cold day, although

Test bars produced from the same material displayed properties well above specification and exhibited normal ductility values.

When an engineer designs for impact or shock resistance and the material unexpectedly fails the result may be catastrophic. On the other hand, the flake graphite General Engineering Types of MEEHANITE irons which are not regarded as ductile behave in a very rational and predictable manner in low temperature service.

While due allowance in design must be made for the fact that these General Engineering Types of flake irons do not offer a high degree of shock resistance, they can be expected to conform to design conditions even at abnormally low temperatures.

Damping capacity

Damping capacity is that property that defines a material's capacity to absorb vibrational stresses. With MEEHANITE Metal, its combination of high strength and damping capacity puts it in a unique position and supplies the MEEHANITE foundry with a very valuable sales tool.

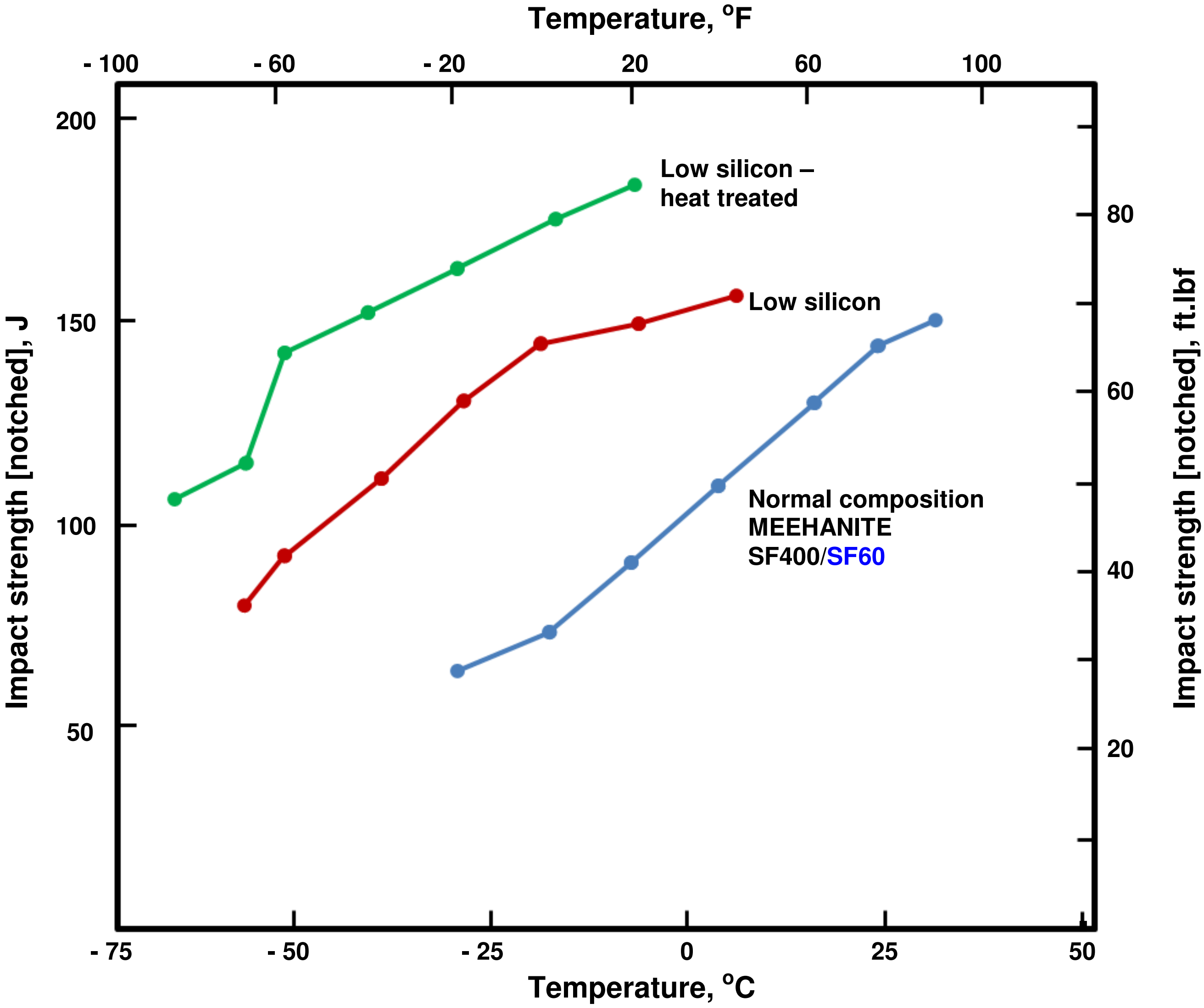


Figure 26 Low temperature impact properties of MEEHANITE nodular iron.

In order to understand the principle of damping vibration, consider what would happen to a tuning fork made of MEEHANITE Type **GE200**/**GE30**: when struck, it would vibrate for few seconds only. A similar tuning fork manufactured from MEEHANITE Type **GA350**/**GA50** would vibrate for approximately a second longer – one of a nodular Type for, perhaps, another second longer. In comparison, a tuning fork made of steel would vibrate five to eight times longer and one produced in aluminium about twelve times longer.

The high damping capacity of MEEHANITE Metal is a result of its controlled metallurgical microstructure; i.e., a random graphite distribution in a uniform matrix. Although it is possible to express damping capacity in fairly precise terms of energy of amplitude absorption, as determined in a laboratory investigation, it is difficult to make use of this information in a quantitative manner.

Along with ductility and impact resistance, damping capacity helps to prevent stresses from getting out of control. Of course, strength is also necessary to control stresses and this is where the basic principles of the MEEHANITE Process are important because the uniform distribution of graphite in MEEHANITE Metal enables it to maintain the high damping characteristics of grey iron together with high tensile strength.

To better understand the value of damping capacity, consider the application of a crankshaft in a combustion engine. If the crankshaft is made of MEEHANITE metal with high damping capacity, then the amplitude of the vibrations caused by the engine's running will be more readily kept within the fatigue limit of the material.

If the same crankshaft were made from a material of similar strength, but with lower damping properties, then the stresses might build up to exceed the fatigue limit and ultimately cause failure. Materials having high damping values are able to be deformed to a higher degree than Hooke's Law predicts without being damaged.

While there are several methods o measuring damping, all methods involve applying a known stress and the measuring the reduction in stress accompanying one or more cycles of vibration. A curve such at that shown In **Figure 27**, is obtained from such a test.

It can be seen that as the applied stress is increased the specific damping capacity increases. The amount of applied stress is just one factor that can change the damping capacity of a MEEHANITE Type once it has solidified with a defined graphite size and distribution.

For example, heat treatment can be used to alter the matrix and hence the damping capacity of a particular Type. Stress relief treatments produce about 20% reduction in damping capacity. On the other hand, annealing to produce a fully ferritic structure increases the damping capacity. The same is true of quenching to produce martensite; however, as the structure is tempered and quenching stresses reduced, the ability to absorb vibration also decreases.

The damping capacity for various materials expressed as the percentage of energy dissipated on the first cycle is given in **Table XIII**. Ordinary grey iron also shows the high damping capacity similar to MEEHANITE Metal; but unless it shows the same high strength of MEEHANITE Metal, it cannot maintain its damping efficiency at high stresses.

Take the example of a power hammer frame which failed when made from ordinary grey iron. Engineers would immediately recommend increasing sections of the replacement casting, but MEEHANITE foundrymen should know that unless a metal with a pearlitic matrix is used, little, if any, advantage is gained because a heavier section and slower cooling rate would result in a weaker casting.

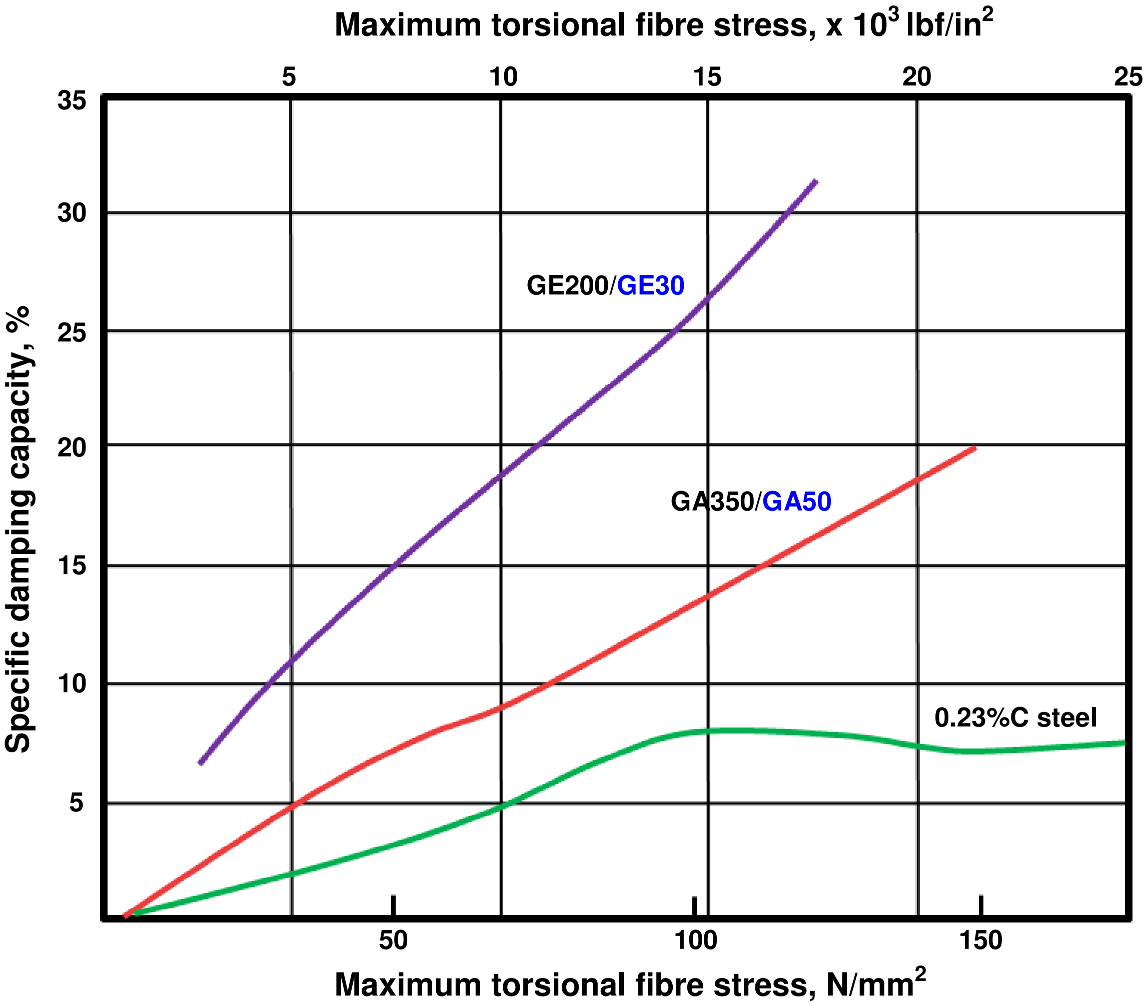


Figure27 Specific damping capacity for MEEHANITE Metals and steel.

MEEHANITE Metal with its various Types makes it possible for the design engineer to select for a given strength an iron of high damping capacity and provides a much wider choice in this respect than all other engineering materials.

Dimensional stability

Maintenance of accuracy of dimension in service is of prime importance in most modern engineering components. In measurements made at the National Physical Laboratory [UK], the movement of MEEHANITE Type **GA350/GA50** samples was found to be as shown in **Table XIV**.

Magnetic and electrical properties

While it is well known that MEEHANITE Metal is not produced primarily for its magnetic properties, and does not compare as such to materials made specifically for this purpose, cases arise when it forms part of a magnetic circuit and it is still important to be familiar with its magnetic properties, **Table XV** and more specifically **Table XVI**.

Table XIII Damping capacity in various MEEHANITE Types.

	% of energy dissipated on the first cycle	
	Torsional load 140N/mm^2 [20000lbf/in^2]	Torsional load 70N/mm^2 [10000lbf/in^2]
Type GF150/GF20	32.0	19.2
Type GE200/GE30	28.0	16.3
Type GC275/GC40	24.0	12.0
Type GA350/GA50	21.0	
Type GM400/GM60	14.0	
Type SF400/SF60	12.0	
Type SPF600/SP80	11.0	
Type SP700/SH700	11.0	
Type GE200/GE30 stress relieved	26.0	
Type GA350/GA50 quenched	32.0	
Type GA350/GA50 Q&T 370°C [700°F]	28.0	
for comparison		
Soft grey iron	40.0	28.2
0.23%C steel	8.0	5.5
Aluminium	42.0	29.4

Table XIV Dimensional stability of MEEHANITE GA350/GA50.

