MEEHANITE®

CASTING DESIGN as influenced by FOUNDRY PRACTICE

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Meehanite®
Metal Corp.

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INTRODUCTION

The advantages of using castings for engineering components are well appreciated by design engineers. Of major importance is the fact that shapes of any degree of complexity and of virtually any size can be produced. Modern metallurgy also has provided a great variety of cast metals, presenting a choice of many physical and mechanical properties, which enable the design of components to meet service conditions, conditions imposed by economy, and conditions imposed by design factors.

Of all the materials available in the cast form, cast iron, and more particularly, Meehanite Metal, offers the greatest versatility, the greatest range of physical and mechanical characteristics, and the lowest cost.

The art of casting metals into those shapes called "castings", is dependent on many basic laws of physical chemistry, and the design engineer can achieve maximum success only when he designs with these in mind.

This manual is written with the express purpose in mind of providing the design engineer with a working knowledge of foundry practice, particularly as related to cast iron, to which general classification the family of Meehanite Metal belongs. In compiling this volume, we have also clearly designated those important characteristics of the Meehanite process that have made Meehanite Metal castings the prime material for quality engineering components. The dependability of Meehanite castings is no accident. It is the result of an intimate knowledge of all phases of metallurgy and foundry practice and the ingenious application of this knowledge to provide the design engineer with the component he had in mind, when he applied his own creative effort.

It is sincerely hoped that this information will give the design engineer greater insight into foundry technology than he has, perhaps had in the past, and that this in turn, will enable him to make better of castings in his engineering creations.

It might be thought that the design engineer had too many problems of his own to give much thought to foundry practice; nothing could be further from the truth, because it is only knowing what the foundryman can and cannot do, that the design engineer can evolve a truly efficient engineering component that will do justice to his creative ability.

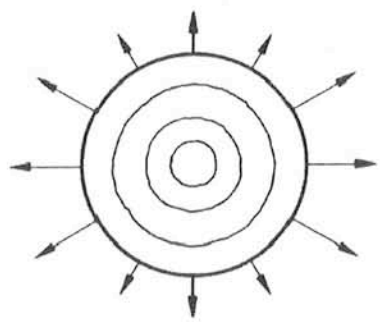
THE MAKING OF A CASTING

In its simplest form, the making of a casting involves starting with a pattern of a given engineering component, preparing a refractory mold containing this pattern, removing the pattern from the mold and, thereafter, filling the resultant cavity with molten metal, and allowing it to solidify into the shape of the engineering component. As each step depends on the one preceding it, as well as on the one succeeding it, it is proposed to discuss each of them; particularly from the standpoint of the design engineer, showing where he necessarily plays an important role in determining the ultimate success of the casting. Following the element of casting design, as related to foundry practice, will be discussed in some detail.

SOLIDIFICATION OF METAL IN A MOLD

While this is not the first step in the sequence of events, it is of such fundamental importance and it is governed by such adamant laws of physical chemistry, that it forms the most logical point of beginning in understanding the making of a casting.

Consider a few simple shapes transformed into mold cavities and filled with molten metal:



In a sphere, heat dissipates from the surface through the mold and solidification commences from the outside and proceeds progressively inwards in a series of layers. As the liquid metal solidifies, it contracts in volume and, unless feed metal is supplied a shrinkage cavity will be formed in the center. In cast iron, feed metal requirements vary according to the type of metal, viz., its carbon equivalent, and may be gauged, very generally, by its tensile strength. This is because graphite in the structure controls strength and graphite is lower in density, thus a cast iron, high in graphitic carbon content, shows less solidification shrinkage, than one which is lower in carbon content. Feed metal is supplied by risers.

Meehanite Type	Solidification Shrinkage
GM60 55,000 p.s.i.	5.0%
GA50 50,000 p.s.i.	4.0%
GC40 40,000 p.s.i.	2.00%
GE30 30,000 p.s.i.	0%
GF20 (soft) 20,000 p.s.i.	+1.00%

White irons containing carbides, instead of graphite, exhibit a 6% shrinkage. Of special interest are the nodular, ductile, or "S" types of Meehanite Metal, which, by virtue of their composition, exhibit from 0 to 1.0% of solidification shrinkage. Extremely soft cast irons exhibit an expansion on solidification and cannot be fed solid by risering. They present special problems, where density is important. The controlled graphitic carbon content, which is inherent to the Meehanite Process, makes it behave predictably and exhibit less solidification shrinkage than any other material of equivalent mechanical properties.

The design engineer must realize that a shrinkage problem exists and that the foundryman will have to attach risers to the casting, or resort to other means to overcome it. *Designing for use of lower mechanical properties, where this is practicable, decreases the foundryman's problem.*

When the simple sphere described on the previous page has solidified further, it continues to contract in volume, so that the final casting is smaller than the mold cavity. This causes the need for correction allowance, in order to hold dimensional tolerances. This contraction also relates roughly to tensile strength and is at its highest in white cast irons.

Shrinkage:

Allowances for shrinkage, unless otherwise specified:

	MEEHANITE Types GE, GD & GC Inches Per Foot	MEEHANITE Types GM, GA & GB Inches Per Foot
Patterns up to 24" open construction	1/8"	5/32
Patterns from 25" to 28" open construction	1/10	1/8
Patterns above 48" open construction	1/12	1/10
Patterns up to 24" cored construction	1/8	5/32
Patterns from 25" to 36" cored construction	1/10	1/8
Patterns above 36" cored construction	1/12	1/10

Approximate allowance for machine work per side:

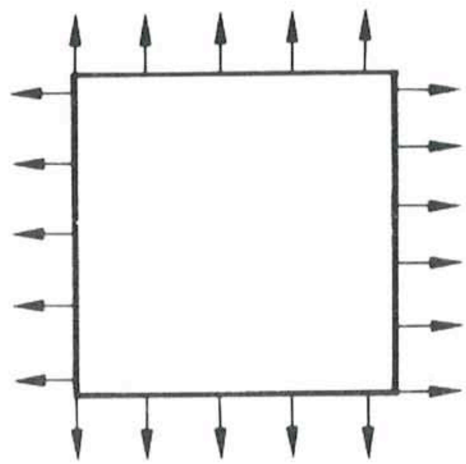
	Plain Face	Bore
Patterns up to 12"	3/32"	1/8"
Patterns 13" to 24"	1/8"	3/16"
Patterns 25" to 42"	3/16"	1/4"
Patterns 43" to 60"	1/4"	5/16"
Patterns 61" to 80"	5/16"	3/8"
Patterns 81" to 120"	3/8"	7/16"
Patterns above 120"	Special Instructions	

PATTERNMAKER'S SHRINKAGE ALLOWANCE FOR MEEHANITE METAL

(Consult Foundry and Patternmaker before specifying.)

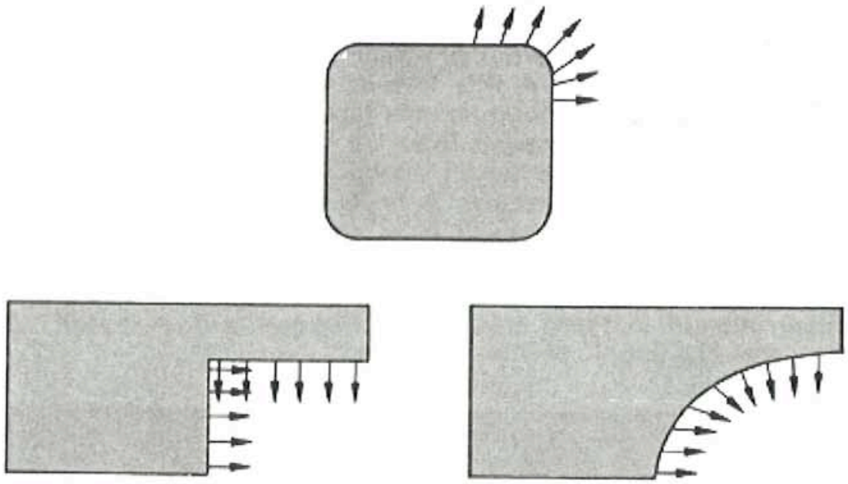
White iron will normally contract at 1/4" per foot. Contraction is not always equi-dimensional, in that it is influenced by mass and configuration. Contraction is normally 1/8" per foot for the flake irons, and about 1/10" per foot for the nodular or "S" Types of Meehanite unless annealing is resorted to. In such cases, an expansion occurs on annealing, making overall size contraction range from 0-1/16" per foot. Contraction, when hindered by the mold, will produce casting stress. Under like conditions, the material of lowest contraction will produce the greatest freedom from stress in the castings.

Consider a shape of square cross-section, such as a cube. Here again, cooling proceeds at right angles to the surface, and is necessarily faster at the corners of the casting. Thus, solidification proceeds more rapidly at the corners. In ordinary cast irons, higher hardness values may be expected at these corners. The Meehanite process, which utilizes nucleation of the melt to graphitize, is less subject to the effects of rapid chilling that might occur at external surfaces, such as corners, that radiate heat in two directions. An improved design of square or rectangular corners, would involve rounding off the corners to promote more equal heat extraction through the mold wall.



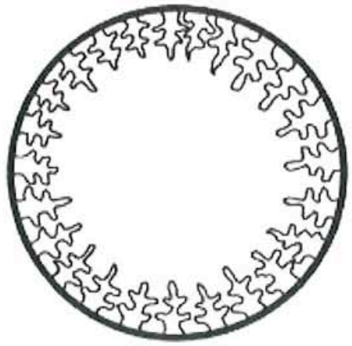
Consider the special case of the internal corner form the standpoint of solidification. As heat transfer is in a direction at right angles to the surface, it is necessarily slowed down at the corner, where heat flow lines intersect. Add to this the fact that sand, which is normally used for the mold has a very poor thermal conductivity, and a condition of a slow down of solidification at this corner, is promoted. The hot spot, so created, prolongs solidification, promoting solidification shrinkage and lack of density in this area. The only logical solution, from the design engineer's viewpoint, is the provision of very generous fillets or radii at these internal corners.

Additionally, the relation of the two sections forming the corner to each other is of importance. If they are materially different, as in the illustration, contraction in the lighter member will occur at a different time from that in the heavier member. *Differential contraction is the major cause of casting stress, warping, and cracking.*



THE METALLURGY INVOLVED IN SOLIDIFICATION

The physical changes that occur during solidification have been discussed, without consideration of metallurgical changes. Cast iron is a material consisting of many distinct constituents, the nature of which is determined during the solidification process and even before the metal is melted for casting. Primarily, the deposition of graphite by the solidification process which itself is affected by design considerations.



Going back to the simple round shape - solidification at the surface commences by deposition of austenite crystals at the surface. These crystals grow in a pine tree or dendritic formation and growth in a linear direction proceeds rapidly, at a rate depending on the rate of heat extraction from the mold. At the same time, the crystals thicken in a lateral direction. Graphite, being more soluble at higher temperatures, is deposited from the remaining liquid after the original deposition of some crystals fo austenite. Graphite deposition occurs from a number of centres or cells, known as eutectic cells or eutectic colonies. Diagrammatically, solidification of cast iron proceeds metallurgically from outside to the centre of a simple section as follows:

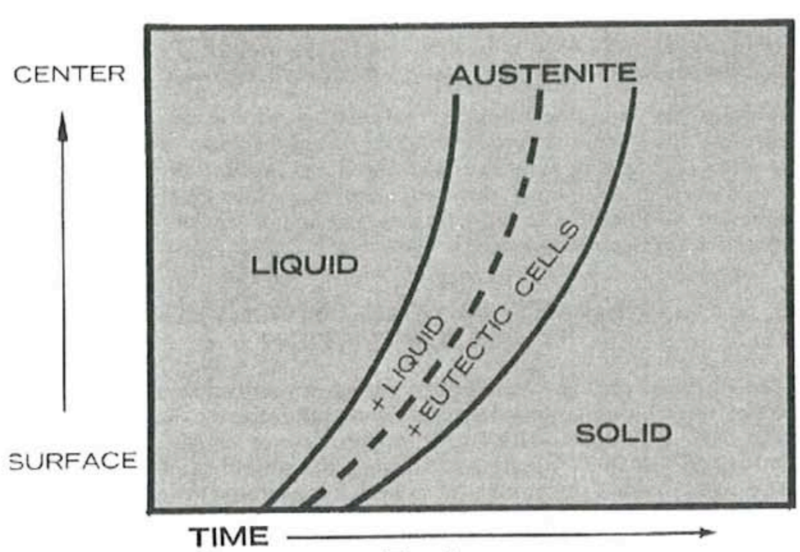


Fig. 1

THE FORMATION OF THE GRAPHITE

Control of the physical properties of a cast iron is normally aimed at exercising some degree of control of the time at which graphite is deposited from the melt, and, broadly speaking, this is done by controlling the composition or more particularly, the carbon equivalent of the iron. Graphite deposited very early during solidification, grows to a large size, producing a low strength, high machinability product, whereas graphite deposited later, is smaller, thereby imparting higher strength to the product. Graphite deposited too late adopts a directional configuration, as it is influenced by the growing austenite crystals. Such directional influence leads to a weak product. The change in properties, as related to graphite deposited from the melt, proceeds as follows:

KISH

LARGE GRAPHITE

SMALL GRAPHITE

UNDERCOOLED GRAPHITE

In the Meehanite Process, carbon equivalent is related to cooling rate or selection and to physical properties forming the first point of control. Typical carbon equivalents (T.C. + 1/3 Si) for the flake types, are as follows:

GM60	3.2% to 3.8%
GA50	3.3% to 3.9%
GC40	3.6% to 4.1%
GE30	3.9% to 4.3%
GF20 (soft)	4.3% to 4.5%

Perhaps the most important factor controlling graphite precipitation from the melt is the phenomenon of undercooling. By understanding undercooling, the formation of eutectic cells is delayed, according to the broken line in **Figure 1**. When once cell formation starts, it proceeds very rapidly, resulting in a small cell size and superior mechanical properties.

Undercooling is a function of the nuclei in the melt and is not dependent on chemical composition. For this reason, specifications involving rigid chemical standards are often quite meaningless.

As all crystallization initiates as nuclei, it follows that absence of such nuclei will delay crystallization, thereby promoting a high degree of undercooling. In the Meehanite process, the most potent source of nuclei i.e., graphite existing in the original furnace charge, is controlled, to a close degree, by judicious selection of charge material and by the use of an exclusive formulation. Higher strength types are produced from a charge with lower graphitic carbon content, usually achieved by using a high proportion of graphite free steel in the furnace charge.

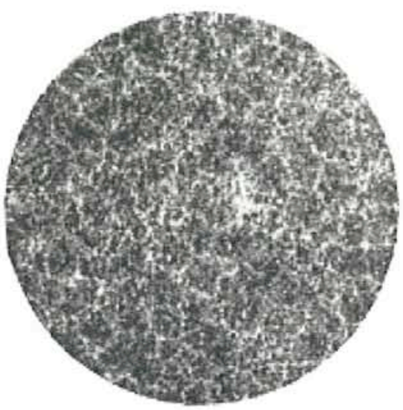
Such undercooling can be measured by means of a wedge test taken on the metal as it flows from the furnace. This wedge is known as the "constitution wedge" and gives a reading of the constitutional carbide value.

Once undercooling has been promoted in the melt. It is followed by deliberate nucleation using inoculating agents. These agents promote graphitization, control the nature of the graphite flake, and remove lingering traces of undercooling, which could promote an undesirable directional effect to graphite precipitation.

This technique, pioneered by the Meehanite process, which uses alkaline earth silicides as nucleants, provides a product exhibiting uniform properties from outside to centre and from section to section.

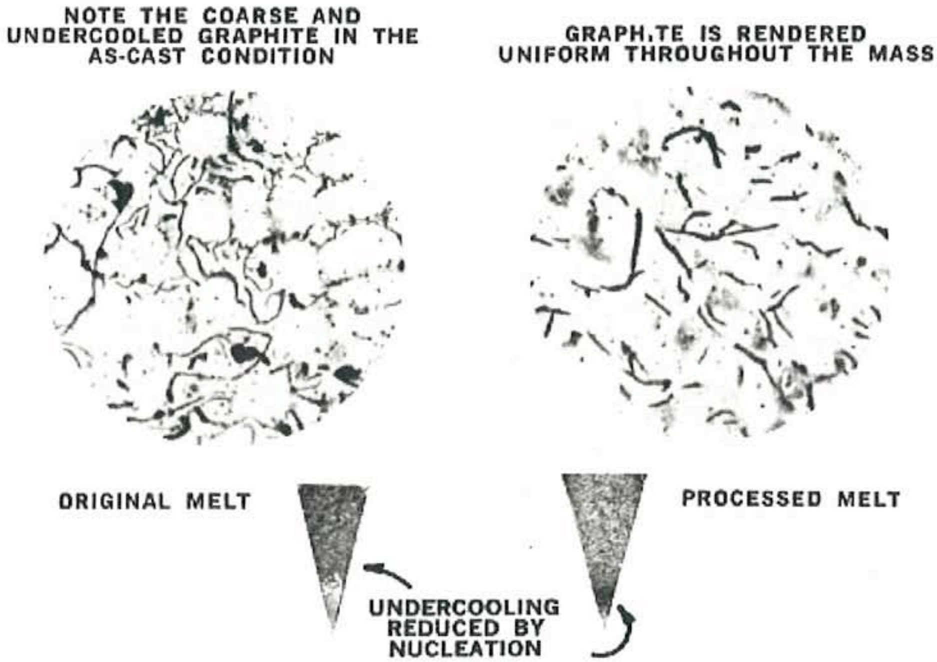
From the design engineers' standpoint, this is indeed important. While ideal conditions would call for a uniform section casting exhibiting the same cooling rate during solidification in all areas, the use of the undercooling-nucleation technique allows more latitude in design and eliminates the differences from the outside to inside, which could not be avoided, even in a design of uniform section.

What nucleation accomplishes may be appreciated from a simple demonstration:



LARGE EUTECTIC CELLS
IN THE AS-CAST CONDITION
TENSILE 40,000 PSI. BHN 217

SMALL EUTECTIC CELLS
AND HIGH DENSITY AFTER NUCLEATION
TENSILE 54,700 PSI. BHN 217

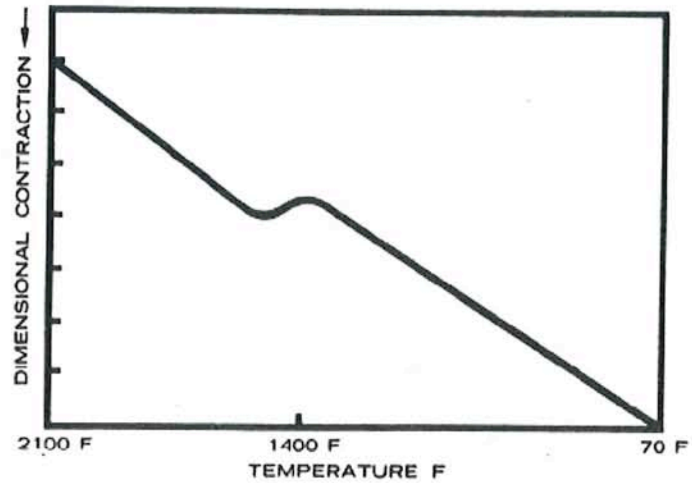


The exclusive constitutional-process control promotes uniform structure and properties throughout a given section and decreases variations from section to section in any given castings, thereby also eliminating the weakening effect at hot-spots and other isolated slow-cooling sections, resulting from improper design. While this should not encourage poor design it does present the engineer conscientiously obeying fundamental rules of metallurgy, greater latitude.

METALLURGICAL CHANGES AFTER SOLIDIFICATION

After solidification, a casting will continue to cool down to room temperature. During this cooling period, it will contract in an amount according to its composition. It will also pass through an important crystallographic change, when austenite existing at higher temperatures transforms into pearlite; which is normally stable at lower temperatures.

A typical cooling curve of Meehanite Metal cast iron or steel will show a dimensional change just below 1400°F, thus:



It is evident, therefore, that slow-cooling is imperative to allow this change to take place, normally, without undue stresses occurring, and those castings of varying dimension or isolated slow-cooling areas, present a somewhat special problem.

The dimensional changes occurring during the pearlite interval, lead to casting strain, cracking, and warping and, apart from resorting to excessively slow-cooling, which may be costly, the foundryman is entirely dependent on the skill of the design engineer. The engineer should seek to provide a design that will cool uniformly and progressively, by avoiding abrupt section changes.

