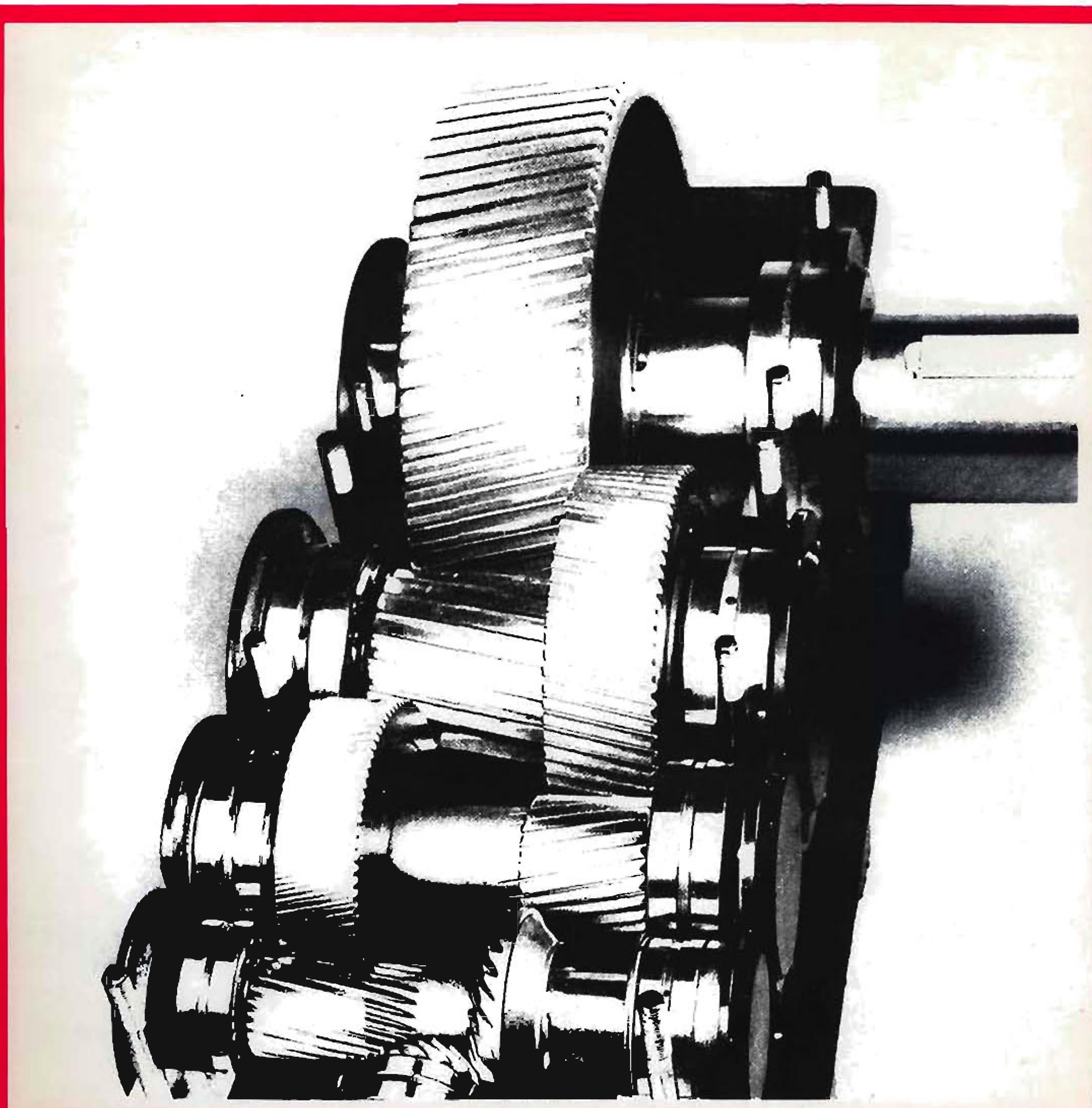
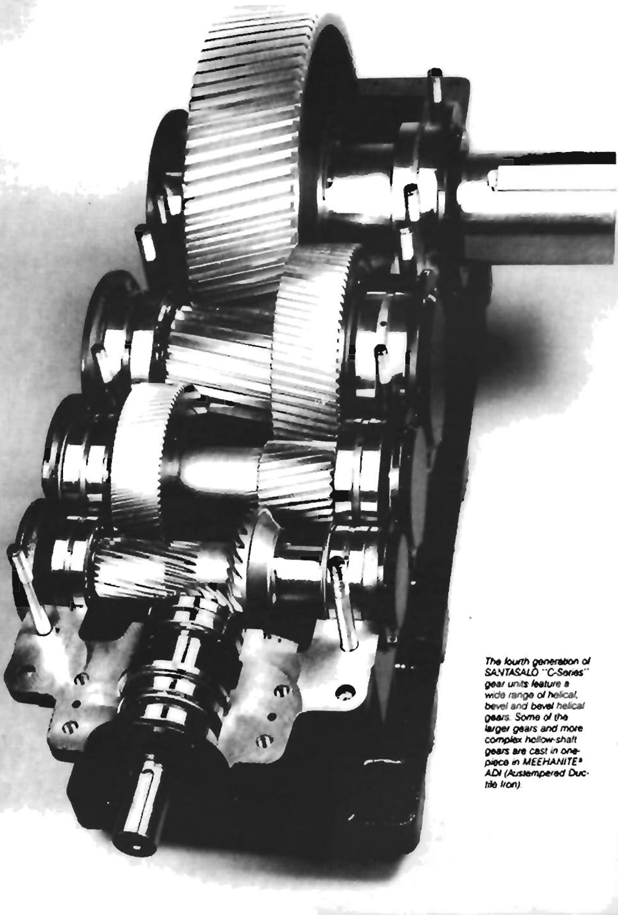
MEEHANITE

MEEHANITE ADI

Guidelines for Designing and Machining Meehanite Austempered Ductile Iron Castings





The fourth generation of SANTASALO "C-Series" gear units feature a wide range of helical, bevel and bevel helical gears. Some of the larger gears and more complex hollow-shaft gears are cast in one-piece in MEEHANITE® ADI (Austempered Ductile Iron).

GUIDELINES FOR DESIGNING AND MACHINING MEEHANITE ADI CASTINGS

AUSTEMPERED DUCTILE IRON'S UNIQUE COMBINATION OF HIGH STRENGTH PROPERTIES AND EXCELLENT MACHINABILITY OFFERS ENGINEERS GREAT FREEDOM OF DESIGN AND THE POTENTIAL FOR MAJOR COST SAVINGS

Application Characteristics

The special features that make MEEHANITE ADI a suitable material for demanding applications are based on the microstructure. It differs from all other unalloyed or lightly alloyed normal carbon steels and cast irons in that its microstructure does not contain any hard and brittle iron carbide, i.e, cementite. Thus the basic components of MEEHANITE ADI are ferrite, retained austenite and nodular graphite.

The microstructure results from austenitizing and austempering at the bainitic transformation temperature. The austempering temperature and holding time determine the quality of MEEHANITE ADI obtained. The aforementioned ferrite is a needle-like bainitic ferrite which does not contain the cementite presents in normal bainite. This structure is now commonly referred to as "Ausferrite"

Another special feature of the microstructure is the retained austenite, which is a metastable component. It transforms into hard martensite during machining or work (deformation) hardening. This means that the hardness of the surface substantially increases and, simultaneously, the wear resistance improves proportionally. This material, unlike surface hardened steel, maintains the hard surface zone at all times despite wear occurring. Meanwhile, the material beneath the surface layer maintains its original toughness.

With such special characteristics, MEEHANITE ADI is especially suitable for gears and other applications subject to dynamic stresses and wear.

Strength Properties

Static Strength

National standards for ductile cast irons are based on ultimate tensile strength and elongation, so it is natural to establish specifications for MEEHANITE ADI which are also based on these criteria.

The static strength properties of the three standard grades of MEEHANITE ADI are shown in Table 1. It can be seen that the classification of the different grades is based on minimum tensile strength and elongation values. In the U.S.A., on the other hand, the classification is based on median hardness value i.e., K295, K325 and K405 respectively.

As with standard ductile cast irons, the tensile strength and hardness of MEEHANITE ADI have a linear correlation. However, because of the austenitic-ferrite structure, the static strength properties are better than those of a standard class ductile iron of the same hardness (see Fig. 1).

The bending strength of MEEHANITE ADI is excellent e.g., for grades K-10005 (K-325), values of 1600-2000 N/sq.mm, may be used. Bending strength approximates to 1.6 x UTS for this particular grade.

In Fig.2., the tensile strength and elongation of different structural materials are compared. In comparison with other metallic materials, it will be noted that the results obtained from MEEHANITE ADI form an area of their own. In fact, MEEHANITE ADI can be considered as a material which is far superior to either cast iron or steel.

Structural design based on static strength properties normally uses only the values for yield strength. Compared with normal constructional steels, the yield strength of MEEHANITE ADI exceeds these values by 2.5-3 times. Thus, it is possible to design lighter weight components with MEEHANITE ADI. This factor is enhanced by the fact that ADI possesses a lower density than steel.