Condition	Time, months	Movement
As-cast	28	3.33×10^{-3} [4.0×10^{-5} in/ft]
Stress relieved	20	1.67×10^{-3} [2.0×10^{-5} in/ft]

Table XV Typical values for magnetic properties for various MEEHANITE Types.

	MEEHANITE Types			
Structure	Flake graphite	Nodular graphite		
	Pearlitic	Ferritic	Ferritic/pearlitic	Pearlitic
Property				
Coercive force [Oe] A/m	7.0 - 9.0 ~750	1 5 - 3.0 160	3.0 - 10.0 450 - 790	8.0 - 16.0 ~875
Max permeability [G/Oe] mH/m	250 – 300 0.5	1000 – 2000 2.1	300 – 1000 1.6 – 0.8	250 – 300 0.5
Remanance [G] T	4000 – 5000 0.54 – 0.58	4500 0.56	5000 0.58 – 0.60	6000 0.62
Resistivity μΩm		0.50	0.51 – 0.53	0.54
Hysteresis loss [when B = 10000G] W/g [when B = 1T]	25 – 30 2.5	4 – 7 0.6	7- 25 1.3 – 2.2	25 – 35 2.7

It is frequently necessary for the engineer to consider other factors such as;

- cost
- machinability
- ease of manufacture
- damping capacity,

and he or she may well chose a MEEHANITE Type for certain components carrying magnetic flux despite its lesser magnetic properties.

An advantage of MEEHANITE Metal over ordinary cast iron lies in the fact that each Type of MEEHANITE Metal is made to definite chemical and metallurgical properties and, therefore, each Type has well defined magnetic properties, while ordinary cast iron covers a broad range of chemistry and metallurgy giving the engineer only vague magnetic property limits unless he specifies the material chemistry himself.

It is sometimes easier to compare magnetic terms to electrical terms which may be more familiar to the reader. In magnetism;

- flux [tesla or gauss] is analogous to current,
- permeability [tesla or gauss] analogous to conductivity, and
- magnetic field or force [oersted or A/m] analogous to voltage.

The most commonly used magnetic properties are illustrated, **Figure 28**, by means of the conventional magnetisation curve and hysteresis loop.

1. Field strength or magnetising force [H] is expressed as oersteds [gilberts/cm, ampere turns/m, or ampere turns/in]
2. Saturation intensity [gauss] is the value of the flux density [B] when saturation is reached, point **A** in **Figure 28**.
3. Permeability, μ [gauss] is the ratio of B to H at any point on the magnetising curve **0A**. It is quite common to quote values of B for particular values of H [magnetising force]. Its value is unity for air or other nonmagnetic media.
4. Remanance [gauss] is the flux density remaining after saturation and the removal of the applied field [value **C** on the y axis].
5. Coercive force [oersted] is the field strength required to demagnetise after saturation [value **D** on the -x axis].
6. Hysteresis loss [ergs/cc/cycle] is the energy dissipated as heat through one cycle, and is proportional to the area of the loop; that is: area in gauss x oersteds/8π. It is more commonly expressed as Watts/g [Watts/lb] at 50 or 60 [hertz] cycles/second for a given flux density, usually, 10000gauss.
7. Flux density maxwell, or formerly line, is the total quantity of magnetism in a circuit.
8. Flux density gauss or maxwell per square inch [B] is the induced magnetic intensity.

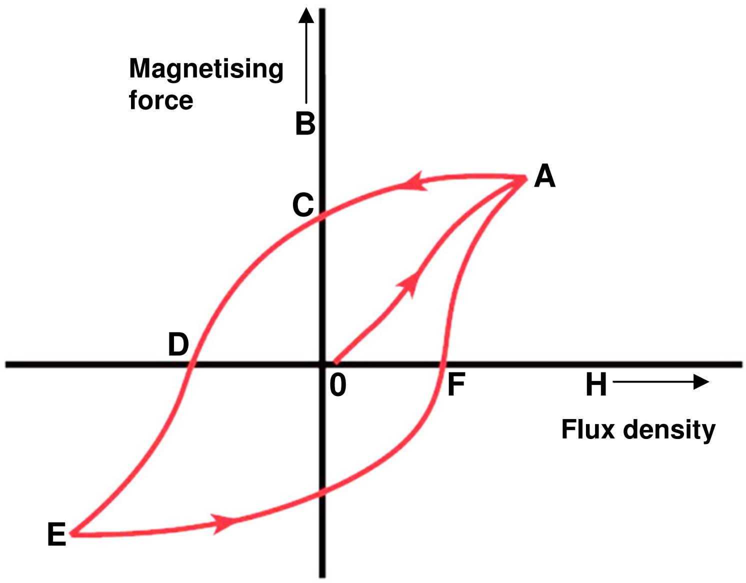


Figure 28 Conventional magnetisation curve and hysteresis loop.

Conversion factors and the interrelation of units of magnetism:

$$1 \text{ oersted} = \frac{1000}{4\pi} \cong 79.577 \text{ A/m}$$

$$1 \text{ oersted} = \frac{1}{0.4\pi} \frac{\text{A turns}}{\text{cm}}$$

$$1 \text{ oersted} = \frac{1 \text{ gilbert}}{\text{cm}}$$

$$1 \text{ gilbert} = \frac{10 \text{ A}}{4\pi} = 0.7958 \text{ A}$$

$$1 \text{ maxwell} = 1 \text{ gauss x cm}^2 = 10^{-8} \text{ weber}$$

$$1 \text{ gauss} = \frac{1 \text{ maxwell}}{\text{cm}^2} = 1 \times 10^{-4} \text{ tesla [100μ tesla]}$$

$$1 \text{ maxwell} = 1 \text{ line}$$

$$1 \text{ gauss} = \frac{6.45 \text{ maxwell}}{\text{in}^2} = \frac{6.45 \text{ line}}{\text{in}^2}$$

$$1 \text{ erg} = 10^{-7} \text{ J}$$

$$1 \text{ W} = 1 \text{ J/s}$$

Machinability and machining

The machinability of MEEHANITE Metal castings is one of their most valuable properties and the MEEHANITE Organisation is actively engaged in devising ways of helping machine shops to obtain the utmost benefit from this property. It is recognised that machinability ratings are of little value without information on the practical details of the machining operation. Emphasis, therefore, is being laid on the provision of the best combination of speed, feed, depth of cut, etc., for the different Types of MEEHANITE Metal.

The value of MEEHANITE quality control and metal processing techniques comes to the fore when machining is under consideration. On the basis of the correct selection of MEEHANITE for section thickness, these factors will ensure that maximum machinability is achieved and that machinability is consistent for casting to casting and from batch to batch. The various Types of MEEHANITE can be classified into a series of groups based on microstructure and, thus, hardness, which has an overriding effect on ease of machinability as shown in **Table XVI**.

On the basis of the groupings in **Table XVI**, it is then possible to indicate recommended values for machining the different types of MEEHANITE by the most common techniques.

The values quoted tend to be conservative and the wide spread of recommended values is due to widely differing operating conditions. Maximum values can be considerably raised in mass production. Actual machining values depend very much on individual applications:

- with slim or unstable castings or when the clamping facilities are inadequate, the cutting rate must be reduced;
- a uniform cutting depth increases tool life;
- cutting speed and feed have to be reduced for interrupted cuts;
- as the tool moves into finally cut of the casting, feed should be reduced;
- for the first rough cut, the starting edge should be given a chamfer with another tool so as to reduce the high initial stress;
- in roughing operations, the cutting depth should not exceed 6mm [$^1/_4$"];
- as few tools as possible should be engaged simultaneously, especially when speeds are high.

Tool life

In modern machining operations, a relatively short tool life can form an acceptable machine shop policy and due attention has been paid to this aspect in the drafting of the tabulated data. As far as carbide tooling is concerned, data on turning operations are based upon a tool life of 30 to 45 minutes while for planning and milling a tool life of 45 to 60 minutes has been assumed.

In the case of ceramic tooling, 20 to 30 minute tool life per edge is possible, depending upon circumstances. If ceramic tooling is used, it is, as a rule, more economical to aim for a shorter life than with carbide tools.

Table XVI Classification – microstructure versus machinability.

Group	Microstructure	MEEHANITE Types	Machinability
1	Pearlite, graphite and some cementite	**WA/W**	**Easier**
2	Pearlite and graphite	**GM400/GM60** **GA350/GA50** **GB300** **GC275/GC40** **GD250** **SPF600/SP60** **SP700/SH100**	
3	Pearlite, graphite and some ferrite	**GF150/GF20** **SFP500** **HE/HE**	
4	Ferrite and graphite	**SFF350** **SFF400** **SF400/SF60** **SF420.12** **SF450.15** **SFF450.15** **SFF500.14/SF70** **SFF600.10**	

Tool form

Tool shapes for rough cuts, based on the use of High Speed Steel and Cemented Carbide Tools, are given in **Figures 29** and **30**.

With the wide spread use of indexable tool inserts, the tool geometry is effectively predetermined by the shape of the insert [**Table XVI**] and its seating in the tool holder or cutter body. MEEHANITE can be machined with either a positive or negative rake. A positive rake offers advantages as far as the cutting process is concerned whereas a negative rake provides certain economic advantages. Indexable inserts with a chamfer in place of the nose radius are used for milling. For the rest, the values given in the table have worked well in practice, the position of the relevant tool angles is shown in **Figure 30**.

Machining practice and types of tooling

High speed steel is listed for drilling operations on MEEHANITE Metal in developed regions and general machining in emerging countries. The recommended machining practice [turning, boring and milling] using high speed steels [and tungsten carbide tools] is given in **Table XVII**. Speeds and feed rates for high speed steel and hard metals twist drills are given in **Table XVIII**.

Cemented carbide tooling is recommended for the other types of machining techniques. Coated inserts offer certain advantages, particularly for roughing operations and under favourable conditions, it may be possible to increase tool life to three times that of ordinary carbide tips, or cutting speeds can be increased by 25% to 40%.

Data on turning and milling MEEHANITE Metal using carbide tools are shown in **Tables XIX** and **XX**. Ceramic tool inserts are used extensively in numerically controlled turning operations and the data relevant to the more recent ceramic tooling has been included **Table XXI** [planning] and **Table XXII** [turning].

Coolants

Many MEEHANITE Metal castings may be machined dry except for tapping and threading. Increased production is obtained by using established water soluble cutting oils that have a high wetting and dispersing quality.

Speed - feed relationship

The best cutting efficiency is obtained by using high feed rates and adjusting the speed to the maximum tool life desired. The speed – feed relationship for the General Engineering Types of MEEHANITE Metal **GA350**/**GA50**, **GM400**/**GM60**, **SPF600**/**SP80**, as well as the softer Types **GC275**/**GC40**, **GE200**/**GE30** and **SF400**/**SF60** are shown in **Figure 31**, based on actual turning tests.

Table XVII Tool geometry for machining MEEHANITE using ceramic tools.

Parameter	Symbol	Turning	Planing	Milling
Side clearance	**α**	5^o	8^o	$8^o – 10^o$
Normal rake	**λ**	$0^o – 12^o$	$15^o – 20^o$	$0^o – 8^o$
Cutting edge inclination	**γ**	-4^o	-10^o - -15^o	0^o
Tool approach angle	**χ**	$45^o – 90^o$	$45^o – 60^o$	$70^o – 90^o$
Tool included angle	**ε**	$50^o – 90^o$	$100^o – 115^o$	$80^o – 90^o$
Nose radius	**r**	0.4 – 1.6mm	0.5 – 2.0mm	Chamfer

Note: With positive normal rake the cutting edge should be honed to a width of [0.2 to 0.3] x feed and an angle of -10^o to -30^o. This is absolutely necessary with interrupted cuts.

