Some Basic Considerations in Controlling the Mechanical Properties of Cast Iron—Part VIII

In Table 1, the carbon content was held constant at 3.50%, and the carbon equivalent was varied by changing the silicon content of the iron. In Table 2, the silicon content was held constant, and the carbon equivalent was varied by changing the carbon content of the iron. In each instance the iron was properly inoculated.

It can be concluded from the results shown that silicon is slightly more effective than carbon in reducing the chill value of a given carbon equivalent gray cast iron. For example, in the case of a 3.9% carbon equivalent gray cast iron, the chill value will be greater if the carbon is 3.50% and the silicon 1.20%, than if the carbon is 3.10% and the silicon 2.40%.

The specifications called for the carbon equivalent of the iron to be in the range of 4.0 to 4.2%. However, in checking the carbon equivalent of the iron, it was found to vary between 3.8 and 4.3%. When the carbon equivalent was on the low side (3.8-3.9%), shrinkage and hard spots were present in the castings.

The melting at this foundry was done in large cupolas. The metallic charges were 10,000 pounds and consisted of steel, returns, purchased iron scrap and some pig iron. From the cupolas, the molten iron went into five-ton unheated forehearts where it was tapped into 3000-pound transfer ladles. From the transfer ladles the iron was distributed into 1000-pound pouring ladles, at which time the iron was inoculated.

When it was found that there was such a variation in the carbon equivalent of the iron tapped from the forehearth, adjustment was made by adding silicon to the pouring ladle. This solved the chill problem, but did not always help the shrinkage problem. Both problems were finally solved by enlarging the forehearts so that they would hold at least three charges of metal. This resulted in more uniform carbon equivalent values in the iron as well as more consistent carbon and silicon contents in the castings. Eventually, large induction holding units capable of holding six charges of metal were installed. This actual example illustrates the importance of not only maintaining close control of carbon equivalent, but also the chemistry of cast iron.

The variations in carbon equivalent as well as chemical analyses can occur in both cupola and electric arc melting of cast iron even though the furnace charges are calculated to produce the required carbon equivalent. This is because there is very little mixing action during these melting operations. In such instances, holding furnaces capable of uniformly mixing the metal and maintaining its temperature are advantageous. In the case of induction melted metal, uniformity of analyses and carbon equivalent consistency are no problem because of the stirring action during the furnace operation.
Effect of Residual Elements on Chill

2. Variation in residual elements can cause differences in chill values during a given melting period. Such elements as chromium, vanadium, molybdenum and boron are carbide formers and can be introduced with the scrap charge. It is difficult to control the scrap analysis so that minor amounts of these elements do not get into the charge. Other elements, not necessarily present in the scrap, that affect the chill in cast iron are tellurium, lead, bismuth and antimony.

Tellurium when added to iron, is an extremely powerful carbide stabilizer. It promotes undercooling by suppressing the eutectic temperature of the cast iron. Its effect is so strong that very minute quantities will convert an iron which would normally be gray in a given section to one which would be entirely white. It is often used specifically for intentionally producing chilled iron castings. Any cast iron scrap containing tellurium should be kept separately and not added to iron requiring low chilling tendencies. Tellurium is often used in mold, or core washes for chilling the surface in certain areas of iron castings. Often, some of the wash adheres to cast iron scrap, or returns, and can be added unintentionally to the iron charge. As little as 0.001% tellurium can cause hard spots and excessive chill in gray iron castings. Figure 1 illustrates the effect of tellurium on the formation of carbides in 1.2" dia. gray cast iron test bars.

![Figure 1. Effect of Tellurium on the chill of gray cast iron test bars.](image)

A—no tellurium
B—0.005% tellurium
C—0.010% tellurium

Lead has very limited solubility in iron. However, amounts as low as 0.001% have been shown to cause a lacy type of graphite structure in gray iron castings over about 1" in section thickness and an increase in chill in thinner section castings. Lead can be introduced in the charge as free machining steel, or as an ingredient in either soldered parts or bearing metals.