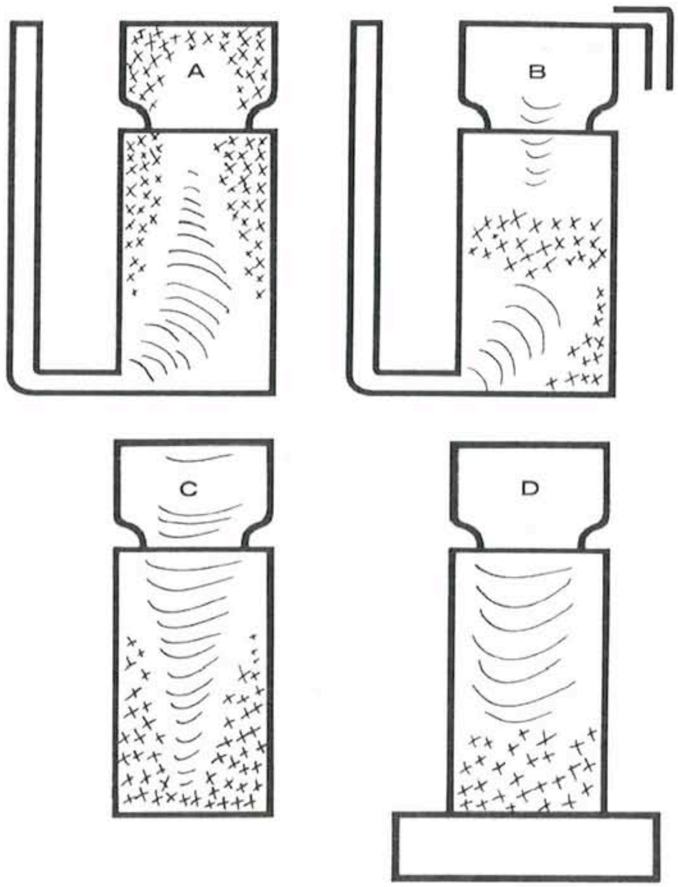
As high strength cast irons exhibit the pearlitic change at lower temperatures, where plastic flow cannot occur as readily, and as these cast irons usually contain less graphite which can act to absorb stresses, it follows that stress free castings are more likely to result in lower strength cast irons, providing these irons are so processed as to be uniform in structure. Therefore, over-design, in terms of tensile strength, should be avoided wherever possible. The Meehanite Process, by the attainment of higher strengths with relatively high proportions of graphite shape within a given casting section, provides the design engineer with greater latitude.

Where stress is unavoidable, a stress relief heat-treatment, involving very slow heating and cooling throughout the pearlite interval, is often necessary.

In cast irons which are heat treated for hardness or which are alloyed to provide a hard wearing martensitic matrix, instead of the usual pearlitic matrix, the contraction stresses are at a maximum and proper design becomes even more important. The Meehanite Process provides a series of irons which may be hardened by air quenching and which are, therefore, less liable to cracking and distortion during the hardening treatment. Heat treatment, for hardness, should not be an afterthought on the part of the design engineer it is, essentially to closely follow design rules in the drawing board stage and make due allowance for the metallurgical and dimensional changes that must, of necessity, occur during the hardening treatment.

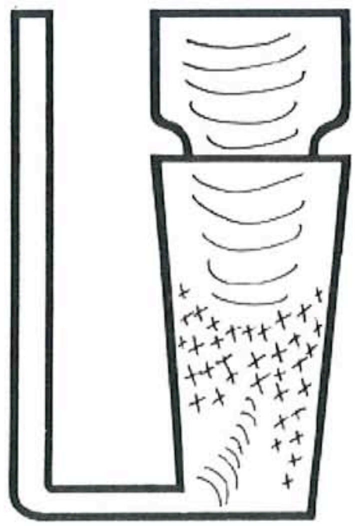
DIRECTIONAL SOLIDIFICATION

In the quest for solid, stress-free, and accurately dimensioned castings, the foundryman can use considerable skill in assuring controlled solidification. As metal is cast at a temperature well above its solidification point, the excess heat may be used to heat up certain areas of the mold and promote what is known as "directional solidification". As an example, consider a simple cylinder:



By casting, as shown at **"A"**, metal entering the ingate area imparts heat to the mold and itself becomes cooled. The riser designed to provide feed metal, thus, is the coldest part of the casting and cannot perform its function of providing feed metal to overcome solidification shrinkage.

The design engineer could help by providing a tapered design:



The heavier mass at the upper end would then provide slower cooling, which will offset the reverse temperature gradient resulting from the casting method.

The foundryman could help himself by flowing off some of the colder metal, as in **"B"**.

Preferably, it could cast as at **"C"**, where a natural temperature gradient from top to bottom would result. By pouring slower, this gradient could be magnified. Alternatively, it may cast at **"B"** using a chiller or densener, as at **"D"**, where rapid heat extraction through the chill would further magnify the gradient. A steep gradient provides initial solidification at the base progressively supplying feed metal to the solid base and eventually to the upper part of the casting. The result is a solid casting and the best assurance of controlled and predictable dimensional changes during and after solidification.

For best results, the foundryman and the design engineer should combine their talents. The foundryman is often limited in cost, and tries to avoid methods which, while metallurgically superior, would increase the cost to manufacture. Here, the design engineer can help. The foundryman also, cannot always arrange the gating to provide true directional solidification. He is limited by such factors as the need to provide a gating system that will give clean, slag-free metal into the mold cavity that will avoid undue impingement of metal on certain mold areas leading to mold erosion, and by cost factors, due to abnormal or non-standard gating procedures.

The design engineer is also limited in that he cannot always design a part to perform a function and, at the same time, make it easy for the foundryman to perform his. The best solution is each realizing the problems faced by the other and cooperating early in the initial design stages.

RULE 1: BEFORE ISSUING THE FINAL DRAWING, CONSULT A COMPETENT FOUNDRYMAN OR PATTERNMAKER

Casting design poses two problems; one for the Engineer, the other for the Foundryman:

1. The Engineer must know:

   "HOW TO DESIGN A CASTING SO THAT IT WILL ACTUALLY HAVE THE REQUISITE STRENGTH AND FUNCTIONAL PROPERTIES".

2. The Foundryman must be able:

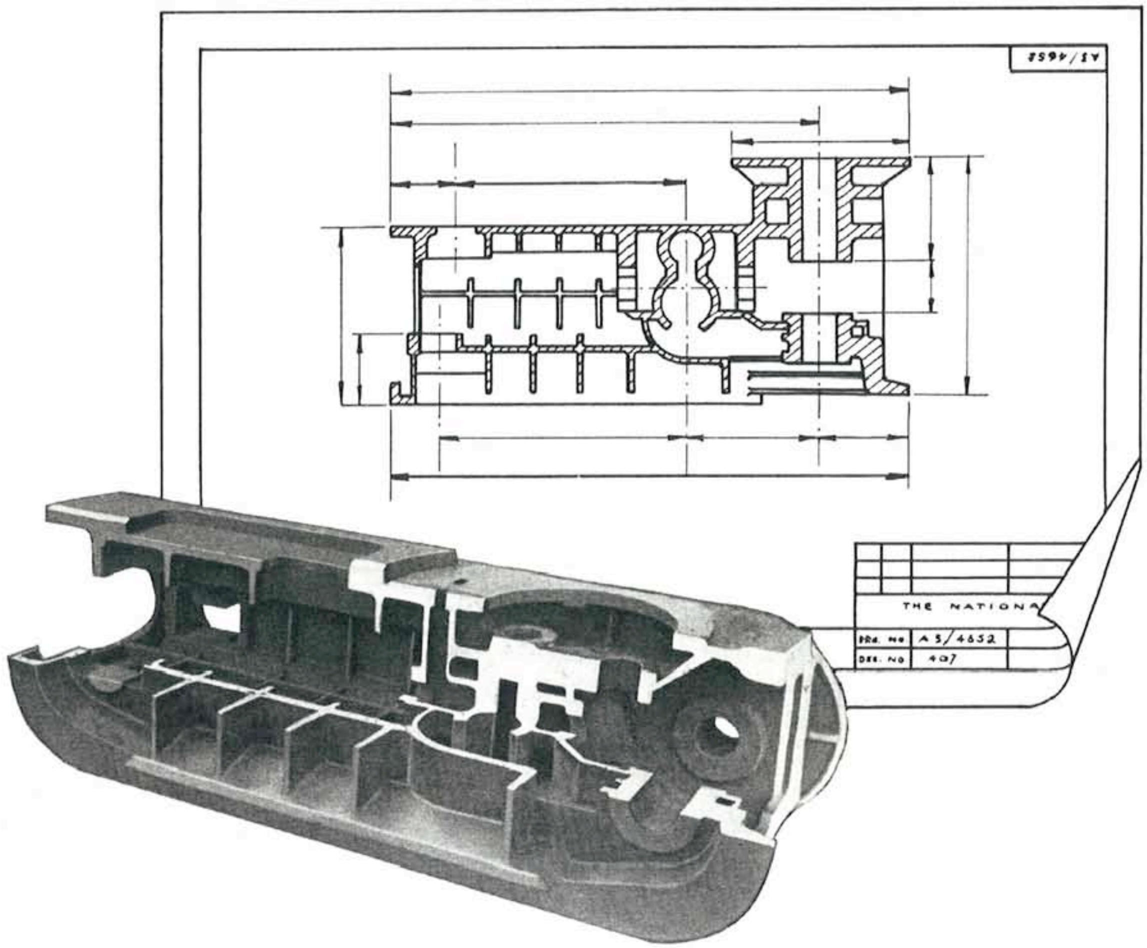
   "TO MAKE THE CASTING SO THAT IT HAS THE STRENGTH AND FUNCTIONAL PROPERTIES THE ENGINEER INTENDED".

It is all too common to *design* to suit the engineering department but not the foundry, and the result may be failure or disappointment. From the foundryman's viewpoint, it is first important to *design* a casting that can be made rather than one that may be perfect engineering-wise but which cannot be produced commercially and free from structural weakness.

Consultation between *Designer* and *Foundryman* will permit consideration of the foundry problems that are likely to be encountered and will promote the making of a sound casting. The time and cost of manufacture can also be considered at this preliminary stage of *casting* design. Important questions that the foundryman can answer include:

1. Type of pattern needed
2. Metal shrinkage
3. Molding method required
4. Conditions necessary top make a dependable casting
5. Machine finish and dimensional limitations

RULE 2: CONSTRUCT A SMALL MODEL OR VISUALIZE THE CASTING IN THE MOLD



Relatively, few engineers or foundry men can follow all section changes and shapes from a blueprint. Create a *three-dimensional drawing or construct a small model.* This procedure permits study of how metal will enter the mold, how solidification proceeds, and shows what parts have to be fed to assure casting soundness. In today's world, this is easily done with CAD and three dimensional isometrics can very often be generated at the touch of a button.

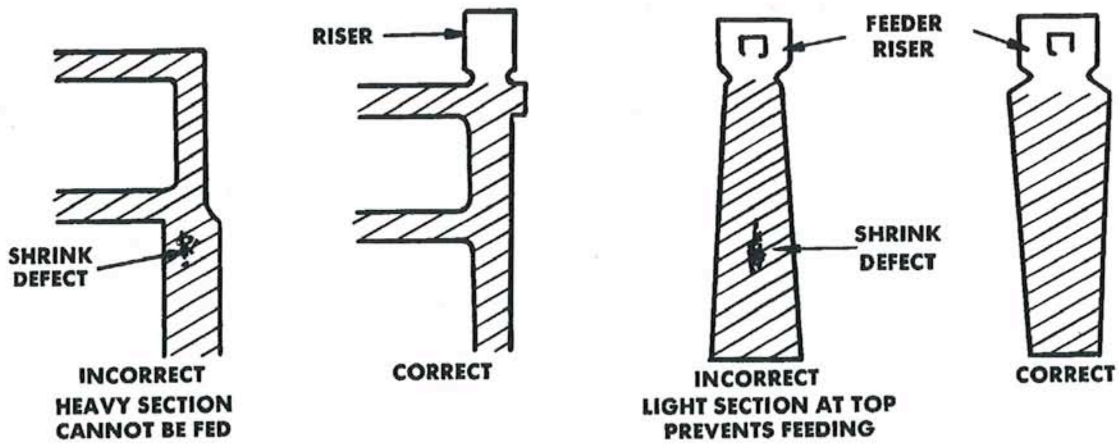
A *model to scale* or full size in the form of a pattern that can be used later will help the designer to see how cores must be designed and placed or omitted. It will help the foundryman to decide how to mold the casting, detect casting weakness (shrinks and cracks), where to place gates and risers, and answer other questions affecting casting soundness, cost, and delivery.

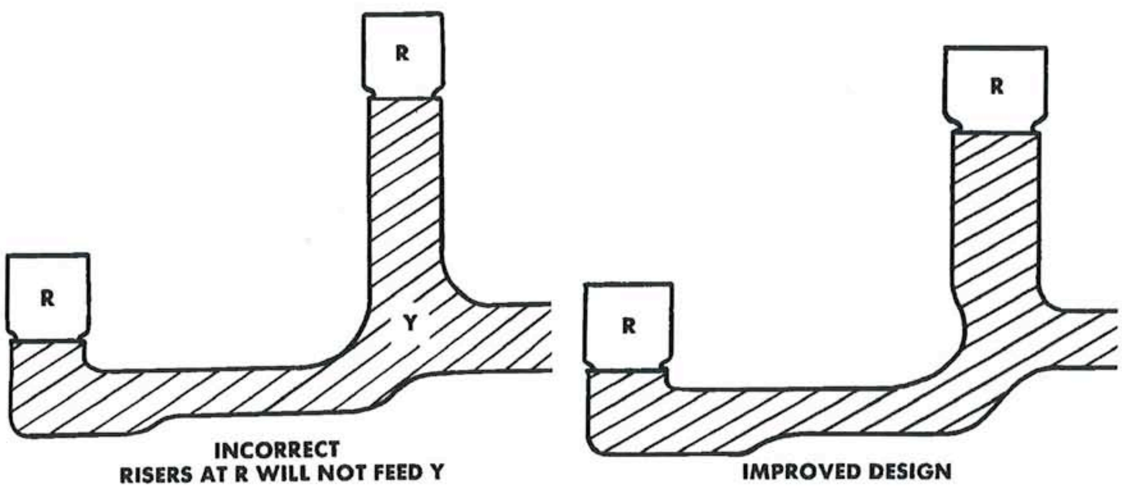
RULE 3: DESIGN FOR CASTING SOUNDNESS

Most metals and alloys shrink when they solidify.

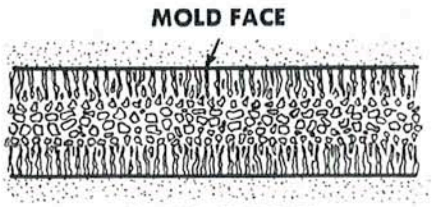
Therefore, design so that all members of the parts increase in dimension progressively to one or more suitable locations where feeder heads can be placed to offset liquid shrinkage.

The illustrations shown portray correct and incorrect methods of design. All of the rules set forth here have been proven in service and assure *soundness of section.*

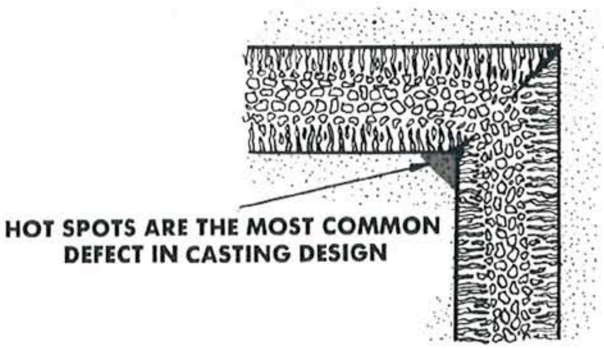




RULE 4: ALWAYS PRESENT A COOLING SURFACE AVOID SHARP ANGLES AND CORNERS



SIMPLE SECTION



CONJOINING SECTIONS

ILLUSTRATING ADVANTAGES OF ROUNDED CORNERS TO AVOID LOCAL STRUCTURAL WEAKNESS

METAL STRUCTURE IS AFFECTED
BY SHAPE OF CASTING SECTION

Solidification of molten metal always proceeds from the mold face, forming unbalanced crystal grains that penetrate into the mass at right angles to the plane of cooling surface. A simple section presents uniform cooling and greatest freedom from mechanical weakness. When two or more sections conjoin, mechanical weakness is induced at the junction and free cooling is interrupted, creating a *"hot-spot"*.

RULE 4: REPLACE SHARP ANGLES AND CORNERS WITH RADII
(continued)

FIGURE 1

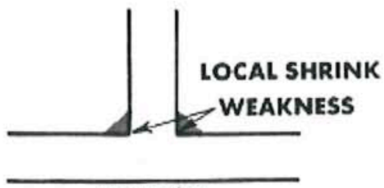


FIGURE 2

POOR DESIGN

FIGURE 3

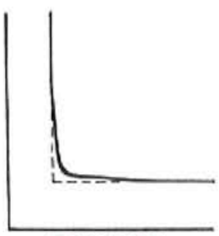


FIGURE 4

IMPROVED DESIGN

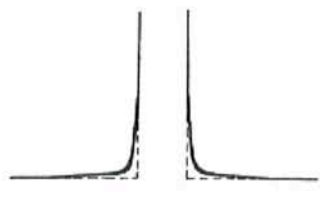


FIGURE 5

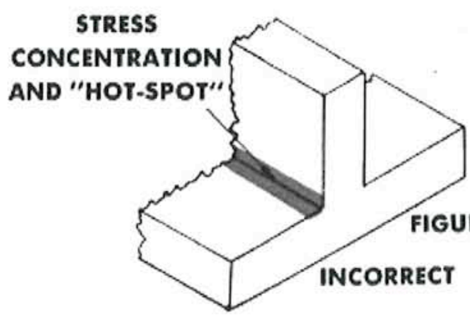


FIGURE 6

INCORRECT

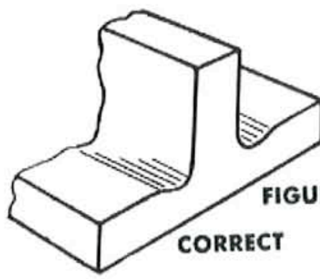


FIGURE 7

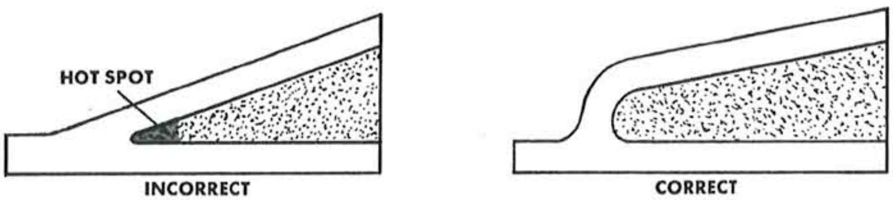
CORRECT

In designing adjoining sections, *avoid acute angles. Replace all sharp angles with radii* and minimize heat and stress concentration. ***Figures 1, 2, and 3*** illustrate poor designs that result in local structural weakness. ***Figures 4 and 5*** show recommended design which assures improved strength and solidity. ***Figure 6*** portrays a common defect involving a "T" section. The improved design as shown in ***Figure 7*** removed the hot-spot and stress concentration.

RULE 4: AVOID SHARP ANGLES AND CORNERS
(continued)

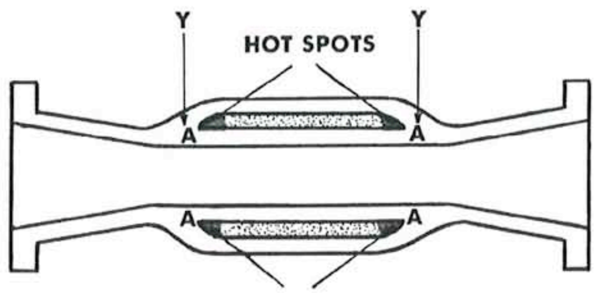
EXAMPLES OF LOCAL STRUCTURAL WEAKNESS CAUSED BY POOR DESIGN

CYLINDER CASTINGS



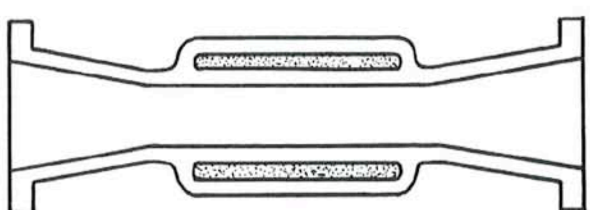
Engine cylinder parts are often designed to cause local casting weakness. Avoid core design which does not present a cooling surface.

STEAM JACKETED CYLINDERS



INCORRECT

Streamlining of exterior resulted in heavy section at "Y". Thin elongated point of core at "A" resulted in heat concentration which accentuated heavy section. Result: Hot spot causing leakage due to shrink defect.



