AN INVESTIGATION ABOUT FEEDING OF NODULAR CAST IRON

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ABSTRACT

AN INVESTIGATION ABOUT FEEDING OF NODULAR CAST IRON

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Pressure relief risering system necessitates blind risers to be able to utilize expansion pressure, otherwise, secondary shrinkage defects may occur. In addition, liquid (primary) shrinkage defect can also be seen with open riser, because its top develops a solid layer which, in turn, prevents atmospheric pressure so 'vacuum effect' becomes inside the riser. This danger increases with decreasing riser size. However, some amount of nodular iron castings have to be produced by using open feeders (risers) because of some manufacturing necessities. Our study aims to adapt the open riser for the pressure relief risering system by using a cover on the open riser. Therefore, soundness of casting can be guaranteed without decrease in casting efficiency.

Keywords : Nodular iron, pressure relief risering system, blind riser, open riser.

ÖZ

KÜRESEL GRAFİTLİ DÖKME DEMİR (KGDD) BESLEYİCİSİ HAKKINDA BİR ARAŞTIRMA

Tokaç, Halit

Yüksek Lisans, Metalurji ve Malzeme Mühendisliği Bölümü

Tez yöneticisi: Prof.Dr.Ekrem Selçuk

Ocak 1998, 50 sayfa

Basınç dengeleyici besleyici tasarımı,genleşme basıncından yararlanmak için kör besleyiciye gerek duyar, aksi halde ikincil çekinti hataları oluşabilir. Ek olarak, açık besleyicilerin üzerinde katı bir katman oluşması nedeniyle besleyicilerin üzerinde atmosfer basıncı ortadan kalkar ve besleyicinin içerisinde sıvı halde çekme sırasında vakum etkisi ortaya çıkar, bu duruma bağlı olarak döküm parçasında birincil (sıvı) çekinti hatalarına da rastlanılabilir. Buna karşın bazı küresel grafitli dökme demir dökümlerin, üretim ve tasarım koşullarına bağlı olarak açık besleyicilerle üretilmeleri gerekebilir. Bu çalışmamız, açık besleyicilerin bir kapak kullanımıyla basınç dengeleyici besleyici sistemine uyarlanmasını amaçlamaktadır. Böylece, döküm parçasının sağlamlığı döküm verimliliği düşürülmeksizin güvence altına alınabilir.

Anahtar Sözcükler: Küresel grafitli dökme demir, basınç dengeleyici besleyici sistemi, kör besleyici, açık besleyici.

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CHAPTER 1

INTRODUCTION

Nodular iron castings are now being extensively used various engineering applications. The main advantage of nodular iron is its steel - like mechanical properties with the advantage of better casting characteristics. The material is being widely explored for replacement to cast/forged steel components. A common defect observed in nodular iron castings is unsoundness resulting from solidification shrinkage during freezing, which, in turn, depend on the design of the feeding and gating system, the dimension and location of feeders, the molding method and the melt quality. Unfortunately, the ideas about an acceptable universal feeding system are pessimistic, because no universal theory about feeding nodular and gray iron has been accepted all over the world [1] . A particular risering system may achieve good results for a time and then suddenly shrinkage appears, with seemingly no other changes. This makes it difficult to develop a dependable design system that feeds nodular iron castings to the required level of soundness within limits of process variability [2] .

This situation is totally contrary to that existing in the steel foundry sector, where the freezing mechanisms steel alloys has been thoroughly researched and are well known and riser size and placement have now reached a position of being a sophisticated science based on the “modulus” concept theory introduced by Chovorinov and application later by Wlodawar. The modulus is a relationship between volume and cooling surfaces of a casting or a riser.

Nodular iron is unlike steel in two particular features:

1. it has a long freezing range and a mushy freezing mechanisms and

2. for a certain period during its solidification it undergoes an expansion due to graphite precipitation (some investigators believe, however, that not all expansion pressure can be accounted for in this way and postulate that a gas phase is the major cause of expansion pressure. Further, some papers have reported the presence of hollow spheroids).

In respect of any evaluation of nodular iron feeding whether by modulus or any other "numbering" system, several factors must be considered.

1. No solid skin is formed(as in steel) during much of solidification cycle of nodular iron (i.e. mushy type freezing prevails).

2. During solidification, the entire casting can be at the same temperature and then only gradients in heat content will exist.

3. The amount of graphite and its growth to compensate for shrinkage is both composition and modulus dependent.

4. Any mold wall movement will create additional feed metal demand [3] . Pressure relief risering system is widely accepted proper in green sand molds for nodular cast iron . This system utilize and control the expansion that occurs near eutectic temperature. In this system, most of the expansion pressure is relieved into the riser to minimize / eliminate mold swelling and / or core collapse. First, choke (gate) solidifies so casting and risering system are isolated from the gating system . During liquid contraction stage, melt is transferred from the riser through the neck connection to the mold cavity. This melt transfer creates a void in the riser. Then, melt begins expanding and liquid iron is forced back into the riser. At the last stage, the neck freezes just

before the expansion is complete and the remaining reduced expansion forces are used to compensate for secondary contraction without deforming the mold. Another important point of the system is the necessity of blind riser as riser type. It is essential to avoid the secondary shrinkage defects by using expansion pressure. Open riser may also cause liquid shrinkage defect. Therefore, open riser application is a risk for nodular castings. In some circumstances, however, open riser application may be more practical than blind riser . In this study , we developed a cover for open riser.

CHAPTER 2

THEORY

2.1. Solidification of Cast Iron

The differences between gray (nodular), mottled, and chilled irons are largely established during the freezing process. The fundamentals of the freezing process are related to the nature of the iron - carbon - silicon ternary equilibrium system. The properties of cast irons are greatly influenced by the thermal and chemical changes occurring during its entire history from liquid melt to cooled casting.

2.1.1. Solidification of Nodular Iron

Nodular iron does not freeze in layers from the surface of the casting, as do steel and gray iron. The eutectic solidification of the nodular iron occurred by the growth of comparatively minute cells, each comprising a nodule of graphite surrounded by austenite. The last liquid to solidify formed a network extending to all parts of the casting, whose solidification occurred at practically the same rate in all regions. Therefore, nodular iron of eutectic composition is believed to exhibit long - range, mushy - type freezing.

