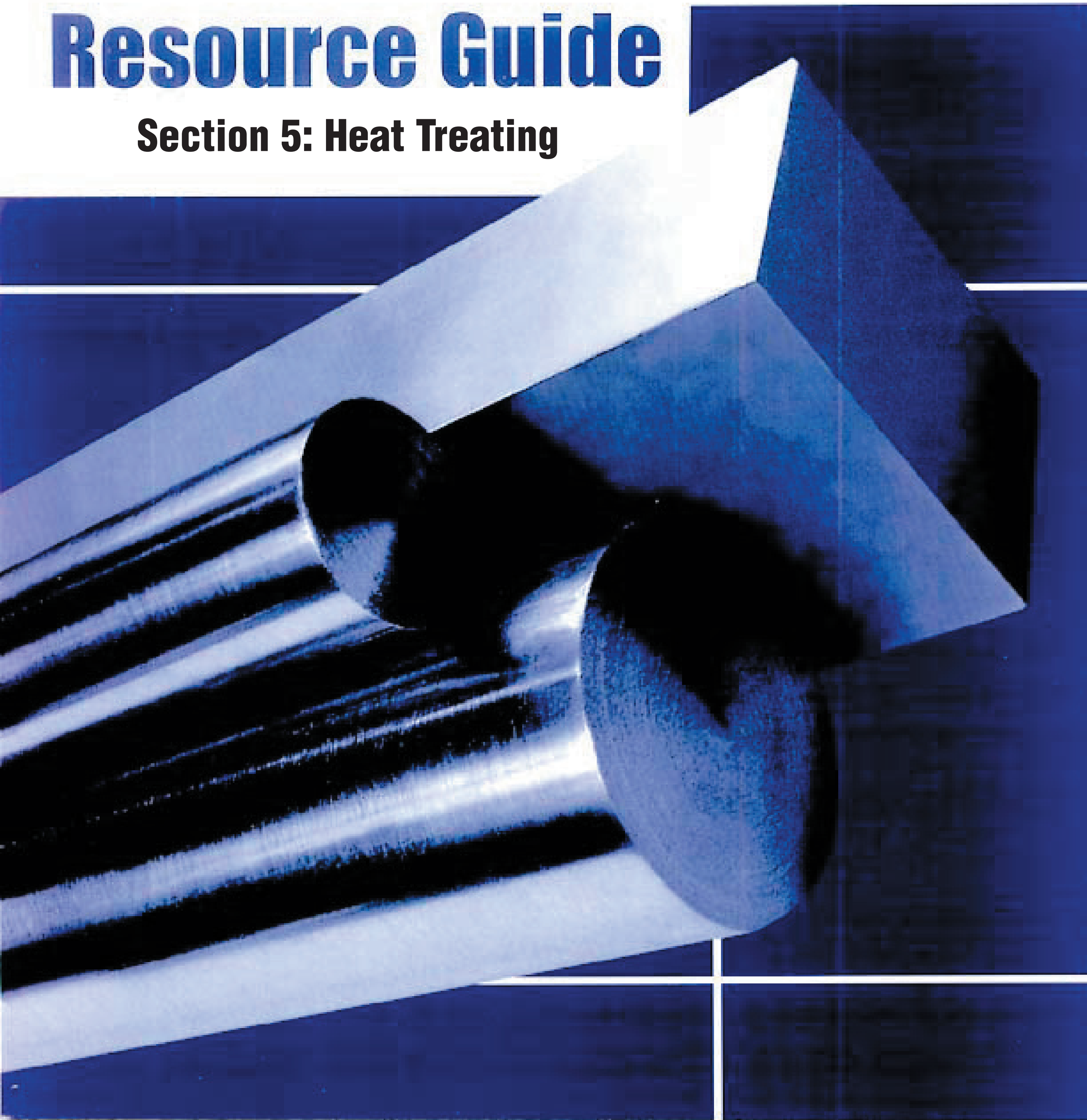
DURA-BAR®

Continuous Cast Iron Bar Stock

Resource Guide

Section 5: Heat Treating



Heat Treating

Heat Treating

Cast iron has a wide variety of properties because of the possible combination of graphite and matrix structures. An even wider variety of properties can be achieved through heat treat. Heat treating of cast iron involves heating to a specified temperature, holding at that temperature for a specified time, then cooling at a specified rate. The conditions under which a part is subjected to each of these parameters will determine the final properties of the part.