CORRECT

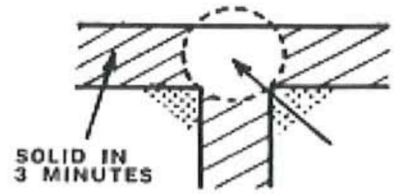
Re-design eliminated defect and resulted in a solid casting of uniform strength properties.

RULE 5: BRING THE MINIMUM NUMBER OF SECTIONS TOGETHER

FIGURE 1

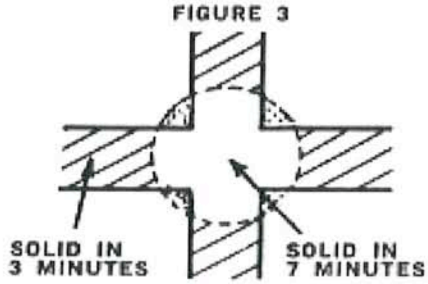
SOLIDIFIES IN 3 MINUTES

Figure 1 portrays a simple section which cools freely from all surfaces.



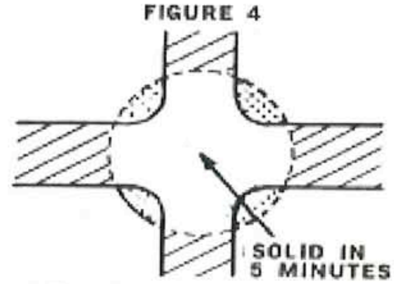
By adding a second section as shown by figure 2, creates "hot-spots", the area inside circle cools at rate of section 50 percent larger.

FIGURE 3



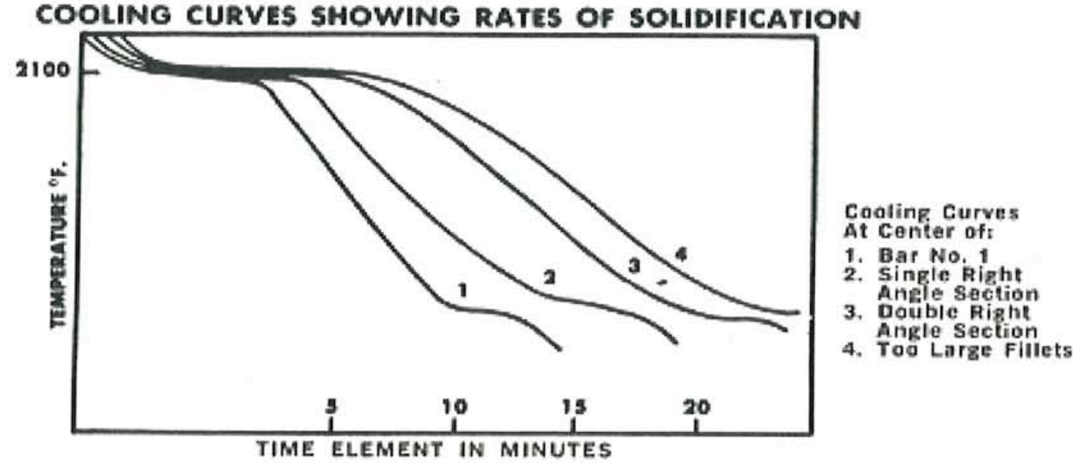
When two sections cross, only material outside circle shown by figure 3, represents true properties. Area inside circle solidifies at the rate of a bar twice its cross-sectional area.

FIGURE 4



Adding too large fillets aggravates defect.

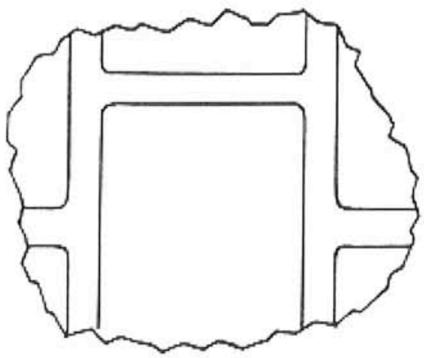
COOLING CURVES SHOWING RATES OF SOLIDIFICATION



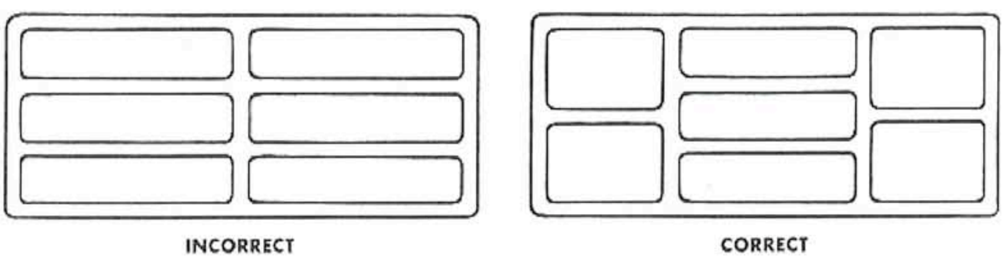
To portray the serious casting problems introduced by joining an excessive number of members, cooling curves were made by inserting thermocouples at the adjoining sections. The results of these measurements are shown on the graph above.

A WELL DESIGNED CASTING BRINGS THE MINIMUM NUMBER OF SECTIONS TOGETHER AND AVOIDS ACUTE ANGLES

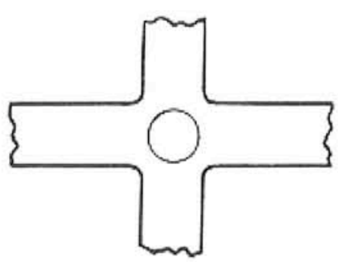
RULE 5: BRING THE MINIMUM NUMBER OF ADJOINING SECTIONS *(continued)* TOGETHER...STAGGER CROSS MEMBERS



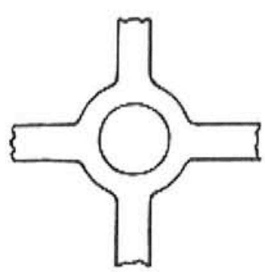
STAGGERED SECTIONS MINIMIZE HOT SPOTS EFFECTS, ELIMINATE STRUCTURAL WEAKNESS AND REDUCE DISTORTION



TO PREVENT UNEVEN COOLING, BRING THE MINIMUM NUMBER OF SECTIONS TOGETHER OR STAGGER SO THAT NO MORE THAN TWO SECTIONS CONJOIN.



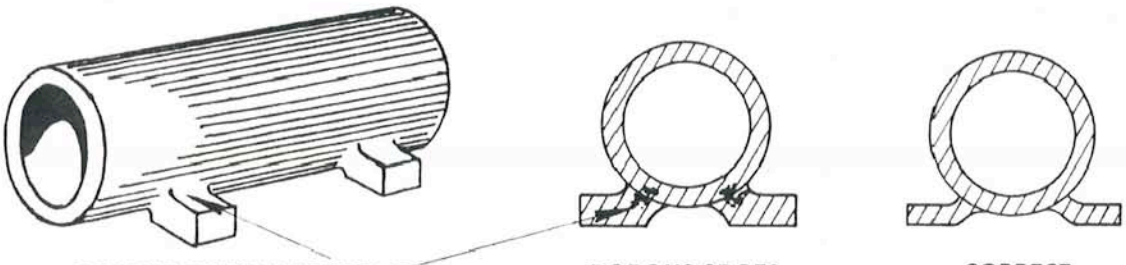
A CORED HOLE WILL HELP TO SPEED UP SOLIDIFICATION WHERE A NUMBER OF SECTIONS CAN JOIN.



A CIRCULAR WEB WITH ADJOINING SECTIONS IS PREFERRED.

RULE 6: DESIGN ALL SECTIONS AS NEARLY UNIFORM IN THICKNESS AS POSSIBLE

CYLINDER WITH LUGS



Design on left caused defects shown. Correct design shown on right. Design all sections as nearly uniform in thickness as possible. Failing this, all heavy sections should be accessible for feeding.

HYDRAULIC PUMP

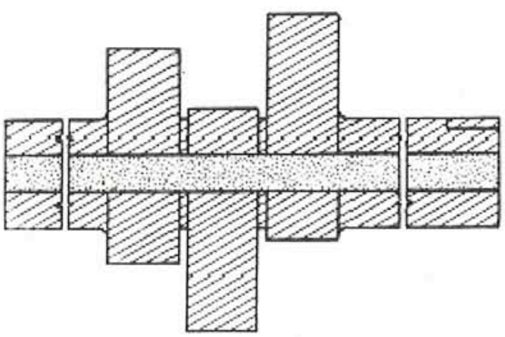


FIGURE 1
ORIGINAL DESIGN INCORRECT

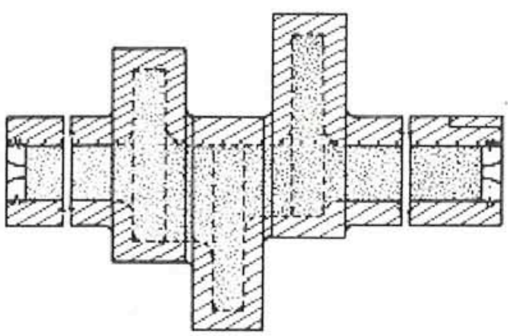


FIGURE 2
CORRECT DESIGN

The hydraulic coupling shown in ***Figure 1*** was originally designed with a 2" core through the center. This gave excessive metal and caused local porosity. Redesigning with sections of reasonable uniformity of thickness corrected the difficulties, reduced the weight of the casting and lowered the cost of manufacture.

RULE 6: DESIGN ALL SECTIONS AS NEARLY AS UNIFORM IN *(continued)* THICKNESS AS POSSIBLE

Shrink defects and casting strains existed in the *Hydraulic Coupling* casting illustrated in ***Figure 1***. Redesigning as shown in ***Figure 2*** eliminated excessive metal and resulted in a casting that was free from defects, lighter in weight, and prevented development of casting strains in the light radial veins.

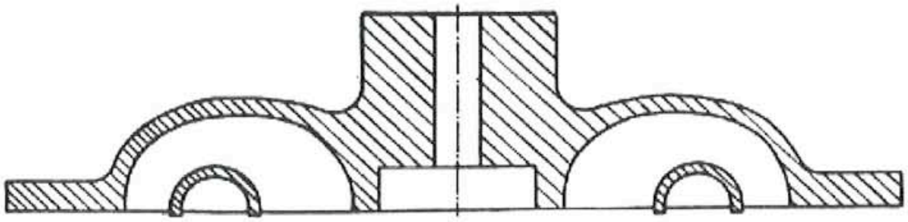


FIGURE 1
ORIGINAL DESIGN INCORRECT

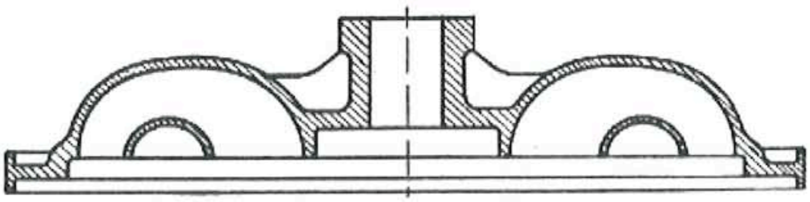
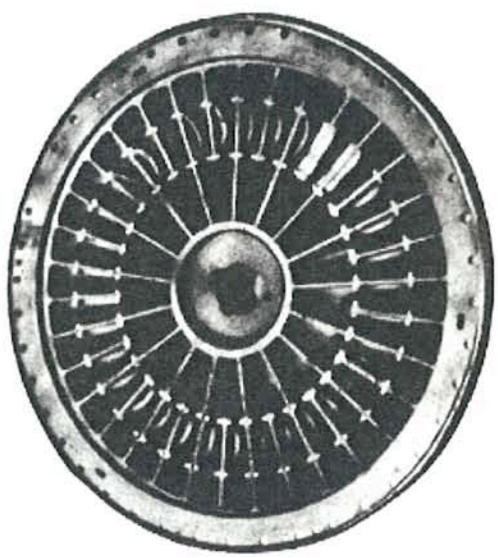


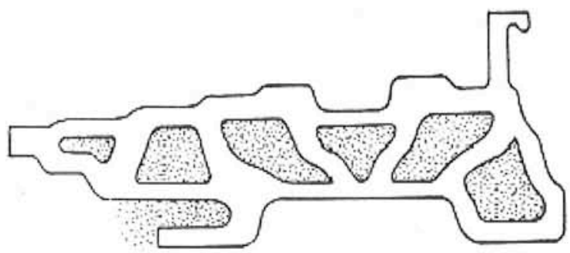
FIGURE 2
CORRECT DESIGN

HYDRAULIC COUPLING

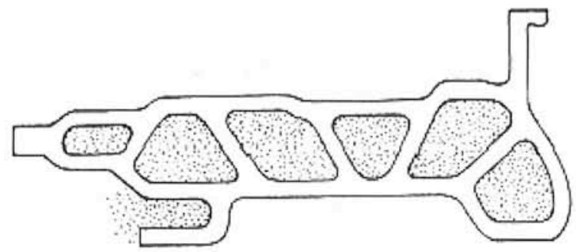


RULE 7: PROPORTION DIMENSIONS OF INNER WALLS CORRECTLY

Inner sections of castings, resulting from complex cores, cool much slower that outer sections and cause variations is strength properties. A good rule is to *reduce inner sections* to 9/10ths of the thickness of the outer wall. *Avoid rapid section changes* and *sharp angles.* Wherever complex cores must be used, *design for uniformity of section* to avoid local heavy masses of metal.



INCORRECT



CORRECT

CYLINDER AND BUSHINGS

The inside diameter of cylinders and bushings should exceed the wall thickness of casting.

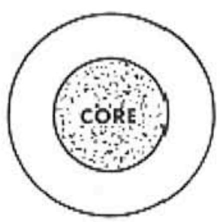
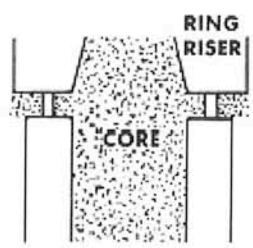


FIGURE 1
CORRECT



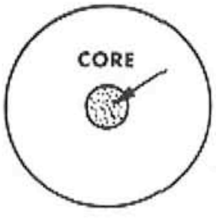
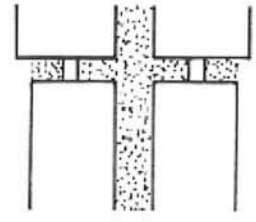


FIGURE 2
INCORRECT



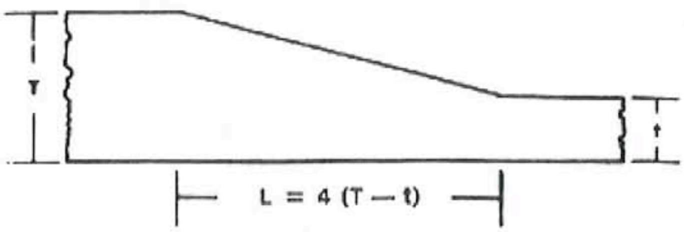
When inside diameter of cylinder is less than the wall thickness of the casting, as shown by ***Figure 2***, it is better to cast solid. Holes can be produced by cheaper and safer methods than by coring.

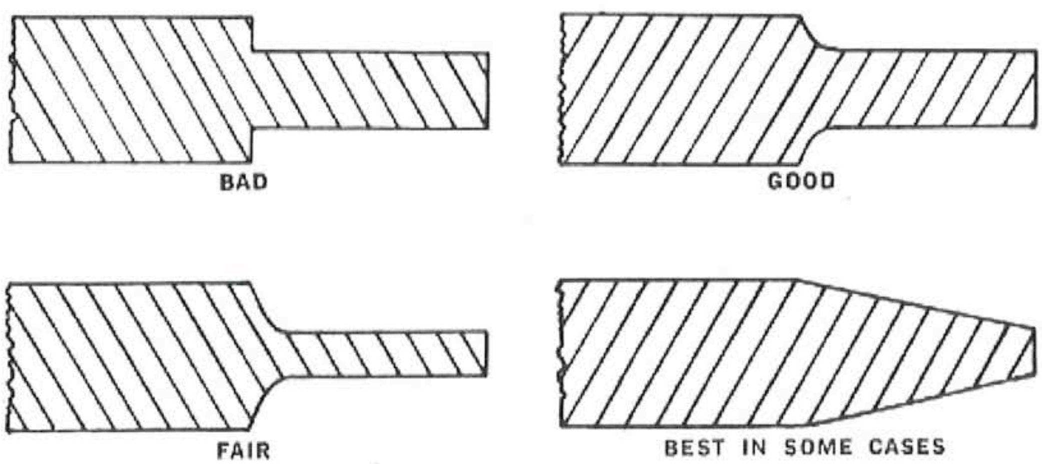
RULE 8: AVOID ABRUPT SECTION CHANGES......ELIMINATE SHARP CORNERS AT ADJOINING SECTIONS

The difference in the relative thickness of adjoining sections should be a minimum and not exceed a ratio of 2:1. Where a greater difference is unavoidable, consider design with detachable parts; for example, the ways of machine tool beds can be bolted, etc.

When a change of thickness is less than 2:1, it may take the form of a fillet; where the difference is greater, the form recommended is that of a wedge.

Wedge-shaped changes in wall thickness are to be designated with a taper not exceeding 1 in 4.





Where light and heavy sections are unavoidable; use proper fillets or tapering sections, or both.

If blending is not permissible, use fillets of fairly large size at junctions.

RULE 9: FILLET ALL SHARP ANGLES

FIGURE 1
POOR

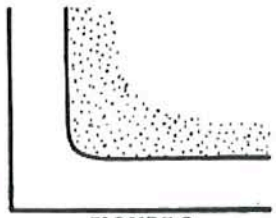


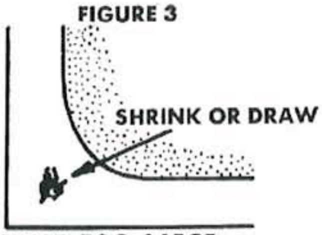
FIGURE 2
IMPROVED

Fillets have three functional purposes:

1. To reduce stress concentration in the casting in service
2. To eliminate cracks, tears and draws at re-entry angles
3. To make corners more moldable and to eliminate Hot Spots

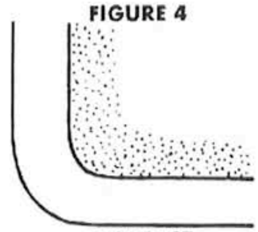
Number of radii in fillets in one pattern should be the minimum possible, preferably only one. To fulfill engineering stress requirements and reduce stress concentration, relatively large fillets are used with radius equaling or exceeding casting section.

FIGURE 3



FILLET TOO LARGE . . .
CAUSES SHRINKAGE OR
WEAK METAL STRUCTURE

FIGURE 4



CORRECT
UNIFORM COOLING
RATE OBTAINED

Where this dimension fillet is used, casting thickness is increased at joint and tends to cause structural weakness as shown in ***Figure 3***. Where large fillets are required design, as shown in ***Figure 4***.

Where this is not possible, consideration must be given as to whether the engineering design of the foundry casting problem is most vital. From the foundryman's viewpoint, too large fillets are undesirable and the radius of the fillet should not exceed one-half the thickness of the section joined.

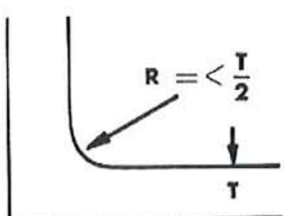
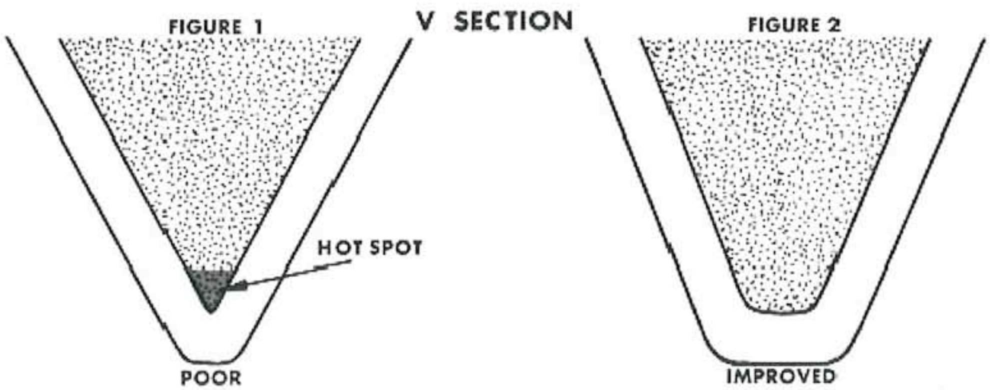
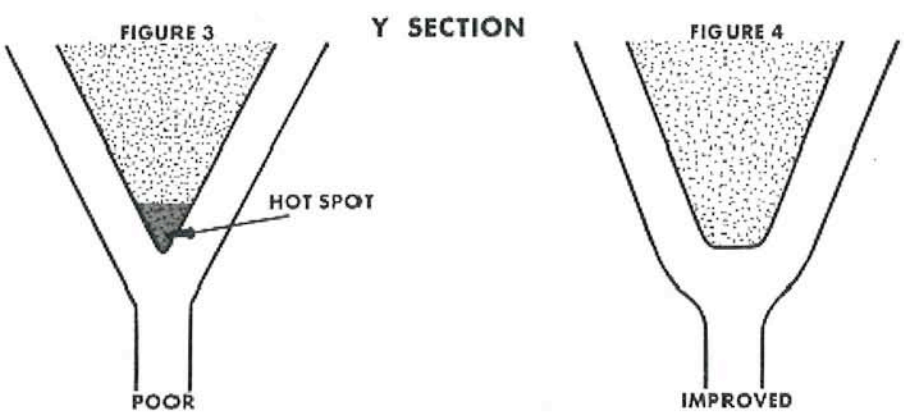


FIGURE 5

RULE 9: FILLET ALL SHARP ANGLES GIVE ANGULAR FORMS AMPLE *(continued)* RADIUS

In the case of "V" or "Y" sections and other angular forms, always design so as to allow a generous radius to avoid localization of heat.