2.2. Solidification Shrinkage

The molten metal in the furnace occupies considerably more volume than the solidified castings which are eventually produced, giving rise to a number of problems for the founder.

As the temperature reduces, the first contraction to be experienced is that in the liquid state. This the normal thermal contraction observed by everyone as a mercury thermometer cools; the volume of the liquid metal reduces almost exactly linearly with falling temperature.

In the casting situation the shrinkage of the liquid metal is usually not troublesome; the extra liquid metal required to compensate for this small reduction in volume is provided without difficulty, usually without even being noticed, by a slight fall in level in the feeder.

The contraction on solidification is quite another matter, however. this contraction occurs at the freezing point, because (in general) of the greater density of the solid compared to that of the liquid. The contraction causes a number of problems. These include ‘feeding’, which is defined as any process which will allow for the compensation of solidification contraction by the movement of either liquid or solid, and ‘shrinkage porosity’, which is the result of failure of the feeding process to operate effectively.

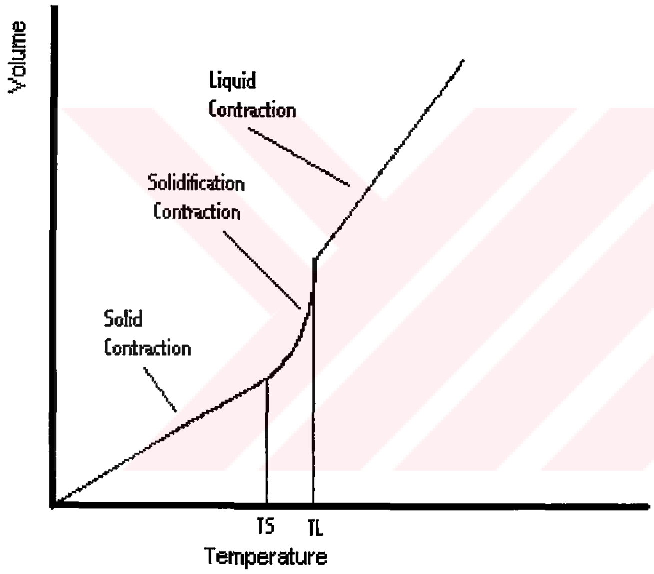


Figure 1. Schematic illustration of three shrinkage regimes: in the liquid; during freezing; and in the solid. [9]

The final stages of shrinkage in the solid state can cause quite different problems. As cooling progresses, and the casting attempts to reduce its size in consequence, it finds itself constrained to some extent by the mold. this constraint always leads to the casting being somewhat larger than would be expected from free contraction alone because of a certain a amount of plastic stretching which the casting necessarily suffers. It leads to difficulties in predicting the size of the pattern since the degree to which the pattern is made oversize (the ‘contraction allowance’ or ‘pattern maker’s allowance’) is not easy to quantify. The mold constraint during the solid-state contraction can also lead to more localized problems such as hot tearing or cracking of the casting.

2.2.1 Shrinkage Behavior of Nodular Iron

The volumetric study of nodular iron solidification related to its shrinkage behavior has long been an important research subject all over the world. Different devices have been developed to measure the graphitic expansion or expansion forces and the consequent mold-wall dilatation during solidification. The graphitic expansion, which has been found to be greater in the case of nodular iron than gray iron, has the most significant influence on the volumetric shrinkage, either by causing mold-wall dilatation or by serving self-feeding. Accordingly, some special feeding methods like pressure risering, the riserless process and pressure relief risering have been developed. Even computer simulation has been adopted in the risering design or in shrinkage estimation. Although the various methods appear to provide satisfactory results in specific circumstances, none can safely universally applied before the shrinkage tendency of the melt can be quantified and controlled [4] .

Nodilization and inoculation should be very influential metallurgical factors in the shrinkage tendency of nodular iron. It is reported that the mold-wall dilatation is strongly dependent on the composition of the nodulizers and that the effect of the magnesium content in the melt is most significant. However, different reports concerning the effects of inoculation are quite conflicting: e.g., inoculation is claimed to promote the mushy solidification mode, the mold cavity expansion and final shrinkage, or improved inoculation is found to decrease the tendency to form secondary shrinkage defects in nodular iron, or inoculation has found to have no influence on the soundness of uniformly sectioned castings. Such a situation is quite understandable, for the shrinkage is multidependent on the process factors. By looking only at one or two factors at a time, one can obtain quite variable results. The composition of the base iron and the pouring temperature are also important metallurgical factors. The carbon equivalent is reported to have the most marked effects among the basic elements in the melt [4] .

2.2.1.1 Volume Changes of Nodular Iron

As well as understanding the mechanism of solidification of an alloy, it is also important to recognize the factors that give rise to the volumetric shrinkage before efficient feeding of the casting can be attempted.

The total volumetric shrinkage of nodular iron is a function of four factors:

- Liquid contraction
- Graphite precipitation
- Solidification shrinkage
- Mold cavity deformation

2.2.1.1.1 Liquid Contraction

Nodular iron, like all other alloys, contracts during cooling in the liquid state. Muhlburger measured liquid contraction as 0,57% per 100°F (56°C) but his work was only on pouring temperature up to 2192°F (1200°C). Other workers experimenting on high carbon equivalent irons at higher superheat values have reported 0.53% and 0.38% per 100°F (56°C) [3] .

2.2.1.1.2 Graphite Precipitation

Since most commercially produced nodular iron is pearlitic in composition graphite is precipitated on cooling the superheated iron from the liquids down to the eutectic temperature. Since one cubic inch of iron weighs 0.284 16, while the same volume of graphite weighs only 0,0802 lb., graphite formation is accompanied by an expansion which can, under certain conditions, counteract the shrinkage due to solidification shrinkage and has been reported on occasions to compensate for the total of liquid contraction and solidification shrinkage.

During this period cooling liquid expands. This may create a positive pressure in the mold of several times atmospheric pressure [5] . A study has also shown that many dry sand and chemically bonded molds cannot withstand these expansion pressures unless properly cured [6] .

2.2.1.1.3 Solidification Shrinkage

In the absence of any graphite formation, iron contracts on solidification. In pure iron the liquid to solid phase change accomplished by volumetric shrinkage of 3.52 %.