Holding temperatures depend upon the type of heat treatment. Temperatures about 1550°F (845°C) are often required to be above the critical, meaning the matrix structure transforms to austenite which can be cooled to form martensite, pearlite or ferrite, depending on the cooling rate.

Temperatures between 1300-1400°F (705-760°C) are considered to be below the critical and the matrix does not transform to martensite; instead the pearlite and carbides begin to dissolve to form ferrite and free carbon. Sub-critical temperatures are normally used to soften cast iron making it more machinable.

Temperatures between 800-1200°F (425-650°C) will not significantly change the matrix structure, and this range is most commonly used to stress relieve the material.

In general, heat treat will not affect the size and shape of the graphite. The matrix structure can be altered dramatically, and it is this change that influences the resulting properties.

This section is divided into six subsections containing general information on each of the following heat treat processes:

A. Stress Relieving
B. Annealing
C. Hardening
D. Surface Treatments
E. Austempering
F. Hardness Measurements
G. Growth

A. Stress Relieving

Residual stresses may be present in either an as-cast or a machined part. The presence of these stresses can cause problems in machining, particularly in the ability of the machine to hold dimension. Differences in cooling rate will cause thermal stresses to develop in a cast part. Simple shapes will cool more uniformly than complex shapes, and residual stresses are minimized in simple shapes. Residual stresses can be thought of as a load on a part that exists internally. That load is not strong enough initially to cause distortion because there is enough machine stock to resist the distortion. During machining, material is removed and the amount of stress may now be sufficient to distort the workpiece. It is, in this case, where residual stresses will be a problem.

Stresses can also be created during machining. As a cutting tool enters the workpiece, the grain structure is deformed slightly before the material is sheared off. Deformed areas will stress the workpiece and may cause distortion of the machined parts.

Stress relieving is used to eliminate residual stresses in a cast part prior to machining so that the deformation will not occur. It is a low temperature operation, and no change in the matrix structure or in the mechanical properties will occur.

In most cases, parts made from continuous cast iron bar stock will not have to be stress relieved. Round bars will have the most uniform cooling and will contain minimal residual stresses in the as-cast state. Rectangles and squares will be subjected to some differences in cooling rate and may have to be stress relieved when cut into plate. Large section parts, such as manifolds, will not normally require stress relieving because the mass of the part is sufficient to contain the residual stresses. Special shapes will be subjected to non-uniform cooling to a degree dependent on the complexity of the shape. The shape, amount of machining, and final section thickness should all be considered. Even under these conditions, stress relieving may not be necessary unless problems are occurring with warping during machining.

Proper stress relieving temperatures are a compromise between the degree of stress relieving and the resulting mechanical properties. Temperature has a stronger influence on stress relieving than the time at temperature. Stress relieving will start at relatively low temperatures but at least 800°F (425°C) is recommended.

A typical cycle is to hold the part at 1000°F (540°C) for one hour per inch of cross section. This will relieve approximately 90% of the residual stress, will prevent a change in the matrix structure, and should be sufficient for most applications. In order to ensure zero percent residual stress, the temperature would be too high to retain the original matrix.

The cooling rate is also important and should be slow enough that the part does not develop high thermal gradients which can induce stresses. Furnace cooling at a rate less than 100°F-600°F (40°-315°C) per hour is recommended. Furnace cooling to 300°F (150°C) will be more costly but will ensure that the ultimate amount of stress relieving was accomplished.

B. Annealing

Annealing is a softening process that is achieved by first heating the workpiece to the desired temperature, then slow cooling the metal through the critical temperature range. Iron can be annealed so that only ferrite is present and optimal machinability will be achieved. Strength, hardness and wear characteristics will be significantly lower.

Several types of annealing are performed depending on the desired results. The following table was taken from the *Iron Castings Handbook* and lists the types of annealing and recommended cycles.

It is important to note that only the matrix structure is changed during the annealing process. The original graphite structure remains essentially unchanged. Alloy carbides that are present due to chrome additions will not be annealed and will still remain as a hard spot in the iron.