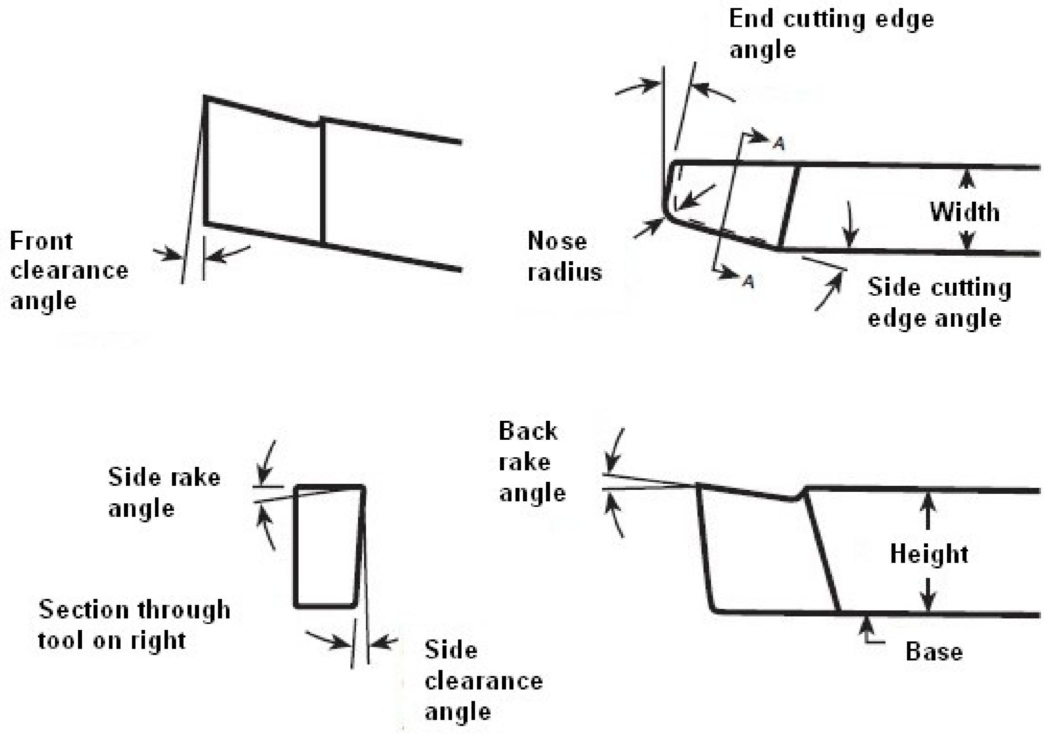


Figure 29 High speed steel tool geometry.

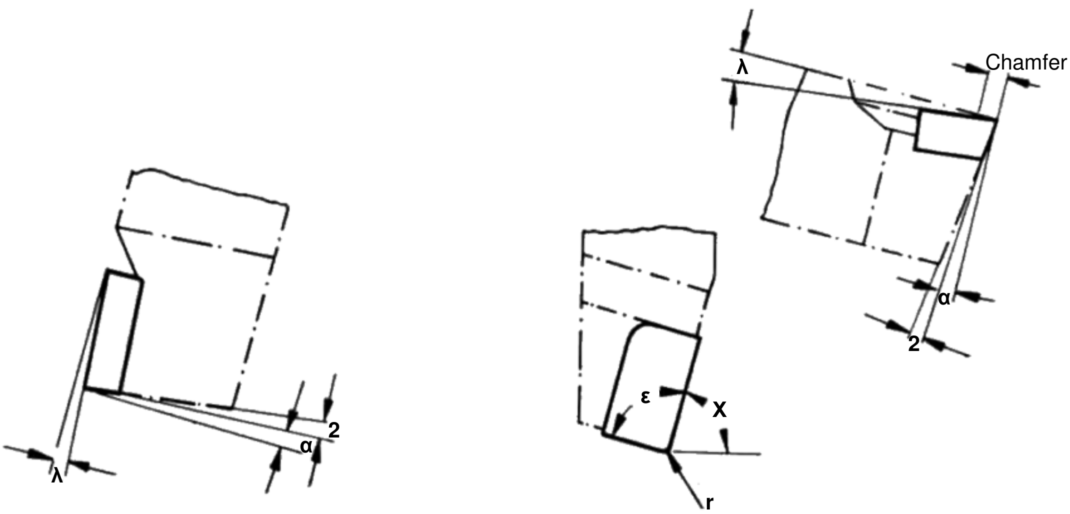


Figure 30 Ceramic tool geometry.

Table XVI Magnetic properties of various MEEHANITE Metal Types [original data units].

	Perme-ability [max]	Flux density at varying magnetising field strengths [H] in oersteds					Saturation intensity [B] in lines/in^2 at		Coercive $_1$ force		Hysteresis at 60 cycles	
	μ	10	20	50	100	200	40At/in	100At/in	gauss	oersted	erg/cm^3	W/lb
Type GA350/GA50 as-cast	300	2200	4800	8000	10000	12000	31000	51000	5400	15	26000	9
Type GA350/GA50 annealed	550	5250	7100	9000	10500	12500	45500	58000	6500	4-7	12000	4
Type GA350/GA50 quenched	80	400	1000	7000	9000	9500	6500	44500	5900	50	6000	20
Type GA350/GA50 quenched & tempered	275	1200	5000	8200	10250	12200	32000	53000	7000	18	30000	10
Type GC275/GC40 as-cast	220	1600	4300	7500	9500	10000	27700	48500	5100	12.5	24000	8
Type GC275/GC40 annealed	500	5000	7000	9000	10500	11000	45000	58000	5000	4-7	9000	3
Type GE250/GE30 as-cast	200	1600	4000	6900	9000	9600	25800	44500	4700	12	22000	7
Type GE250/GE30 annealed	400	4000	5600	7500	9200	9900	36000	48500	5000	4-6	9000	3
Type SPF600/SP60	1450	7500	9100	11500	13500	15000	58500	74000	3600	2	7000	
Type SF400/SF60	425	4200	7000	10200	12700	14000	45000	66000	6000	7.5	28000	

Table XVII Tool geometry for machining MEEHANITE using high speed steel and tungsten carbide tools.

	High Speed Steel Tools			Tungsten Carbide Tools		
	Turning	Planing	Boring	Turning	Planing	Boring
Side cutting edge angle	$6^o – 10^o$	$8^o – 10^o$	$6^o – 10^o$	$8^o – 10^o$	$5^o – 10^o$	$6^o – 10^o$
Edge cutting edge sngle	$8^o – 12^o$	$8^o – 12^o$	$5^o – 8^o$	$8^o – 10^o$	$8^o – 10^o$	$10^o – 12^o$
Front clearance angle	$2^o – 4^o$	$2^o – 4^o$	$4^o – 6^o$	$4^o – 6^o$	$4^o – 6^o$	$2^o – 6^o$
Side clearance angle	$2^o – 5^o$	$2^o – 5^o$	$2^o – 8^o$	$4^o – 6^o$	$4^o – 6^o$	$4^o – 6^o$
Back rake angle	$4^o – 6^o$	$3^o – 5^o$	$0^o – 4^o$	$0^o – 4^o$	$0^o – 8^o$	$0^o – 2^o$
Side rake angle	$6^o – 10^o$	$6^o – 10^o$	$6^o – 8^o$	$2^o – 6^o$	$2^o – 6^o$	$2^o – 10^o$
Nose radius	3.2 – 6.4mm $^1/_8$" – $^1/_4$"	6.4mm $^1/_4$"	3.2 – 4.8mm $^1/_8$" – $^3/_{16}$"	3.2mm $^1/_8$"	3.2mm $^1/_8$"	0.8 – 6.4mm $^1/_{32}$" – $^1/_4$"

Table XVIII Drilling MEEHANITE with twist drills.

MEEHANITE Type	Cutting speed mm/min [in/min]	High speed steel — Feed mm/rev [in/rev] at drill diameter, mm							Cutting speed mm/min [in/min]	Hard metal — Feed mm/rev [in/rev] at drill diameter, mm						
		2 [$^{1}/_{16}$"]	3 [$^{1}/_{8}$"]	5 [$^{3}/_{16}$"]	10 [$^{3}/_{8}$"]	16 [$^{5}/_{8}$"]	25 [1"]	40 [1$^{9}/_{16}$"]		2 [$^{1}/_{16}$"]	3 [$^{1}/_{8}$"]	5 [$^{3}/_{16}$"]	10 [$^{3}/_{8}$"]	16 [$^{5}/_{8}$"]	25 [1"]	40 [1$^{9}/_{16}$"]
GF150/GF20 SFF350 SFF400 SF420.12 SF450.15 SFF450.15 SFF500.14/SF70 SFF600.10	25 – 35 [1" – 1$^{3}/_{8}$"]	0.05 [0.002]	0.08 [0.003]	0.13 [0.005]	0.24 [0.009]	0.32 [0.013]	0.40 [0.016]	0.50 [0.020]	60 – 80 [2$^{3}/_{8}$" – 3$^{1}/_{8}$"]	0.03 [0.001]	0.04 [0.002]	0.07 [0.003]	0.13 [0.005]	0.18 [0.007]	0.22 [0.009]	0.28 [0.011]
GE200-225/GE30 GD250 GC275/GC40 GB300 SFP500	20 – 30 [$^{3}/_{4}$" – 1$^{1}/_{4}$"]	0.05 [0.002]	0.08 [0.003]	0.13 [0.005]	0.24 [0.009]	0.32 [0.013]	0.40 [0.016]	0.50 [0.020]	40 – 65 [1$^{5}/_{8}$" – 2$^{1}/_{2}$"]	0.02 [0.001]	0.03 [0.001]	0.06 [0.002]	0.12 0.005]	0.16 [0.006]	0.18 [0.007]	0.25 [0.010]
GA350/GA50 GM400/GM60 SPF600/SP80 SP700/SH100	15 – 25 [$^{5}/_{8}$" – 1"]	0.05 [0.002]	0.06 [0.002]	0.10 [0.004]	0.22 [0.009]	0.28 [0.011]	0.35 [0.014]	0.45 [0.018]	30 – 55 [1$^{1}/_{4}$" – 2$^{1}/_{8}$"]	0.02 [0.001]	0.02 [0.001]	0.05 [0.002]	0.10 [0.004]	0.12 0.005]	0.16 [0.006]	0.22 [0.009]
WA/W WB/W	-	-	-	-	-	-	-	-	9 – 20 [$^{3}/_{8}$" – $^{3}/_{4}$"]	0.02 [0.001]	0.02 [0.001]	0.05 [0.002]	0.10 [0.004]	0.12 0.005]	0.16 [0.006]	0.22 [0.009]

Table XIX Turning with carbide tooling.

MEEHANITE Type	Roughing			Finishing		
	Cutting speed m/min [s f m]	Feed rate mm/rev [in/rev]	Carbide grade according to ISO R513-1966	Cutting speed m/min [s f m]	Feed rate mm/rev [in/rev]	Carbide grade according to ISO R513-1966
GF150/GF20 SFF350 SFF400 SF400/SF60 SF420.12 SF450.15 SFF450.15 SFF500.14/SF70 SFF600.10	30 – 50 [100 – 160]	0.5 – 1.5 [0.020 – 0.060]	M15, M20 [P25]	40 - 60 [130 – 200]	0.1 – 0.5 [0.004 – 0.020]	K10, M10
GE200/GE30	30 – 40 [90 – 125]	0.4 – 1.2 [0.016 – 0.048]	M15, M20, P25, K20	30 – 45 [110 – 145]	0.1 – 0.5 [0.004 – 0.020]	K10, M10
GD250 SFP500	25 – 35 [80 – 110]	0.4 – 1.1 [0.016 – 0.043]	M15, M20, K20	30 – 40 [100 – 130]	0.1 – 0.5 [0.004 – 0.020]	K10, M10
GC275/GC40 GB300	20 – 30 [70 – 100]	0.3 – 1.0 [0.012 – 0.040]	M15, M20, K20	[30 – 40 [90 – 120]	0.1 – 0.5 [0.004 – 0.020]	K10, K20, M10
GA350/GA50 SPF600/SP80	15 – 25 [50 – 85]	0.3 – 1.0 [0.012 – 0.040]	M15, M20, K20	20 – 30 [70 – 110]	0.1 – 0.5 [0.004 – 0.020]	K10, K20, M10
GM400/GM60 SP700/SH100	10 – 20 [40 – 70]	0.3 – 1.0 [0.012 – 0.040]	M15, M20, K20	20 – 30 [60 – 90]	0.1 – 0.5 [0.004 – 0.020]	K10, K20, M10
WA/W	5 – 10 [15 – 30]	0.15 – 0.3 [0.006 – 0.012]	M15, K10	10 – 15 [30 – 40]	0.1 – 0.25 [0.004 – 0.010]	K10, M10, K05

Notes: The use of carbide coated inserts is recommended.

