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Import Considerations When Selecting ASTM A48 Gray Iron

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Introduction
Despite all the improvements made within the field of casting technologies, gray cast iron products are still shipped throughout the world that are of poor quality or improperly designed. This may be due to poor foundry practices, or simply because basic knowledge necessary to good design is unknown. There also appears to be some lack of understanding regarding the correlation of mechanical properties between separately cast test bars and those found in the related castings. These differences in properties may be unknown, misunderstood, overlooked, or simply ignored when arriving at suitable design safety factors.

When castings are produced and test bars are poured from the same heat of metal, the composition and inoculation of both should be the same. However, the tensile strengths are usually different due to differences in geometry and cooling rates. This is particularly true if the casting geometry is complex, and means that a casting certified to a particular class iron may have tensile strength less than what's required in the casting. As a result, it is difficult to predict the strength in castings from a test bar, unless the supplier or design engineer has performed studies to establish the strength correlation.

Common Misunderstandings
The ASTM A48[1] gray iron specification is often misinterpreted, and creates problems for users and suppliers alike. Many foundries that produce quality iron castings and certify them to ASTM A48, at one time or another have been involved in disputes with customers who assume the strength in their castings will conform to the specified tensile requirements represented by a test bar. The specification requires that a test bar *(size must be specified by buyer)* be used to evaluate the quality of the iron. The iron used to produce the castings is assumed to meet the design requirement, provided the properties in the test bar are met. Customers performing routine quality audits are surprised to discover casting strength falling short of the certified strength. The problem is not with the supplier or the ASTM standard, but with how the standard is used and how engineering requirements are communicated.

One may question; "Is the tensile test made from a separately cast test specimen a useful and reliable test?" The answer is yes! The test bar represents the properties of the metal and its heat treatment (when applicable). Since these tests measure melt quality from heat to heat, it is a judge of a supplier's consistency of practice. As a standardized test, it can be used to compare different grades or compositions and evaluate different supply sources.

However, since the results of a separately cast test bar cannot be assumed to be equivalent to those of the castings represented, serious problems can be encountered if castings are designed and inspected on this basis alone. Whether design safety factors are sufficient to avoid service failures or whether they are excessive is difficult to determine without more accurate knowledge of the properties developed in the casting. For critical applications this should be established, and not left to chance or assumption. Materials testing should be made directly from a representative casting or suitable coupon attachment that more accurately represents the casting conditions. It is up to the product design engineer to establish the suitability of a specific class of iron for a particular geometry.

Closer Review Is Needed
The term "gray cast iron" covers a wide range of iron-carbon-silicon alloys. While the metallurgy of cast iron is very complex and influenced by many factors, the mechanical properties in gray iron castings are controlled primarily by three main variables:

- ☐ Base chemistry
- ☐ Inoculation practice
- ☐ Solidification and cooling rate

While most specifications for castings specify chemical composition requirements, the ASTM A48 iron specification subordinates chemical composition to tensile strength. Castings are classified on the basis of tensile strength in separately cast test bars designed to standardize cooling rate, unless otherwise specified. The specification describes how to conduct a tensile test with regard to the mold materials, the mold design and its gating system, the tensile test bar size in relation to the size of the casting, and the testing frequency.

The required test frequency is a problem of which many suppliers and buyers either aren't aware or ignore. The specification requires a tensile test for each cast lot. A lot is described as:

- ☐ a single heat of metal from a batch furnace
- ☐ two or more batch melts in a single ladle or casting
- ☐ all metal poured from a continuous melting furnace between changes in charge, processing conditions, or aim chemistry or 4 hours, whichever is the shorter period

If requirements are followed many suppliers will realize they are not testing their iron as frequently as the standard requires. In addition buyers may also be reluctant to pay for all the testing required by strictly following the ASTM A48 definition of a lot. Generally a reduced testing frequency can be agreed upon, based on the supplier's historical melt data and standard practices.

Of greater concern are the misunderstandings surrounding what the tensile test bar actually represents. The **ASTM A48 APPENDIX "X1.**