Stability of Structure at High Temperatures

Retained austenite produced by means of the bainite mechanism is very stable within a wide temperature range. Its stability at high temperatures is indicated by the fact that the proportion of retained austenite does not change after 500 hours at 300 deg.C. Temperatures exceeding this level, however, may shorten the time period, as the formation of carbides and low carbon ferrite from the retained austenite takes place. Service temperatures above 300 deg.C. should therefore be avoided.

Stability of Structure at Low Temperatures

Due to the high carbon content of the retained austenite (approximately 1.6%) the Ms-limit of the retained austenite lies considerably below room temperature.

Table 1 **MEEHANITE ADI PROPERTIES**

ADI Grade		Tensile strength	Yield strength	Elongation	Hardness
US	Europe	N/sq mm	N/sq mm	%	HB
K-295	K-9007	900-1100	730- 900	7-18	280-310
K-325	K-10005	1000-1200	800-1000	5-12	310-350
K-405	K-12003	1200-1500	1000-1300	3- 5	380-430

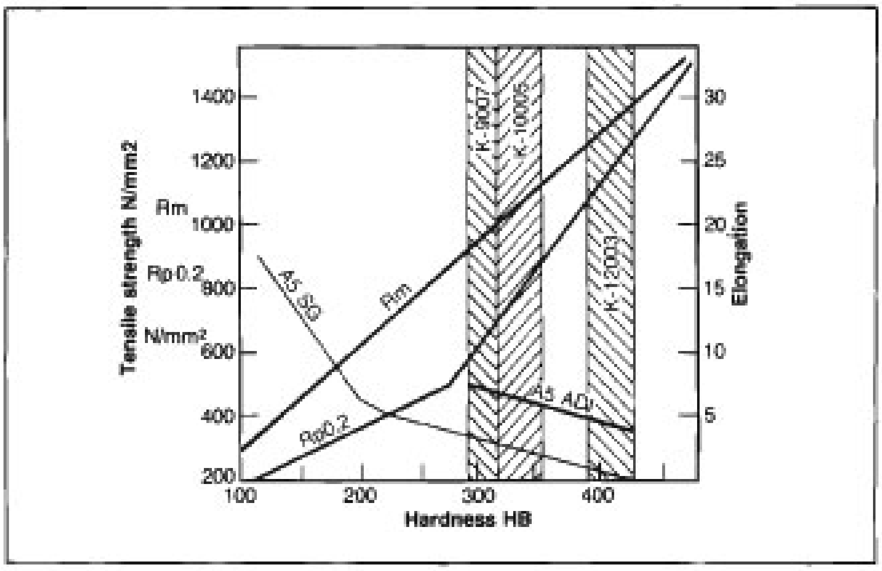


Fig.1. The tensile strength, yield strength and elongation values of MEEHANITE ADI grades are here shown as a function of hardness.

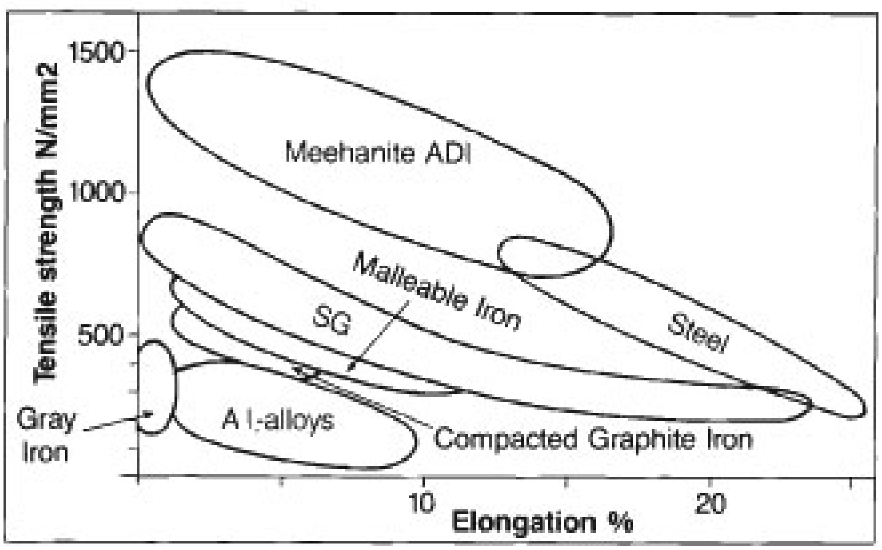


Fig.2. The tensile strength-elongation zone of MEEHANITE ADI compares well with those of other materials.

The starting temperature for martensite formation is below -80 deg.C. This temperature has been confirmed experimentally. MEEHANITE ADI is thus eminently suitable for applications in cold climates or under cryogenic conditions.

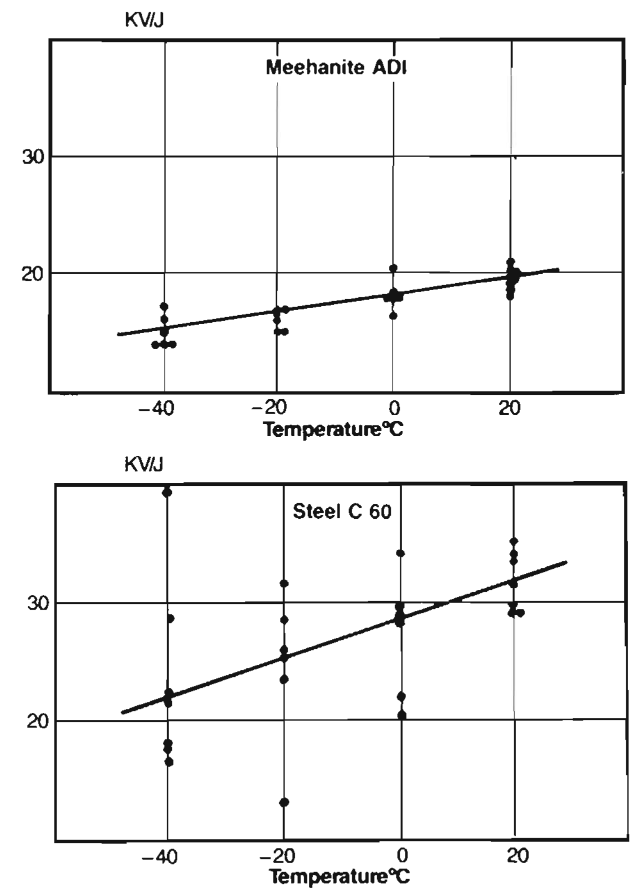
Toughness and Fracture Toughness

The Charpy V-notch impact test measures the energy needed to break a test bar. The method is normally used to measure the toughness of low strength steels while the transition temperature at which the steel changes from a tough to a brittle condition can also be determined. A comparison of different materials is difficult because energy values vary at the particular transformation temperature of each material. In spite of the limitations of the method, however, it is commonly used because the test is easily carried out.

MEEHANITE ADI is often used to replace quenched and tempered or flame hardened steels. In Table 2, the strength values including Charpy V-notch values, at 20 deg.C. and -40 deg.C. of the middle grade MEEHANITE ADI and a C 60 type steel in the quenched and tempered condition, are compared (C 60 is a nominal 0.60% carbon steel).

Table 2

PROPERTY	ADI	C60
Tensile strength N/sq mm	1125	920
Yield strength N/sq mm	820	600
Elongation %	9	18
Hardness HB	290	270
Charpy V, 20 deg.C Joule	20	32
-40 deg.C Joule	15	22



Figs.3.& 4. The Charpy V notch values for MEEHANITE ADI and a C 60 steel in the quenched and tempered condition are compared. (C 60 is a nominal 0.60% carbon steel.)

The Charpy V-notch value for MEEHANITE ADI falls between the temperatures of +20 to -40 deg.C. by approximately 25%, but at the same time, the value for C 60 steel falls by more than 31%. The lower values obtained from ductile iron are due to the presence of graphite nodules in the matrix—these are brittle. On the other hand, the values for steel exhibit more scatter than those for MEEHANITE ADI. It must be concluded, therefore, that the steel is inclined to be brittle at low temperatures whereas MEEHANITE ADI behaves more reliably. In Figs. 3 and 4, the Charpy V-notch values for MEEHANITE ADI and a quenched and tempered steel of type C60 are shown as a function of temperature.