Alloying elements dissolved in the austenite will probably affect this value, but in the absence of quantitative data it is generally assumed that their effect is not significant. The solidification shrinkage of nodular iron is usually assumed to be 3%.

2.2.1.1.4 Mold Cavity Deformation

It has been appreciated for many years that flake graphite iron castings produced in rigid molds (e.g. dry sand or CO2 silicate bonded sands) tend to be sounder and more true to pattern size than those produced in green sand molds. Extensive studies on flake graphite iron castings that have dilated have shown that this phenomenon is due to expansion forces which accompany the austenite/graphite eutectic solidification of the metal. Graphitic expansion in nodular iron is greater than in gray iron. Shrinkage tendency increases with the expansion before the liquidus temperature, and decreases with the expansion after the liquidus temperature. The reason should be that the expansion before the liquidus temperature cannot be fully used to compensate for the contraction caused by the austenite formation. More graphite that forms before the liquidus temperature, the less amount of graphite precipitating when the austenite grows. The graphite precipitating after the liquidus temperature posses stronger self feeding effects. In addition, the expansion force before the liquidus temperature makes the mold cavity deformation.

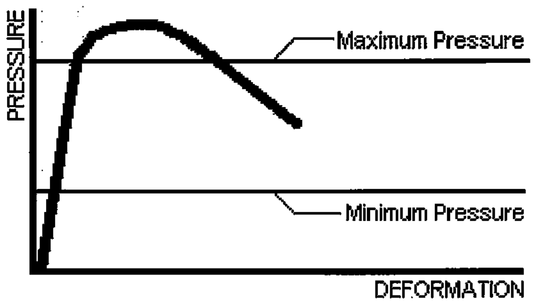


Figure 2. Schematic of expansion pressure containable by green sand mold. [5]

The absence of a completely solid skin of metal during freezing means that for nodular iron the mold wall alone gives resistance to expansion. Therefore, the requirement of mold stability or minimal wall movement is important for nodular iron in order to minimize shrinkage.

Liquid metal contraction, rather than expansion, prior to eutectic solidification is desirable because it causes the beginning of transport of feed metal from the riser to the casting with certain processing conditions, liquid contraction will begin before eutectic solidification proceeds.

2.3. Feeding Principles

To allow for the fact that extra metal needs to be fed to the solidifying casting to compensate for the contraction on freezing, it is normal to provide a separate reservoir of metal. We call this reservoir a feeder (riser), since its action is to feed the casting (i.e. to compensate for the solidification shrinkage).

It is most important to be clear that the running system is not normally required to provide any significant feeding. The running system and the feeding system have two quite distinct roles: one fills the casting, and the other feeds the shrinkage during solidification. Filling normally takes seconds, whereas feeding takes minutes. For very large castings filling may take minutes and feeding take hours or days. The two processes are very different.

The main question relating to the provision of a feeder on a casting is 'Should we have a feeder at all ? ' Just for the moment we shall assume that the answer is 'yes'. The next question is 'How large should it be?' It is mainly concerned with two feeding rules:

1. The feeder must solidify at the same time as, or later than, the casting. This is the heat - transfer criterion.

2. The feeder must contain sufficient liquid to meet the volume contraction requirements of the casting. This is usually known as the volume criterion.

However, there are additional rules which are also often overlooked, but which define additional thermal, geometrical and pressure criteria which are absolutely necessary conditions for the casting to freeze soundly:

3. The junction between the casting and the feeder should not create a hot spot, i.e. have freezing time greater than either the feeder or the casting. This is a problem, which, if not avoided, leads to 'under - feeder shrinkage porosity'.
4. There must be path to allow feed metal to reach those regions which require it.

5. There must be sufficient pressure differential to cause the feed material to flow, and the flow needs to be in the correct direction.

6. There must be sufficient pressure at all points in the casting to suppress the formation and growth of cavities.

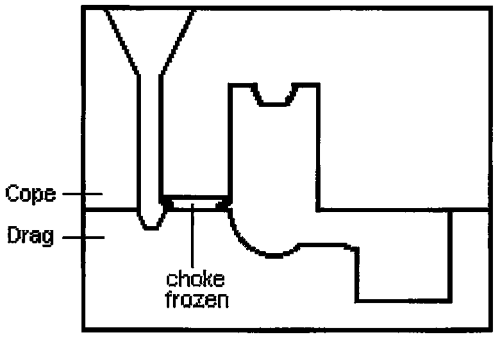
2.3.1. Feeding of Nodular Iron

2.3.1.1. Pressure Relief Risering

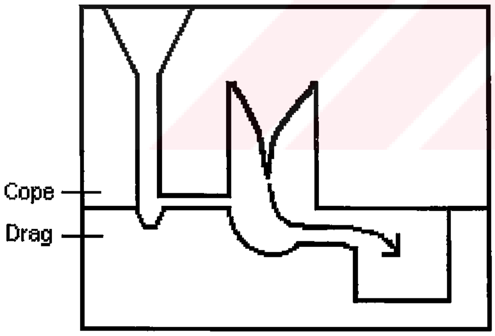
From an economic viewpoint, green sand molding is still the least expansive for high volume production. However, such molds are the weakest in common use and therefore are more prone to swelling under the influence of the expansion forces developed during the solidification of all types of graphitic cast irons.

The main feature of pressure relief risering system is utilization and control of the expansion that occurs near eutectic temperature. this expansion, which pressures all mold and core surfaces, is greatest in nodular iron and greater in compacted graphite irons than in flake graphite irons.

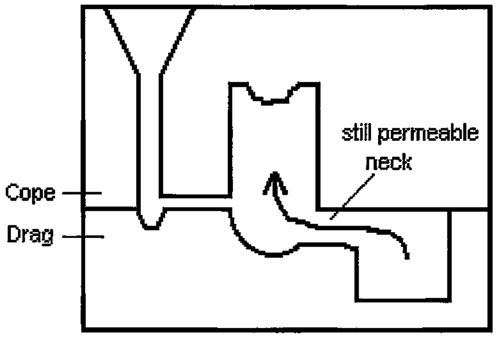
During the solidification of all types of graphitic cast iron, liquid contraction is followed by a significant expansion, which is associated with graphite formation, and then by a secondary contraction. At this point, it is important to distinguish between primary and secondary shrinkage defects; the former are revealed usually as surface shrinks or depressions, whereas the latter are internal porosity type defects or large voids that always occurred at the location of thermal centers.



