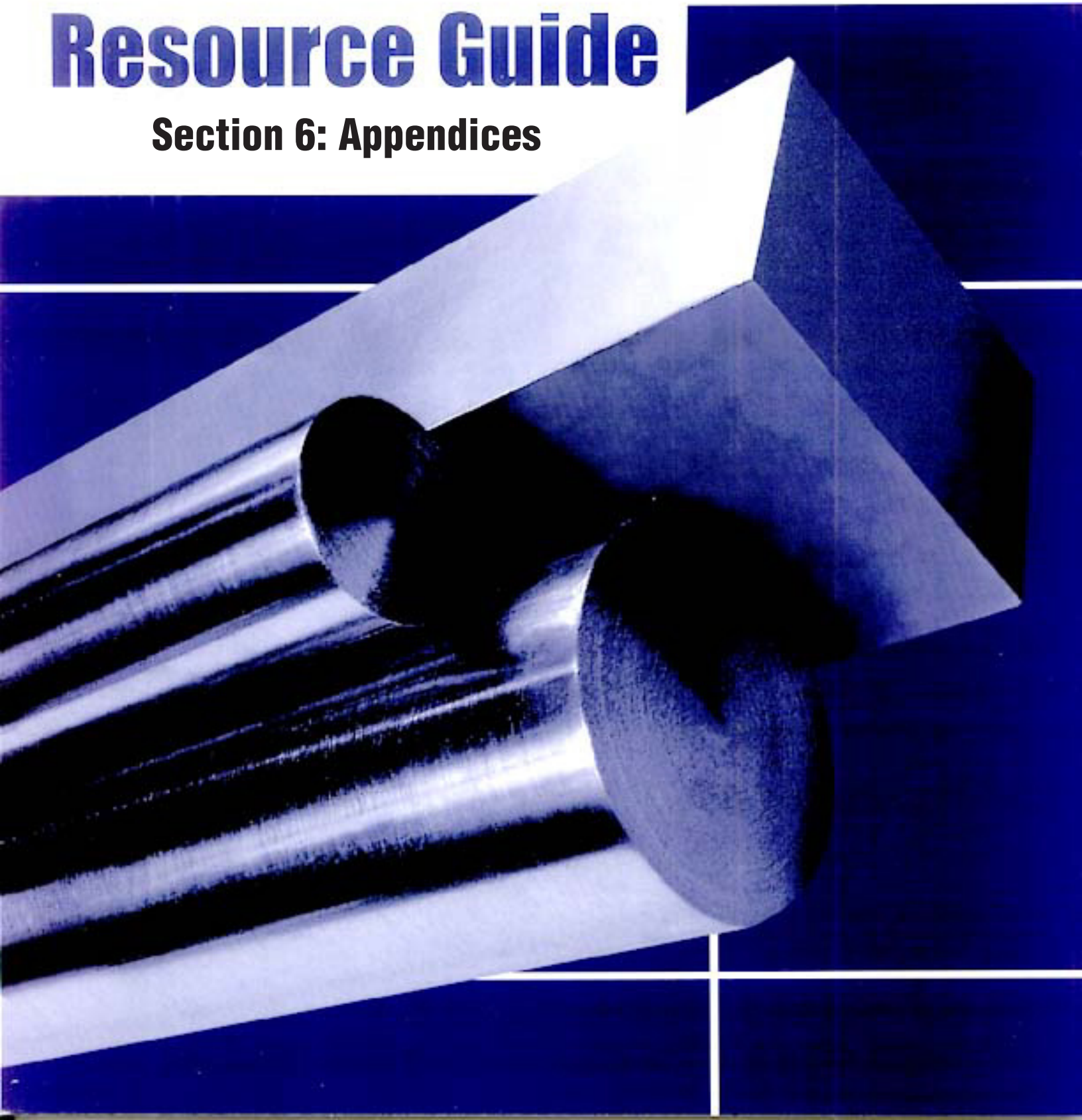
DURA-BAR®

Continuous Cast Iron Bar Stock

Resource Guide

Section 6: Appendices



Appendices

- Tolerances 6-2
- ASTM References.....6-8
- Glossary..... 6-13
- Useful Formulas/Calculations 6-21
- Typical Hardness Value Conversion Table 6-24
- Mechanical Properties..... 6-25

Tolerances

This section lists Dura-Bar dimensional tolerances. Metallurgical tolerances and mechanical properties are listed under each metal grade in the specification section. Customer specifications may be written from the information contained in this section. If tighter tolerances or additional testing is required for a custom item, a customer specification may be written.

Rounds

Round bars are made with sufficient stock on the outside diameter to guarantee clean-up at the nominal dimensions. Stock allowances and allowable deviations for round bars are listed in Table 1 below.