Fracture Toughness at Low Temperatures

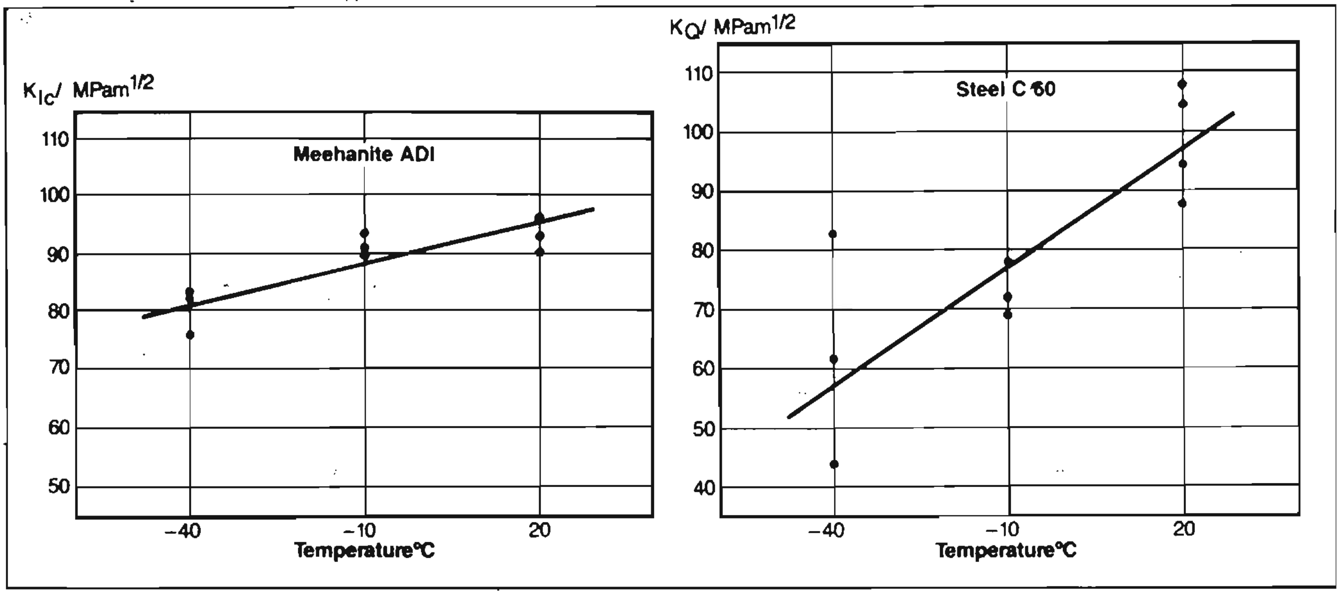
The fracture toughness test gives information on how a material behaves in a situation where repeated stresses try to extend a crack. In fracture toughness tests, a critical stress intensity factor (KIc) is determined. At this value, the crack starts to grow with a brittle mechanism. In this test method, the thickness of the test piece must exceed a certain material-dependent minimum, in order that the results can be considered reliable. In the case of MEEHANITE ADI, this thickness value is appoximately 30-33 mm.

When the fracture toughness of the middle grade MEEHANITE ADI and the quenched and tempered steel, type C60 are compared, it will be noted that the toughness of the steel is more dependent on temperature. The results are shown in Figs. 5 and 6, where the KIc values are used because they are not dependent on wall thickness. At the lowest testing temperature, -40 deg.C., the critical stress intensity factors are as follows:-

MEEHANITE ADI 80 MN m-3/2
Steel C 60 55 MN m—3/2

Here again the results from the steel exhibit wide scatter. At room temperature, MEEHANITE ADI has the same fracture toughness as the steel but at lower temperatures, MEEHANITE ADI is superior.

An interesting feature of MEEHANITE ADI is that it breaks only after plastic deformation whereas the reference steel C 60 breaks, without any warning, in a brittle manner. This means that if for some reason, the maximum load is exceeded, MEEHANITE ADI will bear a 10% overload before finally breaking.



Figs.5 & 6. The fracture toughness values for MEEHANITE ADI and type C 60 steel, in the quenched and tempered condition, are shown above.

Notch Sensitivity and Fatigue Strength

Notch Sensitivity

In a fatigue strength situation, the effect of a notch on fatigue strength is indicated by a notch factor K where:

$$K = \frac{\text{fatigue strength of unnotched test bar}}{\text{fatigue strength of notched test bar}}$$

This factor is dependent on the material used and on the form of the notch. The notch sensitivity factor q can be calculated when the theoretical stress concentration factor Kf is known:

$$q = (K - 1)/(Kf - 1)$$

Conventional nodular iron possesses q values of 0.3-0.4 and cast steel of 0.4-0.7. Normally, cast irons have lower values because of the internal notch effect caused by the graphite. Usually, notch sensitivity increases with increasing strength, but MEEHANITE ADI behaves anomalously for its notch sensitivity decreases with increasing strength! This fact can be observed in Fig.7, where the upper curve represents the fatigue strength of an unnotched test bar whilst the lower curve is that of a notched test bar. The notch sensitivity factor q shows a value of 0.25 for a material with a tensile strength of 900 N/sq.mm. and a value of 0.12 for a material with a tensile strength of 1350 N/sq.mm.

Low notch sensitivity values, as shown can be obtained only if the machining of the notch has been carried out after isothermal austempering. The notch sensitivity is normal, (q = 0.4), if the notch has been cut prior to

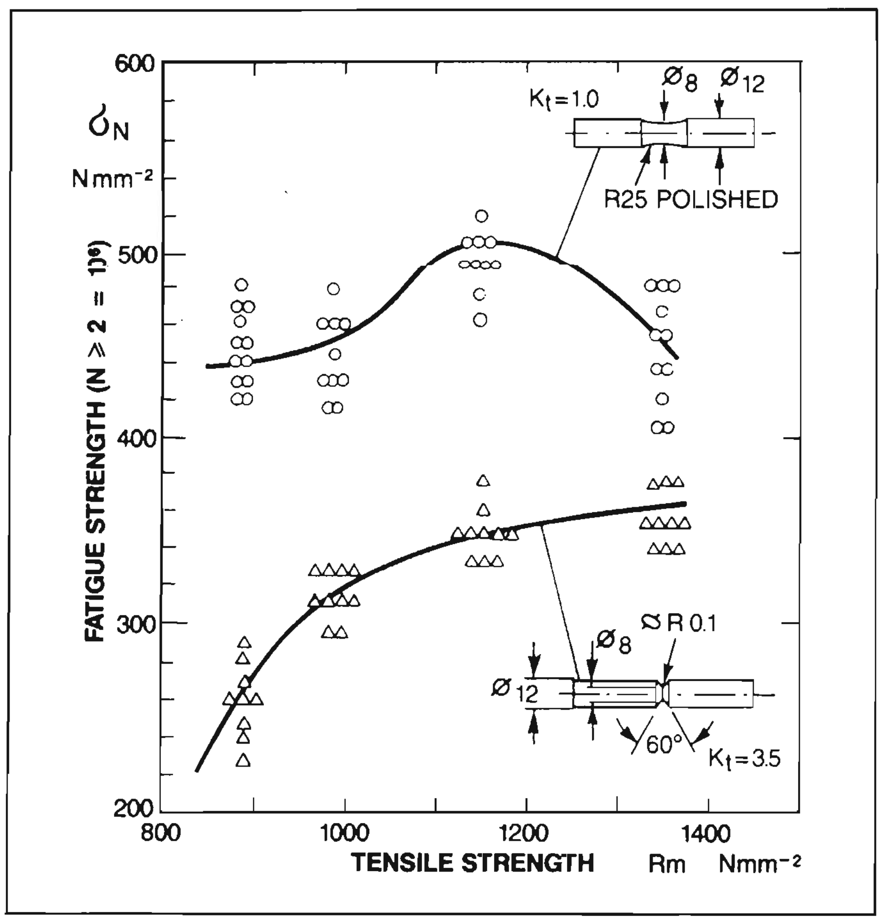


Fig.7. Beam fatigue tests on MEEHANITE ADI have provided the above fatigue strength values as a function of tensile strength for both notched and unnotched test bars.

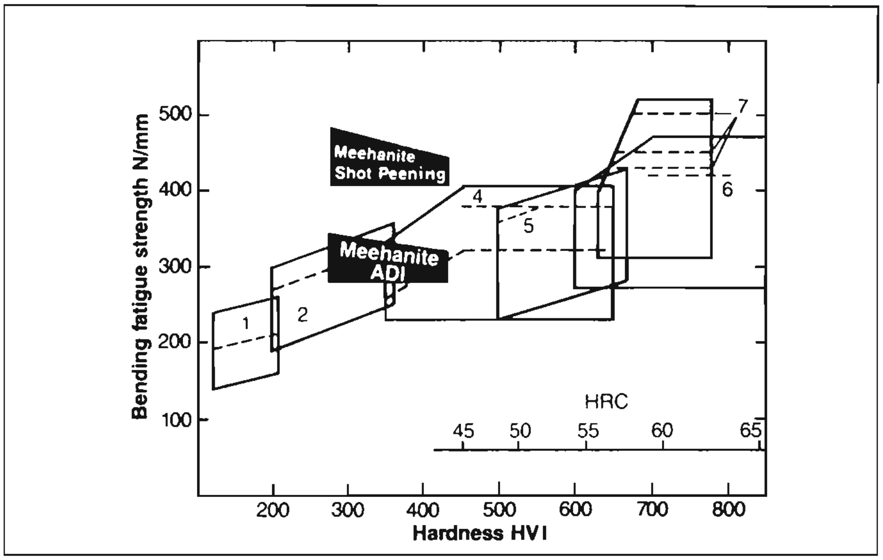


Fig.8. Bending fatigue strength values for a gear wheel tooth root made in several materials are related to hardness.