Table 1
Recommended practices for annealing gray iron castings

Type of Anneal	Purpose	Temperature	Time	Cooling Rate
Low temperature (Ferritizing)	For conversion of pearlite to ferrite in unalloyed irons for maximum machin-ability	1300-1400°F 705-760°C	45 min. per inch of cross section	Furnace cool (100°F or 40°C per hour) to 600°F (315°C). Cool in still air from 600°F (315°C) to room temperature.
Medium temperature (Full anneal)	For conversion of pearlite to ferrite in irons unre-sponsive to low tempera-ture annealing. For elimi-nation of minor amounts of well displaced carbides in unalloyed irons.	1500-1650°F 815-900°C	1 hr. per inch of cross section	Furnace cool to 600°F (315°C). Cool in still air from 600°F (315°C) to room temperature. Furnace cool to 600°F (315°C). Cool in air from 600°F (315°C) to room temperature.
High temperature (Graphitizing) Full anneal	Elimination of massive carbides in mottled or chilled irons and conver-sion of pearlite to ferrite for maximum machinability.	1650-1750°F 900-955°C	1-3 hrs. plus 1 hr. per inch of cross section	Air cool from annealing temperature to below 900°F (480°C). May require subsequent stress relief.
Normalizing anneal	Elimination of massive carbides with the retention of pearlite for strength and hardness.	1600-1750°F 870-955°C	1-3 hrs. plus 1 hr. per inch of cross section	

C. Hardening

Austentizing, then quenching and tempering will produce maximum hardness on an iron part. This process will increase strength, and a wide range of both hardness and strength is possible by altering the tempering temperature.

Maximum obtainable hardness and depth of hardness for a particular grade of metal is determined by Jominy end quench tests. Jominy curves are important for heat treaters to know what can be expected from the material under ideal conditions. Dura-Bar stock grades are low alloyed irons that can be hardened to 50 Rc on the outside edge. Jominy curves for G2, 80-55-06 ductile iron and nickel-alloyed ductile iron are shown on the following pages.