Table 1
Dimensional tolerances for as-cast round bars

Nominal Diameter Bar Size	Stock Allowance		Stock Allowance Variation (+/-) All Metal Specs
	Gray Iron	Ductile Iron & Ni-Resist	
00.750 - 01.250"	0.085"	0.088"	0.017"
01.251 - 02.000"	0.090"	0.095"	0.024"
02.001 - 03.000"	0.110"	0.118"	0.030"
03.001 - 04.000"	0.125"	0.136"	0.038"
04.001 - 05.000"	0.140"	0.154"	0.048"
05.001 - 06.000"	0.155"	0.172"	0.055"
06.001 - 07.000"	0.170"	0.190"	0.062"
07.001 - 08.000"	0.190"	0.213"	0.085"
08.001 - 09.000"	0.216"	0.242"	0.108"
09.001 - 10.000"	0.254"	0.283"	0.129"
10.001 - 11.000"	0.400"	0.432"	0.150"
11.001 - 16.000"	0.582"	0.623"	0.206"
16.001 - 18.000"	0.762"	0.815"	0.262"
18.001 - 20.000"	0.762"	0.819"	0.262"

Cold Finished Bars

Cold finished bars are made to the actual dimensions. Clean-up stock must be considered when ordering. Cold finished centerless grinding tolerances are listed in Table 2 below. Centerless turning tolerance is +0.003"/+0.008".

Table 2
Standard centerless grinding tolerances

Nominal Length	Bar Diameter	Centerless Grinding Tolerance
72"	0.750 - 4.00"	+0.010"/-0.000"
72"	4.001 - 6.00"	+0.015"/-0.000"
144"	0.750 - 3.00"	+0.010"/-0.000"
144"	3.001 - 4.00"	+0.015"/-0.000"

Rectangles

Rectangles are made to the actual dimensions. Clean-up stock must be considered when ordering. Minimum clean-up stock allowances are shown in Table 3 below:

Table 3
Clean-up stock allowances - rectangles.

	Ratio (Width:Height)				
Height	0.000-1.999	2.000-2.999	3.000-4.999	5.000-7.999	8.000 & Up
00.750 - 01.500"	0.090"	0.100"	0.125"	0.188"	0.188"
01.501 - 02.500"	0.090"	0.100"	0.125"	0.125"	0.188"
02.501 - 04.000"	0.100"	0.188"	0.250"	0.250"	--
04.001 - 06.000"	0.112"	0.188"	0.250"	--	--
06.001 - 08.500"	0.125"	0.250"	0.250"	--	--
08.501 - 11.500"	0.188"	0.250"	--	--	--
11.501 - 14.125"	0.250"	--	--	--	--
14.126 - 20.000"	0.500"	--	--	--	--

Clean-up stock for special shapes is based on the maximum width and the maximum height of the cross section.

Dimension in the vertical center of rectangles and shapes may be larger than the vertical ends. Allowable swell is based on the dimension of the bar according to the data in Table 4 below.

Table 4
Swell allowances - rectangles

Height	Ratio (Width:Height)				
	0.000-1.999	2.000-2.999	3.000-4.999	5.000-7.999	8.000 & Up
00.750 -01.500"	--	--	--	0.350"	0.460"
01.501 -02.500"	--	--	0.262"	0.370"	0.485"
02.501 -04.000"	--	0.189"	0.282"	0.395"	--
04.001 -06.000"	0.143"	0.209"	0.307"	--	--
06.001 -08.500"	0.153"	0.234"	0.337"	--	--
08.501 -11.500"	0.163"	0.254"	--	--	--
11.501 -14.125"	0.173"	--	--	--	--
14.126 -18.000"	0.250"	--	--	--	--
18.001 -20.000"	0.500"	--	--	--	--

Swell allowance for special shapes is based on the maximum width and the maximum height of the cross section.

Duplex Milling

Duplex milling tolerances are listed in Table 5 below:

Table 5
Duplex milling tolerances

Material Grades	Any
Surfaces Milled	2 or 4 sides
Maximum As-Cast Size	6.250" x 6.250"
Minimum Milled to Size	2.000" x 2.000"
Standard Tolerance	+/- .005"
Square, Parallel, & Flat	Within .010" in any 6.00" section
Surface Finish	125 RMS maximum
Bar Length	72" bars only
Coating	Coated with a rust prohibitive

Planner Milling

Planner milling tolerances are listed in Table 6 below:

Table 6
Planner milling tolerances

Material Grades	Any
Surfaces Milled	1, 2, 3, or 4 sides
Maximum As-Cast Size	14.000" x 21.000"
Minimum As-Cast Size	4.500" x 4.500"
Minimum Bar Length	72"
Maximum Bar Length	102"
Size Tolerances	**2 Surfaces** Dim. "A" (Height): +.062"/-.000 Dim. "B" (Width): +.062"/-.000 **3 Surfaces** Dim. "A" (Height): +.030"/-.000 Dim. "B" (Width): +.062"/-.000 **4 Surfaces** Dim. "A" (Height): +.030"/-.000 Dim. "B" (Width): +.030"/-.000
Square, Parallel, & Flat	Within .010" in any 6.00" section
Surface Finish	N/A
Coating	Coated with a rust prohibitive