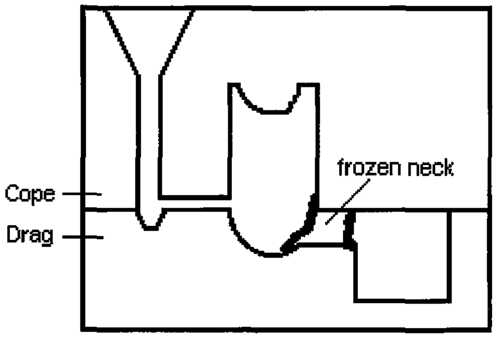
STAGE 1. Soon afterthe mold has been poured choke has solidified



STAGE 2. Riser compensates for primary shrinkage



STAGE 3. Expansion: Metal flows back into the riser



STAGE 4. Expansion continues and compensates for secondary shrinkage at location of hot spots.

Figure 3. Pressure relief risering system . [6]

To produce large shrinkage free, riserless nodular iron castings, a very rigid mold is necessary, capable of resisting the considerable expansion pressure of the cooling liquid nodular iron. A very favorable casting yield results from these circumstances. Many high volume foundries are unable to produce molds of sufficient rigidity to allow them to adopt a riserless production technique. Economics dictate the use of clay water bonded green sand which, no matter how prepared, can not withstand expansion pressure, except in the case of very thin castings.

At the pressure relief risering system, first of all, the gate solidifies soon after the mold is poured. Therefore, the casting and risering system are isolated from the gating system. Then, iron flows from the riser, through the neck connection to compensate for liquid contraction in the mold cavity. contraction is also taking place in the riser creating a void in the riser. Sufficiently high pouring temperatures are essential to ensure this void formation and for this reason, hot risers are preferred. After liquid contraction stage, the iron in the mold begins expanding and liquid iron is forced back into the riser through a sill ‘permeable’ neck connection . At the next stage, the neck freezes just before the expansion stage is complete and the remaining reduced expansion forces are sufficient to compensate for secondary contraction without deforming the mold. The desired result is a sound casting and an almost refilled riser.

Another paper describes the system as follows: “Initially the blind riser compensates for liquid contraction in the casting cavity. Thus a void is created inside the riser, as the liquid in the casting cavity starts to expand, during the second period of the cooling cycle, pressure increase in the liquid in the casting cavity is initially avoided since the pressure energy drives liquid from the casting cavity back into the riser which is ideally refilled. Once the riser is refilled it is obviously not possible to transfer any more liquid from the casting cavity and so the liquid in the casting/riser complex experiences a moderate pressure increase which continues to the end of the second stage of cooling. Providing the positive pressure in the liquid iron at the end of the second period of cooling is greater than the pressure decrease resulting from volume contraction of the last liquid to solidify during the third period of cooling, a secondary shrinkage defect will not form”. The difference between two descriptions is that, the first one starts the 'auto - feeding by pressure increase' with freezing of neck. However, the second one utilizes the pressure via refilling of the riser. To gain the pressure after refilling of riser , it is obvious that the expansion degree must be greater than liquid contraction and secondary contraction.

The important point in pressure relief risering is that most of the expansion pressure is relieved into the riser to minimize / eliminate mold swelling and / or core collapse. If significant mold swelling or core movement occur, it is often after riser contact has been lost and additional compensating feed metal from the riser is not available unless excessively large risers and neck connections are used. Such defects, then, are expansion induced secondary shrinkage (EISS) defects.

2.3.1.1.1. Metallurgical Quality Factor (Metallurgical Feeding Factor)

When designing a pressure relief risering system , two main factors must be considered. They are (a) the significant casting modulus (Ms) which is almost always the largest modulus section in the casting and (b) the so called 'metallurgical quality factor' (MQF) which describes the feeding characteristics of the iron . Because MQF is not related to mechanical properties and only to a limited degree to microstructure, 'metallurgical feeding factor' (MFF) may be better terminology because it relates to the ability of the iron to transport liquid metal through the casting back into the riser. An investigator states the range of MFF is 0.57 to 1.00 although another investigator suggests it may be broader , 0.50 to 1.20 . It should be noted that irons of high metallurgical feeding ability are at the low end of the MFF range. The product of Ms and MFF is transfer modulus (Mt). Mt = MFF x Ms .The transfer modulus is the least modulus section possible in a casting / risering system that will permit the transfer of liquid iron. In other words, this means that where two heavy sections of a casting are separated by a smaller section , if only one riser is to be used , the modulus of the smaller section must equal or exceed the transfer modulus. In this situation, the smaller section must not only be able to transfer liquid from the risered heavy section to the unrisered heavy section but also it must remain liquid long enough to transfer iron resulting from expansion back through the riser neck and into the riser . If the modulus of this smaller section is less than Mt then

1. each heavy section must be risered separately or

2. the smaller section modulus must be increased , in other words the casting must be re - designed, or

3. Mt must be lowered which means the MFF must be improved (MFF lowered) .

2.3.1.1.2. Riser Neck

Because the riser neck must remain permeable to liquid iron both at the liquid contraction stage and at the expansion stage (transferring liquid back into the riser, due to expansion) the riser neck modulus should equal or preferably slightly exceed the transfer modulus Mt . Because two non cooling surfaces of the neck connection are lost , i.e. the neck joins both casting and riser , and because of the increased hot spot in this area of the mold, the effective neck modulus Mn = 0.67Mt .This 0.67 factor has been found by previous investigators. With a neck connection smaller than that required the neck would solidify too early in the expansion period and expansion pressure results in not only a swollen casting but also secondary shrinkage defects in the thermal center.

2.3.1.1.3. Risers

The riser modulus must equal the transfer modulus : Mr = Mt . If the risers are too small, they will not be able to compensate for primary contraction . when the riser modulus is lower than Mt, but still able to compensate for primary shrinkage, the riser solidifies before the expansion forces have refilled it, and secondary shrinkage will appear, usually near the neck connection . Contrary to earlier beliefs, a severely piped riser should be regarded as a sign of danger, but an almost sound , refilled riser is a positive sign that the liquid transfer mechanism is working .