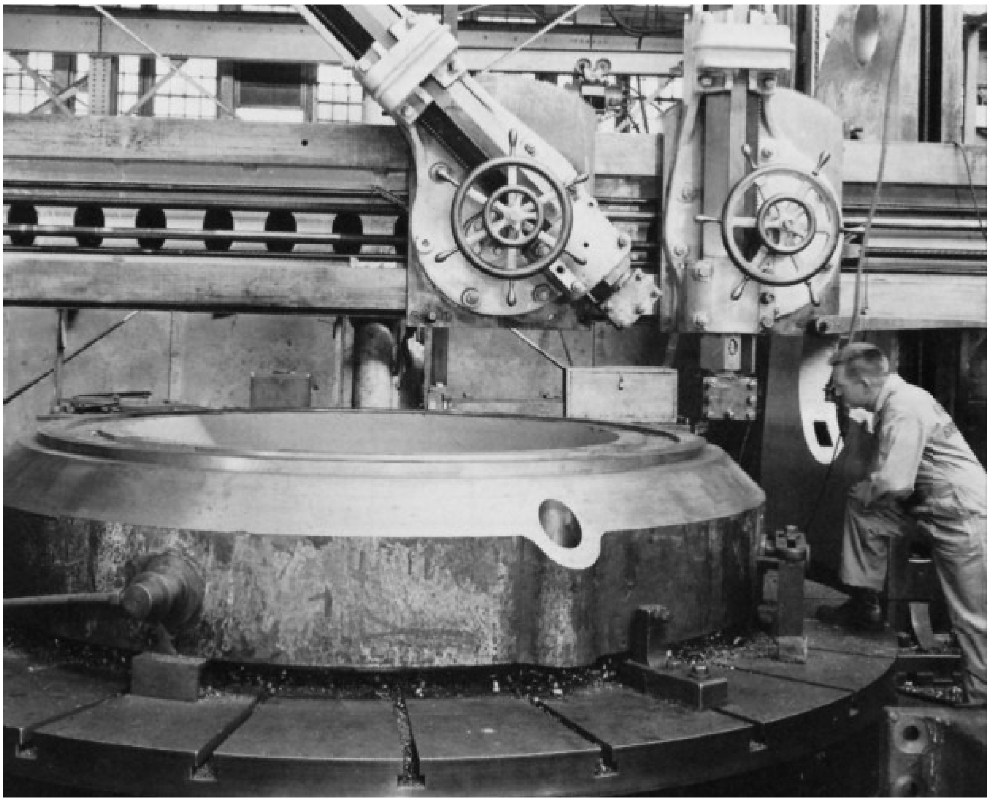
Drilling MEEHANITE Type **CB3**.

Table XX Milling MEEHANITE with carbide tooling.

MEEHANITE Type	Cutting speed mm/min [in/min]	Feed mm/tooth [in/tooth]	Carbide grade according to ISO R513-1966
GF150/GF20 **SFF350** **SFF400** **SF420.12** **SF450.15** **SFF450.15** **SFF500.14/SF70** **SFF600.10**	80 – 130 [3" – 5"]	0.2 – 0.8 [0.008 – 0.030]	M15, M20, P25
GE200-225/GE30 **GD250** **SFP500**	60 – 110 [$2^1/_2$" – $3^1/_4$"]	0.2 – 0.7 [0.008 – 0.028]	M15, P25, K20
GC275/GC40 **GB300**	55 – 110 [$2^1/_4$" – $4^1/_4$"]	0.2 – 0.6 [0.008 – 0.024]	M15, P25, K10, K20
GA350/GA50 **SPF600/SP80**	45 – 75 [$1^3/_4$" – 3"]	0.2 – 0.4 [0.008 – 0.016]	K10, K20
GM400/GM60 **SP700/SH100**	35 – 55 [$1^1/_2$" – $2^1/_4$"]	0.2 – 0.4 [0.008 – 0.016]	M15, P25

Notes:

K types: Roughing on casting skin and finishing.
P25: Roughing below the cast surface.
M types: Roughing below casting surface at high speed with long tool life.
The use of carbide coated inserts is recommended.



MEEHANITE adaptor ring for a nuclear reactor.

Table XXI Planing MEEHANITE Metal with carbide tooling.

MEEHANITE Type	Cutting speed mm/min [in/min]	Feed mm/tooth [in/tooth]	Carbide grade according to ISO R513-1966	Cutting speed mm/min [in/min]	Feed mm/tooth [in/tooth]	Carbide grade according to ISO R513-1966
GF150/GF20 SFF350 SFF400 SF420.12 SF450.15 SFF450.15 SFF500.14/SF70 SFF600.10	30 – 45 [1 1/4" – 1 3/4"]	1.0 – 1.2 [0.040 – 0.050]	K20, K30, P40	35 – 45 [1 3/8" – 1 3/4"]	4.0 – 5.0 [0.160 – 0.200]	K10, K20, P30, P40
GE200-225/GE30	30 – 45 [1 1/4" – 1 3/4"]	1.0 – 1.2 [0.040 – 0.050]	K20, M20, P30	35 – 45 [1 3/8" – 1 3/4"]	3.0 – 4.0 [0.120 – 0.160]	K10, K20, P30, P40
GD250 GC275/GC40 GB300	30 – 40 [1 1/4" – 1 1/2"]	0.8 – 1.2 [0.030 – 0.050]	K20, M20, P30	30 – 40 [1 1/4" – 1 1/2"]	1.8 – 2.0 [0.070 – 0.080]	K10, K20, P30
GA350/GA50 SPF600/SP80 GM400/GM60 SP700/SH100	25 – 30 [1" – 1 1/4"]	0.5 – 0.8 [0.020 – 0.030]	K20, M20, P30	25 – 30 [1" – 1 1/4"]	1.5 – 2.0 [0.060 – 0.080]	K10, K20, P30

Notes:
1) Preference is given to K20 for rough operations and to K10 for finishing operations.
2) If cutting speeds are in the upper ranges and/or for especially heavy cuts, P30/40 can also be used.
3) Higher cutting speeds are possible but this depends upon the machine tool and work piece.

Table XXII Turning MEEHANITE with ceramic tooling.

MEEHANITE Type	Roughing Cutting speed m/min [s f m]	Roughing Feed rate mm/rev [in/rev]	Finishing Cutting speed m/min [s f m]	Finishing Feed rate mm/rev [in/rev]	Recommended type of ceramic
SFF350 SFF400 SF420.12 SF450.15 SFF450.15 SFF500.14/SF70 SFF600.10	450 [1500]	0.3 – 0.6 [0.012 – 0.024]	700 [2300]	0.2 – 0.3 [0.008 – 0.012]	Pure alumina
GF150/GF20 SF400/SF60	400 [1300]	0.3 – 0.6 [0.012 – 0.024]	650 [2100]	0.2 – 0.3 [0.008 – 0.012]	
GE200-225/GE30 GD250 SFP500	350 [1100]	0.3 – 0.6 [0.012 – 0.024]	550 [1800]	0.2 – 0.3 [0.008 – 0.012]	
GC275/GC40 GB300 GA350/GA50 SPF600/SP80	300 [1000]	0.3 – 0.6 [0.012 – 0.024]	500 [1650]	0.2 – 0.3 [0.008 – 0.012]	
GM400/GM60 SP700/SH100	275 [900]	0.3 – 0.6 [0.012 – 0.024]	450 [1500]	0.2 – 0.3 [0.008 – 0.012]	
WA/W SH800/SH100	200 [650]	0.2 – 0.5 [0.008 – 0.020]	350 [1150]	0.1 – 0.3 [0.004 – 0.012]	Pure or mixed ceramic
WB/W	75 [250]	0.15 – 0.3 0.006 – 0.012	125 [400]	0.05 – 0.3 [0.002 – 0.012]	
WH/W	20 [70]	0.15 – 0.3 0.006 – 0.012	30 [100]	0.05 – 0.3 [0.002 – 0.012]	Mixed alumina/titanium carbide

Notes:
1) If machining conditions are difficult, the above values can be reduced by up to 50%; in favourable conditions they can be increased by 50%; and circumstances permitting by 100%.
2) When fine turning in order to achieve a very smooth finish, an insert of mixed ceramic type should be used on all MEEHANITE Types, using a chamfer of 0.05mm [0.002in] (instead of the usual 0.2mm [0.008in] x 20°) and a feed of 0.1 – 0.2mm/rev [0.004 – 0.008in/rev], and a cutting depth of no less than 0.2mm [0.008in].
3) In the case of machining the hard MEEHANITE Types **WB/W** and **WH/W**, the depth of cut should be less than 0.15mm [0.005in], the approach angle, χ being 20°, using a chamfer of 2mm x 15°.

Preparation and sharpening of tools

Dull tools cost money and waste time. Correct angles, rakes and clearances are vital for efficient metal removal. Grinding of tools must be exact. This requires use of fixtures and competent tool grinders. Hand grinding is undesirable.

Avoid water quenching cutters after grinding. This causes minute edge cracking and premature failure in operation. Use grinding-cutters entirely dry or when using a wheel ensure ample water is directed on the cutter.

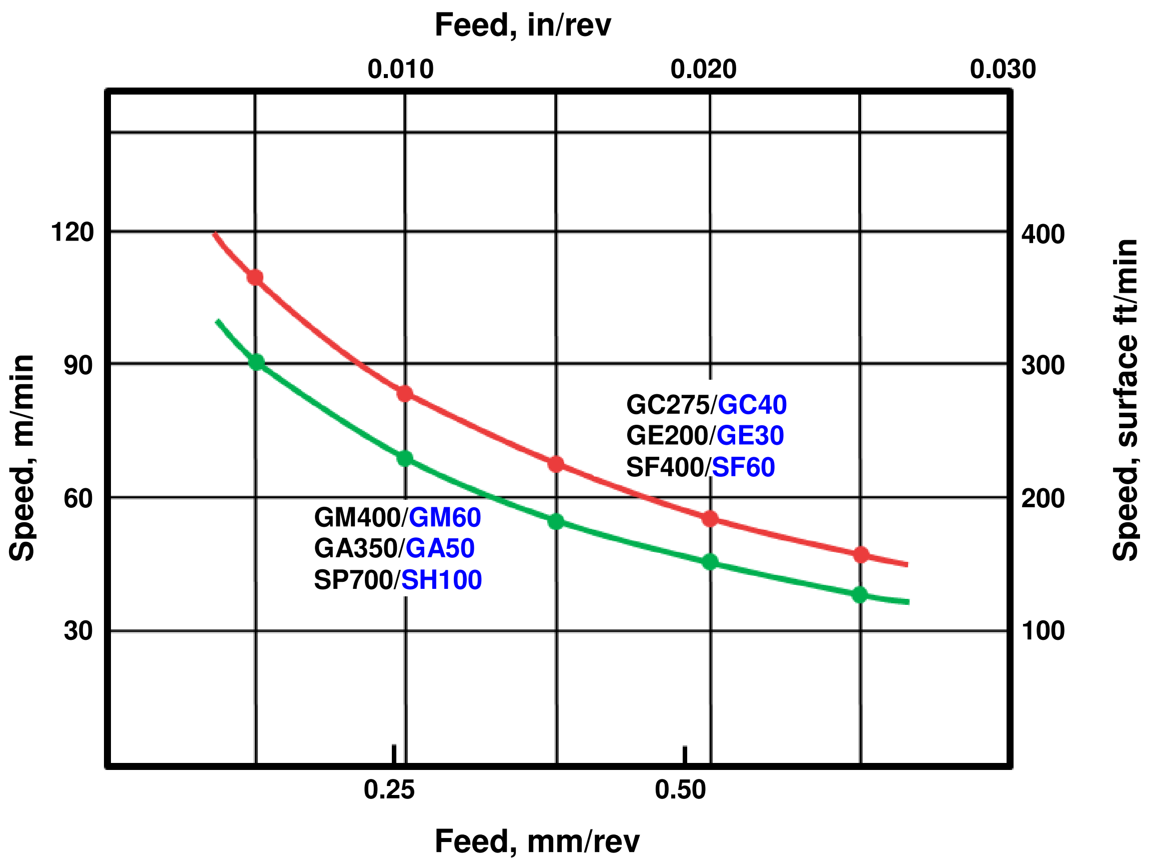


Figure 31 Speed – feed relationship for MEEHANITE flake and nodular iron Types.

Avoid forcing cutters against a grinding wheel. This overheats and burns the cutting edge of the tool causing flaking during machining operations. Check all cutter angles with a cutter grinding gauge.

Machining allowance

Do not skimp on finish limits. The quality of the surface of a casting is usually better on the bottom face of the casting. Therefore, design the pattern so that the important surface may be in the most favourable casting position.

Complicated and large castings require wide tolerance limits. Castings having large flat areas require extra finish 9.5mm – 12.5mm [$^3/_8$" – $^1/_2$"] on the top face, while 3mm [$^1/_8$"] may be enough on the bottom face. If only one face must be perfect, top limits may be reduced.

Before commencing machining, lay out surface to be machined at small end or side of casting with draft to ensure “clean-up” on all surfaces. Castings may not clean-up on all surfaces if the casting draft is not taken into account. Machining allowances involve many variables consult with your MEEHANITE supply foundry.

Gear factors for MEEHANITE helical gears

The exact control of composition and microstructure is essential if gears are to wear well and give good and continuous service. Ordinary cast iron varies too greatly in its physical properties to be completely dependable in all forms of gearing. Even with MEEHANITE Metal, some knowledge of the type of gearing and the service demanded is essential to obtain the best from its use. Iron for gears should be as hard as is practicable, consistent with machinability.

In MEEHANITE Metal this is accomplished by control of the graphite size and its distribution within the pearlitic matrix, together with judicious control of the phosphorus content; also by heat treatment to suit special applications.

All this, in effect, means giving the gear designer knowledge of the mechanical properties of each Type as listed in the preceding pages. In addition, the evaluation of the wear resistance of the material, in terms of its surface behaviour, and the strength, in terms of tooth strength, are special properties which have been empirically determined by test and confirmed by experience.

In the UK, David Brown & Sons has developed the DBS system for the evaluation of gear materials. The relevant testing techniques have been adopted by the British Standards Institution [BSI] and the resulting values are commonly used by UK gear designers.