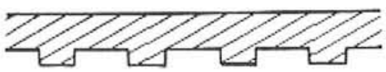


RULE 10: DESIGN RIBS AND BRACKETS FOR MAXIMUM EFFECTIVENESS

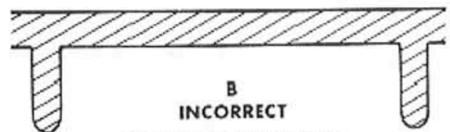
Ribs have two functions:

1. To increase stiffness
2. To reduces weight

If too shallow in depth, or too widely spaced, they are ineffectual.

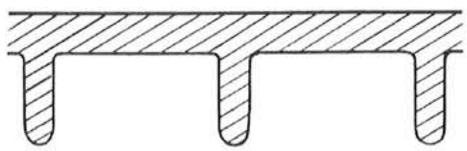


A
INCORRECT
RIBS TOO SHALLOW

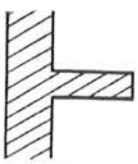


B
INCORRECT
TOO WIDELY SPACED

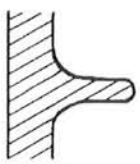
Correct *rib* depth and spacing is a matter of engineering design.



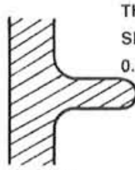
C
CORRECT



D
INCORRECT
THIN RIBS SHOULD BE AVOIDED WHEN JOINED TO A HEAVY SECTION. OTHERWISE, THEY WILL LEAD TO HIGH STRESSES AND CRACKING.



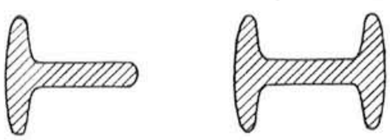
E
INCORRECT
AS FAR AS POSSIBLE, JUNCTION BETWEEN RIBS AND MAIN CASTING SHOULD PREVENT ANY LOCAL ACCUMULATION OF METAL.



THICKNESS OF RIBS SHOULD APPROXIMATE 0.80 CASTING THICKNESS

F
CORRECT
RIBS SHOULD SOLIDIFY BEFORE THE CASTING SECTION THEY ADJOIN.

THICKNESS OF RIBS SHOULD EQUAL 80% OF CASTING THICKNESS, SHOULD BE ROUNDED AT EDGE AND CORRECTLY FILLETED.



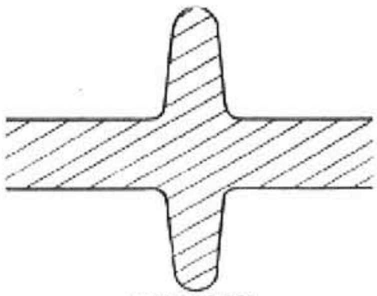
G

T AND H SHAPED RIBBED DESIGNS HAVE THE ADVANTAGE OF UNIFORM METAL SECTIONS AND HENCE UNIFORM COOLING

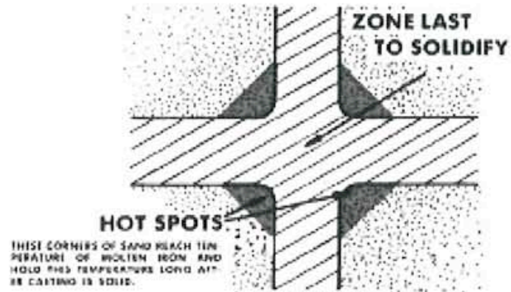
Design preference in average design is for ribs to have a greater depth than thickness.

Ribs in compression in general, offer a greater factor of safety than ribs in tension. However, castings having thin ribs or webs in compression may require design changes to give necessary stiffening to avoid buckling.

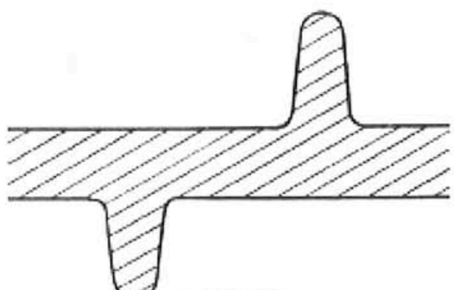
RULE 10: DESIGN RIBS AND BRACKETS FOR MAXIMUM EFFECTIVENESS AVOID CROSS RIBS OR RIBBING ON BOTH SIDES OF A CASTING
(continued)



INCORRECT
RIBBING ON BOTH SIDES OF CASTING IS UNDESIRABLE FROM A FOUNDRY VIEWPOINT. IT INCREASES CASTING DEFECTIVES AND COSTS.



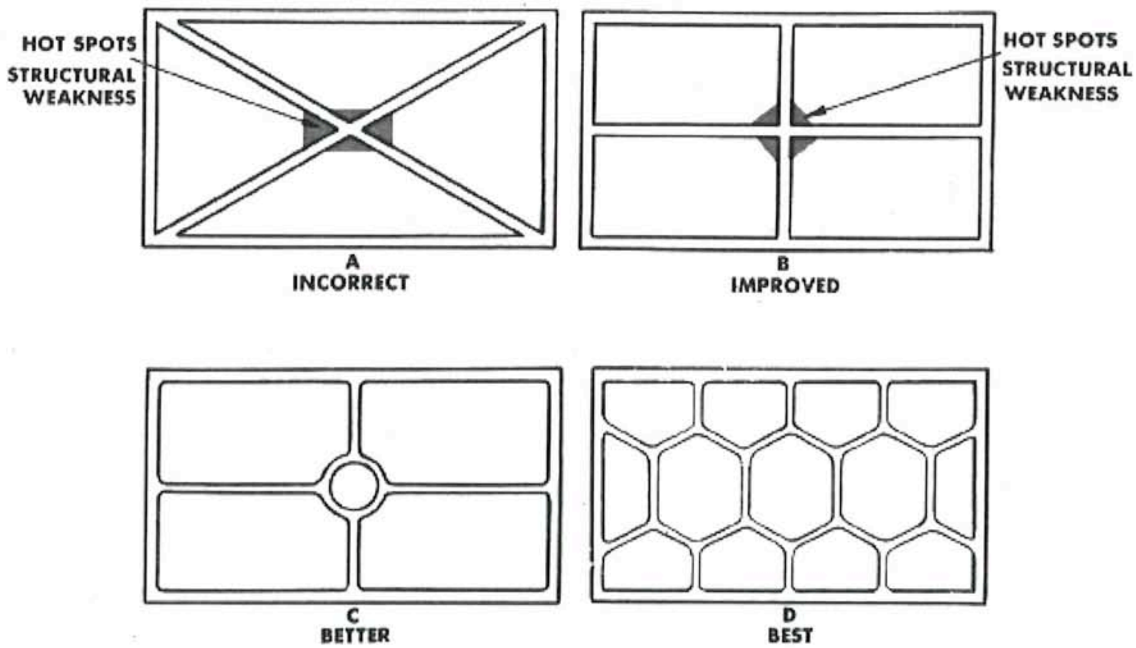
INCORRECT
CROSS RIBBING CREATES HOT SPOTS, RENDERS FEEDING SOLID DIFFICULT, CAUSES LOCAL WEAKNESS AND POROSITY.



CORRECT
CROSS COUPLED RIBS SHOULD PREFERABLY BE DESIGNED AS DOUBLE T FORMS.

Avoid complex ribbing. It simplifies molding procedure, assures more uniform solidification conditions and eliminates *Hot Spots*. Casting stresses and stress distribution favor omission of ribbing if the casting wall can be made of ample strength and stiffness without.

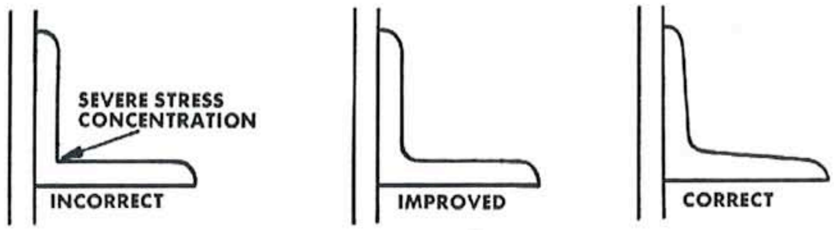
RULE 10: AVOID THE USE OF RIBS MEETING AT AN ACUTE ANGLE
(continued)



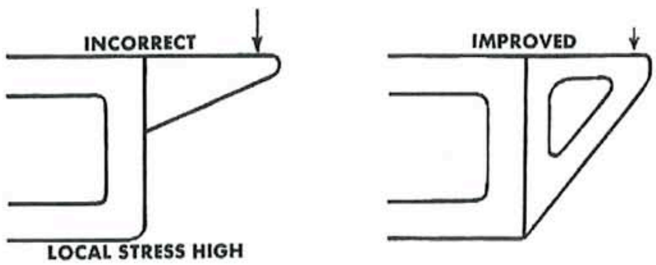
Ribs meeting at acute angles cause molding difficulties, increase costs and aggravate the risk of defective castings. ***Figure A*** shows incorrect design and hot spot effects. Cross ribs in ***Figure B*** are an improvement. They avoid acute angles, but are undesirable in that four sections are brought together. ***Figure C*** brings only two sections together. However, the best design is shown in ***Figure D***. Here the honeycombing effect creates more uniform cooling conditions. This type of ribbing assures improved strength with minimum risk of distortion and structural weakness.

RULE 10: DESIGN RIBS AND BRACKETS FOR MAXIMUM EFFECTIVENESS
(continued)

Stress concentrations should be carefully considered.



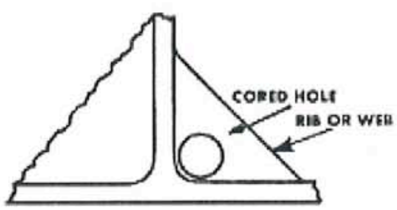
Brackets carrying offset loads introduce bending moments both local and in the body of the casting.



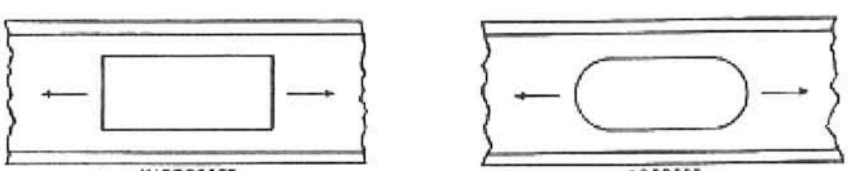
Make length of contact with main casting as ample as possible.

Brackets may frequently be detached from the main casting (cast separately) and attached to the main structure. Simplifies molding, reduces cost of manufacture.

Ribbed bracket offers advantage as to stiffness.



Avoid concentration of heat by providing cored openings in webs and ribs. Such openings should be as large as possible, consistent with strength and stiffness.



Avoid rectangular shaped cored holes in ribs or webs. Use oval shaped cored holes with the longest dimension in the direction of the stresses.

RULE 11: BOSSES, LUGS AND PADS SHOULD NOT BE USED UNLESS ABSOLUTELY NECESSARY

Bosses and *pads* increase metal thickness, create *hot spots* and cause open grain or draws. Blend into casting by tapering or flattening the fillets. *Bosses* should not be included in casting design when the surface to support bolts, etc., may be obtained by milling or countersinking.

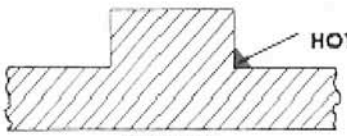


FIGURE 1
INCORRECT


FIGURE 2
CORRECT

A continuous rib instead of a series of bosses permits shifting hole location.

Thickness of *bosses* and *pads* should preferably be less than thickness of the casting section they adjoin, but thick enough to permit machining without touching the casting wall. Where the casting section is light and does not permit use of this rule, then the following minimum recommended heights can serve as a guide.

APPROXIMATE CASTING LENGTH - FEET	HEIGHT OF BOSS - INCHES
Up to 1 1/2	0.25
1 1/2 to 6	0.75
Over 6	1.0

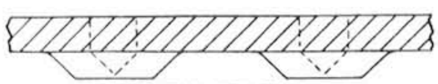


FIGURE 3
INCORRECT

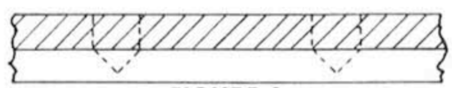


FIGURE 4
CORRECT

Continuous rib instead of a series of bosses permits shifting hole location.

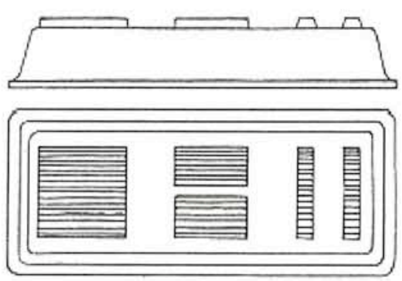


FIGURE 5
INCORRECT

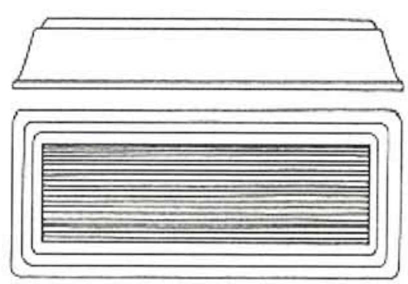


FIGURE 6
CORRECT

When there are several *lugs* and *bosses* on one surface, they should be joined to facilitate machining of possible. Panel of uniform thickness instead of many pads of varying heights simplifies machining.

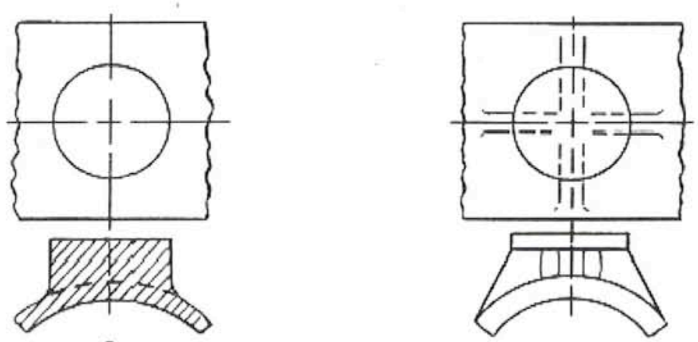
RULE 11: BOSSES, LUGS AND PADS SHOULD NOT BE USED UNLESS ABSOLUTELY NECESSARY
(continued)

BOSSES ON LARGE CASTING

A
POOR
METAL SECTION TOO HEAVY AT BOSSES.
DIFFICULT TO FEED SOLID.

B
IMPROVED
UNIFORM METAL SECTION ASSURES SOUND CASTING, LESS WEIGHT, LOWER MACHINING COSTS.

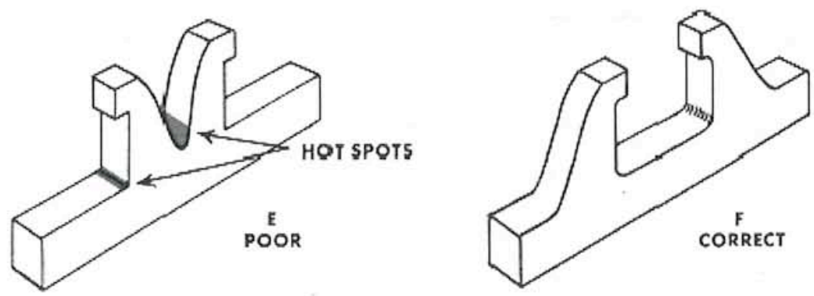
DESIGN FOR BOLTING OR BEARING BOSSES



C
POOR

D
IMPROVED

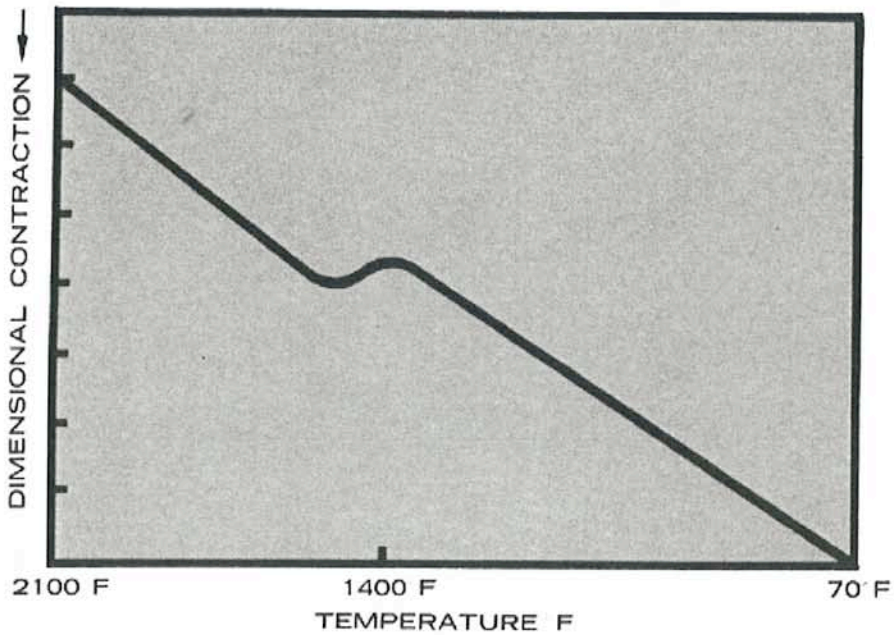
SPREAD LUGS TO AVOID HOT SPOTS



E
POOR

F
CORRECT

THERMAL STRESSES

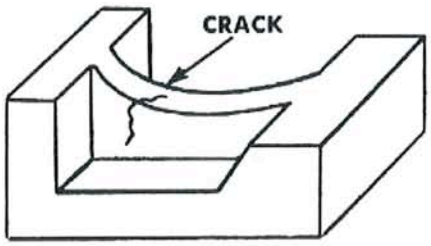


Typical cooling curve of Meehanite Metal or steel after solidification showing contraction and expansion with temperature fall. Note the expansion that occurs at about 1400°F. during the austenite pearlite inversion, which is followed by contraction to room temperature

Casting design creating a variance in cooling rates between its different parts is the most common cause of *casting strain*. Cracks, distortion, and structural weakness usually result from differential or hindered solid contraction. When a casting cools from solidification to room temperature, it contracts until the austenite-pearlite critical temperature range is approached. During this inversion, the casting actually expands during cooling. Thereafter, normal reversal contraction takes place.

RESIDUAL CONTRACTION STRESSES

All castings, except those of very simple form, contain *residual casting stresses.* These may be of such magnitude as to cause distortion in machining, or exceed the strength of the material from which it was made. In the latter case, the casting fractures either in the mold or in service.



UNEVEN SECTIONS AND SHARP ANGLES
CAUSE CASTING STRAINS AND CRACKING

It is apparent that different cooling rates of light and heavy sections result in lighter sections contracting ahead of the heavier sections. This may be exaggerated by mold or core rigidity. It is further complicated by the critical carbide change expansion. Frequently, in castings of extreme variation in section thickness, contraction may be taking place in some members and expansion in other members. If details of member junctions are not therefore carefully designed with this in mind, cracked, deformed or weakened castings will result.