Trepanned Tubes

Trepanned tube tolerances are listed in Table 7 below:

Material Grades	Any gray, ductile, or Ni-Resist grade			
Minimum O.D.	3.00"			
Maximum O.D.	16.0"			
Length	72" only for bars with O.D. of 9" or smaller 10"-24" for bars with O.D. greater than 9" diameter up to & including 16" diameter			
Minimum Wall Thickness*	**Nominal O.D.**	**Mininimum Wall Thickness**		
	3.000"	0.562"		
	3.001" - 6.000"	0.625"		
	6.001" - 12.000"	0.687"		
	12.001" - 16.000"	0.750"		
Available I.D.s	**Nominal I.D.**	**Actual I.D.**	**Nominal I.D.**	**Actual I.D.**
	1.500"	1.250"	4.000"	3.750"
	2.000"	1.750"	4.250"	4.000"
	2.250"	2.000"	4.500"	4.250"
	2.500"	2.250"	4.750"	4.500"
	2.750"	2.500"	5.000"	4.750"
	3.000"	2.750"	5.500"	5.250"
	3.250"	3.000"	6.000"	5.750"
	3.500"	3.250"	6.500"	6.250"
	3.750"	3.500"	7.000"	6.750"

Table 7
Trepanned tube tolerances

**Wall thickness minimums are based on actual O.D. and I.D.*
Example: 3.000" O.D. as-cast x 2.000" I.D.
Actual: 3.110" O.D. x 1.750" I.D.
Overall wall thickness: 3.110"-1.750"=1.360"
Single wall thickness: 1.360"/2=0.680"

Length

Continuous cast bars are notched and broken off on the production line in standard lengths of 6 feet and 12 feet. (Larger bars will be shorter because of their weight.) Stock is added on to the break-off length in order to guarantee the nominal length. The stock allowance for bar lengths is shown in Table 5 below.

Table 8
Standard Dura-Bar length tolerances

Nominal Bar Diameter	Tolerance on Standard Lengths		Non-Standard Lengths
	6-Foot Bars	12-Foot Bars	
00.625 - 03.999"	72 - 74.5"	144 - 147"	Nominal +3"
04.000 - 09.999"	72 - 75.5"	144 - 148"	Nominal +4"
10.000 - 18.000"	72 - 76.0"	144 - 149"	Nominal +5"
19.000"	57 - 60.5"	--	Nominal +5"
20.000"	54 - 57.5"	--	Nominal +5"

Bend-and-bow tolerance is 1/8" per 6-foot section.

Special Shapes

Dimensional tolerances for special rectangle sizes and for special shapes depend upon customer requirements and the capability of the process. Three runs are used to establish the capability for repeatability and reliability to maintain dimensional tolerances. When customer approval is obtained, the tolerances are included on the inspection forms.

ASTM References

There are no ASTM specifications written specifically for continuous cast iron bar stock, although all grades of Dura-Bar are similar to ASTM gray and ductile iron standards. In most cases, ASTM allows deviations in the written specification, as long as those deviations are acceptable and agreed upon by the customer and the supplier.

The three most common ASTM specifications for cast iron are A48 representing gray iron, A536 representing ductile iron and A436 representing austenitic iron.

ASTM A48

Cast iron properties are controlled by four foundry variables:

1. The base chemistry
2. Inoculation
3. The rate of solidification
4. The rate of cooling

Any one of the four variables can significantly affect mechanical properties, especially tensile strength in gray or ductile iron castings. Castings that solidfy and cool at different rates will have different mechanical properties even if the base chemistry and inoculation are the same. Large section castings have longer solidification rates than small section castings, and the base chemistry and inoculation practices have to be adjusted by the foundry in order to control mechanical properties in different size castings. Individual castings that have different section thickness will have variations in mechanical properties within the same part.

ASTM A48 is the most popular gray iron casting specification and classifies castings to various grades by their tensile strength. In order to standardize solidification and cooling rate, standard test specimen sizes are used to ensure conformance to the specification. The minimum required tensile strength in a separately cast test bar is established for each of the grades. The tensile strength in the separately cast test bar is not intended to represent the tensile strength in the casting poured from the same iron, but it is intended to provide some degree of measure of consistency between different production lots or between different foundries pouring the same part. Specific wording to this effect is in the ASTM A48 standard.

The specification also states that when the relationship between tensile strength in the separately cast test coupon and the actual casting is important, it can be established through experimentation.

Dura-Bar G2 is a fully pearlitic gray cast iron containing Type VII graphite, type A, size 3-8, depending on bar diameter and on the location within the cross section of the bar. It is developed to correspond with ASTM A48 Class 40 castings. Continuous cast iron bar size ranges from 0.625" to 20.000" in diameter. Tensile strength decreases with increasing bar diameters because of the difference in solidification and cooling rates. The graphite flake size in the center of a 20.000" diameter bar will be larger than the flakes in a 2.000" diameter bar on the outside edge. Because of this, the tensile strength in the 20.000" diameter bar is lower than the strength in the 2.000" bar. However, if a separately cast test specimen was poured from the iron used to produce the 20.000" diameter bar, the graphite flake size would be considerably smaller by comparison with a test specimen poured from the iron used in the 2.000" continuous cast bar. The same is true for foundries that cast large-section castings. For this reason, separately cast test bars are not useful in predicting the strength in castings or in Dura-Bar continuous cast bar stock.