The following values have been determined for the two design criteria, basic bending stress factor [S_b – **Table XXIII**] and basic surface stress factor [S_c – **Table XXIV**] , for several pearlitic Types of MEEHANITE in the as-cast and heat treated condition.

Table XXIII Basic bending stress factor [S_b] for various MEEHANITE Types and heat treated conditions.

<table>
<tr><th rowspan="2">MEEHANITE Type</th><th rowspan="2">Condition</th><th colspan="2">S_b Factor</th><th rowspan="9">Basic bending stress factors</th></tr>
<tr><th>N/mm^2</th><th>lbf/in^2</th></tr>
<tr><td>GM400/GM60</td><td>As-cast</td><td>107</td><td>15500</td></tr>
<tr><td>GA350/GA50</td><td>As-cast</td><td>104</td><td>15000</td></tr>
<tr><td>GC275/GC40</td><td>As-cast</td><td>97</td><td>14000</td></tr>
<tr><td>GM400/GM60</td><td>Heat treated to BHN500</td><td>110</td><td>16000</td></tr>
<tr><td>GM400/GM60</td><td>Heat treated to BHN400</td><td>120</td><td>17500</td></tr>
<tr><td>SPF600/SP80</td><td>As-cast</td><td>131</td><td>19000</td></tr>
<tr><td>SH1000</td><td>Heat treated to BHN350</td><td>207</td><td>30000</td></tr>
</table>

Table XXIV Basic surface stress factor [S_c] for various MEEHANITE Types and heat treated conditions.

MEEHANITE Type	Condition	S_c Factor		Basic surface stress factors
		N/mm^2	lbf/in^2	
GM400/GM60	As-cast	11.0	1600	
GA350/GA50	As-cast	10.0	1450	
GC275/GC40	As-cast	9.7	1400	
GM400/GM60	Heat treated to BHN450	16.8	2400	
SPF600/SP80	As-cast	12.4	1800	
SH1000	Heat treated to BHN350	18.6	2700	

Pattern maker's contraction allowance

A rule sometimes applied is that dimensional tolerances should be approximately half the maximum shrinkage allowable for a particular Type of MEEHANITE Metal. This rule should be applied with extreme caution, for it does not hold in the case of extremely large and complex castings and is affected by a series of factors; such as, size of casting, design complexity, relative mass of core to metal, varying metal thickness, Type of metal, temperature of pouring and mould material.

The advent of rigid moulding techniques utilising chemically bonded and cement sands, in rigid box parts, results in castings that can be substantially under-size relative to the pattern, so that both contraction and machining allowances must be increased above those normally accepted.

Hardening i.e. the change from pearlite to cementite gives a negative volume change. Annealing i.e. the change for pearlite to ferrite, on the other hand, gives a positive volume change. Certain foundries use an annealing heat treatment in the production of ferritic nodular iron, whereas others achieve a ferritic structure by suitable adjustment to the chemical composition. It is, therefore, extremely foolhardy to predict final casting dimensions unless the production cycle is clearly established.

A guide to the approximate contraction allowances for patterns used for the production of castings in various Types of MEEHANITE is given in **Table XXV**. These values should only be used with caution and after consultation with the foundry to determine whether their production techniques will affect these figures in any way.

Table XXV Pattern maker's contraction allowances for various MEEHANITE Types.

MEEHANITE Type		Contraction allowance, %
GM400/GM60		1.1 – 1.4
GA350/GA50		1.0 – 1.4
GB300 & GC275/GC40		0.9 – 1.3
GD250, GE225 & GE200/GE30		0.8 – 1.2
GF150/GF20		0.6 – 1.0
SFF350 & SFF400		0.0 – 0.5
SF400/SF60 & SFP500		0.2 – 0.8
SPF600/SP80 & SP700		0.5 – 1.1
SH800/SH100 & SH1000		0.0 – 1.5
HE/HE	Heat resisting	~0.9
HR/HR		~1.6
HS		1.0 – 1.4

Galling, seizing and pick-up

In the design of industrial machinery, it is impossible to avoid the mating of two or more metallic surfaces under conditions that involve movement and some degree of friction. Under many conditions, this friction may exceed a critical value causing adherence. The tearing action that results damages one or both of the surfaces and is usually referred to as galling.

Where it is severe enough to cause welding, this is known as seizing. Pick-up, scuffing and scoring represent various manifestations of the same problem. Metal surfaces are attracted to one another by the natural tendency of atoms and molecules to combine. As surface molecules are only bonded on three sides, they exert a strong attraction towards similar surface molecules.

By conditioning the metal so that an amorphous non-crystalline layer known as the Beilby layer occurs, it is possible to considerably reduce this molecular attraction and decrease the surface friction between the moving parts. The ability of a material to be so conditioned together with any built-in lubricative properties the material may possess play a vital part in avoiding galling action.

MEEHANITE Metal contains free graphite, which gives a certain "built-in" protective feature when metal parts operate together for a short time without lubrication. This feature is well illustrated by the friction torque that results when MEEHANITE slides against MEEHANITE, compared to when it slides against steel containing no free graphite, **Figure 32**.

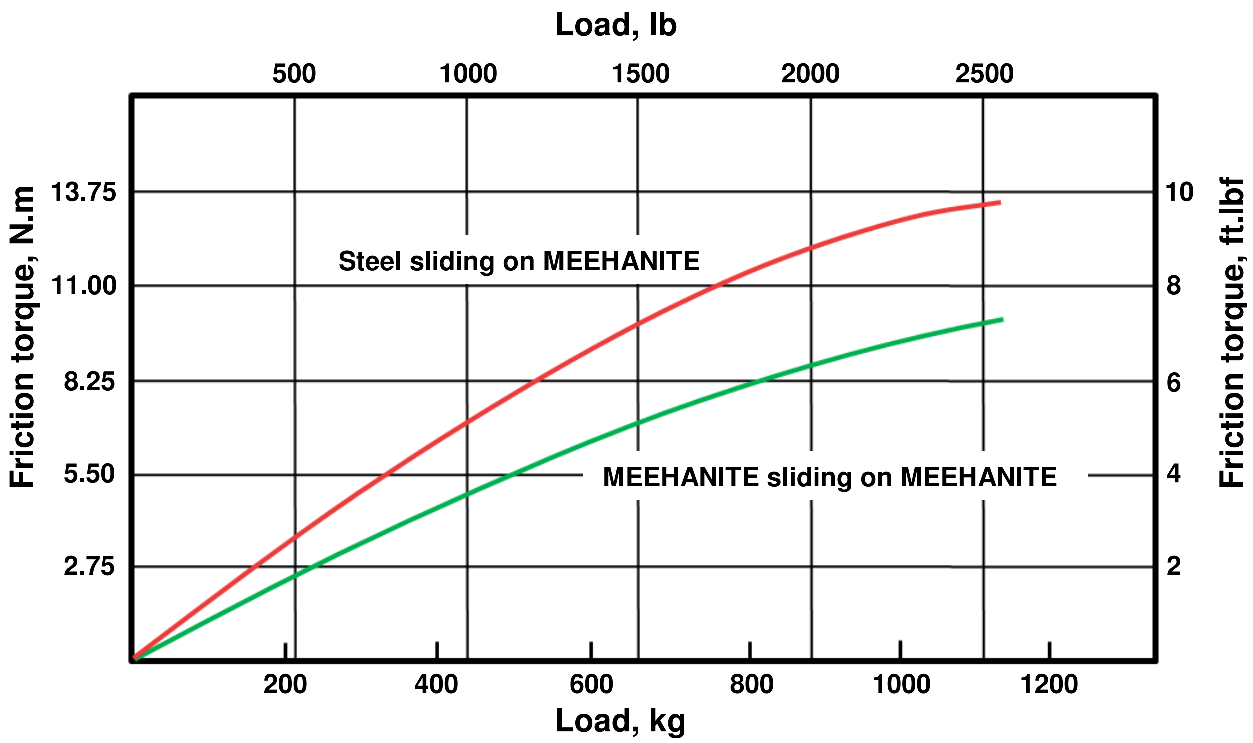


Figure 32 Friction torque versus load steel on MEEHANITE and MEEHANITE on MEEHANITE.

Comparative tests run using steel as the rotating member and increasing the working load in increments of 45kg [100lb] until seizing occurs show the proportionate galling values of the materials listed in **Table XXVI**.

Table XXVI Seizing loads of steel against various materials.

Material	Seizing load	
	kg	lb
MEEHANITE Type GA350/GA50	590	1300
MEEHANITE Type GE200/GE30	545	1200
Graphitic cast iron	454	1000
Navy bronze	363	800

By far the most important factor that is operative in any galling problem is the condition of the mating surfaces. The effect of surface finish as measured in a special series of tests is shown in **Table XXVII**.

Table XXVII Seizing loads versus surface finish.

Surface condition	Finish		Seizing load	
	mm x 10^{-6}	in x 10^{-6}	kg	lb
Machined	1651	65	454	1000
Ground	305	12	Did not seize at 1135	Did not seize at 2500
Lapped	203	8	Did not seize at 1135	Did not seize at 2500

The finer the surface finish, the closer the surface is to having a Beilby layer. Consequently, the running-in period needed to develop such a layer becomes increasingly more critical as the original surface becomes rougher. In general, a material having a finish of 305 µ mm [12 µ inches] or less will not require a careful “wearing-in” period.

“Wearing-in” may be accomplished by running at light loads for short periods of time, allowing adequate time for rest, or recovery between the running periods. The graphical illustration shows how the friction coefficient varies with “running in”. The final low coefficient indicates the production of a Beilby layer on the surface, **Figures 33** and **34**.

On the other hand, a part that has been “super finished” and “worn-in” at a heavy load as shown in **Table XXVII**, may be regarded as being in the “run-in” condition because it exhibits a low friction coefficient right from the start. Heat treatment of MEEHANITE Metal followed by honing gives a surface that is virtually gall resistant. Additionally, the hardening treatment will result in excellent wear resistant characteristics.

Lubrication is obviously important in any metal to metal contact. MEEHANITE Metal with its “built-in” lubricant in the form of graphite is less critical in this regard. Be sure that lubrication is adequate and that only the best lubricants are used.

Metals of high density [specific gravity 7.15 to 4.50] and with a uniform distribution of graphite in an all pearlitic matrix, or in a sorbitic matrix, offer the ultimate in galling resistance.

Avoid the use of castings that exhibit excessive variation in Brinell hardness across a surface or from section to section. It is quite likely that such castings will not possess the structure to resist galling where the conditions of service are such that galling is a problem.

Endurance – fatigue

The fatigue strength of MEEHANITE metal is higher in relation to tensile strength than that of many other materials, and its notch sensitivity is low. In addition, its ability to withstand occasional dynamic overload is superior to that of steels. For these reasons, MEEHANITE castings frequently replace steel castings and forgings of much higher tensile strength, in moving parts, such as crankshafts.

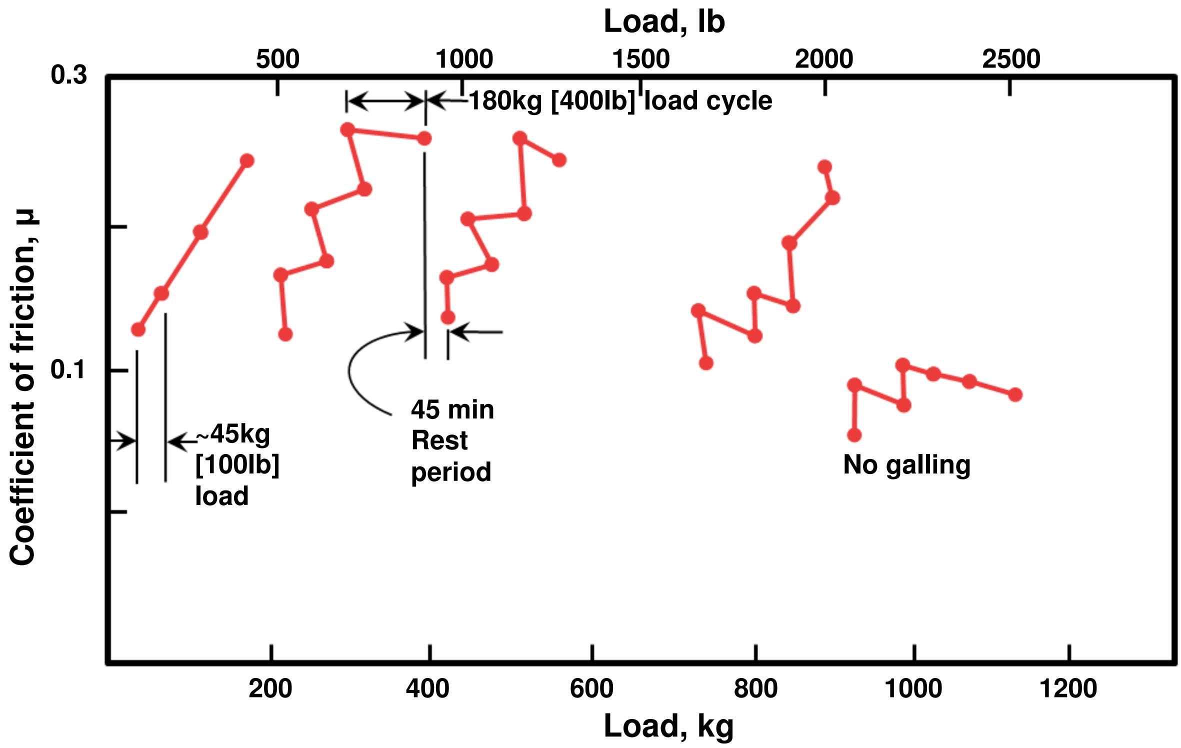


Figure 33 Variations in coefficients of friction for differing loads [Condition: machined steel sliding on MEEHANITE].