1. *Carbon steel, normalised or quenched and tempered*
2. *Alloy steel, quenched and tempered*
3. *Normalised or quenched and tempered steel, nitrided*
4. *Quenched and tempered steel, given long nitriding treatment*
5. *Quenched and tempered steel, flame or induction hardened*
6. *Nitrided steel given long treatment*
7. *Carburised steel, hardened*

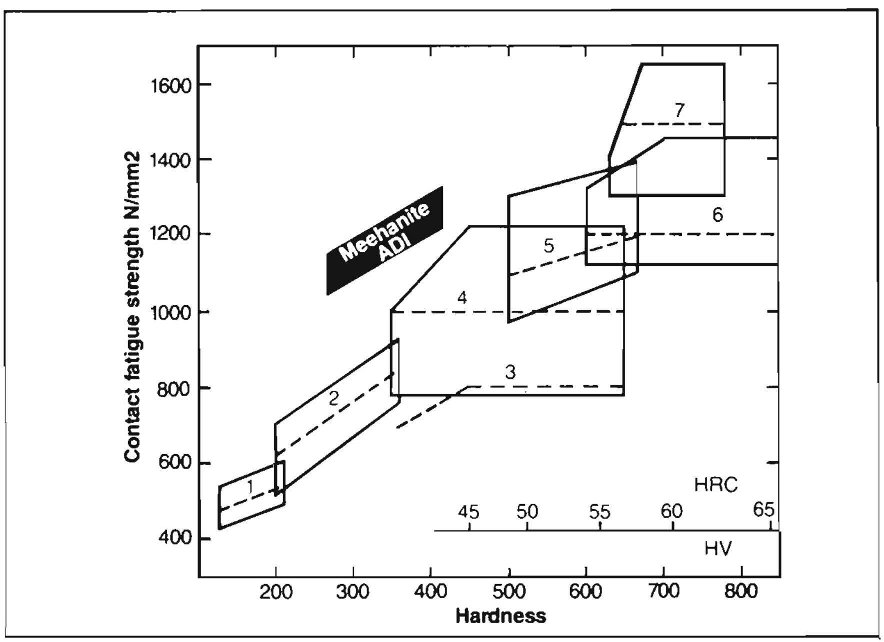


Fig.9. Contact fatigue strength strength values for a gear wheel tooth wall made in several materials are related to hardness.

1. *Carbon steel, normalised or quenched and tempered*
2. *Alloy steel, quenched and tempered*
3. *Normalised or quenched and tempered steel, nitrided*
4. *Quenched and tempered steel, given long nitriding treatment*
5. *Quenched and tempered steel, flame or induction hardened*
6. *Nitrided steel given long treatment*
7. *Carburised steel, hardened*

the bainitic heat treatment. This difference can be compensated for by shot peening after austempering, so that deformation hardening of the surface increases the fatigue strength.

MEEHANITE ADI may be shot peened after machining, which treatment results in even better fatigue properties.

Fatigue Strength

As already mentioned, the fatigue strength of MEEHANITE ADI is one of its outstanding properties. Compared with other structural materials, it will be noted that MEEHANITE ADI and a quenched and tempered steel have the same levels of fatigue strength. As shown in Fig.8, with shot peening, the fatigue strength of MEEHANITE ADI can be raised to the level of that of the best steels. The effect of shot peening, however, decreases with increasing wall section. This is why heavier sections should be cold worked more extensively e.g., by cold rolling the surface. If hobbing of the gear teeth is carried out after bainitic heat treatment, the fatigue strength of the teeth is about 20% higher than if hobbing is done before the bainitic heat treatment. This is due to the work hardening effect. With increasing wall section, fatigue strength decreases.

Contact Fatigue Strength

Contact fatigue strength values are used for calculating the surface areas of gear wheels under contact stresses. It is usually called the allowed Hertzian contact stress on the gear wheel surface. Such stresses are formed on gear wheel teeth, at the contact point of a roll or a wheel, etc.

The contact fatigue strength of MEEHANITE ADI is almost at the same level as that of quenched carbon steels. Similar values are obtained with flame and induction hardened steels as well as with nitrided steels. In Fig.9, the contact fatigue strength of MEEHANITE ADI and some other materials is shown. The excellent contact fatigue strength values of MEEHANITE ADI can be explained by the effect of cold work at the surface and by its lower modulus of elasticity in comparison with steels. Its lower modulus of elasticity will decrease the Hertzian stress on the surface..

Modulus of Elasticity, Vibration Damping and Noise

The modulus of elasticity of MEEHANITE ADI is about 20% less than that of steel. In Table 3, a comparison of modulus of elasticity values for various materials is made.

Table 3

MATERIAL	MODULUS OF ELASTICITY (E) N/sq mm
Steel	210 000
MEEHANITE ADI	170 000
Grey Iron	110 000
Aluminium	70 000

The lower value of modulus of elasticity for ADI, in comparison with that of steel, means that the surface in contact is larger and thus the surface stress is lower. In practice, this means that when a wheel made of steel is replaced by one in MEEHANITE ADI, the ratio of diameters is 2.1:1.9, i.e. the MEEHANITE wheel can be 10% smaller and still achieve the same loading on the contact material.

The smaller modulus of elasticity also means that with the same wheel diameter and load, the Hertzian surface stress is 5% less than where the roll is in steel. In addition, the vibrations in MEEHANITE ADI are dampened about 40% faster than in steel due to its lower modulus of elasticity (see Fig.10).

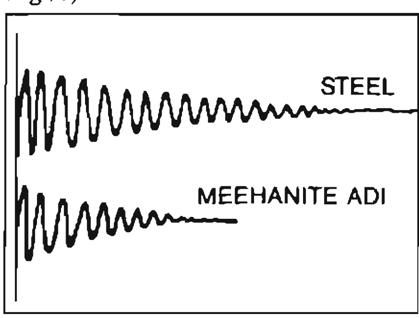


Fig.10. The vibration damping capacity of MEEHANITE ADI is compared to that of steel.

For the same reason, with MEEHANITE ADI, a 20% higher shock load at the same stress level as steel may be adopted. This means that MEEHANITE ADI can absorb impact forces more readily and also allows a rougher finished surface to be used. The lesser effect of surface defects and its better damping capacity lead to smoother running of designs made in MEEHANITE ADI. The replacement of one steel gear wheel by one in MEEHANITE ADI can reduce the noise level of an industrial gear by about five decibels.

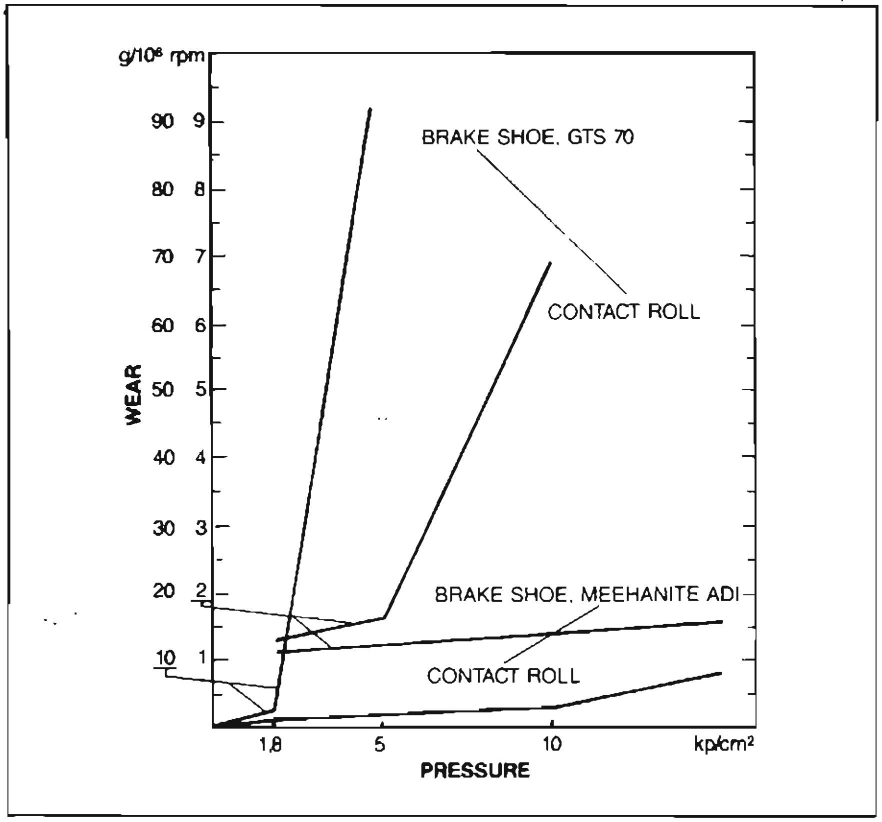


Fig.11. The adhesive wear of brake shoes made in MEEHANITE ADI and malleable iron, GTS 70 (DIN) in contact with steel Ck 45 (DIN) (Ck 45 is a nominal 0.45% carbon steel).

Wear Resistance

Adhesive Wear

Adhesive wear is caused by the fracture of small areas where surface irregularities have welded together or galled. Here again, MEEHANITE ADI is very resistant to adhesive wear. MEEHANITE ADI can absorb larger compressive stresses and shows less wear than a malleable cast iron, when the contact material is flame hardened steel Ck45 (Ck45 is a nominal 0.45% C steel). The results of a brake test are reported in Fig.11.