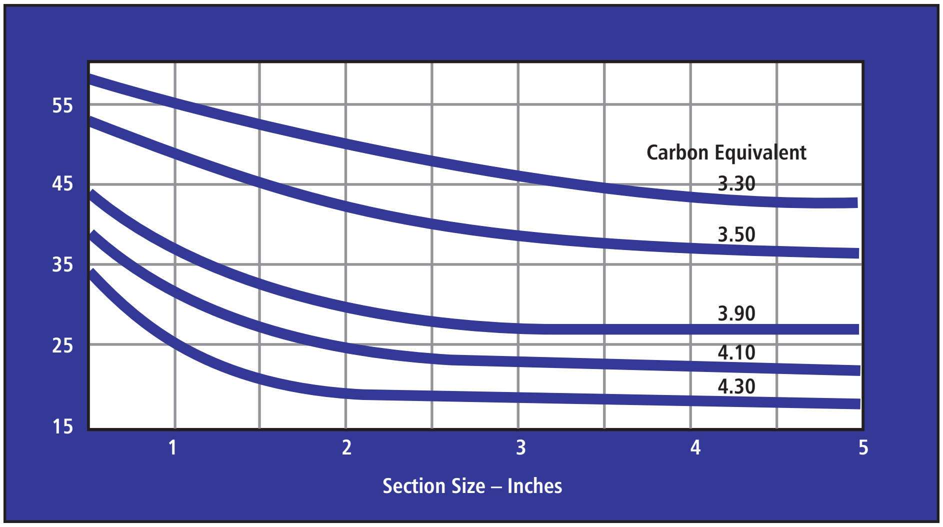

Figure 1. The influence of carbon equivalent on the maintenance of tensile strength with increasing casting thickness in gray iron. [2]

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MECHANICAL PROPERTIES OF CASTINGS" [1] addresses the major differences between mechanical properties in a casting and those in a separately cast test specimen. The following is taken from that APPENDIX and should be closely reviewed by all specifying this material:

X1.1 *"The mechanical properties of iron castings are influenced by the cooling rate during and after solidification, by chemical composition (particularly carbon equivalent), by the design of the casting, by the design and nature of the mold, by the location and effectiveness of gates and risers, and by certain other factors."*

X1.2 *"The cooling rate in the mold and, hence, the properties developed in any particular section are influenced by the presence of cores; chills and chaplets; changes in section thickness; and the existence of bosses, projections, and intersections, such as junctions of ribs and bosses. Because of the complexity of the interactions of these factors, no precise quantitative relationship can be stated between the properties of the iron in various locations of the same casting or between the properties of a casting and those of a test specimen from the same iron. When such a relationship is important and must be known for a specific application, it may be determined by appropriate experimentation."*

X1.4 *"When reliable information is unavailable on the relationship between properties in a casting and those in a separately cast test specimen, and where experimentation would be unfeasible, the size of the test casting should be so selected as to approximate the thickness of the main or controlling section of the casting."*

What this is really saying, is that the cast test bar may or may not represent the tensile strength in the casting! Many design engineers and/or customers using ASTM A48 assume castings meet the minimum tensile strength for the grade specified. This is a common mistake that can lead to failures and disputes.

Influence of Base Chemistry
It should be recognized that the structure controls the strength and other properties. The structure depends primarily upon the chemical composition, the processing of the molten metal in the ladle before and during pouring, and the cooling rate to room temperature. While the ASTM specification subordinates chemistry to tensile strength, it is known that close chemistry control must be achieved. Carbon and silicon play a major role in the strength of cast iron. The composition range for a given grade may vary according to the prevailing or governing section of the castings being produced. In general high strength irons are produced with carbon contents in the range of 2.80/ 3.10 wt.%; while medium strength irons range from 3.20/3.40 wt.% carbon; with low strength irons in the 3.50/ 3.70 wt.% carbon range. As shown in **Figure 1**. tensile strength is reduced with increasing carbon equivalent: **$CE = C + \frac{1}{3}(SI)$**.

Silicon is the other key element in plain *(unalloyed)* gray cast iron that exerts a powerful influence on structure and properties. Silicon lowers the solvent power of iron for carbon and increases the tendency of the carbon to precipitate as graphite. It is the predominant element, which determines the relative portions of combined and graphitic carbons. It is especially useful as an inoculant to prevent the formation of hard carbidic irons in thin sections, and acts as a powerful graphitizer.

Additionally, alloying elements may be used to meet specific hardness, strength, or microstructure requirements. Alloys enhance the properties of gray cast iron, just as with cast steels. With close control of carbon and silicon, and good inoculation practice gray cast irons of up to 40ksi tensile strength can be produced consistently without alloying. Higher strength irons over 40ksi tensile strength generally require some alloying to obtain the required mechanical properties. In castings with complicated section variations, it is difficult if not impossible to obtain uniformity without alloying *(generally with nickel, molybdenum, chromium, or copper)* to promote a more uniform structure. Alloyed cast irons are usually specified for castings with moderate cross-sectional thickness variability and complicated geometry.

Influence of Inoculation Practice
Inoculation *(seeding the iron)* improves the properties, and directly influences strength. The greater the tensile strength specified the more beneficial inoculation becomes. The mechanical properties are directly related to the solidification rate and transformations, which are dependent upon chemical composition, inoculation practice, section thickness, and casting techniques.