2.3.1.1.4. Melt Variables

The following variables can influence the MFF :The type of furnace used ,charge materials ,metal melt temperatures , furnace holding times, chemical composition , inoculant composition , inoculation method. Magnesium is an essential element in the commercial production nodular iron but it is a carbide forming element which adversely affects MFF . Therefore, the minimum amount of Mg necessary to achieve a satisfactory nodularity is recommended in order to minimize shrinkage. Manganese also increases carbide formation tendency so it must be controlled as low as the economic use of the available raw materials will allow.

2.3.1.1.5. The Importance of Pouring Temperature

If the pouring temperature is below 1357°C , shrinkage defects increase. The success of the pressure control risering system depends essentially on creating a sufficiently large shrinkage void in the blind riser during the initial period of liquid contraction . This void is required to receive the liquid expansion stage.

2.3.2. Open Feeders versus Blind Feeders

Millions of gray and nodular iron castings had been produced satisfactorily using open feeders. Some of these mightn't even contain internal porosity .

The univocal advice: never use open feeders ,always use closed feeders, then, may come as a surprise .

The advice arises from the roots of applied feeder design .Since the method utilizes expansion to compensate for secondary contraction, a sufficiently large open feeder with an equally large contact - both active to the end of expansion - will consume all expansion through transferring expanding liquid into the open feeder. Exuded beads on top of open feeders are well known to gray iron foundrymen.

Besides being proof of expansion , these also explain the painfully known defect : shrinkage hole or porosity in the feeder contact area. Should all or most of the expansion be spent on liquid transfer into the open feeder, then no or inadequate expansion is left to pressurize the remaining liquid so as to compensate for secondary contraction.

Success with the use of open feeders is a matter of luck which may vary with varying pouring temperature. Success with the use of closed feeders is assured, provided the design is correct, and reasonable control is exercised over pouring temperature.

CHAPTER 3

EXPERIMENT

As we mentioned before, pressure relief risering system needs blind risers to be able to utilize expansion pressure. However, some amount of gray and nodular iron castings have to be produced using open feeders because of some manufacturing necessities. For this aim, we developed a cover system which converts the open risers to the blind risers. At the experiments three types of system are compared: 1. Blind riser, 2. Open riser, 3. Covered open riser. The third one has been developed to use open risers safely like blind risers without decrease in efficiency. Efficiency of open risers is lower than that of blind risers of pressure relief risering system. In addition, application of pressure relief risering system is not possible to open risers.

3.1. Determination of Riser and Gate Dimensions

A cube is chosen as casting part to simplify the calculations. Its dimension is 6.6 x 6.6 x 6.6 cm^3 .

3.1. 1. Riser Design

1. Determine the significant modulus Ms of the casting . This involves breaking down the complex casting shape into simple shapes and determining the modulus of each simple shape [5] .

   Modulus is defined as the ratio:

   Ms = Volume / Effective Cooling Surface Area

   Ms is equal to the casting modulus in this study because it is a single segment. Modulus is considered to be the only parameter which allows an accurate prediction of cooling and solidification rate. Under the given conditions Ms is the largest segment modulus.

   Since Ms is equal to Mc (casting modulus) , Ms = 1.1 cm

2. From Ms , transfer modulus (Mt) is determined . Mt is defined as the modulus of a segment through which liquid transfer will take place from an adjacent larger segment, for as long time as necessary .

The necessary time is that required for the significant (heavier) segment (modulus = Ms) to dissipate its expansion pressure by transferring expanding liquid through an adjacent (smaller) segment. Obviously the adjacent segment must remain permeable to liquid iron for the necessary length of time. In other words , the adjacent segment must have a certain minimum modulus , Mt. The value of Mt was determined by using figure 4 which has its basis in the laws of Chvorinov and Newton , subsequently modified in the light of practical experience with ductile iron by previous researchers.

Mt = 1.0 cm (metallurgical quality was taken as ‘ average ‘ because good metallurgical quality requires cupola melting and almost completely special pig iron charge , however , it is not always practical in the foundry industry today). Mt is not critical for the casting in this study but it has importance to determine riser dimensions .

Figure 4. Transfer modulus vs. significant modulus as a function of metallurgical quality. [5]

3. As long as the significant segment of the casting needs to transfer liquid (to maintain containable pressure in the mold cavity) , the riser must be able to receive that liquid. That is to say the riser and riser contact must be permeable to liquid iron . Therefore, the riser and riser contact also must have a certain minimum modulus . It is obvious that the minimum modulus for riser must be equal to Mt .

As a result , Mr (riser modulus) = Mt , so that Mr = 1.0 cm .

Diameter of the riser (Dr) = 4.91 x Mr = 5 cm . [5]

Height of the riser = 1.5 x 5 = 7.5 cm

4. Construction of the riser neck (contact) needs to be such that the contact also has a modulus Mn where Mn is equal to Mt . However, providing the riser contact is short , a reduction in riser contact modulus is permissible, because the sand mold immediately surrounding the riser contact becomes superheated. Hence, the acting riser contact modulus is larger than what would be calculated from its dimensions. In other words , providing riser contact length is short, smaller riser contact can be used.

Consequently, Mn = 0.67 x Mt was used . [5]

Mn = 0.67 x Mt = 0.67 x 1.0 = 0.67 cm .

Contact shape was chosen as square.

Side length = 4 x Mn = 4 x 0.67 = 2.7 cm. [5]

5. Having constructed a suitable riser, it was necessary to determine whether or not the riser contained sufficient effective volume to compensate for the initial liquid contraction occurring in the casting during the first stage of the cooling cycle . Only the iron contained in the riser above the top most point of the casting is effective in feeding the liquid contraction of the casting. Since the casting is entirely at the drag half of the mould in this study , the whole volume of riser was considered as effective riser volume. An estimation of expected liquid

contraction was obtained using figure 5 which relates casting modulus to contraction. According to this figure % feed metal requirement is approximately 3 % .

Casting volume = 280 cm ^{3} .

Required feed metal = 3 % of 280 cm ^{3} = 8.4 cm ^{3}

Effective riser volume = total riser volume at cope half of the mould

Therefore, effective riser volume = 147 cm ^{3} .