Bismuth in amounts up to 0.025% is often added to malleable iron to prevent graphite precipitation during the solidification of heavy section castings. In fact, additions of 0.025% bismuth and 0.002% boron have made possible the casting of white iron in sections up to 5" in thickness.

Antimony added to cast iron has been found to stabilize carbides when present in quantities over 0.01%. This element can be unintentionally added when using soldered parts as scrap, or if improperly stripped motor blocks are part of the furnace charge. Some bearing metals used in the automotive industry contain antimony and are often present in motor blocks.

The first of the residual elements discussed—namely, chromium, vanadium and molybdenum—are popular alloying elements in cast iron, primarily in the high strength alloy cast irons. Chromium and vanadium have a strong affinity for carbon, and, therefore, are strong carbide forming elements. However, they are also excellent for imparting other beneficial properties to cast iron, including strength, hardness, wear resistance and strength at elevated temperatures. Also, vanadium, because of its tendency to promote small graphite flakes and a fine pearlitic matrix structure in gray cast iron, improves the repeated impact strength of the iron. This was discussed on page 3 of Foundry Facts No. 17. One important fact to remember if these elements are used, is that some nickel and/or copper should be added along with the vanadium and chromium to neutralize the carbide forming tendencies of the latter two elements. If, however, there is a build-up of the carbide forming elements, and no nickel or copper are present in the iron, there is a strong tendency for increased chill in thin section gray iron castings, especially if the carbon equivalent is under 4.00%. Also, as the carbide forming elements increase in gray cast iron, it is very important to properly inoculate the cast iron to minimize the formation of primary carbides. In the cases of high residual chromium (0.20%) and vanadium (0.08%), an inoculant containing about 10% cerium added in the proper quantities (0.10-0.20%) is often helpful in preventing carbides in castings under 1/2" in thickness.

Residual amounts of molybdenum (up to 0.15%) in the absence of residual amounts of strong carbide forming elements, are not too harmful in increasing chill in cast iron. However, the effect of residual carbide forming elements is additive in cast iron. It might be that a residual amount of one of the carbide forming elements (except tellurium, boron and bismuth) will not increase the chilling tendencies of the iron. But if several are present in small quantities, chill problems may be encountered. Again, proper inoculation can help this problem.

Effect of Pouring Temperature Variations

3. Variations in chill depth of cast iron during a given melting period can involve differences in pouring temperatures. Usually, with a constant metal chemistry, a higher pouring temperature will result in a lower chill because of a slower rate of solidification. When an iron solidifies slowly, it will solidify at a higher temperature than when faster solidification, which promotes undercooling, takes place. If equilibrium conditions of solidification take place, the cast iron will solidify in accordance with the iron-carbon-silicon equilibrium diagram and, depending on the carbon equivalent value of the iron, no chill will be present in the castings after solidification.

As an example of the importance of controlling the pouring temperatures of cast iron, the experience at an eastern foundry where both gray and ductile iron are produced will be discussed. The melting at this foundry is carried out in coreless induction furnaces.

During the day it was noticed that, periodically, hard castings were being produced. In examining the fracture and microstructure of these castings, it was found that considerable carbide areas were present, especially on the edges of the castings. Various inoculants were tested, but the problem still continued. The charge materials were carefully checked. In fact, handpicked steel and pig iron were used in several heats. Even then, the problem persisted. Finally, the possibility of pouring temperature variation was considered and carefully checked. It was found that the pouring temperatures varied from 2700° down to 2350°F. The castings that were poured at temperatures under 2450°F were more prone to the chilled edges than those poured at the higher temperatures. The castings involved were not heavy section castings, but ranged from 3/4" to 1 1/2" in thickness. The carbon equivalent of the iron was about 4.0% with the carbon about 3.30% and the silicon around 2.10%.

In checking the furnace tapping temperatures, it was found that during an eight hour shift, they ranged from 2800° to 2600°F. The iron was tapped into a 3000-pound transfer ladle and split into six 500-pound pouring ladles. The iron was inoculated during the filling of the pouring ladles. No covers were used on the ladles during the transfer and pouring operations.

