ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 2, Issue 2, February 2017

Thermal Analysis of Ca-FeSi inoculated. Ductile Iron

[1]Mr. Bahubali.B. Sangame, [2]Mr. Vikram. B. Nalawade , [3] Mr. Suyog S. Patil, [4]Mr. Swapnil S. Mali, [5]Mr. Vishal R. Naik

[1]-[5] Assistan Professor at Sharad Institute Of Technology College Of Engineering ,Yadrav

Abstract- **Ductile iron is an alloy of iron alloyed with carbon and silicon and manufactured by casting which offers good combination of strength and ductility. The presence of silicon in higher amount promotes the graphitization, inhibiting carbon to form carbides with carbide forming elements present. When Ce, Mg are added to the melt of iron with very low sulphur content, the carbon solidifies as spheroidal graphite. Due to this special microstructure containing graphite in nodular form, ductile iron possesses ductility & toughness superior to that of any cast iron & steel structure resulting in numerous successes in industrial application. The current work proposes thermal analysis system for analysis of ductile iron solidification processing. The system consists of standard pouring cup with built in thermocouple. The thermocouple is connected to data logger system so as to measure the time-temperature data of solidification sequence. The ductile iron treatment consists of composition control, melt pre-treatment, magnesium treatment and inoculation processing. Even small change in processing can be monitored by thermal analysis and its effects on final microstructure and mechanical properties. The melting trials were conducted for varying amount of inoculant addition rate for "Ca-FeSi" inoculant, to study its effect on parameters of thermal analysis like eutectic undercooling temperature, recalescence, solidification pattern, final microstructure, and shrinkage tendency.**

***Index Terms*—About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

Many of the steel components are replaced by ductile iron due to high strength to weight ratio and range of properties. The ductile iron provides good combination of strengths and ductility due to presence of spheroidal graphite. From a metallurgical view, ductile iron is one of the most complicated materials. During solidification several phases were nucleating and interaction of these different phases during growth is very complicated [1]. The occurrence and distribution of these phases have major impact on the final mechanical properties of the casting. It is therefore interesting to understand how the different phases nucleate and grow during solidification in order to be able to control the casting process and achieve the right mechanical properties. The commonly used mechanical properties for ductile iron are tensile strength, yield strength, percent elongation and brinell hardness [2]. Because of the nominal and consistent influence of spheroidal graphite, the tensile properties and the brinell hardness of ductile iron are well related. The relation between tensile properties and hardness depends on structure of its base matrix. In the matrix, the softer ferrite gives higher ductility but lower yield strength than pearlite [3].. Even small changes of the elements show significant increase or decrease in mechanical properties of ductile iron. The chemical composition, melt treatment and cooling rate are important processing parameters which decide the final properties of ductile iron. The graphite nodule count and nodularity (deviation from spherical shape) and the amount of phases are to be controlled to achieve better combination of properties in ductile iron. Melt treatment consisting of modification and inoculation, in which initially magnesium treatment of the melt is done (for changing graphite shape from flake to spheroidal) and further inoculation (for increasing the nodule count or to suppress carbide formation) is must [4,5]. In case of hypoeutectic ductile iron, solidification proceeds by nucleation of austenite, and graphite spheroids nucleate on pre-existing austenite and grow in the interdendritic regions.

In hyper eutectic melts, solidification starts with graphite nodules [6,7], which reduces the remaining carbon in the liquid, upon further cooling, the austenite grows dendritically and thus allowing new graphite spheroids in interdendritic regions. Graphite nodules nucleate on small inclusions [8] but further growth solely depends on foreign particles or solutes which are added as inoculant [9]. Rare earth elements reduce the magnesium requirement for a particular set of nodule count and nodularity. As some of the magnesium measured is in the form of magnesium sulfide, final iron sulfur level affects the magnesium needed to result in nodular graphite. Maximum nodularity can be achieved by keeping magnesium residual just enough (0.02%) will deteriorate the nodule shape from fully spherocity. Nodule count can be maximized by sound

IFERP
connecting engineers... developing research

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 2, Issue 2, February 2017

base iron melting practice and good inoculation practice. Nodule count and nodularity is affected by cooling rate [10].