Since this value is much greater than required feed metal amount , only one riser was used per each casting.

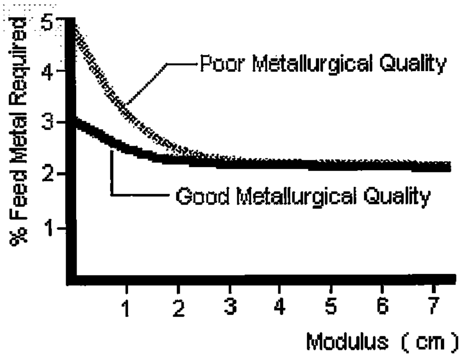


Figure 5. Relationship of modulus to shrinkage. [5]

3.1.2. Gating System

The choke must freeze as soon as possible to isolate the casting with riser at the end of the pouring. However, at the same time , choke dimension must allow fast pouring to keep the temperature high enough for pressure relief risering system. An optimum gate dimensions were selected .

$A = (1000 \times W) / (V \times d \times t)$

where A = total choke cross sectional area of the choke in cm^2

W = total weight of the metal poured into mould

V = velocity of the metal at the choke (cm / sec)

t = casting time

d = density of the melt ($7.3\ g / cm^3$)

$V = (2 \times 981 \times H)\ 1/2$

where H = effective casting height (cm)

$t = 1.64 \times (W)\ 1/2$

As a result, total choke cross sectional area was calculated as 0.8 cm2 and its dimension is determined as 18 x 4.5 mm . In addition, dimensions of runner bar and sprue are also determined as proportional to the choke

3.2. Some Other Casting Parameters

3.2.1. Melting

Metal was melted in a high frequency induction furnace . Charge was prepared by using special (sorel) pig iron , steel scrap, foundry nodular iron scrap, and required amounts of carbon and ferrosilicon for tuning the chemical composition of melt. Temperature of the melt did not exceed 1520 °C during melting and holding.

3.2.2. Magnesium Treatment

A 350 Kg sandwich Mg treatment ladle was used. 5.5 % FeSiMg master alloy was used for treatment. The melt was tapped from the furnace to the treatment ladle at 1500 °C.

3.2.3. Casting Temperature

Treated metal was tapped from treatment ladle to a small ladle and from this ladle it was poured into the moulds at 1385 °C. This temperature is high enough for pressure relief risering design, because the critical minimum temperature is 1370 °C for this risering design as mentioned before.

3.2.4. Chemical Composition

All of the castings were tapped from the same ladle. Therefore, composition , casting temperature, Mg treatment conditions and inoculation degree were almost identical for them .

Chemical composition of the casts is as follows :

C = 3.45 %

Si = 2.59 %

Mg = 0.041 %

Mn = 0.19 %

S = 0.007 %

P = 0.03 % .

3.2.5. Molding

Castings were molded by using wooden patterns into green sand molds (figure 6 , 7 and 8) . Molding conditions and the mould sand properties were same for all of the casts (5.5 % humidity , 8 % bentonite , and hardness number). A special design cover was used for covered open riser which was obtained by using a core box with furane resin core (figure 8) . A hot spot was created in the top of the riser like in the top of the blind riser. This is to prevent formation of a complete solid skin around the riser , to ensure the liquid iron in the riser remains at atmospheric pressure through the mold hot spot. Under conditions where riser hot spot is formed, a completely skin may form around the riser mold interface. As the riser supplies liquid to the casting, a void is formed in the riser. If this void is surrounded by a pressure tight solid skin, pressure inside the void will fall below atmospheric pressure and the riser will stop feeding as in open feeders. The cover also withstands the expansion pressure which becomes during graphite formation at the solidification .Therefore, secondary shrinkage possibility also decreases . For that, the cover must be loaded with the mold weights to withstand the graphitic expansion pressure.

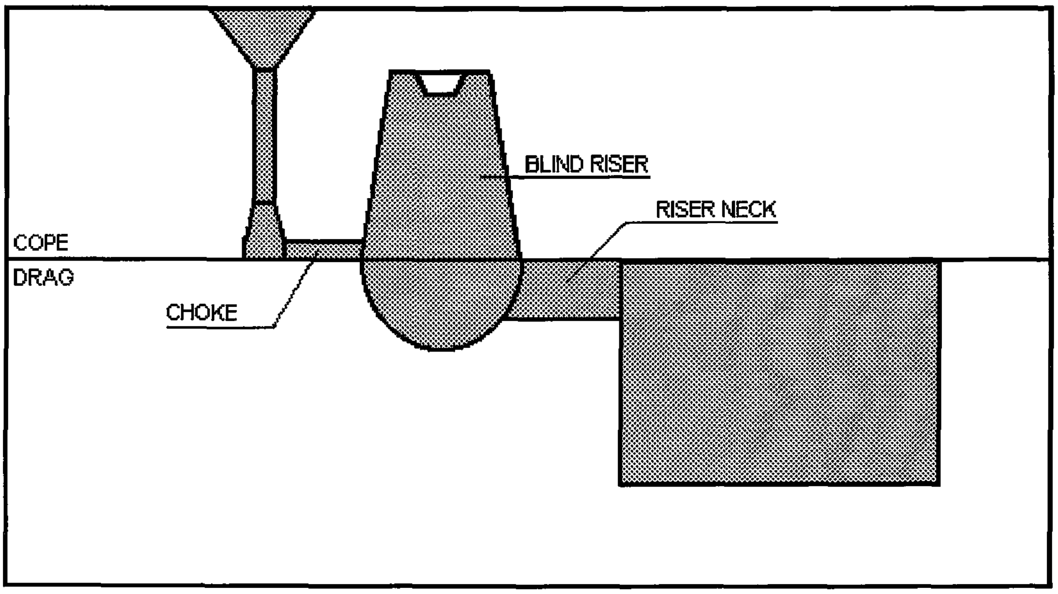


Figure 6. The cast with blind riser. Sprue, runner bar and choke are in the cope half of mould. Riser base, riser neck and the cast are in the drag half.