In solving the problem at this foundry, the tapping temperatures were controlled between 2800° and 2725°F. Ladle covers were added to prevent temperature loss during metal handling. This resulted in higher and more consistent pouring temperatures. Actually, instead of pouring from 2700° down to 2350°F, the range narrowed to 2700° to 2550°F. This has resulted in more uniform castings, freedom from hard spots, and primarily Type A graphite flakes in a fully pearlitic matrix structure.

Oxidation Can Effect Chill

4. Variations in the chill depth of test specimens can also be caused by the oxidation of the molten metal. Molten metal oxidation can occur from the condition of the charge materials, and over exposure to air during the melting, tapping, transporting and pouring operations.
At a foundry producing gray iron castings, the melting was carried out in coreless induction furnaces. The furnace charges consisted of 20% pig iron, 50% steel scrap and 30% returns, plus sufficient carbon raiser and 50% ferrosilicon to bring the final carbon and silicon to the desired levels. The pig iron was used to make the melted iron more responsive to inoculation. It was found that a certain amount of pig iron helped graphite nucleation. However, at times the iron castings contained chilled areas which caused machining difficulty as well as cracked castings. One of the steps taken to control this problem involved more frequent chill tests on the metal being tapped from the furnaces. Over a period of time the chill values of the base irons varied considerably, resulting in the use of more inoculation.

In checking the chemical analysis of the base iron at periodic intervals, it was found that carbon and silicon recoveries were not consistent. Even though the charges were carefully calculated for carbon and silicon contents, these elements were frequently well below the desired amounts. This resulted in higher chill values because of the lower carbon equivalent of the iron.

It was suggested that the high losses of silicon and carbon might be due to the use of excessively rusty charge materials. Examination of the pig iron and steel scrap in the storage area revealed a considerable difference in the amount of rust present in these charge materials. Toward the bottom of the piles, more rust was present as loose scale. Also the individual pigs and pieces of steel scrap themselves varied in the amount of rust they contained.

In order to determine the effect of the rust on the loss of carbon and silicon, a quantity of pig iron and steel scrap was cleaned by sand blasting and several charges were melted using the cleaned material. Immediately, the carbon and silicon contents of the iron were right on target and the chill values remained fairly constant during the balance of the test. In addition, it was noted that much less slag was produced during the melting operation, resulting in cleaner metal and better furnace lining life.

Even though this example illustrates the benefits of using clean charge materials for the induction furnace melting of metal, it would be impractical to sand blast all the pig iron and steel scrap added to the furnace. However, by being a little more selective in making up the charges, and possibly storing the oxidizable materials under cover, more consistent and suitable results can be obtained.

In cupola melting, similar conditions can result from the use of excessively rusty charge materials, inferior coke, and poor furnace operating practice.

Sulfur Content Can Be Critical

5. Variations in the chill tendencies of gray cast iron chill tests specimens, as well as in gray iron castings, may also be due to the sulfur content of the iron. Too high a variation in sulfur content can cause variations in chill depth. This subject was discussed in Foundry Facts Nos. 6, 23, 24 and 25. It was pointed out that the ideal sulfur range for insuring satisfactory response to inoculation in gray cast iron appeared to be in the range of 0.05-0.12%, provided that sufficient manganese was present to prevent iron sulfide from forming. The usual manganese content for best results is 0.50-0.70% when the sulfur is in the range of 0.05-0.12%. This assures all of the sulfur in the gray cast iron of being in the form of manganese sulfide. If any iron sulfide is present, the chill will usually increase in the iron and embrittlement can result. Careful and frequent checks should be made to determine the sulfur content of gray cast iron so that it can be properly controlled through the use of manganese. The manganese sulfide formed, apparently helps the nucleation of graphite during the solidification of gray cast iron.

An example involving cupola melting illustrates the influence of sulfur in controlling chill in gray cast iron.