One reason for the good wear resistance of MEEHANITE ADI is the presence of nodular graphite which lubricates the surface. It has been experimentally shown that a gear wheel made of MEEHANITE ADI could be runs for 10 minutes without lubricant and no damage would occur. On the other hand, the reference test piece of quenched and tempered steel showed considerable damage on the gear wheel surface.

Abrasive Wear

Abrasive or grinding wear is caused by a harder surface sliding on a softer one, or where hard loose particles slide against or between surfaces. The abrasive wear resistance of MEEHANITE ADI is considerably better than would be expected from the hardness of the material and much better than that of a steel of similar hardness. This is based on the fact that, even with small particles, some work hardening takes place on the surface and the hardness increases. In Fig.12, it can be seen that only a Ni-Hard type cast iron offers better resistance against abrasive wear, but this, of course, is accompanied by a considerably lower toughness level. The reference steel (FE37) used in these trials is a nominal 0.15% C steel.

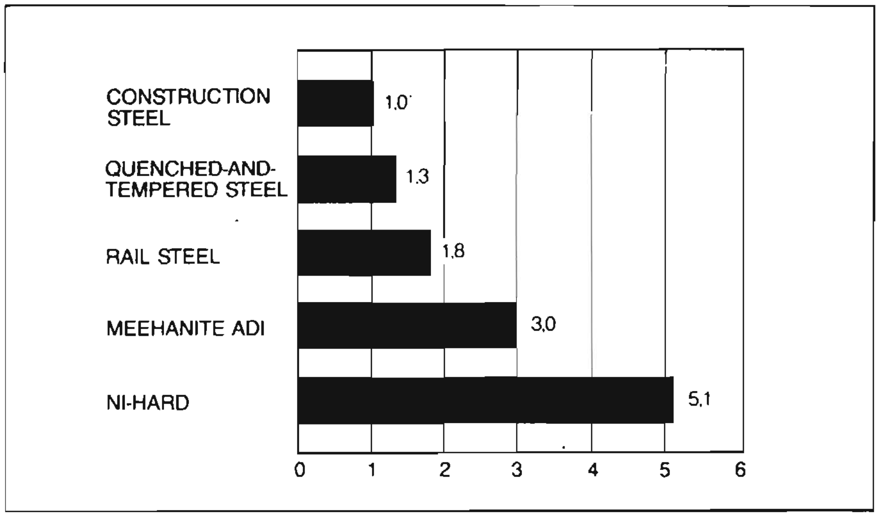


Fig.12. The abrasive wear resistance of MEEHANITE ADI is compared to that of other materials. (FE 36 is a nominal 0.15% carbon steel.)

Other Characteristics

Corrosion Resistance

The corrosion resistance of cast irons is usually much better than that of carbon steel and, in addition, cast irons do not scale as badly as steel. In the case of an interference fit with a steel/steel combination, undoing the joint may prove difficult because of fretting corrosion having occurred. No such difficulty has been met with MEEHANITE ADI in gear units.

Physical Properties

The physical properties of MEEHANITE ADI do not differ materially from those of normal ductile irons. In Table 4, values for some of the more important physical properties of MEEHANITE ADI are quoted.

Table 4.

Modulus of elasticity	**170 000 N/sq mm**
Poisson's ratio	0.28
Coeff. of Thermal expansion	12x10–6/deg.K
Specific heat	J/g.deg.K
Thermal conductivity	0.26 W/deg.K.cm
Density	7.1 kg/cu.dm.

In addition, lighter designs are possible due to ADI being 10% lighter than steel.

Welding

MEEHANITE ADI is not readily weldable, as is the case with any high carbon material. Due to its good casting qualities, however, it is possible to produce accurate cast components which conventionally, would be constructed as steel fabrications.

MEEHANITE ADI—STRUCTURAL DESIGN

General Aspects of Applications

With MEEHANITE ADI, there are two approaches possible when a structural material is being selected:

1. Replacement of an existing constructional method by a better material.
2. Planning a new application using the advantages of MEEHANITE ADI's special properties in regard to both production and service.

Typical fields of application for MEEHANITE ADI are those where both wear resistance and fatigue strength are required.

When a new application is being considered, the designer can use several of the unusual properties of MEEHANITE ADI to improve the final product. Very often the exact analysis of the application requirements and the use of the benefits of the casting route can make the machining of certain surfaces unnecessary. This is especiallly true where machining is impossible due to lack of access. The surface can be cast readily from MEEHANITE ADI and machining thereby avoided. In such a case, a machining allowance is unnecessary and material can be saved.

In view of the high strength of MEEHANITE ADI, wall thickness may be reduced by 20-40% depending on the reference material.

Designing a simpler component in MEEHANITE ADI is also often possible. A bronze sleeve in the hub of a gear wheel can be omitted because of the good tribological properties of MEEHANITE ADI. If the sliding speed is low, it is possible to reduce wear to one tenth of that of the bearing metal. However, a radial clearance must be allowed. This is because a minor volume growth takes place when MEEHANITE ADI is loaded beyond its deformation limit.

On the other hand, unlike normal quenching, the austempering treatment of MEEHANITE ADI does not result in any serious volume change. The bainitic heat treatment only gives a volume expansion of 0.2-0.4%.

Examples of MEEHANITE ADI Applications

Gears

Gear wheels and gear couplings were among the first applications of MEEHANITE ADI. The tough work hardening material possessing low notch sensitivity proved to be excellent in such applications, where a direct competitior is induction hardened steel. The power transmitting capacity of MEEHANITE ADI and induction hardened steel is about twice that of quenched carbon steel. The use of MEEHANITE ADI can be both technically and commercially justified, however, when, with good casting practice, the weight and the number of component parts can be reduced. In Fig.13, a design comparison is shown for a gear wheel made in MEEHANITE ADI and an alloyed casehardened steel gear with case car-

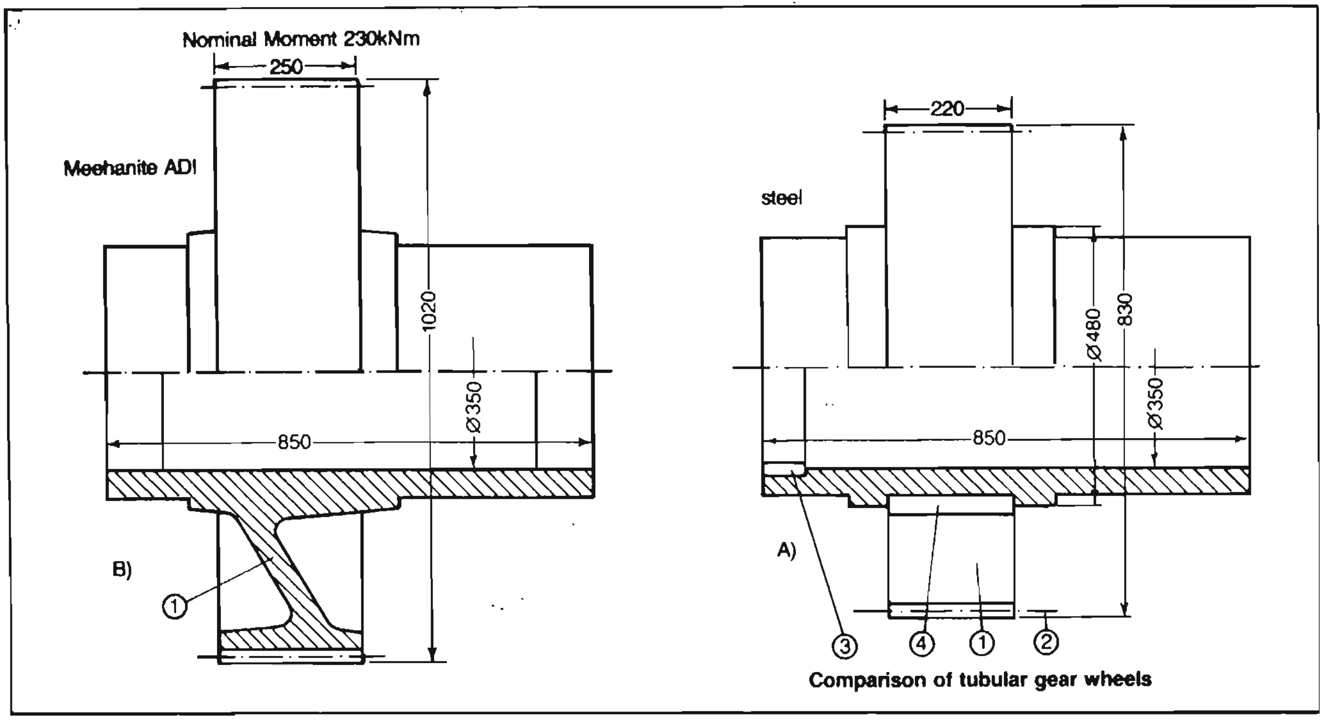


Fig.13. Comparison of gear wheels made in MEEHANITE ADI and steel.

burised and ground teeth, respectively. Despite the larger pitch circle diameter of the ADI design, its weight would be reduced to 93% and production costs to 75% of the original. By shot peening, the root fatigue strength of the teeth can, in some cases, be doubled. With larger moduli and harder grades of material, the effect of shot peening is lessened. Shot peening does not affect the ability of the material to withstand surface stresses.