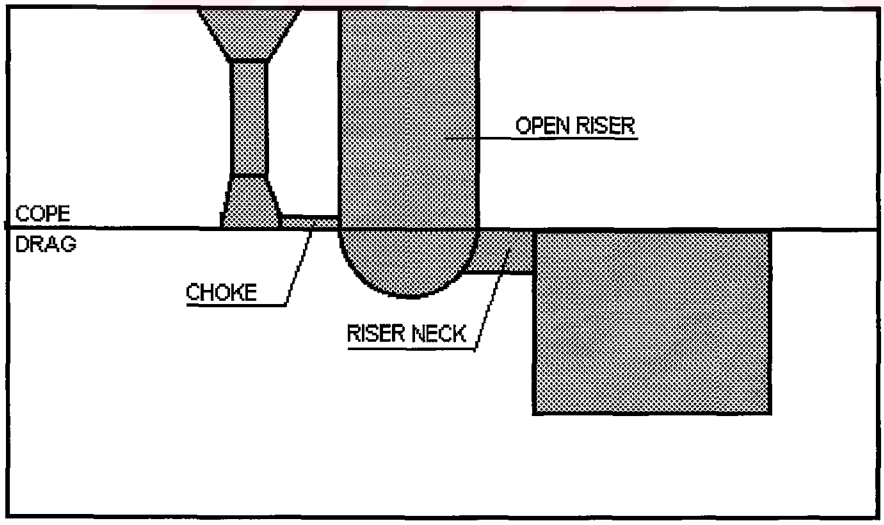


Figure 7. The cast with open riser. The unique difference from the cast with blind riser is type of riser.

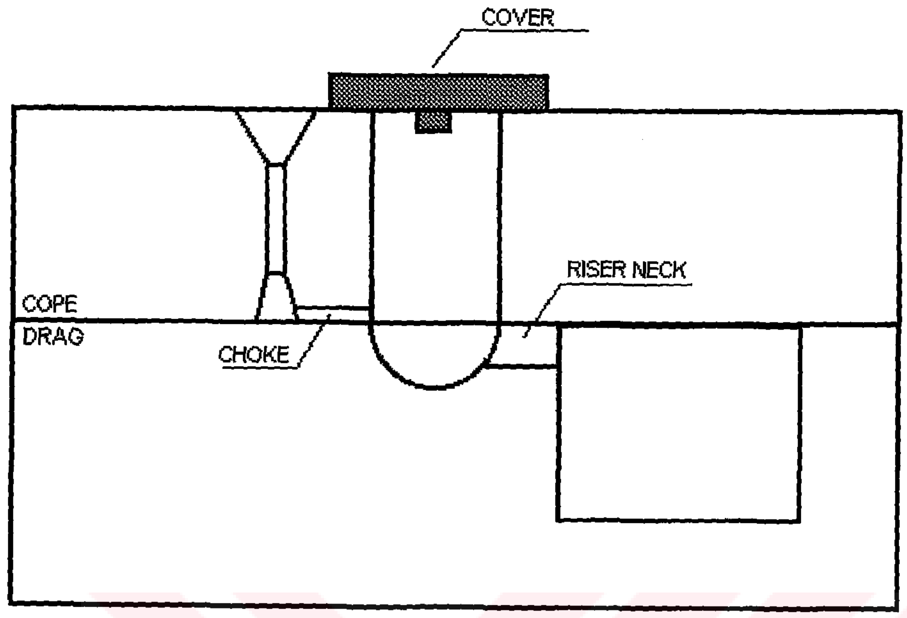


Figure 8. The cast with covered open riser. A cover is placed on the top of open riser as a difference.

CHAPTER 4

RESULTS AND DISCUSSIONS

The surfaces of castings were scanned before they were cut to test their soundness . The following data was obtained :

1. The cast with blind riser has flat surfaces (figure 9). There is not sink on the surfaces . In addition, a volcanic view was observed on the blind riser . These indicate that the blind riser is effective during first stage (liquid) shrinkage . Furthermore, graphitic expansion related mold cavity deformation was not seen. This shows that riser neck was permeable during graphitic expansion stage for the melt to feed back into the riser.

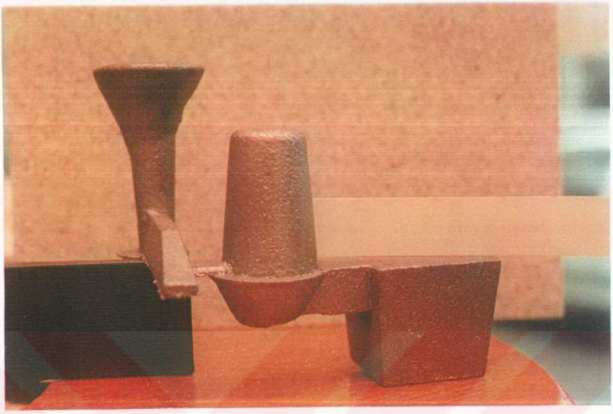


Figure 9. Photograph of the cast with blind riser.

2. The cast with open riser has only bottom surface as flat surface . The other surfaces (top surface and lateral surfaces) have sinks (figure 10) . Therefore, we can say that open riser could not feed the cast effectively even at the first stage (liquid) shrinkage. As expected, since there was no a hot spot in the top of the riser , a solid skin around the riser formed which isolated the liquid metal in the riser from the atmospheric pressure . As a result, pressure inside the void fell below atmospheric pressure and the riser stopped feeding . Therefore, due to the liquid shrinkage, sinks occurred.

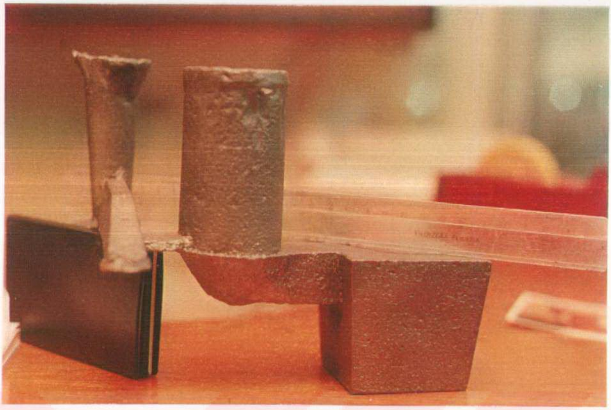


Figure 10. Photograph of the cast with open riser.