The correlation between separately cast test bars and continuous cast bars made from the same iron has been established by Dura-Bar, and the graph below shows that data.

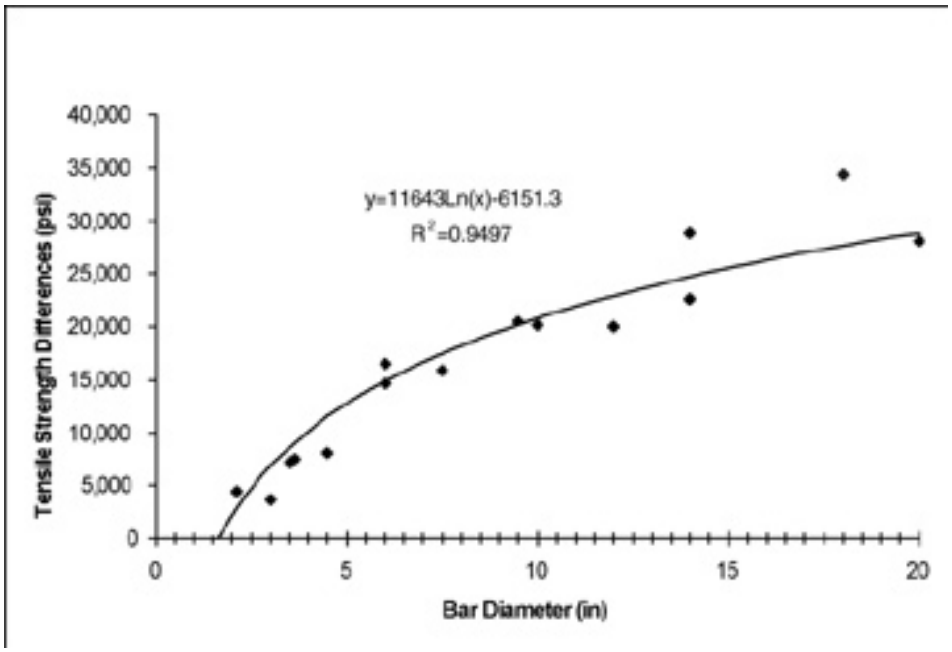


Fig. 1
Differences in B-bar & continuous cast bar tensile strengths

Continuous cast bars made from Dura-Bar G2 can be certified to ASTM A48, Class 40 when the separate cast test coupon has a minimum tensile strength of 40,000 psi. As mentioned previously, separately cast test bar tensile strengths will be much

higher when poured from iron used to produce 20.000" diameter continuous cast bars than they will be with iron used to make 2.000" diameter bars. The chart and formula on the previous page can be used to predict the difference between tensile strength in the continuous cast bars and the separately cast (1.200" diameter) test coupons.

The minimum tensile strength required for ASTM A48, Class 40b is 40,000 psi in the separately cast test coupon. Tensile tests taken from the continuous cast bars must meet the minimum strength that will give 40,000 psi in a test coupon. Using the formula in the chart on the previous page, the minimum strengths listed below in Table 1 are required for continuous cast bars ranging in diameters from 1.000" to 20.000".

Table 1
Minimum required strengths

Dura-Bar Bar Diameter	Tensile (ASTM A48, Class 40b)
01.000"	40,000
02.000"	38,081
03.000"	33,360
04.000"	30,011
05.000"	27,413
06.000"	25,290
07.000"	23,495
08.000"	21,940
09.000"	20,569
10.000"	19,342
11.000"	18,233
12.000"	17,220
13.000"	16,288
14.000"	15,425
15.000"	14,621
16.000"	13,870
17.000"	13,164
18.000"	12,499
19.000"	11,869
20.000"	11,272

Unless otherwise required by the customer, the above minimum tensile strengths are used to specify conformance to ASTM A48, Class 40.

ASTM A536

ASTM A536 covers castings made of ductile iron, and the grade designation within the specification is consistent with Dura-Bar grades.

As with A48, this specification also refers to the mechanical properties in a separately cast test bar--called a keel block.

As in the case of A48, there is no correlation between the mechanical properties in the keel block to the casting. The cooling rate will strongly influence mechanical properties and will vary with molding methods and section size. Keel blocks are not typically poured as part of the Dura-Bar continuous casting process.

Tensile, yield and elongation in the continuous cast bar, taken from a longitudinal test specimen in the mid-radius, will conform to A536. The minimum property requirements in the keel block will be obtained in the bar. Dura-Bar can be certified to A536 when required by the customer.