Fig. 1
Jominy curve for Dura-Bar gray iron

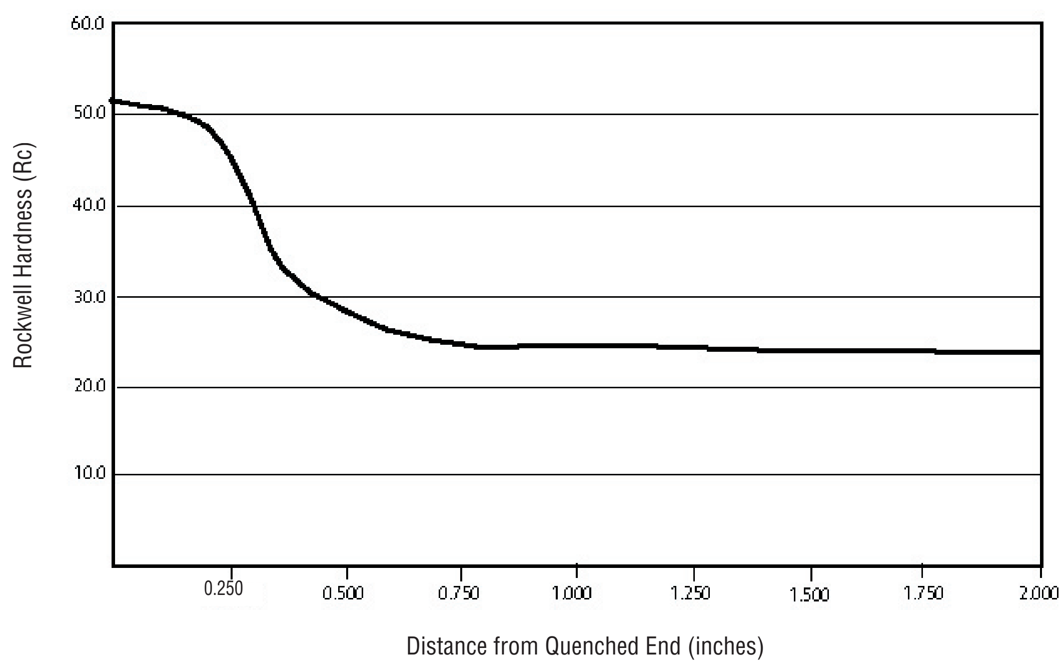


Fig. 2
Jominy curve for ductile iron

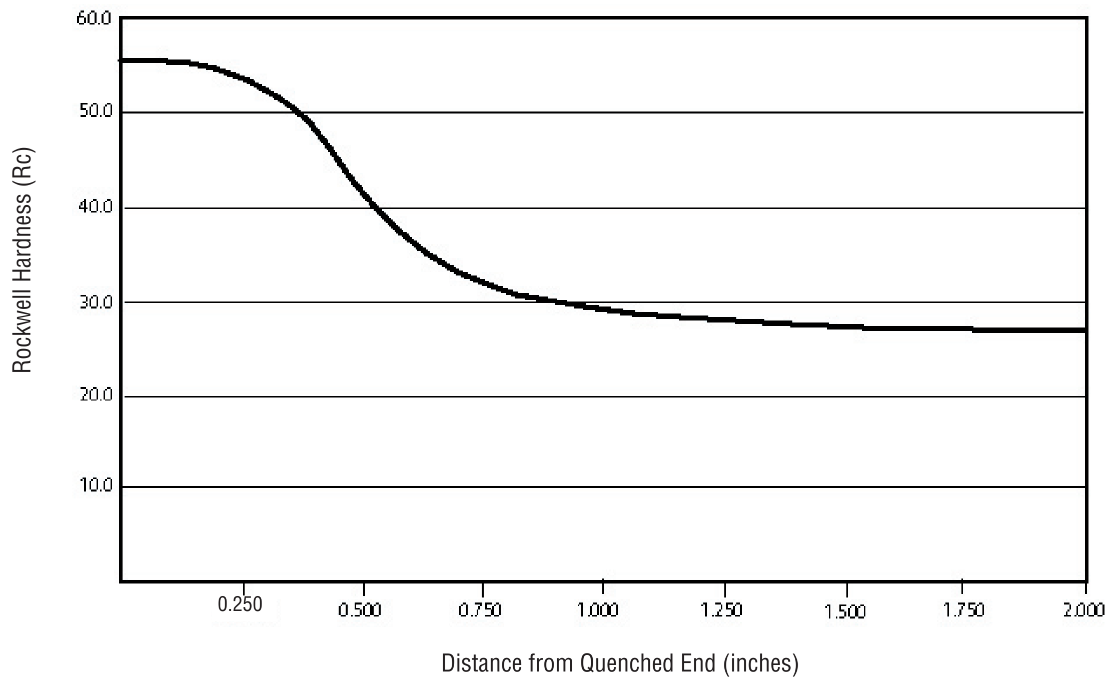
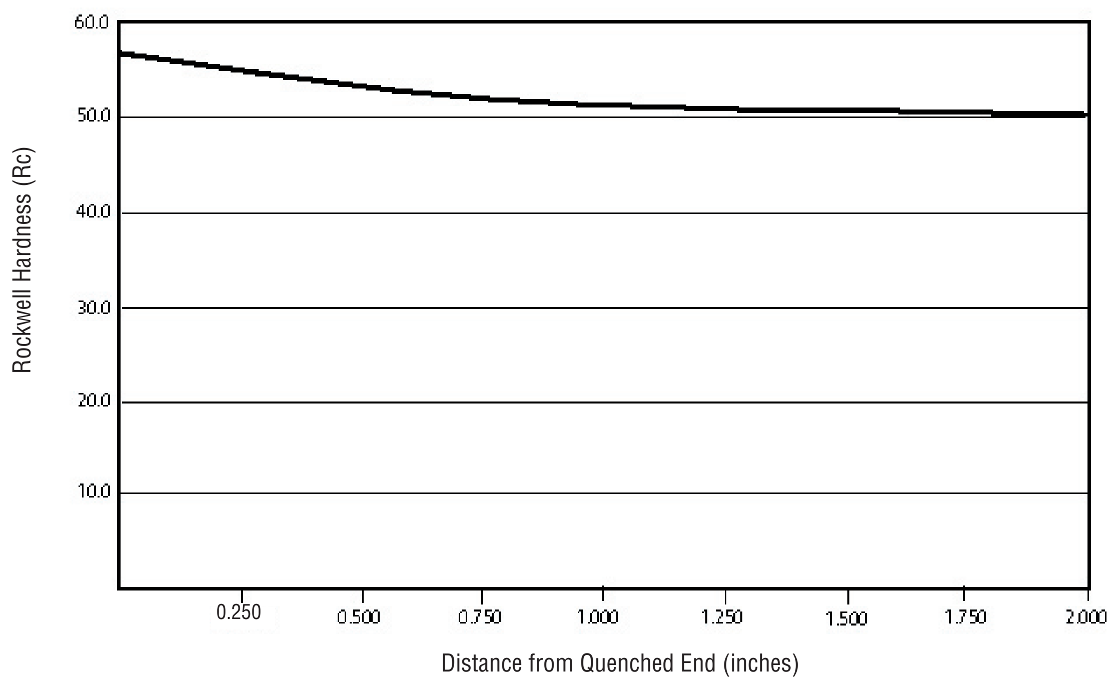