3. The cast with covered open riser has flat surfaces like the cast with blind riser , and no sink was observed . In addition, top of the riser indicates working in the riser (figure 11) . Therefore, we can say that the riser worked effectively during liquid shrinkage stage . As in the first one , graphitic expansion related mold deformation was not observed.

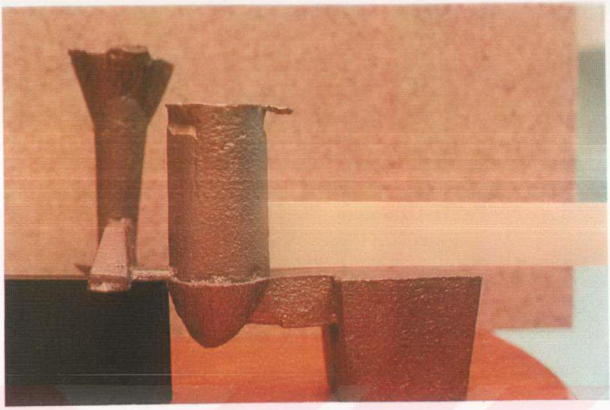


Figure 11. Photograph of the cast with covered open riser.

The soundness of castings were scanned by means of a milling cutter. They were scanned from the surface to center. The results were obtained as follows:

1. The cast with blind riser is completely sound. There is neither liquid shrinkage defect nor secondary shrinkage defect (figure 12) . This proves the reliability of blind risers. This point is very important , because pressure relief riser design make smaller modulus riser possible than casting modulus with blind riser. This situation gets higher casting efficiency . For example, in this study , casting modulus is 1.1 cm , but modulus of all of the risers is 1.0 cm. However , previous methods dictate that riser must have greater modulus than the casting like steel castings.

Figure 12. Photograph of internal view of the casting with blind riser.

2. The cast with open riser is not sound . It has a large liquid shrinkage defect in its thermal center (figure 13) . It shows danger of use of open risers. Remedy may be larger riser which causes decrease in casting efficiency. In addition, larger risers do not always guarantee the soundness for nodular iron. It is obvious that the use of blind riser solves the problem , but the use of blind riser may not always be practical due to manufacturing and design conditions. Therefore, we have already developed covered open riser design . This system make possible the use of open risers with a simple cover which can be produced from any core sand by using a core box.

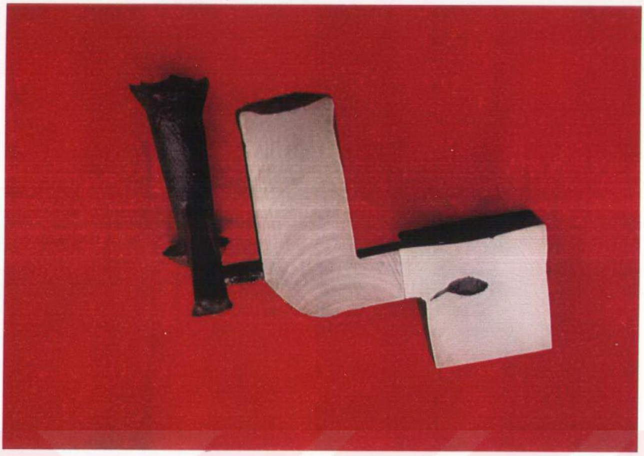


Figure 13. Photograph of internal view of the cast with open riser.

3. The cast with covered open riser is also sound like the first one and even secondary shrinkage defects were not observed (figure 14) . Therefore , we can claim that the covered open riser is as reliable as blind riser and it has same efficiency. However , some criterion must be considered to guarantee casting soundness . This considerations are summarized as follows:

Figure 14. Photograph of internal view of the cast with covered open riser.

If temperature drops below 1357°C , the incidence of castings with shrinkage defects increases significantly. The success of the pressure control risering system depends essentially on creating a sufficiently large shrinkage void in the blind or covered open riser during the initial period of liquid contraction . After all, it is this void which by liquid transfer allow the pressure of the expanding cooling liquid in the casting cavity to be maintained at a level which is containable by the weak green sand mold. This directly influences the occurrence of contraction related defects in the castings.

Metallurgical quality of the liquid iron can be influenced by : melt charge composition , method of melting ,degree of superheat experienced by the liquid iron, dwell time in the furnace and degree of inoculation .

At this time, metallurgical quality assessment for the purpose of riser design, is restricted to making an educated guess. We simply do not yet have reliable means to evaluate the influence of the individual factors mentioned above , and others, on metallurgical quality.

The significance of the possible range of Mt (transfer modulus) values is that the higher in the range the value chosen , the larger will be the riser required. Hence, casting yield suffers. Nodule count can be taken as a criterion for metallurgical feeding factor which determines the Mt and so dimension of feeder.

CHAPTER 5

CONCLUSION

Three types of riser were compared in the identical conditions . Conclusions drawn from the results of this study can be summarized as follows:

1. The blind riser is reliable and it has high efficiency if it is designed by means of rules of pressure relief risering system . The main rules of ductile iron risering must also be considered. In addition, for the production of sound nodular iron castings in green sand molds, the skills of both the methods engineer responsible for designing risering systems and the metallurgist/melting supervisor must be complimentary to each other. Without an adequate control over melt variables, no risering system can be expected

for function as intended at all times. Also the best feeding irons will not produce sound castings if the basic laws of solidification are ignored. In a practical sense, using the significant casting modulus concept and a relatively simple method of determining metallurgical feeding factors of the melt, it has been possible to design risering systems from which sound castings have been produced for a large number of different castings.

2. 0pen risers are definitely not proper for pressure relief risering design. They may be used in traditional designs with higher riser modulus. This situation causes decrease in casting efficiency and they can not guarantee the casting soundness.

3. Covered open risers can be alternative when the foundry conditions and the mould design dictate the use of open riser. This makes possible to determine the dimension of open riser by means of pressure relief risering design. Therefore, high casting efficiency can be obtained with covered open riser, and the soundness of casting can be guaranteed if other variables can be determined and controlled (like mold hardness, modulus of choke, pouring time, melt properties which include melt temperature, chemical composition, metallurgical quality that depends on type of furnace used for melting, charge materials, maximum melt temperature during melting and holding, furnace holding times, melt chemical composition, Mg

treatment method, degree of fading after Mg treatment, inoculant composition, inoculant addition method.

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