

# Quality Improvement of Ductile Iron Casting by Thermal Analysis

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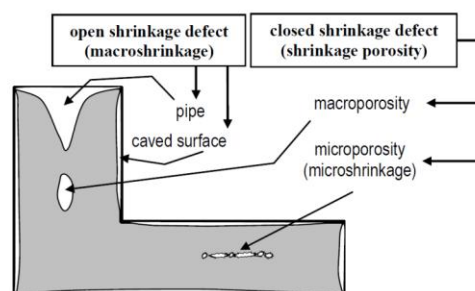
**Abstract** - Solidification of ductile Iron is complex & often leads to shrinkage. Melt Chemistry of charge prepared is insufficient to explain the way ductile iron shrinkage occurs in castings. The variations in melting, holding, treating and inoculating processes during the manufacturing of ductile iron impacts ductile iron solidification. Experimental results of thermal analysis in the casting where changes in cooling curves explained metallurgical characteristics to quality (shrinkage) of castings. Thermal Analysis of castings reduces quality issues such as shrinkage. Thermal Analysis (TA) is recording, analyzing the data & then interpret on the basis of temperature variation with respect to time of cooling or heated material. In ductile iron castings, the cooling curve gets recorded while solidifying metal in a mold and further analysis of this data is done. Interpretation is done on the basis of belief that during solidification, different events occurring leave their mark on the shape of cooling curves. With the help of this theory, the quality problems especially sinking or shrinkage problems faced for this casting are resolved.

**Key Words:** Thermal Analysis, Ductile iron casting, Shrinkage, Quality of casting, Cooling Curve

## 1. INTRODUCTION

The automobile industry is becoming cost effective. Ductile Iron castings are cheaper and it's possible to produce castings with lesser thickness. This reduces cost as well as weight. So these day's steel castings and forgings are getting converted into ductile iron such as crank shaft, gear shifter fork, connecting rod. Solidification of ductile Iron is complex & often leads to shrinkage. Melt Chemistry of charge prepared is insufficient to explain the way ductile iron shrinkage occurs in castings. The variations in melting, holding, treating and inoculating processes during the manufacturing of ductile iron impacts ductile iron solidification. The Experimental results of thermal analysis in the casting where changes in cooling curves explain metallurgical characteristics to shrinkage of castings.

Different researchers and foundries classify the same defects using different classification methods and terminology. Shrinkage defects are classified in two distinct groups, presented in Figure 1: open shrinkage (macro shrinkage) and closed shrinkage defects (shrinkage porosity). Open shrinkage defects are characterized by shrinkage cavities that are in contact with the surface of the casting and can have a pipe shape or simply a caved surface (on the side or top surface of the casting). These defects are a consequence of metal contraction during cooling in the liquid state (caved surfaces) and during solidification (pipe shape). Closed shrinkage defects are characterized by not having contact with the casting surface and are formed due to metal contraction during the solidification, as a consequence of the mushy zone. According to the size of the shrinkage defect, it can be classified as macro-porosity when the defect is a single big shrinkage volume or micro-porosity/micro-shrinkage when the cavities are small and interconnected (inter-dendritic cavities) as shown in Figure1.



**Fig 1.** Macro and micro porosity/shrinkage defects

The different parameters which are responsible for Shrinkage Defect in casting could be nicely explained by use of different techniques. One on such method is man- machine diagram or Fish Bone Diagram is shown in figure 2.

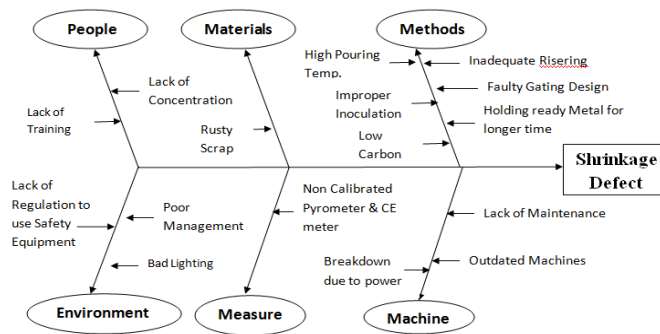


Fig.2: Fish Bone Diagram for Shrinkage Defect in particular casting

### 1.1 Typical casting procedure

Molten metal is generally used to manufacture castings. Molten metal is poured into mould, cavities get filled with liquid metal & it takes the formation of mould cavity. Hence desired shape casting is achieved. This process looks very simple, but in general manufacturing casting is complex process due to metallurgy of metal. Here mould used can be expendable or permanent.