While composition, solidification and cooling rates are of great importance; inoculation just before and/or during pouring improves the graphite shape, size and distribution. When applied to gray cast irons, inoculation promotes the formation of the most desirable Type VII-A *(uniform distribution, random orientation)* flake graphite, reduces chilling tendencies and carbide formation, and assists in promoting a more uniform microstructure and graphite orientation.

The amount of graphite present, type, size and distribution are important factors affecting the mechanical properties. Graphite comes in many forms and occupies considerable volume. The specific gravity of graphite is much lower than the ferritic or iron-rich matrix *(i.e. 2.25 vs. 7.87 g/cm^3 with about a 1:3 ratio)*, so the volume present in cast iron is significantly larger than generally realized. For example, a gray iron having 2.5 to 3.0 wt% available carbon *(graphite)* by weight will have about 8 to 9% graphite by volume. These flakes interrupt the continuity of the steel like matrix, and directly influence strength. Larger flake size is generally associated with higher carbon equivalent irons, and/or slower cooling rates; and is usually associated with softer and weaker iron as shown in **Figure 2**. Finer/smaller size flakes are usually characteristic of higher strength irons and/or faster cooling rates. However, fine flake size does not always indicate high strength. Distribution and orientation are also important, as well as the matrix structure surrounding the graphite, which influences the strength of the iron.

Solidification and Influence of Geometry
One of the principle variables having a strong influence on the mechanical properties of cast metals is the thickness of the cast section, which affects the solidification and cooling rate. Thin sections cool more rapidly than heavier ones, surfaces more quickly than centers. Thus, thin sections usually exhibit finer graphite with more pearlite, and are stronger/harder than heavier sections containing coarser graphite and more softer/weaker ferrite.

Gray irons are considered ***"section sensitive,"*** which means the tensile strength and other properties, varies with the casting section size *(cross-sectional thickness)*. Because the effect of section size on tensile strength is related to cooling rate, the tensile strength of an iron with fixed chemical composition will

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depend upon the molding materials and foundry practices as well as the part geometry. In some castings with both thick and thin sections, widely different cooling rates exist.

There are many pump components such as casings, diffusers, impellers and others that are ***"section sensitive."*** For instance, faster cooling vanes or thin shrouds of an impeller will be considerably stronger and harder than the metal in the heavier or slower cooling hub. The vanes may have tensile strength of 50ksi or more, while the tensile strength may be only 25ksi in a three-inch thick hub for a class 35B iron. **Figures 3 and 4** illustrate how section thickness (cooling rate) influences the tensile properties.

Correlating the Strength

To a design engineer the actual tensile strength in a gray iron casting section can be critical. It is important that engineers understand the true intent of ASTM A48, and need for correlation of test bar data to the actual castings. As previously mentioned, it is a common mistake to assume that iron castings certified to a particular ASTM A48 iron classification has the strength indicated. It is possible, however, to establish a correlation between test bars and castings, by appropriate testing. Since differences in properties between test bars and castings depends upon the foundry practices and methods used, the best solution to this problem is to develop correlation data between cast test bars and castings made from the same iron, and communicate that information to the supplier. Once differences are known, the casting strength can be predicted from the test bar results.

Because gray cast iron is very section sensitive, correlation of separately cast test bars and the metal in castings is difficult to achieve. The rate of cooling of the test bar and section thickness should closely approximate that of the controlling or critical section of the casting represented. For instance, specifying a class 30 iron is meaningless without indicating what it relates to. The size of the separately cast test bar *(letter classification - A, B, C, or S)* that best represents the thickness of the critical or controlling section of the casting must be specified along with the class of iron. The ASTM A48 specification states that the test bar diameter must be similar to the thickness of the wall of the controlling section of the casting. When a specific correlation has not been established between the test bar and the casting, the thickness of the controlling section (wall thickness) is related or estimated to the test bar as follows:

- ☐ The Type ***"A-bar"*** (0.0875 inch as-cast diameter machined to 0.500 inch) is related to a sectional thickness of 0.25 to 0.50 inch.
- ☐ The Type ***"B-bar"*** (1.20 inch as-cast diameter machined to 0.750 inch) is related to a sectional thickness of 0.51 to 1.00 inch.
- ☐ The Type ***"C-bar"*** (2.00 inch as-cast diameter machined to 1.250 inch) is related to a sectional thickness of 1.01 to 2.00 inch.
- ☐ Other specified thickness is related to the ***"S-bar"*** and must be agreed upon.