The cooling rate of a test bar and a casting will have a significant impact on resulting mechanical properties. Breaking a test bar out of a sand mold while it is hot and cooling it rapidly in air or water will show higher mechanical properties than if the sample cooled in the mold. Likewise, castings shaken out of a sand mold will vary in mechanical properties as the shakeout temperature varies.

It is important to be aware of this effect when mechanical properties and ASTM specifications are critical for an application. All mechanical properties for Dura-Bar products are given for the actual bars--not on a separately poured test piece.

ASTM A436

ASTM A436 covers austenitic gray iron castings that are characterized by uniformly distributed graphite flakes, some carbides and the presence of sufficient alloy content to produce an austenitic structure. Dura-Bar 201 and 202 Ni-Resist will conform to the requirements for ASTM A436 Type 1 and 2 with the exception of the test bar specimen. A436 requires a separately cast test bar similar to the ASTM A536 and A48. Test bars are taken longitudinally out of the mid-radius of the as-cast bar.

Other ASTM Specifications

There are additional ASTM specifications that can be applied to Dura-Bar products. Most of these are written for specific applications, such as pressure vessels and for specific automotive applications. Other specifications are written to standardize a method of materials testing. In many cases, Dura-Bar will conform to these standards.

The following selected terms and definitions were taken from the *Iron Castings Handbook*, published by the American Cast Metals Association.

ALLOY - A substance having metallic properties and composed of two or more chemical elements of which at least one is a metal.

ALLOYING ELEMENTS - Chemical elements constituting an alloy; usually limited to elements added to modify the properties of the base metal.

ANNEALING - Generally a heat treatment to soften metals; for iron and steel, consists of heating above the critical temperature followed by slow cooling usually in the furnace.

AS-CAST CONDITION - Castings as removed from the mold, without subsequent heat treatment. In continuous cast, the surface condition of the bar as it exits from the die. (Prior to machining).

AUSTENITE - Solid solution of cementite, or iron carbide, in gamma iron, which is nonmagnetic and characterized by a face-centered cubic crystal structure.

AUSTEMPERING - A heat treatment process that consists of quenching a ferrous alloy from a temperature above the critical range in a medium having a rate of heat abstraction (usually molten salt) sufficiently high to prevent the formation of high temperature transformation products; and in maintaining the alloy, until transformation is complete, at a temperature below that of pearlite and above that of martensite formation.

BAINITE - A constituent in the microstructure of steel; formed by the transformation of austenite below the pearlitic and above the martensitic transformation temperatures.

BRINELL HARDNESS - The value of hardness of a metal determined by measuring the diameter of the impression made by a ball of given diameter applied under a known load. Values are expressed in Brinell hardness numbers (BHN).

BULL'S-EYE - The inside area of a bar that exhibits equilibrium type(s) of graphite.

CAPTIVE FOUNDRY - A foundry that is an element of a manufacturing establishment where foundry operations are a part of the regular operation of the plant.

CARBIDE - A compound of carbon with one or more metallic elements.

CARBON EQUIVALENT - A relationship between carbon, silicon and phosphorus in cast irons:

$$C.E. = \% \text{ T.C.} + \frac{\% \text{ Si} + \% \text{ P}}{3}$$

CARBURIZING - Introducing carbon into solid iron by heat treating above the temperature at which austenite begins to form in contact with a suitable carbonaceous material.

CASE HARDENING - A process of hardening a ferrous alloy so that the surface layer or case is made substantially harder than the interior or core. Induction hardening and flame hardening are most commonly used for iron castings.

CAST IRON - A generic term for the family of high carbon-silicon-iron casting alloys including ductile (nodular iron, gray iron, malleable iron and white iron).

CASTING (noun) - Metal object cast to the required shape by pouring or injecting liquid metal into a mold, as distinct from one shaped by a mechanical process.

CASTING (verb) - Act of pouring molten metal into a mold.

CEMENTITE - A very hard, intermetallic compound of iron and carbon, usually containing other carbide-forming elements. (Loosely referred to as iron carbide or Fe_3C.)

CENTERLESS GROUND - A grinding operation to size an as-cast bar for collet tolerances in machining centers.

CENTERLINE SHRINKAGE - Shrinkage or porosity occurring along the central plane or axis of a cast part.

CENTRIFUGAL CASTING - A process of filling molds by pouring the metal into a sand or permanent mold that is revolving about either its horizontal or its vertical axis.

CHARGE - 1) The materials placed in a melting furnace; 2) Castings placed in a heat treating furnace.

CLOSE GRAINED - Term used to describe the density and size of graphite flakes.

COMMERCIAL FOUNDRY - An organization that produces castings for sale as opposed to a captive foundry. Either, however, may use production foundry or jobbing foundry facilities.

COMPRESSIVE STRENGTH - (Yield) The maximum stress that a metal, subjected to compression, can withstand without a predefined amount of deformation. (ultimate) The maximum stress that a brittle material can withstand without fracture when subjected to compression.