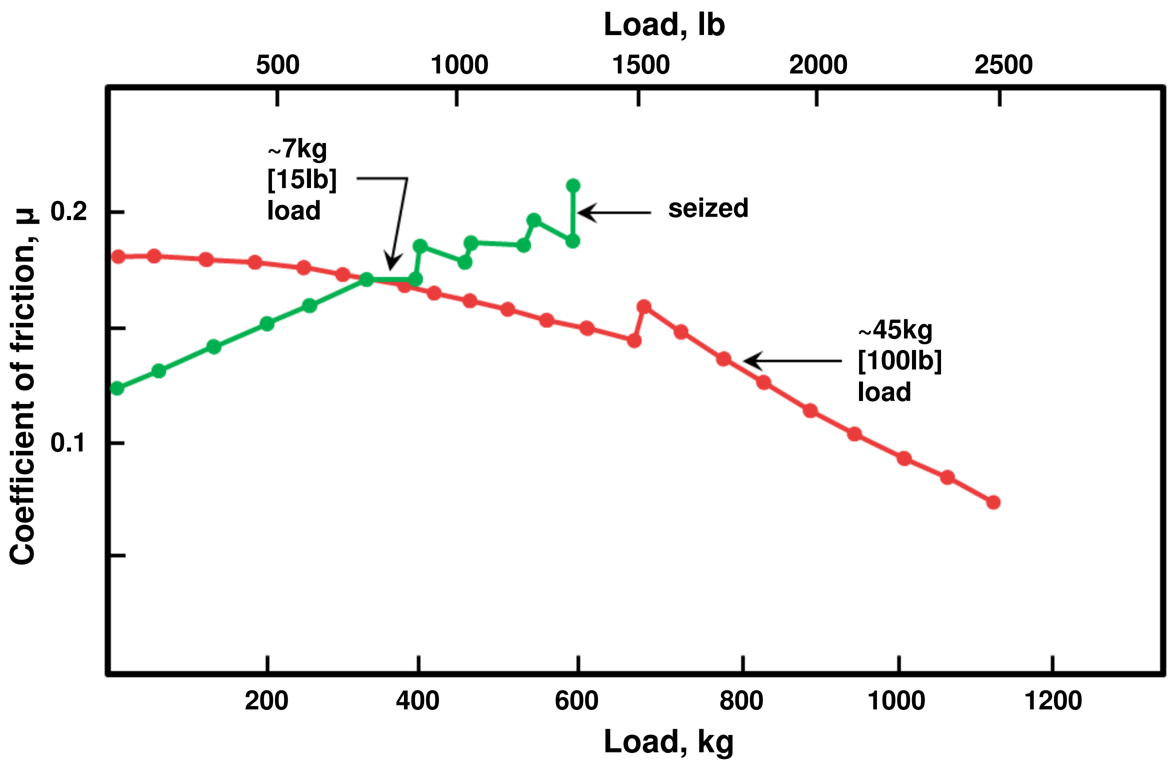


Figure 34 Variations in coefficients of friction for differing loads [Condition: super-finished machined steel sliding on MEEHANITE].

This is particularly the case with the pearlitic nodular Types which are used in the normalised condition for automobile crankshafts. Independent tests have shown how well normalised pearlitic nodular iron produced by the Inmold® Process compares with a quenched and tempered 0.4% carbon forged steel and normal ladle-treated nodular iron, measured on crankshafts, over a period of years*, **Figures 35** and **36**.

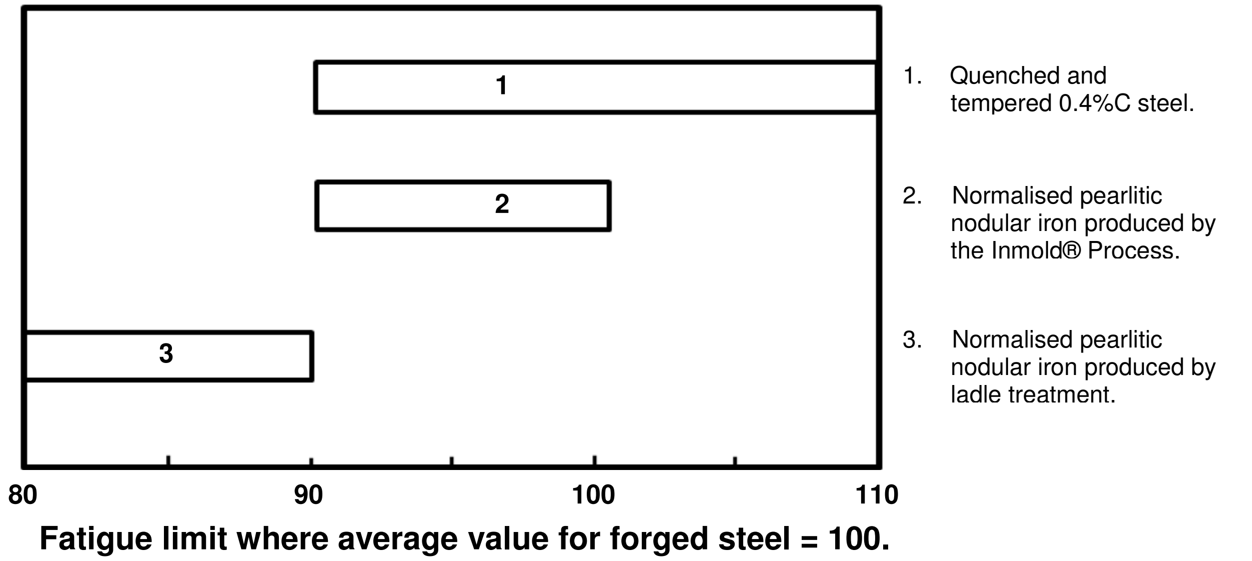


Figure 35 Comparison between the fatigue limits of MEEHANITE processed nodular irons and 0.4% carbon steel.

Evaluations were also carried out simultaneously on specimens cut from crankshafts to determine ultimate tensile strength, as follows:

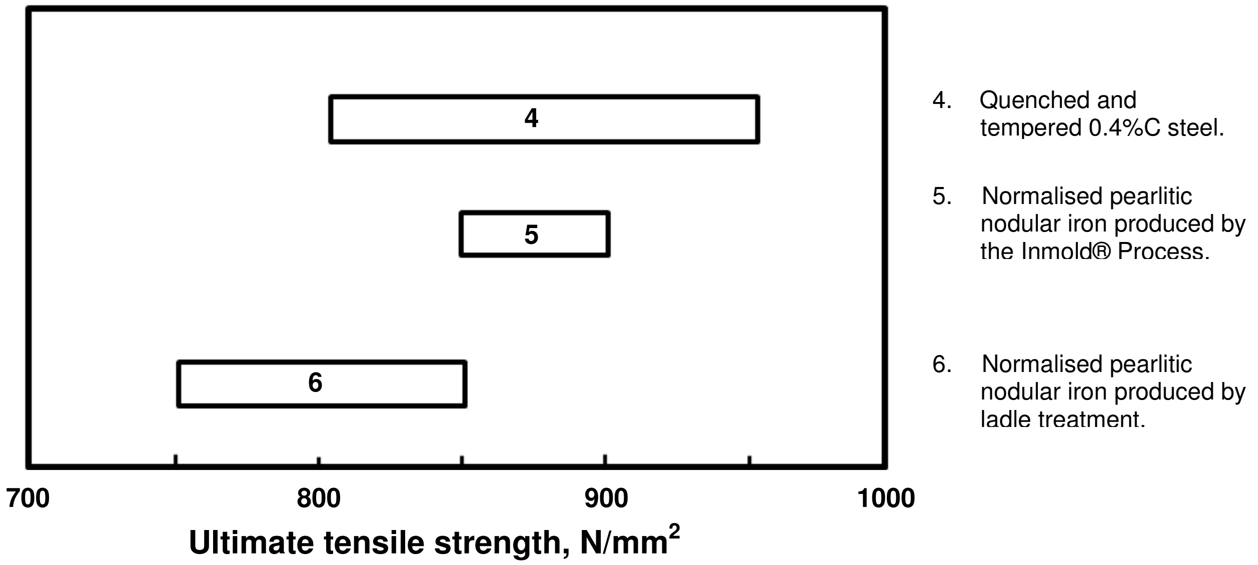


Figure 36 Comparison between the tensile strengths of MEEHANITE processed nodular irons and 0.4% carbon steel.

*Ductile iron replaces steel in the manufacture of engineering components, Callo, Remondino and Pilastro. Paper presented to the ILAFA [Instituto Latinamericano del Fierra y el Acero] Congress, Rio de Janeiro, 7 November 1976.

An introduction to the heat treatment of MEEHANITE castings

The range of structures and physical properties which are obtainable in MEEHANITE Metal in the "as-cast" condition can be significantly altered by heat treatment. Wide use of this fact is made by employing heat treatments designed to improve certain properties which are considered necessary to service requirements.

Needless to say, however, a poor casting cannot be made good by any method of heat treatment. Similarly, the full benefit from any imposed heat treatment will only be achieved if the casting itself has been produced from metal which is correctly melted and processed. It follows, therefore, that consultation with the foundry is strongly advised in all cases in order to ensure the selection of the correct MEEHANITE Metal Type in relation to casting section, design features, heat treatment and service conditions.

The importance in design, in particular, cannot be over emphasised, because in the heat treatments involving rapid differential heating or cooling, especially flame and induction hardening, a high degree of internal stress is introduced into the casting. If, at some point, these induced stresses exceed the tensile strength of the material, then fracture will occur where stress concentrations are at a maximum; viz, in the thinnest section or where a severe notch effect is experienced, say, at a re-entrant angle or keyway.

Alternatively, where the induced stress is not in excess of the tensile strength, but exceeds the yield strength of the material, then distortion may occur. Essentially, these are the principal dangers inherent in heat treatment.

The principal objectives in the heat treatment of MEEHANITE castings are:

flake irons

a) sub-critical temperature heat treatments for stress relief only
b) heat treatment for improved machinability
c) heating and quenching for increase in hardness levels
d) heating and quenching and tempering to increase strength and hardness.

nodular irons

e) high temperature annealing [ferritising] for improved ductility and impact strength [particularly for cryogenic applications]
f) normalising for improved strength, particularly fatigue strength
g) heating quenching and tempering to increase hardness, strength and toughness.

and for both flake and nodular irons

h) surface hardening for improved wear resistance.

General heat treatment instructions

Preheat the casting to 590°C [1100°F]. Raise the temperature to 860°C [1580°F to 870°C [1600°C] as quickly as possible. When the casting temperature reaches that of the furnace, quench in oil or water according to the degree of hardness required. Withdraw the casting from the quenching tank whilst still warm - above 150°C [300°F] – and temper immediately.

The quenching medium used; i.e. oil, polymer, cold or warm water, should be modified according to the complexity of the casting to avoid overstress causing cracking.

To temper hardened castings to remove stresses without loosing any hardness, reheat in oil at 200°C [390°F] for 1 to 2 hours per 25mm [1in] of casting thickness. Small castings in MEEHANITE Type **GC275**/**GC40** also respond to heat treatment, but all castings to be treated should be specified on the casting order.

Annealing for improved machinability

There are two kinds of annealing for the purpose of improved machinability:

Low temperature annealing

Improves machinability without markedly affecting the hardness, but may cause about 10% loss in strength values.

High temperature annealing

May cause loss of both strength and hardness to a marked extent if annealing time is excessive; in the case of high temperature annealing, which involves heating through the critical range, it is recommended practice to heat slowly to 650°C [1200°F] and allow to soak at this temperature.

The casting may then be transferred to another furnace which has been previously heated to the full annealing temperature or else the temperature of the pre-heating furnace may be raised as quickly as possible to the full annealing temperature.

This procedure is recommended to avoid excessive thermal shock with the possible development of cracks in the casting.