An Engineering Selection Guide

The Table shown in **Figure 4**. illustrates the relationship between the tensile strength specified on standard ASTM A48 test bars and the tensile strength expected in actual casting of various thicknesses. As a rough approximation for use when more reliable information is not available, the size of the test bar may be selected on the basis of thickness of the design or controlling section of the casting. While test bars predict the properties expected in casting sections of equivalent controlling section thickness, it must be emphasized that properties diminish with increasing section thickness.

As **Figure 4** shows: A class 30B iron would be expected to have a minimum tensile strength of 30ksi in a 1.2 inch cast test bar *(a test diameter of 0.75 inch representing a section thickness of 0.51 to 1.00 inch)*, and 35ksi for sections under 0.500 inch, with only 25ksi strength for sections over 1.00 inch. If a class 35 iron is desired in a 1.00 inch thick cross-section then a class 40B iron having 40ksi minimum tensile should be specified or an equivalent class 35C iron. Likewise, if a class 35 iron is desired in a 2.00 inch thick cross-section then a class 50B iron having 50ksi minimum tensile strength should be specified or an equivalent class 40C iron.

Tensile strength should be specified bearing in mind the thickness of the critical "controlling" section and then selecting the appropriate class of iron and test bar accordingly. Specifying or indicating the "controlling" section on the part drawing is an excellent method of establishing the design requirements, and assuring that the proper grade of iron is selected for the casting and communicated to suppliers.

While these data are useful in pointing to the influence of mass on properties, it should be emphasized that this should be used only as a guide. For critical applications, where low safety factors are contemplated, actual tests from castings should be made.

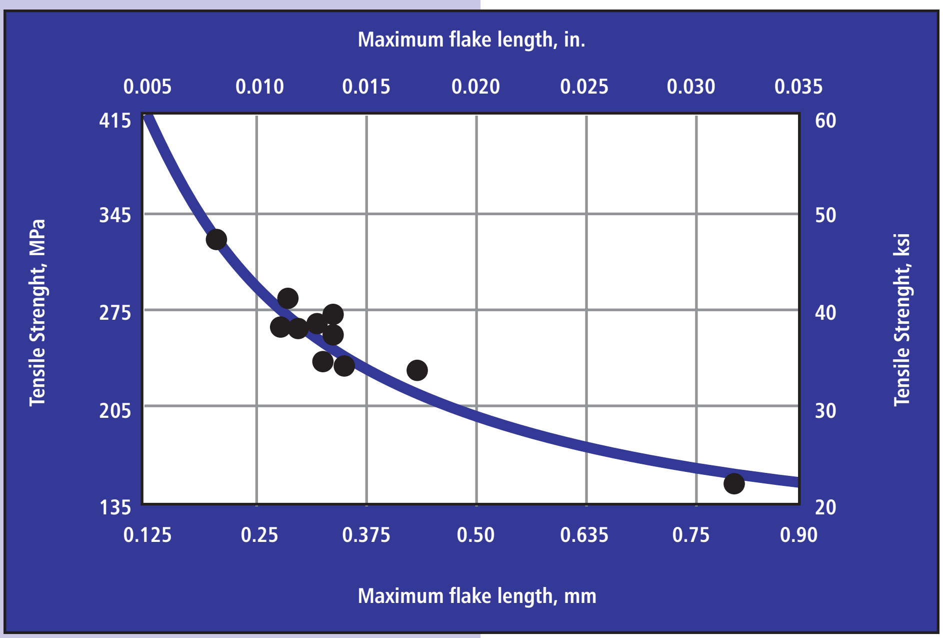

Figure 2. Effect of maximum graphite flake length on the tensile strength of gray iron. [3]

References

(1) *ASTM A48 Standard Specification for Gray Iron Castings,* Annual Book of ASTM Standards, Volume 01.02, Ferrous Castings;Ferroalloys, American Society for Testing and Materials, 2001, page 10-14.

(2) Figure 1 Source is C.F. Walton, *Iron Castings Handbook*, Iron Founders' Society, 1971, page 201