CUPOLA - A vertically cylindrical furnace for melting metal, in direct contact with coke as fuel, by forcing air under pressure through openings near its base.

DAMPING CAPACITY - Ability of a metal to absorb vibration, changing the mechanical energy into heat.

DESULPHURIZING - Removal of sulphur from molten metal by reaction with a suitable slag or a chemical such as soda ash.

DUCTILE IRON (Nodular Iron) - Cast iron treated with a special alloy while in the liquid state so that the graphite is spherulitic rather than flake. Also called spherulitic graphite iron or S.G. iron.

DUCTILITY - The property permitting permanent deformation without rupture in a material by stress in tension.

ELECTRIC FURNACES - Furnaces which use electricity to melt a metal charge.

ELONGATION - Amount of permanent extension in the vicinity of the fractures in the tensile test; usually expressed as a percentage of original gauge length, such as 25 percent in two inches.

ETCHING - In metallography, the process of revealing structural details by preferential attack of reagents on a metal surface.

EXIT TEMPERATURE - The temperature at which the bar exits the graphite die.

FERRITE - An essentially carbon-free solid solution in which alpha iron is the solvent, and which is characterized by a body-centered cubic crystal structure.

FERRITIC SKIN - Ferrite on the outside diameter of an as-cast bar usually removed during machining operations.

FLAKE GRAPHITE - Graphitic carbon, in the form of platelets, occurring in the microstructure of gray cast iron.

FLAME HARDENING - Process of hardening a casting surface by heating it above the transformation range with a high-temperature flame followed by rapid cooling.

FRACTURE - Method of breaking the as-cast bar to a predetermined length.

FREE FERRITE - Ferrite formed into separate grains and not intimately associated with carbides as in pearlite.

GALLING - The mechanism whereby engaged metallic surfaces undergo damage through superficial welding and material transfer.

GAS HOLES - Rounded cavities, either of spherical or elongated round shape, caused by the generation and/or accumulation of gas or entrapped air during solidification of the metal.

GRAPHITE - One of the crystal forms of carbon; also the uncombined carbon in cast irons.

GRAPHITE DIE - A graphite block that is machined to determine the size and shape of a continuous cast bar.

GRAY IRON - Cast iron which contains a relatively large percentage of the carbon present in the form of flake graphite. The metal has gray fracture.

HARDNESS - The property of a substance determined by its ability to resist abrasion or indentation by another substance. For metals, hardness is usually defined in terms of the size or depth of an impression made by a standard indenter. (Brinell, Rockwell, Diamond, Pyramid, etc. tests.)

HEAT TREATMENT - A combination of heating, holding and cooling operations applied to a metal or alloy in the solid state in a manner which will produce desired properties.

INCLUSIONS - Non-metallic particles, such as oxides, sulphides or silicates that are held within solid metal.

INDUCTION FURNACE - An alternating current electric furnace in which the primary conductor is coiled and generates a secondary current by electromagnetic induction which heats the metal charge.

INDUCTION HARDENING - Process of hardening the surface of a casting by heating it above the transformation range by electrical induction, followed by rapid cooling.

INOCULANT - Materials which, when added to molten metal, modify the structure, and thereby change the physical and mechanical properties to a degree not explained on the bases of the change in composition resulting from their use.

INTERNAL SHRINKAGE - A void or network of voids within a casting caused by inadequate feeding of that section during solidification.

MARTENSITE - In iron or steel a very hard micro-constituent with an acicular (needle-like) appearance; produced in heat treating by quenching or with alloys.

MATRIX - The principal phase in microstructure in which another constituent, such as graphite, is embedded or enclosed.

MATRIX STRUCTURE - In the microstructure of an alloy, the principal, continuous constituent in which other constituents or phases reside.

MECHANICAL PROPERTIES - Those properties of a material that reveal the elastic and inelastic reaction when force is applied, or that involve the relationship between stress and strain; for example, the modulus of elasticity, tensile strength, and fatigue limit. These properties have often been designated as physical properties but the term mechanical properties is preferred.

METALLURGY - Science and art of extracting metals from their ores, refining them and preparing them for final use.

MICROSTRUCTURE The structure of polished and etched metal and alloy specimens as revealed by the microscope at magnifications over ten diameters.

MODULUS OF ELASTICITY - The ratio of tensile stress to the corresponding strain within the limit of elasticity of a material.

NORMALIZING - A heat treatment in which ferrous alloys are heated to a suitable temperature above the transformation range and cooled in still air to room temperature.

NOTCHING WHEEL - Abrasive tool that cuts or notches a continuous cast bar.

PEARLITE - Lamellar aggregate (alternate plates) of ferrite and cementite in the microstructure of iron and steel.

PHYSICAL PROPERTIES - Properties, other than mechanical properties, that pertain to the physics of a material.

POROSITY (Metal) - Unsoundness caused in cast metals by presence of blow-holes and shrinkage cavities. Also, the voids resulting from tearing out of metal between coarse graphite flakes in the machining of soft cast iron.