A series of experiments was conducted in a ductile iron foundry to determine the optimum addition rate of inoculant for their given casting application. The long-time practice at foundry has been to inoculate all ductile iron by a fixed 0.7wt% addition of barium bearing 50% ferrosilicon inoculant to the pouring ladle. Some studies have shown that a drop in addition rate to 0.4wt% resulted in beneficial effects on process costs without impairing casting quality. The objective of the investigation was to acquire quantitative data through thermal analysis in order to verify this and determine the optimum addition rate of the specific inoculant in use.

II. EXPERIMENTAL PROCEDURE

The current study comprises of capturing solidification temperature data by built in thermocouples fitted in cup casting. Measuring and correlating the properties in castings by analyzing cooling curves. The cup is made up of shell sand, with 21x21x42mm cavity (Electronite standard QC-4010) as shown in Fig.1. The weight of cup casting is 0.315 kg having modulus (volume/surface area) of 7 mm. The melt charge consisting of 15-20% pig iron, 30-35% Cold rolled steel scrap and remaining foundry returns is melted in 500 kg capacity coreless medium frequency induction furnace. The raw materials are tested for its chemical compositions by spectrometer analysis and are reported in Table 1.The molten metal was tapped in a preheated ladle containing Ferro-silicon-magnesium alloy of size 10-15mm at the bottom covered with steel scrap. The tapping temperature of molten metal was 1450oC. The inoculant is then added in the melt, while pouring directly in the stream for proper mixing. Total four ductile iron melts were poured using transfer ladle treatment method as shown in Table 2. A set of experiments were conducted on day where Ca-FeSi inoculant was used for thermal analysis. Where four ladles each of 50 kg was inoculated for four different addition rates 0.2% (0.1 kg), 0.4% (0.2kg), 0.6% (0.3 kg) and 0.8% (0.4 kg) respectively. While pouring, sample was taken from the melt for spectroscopic analysis.

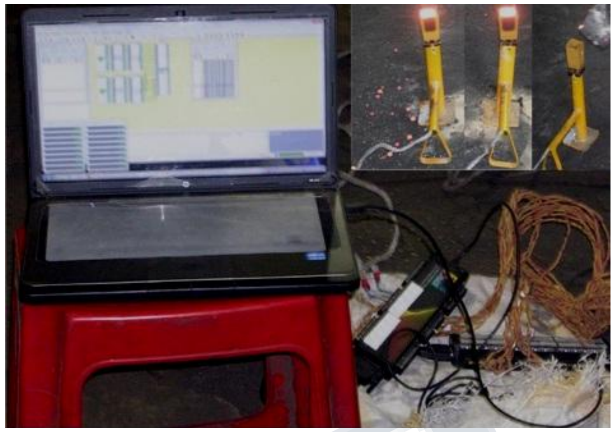

Fig.1: Data acquisition system comprising of DAQ, thermocouples and pouring cup

The pouring temperature recorded is 1380oC. In the varied inoculation trials, three cups were arranged in such a manner that pouring will be done in a sequential manner. K type thermocouples connected to each cup casting to capture temperature during solidification. ADAQ-3005 (MCC-USA) data logger for data acquisition synchronized with Desylab 12.0 software for analysis (Fig.1). Metal samples are taken for spectroscopic analysis while pouring so as to measure final chemistry of the castings being poured. The final chemistry for each melt was determined using Spectrometer (Spectro-lab, M-9 model, Germanmake). Temperature time data thus captured was further processed by using Origin-8 software to plot cooling curves of individual melts processed differently. Also the first derivative of temperature data of individual melts was determined by using Origin-8 software.

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	65 kg	Briquettes	4.13	1.91	0.14	0.075	0.025	--	--	--	--
Foundry returns	135 kg	Gating	3.68	2.21	0.18	0.010	0.026	--	--	--	--
Steel scrap	300 kg	Punching	0.038	0.001	0.302	0.025	0.008	--	--	0.04	--
Fe-Si-Mg alloy	1.8 kg/150 kg ladle	10-15 mm	--	47.50	--	--	--	5.82	1.23	0.92	--

Table2: Chemical analysis of base (uninoculated) metal, 0.2%, 0.4%, 0.6% and 0.8% inoculated metal