Due to the lower imposed Hertzian surface stresses and greater capacity for capacity for surface loads, smaller diameters or narrower teeth can be adopted when using MEEHANITE ADI. In addition, the material has an ability to take overloads and to run temporarily without lubricant.

Gear Wheel Segments

Large gear wheels of diameters of 3-8 m have normally been constructed of softer steel castings or pearlitic ductile iron in the form of 2-4 segments. The problem has been the expense of production and the poor tooth contact caused by using wide wheels, which factor has led to rapid wear on the teeth.

When using MEEHANITE ADI, the width of the gear wheel need only be half that normally used. On the other hand, more segments are required because of the difficulty of austempering large pieces. Never the less, the requirement for less material more than compensates for the increase in the number of segments. A narrower wheel is easier to run axially and it is easier to get the whole tooth surface into contact. Typical gear wheel segmented designs are shown in Fig.14.

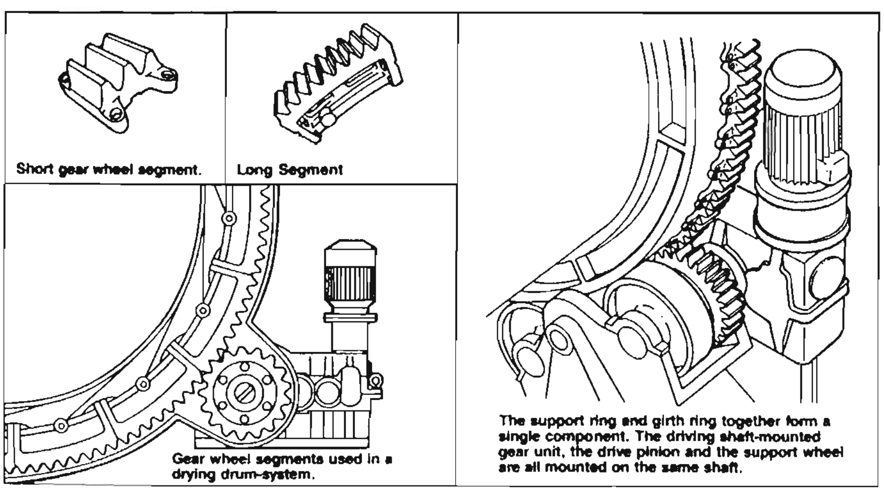


Fig.14. Typical MEEHANITE ADI gear wheel segmented designs.

Rollers and Railroad Wheels

Other typical fields of application for MEEHANITE ADI are rollers or wheels that can be superficially deformation hardened when rolling or sliding against a contact surface. The graphite in the structure in the iron reduces the modulus of elasticity so that there is a larger surface area in contact and this results in less friction. It has been proved experimentally that a MEEHANITE ADI railroad wheel can take much larger loads than a quenched and tempered steel wheel of the same hardness. It has also been shown that wear on the material is reduced. If sliding between the wheel and the rail exceeds 10%, say, on the flange of a railroad wheel, then MEEHANITE ADI would be a superior material and reduce the wear of both materials in contact. A railroad wheel in MEEHANITE ADI should not be used where braking is achieved by pressing a brake block onto the periphery of the wheel in order to stop the wagon. This kind of braking system leads to thermal stresses being induced on the surface of the wheel and crazing and cracking will occur. MEEHANITE ADI wheels are suitable for systems where disc brakes are used.

Railroad Brake Blocks

It has been shown experimentally that a replacement of old type cast iron brake blocks with MEEHANITE ADI blocks has resulted in a service life of five times more than previously. At the same time, the wear on the steel railroad wheels has been reduced by 20-25%. The design of such a brake block is shown in Fig.16. It should be noted that this advice applies to low speed trains only where the heat generated by braking is not too severe.

Railroad Wagon Buffers

The replacement of steel buffer plates in wagon buffers by plates made by MEEHANITE ADI was shown to reduce wear by one-third (see Fig.17).

Conveyor Chains

In the mining industry, ore is normally transported by steel conveyor chains or belts. Conditions are normally rather severe and abrasive wear quickly ruins the material. Such conveyor chains in MEEHANITE ADI have lasted four times longer than previously, while a higher load capacity has been achieved.

Crankshafts and Axles

The crankshaft is a perfect application for an austenitic-bainitic ductile iron. Automobile crankshafts are normally specified as induction hardened steel forgings or in conventional normalised nodular iron. MEEHANITE ADI has a yield strength which is 40% higher, a tensile strength 35% higher, a density 10% less and a modulus of elasticity 20% lower than that of such a steel.

Axles are generally applications suitable for MEEHANITE ADI. Here, the material's low notch sensitivity, good fatigue strength and reasonable machinability are of advantage.

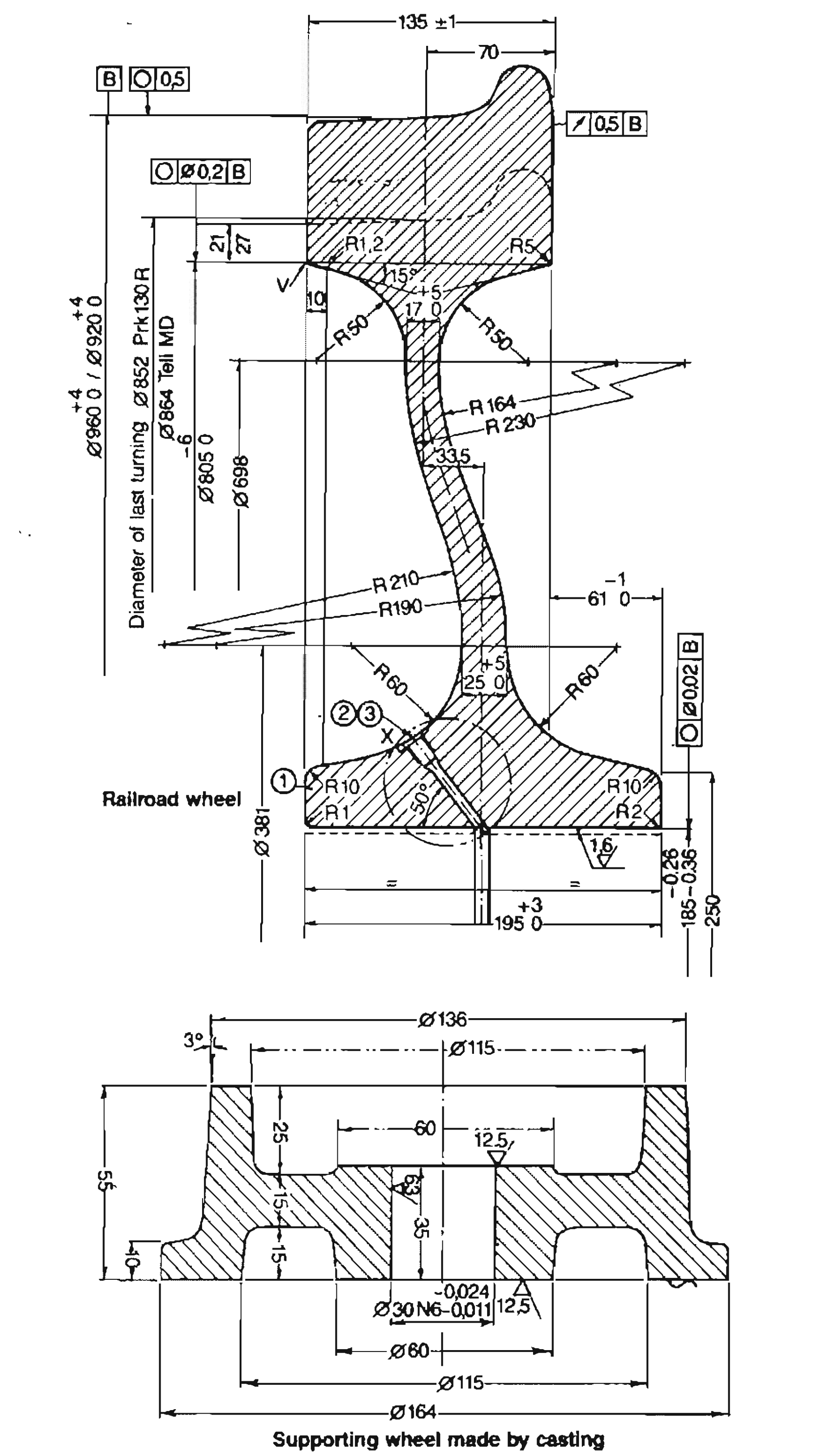


Fig.15. Designs for a railroad wheel and a roller made in MEEHANITE ADI are shown.