Table XXVIII shows the recommended temperature for annealing for improved machinability. Heating time should not exceed 1 hour per 25mm [1in] of casting section followed by slow cooling.

No MEEHANITE casting should require annealing for softening for machining purposes except in unusual circumstances, in which case the foundry supplying the castings should be advised.

Table XXVIII Annealing temperatures for improved machinability.

MEEHANITE Type	Anneal			
	Low Temperature		High Temperature	
	°C	°F	°C	°F
GE200/GE30	665 - 680	1230 - 1260	845	1550
GC275/GC40	670 - 695	1240 - 1280	860	1580
GA350/GA50 GM400/GM60	675 - 705	1250 - 1300	870	1600

Stress relieving heat treatment

Dimensional stability is the ability of a casting to maintain its critical dimensions at any stage from the as-cast condition through the various machining and finishing operations into service. For all practical purposes, the casting is dimensionally stable and failure to maintain these dimensions is due to residual stresses which develop during the cooling and solidification of the casting. These stresses are caused by differential cooling rates in various section thicknesses of the casting. The extent of these residual stresses depends on several factors, viz:

a) the metallurgical characteristics of the cast material
b) the design of the individual casting
c) the period of time that the casting is allowed to cool in the mould.

Residual casting stresses can cause a casting to move or distort when the stress pattern is altered by removing metal, say, by machining or, in the extreme case, cause a section of the casting to fracture. Annealing to a specific temperature followed by slow cooling is the correct technological method of removing casting stress. The older method of ageing or weathering is only partially effective.

The temperature and time of annealing depend upon the Type of MEEHANITE used and on the size of casting; the higher strength Types necessitate a somewhat higher temperature than the medium strength Types; and on the degree of stress relief required.

Recommended practice is to slowly heat the casting to one of the temperature ranges recommended in **Table XXIX**, hold at the temperature, normally for 4 to 6 hours and cool at a rate not exceeding 50°C [120°F] per hour, down to a temperature of 150°C [300°F].

Table XXIX Recommended stress annealing temperatures.

MEEHANITE Type	Recommended stress annealing temperatures	
	°C	°F
GE200/GE30	510 - 540	950 – 1000
GC275/GC40	550 - 580	1020 – 1075
GA350/GA50 GM400/GM60	590 - 620	1100 - 1150

Quenching and tempering to improve strength, toughness and hardness

The high strength MEEHANITE Types with a tight pearlitic matrix, with either flake or nodular graphite, respond to heat treatment in the same way as carbon steels. Three treatment stages are involved; viz, heating to and soaking at a predetermined temperature, quenching into a suitable quenching medium and then tempering [drawing].

Heating and soaking should be carried out slowly and uniformly to 600°C [1110°F], then the temperature is raised to 850°C [1560°F] to 900°C [1650°F] as quickly as possible. When the casting temperature blends with that of the furnace, quench in oil, polymer or water, according to the degree of hardness required. Withdraw the casting from the quenching bath while above 150°C [300°F] and temper immediately.

The quenching medium used, i.e. oil, polymer, cold or warm water, should be modified according to the complexity of the casting to avoid inducing high stresses which could cause cracking. To temper hardened castings to remove stresses without losing any hardness, reheat in oil at 200°C [390°F] for one to two hours per 25mm [1”] of casting thickness.

Maximum toughness and strength are obtained by tempering in the range 380°C [720°F] to 430°C [805°F].

When improved wear properties are required but machining is necessary, tempering in the range 550°C [1020°F] to 600°C [1110°F] will give Brinell hardness values around 280 to 300. Where hardness is required in combination with improved toughness, this may be obtained by quenching from above the critical temperature directly into molten lead, or into a salt bath at 250°C [480°F] to 380°C [720°F], where it should remain for one or more hours , according to the degree of hardness or toughness desired.

MEEHANITE Types **SPF600**/**SP80**, **GM400**/**GM60** and **GA350**/**GA50** respond to heat treatment in the same way as carbon steels. Using correct heat treatments improved toughness and/or hardness may readily be obtained. The effect of heat treatment on tensile strength and hardness is illustrated in **Figure 37** for MEEHANITE Type **SPF600**.

The effect of heat treatment on tensile strength and hardness is illustrated in **Figure 38** for MEEHANITE Type **GA350**/**GA50**. It will be noted that hardness is not influenced by tempering at temperatures up to 200°C [390°F]; therefore, when full hardness is required in a casting, tempering treatment at this temperature is recommended to remove hardening stresses.

Maximum combined toughness and strength are obtained by tempering in the range 380°C [720°F] to 430°C [805°F]. Where improved wear properties are required but machining is necessary tempering in the range 540°C [1000°F] to 590°C [1100°F] will give Brinell hardness values around 280 to 300.

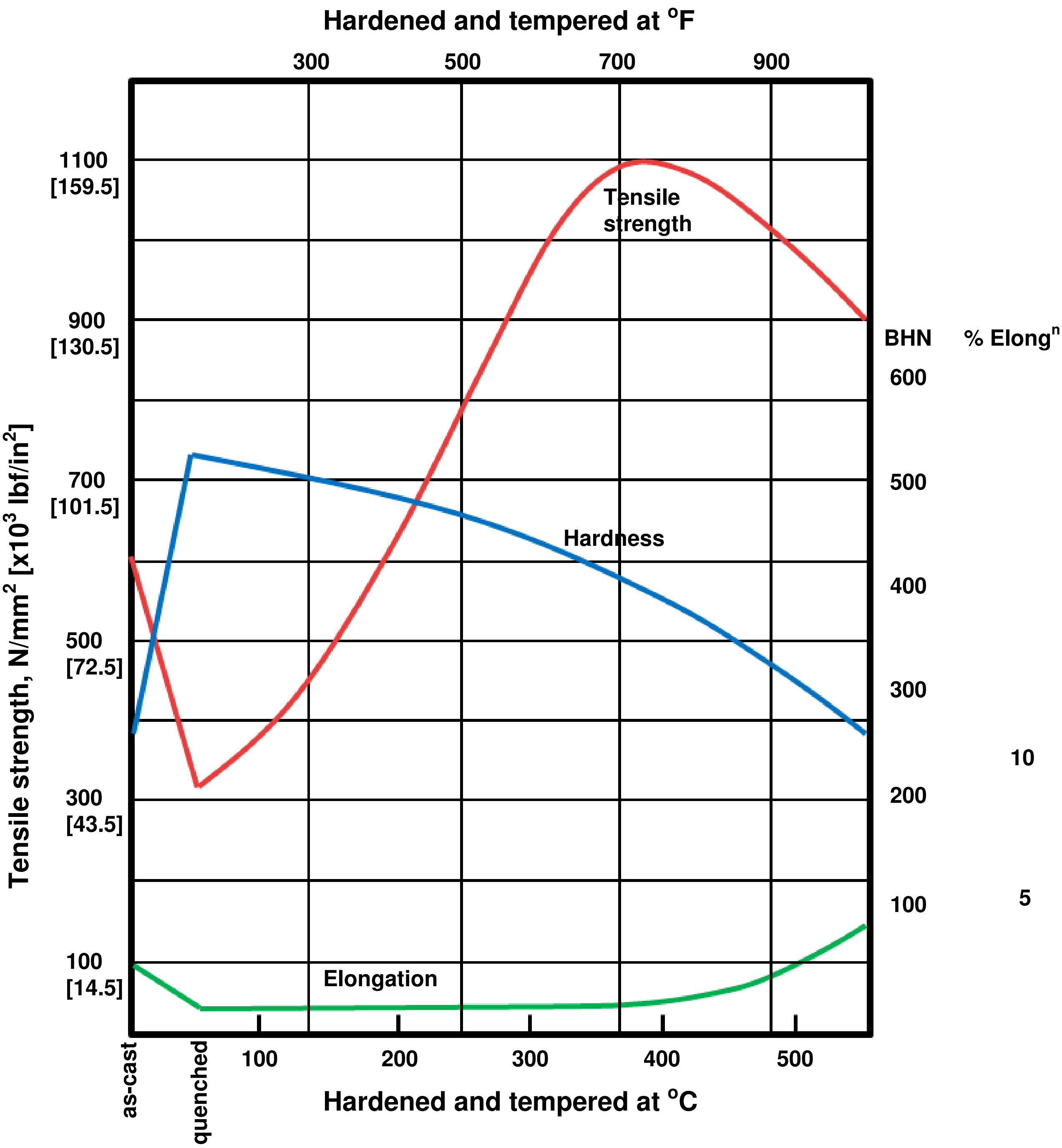


Figure 37 The effect of quench and tempering [drawing] treatment on the mechanical properties and hardness of MEEHANITE Type **SPF600**.

When hardness is required in combination with improved toughness, this may be obtained by quenching from above the critical temperature direct into molten lead or salt bath at 260°C [500°F] to 380°C [720°F] where it should remain for one or more hours, according to the degree of hardness or toughness desired.

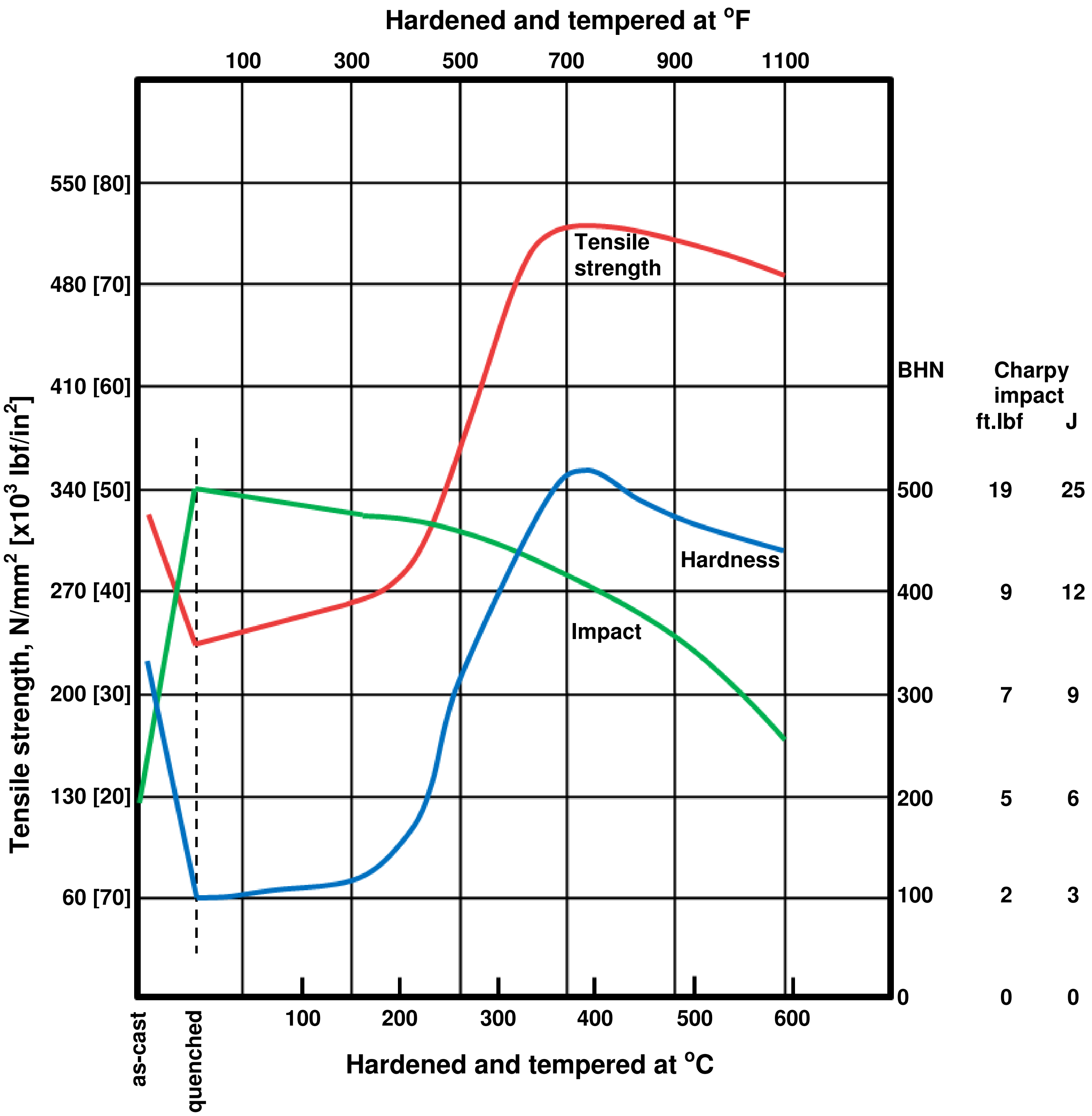


Figure 38 The effect of quench and tempering [drawing] treatment on the impact strength and hardness of MEEHANITE Type **GA350**/**GA50**.