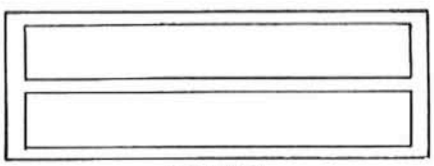


FIGURE 1
ORIGINAL PATTERN

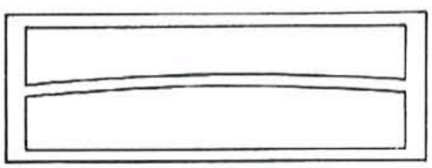


FIGURE 2
CONTRACTION STRESS INDUCED IN CENTER MEMBER

A casting of simple shape, consisting of three straight and parallel members of equal length, joined at their extremities by rigid cross members of equal length, will commonly result in the outer members cooling faster than the center member, causing distortion as indicated in ***Figure 2.***

RESIDUAL CONTRACTION STRESSES

GEARS

The ordinary gear wheel is an excellent example of design where sectional dimensions and form of member junctions are not always carefully considered in design. The rim may be heavy and the boss higher, or the boss heavy and the rim light. The spokes may approximate the sectional dimension of the boss or the rim, or they may be much higher than either. The rim and the boss may be in proportion, but the spokes to light, which will create excessive internal stress or cracking.

Where such variation is encountered, the Foundryman may have to treat each portion of the casting, i.e. the rim, spokes and boss as separate castings in order to obtain soundness and solidity, which is not always to the advantage of the gear in service.

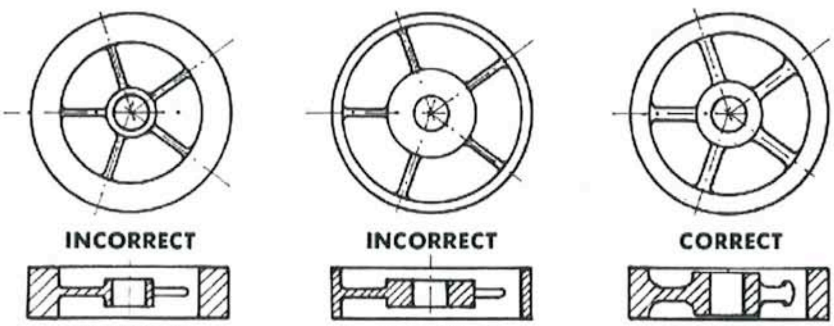


FIGURE 1 FIGURE 2 FIGURE 3

Figure 1 shows an abnormal heavy rim and a lighter boss joined by lighter spokes. Such a wheel is obviously risky to cast and limited in service. ***Figure 2*** displays a light sectioned rim and heavy boss joined by light spokes. ***Figure 3*** shows an improved design with rim, spokes, and hub in balance and avoids sharp corners. This represents good design casting wise and reduces the magnitude of casting stresses to a minimum.

FIGURE 1
HEAVY SPOKE RADIUS AT RIM

FIGURE 2
THIN RIM AND HUB
HEAVY SPOKE

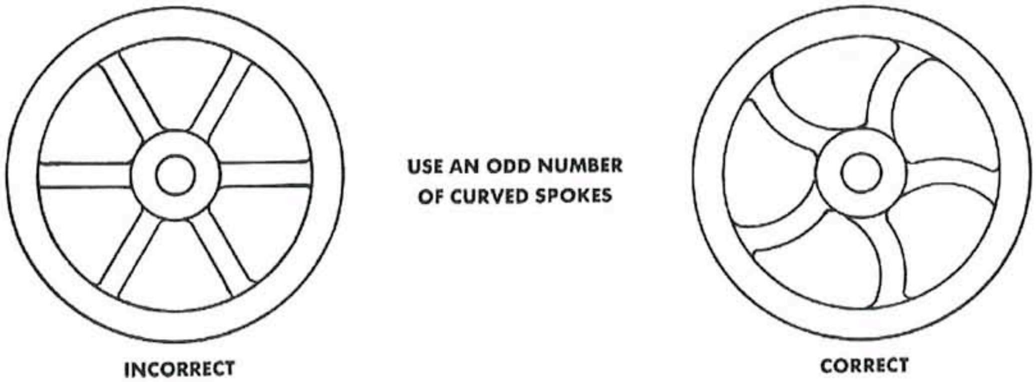
FIGURE 3
WELL PROPORTIONED RIM
AND SPOKE; LARGE HUB

Three examples of the effect of casting strains produced by lack of proportioning the rim, arms, and hub of a *pulley* are illustrated. Under conditions of ***Figure 1***, the rim and then the hub solidify, while the spoke is still partially liquid. Since the rim and hub are fixed, the tension in the arm produced by liquid-solid shrinkage may result in cracking. By joining the hub to the rim with a heavy radius, as shown in Figure 2, tearing of the rim may result. With the arms and rim well proportioned, and the hub to heavy **(*shown in Figure 3*)** a tear can occur near the hub.

RESIDUAL CONTRACTION STRESSES

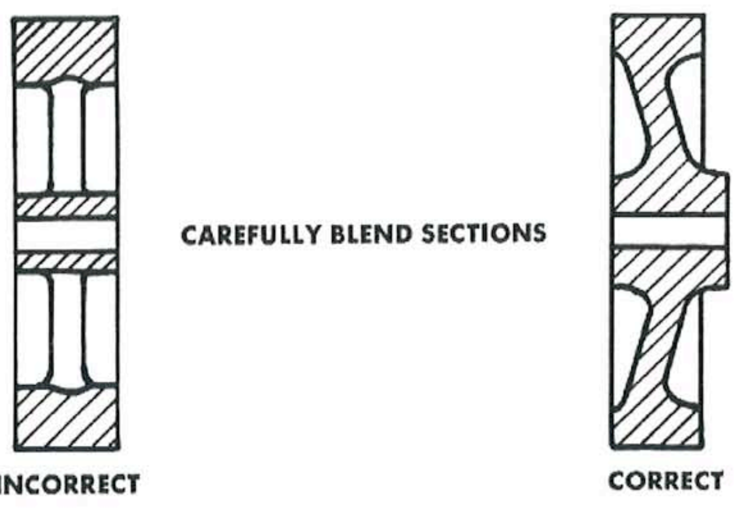
SPOKED WHEELS

It must be remembered that compression stresses are developed in the first part of a casting to solidify and tension stress in the last sections to change from liquid to the solid state. For this reason, provide as far as possible for the rim, spokes and hub to cool as evenly as possible. Carefully blend sections of varying sizes.



A curved spoke is preferred to a straight one. It will tend to straighten slightly, thereby offsetting the dangers of cracking. Use an odd number of spokes. A wheel having an odd number of spokes will not have the same direct tensile stress along the arms as one having an even number and will have more resiliencies to casting stresses.

AVOID EXCESSIVE SECTION VARIATION



Stress relief treatment of the finished casting may be advisable where positive assurance of absence of casting stresses is required.

DISTORTION ALLOWANCES

Bed and *base plates* having the bottom side heavier than the top one, should have the middle of the pattern lower than the ends. Then, as the underside of the casting cools, it pulls down the ends and a straight casting can be obtained. The camber required depends on the design and the length of the casting, varying from 1/4" for castings 6' long to 3/4" for castings 15' long. The greater the distance between the masses of the opposing sides, the greater must be the camber.

Other examples are castings having large flat areas or those of U-shape. Again, the patterns have to be purposely distorted to secure a straight casting. The amount of distortion is called *"distortion allowance"*.

The engineer should be guided in such cases in the application of *allowances* by the advice of the *foundryman* and *patternmaker*, as there are no fixed rules governing such *allowances*.

The *foundryman* can help to reduce *distortion* and *strain* by skillful practice:

1. Control of pouring temperature
2. Choice of gating and risering
3. Resisting or assisting normal contraction at local points by the use of gaggers, chills, cores, sand or other device

These foundry methods will not remove *distortion* or *strain*. Therefore, complex castings should be heat-treated by STRESS RELIEF ANNEAL.

STRESS RELIEF

Complex castings of varying sectional dimensions always contain some *casting strain*. Where full strength properties are mandatory, *stress relief* is recommended. Sometimes castings are "aged" or "weathered" for long periods of time for this purpose, but a straight stress relieving treatment assures complete removal of all pent-up stresses, whereas aging and weathering do not.

STRESS RELIEF HEAT TREATMENT

Stress relief is important with complex castings, especially where there is much variation in casting section thickness. Slow uniform heating and cooling, approximately 50° to 100°F. per hour, is recommended. The former mitigates against cracking or warping of cast parts with high internal casting strains from non-uniform contraction during cooling. All stress relief must be distinguished from normalizing, since the maximum temperatures is below the critical and ranges from 1000°F to 1150°F according to the tabulation:

For types GA, GM, & GS:	temperature 1100-1150°F.
For types GC & GB:	temperature 1050-1100°F.
For types GE & GD:	temperature 1000-1050°F.

Castings should be retained at this temperature for one hour per inch of casting section and allowed to cool in the furnace.

SUMMARY OF RULES AND FACTORS IMPORTANT IN DESIGN RELATED TO THE MANUFACTURE OF SOUND, ENGINEERED CASTINGS

CASTING DESIGN AND THE ENGINEER

1. Consult Foundryman or Patternmaker – explain strength requirements, service functions and where it fits into total assembly.

2. Investigate possibility of making part in sections which later can be joined together, rather than attempt too complicated a casting. This applies particularly to designs which include large projections or extensions from the main body of a casting.

3. Make casting sections no thicker than essential to the desired unit of strength and functional requirements, but of sufficient thickness to insure proper running of the metal in the mold. Avoid sharp angles – use gentle contours.

4. Design sections as nearly uniform in thickness as possible. Avoid abrupt section changers. Make transition gradual, blending heavier sections into light ones.

5. Design so that all members of the parts increase progressively in thickness to convenient locations where risers can be placed.

6. Bring the minimum number of sections together. Three is inviting trouble; four is bad. Shrink and porosity troubles most often occur at member junctions. Stagger if possible.

7. In designing adjoining sections, replace corners with radii, and avoid heat and stress concentration.

8. Avoid multiplicity of cores. The thickness of inner walls of a casting should be 70-90 % of outer walls, depending intricacy of coring.

9. Avoid intersecting ribs. Consider staggering, or in case of large castings, use simple cores at the intersections to equalize cross-section at the junctions.

10. Employ ribs only where necessary to increase strength, or reduce weight, or to avoid warpage.

11. Reduce bosses, lugs or pads and other projections to a minimum. When necessary, design to conform to the thickness of the adjacent section.

12. The form of openings in walls of castings depends upon the size of the opening, stiffness or flexibility of surrounding material, and type and distribution of loads. Contours with large radii of curvature of gradual changes are preferred. An elliptical opening may have advantages if the major axis is oriented correctly.

13. Machining allowances involve many factors and variables. Consult the Foundry man.

14. In the case of complex designs, make a three-dimensional drawing or model before making the final pattern if an isometric is not available.

CASTING DESIGN AND REDUCTION OF CASTING STRAIN AND DISTORTION

1. Avoid sudden changes of form producing a corresponding change in the direction of shrinkage.

2. Avoid re-entrant angles.

3. Avoid multiplicity of cores. These expand under influence of heat and may offer rigid resistance to free shrinkage with resultant cracking of the casting.

5. Avoid widely differing section sizes, especially those in close juxtaposition, which might give rise to different rates of cooling.

6. Where internal casting strain must be a minimum, or where dimensional stability is vital, provide for stress relief anneal.

FOUNDRY PRACTICE AND REDUCTION OF CASTING STRAIN

1. Select metal having minimum contraction.

2. Control pouring temperature.

3. Use special molding procedure.

4. Distribute gates uniformly.

5. Avoid rigid cores and restrictions.

7. Use molding devices to obtain uniform contraction conditions.

8. Do not shake out too soon.

CASTING DESIGN AND COST REDUCTION

1. Aim to simplify design as much as possible. It may reduce pattern-making costs, eliminate core boxes and save in molding expense.

2. Avoid use of loose pieces in the pattern. Where projections exist, put dovetail slide on pattern or provide core box. (Consider which will make better casting.)

3. Avoid designs that involve irregular parting lines in the pattern equipment.

4. Avoid the use of deep pockets in designs. Such designs usually involve extra molding and cleaning shop costs.

5. Do not specify dimensional tolerances closer than are necessary. This costs money.

6. When lettering and special markings are required, see that they come on a surface of casting parallel or nearly so with the mold parting.

7. Consult Foundry if metal inserts or cores requiring chaplets or stalks are necessary.

8. Draft should be ample for a straight draw without severe rapping of pattern.

    a. Average draft - 1/16" per foot
    b. Draft decreases in deep draws
    c. More draft for hand molding than machine
    d. Interior draft should be greater than exterior, and not less than 3° inside and 2° outside

9. No Bake cores are costly. Patterns made to leave their own green sand cores in the mold are most economical to manufacture. Any part of the pattern which will not draw from the sand requires coring.

10. Where cores are necessary, make them as few and as simple of form as possible. Provide adequate core prints. In castings that must contain liquids or be pressure-tight, design so cores are used that will not require chaplets.

11. Avoid the use of slender cores surrounded by heavy chunks of metal. Holes can be produced by cheaper and safer methods.

12. Provide vent outlets and cleanout openings when using interior cores which are nearly or entirely surrounded by metal.

PATTERN MAKING

The function of the *pattern-maker* is to translate design into terms of foundry practice.

Pattern-making, molding and core making must be considered as a whole, since engineering requirements of the casting determine too a great extent the process of pattern and casting manufacture.

A pattern suitable for soft gray cast iron may be quite unsuitable for one made in higher strength cast iron or steel, due to difference in contraction and the inability to feed molten metal to certain parts or the shape.

Many patterns and core boxes today are made from urethane because of it superior life. These can be urethane cast onto a wooden structure or cut from solid urethane blocks. The solid urethane blocks (red board) are rather brittle and so cannot be used for all patterns. The urethane which is "poured" onto a wooden structure is far more successful in the foundry.

Urethane patterns are more costly that wooden patterns and so low volume (or very large) patterns are still constructed with wood. Very high volume patterns should be made from metal, and so urethane fits handily into the vast majority of job shop medium-volume work.

The following information applied to wooden pattern construction and also applied to the wooden backing structure used for patterns made with cast urethane surfaces.

Consultation with an experienced foundryman and pattern-maker will pay good dividends.

COLOR YOUR WOODEN PATTERNS

Patterns have a clear finish and be suitably colored for identification purposes.

A practice that is sometimes used is to color surfaces that are to be machined RED.

Seats of and for loose pieces should have RED STRIPES ON YELLOW.

Core prints and seats of a loose core print should be YELLOW.

Stop-offs should be indicated by a BLACK STRIPE ON A YELLOW BASE.

The most common negligence in the *making of patterns* is to fail to break or round all sharp corners and edges, and to adequately fillet re-entry angles. Radius of fillets should not be under one quarter or over one half of the section joined.

MARKING THE PATTERN

The pattern should have space allowed on it, varnished YELLOW, for the following information:

NAME OF CONCERN

NAME OF PART

PATTERN NUMBER

MATERIAL OF CASTINGS

SHRINKAGE ALLOWANCE PER FOOT

NUMBER OF PIECES TO PATTERN

NUMBER OF CORE BOXES

Core prints should be marked Core No. 1, No. 2, No. 3, etc., in rotation as they are placed in the mold. This is especially helpful with urethane patterns that cannot be painted.

Core Boxes should be marked in a similar manner.

Pattern Number should be stamped on all loose pieces.

PATTERN-MAKER'S SHRINKAGE

This is the *shrinkage allowance* for patterns which must be made to compensate for the change in dimension caused by contraction of the metal as it cools.

Shrinkage:

Allowances for shrinkage, unless otherwise specified:

	MEEHANITE Types "GE", "GD" & "GC" Inches Per Foot	MEEHANITE Types "GM", "GA & "GB" Inches Per Foot
Patterns up to 24" open construction	1/8	5/32
Patterns from 24" to open construction	1/10	1/8
Patterns above 48" open construction	1/12	1/10
Patterns up to 24" cored construction	1/8	5/32
Patterns from 25" to 28" cored construction	1/10	1/8
Patterns above 36"cored construction	1/12	1/10

Approximate allowance for machine work per side:

Pattern size	***Plain Face***	***Bore***
Patterns up to 12"	3/32"	1/8"
Patterns 13" 10 24"	1/8"	3/16"
Patterns 25" to 42"	3/16"	1/4"
Patterns 43" to 60"	1/4"	5/16"
Patterns 61" to 80"	5/16"	3/8"
Patterns 81" to 120"	1/2"	7/16"
Patterns above 120"	Special Instructions	

PATTERN-MAKER'S SHRINKAGE ALLOWANCE FOR MEEHANITE METAL

(*Consult Foundry and Pattern-maker before specifying*)

These figures are to be used with caution, because most castings have several different *shrinkage* allowances according to their size, design complexity, relative mass of core vs. metal, varying metal thickness, nature of metal, temperature of pouring and mold material, etc. Actually, close control of *shrinkage allowance* for a particular casting can only be obtained by manufacture and measurement. For example, shrinkage may be nil on height, but excessive on width.

A common trouble with cylinders and cylinder liners is that they do not clean up in the bore due to casting contracting length-wise according to *shrinkage allowance*, but without contraction in the bore.

CONSTRUCTION OF PATTERNS

Small patterns (up to 24") may be built or made from solid stock, with fillets carved from the stock or made from leather.

Medium-size patterns (24" to 60") shall be made of 1 ¼" or 1 ½" stock.

Large-size patterns (over 60") shall be made of 1 ½" or 2" stock.

Hollow work to be built on headers about 22" in centers, the grain of wood next to the sand to run in direction of draft when ever possible.

Headers shall be constructed on stile and rail method, firmly braced both laterally and longitudinally.

Concentric or eccentric circular work to be built up with segments, any number of layers to one unit, glued and nailed where practical.

Barrel-type circular work to be staved and the hollow method of construction to be used.

Flat work may be supported by stop-off pieces.

All loose pieces shall be secured with one or more dowels of differing sizes.

Bosses - Lugs and Brackets, and all other protruding elements should be so designed that they can be removed from the mold together with the main pattern.

Wood backed urethane patterns to have to wooden backing construction as described above.

All tapered round core prints for cope to have ten-degree taper.

All round core prints for drag to have one-degree taper.

All loose round core prints to be doweled in center only.

Lifting plates and raping plates of sufficient size, properly secured, shall be provided. (This is of utmost importance to prevent damage to patterns due to the use of spikes for this purpose).

Screw holes on working surface shall be countersunk and filled flush.

Thin patterns; of which any number of castings are to be made, should be made of metal. A cast iron pattern costs very little more than a high grade of wood pattern, because the master pattern need not be so well constructed, and the filing up of an iron pattern is not particularly expensive process.

The cast iron or aluminum pattern will give true castings for an indefinite period, whereas a thin wood pattern cannot be let in shape very long. The damp molding sand and the strain of ramming it in the mold is bound to deform it in time.

The most common negligence on the part of the pattern shop is their failure to break or round corners and edges, and to adequately fillet re-entry angles. The importance of this little detail is immeasurable in producing a sand mold free from tears and stickers that require patching.

Radius of fillets should not be under ¼ or over ½ of the thickness of the section joined.

MAINTENANCE OF PATTERNS

Wooden patterns being frequently in contact with wet sand should be shellacked at regular intervals depending on the use they get.

The molder's vent wire will eventually cover the face of a *pattern* up with small holes, which if not filled up, will given the casting a pock-marked appearance. *Patterns* in this condition should have the surfaces filled with wax or plastic wood and shellacked.

The owners of *patterns* should insure them against fire because the foundry, which has no insurable interest in the patterns, does not.

CONSTRUCTION OF CORE BOXES

Core boxes shall be assembled in a workmanlike manner with screws, no glue to be used except where unavoidable, interior construction to be fastened so that it can be removed. Small *core boxes* may be built up or made of solid material with wood or leather fillets. Medium size *core boxes* may be built up or assembled of ¼" to 2" stock.

Large size core boxes shall be built up or assembled of 2" stock; built-up core boxes and crates to be assembled on tongue-and-groove method and reinforced on bottom and sides with vertical and horizontal braces or cleats. Ends to be provided with vertical cleats to reinforce the tongue and groove.

Concentric and eccentric circular work to be built up with segments well glued and nailed.

Barrel-type circular *core boxes* to be built up on headers and staved and braced both laterally and longitudinally.

Core box surfaces not otherwise supported shall be braced with cleats.

All loose pieces shall be supported by dowels of differing sizes.

All core boxes to be made smaller than the core prints as follows: (Allowances to be made for length and width)	
Under 2 Inches	1/64" Clearance
3 Inches to 6 Inches	1/32" Clearance
7 Inches to 15 Inches	1/16" Clearance
16 Inches to 30 Inches	3/32" Clearance
31 Inches to 46 Inches	1/8" Clearance
47 Inches to 65 Inches	3/16" Clearance
66 Inches to 88 Inches	1/4" Clearance
89 Inches to 120 Inches	5/16" Clearance
Over 120 Inches	3/8" Clearance
Depth of *core box* to be pattern size	

Screw holes on working surfaces shall be countersunk and filled flush with a quick-hardening putty.