### 1.2 Different casting defects

Liquid contraction of cooling metal is not compensated either from the sprue or from the riser. At the time of defect formation, the initial skin that formed on the casting surface is too thin at the location of the defect, due to a hot spot, soft mold, and/ or any inclusion on the surface (low rate of heat extraction). As the feed metal supply is cut off due to in-gate freezing or riser top freezing, the thin skin at the defect area is punctured by atmospheric pressure and mold gases enter into the casting cavity compensating the shrinkage volume. This location in the casting acts as a feeder for the rest of the casting and sometimes for the riser also. If metal has to feed through a thinner section to a heavier section, the freezing time of the thin section will influence the shrink formation in the heavier section.

## 2. Solidification theory of ductile iron

A) Pouring temperature, casting thickness (effects of each)

During solidification, the graphite is precipitating from the liquid metal; the time that it does that is depending on the carbon equivalent. Hypo-eutectic iron is first solidifying by dendrites of iron in order to increase the carbon equivalent of the liquid metal to the eutectic one (CE<sub>eutectic</sub> = 4, 33).

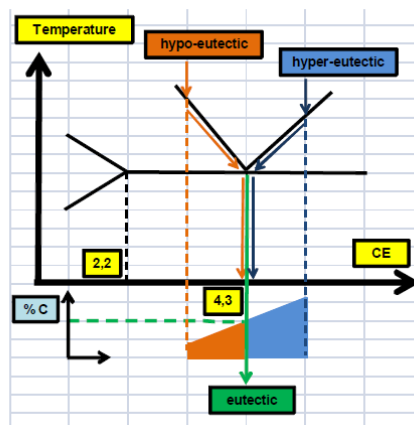


Fig.3: Solidification of Iron

From the moment this eutectic composition is achieved, also free carbon is appearing. This carbon is restricted in growth by the already existing metal dendrites and will have a short time to form. They will mostly not float up in the casting. Hyper-eutectic iron is first releasing free graphite to align the liquid chemical composition with the eutectic one (CE<sub>eutectic</sub> = 4, 33). The free

carbon is continuously growing until the material is completely solidified. Graphite is significantly less dense than iron, so it has the tendency to float when it precipitates in the liquid iron. The tendency is larger if the graphite nodule is larger. When this flotation occurs prior to the complete solidification of the metal, a concentration of graphite nodules occurs at the cope surface (top part of the mould) and immediately under cored surfaces.

## 2.1 Influencing factors for solidification

The three most important factors associated with the presence of graphite flotation are:

- Carbon equivalent (CE)
- Casting section size and shape
- Size of the graphite
- Solidification rate
- Pouring temperature

### A) Carbon Equivalent

Graphite flotation may occur in all hypereutectic irons (CE > 4,33), but is mostly present in ductile iron with a carbon equivalent (CE) that exceeds 4,5%. The nodule size will mostly be large and they can float up quickly. Carbon equivalent is defined by the expression:

$$CE = \%C + (\%Si/3) + (\%P/3)$$

For alloyed irons, sometimes the following formula is used;

$$CE = \%C + (\%Si/3) + (\%P/3) + 0,076 (\%Cu) + 0,051 (\%Ni) + 0,4 (\%S) - 0,028 (\%Mn)$$

The extent of flotation is small when irons are just hypereutectic (i.e., their CE values just exceed 4,33, depending on the wall thickness).

### B) Casting section size and shape

The concentration of graphite can only happen if the nodules float up in the liquid.

This requires a long solidification time, which means heavy section. Therefore flotation effects are confined mainly to heavier sections and the area below a riser.

The shape is also important because if this is very complex, the graphite will never reach the top. If this is straight up, it is very easy to float up.

### C) Size of the graphite

The larger the graphite nodule size, the higher the float up speed will be. The float speed can be calculated by Stokes law:

$$V = 2 * (\delta_{\text{metal}} - \delta_{\text{graphite}}) * r^2 / g * \eta$$

$\delta_{\text{metal}}$  -density of metal

$\delta_{\text{graphite}}$ - density of graphite segregation

r- Radius of graphite nodule

g- Gravity factor: 9.81 m/s<sup>2</sup>

$\eta$  -viscosity of liquid metal: g.s / cm<sup>3</sup>

#### D) Solidification rate

If the solidification rate of the metal is increased by chills (or another tool), the metal will completely solidify much quicker and the time for floating up will be much lesser. So the effect will be less.

#### E) Pouring temperature

If the pouring temperature is high, the mould material will heat more, which leads to a longer solidification time of the metal because the heat will be removed more slowly.

### 2.2 Processing sequence

- A) molding,
- B) melting,
- C) desulphurization,
- D) inoculation,
- E) Mg addition.