In a large automotive foundry, excessive chill variations were encountered that could not readily be explained. The usual factors affecting chill, such as carbon equivalent, carbide forming elements, inoculation, temperature, etc. were checked. Still, no success resulted. Finally, it was suggested that the sulfur content of the metal be checked. Normally, the sulfur in the iron varied from 0.09-0.12%. The amount of manganese was usually about 6 times the sulfur content and ran about 0.60-0.70%.

In checking the sulfur in the iron showing excessive chill, it was found to be as high as 0.20%. At the time, they couldn't account for this apparent sudden increase in sulfur. Further investigation, however, led to an inspection of the coke. It was found that it contained considerably more sulfur than the coke previously used. So, the molten iron picked up more sulfur which, in turn, formed iron sulfide. This occurred because insufficient manganese was present to tie up all the sulfur as manganese sulfide. By increasing the manganese to 0.80% during the period that the higher sulfur coke was in use, and by adding additional limestone to the charge in order to slightly reduce the sulfur in the iron, the chill was brought under control and satisfactory results achieved.

Effect of Furnace Charge Materials

6. Quite a bit has already been said about furnace charge materials and their effects on the chilling tendencies of gray cast iron. They can contribute to variations in carbon equivalent, residual elements, oxidation of the metal and sulfur content in the iron. However, it is important to know the exact composition of all charge materials in order to be able to compensate for changes in residual elements that might cause carbide problems in castings. As stated previously, such elements as chromium, vanadium, boron, bismuth, tellurium, manganese in excess of that required to tie up sulfur, and lead can promote nucleation of gray and ductile iron castings to produce chilled areas. It is important to note that the effect of the above alloying elements on chilling tendencies in cast iron is additive, and that they can build up over a period of time. If this should happen, it is a good idea to dilute the concentration of the elements with a high purity pig iron added to the charge. This is especially true in the case of ductile cast iron where the elements of magnesium and cerium are present. These latter elements, being carbide formers themselves—if present in excessive amounts—can contribute to the carbide forming tendencies of the other elements. Another such element is molybdenum. Although it is considered to be only a mild carbide former, molybdenum can increase the chilling power of the other carbide forming elements.

Since variations in carbon equivalent, as previously mentioned, can affect the chill values in cast irons, care must be taken in preparing the charges. All the components of a charge should be carefully weighed and held within fairly close limits each time an addition is made to the furnace. For example, if the major portion of a furnace charge consists of steel, cast iron returns and pig iron, even a variation of 10% in any one of the items can have a major effect on the carbon equivalent of the iron. If the steel charge varies on the high side, the carbon equivalent of the iron will be lower and the chill value higher than if the steel addition is on the low side and the other components on the high side, even though the total charge weight is the same. This might seem very elementary, but it is surprising how often it happens in actual practice. The people responsible for the charging operation at the foundry should be advised of the importance of this extremely fundamental fact. Remember, the production of consistent quality castings starts with consistency in the charging operation.

Consistent Inoculation a Key

7. Another important factor in controlling the chill in both gray and ductile iron castings is the inoculating practice. A standard inoculating practice should be established and consistently followed. If inconsistent techniques are used, variable results in the chilling characteristics of the iron are going to be obtained. One of the most efficient and simple ways for adding inoculants and alloys to cast iron is shown in Figure 2, taken from the "Alloy Cast Irons Handbook," published by the American Foundrymen's Society.
As an example of the effects of iron, the experiences at a large foundry were completely poured into the molds in the castings. Inconsistent and incorrect inoculating practices on the chill in the castings, at the given shift operation. The furnace operator would fill the ladle until after the iron was inoculated in the transfer ladles. Variations in the chill values from 50% during an 8-hour period. For this reason, extra inoculant was frequently added in the pouring ladles at the pouring station in order to prevent chilling in the castings. Normally, the elapsed time from filling the transfer ladle until the iron was completely poured into the molds was less than 8 minutes. In other words, the nucleating effect should still have been sufficient to properly control the chill in the castings.