CORE LENGTH VS. DIAMETER

When the length of a core is more than twice its diameter, designers should allow for it to be fixed at both ends with core prints and these should be constructed as shown in the section entitled ***"CORE PRINT CONSTRUCTION"***.

ACCURACY

On small intricate work, a tolerance of 1/32 inches plus or minus is allowable.

On medium size work, a tolerance of 1/16 inches plus or minus is allowable.

On large size work, a tolerance of 1/8 inches plus or minus is allowable.

CORE PRINTS

This is the projection on the pattern for and anchoring the core. There are no fixed rules as to length to taper, but the following will serve as a guide:

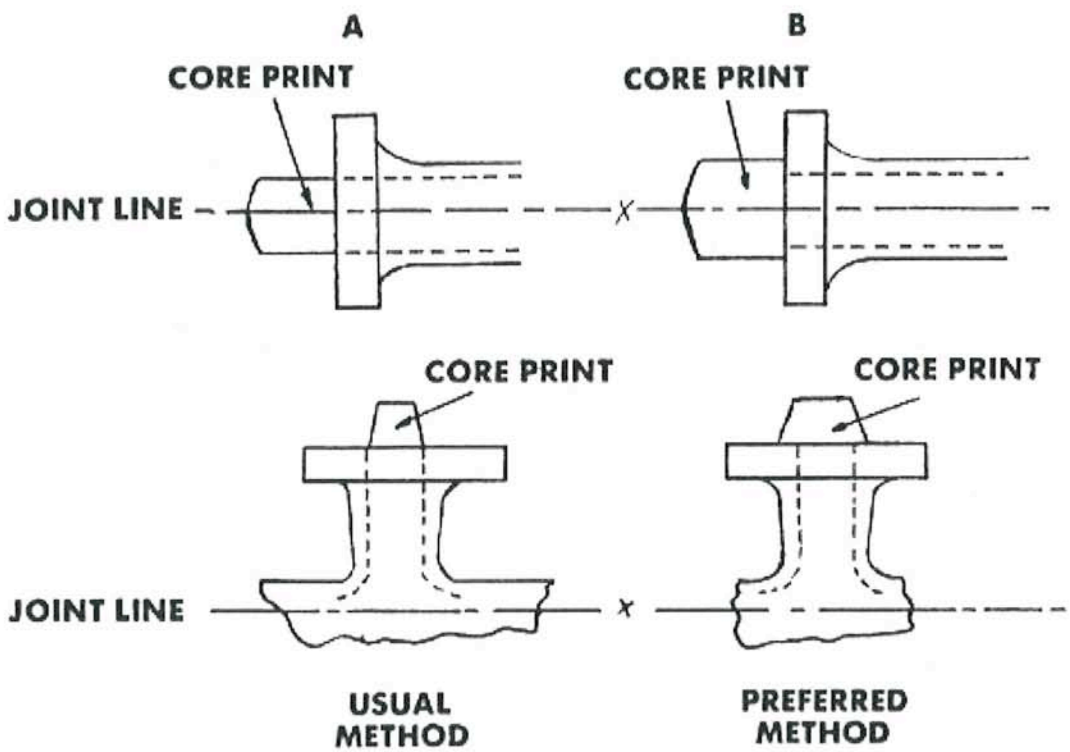
SIZE OF CORE	*LENGTH OF CORE PRINT*
Up to 1 1/2" diameter from 2" - 5"	At least equal to diameter of core print
Above 5" in diameter	6" core print (minimum)

Length of a core print should as a rule; be ample. The larger the core print, the better location and support in the mold.

CORE PRINT CONSTRUCTION

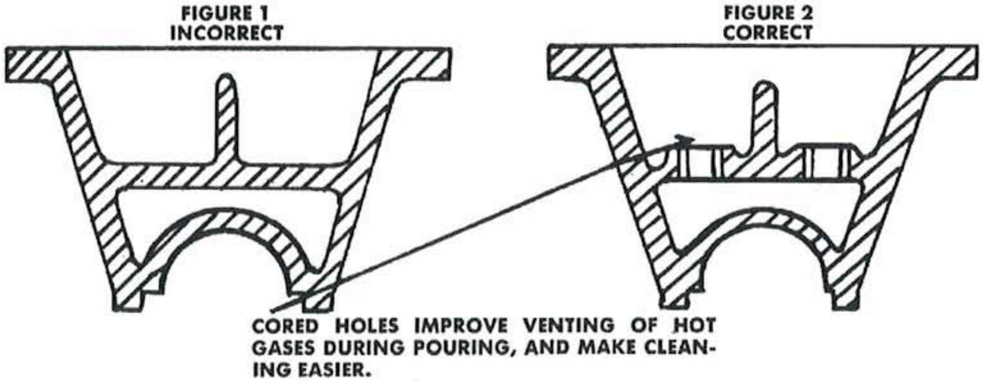
Where core prints can be tapered, that taper should be 1 ½" to the foot. Pattern-makers are apt to allow insufficient taper to core prints, with the result that in setting the core, sand is shaved off the mold, and loose sand is present in the casting.

Core prints should always have "tell-tales" on them so that it is impossible to reverse or set the core in the mold up-side-down. Even in such cases as it is possible after a short inspection to determine the proper setting of the cores, the prints should be constructed that it is impossible to set them otherwise than the proper way.



VENTING OF CORES
PROVIDE CLEAN-OUT HOLES

Venting of cores is important from a design standpoint. *Internal cores* require adequate provision for removing the gases generated when the *core* comes in contact with the molten metal. The designer must provide for the passage of this gas through one or more prints.



Interior cores which are nearly surrounded by metal should be provided with *clean-out holes.* A *cored hole* can be cleaned with minimum cost when:

A. The opening has an area proportionately large as compared with the thickness of the surrounding wall of metal;

B. The recess or hole is not of excessive depth as compared with outlets accessible for removing the core used to form it;

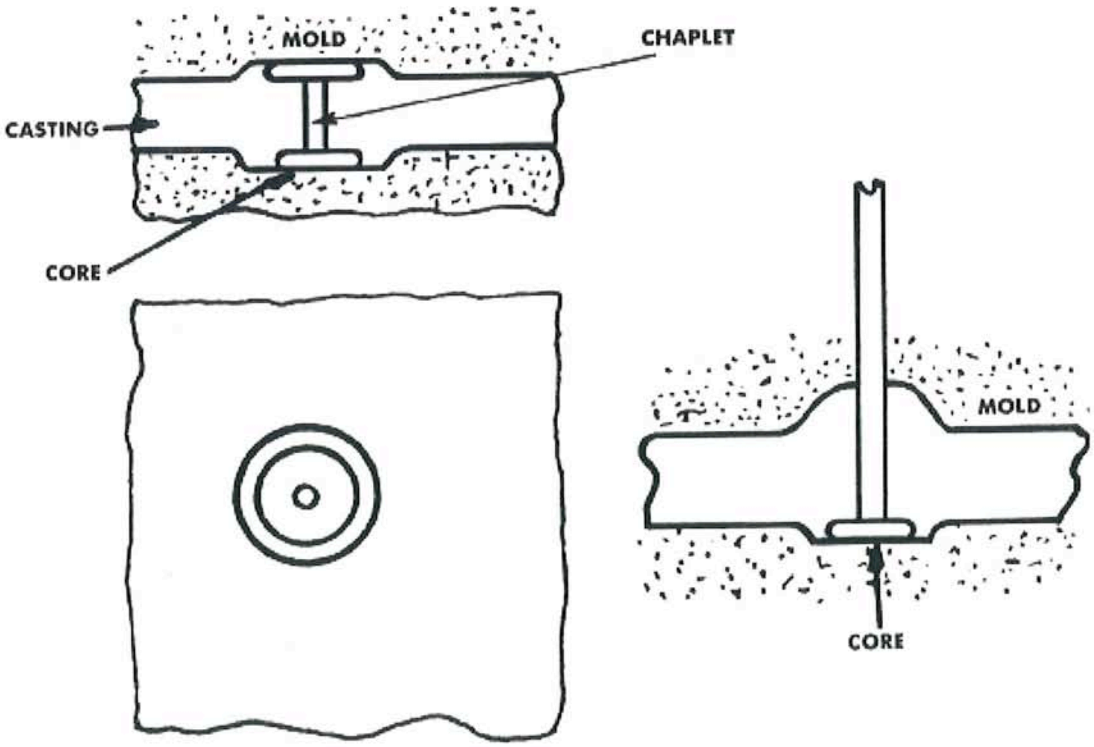
C. When the recess, or hole is long; it should be straight rather than curved.

CORED HOLES

1. Small *cored holes* may prove costly. Consult your foundryman.
2. No *core* smaller than 1" diameter. *Cores* for castings should not have a diameter less than the thickness of the wall they pierce.
3. *Cylindrical castings* - in the case of single bore castings and bushing stock, There may be no shrinkage in inside bore.
(See Machining Allowance for Cylinder Bores Section)

AVOID USING CHAPLETS

When the design is such that additional core support over and above that given by the core prints is needed, it is necessary to use *chaplets*, which are simply steel rods. When *chaplets* are used, design for local thickening so that the mass of metal is sufficient to fuse with *chaplet*, otherwise local defects result.



CHAPLET RODS

The use of *chaplets* should be avoided, particularly on pressure castings or liquid containers.

ALLOW FOR SHRINKAGE AND MACHINE FINISH IN DIMENSIONAL TOLERANCES

A rule sometimes applied is that dimensional tolerances should be approximately half the maximum shrinkage allowable for the type of metal involved. This rule does not hold in extremely large or in castings of complex design. Here some previous experience must be used to predict shrinkage.

As a result of close cooperation of designer and foundryman, special castings can be made to extremely close tolerances and with sufficient accuracy that no machining or finishing outside the Foundry is required. However, these call for special procedures and pattern changes according to findings from sample test castings.

Do not specify closer tolerances than are absolutely necessary; otherwise delay and misunderstanding may result.

CAST METAL SHRINKAGE ALLOWANCES
(Contraction in. per. ft.)

Gray Cast Iron	1/10 – 5/32	Gun Metal Bronze	1/8 – 3/16
White Cast Iron	1/4	Phosphor Bronze	1/8 – 3/16
Malleable Cast Iron	1/8 – 3/32	Aluminum Bronze	1/4
Meehanite Metals	1/8 – 1/10	Manganese Bronze	1/4
Aluminum Alloys	5/32	Open Hearth Steel	3/16
Magnesium Alloys	5/32	Electric Steel	1/4
Yellow Brass	5/32 – 3/16	High Manganese Steel	5/16

These figures are to be used with caution because most castings have several different shrinkage allowances according to their size, design complexity, relative mass of core vs. metal, varying metal thickness, nature of metal, temperature of pouring and mold material.

MACHINE FINISH ALLOWANCE

The allowance for machine finish depends on the following:

a. Type of metal used;

b. Design and size of castings;

c. Tendency to warp and machining method used.

In determining casting section thickness, the designer must also allow for pattern maker's shrinkage on machining dimension, e.g.

2¼" in rough. Therefore calculated strength of material must be based on 2¼" thickness of metal; but allowable stress must be for a 2" section.

Wherever possible, the casting should be designed in such a manner that surfaces to be machined or critical surfaces can be cast in the drag section of the mold. When there is no way to avoid castings such surfaces in the cope, an extra allowance for finish should be made. Allowances for finish are not covered by fixed rules because they involve many variables and should be agreed upon in conference with the foundryman.

The designer should keep in mind that the pattern shop must also allow for the finish machined surfaces and this may affect the strength and machinability to some degree.

DIMENSION OF CASTING	DRAG	COPE	APPROXIMATE TOLERANCE WHICH CAN BE EXPECTED FOR "AS CAST" DIMENSION SAND CASTINGS
Up to 8"	1/8"	5/32"	± 1/16"
Up to 14"	5/32"	3/16"	± 3/32"
Up to 18"	3/16"	1/4"	± 1/8"
Up to 24"	1/4"	5/16"	± 5/32"
Up to 30"	5/16'	7/16"	± 3/16"
Up to 36"	3/8" to 1/2"	5/8" to 3/4"	± 1/4"

MACHINING ALLOWANCES FOR CYLINDER BORES

This is most difficult to specify in a general way. Often a plain cylinder such as is cast for piston ring stock, or for a cylinder liner will contract a normal amount length-wise but there may be no contraction in the inside bore. This must be watched or the casting will not clean up in the bore.

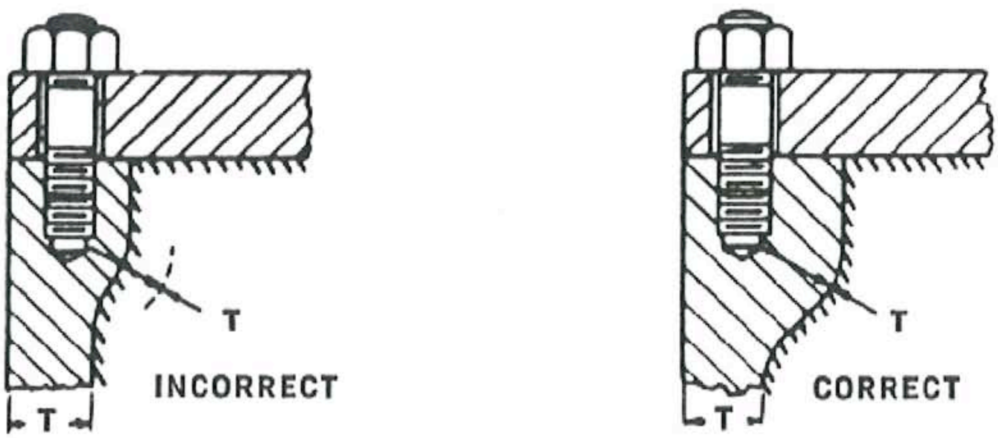
ALLOWANCES FOR MACHINING CYLINDERS OF SINGLE BORE *(Use rough guide only)*	
DIAMETER INCHES	RANGE OF ALLOWANCES IN INCHES
4"	0.12 – 0.2
4 – 8"	0.12 – 0.24
8 – 12"	0.2 – 0.32
12 – 20"	0.25 – 0.40

ALLOWANCES FOR MACHINING CYLINDERS OF MORE THAN ONE BORE *(Use rough guide only)*	
CYLINDER BORE DIAMETER INCHES	RANGE OF ALLOWANCES IN INCHES
8"	.16 – .24
8 – 12"	.2 – .28
12 – 20"	.24 – .32
20 – 32"	.24 – .40
32 – 48"	.32 – .47
48 – 71"	.40 – .55
71 – 102"	.4 – .65
102 – 150"	.55 – .65
150 – 215"	.7 – .8
Over 215"	.8 – .9

MAINTAIN CORRECT CASTING SECTION SIZE AFTER DRILLING OR MACHINING

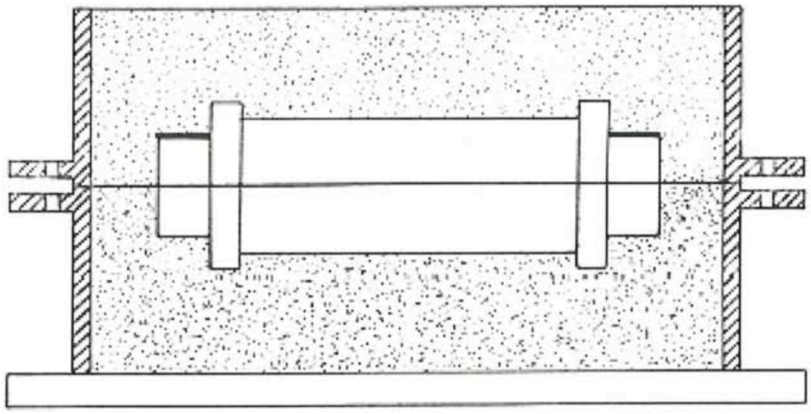
Casting section should not be reduced by drilled holes or machining.

An inserted stud cannot restore the effectiveness of the original metal section. Therefore, the wall section adjacent to drilled holes should be equivalent to the main body of the casting. (Pressure on shaded side)



MEEHANITE®

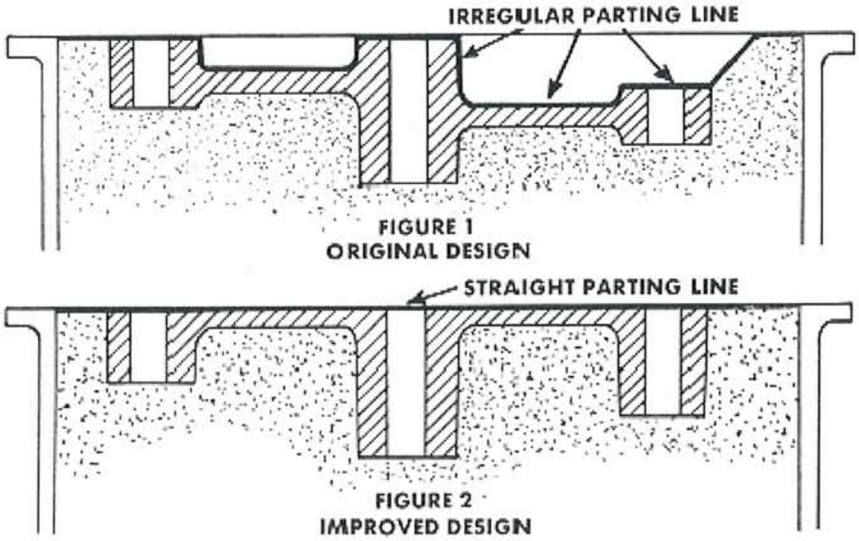
SPLIT PATTERN...STRAIGHT PARTING LINE



Possibly the first question the Foundryman asks on receiving a pattern is, *"Where is the parting line?"* Patterns with *straight parting lines*, that is, with *parting lines* in one plane, can be produced more easily and at a lower cost than those with *irregular parting lines.*

Casting shapes symmetrical about one center line or plane readily suggest the parting. Such casting design simplifies molding and coring, and should be used wherever possible.

DESIGN TO AVOID IRREGULAR PARTING



Designs necessitating the use of irregular parting involve more costly patterns, more skillful molding and the losses are always higher. By changing the design to a straight parting line, greater production is assured at lower cost.

Figure 1 shows a design which required *an irregular parting line*. By changing the design as shown in ***Figure 2***, substantial economies in production were achieved.

HORIZONTAL PARTING LINE PREFERRED

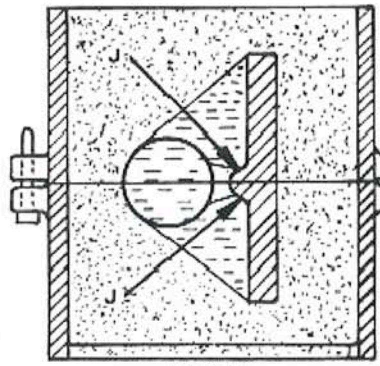


FIGURE 1

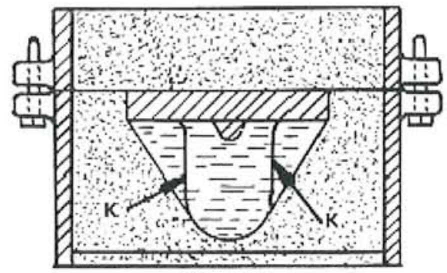


FIGURE 2

Shown above in ***Figure 1*** illustrates a design which permitted the use of a *straight parting line*. However, it was costly to manufacture because the *parting line* was vertical. By making a minor change in design at "J" to the form shown at "K" in ***Figure 2***, a *horizontal parting line* was made possible. This simplified molding and reduced cost of manufacture.

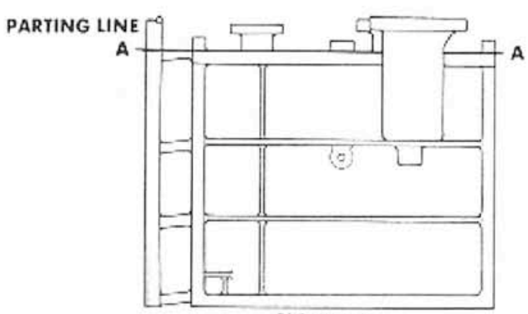


FIGURE A
PIT MOLDED

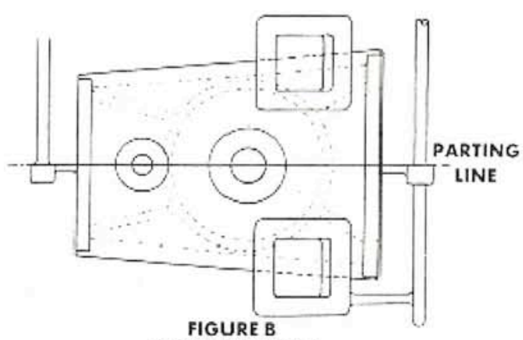


FIGURE B
FLASK MOLDING

Large cylinders are normally cast in a pit with the bore in a vertical position, as shown above in ***Figure A*** - using a *parting line* at A and A. Another foundry, experienced in flask molding, made the same casting and parted it in the center for machine molding, ***Figure B***. Both foundries produced good castings, but the latter was able to manufacture in production at a much lower cost.