QUENCH HARDENING - Process of hardening a ferrous alloy of suitable composition by heating within or above the transformation range and cooling at a rate sufficient to increase the hardness substantially. The process usually involves the formation of martensite.

RING GAUGE - Instrument used to check the roundness of a centerless ground bar.

ROCKWELL HARDNESS - The relative hardness value of a metal determined by measuring the depth of penetration of a steel ball (1/16 inch diameter for B Scale) or a diamond point (C Scale) with controlled loading, the Rockwell number being the difference between the depth obtained with a minor and major loading.

SNAP GAUGE - Instrument used to determine if centerless ground bar is within size tolerance.

SHRINK HOLE - A hole or cavity in a casting resulting from shrinkage and insufficient feed metal, and formed during solidification.

SLAG - A product resulting from the action of a flux on the oxidized non-metallic constituents of molten metals. May also be produced by oxidation of the molten bath, ash from the fuel, erosion of the refractories, and floating of non-metallics in the charge.

SPECTROMETER - An instrument used to determine the elements and percentage of elements in the material.

STABILIZER - Any substance that increases the tendency of carbon to remain as iron carbide; i.e. retards graphitization.

SURFACE FINISH - Generally refers to the roughness of a machined surface, numerically stated as the root-mean-square height of irregularities in micro-inches.

TAPPING - 1) The process of removing molten metal from the melting furnace; 2) Opening the tap hole.

TEMPERING - A heat treatment consisting of reheating quench-hardened or normalized iron to a temperature below the transformation range, and holding for sufficient time to produce the desired properties.

TENSILE STRENGTH The maximum load in tension which a material will withstand prior to fracture. It is calculated from the maximum load applied during the tensile test divided by the original cross-sectional area of the sample.

WAFER - A section of the continuous cast bar that is used to determine the hardness, matrix structure, and chemistry of the material.

WORK HARDENING - Hardness developed in metal as a result of mechanical working, particularly cold working.

YIELD STRENGTH - The stress at which a material exhibits a specified limit of permanent strain; often the maximum unit load with a 0.2% deviation from a proportional stress-strain relation.

Density of Iron - Calculating Bar Weights

The average density of cast iron is:

0.260 lbs/in^3 for gray iron
0.255 lbs/in^3 for ductile iron
0.265 lbs/in^3 for Ni-Resist irons
0.284 lbs/in^3 for steel

Calculate the weight of a bar using the following formula:

$$\text{Weight} = \text{Area} \times \text{Length} \times \text{Density}$$

Where:

Rounds: $\text{Area} = \pi/4 \times (\text{Diameter})^2$
Rectangles: $\text{Area} = \text{Width} \times \text{Height}$

Note: Dimensions must be in centimeters or inches, depending on the density value calculated weights will be in pounds (English) or grams (Metric)

Coefficient of Linear Expansion for Iron

Gray iron: $\alpha = 5.5 \times 10^{-6}$ in/in/°F
Ductile Iron: $\alpha = 6.4 \times 10^{-6}$ in/in/°F
Ni-Resist: $\alpha = 11.0 \times 10^{-6}$ in/in/°F

To calculate change in length for a change in temperature, use the following formula:

$$\Delta L = \alpha \times \text{original length} \times \Delta T$$

Determination of Hoop Stress in Pressure Vessels

Forces developed on the walls of a pressure vessel are called hoop stresses. Hydraulic cylinders are a specific type of pressure vessels and the hoop stresses developed on the walls of the cylinder are a function of three variables

#1: The internal pressure inside the cylinder.
#2: The radius of the bore, or vessel chamber
#3: The wall thickness of the vessel.

The formula used to determine hoop stress is:

$$\text{Hoop Stress} = \frac{\text{(Maximum Cylinder Pressure) x (Radius of the Bore)}}{\text{(Wall Thickness of the Cylinder)}}$$

Modulus of Elasticity of Gray and Ductile Iron

The modulus of elasticity of a material is used to predict the amount of elastic deformation that occurs when it is under a load that is less than its yield strength. The elastic modulus is the slope of the stress / strain curve and can be obtained during a routine tensile test.

The modulus of elasticity for ductile iron is between 20 - 30 ($x\ 10^6$) psi and between 10 – 18 ($x\ 10^6$) psi in gray iron.

To calculate the elastic deformation in inches per inch, divide the amount of load applied on a part in pounds per square inch by the modulus of elasticity in pounds per square inch. The applied load must be below the yield strength of the material.

For example, an 80-55-06 ductile iron rod, 1.0" in diameter has a modulus of elasticity of 25 x 10^6 psi. A load of 10,000 pounds is being applied as a tensile load. How much does it stretch in a 1.0" length?

The cross sectional area of the rod is: $P/4 * (1.0)^2 = 0.7854\ in^2$

The applied stress is: 10,000 lbs / 0.7854 in^2 = 12,732 psi

The strain, in inches/inch = 12,732 / 25,000,000 = 0.000509

Therefore, the rod stretches 0.0005" in the 1.0" length. Since the applied load is below the yield strength of the material, the rod returns to its original length when the load is removed. It is very important to remember that elongation determined through tensile testing and the amount of deformation calculated above are in no way related.