Fig. 3
Jominy curve for ductile iron with 0.50% nickel added



The G1, G1A and G2A grades will have a Jominy curve similar to G2. The 65-45-12 and 100-70-02 will have a curve similar to 80-55-06.

It is important to note the effect of nickel additions on the ductile iron Jominy curves. Hardenability and depth of hardness are dramatically improved, and a greater degree of through-hardening is possible. Steels alloyed with nickel and molybdenum are usually done so for this purpose.

A hardened part may not need to be fully martensitic depending on the application. The depth of hardness obtained after quench and tempering is usually sufficient to achieve desired results. It is also important to note that the depth is achieved on all outside surfaces. A part 1" x 1" x 1" will be through-hardened even if depth of hardness is only 0.500". It is always best to leave the specific cycle for heat treating to the heat treater. A suggested cycle is given below:

1. Heat uniformly to 1650°F (900°C).

2. Hold at temperature for one hour per 1" of cross section at the maximum thickness.

3. Quench in agitated oil.

4. Temper to desired hardness. Hold at tempering temperature for twice the length of time it takes to heat the part to temperature.

Tempering temperatures will typically be between 400°F and 1000°F (205°C and 540°F). Maximum hardness will be achieved at a 400°F (205°C) temperature. Temperatures above 1000°F (540°C) are usually not recommended because the martensite can start to break down, significantly lowering the hardness of the quenched part.

Tempering must immediately follow the quench. Thermal stresses will develop because of the temperature gradients within the part while it is cooling. A quenched part can develop cracks if it is not tempered soon enough.

NOTE: Any surface imperfection can cause stress risers to occur during the quenching operation. In order to minimize the chance of cracks occurring, all bars should be machined with the as-cast surface removed prior to hardening.

D. Surface Hardening

Surface hardening of Dura-Bar will improve wear resistance on outside surfaces as needed. The two most common methods are induction hardening and flame hardening. Each method requires that the area to be hardened is heated, held at temperature and rapidly cooled.

E. Austempering

Austempering utilizes a high temperature salt quench tank that causes austenite to transform to acicular ferrite and high-carbon austenite. The process is commonly performed on Dura-Bar 65-45-12 and 80-55-06. Nickel additions may be required for austempering ductile iron parts greater than 2.0" thick.

The resulting structure will give excellent wear characteristics, high impact strength and mechanical properties.

F. Hardness Measurements

The best method of evaluating heat treat results is the hardness of the finished part. Brinell tests are preferred for cast iron, but Rockwell tests are acceptable if used and interpreted correctly. The average value of several Rockwell tests is preferred in order to avoid the negative effect of graphite on the results.

A typical hardness value for a gray iron part that was quench and tempered is 45 Rc. The matrix structure is fully martensitic, which will have a hardness of 60-65 Rc, as determined by a micro-hardness test. The influence of graphite causes a lower apparent hardness on the finished part.

A more conclusive test for successful heat treat is to prepare a sample for microstructure evaluation and examine the etched structure at 100x.

G. Growth

Cast irons will increase in size when heat treated primarily because of the decomposition of carbides from the pearlitic structure. The amount of growth depends on the chemistry and microstructure of the material. It is also difficult to perform the exact same heat treatment on every part, and growth variations may be inherent in the process. To a certain extent, growth can be predicted to a range which helps to determine initial machining tolerance.

Since growth occurs as a result of the decomposition of carbide, irons having a higher pearlite content will grow more when heat treated than ferritic grades. If the heat treat process is exactly the same every time, a fully pearlitic part or a fully ferritic part will show the most consistent growth.

Dura-Bar G1, G1A, G2A and all ductiles have a pearlite/ferrite matrix, and consistent growth after heat treat will be difficult to achieve because of the normal variation in the ratio. Expected growth will be between .05-.20% in ductile irons and .10-.50% in gray irons.