DESIGN WITH ADEQUATE DRAFT

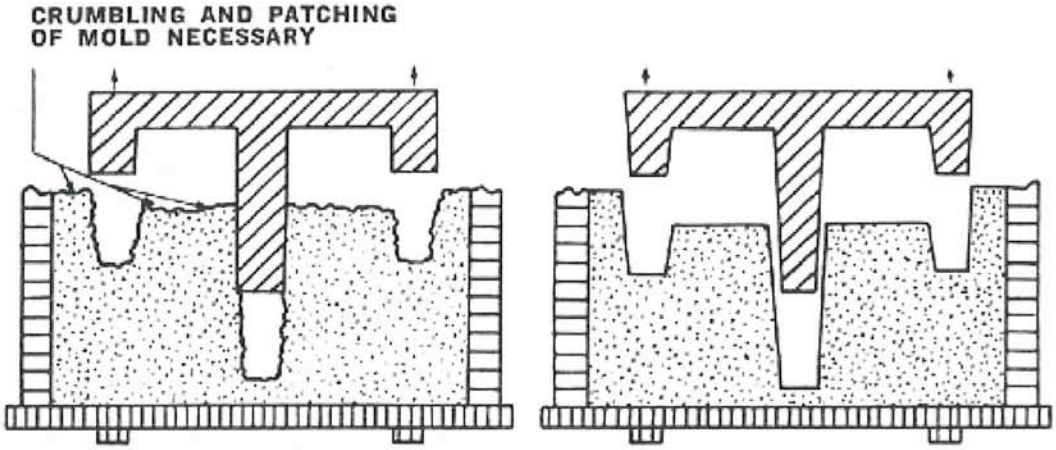
Draft is the amount of taper given to the sides of projections, pockets and the body of a pattern so as to permit withdrawal from the mold without breaking the sand away. Draft should be added to the design dimensions, but metal thickness must be maintained.

For general "one-off" purposes, an average draft equals 1/16" per foot.

The draft depends upon the depth of the pattern in the flask. The standard draft is 1:100 for heavy, bulky wooden patterns, which can be rapped. It amounts to 1:30 to 1:20 for patterns only which are to be drawn without rapping

If a draft of a ratio of 1:10 to 1:5 is admissible, such as foundation frames, eyes, etc., the larger one should be used at all times, as it is cheaper for the foundry. A suitable draft for stripping plates is 1:100.

Patterns that are cheaply constructed should not be expected to last, because they will not. Before the foundry is blamed for making poor castings, it might be well to have a look at the pattern. The foundry cannot make castings smoother and more true to the blue-print than the pattern.



POOR STRIPPING FROM THE MOLD RESULTS WHEN NO ALLOWANCE IS MADE FOR DRAFT AND PATTERN WILL BE HEAVILY RAPPED AND DAMAGED

AMPLE DRAFT PERMITS EASY AND SAFE STRIPPING, THE PATTERN WILL LAST MUCH LONGER

DESIGN TO SIMPLIFY MOLDING

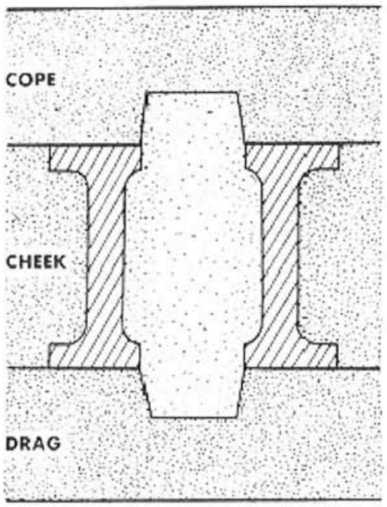


FIGURE 1

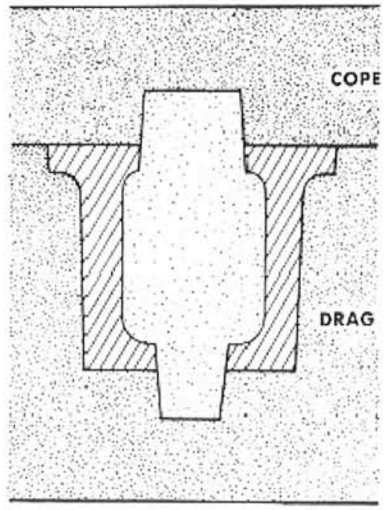
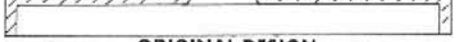
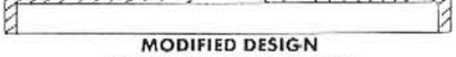


FIGURE 2

When designs become complex, molding problems increase. The casting shown in ***Figure 1*** typifies this problem. Here the casting involved the use of a three-part flask. The new design, as shown in ***Figure 2***, involving the use of only two flasks, simplified production and reduced molding costs by 35 percent. This cost reduction was made possible simply by omitting the outside flange at the base of the casting and extending it inward to give added strength to the casting.



ORIGINAL DESIGN
REQUIRED CORE TO FORM 11" DIA. SECTION



MODIFIED DESIGN
OUTER CORE ELIMINATED
COST OF MANUFACTURE REDUCED

AVOID OVERHANGING CORES

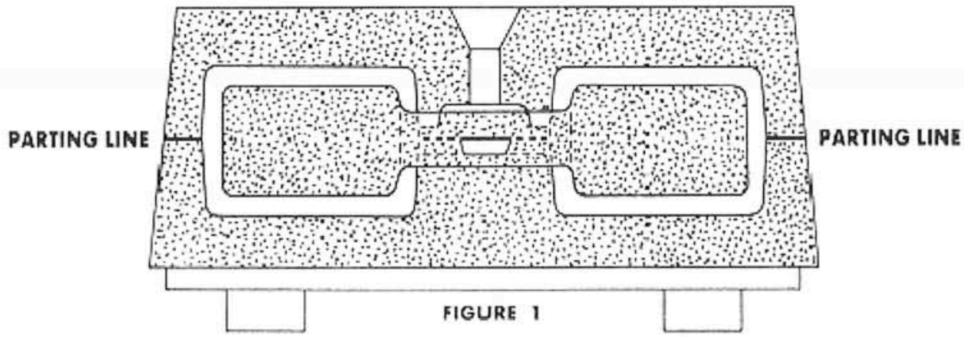


FIGURE 1

SHOWS HOW UNSUPPORTED CORE IS HELD IN POSITION BY BALANCING IN A SUBSTANTIAL PRINT. UNBALANCED OVERHANGING CORE REQUIRES LONGER PRINT FOR SUPPORT.

Overhanging cores, whether formed in green or core sand should be avoided at all times, if possible. They are difficult to be set in position and risky to hold when set. The practice of balancing *overhanging cores* by making two castings at opposite ends of the core, with substantial print between, materially reduces the risk involved.

METHOD OF MOLDING DETERMINES COST

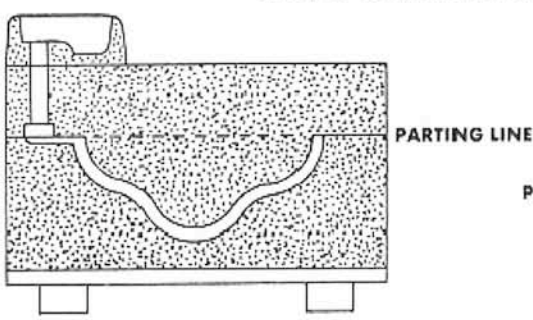


FIGURE 2

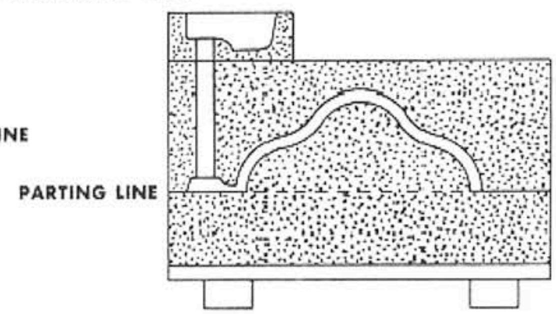


FIGURE 3

A simple type of casting having a deep pocket and showing two different methods of producing with a green sand core. The method shown by ***Figure 3*** is much faster than that shown by ***Figure 2***, since little securing or reinforcing would be required. However, the method shown by ***Figure 3*** would require a mounted pattern or follow board so time saved in molding would not be lost in arranging the pattern for this method. This procedure also presents less risk from sand drops but increases hazard of mis-runs and gas defects at dome section of casting.

AVOID UNDERCUTS...ELIMINATE LOOSE PIECES

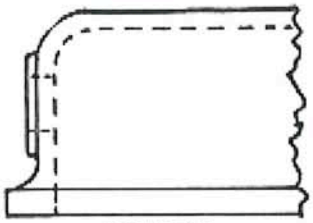


FIGURE 1
INCORRECT

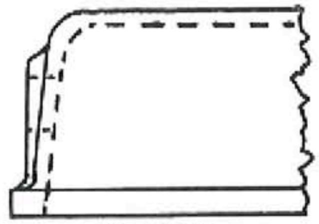


FIGURE 2
CORRECT

Loose pieces and outside cores should be dispensed with wherever possible. Undercuts, as shown by ***Figure 1,*** involve the use of loose pieced or the use of cores. These increase costs and often serve no particular advantage. By eliminating the *undercut* as shown in ***Figure 2***, a much simpler and less costly molding procedure results.

OMIT OUTSIDE RIBS

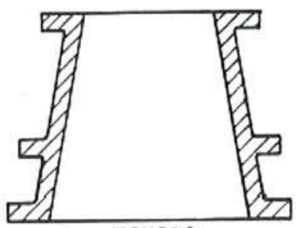


FIGURE 3
INCORRECT
OUTSIDE CORES

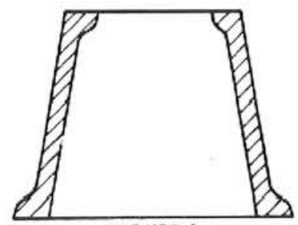


FIGURE 4
CORRECT
NO CORES

The unnecessary use of *ribs, lugs* and *bosses* increases costs. Often times, the engineer will place *circular ribs* around the outside of a casting to give strength and to obtain a lighter structure as shown in ***Figure 3***. In this case, the extra moldings is justified, but more often than not, such ribbing may be dispensed with to achieve molding cost reductions of 50 percent or more as shown in ***Figure 4.***

OMIT OUTSIDE BOSSES

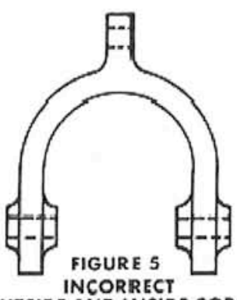


FIGURE 5
INCORRECT
OUTSIDE AND INSIDE CORES

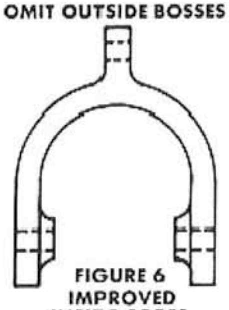


FIGURE 6
IMPROVED
INSIDE CORES

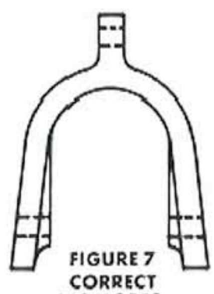


FIGURE 7
CORRECT
NO CORES

Outside bosses require coring or use of loose pieces. Such designs as shown in ***Figure 5*** increase molding costs. Pattern and molding costs can be reduced by omitting the *outside bosses* and leaving inside boss which requires only a center core, ***Figure 6***. The design, shown in ***Figure 7***, is best in that it permits a straight draft and does not require the use of any cores or loose pieces.

DESIGN FOR UNIFORMITY OF SECTION AND STRAIGHT DRAFT

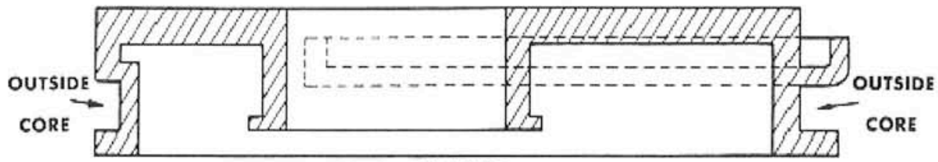


FIGURE 1
INCORRECT

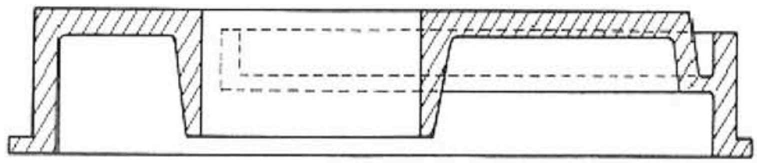


FIGURE 2
CORRECT

Castings of uniform section and of correct draft are lighter, stronger and cost less. ***Figure 1*** shows a design in which the base was of varying thickness. It gave trouble on casting. Molding was costly and complicated by the necessity of using outside cores. As redesigned ***Figure 2*** the casting was of uniform thickness, weighed less, and was stronger; a saving of 30 percent in pattern-making and molding costs resulted.

USE AS FEW CORES AS POSSIBLE...DECREASES COSTS

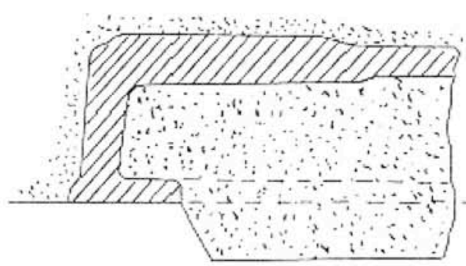


FIGURE 3
INCORRECT

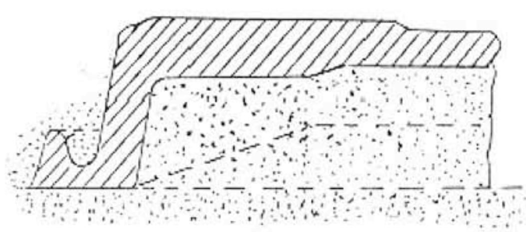


FIGURE 4
CORRECT

Cores are masses of sand placed or created in the mold to form cavities in the casting at desired locations. *Cores* add expense and increase cleaning costs. Castings which can be molded to leave their own *cores* are cheaper to make. Often a two-piece design will permit this. ***Figure 3*** shows a base plate where the original design was complicated and involved the use of *cores*. ***Figure 4*** shows how by a slight design change, *cores* were eliminated, thereby, simplifying molding and reducing costs.

DESIGN TO FACILITATE MACHINING

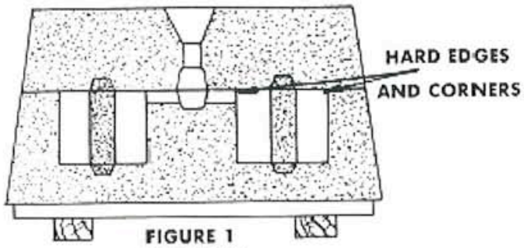


FIGURE 1
INCORRECT

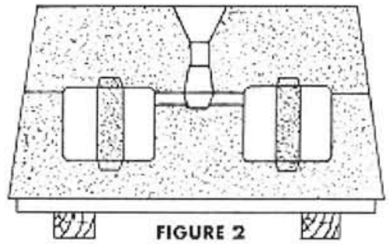


FIGURE 2
CORRECT

Castings designed with sharp angles or edges are a common source of machine shop trouble. This is caused by the faster cooling of the corner section at the joint and is accentuated by the presence of a fin or flash (***Figure 1***).

By rounding edges and corners sufficient to eliminate chilling (***Figure 2***), the risk of hard corners or edges is avoided, and in turn, machine shop costs are reduced. Where this is done, the parting should be made to permit all corners and edges to be rounded.

DESIGN TO REDUCE WEIGHT

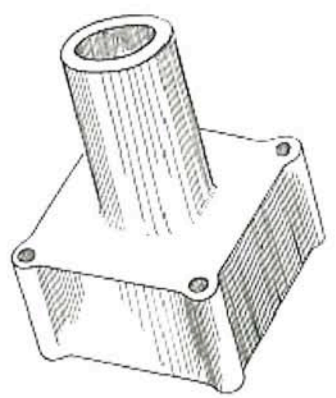


FIGURE 3
ORIGINAL CASTING WEIGHT
3,150 LBS.

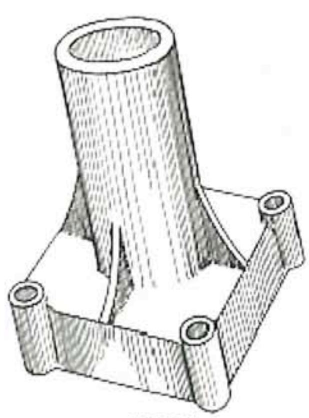


FIGURE 4
REDESIGNED MEEHANITE
WEIGHT 2,100 LBS.

Heavy casting sections, excessive section changes, and sharp angles often reduce the strength of a casting rather than increase it. The Hydraulic Ram Head shown in ***Figure 3*** as originally designed weighed 3,150 pounds. It was redesigned to obtain uniform section and was made in "Type GA" Meehanite metal. The weight was reduced to 2,100 pounds, and a sound and stronger casting was obtained. (***See Figure 4***).

GATING

This defines the means whereby the molten metal is introduced into the mold, which is called the "gate". It is of first importance that consideration be given to what happens to the molten metal as it follows a prescribed path in both entering and filling the mold. A well-designed gating system plays an important part in:

1. Determining uniformity or otherwise of the physical properties throughout the whole casting.
2. Eliminating structural weakness.
3. Reducing or eliminating casting strains.
4. Reducing or preventing warping and cracking.
5. Reducing defective castings.
6. Influencing total cost of manufacture.
7. Machining cost.

A correctly designed gating system should take care of:

1. Ratio of ingates to runner bar to downsprue.
2. Trap dirt.
3. Insure uniform distribution of heat.
4. Controlled speed of pour.

The gating system should always be included and permanently attached to pattern if possible; except in very large castings, which requires the use of bottom tile gates to achieve quality castings. Mounting patterns facilitates permanent gating and is always the most successful and also provides the best quality.

Gates should be distributed to avoid local heating and to assure uniform solidification conditions.

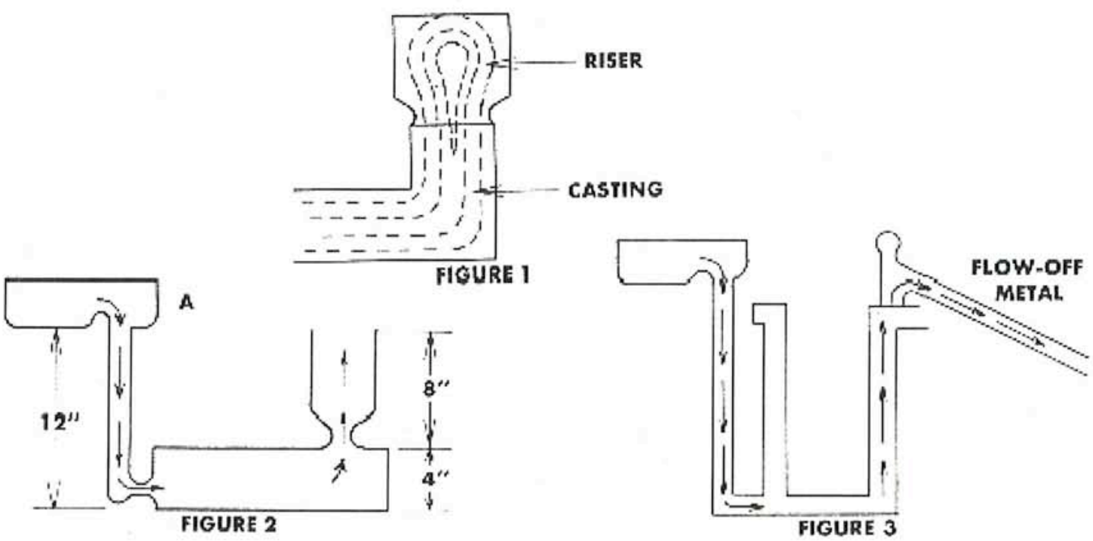
RISERS

Risers serve three purposes:

1. To supply liquid metal to the casting as it shrinks in volume during solidification, ***Figure 1***.

2. To relieve gas pressure in the mold and to reduce pressure upon the lifting surfaces of the mold, ***Figure 2***. Open riser allows gas to vent from mold cavity as it is displaced by the entering iron.