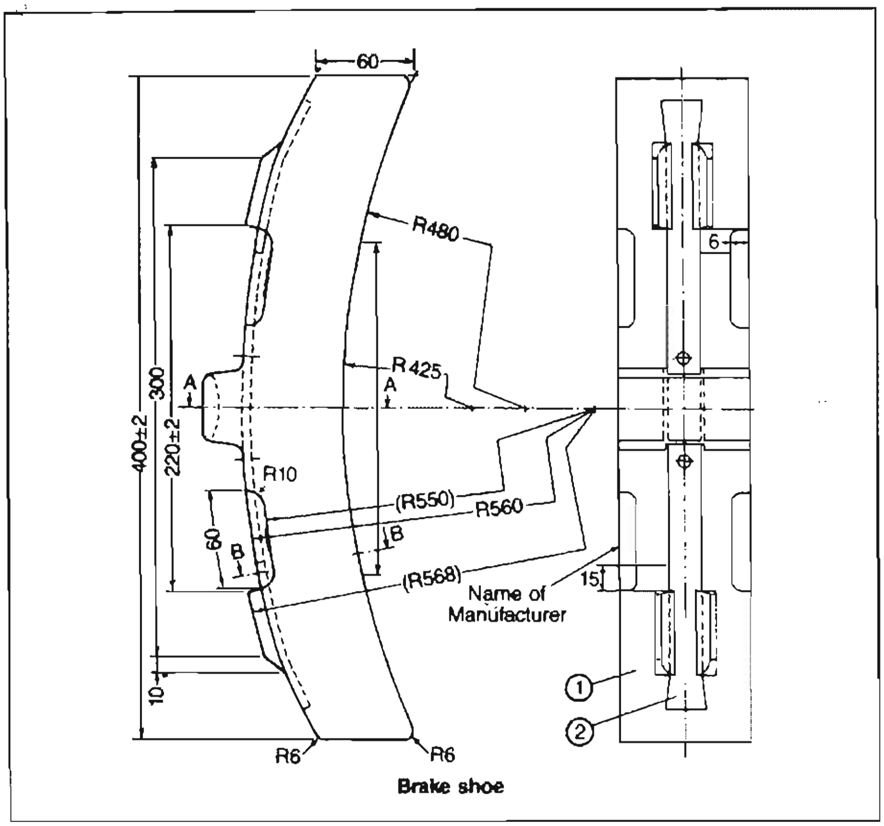


Fig.16. Design of a railroad brake block cast in MEEHANITE ADI.

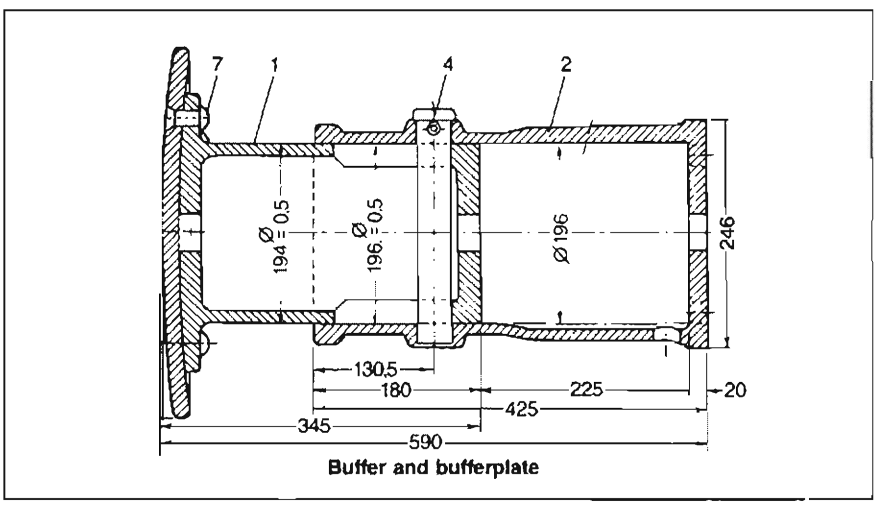


Fig.17. Design of a railroad wagon buffer assembled from MEEHANITE ADI components.

Machining MEEHANITE ADI

General Aspects

Machining an austenitic-bainitic ductile iron is, generally speaking, possible using all normal machining techniques. If the incidence of metallurgical or casting defects is excluded, only the tapping of small diameter holes (<M6) cannot be carried out successfully.

Opinions differ as to what can be considered as normal machining techniques and for some time, there have been considerable developments in cutting tool technology.

Various Machining Operations

The machining method is of extreme importance when the cutting of MEEHANITE ADI is being considered. The various machining methods do not respond equally in this regard. MEEHANITE ADI is machinable, independently of the grade being considered, but scraping of the softest type in gear wheel production is impossible. This is due to the work hardening phenomenon.

Turning

A short broken chip is produced when turning MEEHANITE ADI as is the case with all cast irons. This is an advantage in comparison with steel where, for safety reasons, chip breakers are required.

As in turning generally, tool inserts of hard metal type K are used for MEEHANITE ADI, the tool angles being as follows:

tool clearance angle α = 5-6 deg.
rake angle δ = 0-6 deg.
cutting edge angle ζ = 60-90 deg.

Some general information on ceramic tools is given in Appendix I. Nowadays, fine-grained, high-density hard metal tool inserts are readily available. For instance, the hardness of type K 01 is over 1700 Hv. When a good surface finish is required, such tools are recommended for turning problem materials, viz. hardened steels as well as various hard irons.

Drilling

Drilling tools are normally made of high speed tool steel (DIN S6-5-2), which possesses a critical temperature of 500 deg.C. When drilling is done without coolant, it is important that chips are produced in order to remove the heat generated. In addition, the drilling speed must be kept low. It is also obvious, that if the tool meets some hard particles, such as cementite, martensite, etc., then the cutting edges of the drill will be ruined. For such applications, hard metal drills (especially type K 01) should be used. Its hardness, at Hv 1700, is more than twice the hardness of martensite. According to the old rule of thumb, no wear should occur under such conditions. Hard metal can tolerate temperatures up to 1000 deg.C. Such drills are available with three cutting edges, which means a significant reduction in cutting forces.

The powder vacuum deposition types of TiN coated high speed tool steels and hard metals are in a totally different category and such tools should soon be generally available.

Fig.18, presents the results of drilling an austempered ductile iron using a drill made of high speed tool steel (DIN S6-5-2), diameter 8mm, 1 = 40 mm, feed = 0.09 mm/rev. With three different ceramic coated tools, results Z6, Z3 and Z7 have been obtained. In addition, a softer grade of iron (HB 280) was drilled using the same TiN coated drills. This result can be identified as point A, which means that, in this case, the drilling time was only one quarter of that required for the result Z7.

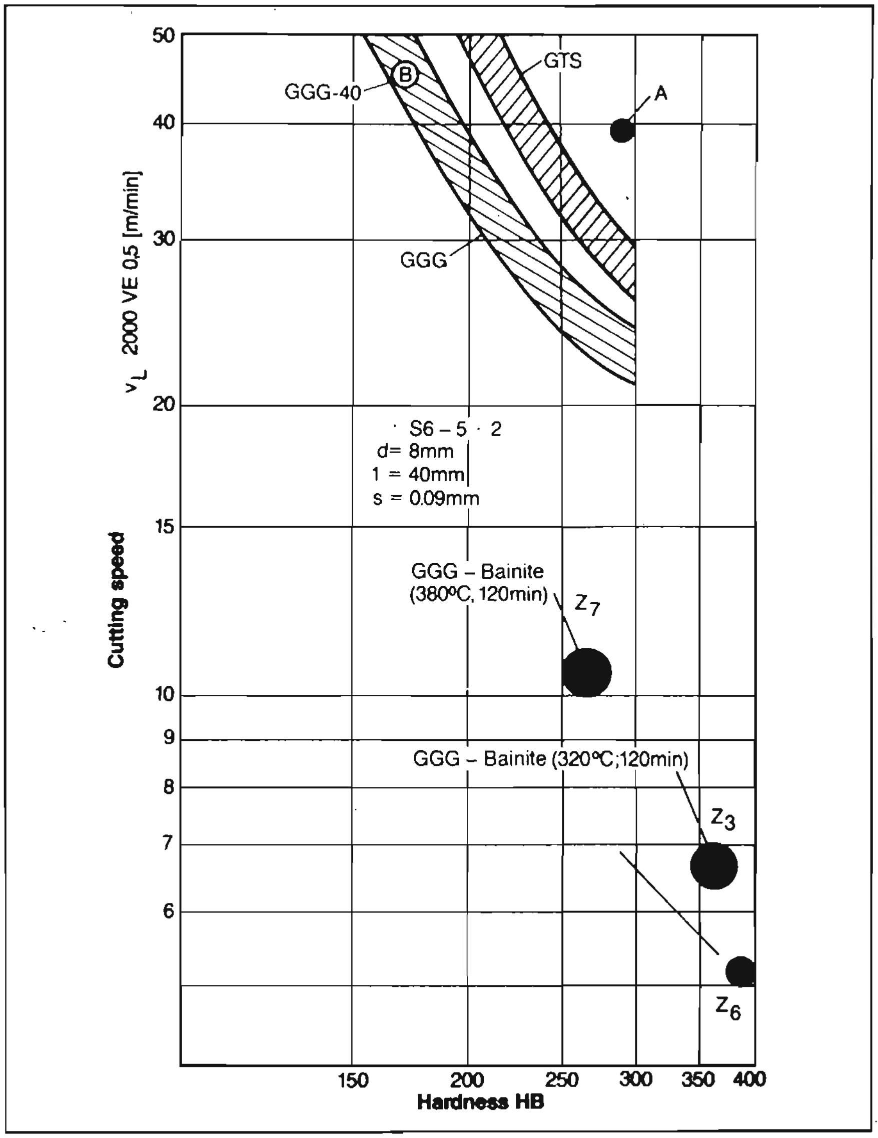


Fig.18. Cutting speed as a function of hardness when drilling austenitic-bainitic ductile iron compared to the results achieved with some other irons.