Processing sequence is normal sequence followed for ductile Iron. But, we found high percent rejection of this job due to macro shrinkage in the foundry unit. This part is of hydraulics industry in ductile iron & It has 600 bar pressure. For such high pressure it is required that this part should be defect free and having no shrinkage defect. When this was part developed it was having shrinkage as shown in fig3, Fig4, fig5. We did few gating modifications, but this defect was not completely removed. Hence, we did experimentation



**Fig.4**



**Fig.5**



Fig.6

Fig.4, Fig.5 & Fig.6: Show actual micro shrinkage occurred

### 2.3 Experimentation

In this work, experiments were conducted to record, analyze the data & then interpret on the basis of temperature variation w.r.t. time of heated material in ductile iron on casting with various sections of thickness. Simply, for metal castings, the cooling curve gets recorded while solidifying metal in a mold & then analysis of data is done. An aluminum pattern was made as per drawing of casting. Green sand mold was prepared using this pattern as shown in fig.6. A total of 9 moulds prepared. Four cavities are provided on each mould with common gating system. The casting produced in the other cavity was used for shrinkage studies. The thermocouples (K type) were connected to an 8-channel data logger (MCS make), which is capable of storing 2995 readings for each port. The data were used for plotting the cooling curves for each section thickness using Smartlog 2000 software. Out of Chemical composition, Inoculation, Si-Mg Alloy, Pouring temperature, Carbon Equivalent variables for thermal analysis are important. These critical variables are selected in the range on 0.2 to 0.6%. Hence, 9 experiments were planned based on range of these three variables with the help of **Orthogonal Array method**.



Fig.7



Fig.8





Fig 9.

Fig.7,8,9:Green sand Mould, Cup Pouring and Mould Pouring

Table 1: Details of furnace charge mix along with spectroscopic analysis

Charge materials	Amount	Size/ Shape	C	Si	Mn	P	S	Mg	Ca	Al	Ba
Pig iron	50 kg	Briquettes	4.3	1.55	0.12	0.05	0.027	...	...	...	...
Foundry returns	100 kg	...	3.7	2.2	0.19	0.01	0.02	...	....	....	...
Steel scrap	150 kg	Punching	0	0.038	0.14	0.01	0.017	...	...	...	...
Fe-Si-Mg	400g/ladle	10-15 mm	...	46.55	...	...	...	5.89	1.25	0.9	...
Innoculant	3.5 kg	2-6 mm	...	73.52	...	0.04	0.003	...	0.2	1.07	2.02

Table 2 :Spectroscopy analysis

	C	Si	Mn	P	S	Cu	Mg	Al	Cr
A	3.65	2.44	0.197	0.013	0.013	0.25	0.045	0.005	0.019
B	3.65	2.49	0.192	0.0156	0.0112	0.43	0.046	0.007	0.019
C	3.66	2.49	0.198	0.0135	0.0087	0.62	0.036	0.007	0.017

150 kg (CRC) cold rolled steel scrap and 100kg foundry returns. The chemical compositions of raw materials were tested and reported in Table 1. The charge mix was melted in 300 kg capacity coreless medium frequency induction furnace. The molten metal was tapped into a preheated ladle of 300 kg capacity containing ferrosilicon magnesium alloy granules of size 10–15 mm at the bottom covered with steel scrap. The treatment was performed by sandwich method using steel punching to cover the magnesium alloy in a 300 kg treatment ladle. Same was used to take 300 kg of treated metal and pour it into the first mould at a temperature of 1400uC. Pouring temperature was maintained from 1350uC to 1400 uC. This was achieved by adding fine sized (2–6 mm) innoculant in the melt stream during pouring. A spectroscopy coin and one cup core attached to data logger using thermocouple were also poured at the same time. Then, copper was quickly added in the remaining metal in the ladle, stirred and poured into the second mould. In a similar manner, the third and fourth moulds were filled with molten metal with increasing amount of copper. The spectroscopy analysis of the coins was carried out (Bruker, model Q-4 Tasman), and the average values of three castings of each composition are shown in Table 2.

### 3. CONCLUSION

Defects in ductile iron manufactured in foundry for their grades are mainly decided by microstructure. Microstructure is decided by mainly section thickness & chemical composition of charge prepared. Summary of experimentation as follows.

1. A thermal analysis is very effective tool for understanding and controlling the melt quality in ductile iron castings. Nil under-cooling shows sufficient inoculation for a given composition and section thickness which avoids shrinkage.
2. Nodule count reduces with increase in casting thickness and increases with increase in copper addition (Cu = 0.62%)
3. Addition of copper in ductile iron improves nucleation, nodularity and reduces shrinkage.

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