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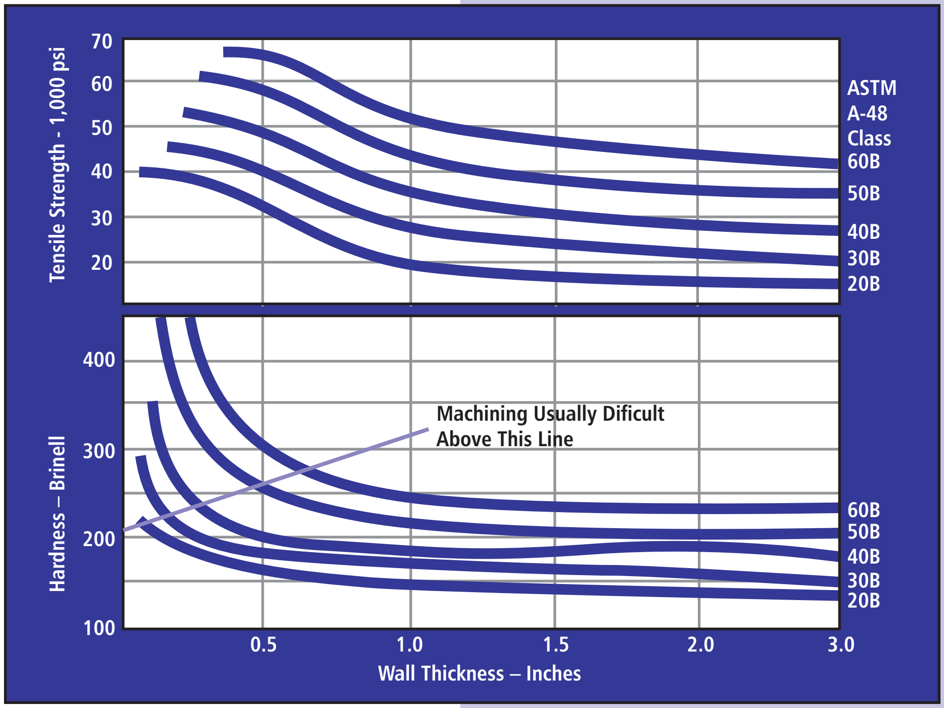
(3) Figure 2 Source is *ASM Metals Handbook*, Tenth Edition, Volume 1, Properties and Selection: Irons, Steels, and Performance Alloys, ASM International, 1990, page 6

(4) Figure 3 Source is C.F. Walton, *Iron Castings Handbook*, Iron Founders' Society, 1971, page 200

(5) Figure 4 Source is *Engineering Properties and Applications of Nickel Cast Irons,* The International Nickel Company, Inc., August, 1962.



(Right) Figure 3. The influence of casting section thickness on the tensile strength and hardness for a series gray iron classified by their strength as-cast in 1.2" diameter, "B" bars.[4]

(Bottom) Figure 4.
** Not Applicable*
ø Standard A.S.T.M. Arbitration Bars in Conformance to A48 Have the following Diameters, As Cast Type A Bar-7/8, Type B Bar-1.2, Type C Bar-2.0.[5]

Approximate Tensile Strengths to be Specified on Standard A.S.T.M. Test Barsø, in Order to Assure Desired Tensile Strengths in Actual Castings of Various Wall Thicknesses

Type Test Bar	Tensile Strength (psi) to be Specified	Equivelent Minimum Tensile Strengths (psi) in Castings of Indicated Section Thicknesses				
		1/2"	1"	2"	3"	4"
A	30,000	30,000	25,000	*	*	*
A	35,000	35,000	30,000	*	*	*
A	40,000	40,000	35,000	*	*	*
A	45,000	45,000	40,000	*	*	*
A	50,000	50,000	45,000	*	*	*
A	55,000	55,000	50,000	*	*	*
A	60,000	60,000	55,000	*	*	*
A	65,000	65,000	60,000	*	*	*
A	70,000	70,000	65,000	*	*	*
B	30,000	35,000	25,000	*	*	*
B	35,000	40,000	30,000	*	*	*
B	40,000	45,000	35,000	*	*	*
B	45,000	50,000	40,000	30,000	27,000	25,000
B	50,000	55,000	45,000	35,000	32,000	30,000
B	55,000	60,000	50,000	40,000	37,000	35,000
B	60,000	65,000	55,000	45,000	42,000	40,000
B	65,000	70,000	60,000	50,000	47,000	45,000
B	70,000	75,000	65,000	55,000	*	*
B	75,000	80,000	70,000	60,000	*	*
B	80,000	85,000	75,000	65,000	*	*
C	30,000	*	30,000	25,000	*	*
C	35,000	*	35,000	30,000	*	*
C	40,000	*	40,000	35,000	33,000	30,000
C	45,000	*	45,000	41,000	39,000	35,000
C	50,000	*	50,000	48,000	46,000	42,000
C	55,000	*	55,000	53,000	51,000	49,000
C	60,000	*	60,000	57,000	55,000	55,000
C	65,000	*	65,000	62,000	60,000	60,000
C	70,000	*	70,000	70,000	68,000	68,000
C	75,000	*	75,000	75,000	73,000	73,000
C	80,000	*	80,000	80,000	80,000	80,000