In observing the inoculating practice at the holding furnace, it was noted that when the empty transfer ladle operating on a monorail system, approached the filling station, the furnace operator would frequently throw the inoculant on the ladle bottom. Other times, he would be doing something else at the moment, and would not throw the inoculant into the transfer ladle until after the filling operation had started. When delays were experienced on the pouring lines, the transfer ladle would be held at the filling area and not filled until the metal was again needed at the pouring floor. In the cases where the inoculant had been thrown on the bottom of the hot transfer ladle, it would often lay there as long as 15 minutes, depending on the length of the delay, before the ladle was filled. During this time, the smaller particles of the inoculant would oxidize and fuse to the ladle bottom, thus losing much of its nucleating power. Under these circumstances, the chill value of the iron when it reached the pouring floor was high, and further inoculation was necessary. However, when no delays were experienced, and the inoculant was added during the filling of the transfer ladle, the chill value was satisfactory and no additional inoculant would be added.

This situation was discussed with the person responsible for inoculating the iron, and it was suggested that the inoculant be added at the time the transfer ladle was being filled, using the technique shown in Figure 2. Since following this practice much more consistent results have been obtained.

**Importance of Consistent Chill Testing Procedures**

The second point to be reviewed in connection with the chill testing of cast iron is the importance of consistent chill testing procedures both before and after pouring the chill specimens. This was discussed in some detail in Foote Foundry Facts 20 and 21. However, a little more discussion in the form of an example is appropriate.

Probably, one of the most interesting examples of the importance of using a consistent practice in pouring chill test specimens, is the experience at a large eastern foundry. Problems were being encountered with hardness variations in the same design castings poured during a given shift. Customer specifications called for a hardness of HB 217 to 235 in a given section of the casting. However, frequently, the readings would be as low as HB 200. Chemical analyses run on the soft castings versus those in the proper hardness range did not show enough difference to account for the hardness variation. The pouring temperatures and shake out times were very consistent.

In checking the chill testing procedure it was found to vary considerably. Normally, the chill value of the base iron was checked at the furnace by catching a sample during the tapping operation. However, occasionally the person responsible for running the chill tests would neglect to have a chill mold at the furnace location. In such instances he would carry the molten iron in the small spoon ladle to an area about 75 feet away where several chill molds were stored on a bench. Here the chill sample would be poured. In comparing the chill values of samples poured at the furnace versus those poured in the bench area, it was found that the latter showed a somewhat higher chill value. Since the chill value of the base iron was used for determining the amount of inoculant added to the pouring ladle, more inoculant would be added when the chill reading was high. Castings poured from the more heavily inoculated irons were softer than those poured from irons containing less inoculant. In other words, inconsistent chill testing resulted in some castings being poured from over-inoculated irons. Since standardizing on the chill testing procedure by pouring the chill molds at the furnace, the proper amount of inoculant is now added and satisfactory hardness values are being obtained.

**Solidification of Chill Test Specimens**

Chill test specimens can be removed from the molds any time after solidification is complete. Since carbides in cast iron are formed during solidification, once the iron is solid, no further carbides will be formed. However, before a chill specimen is quenched in water, it should be completely solidified. Otherwise carbides will be present in the area where solidification was not complete at the time of quenching.

There are two reasons why, if time is available, it is desirable to allow the test specimens to cool below 1300°F before quenching:

1. to keep the wider portion of the test piece soft enough for metal sample drilling;
2. to make it easier to read the chill value. Quenching the sample immediately after solidification will produce a hard martensitic structure compared to the softer pearlitic structure formed by slower cooling. The fracture of pearlite is a darker gray color than the fracture of martensite and therefore the contrast in color between the chill portion and the unchilled area will be greater in the case of pearlite.

In summary, we have reviewed important aspects of chill testing covering variables that can occur during the melting and testing of cast iron, which can affect chill testing results. Controlling these variables and being consistent in all of the foundry practices are necessary steps for producing uniform high quality gray and ductile iron castings.