3. For "flow-off" purposes to equalize, the temperature in the mold and to avoid casting strain, or to wash out slag or dirt, ***Figure 3***.

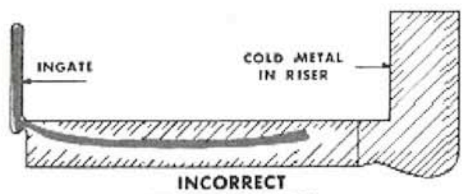


MEEHANITE®

USE INSCRIBED CIRCLE METHOD TO ILLUSTRATE THE SECTION WHICH MUST BE FED

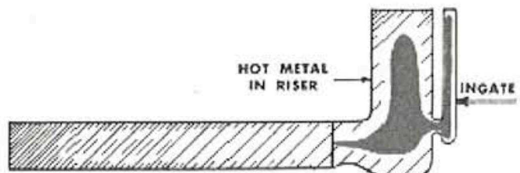
The most important function of a RISER is to supply molten feed metal to the shrink

FIG. 1



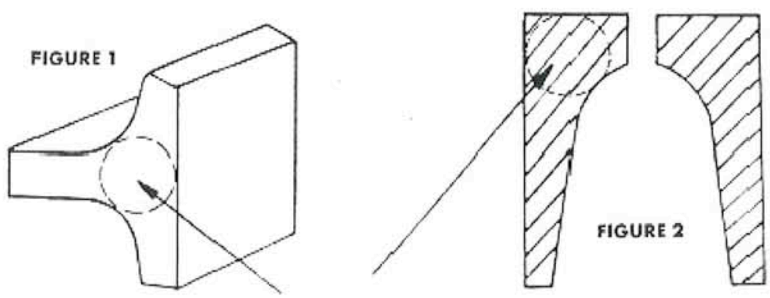
INCORRECT
COLD METAL IN RISER
CAUSING SHRINK DEFECT

FIG. 2



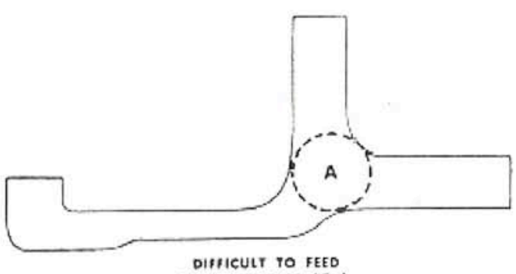
CORRECT
GATE INTO RISER TO SECURE
HOT METAL IN RISER

Example: Take the diameter of the largest section of the casting and drawing a circle shown by dotted lines in ***Figures 1 & 2***. This represents the section of the casting to which to feed metal must be supplied; otherwise a shrink defect will result.

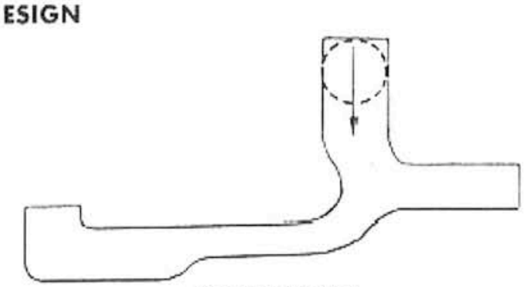


IMAGINARY SPHERE
DIAMETER OF IMAGINARY SPHERE = CASTING SECTION

HUB DESIGN



DIFFICULT TO FEED
SHRINK DEFECT AT A



BY DESIGN CHANGE
HEAVIEST SECTION HAS BEEN
RAISED TO PERMIT DIRECT
FEEDING.

TYPICAL MECHANICAL AND PHYSICAL PROPERTIES OF MEEHANITE METAL

Nodular Graphite

Types	SP-80	SH-100	SF-60	AQS
Tensile Strength — psi	80/100,000	100/170,000	>60,000	80/180,000
Yield Strength — psi	60/75,000	70/130,000	>45,000	70/140,000
Modulus of Elasticity (tension) EX 10^6	25	24	23	25
Elongation %	3% — 10%	1% — 5%	15% — 25%	1% — 3%
Endurance Limit (unnotched)	39,000	43,000	30,000	53,000
Endurance Ratio (unnotched) (45° notch)	0.49 0.35	0.33 0.25	0.50 0.35	0.33
Poisson's Ratio	0.37	0.37	0.32	
Brinell Hardness (Approx.)	200	240/600	up to 160	225/500
Impact Strength — Charpy Ft. lbs. 10 m m Square bar "V" notch	1-5	1-3	7-15	1-3
Specific Gravity	7.20	7.22	7.18	
Solid Contraction	5/32" per ft.	5/32" per ft.	5/32" per ft.	5/32" per ft.
Patternmaker's Shrinkage	1.3%	1.3%	1.3%	1.3%
Specifications Met	ASTM-A536-70 MIL-1-11466(A) ASM #5316	MIL-1-11466(A) ASTM-A536-70	ASTM-A339-55 MIL-1-11466(A) MIL-1-17166 Ships AMS #5315 ASTM A395-70 ASTM-A536-70	

Flake Graphite

Types	AQ	GM-60	GA-50	GC-40	GE-30	GF-20
Tensile Strength — psi	50/65,000	55,000	50,000	40,000	30,000	20,000
Proportional Limit — psi .01% permanent set	25,000	25,000	20,000	14,500	11,500	9,500
Modulus of Elasticity — psi	22,000,000	21,500,000	20,000,000	16,500,000	13,000,000	9,000,000
Modulus of Rigidity — psi	9,500,000	9,500,000	8,750,000	7,250,000	5,500,000	4,000,000
Poisson's Ratio	0.33	0.33	0.32	0.30	0.27	0.24
Modulus of Rupture — psi	93,000	93,000	90,000	80,000	61,000	41,000
Compression Strength — psi	200,000	200,000	180,000	150,000	120,000	90,000
Fatigue Strength — psi	30,000	25,000	22,000	17,500	13,500	11,000
Shear Strength — psi		53,000	50,000	40,000	30,000	21,550
Single Impact — Izod .798" Dia. Unnotched Bar	30-40	30-40	25-35	12-20	6-12	4-9
Brinell Hardness (Approx.)	280-550	> 230	> 220	190	180	160
Machinability Rating (Dalcher)	52	50	48	47	38	30
Thermal Conductivity 50-450°F. BTU/Hr/Sq. Ft./Inch Thickness/°F		355	350	325	290	—
Coefficient of Thermal Expansion Per °F. from 100° to 1000°F.	.00000675	.00000705	.00000720	.00000760	.00000790	—
Specific Gravity	7.34	7.34	7.31	7.25	7.06	6.80
Solid Contraction	5/32"-6/32" per ft.	5/32"-6/32" per ft.	5/32"-6/32" per ft.	4/32"-5/32" per ft.	1/10"-1/8" per ft.	1/10"
Patternmaker's Shrinkage	(1.3-1.5%)	(1.3-1.5%)	(1.3-1.5%)	(1.0-1.3%)	(0.8-1.0%)	(0.8%)

ABRASION RESISTING MEEHANITE®

Almanite Type	W1	W2	W4	WS	WSH
Tensile Strength — psi	50/60,000	50/60,000	60/80,000	60/80,000	>100,000
Yield Strength — psi				50/65,000	75,000
Modules of Elasticity — psi	26,000,000	26,000,000		24,000,000	24,000,000
Elongation %				2-4	4-10
Brinell Hardness	500/600	500-600	400/700	400/525	350/500
Izod Impact 1.2" bar unnotched ft. lbs.	30-50	40-60	40-70	up to 180	up to 120

HEAT RESISTING MEEHANITE®

Type	HS	HSV	HR	HE
Tensile strength — psi	60/100,000	100/120,000	40,000	25,000
Modules of Elasticity — psi	23,000,000	50/80,000,000	21,000,000	14,000,000
Elongation %	2-10	2-10		
Brinell Hardness (Min.)	200	200	300 or over	170
Thermal Conductivity 50°/450°F. BTU/Hr./Sq. Ft./Inch Thickness		278	360	298
Coefficient of Thermal Expansion Per °F from 100° to 1000°F	.00000700	.00000674	.00000743	.00000666

CORROSION RESISTING MEEHANITE®

Type	CC	CR	CRS
Tensile Strength — psi	40,000	25,000	58,000
Brinell Hardness	200	131/183	139/202
Elongation %			6-20

SIZE AND WEIGHT TOLERANCE

A size and weight tolerance may be negotiated between a buyer and producer, because it has significance in relation to both the cost and the quality of the product.

While machining stock is a separate consideration, inspection of size and weight tolerance is necessary because of:

A. Distortion that affect the position of locating points and may fall outside normal machine allowance.

B. Swells that affect internal solidity.

C. Excess stock as it affects unit price.

D. Stock deficiencies as it affects the strength of certain sections.

E. Overall dimension as it affects assemblies.

In establishing specifications the following factors should be considered:

1. A weight tolerance cannot be applied to castings of over 1000 lbs unless they are mounted or unless as experience has been built up from pilot castings. Dimensional tolerances are valid, however, as agreed upon by purchaser and manufacturer.

2. Weight tolerances on mounted production castings may be made by making a random sampling or prototype casting followed by a statistical study of standard deviations, in accordance with recommended practice A.S.T.M. designations E122, E105 and E141.

3. The tolerance given below are to be expected for castings made from mounted patterns in jolt squeezer and match-plate molding process:

Max. Horizontal Casting dimension	Max. Deviation From Drawing	Max. Cross joint Error
Up to 2"	-.04 plus .06"	-0 plus .06"
2 to 4"	- .06 plus .08"	-0 plus .08"
4 to 8"	- .06 plus .10"	-.04 plus .10"
8 to 16"	- .06 plus .125"	-.06 plus .125"
16 to 24"	- .06 plus .18"	-.06 plus .18"
Over 24"	As agreed with customer	

4. Meehanite normals for dimensional accuracy, machine molding cope and drag method

Max. Horizontal Casting dimension	Max. Deviation From Drawing	Max. Cross joint Error
Up to 2"	± .04"	-0 plus .04"
2 to 4"	± .06"	-0 plus .06"
4 to 8"	± .08"	-.04 plus .08"
8 to 16"	± .10"	-.04 plus .10"
16 to 24"	± .14"	-.06 plus .16"
32 to 48"	± .25"	-.08 plus .25"
Over 48"	As agreed with customer	

5. Special molding techniques may be arranged to get accuracies up to the following:

Max. Horizontal Casting dimension	Max. Deviation From Drawing	Max. Cross joint Error
Up to 2"	± .020"	.020"
2 to 4"	± .040"	.040"
4 to 8"	± .060"	.060"
8 to 16"	± .080"	.080"
16 to 24"	± .110"	.110"
32 to 64"	± .170"	.170"
Over 64"	As agreed with customer	

In larger massive castings full agreement on tolerance between customer and producer before placement of the order is suggested.

MACHINING ALLOWANCE

Machining allowance is like a factor of safety in engineering design. It is a blanket covering a number of uncertainties and imponderables in the manufacture of a casting. Some of these are as follows:

1. Casting roughness
2. Surface defects that may accrue
3. Inaccuracy of a pattern
4. Inaccuracy of the molding method
5. Inaccuracy of cores and the settings thereof
6. Change in mold dimension during casting
7. Deviations from normal pattern makers shrinkage during cooling
8. Strain

While one looks at the complete list, one might wonder if it is possible to get a casting which can compete successfully with other types of fabrication. Reducing these uncertainties, one by one, has enabled the foundry to maintain its position and even increase it where design is in its favor. For example, it is seldom that every single dimension of a rough casting is of equal importance so a certain amount of selectivity is possible in making the pattern and using it in the foundry.

It is quite important that all locating points be clearly delineated on drawings of castings that are to be machined by automatic methods.

TYPICAL MACHINE FINISH

Allowances (over and above allowance for draft and solid contraction) usually have to be provided for on a pattern. A rough guide to general castings is shown in the following table:

DIMENSION	DRAG	COPE
Up to 8"	1/8"	5/32"
Up to 14"	5/32"	3/16"
Up to 18"	3/16"	1/4"
Up to 24"	1/4"	5/16"
Up to 30"	5/16'	7/16'
Up to 36"	3/8" – 1/2"	5/8" – 3/4"

Using this as a starting point, refinements in the foundry technique may enable a reduction in machine finish.

With recent innovations in molding techniques, it should be quite possible to narrow present tolerances so that heavy plaining cuts are unnecessary.

a. Changing from a conventional green molding sand rammed to 50-70 mold hardness to a machine molded green sand rammed to 90 hardness can reduce finish and increase accuracy in the smaller sizes.

b. Cope and drag molding is more accurate than squeezer molding. Well vented metal flasks and bottom plates with machined joints or parting lines eliminates many of the uncertainties that result in extra finish.

c. No Bake molding will provide the best dimensional accuracy and consistency and this may permit a lesser amount of finish allowance.

A plain cylinder will show normal pattern makers shrinkage is its length, but might show none across its diameter. If this is not guarded against, the bore may not clean up.

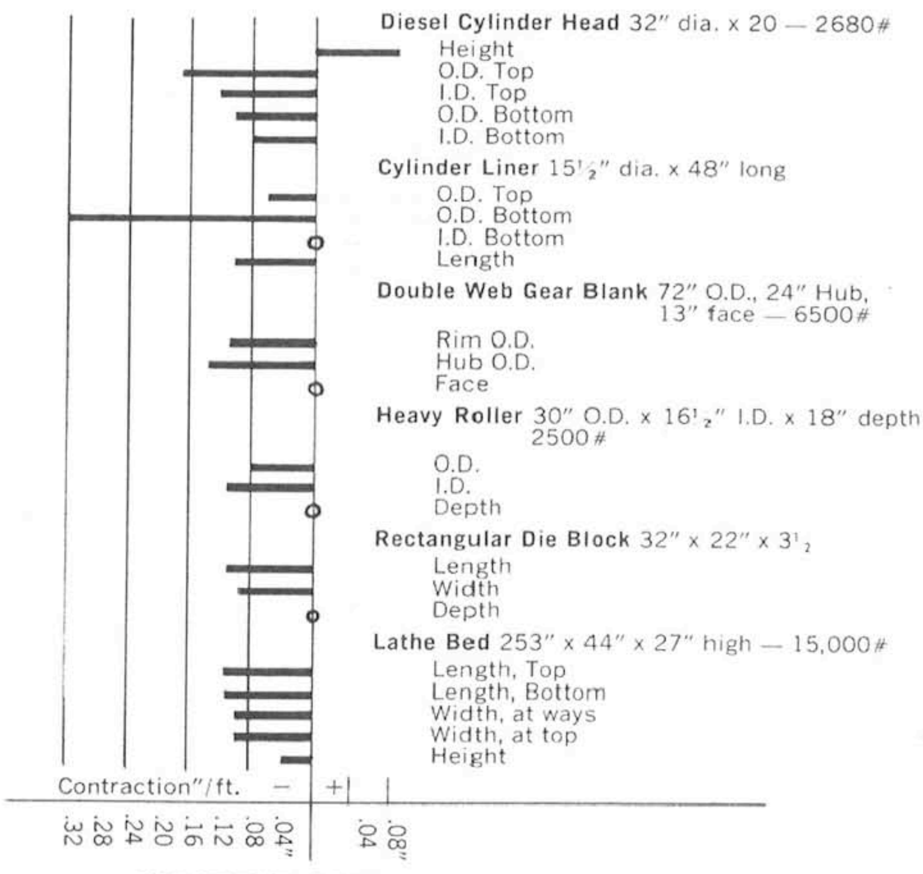
Likewise, a die recess may show no contraction whereas the punch will show normal contraction.

TYPICAL ALLOWANCES IN CYLINDER BORES

DIAMETER	SINGLE BORE	MORE THAN ONE BORE
4"	.12 – .20"	
4" – 8"	.12 – .24"	.16 – .24"
8" – 12"	.20 – .32"	.20 – .28"
12" – 20"	.25 – .40"	.24 – .32"

Uneven distribution if ingates can cause uneven cooling and distortions that prevents certain areas from cleaning up. The obvious results of shaking out too hot or rough handling while hot, is sometimes overlooked.

With careful planning and cooperation between designer, pattern maker and foundryman, machining finish can be held to a minimum. Detailed study is necessary. Below is a chart which illustrates the variations in *apparent* shrinkage of various shapes in conventional molding. In all cases, the normal shrinkage of the iron by Keep test was 1/8" - 5/32".



APPARENT SHRINKAGE AND VARIOUS SHAPES

DIMENSIONAL STABILITY

Dimensional stability is a relative term, i.e., relative to the degree of precision required in a certain machine or casting. For example, in an optical machine, a movement of .0001" may be unsuitable while in a less demanding application; a movement of 1/8" may be tolerated. The vast majority of precision machines rely for their stability on the castings used in their construction. Stability is a complex phenomenon influenced by numerous independent factors, among which the following are the most important:

1. Metallurgical characteristics of the cast material
2. Design of the individual castings
3. Production techniques
4. Heat treatment
5. Machining operations carried out on the casting
6. Service conditions imposed on the casting

The extreme stability of Meehanite metal properly made, properly heat treated, and poured into properly designed castings can be demonstrated by the following table. In this case, the casting design variable was practically eliminated by using a standard round test bar:

TREATMENT OF BAR	LENGTH OF TIME	CHANGE IN LENGTH
As-cast	120 weeks	-0.000004 in/in.
Stress relief 950°F – 4 hours	86 weeks	-0.000003 in/in.
Oil quenched from 1600 °F	90 weeks	-0.000151 in/in.
Oil quenched and tempered at 400°F	90 weeks	+0.000001 in/in.

Notice that in all cases, except when the bar was quenched and then not tempered, the stability of the Meehanite metal bar is satisfactory for even the most exacting requirements.

Unfortunately, once the variable of design is introduced, then it is found that the stability of the metal is changed. For example, in studies on a "U" shaped casting, 10" long with a 1" section size, it was found that after 52 weeks, the change in dimensions were as follows:

As-cast	plus	0.0003in. / in.
Stress Relieved	minus	0.0001 in. / in.

When these "U" shaped castings were machined along one face, there was a change in dimension occurring within 3 days of the machining operation. This amounted to between +0.004 in. / in. and +0.005 in. / in. in the as-cast pieces, and -0.0003 in. / in. in the stress relieved casting. Here we see the advantage of stress relieving prior to machining on stability. This investigation also showed that the total distortion is only slightly changed by the amount of metal that is removed, with the major movement taking place when the skin is first broken.

Casting design is perhaps the largest contributing factor to distortion. Uneven cooling rates, due to variation in section thickness, can result in abnormal stresses in the as-cast part. On subsequent heat treatment these uneven sections will make the removal of stresses difficult, if not impossible, by preventing uniform cooling of the casting.

Stress relief can certainly remove some of the stresses in a casting, but since any stress relief is, at best, only 90% effective, two stress relief treatments are the minimum that will be satisfactory for the most critical jobs. The three most important rules for effective stress relief are:

1. Support the casting in a stress free position.

2. Hold the casting at temperature at least 4 to 6 hours.

3. Heat and cool at a rate not to exceed 100 F./hour, or 400 F. divided by the section thickness in inches.

The degree of care necessary during stress relief is proportional to the degree of stability required. While stress relief is frequently specified in critical castings, the stress relief procedure, itself, is seldom outlined. The possible causes for faulty stress relief are too numerous to be covered in this publication, and it is suggested, that the "Quality Talks" on "Stress Relief" be consulted.

In almost every case where instability has been experienced in hardened castings, the hardening has either not been followed by a tempering operation, or only by an inadequate tempering cycle. When a casting is quenched, it is recommended that the casting be removed from the quenching medium while still in the region of 300°F. to 400°F. and transferred to the tempering furnace. Where maximum hardness is required; six (6) hours at 300°F. has shown to give more complete stress relief, than two (2) hours at 400°F. If through hardening is not required, then flame hardening is recommended as it will introduce only minor stresses during heat treatment.

Further cases of distortion are machining, particularly grinding, and cleaning by shot blasting. Careless grinding that causes over-heating has been shown to be responsible for distortion. Unfortunately, the distortion may not be immediately evident, usually occurring over a period of 3 to 7 days. This in itself is an argument in favor of aging, which was the only type of stress relief used years ago in the gray iron industry. Aging is returning to popularity among manufacturers of equipment requiring high dimensional stability.

A typical treatment involves allowing the casting to sit 3 to 7 days in between operations. While the aging time may not always seem available, it is definitely better to take the time during manufacture than have to remake the part if it distorts following completion.

Shot blasting; whether done by the foundry in its initial cleaning operation or by the heat treater to remove scale, can definitely cause distortion, especially if steel shot is used. Where stability is a requirement sand blasting is the only type of blasting that should be used.