Milling

From the viewpoint of chip formation, milling is the most difficult machining method. All sorts of milling tools in high speed tool steel or hard metal are available. Tool costs, however, are considerably higher per working hour than is the case for turning.

Chip formation and a homogeneous material are the most important factors in the milling of MEEHANITE ADI. Work hardening must also be borne in mind. Fig.19 shows two different methods of milling gear wheel teeth, viz. a) clockwise and b) counter clockwise. The clockwise milling method should always be used with MEEHANITE ADI because the cutting begins in an unhardened area. Unfortunately, this is not always possible with all milling machines, especially the older models.

It has been shown that ductile iron with a hardness of HB 280-330 can be

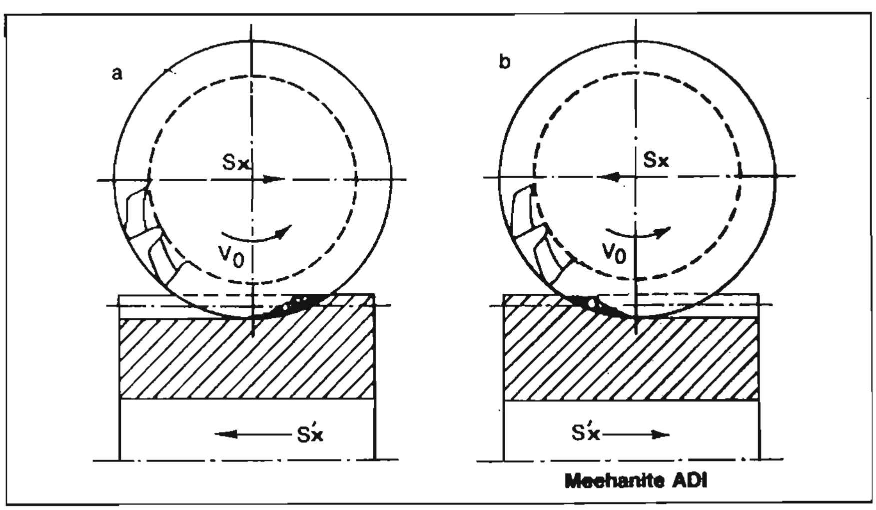


Fig.19. When milling MEEHANITE ADI, clockwise milling (a) is preferred rather than counter clockwise milling (b).

hobbed in sizes up to m = 10, under the following conditions:

The casting is metallurgically and technically correct.

The hobber is made of P.M. high speed tool steel ASP 30, with a TiN coating.

Cutting speed is approximately 30% less than with steel using a correspondingly greater feed because a much smoother surface is achieved in comparison with steel.

Lubricant must be used generously.

Both the rough and final hobbing cuts should be made clockwise and between cuts, a transverse adjustment of the hobber is made where necessary.

With larger components, an optimal solution would be to rough mill the gear wheel teeth prior to the bainitic heat treatment. Subsequently, the root of the gear teeth should be shot peened and finally the sides of the teeth should be hobbed using a hard metal tool.

A further possibility exists with the availability of the new range of boron nitride tools (Amborite), which tolerate temperatures up to 1400 deg.C. With such tools the cutting speed is increased to a stage where the material is melted in front of the cutting edge. Thus the cutting forces required are only a fraction of normal. No lubrication is used but a coolant is normally required to dampen down the temperature of the chips. There is some limitation in the use of these ceramic tools, in that to prevent adhesion, no more than 4-5% ferrite or austenite must be present in the structure. What happens with MEEHANITE ADI which contains 30-40% retained austenite is not yet clear. If the use of boron nitride tools is sucessful, then any type of ADI will be readily machined.

Tapping

As previously mentioned, the tapping of MEEHANITE ADI is possible with diameters of M6 and above. An example is an adjustment nut for a high precision device which was threaded with a Noris 6522 tap using a cutting lubricant. The hardness of the nut was HB 320.

Tapping holes that go completely through a wall is usually easy, because the chips are removed from below. If dead-end holes are tapped, a strongly rising chip removal tap is required, and it would be difficult in any case. One way out of the dilemma is to leave sufficient space to hold the chips at the bottom of the hole.

Nowadays, it is possible to obtain TiN taps, which are well worth their cost. When using a chip removing tap, the tool should be conical otherwise the tap becomes jammed due to adhesion and is destroyed.

A properly used TiN tap increases the working time between sharpening operations, improves the surface finish and retains better dimensional precision. The recommended tapping speeds for MEEHANITE ADI are 30-40% of the values used for steels, i.e. 2-6 m/min.

Cutting Keyways

When cutting keyways, good results can be obtained by using a hard metal tool of type K 20 and improved results can be achieved with a TiN coated tool. The following machining factors should be used:

rake angle	$\delta = 0$ deg.
tool clearance angle	$\alpha = 5$ deg.
speed	v = 6-10 m/min.
feed	s = 0.10-0.14 mm/stroke

Broaching

Gear wheels, with teeth on the inside, for instance, wheels for planetary gearboxes, holes with several keyways, etc. are usually machined by broaching. A broach tool is made of high speed tool steel which nowadays often has a TiN coating. This is because the machines are really quite expensive. Broaching speeds must be kept low, i.e. 1-2 m/min. which means that any rise in temperature will not cause a problem. In broaching MEEHANITE ADI with a hardness of HB 280-300, the tool will last longer than when broaching steel.

At Karlsruhe University, MEEHANITE ADI was broached without lubricant at double the normal speed. As a result, the temperature of the chips was approximately 90 deg.C, but the tool was worn only about 50% of normal. The conclusion to be drawn from this trial was that when the chip forming temperature exceeds a certain limit, then the work hardening effect becomes weaker. Similar results are obtained in broaching an austenitic stainless steel. Normally, the broaching speed is kept low (v = 3 m/min.), but the feed value must be high.

APPENDIX I

Hard metal (cemented carbide) tool inserts are produced by means of powder metallurgy, i.e. hard powders of tungsten carbide, titanium carbide, tantalum carbide or niobium carbide (WC, TiC, TaC, NbC) are mixed in a certain ratio with cobalt powder being used as a binder. The mixture is then thoroughly mixed, pressed and sintered.

The ISO standard has divided hard metals according to their field of application into three different categories: P, M and K. The number after the letter indicates the percentage of cobalt in the mixture. With increasing amounts of cobalt, the toughness increases, but, on the other hand, the amount of hard carbides decreases and wear resistance is impaired.

In the K-grade, WC is mainly used (α-phase) while in the P-grades, the δ-phase consisting of TiC, TaC and NbC is the main component. The wear resistance of the δ-phase is considerably better than that of the α-phase.

The P-grades are more brittle than the K-grades with the same numerical classification.

Chemical composition has a correlation with operating properties while the final characteristics of the tool are strongly dependent on how accurately and repeatedly the mixing and granulation of the powdered ingredients have been achieved. This is of great importance, not only for vapour deposition coating, but also for cutting, where thermal and mechanical stresses vary a great deal, e.g. in milling operations. Thermal conductivity is the same for the P-grades as for steels and rather better for the K-grades, while the thermal coefficient of expansion (2-3 times greater than for steel) together with tensile strength, are all factors to be considered when a CVD surface, design and thickness are chosen.

As as example, the following can be quoted: in the case of a round rotatable tool insert for turning, the hard metal tool surface is approximately 10-20 micrometres thick, whereas in milling, it should only be half of this. In addition, the surface must be as fine as possible. The surface to be finished should be very smooth (Rt 1-2 micrometres) and the cutting edges should be rounded (r = 0.03-0.04 mm) before implanting the ceramic layer.

Vibrations are particularly harmful in machining operations and this is especially the case when hard metal tools with ceramic coatings are used. To make matters worse, hard metals have a very high modulus of elasticity which means that there is very little capability for damping vibrations. In particularly difficult circumstances, steadies must be used to hold the work piece. In the case of larger work pieces, and for rough machining operations, a tool with as large an edge radius as possible and of the toughest hard metal type, should be utilised. If the use of an uncoated tool can be avoided, then a tool with a ceramic coating will certainly improve machining operations.

For carousel turning operations on pearlitic or heat treated ductile iron, good results can be achieved with a TiN coated indexable insert of Kennametal KC 210. This is a tool insert, with more than four cutting edges, which is very suitable for rough turning. If the same grade of tool is used on the same materials in a modern NC machine, however, the cutting edges of the tool insert will tend to break up, due to thermal stressing. The best tool for such operations would be a Sandvik K 315.

A comparison of the service life, cutting speeds and costs for various types of tooling are given in Table 5.

Table 5.

TOOL	SERVICE LIFE	CUTTING SPEED	RELATIVE TOOL REQUIREMENT	RELATIVE TOOL COSTS
Hard Metal (uncoated)	100	100	100	100
Hard Metal (normal coating) Ti-Ti(CN)-TiN	250	140	40	52
Hard Metal (ceramic coating)	350	160	28	37