Annealing of nodular graphite Types to improve ductility and impact strength

The ductility and impact resistance of the as-cast ferritic and ferritic/pearlitic Types can be improved at the expense of tensile strength by a simple sub-critical ferritising anneal. This involves heating the casting to 720°C [1330°F] and holding between 5 to 10 hours, depending upon section thickness, followed by furnace cooling to 600°C [1110°F] and then air cooling.

Where a high degree of impact resistance at sub-zero temperatures requires the use of Types **SFF350** and **SFF400**, a high temperature annealing treatment is adopted.

It should be pointed out, however, that these types of heat treatment are invariably the responsibility of the foundry supplying the castings to the particular specification.

Normalising of nodular graphite Types for improved tensile and fatigue strength

The as-cast pearlitic Type of MEEHANITE nodular iron can be given a normalising treatment which will produce an appreciable increase in the tensile, and particularly fatigue strength, of the material. An improvement in machinability is also reported.

The normalising treatment is as follows:

i). heating the casting slowly to about 600°C [1110°F]
ii). raise the temperature rapidly to 850°C [1560°F] to 900°C [1650°F] according to average casting section
iii). hold at the soaking temperature long enough to ensure uniform temperature throughout [in general, 1 hour per 25mm [1”] of section]
iv). withdraw and air cool – for sections in excess of 75mm [3”] the use of an air blast is advised.

Again, this type of heat treatment is a normal part of the production procedures of the foundry, carried out to meet the specification.

Austempering

Austempering is an interrupted quench to develop an acicular structure of high strength. The procedure is:

i). heat castings slowly to about 650°C [1200°F]
ii). transfer the castings to a furnace held at 860°C [1580°F] to 875°C [1610°F], for rapid heating through the critical range
iii). hold at 875°C [1610°F] until the colour of the castings blend with that of the furnace
iv). quench in a salt bath at 320°C [610°F] to 370°C [700°F] for two to five hours [The longer the holding time the higher the tensile strength and the lower the hardness].
v). withdraw castings and allow to air cool

Martempering

Martempering is an alternative method of obtaining high hardness with reduced quenching stresses. It develops a fully martensitic structure and is used with castings of complex design. It reduces the danger of cracking and gives more uniform hardness throughout the sections. The procedure is:

i). preheat castings slowly to about 650°C [1200°F]
ii). transfer to furnace held at 860°C [1580°F] to 875°C [1610°F], for rapid heating through the critical range
iii). hold at 875°C [1610°F] until the colour of the castings blend with that of the furnace
iv). quench in a salt bath at 200°C [390°F] to 250°C [480°F] for a minute or two, for temperature equalisation
v). withdraw and air cool for full hardness
vi). subsequent tempering has the same effect as for conventional quench and temper [draw] treatment.

Temper brittleness

In the heat treatment of ferrous metals it is possible to develop an unexpected degree of brittleness in an otherwise ductile material. Basically three types of brittleness may occur; viz, the ductile-brittle transition which occurs at near zero or sub-zero temperatures, brittleness that results on tempering or drawing a previously hardened part, and brittleness in a ductile part resulting from slow cooling after the annealing treatment.

There is some similarity between these three types of brittleness; and up to now, no completely satisfactory answer has been found for this phenomenon. However, its existence has been recognised and means of avoiding it are being used.

In flake graphite cast iron, the question of temper brittleness may be ignored because the graphite flakes themselves are so effective in lowering the toughness or impact strength that the effect of secondary factors, such a temper brittleness, are completely masked.

In steels and in nodular cast iron, however, care must be taken during heat treatment to avoid the development of this unexpected brittleness. In steels which may be considered as closely parallel to nodular irons, temper embrittlement was first observed on drawing back [tempering] steels which had been hardened by an oil quench treatment.

Figure 39 shows the change in impact value with increasing tempering temperature. In curve "**B**", the sample is slowly cooled from each temperature; whereas in curve "**A**", it is rapidly cooled.

It is evident; therefore, that rapid cooling from the drawing [tempering] temperature produces higher toughness. It has been recognised that steel may be susceptible to temperature embrittlement and a method of determining its susceptibility to temper brittleness has been proposed.

The susceptibility ratio is the comparison between the impact strength after water quenching from a tempering temperature of 650°C [1200°F] and the impact strength after slow cooling from this temperature.

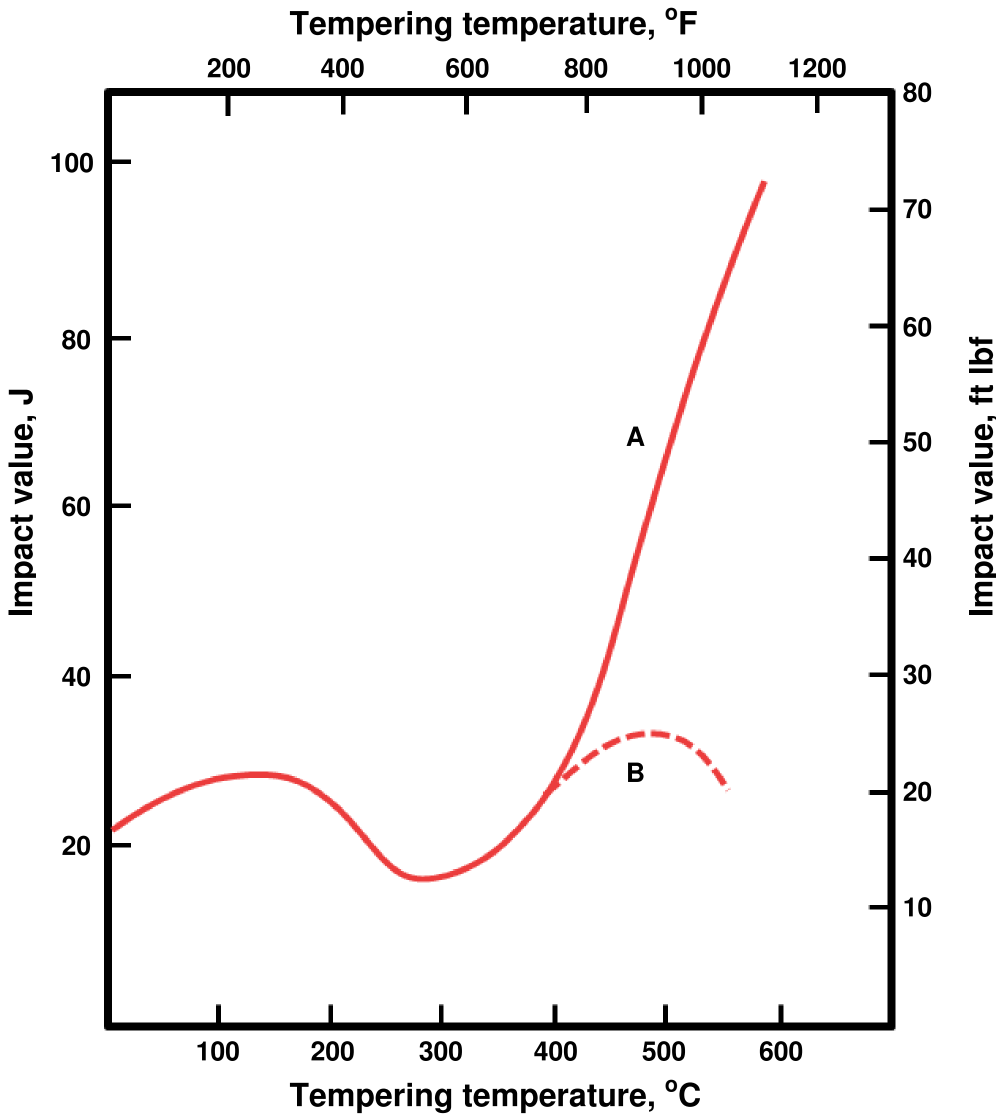


Figure 39 Impact strength for different cooling rates from various tempering temperatures.

Elements such as chromium, manganese and phosphorus increase susceptibility to temper brittleness – carbon, nickel, silicon and vanadium have little effect while molybdenum has a very marked effect in preventing this brittleness. Molybdenum has, therefore, become a standard addition to steels where embrittlement must be avoided.

In nodular cast irons where the structure is ferritic, and where good elongation and impact strengths are desired, this embrittlement is also an important factor. It may occur in hardened nodular irons which are tempered [drawn] at temperatures ranging from 450°C to 500°C [840°F to 930°F] or in ductile irons which are slowly cooled through this temperature range after an annealing treatment.

An iron quenched from 650°C [1200°F] is more ductile than one cooled slowly from this temperature. Maximum ductility and the lowest impact transition temperature will result when the sample is water quenched from 650°C [1200°F] and then aged for 24 hours at 200°C [390°F].

Embrittlement produced in an iron by tempering at 450°C [840°F] may be removed by quenching from 650°C [1200°F]. The susceptibility of nodular irons to embrittlement is increased by additions of phosphorus and silicon, but phosphorus is more harmful than silicon.

The addition of molybdenum inhibits embrittlement obtained in the 450°C to 500°C [840°F to 930°F] range, providing that other composition factors such as silicon and phosphorus are normal.

Galvanising embrittlement occurs in irons which are galvanised primarily because treatment during galvanising involves heating the parts in the critical 450°C to 500°C [840°F to 930°F] range during immersion in the galvanising bath. Galvanising embrittlement may be reduced or eliminated by a pre-quenching treatment from 650°C [1200°F] before the galvanising treatment. In addition to this, a minimum time in the galvanising bath is desirable because embrittlement, in general, increases with the time of exposure of the part in the embrittlement range.

While embrittlement may not normally be a factor in producing commercial nodular irons, it is important to recognise that it can occur and, where impact strength requirements are important, it may be advisable to avoid the temper embrittlement range by cooling rapidly from above this range and also to keep the composition where the iron will be less susceptible to such embrittlement.

Welding

MEEHANITE castings may be joined by means of either electric arc welding processes using steel or alloy rod, or special cast iron rod, or by gas welding techniques, using cast iron, cast MEEHANITE or bronze rods. Both flake and nodular Types present the same type of problems; namely:

i). solution of carbon into the filler metal and the formation of cementite
ii). quenching of the surrounding heat affected zone to form martensite
iii). - resulting in cracking in either the weld or heat affected zone.

There problems are overcome by preheating and slow cooling the casting and/or by using a low heat input welding technique. Gas fusion welding with cast iron filler rods can be extremely successful for reclamation and reconditioning cylinder blocks, cylinder heads and machinery in general if a preheat and interpass temperature 700°C [1290°F to 800°C [1470°F] is maintained.

Deposits of nodular iron are possible using nodular iron filler rods and fluxes of suitable composition [basically a content of cerium or other rare earth elements is required].

Powder welding, using proprietary alloy powders, is a low heat input non-fusion gas welding process and can be usefully and profitably employed.

High nickel alloys are successfully used for both manual-arc welding and short-arc MIG welding.

For more information please refer to Bulletin No 59 – Welding MEEHANITE.

Surface hardening by flame, induction and laser treatment

The MEEHANITE Types with a tight pearlitic matrix respond well to flame, induction and laser hardening.

Surface hardness values in excess of BHN500 can be obtained. Whilst there is no practical limit to the depth of hardness which can be achieved, it is generally accepted that depths of hardness [i.e. with >BHN500] of up to 6mm [0.25”] can be achieved. Beyond this depth, the dangers of distortion and cracking become more acute.

Flame hardening is fundamentally a simple process employing an oxy-acetylene flame directly against the surface to be hardened. Rapid cooling is affected by contact with a suitable quenching medium [usually water spray] immediately after heating. With induction hardening a heated layer is induced in the surface of the casting with quenching taking place immediately after heating.

More recently induction heating has been replaced by laser heating. The advantage of this technique is heat input in much quicker and may be controlled over a more precise area. Such is the localised area of heat input that quenching may be derived solely from the bulk of the casting otherwise the usual quenching media are employed.

The zone of maximum surface hardness obtained is usually ½ to ¾ of the total depth of the case and is file hard.

Points to be remembered about castings for surface hardening are:

1. extra metal is desirable to take car of distortion and ensure clean-up on machining
2. holes cause difficulty but if necessary, should be countersunk and should not be too near the edge of a casting
3. designs which involve sudden changes to light and heavy sections should be avoided
4. if full hardness is desired on the extreme ends of hardened surfaces, it must be specified

5. wall sections and ribs adjoining a hardened surface should not be less than 12mm [$^{1}/_{2}$"] thick.

Surface hardening by weld deposition

MEEHANITE castings can also be surface hardened by welding hard alloy such as Stellite® on the surface.

Surface coatings

The various Types of MEEHANITE Metal readily accept a variety of coatings in order to enhance resistance to heat and corrosion; viz, galvanising, tinning, chromium plating, enamelling etc., as well as metal spraying, aluminising, cruising, etc.

In certain cases it may prove necessary to degraphitise the casting surface prior to treatment. Organic coatings in the form of paint and plastic [PVC, nylon, PTFE etc] are also successfully applied.