Conversion Factors

To Convert	Multiply by	To Obtain
pounds/in^2 (psi)	6.944 x 10^{-3}	Newtons per mm^2
Newtons/mm^2	144	psi
pounds	4.48	Newtons
Newtons	0.223	pounds
centimeters	0.394	inches
inches	2.54	centimeters
pounds	454	grams
grams	2.20 x 10^{-3}	pounds
cubic inches	5.87 x 10^{-4}	cubic feet
cubic feet	1,728	cubic inches
pounds/inch^3	27.68	grams per cc
grams per cc	0.036	pounds/inch^3
pounds per foot	1.488	kgs/meter
kgs/meter	0.672	pounds per foot

Typical Hardness Value Conversion Table

This conversion chart applies to steel products and can be used as a guideline for cast iron. Actual values obtained from each method will vary because of the influence of graphite in iron.

Diameter Depression[1]	BHN	Rockwell C	Rockwell B	Vickers[2]	Shore[3]
2.80	477	50	-	513	67
2.85	461	48	-	484	64
2.90	444	47	-	471	63
2.95	429	46	-	458	62
3.00	415	45	-	446	60
3.05	401	43	-	423	57
3.10	388	42	-	412	56
3.15	375	40	-	402	55
3.20	363	39	-	382	52
3.25	352	38	-	372	51
3.30	341	37	-	363	50
3.35	331	35	-	354	49
3.40	321	34	-	336	47
3.45	311	33	-	327	46
3.50	302	32	-	318	44
3.55	293	31	-	310	43
3.60	285	30	-	302	42
3.65	277	27	-	294	41
3.70	269	28	-	286	41
3.75	262	27	-	279	40
3.80	255	25	-	266	38
3.85	248	24	-	260	37
3.90	241	23	-	254	36
3.95	235	22	-	235	35
4.00	229	20	-	238	34
4.05	223	19	98	234	34
4.10	217	17	97	230	33
4.15	212	16	96	222	32
4.20	207	15	95	217	32
4.25	201	14	94	213	31
4.30	197	13	93	207	30
4.35	192	12	92	204	29
4.40	187	10	91	196	28
4.45	183	9	91	192	28
4.50	179	8	89	188	27
4.55	174	7	87	184	27
4.60	170	5	87	177	26
4.65	167	4	86	173	25
4.70	163	3	85	169	25
4.75	159	2	84	166	24
4.80	156	1	83	160	24
4.85	152	-	81	153	23
4.90	149	-	80	150	23
4.95	146	-	79	147	22
5.00	143	-	78	144	22
5.05	140	-	77	141	21
5.10	137	-	75	137	20
5.15	134	-	74	137	20

[1]Brinell 3000kg load, 10mm ball

[2]10kg diamond pyramid (matrix hardness)

[3]Scleroscope diamond (surface hardness)

Mechanical Property Comparisons

Material Property	Ductile Iron			Gray Iron	
	65-45-12	80-55-06	100-70-02	G2	G1
Tensile Strength (psi)	65,000	80,000	100,000	40,000	20,000
Yield Strength (psi)	45,000	55,000	70,000	—	—
Elongation (%)	12	6	2	—	—
Machinability Rating*	150%	125%	75%	135%	125%
Fatigue Strength (psi)	40,000	40,000	40,000	20,000	10,000
Endurance Ratio	0.6	0.5	0.4	0.4	0.5
Shear Strength (psi)	54,000	72,000	90,000	58,000	29,000
Compressive Strength (psi)	110,000	115,000	120,000	120,000	90,000
Torsion Strength (psi)	54,000	72,000	90,000	60,000	30,000
Impact Strength** (ft-lbs)	10	15	20	—	—
Density (lbs/in$^{3)}$	0.260	0.260	0.260	0.260	0.260
Hardness (BHN) (avg.)	180	229	279	241	160
Modulus of Elasticity (psi)	23,000,000	25,000,000	25,000,000	20,000,000	20,000,000
Relative Wear Resistance	Fair	Good	Excellent	Excellent	Fair
Coefficient of Thermal Expansion (in/in/°F) (Range: 70-212°F)	6.4x10 $^{-6}$	6.4x10 $^{-6}$	6.0x10 $^{-6}$	5.5x10 $^{-6}$	5.5x10 $^{-6}$
Thermal Conductivity (Btu/hr/ft°F) Range: Room Temp-212°F)	18.68	18.68	18.68	30.84	30.84
Relative Damping Capacity***	20	20	20	250	250
Heat-Treat Response (Rc)	55-60	55-60	55-60	55-60	55-60
Electrical Resistivity (Microhms x Cm)	75	75	75	110	110

** Based on 1212=100%*

*** V-notched Charpy room temp.*

**** Natural log of rate of successive amplitude*

Notes