Un-inoculated	Base Metal	3.64	1.2	0.183	0.034	0.01	0.099	0.009	0.02	0.001	0.001	0.005
	0.2% Inoc.	3.64	2.2	0.125	0.021	0.006	0.098	0.024	0.03	0.001	0.002	0.030
(Ca-FeSi)	0.4% Inoc.	3.65	2.32	0.149	0.025	0.008	0.099	0.025	0.035	0.001	0.002	0.034
	0.6% Inoc.	3.64	2.45	0.171	0.033	0.011	0.10	0.023	0.04	0.001	0.003	0.036
	0.8% Inoc.	3.66	2.58	0.189	0.035	0.009	0.11	0.027	0.004	0.02	0.003	0.40

III. RESULTS & DISCUSSION

In the (Fig.2) of base metal curve, the vertical axis represents temperature in oC, while the horizontal axis is time in seconds. The smaller graph at the bottom of the screen displays the first and derivative. The cooling curves itself as well as its first derivative and related temperatures can be used to predict the characteristics of the iron. A cooling curve is often easier to interpret if the first derivative is plotted. It represents the cooling rate and it is useful in detecting various events during solidification. If the curve value at a given point is negative it means that the basic curve slopes downwards. The horizontal line in the middle is where the cooling rate is zero. When dT/dt=0 it means that heat generated inside the sample just balances the heat.

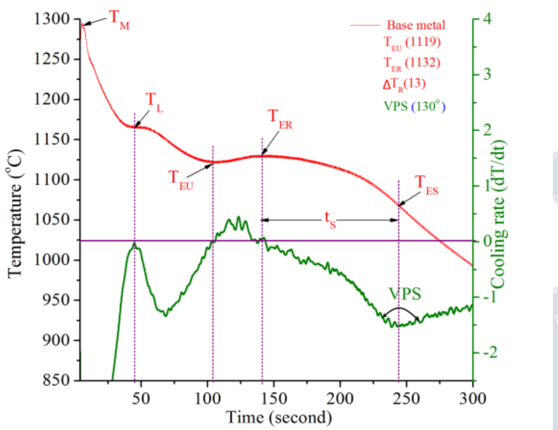

Fig.2 Cooling curve for base (uninoculated) metal.

Thermal analysis records and determines many parameters. This study focuses on nine parameters that are shown in Fig. 3 and defined in the section below. We will also describe their influence on the quality of the metal and indicate for each an optimum range of variation.

- TM - Maximum temperature of the poured melt, oC.
- TL- Temperature of liquidus, oC.
- TEU-Temperature of eutectic undercooling, oC.
- TER - Temperature of the graphitic recalescence, oC
- ΔTR- This is the recalescence. It is defined as the difference between the maximum and the minimum temperatures of the eutectic reaction Rec. ΔTR = TEU - TER. The recalescence is directly related to the graphitic expansion (thrust on the mould) and therefore its value influences the shrinkage cavities prediction. The recalescence should be between 2 and 5°C.
- TES - Solidification temperature oC. This is the temperature at which solidification ends.
- tS- Time of eutectic solidification, sec; length of the eutectic range in second (time between TER and TES). It tells us about the growth of the eutectic cells.
- VPS- Angle formed by the cooling rate curve at the solidus. It indicates the thermal conductivity of the cast iron at the end of solidification, which indicates the possibility of formation of shrinkage and porosity. The desired interval ranges from 25° to 45° to avoid shrinkage and porosity.

Just after pouring the melt the cooling begins. When the liquidus temperature referred to as (TL) liquidus is reached, the cooling curve shows a quasi-horizontal plateau which corresponds to zero point on the first derivative. This zero point means that the heat losses at that time exactly balance the released heat in the sample. The length of the horizontal plateau is a function of the time it takes for the graphite to grow from the walls of the cup to the center where the thermocouple is located. Then, there is contraction of the melt at both the liquidus state and during the crystallization of the primary graphite. However, the decrease of temperature continues until lowest eutectic temperature TEU. At that time the eutectic reaction where simultaneously austenite and graphite are precipitated has just started.

The lowest eutectic temperature (TEU) which is reached when the heat generated from recalescence, specific heat and latent heat just balances the heat losses is shown as a zero-point on the first derivative curve. At this zero-point, the eutectic reaction occurs, and the recalescence energy causes the temperature to increase to the temperature of graphite recalescence (TER). A second zero-point on the first derivative curve then occurs. The difference between (TER) and(TEU) is called recalescence (ΔTR).It is observed that lower eutectic undercooled temperature (TEU) for base metal is 1119oC and TER temperature is 1132 oC which shows the larger undercooling effect which gives larger recalescence degree.

In the current experimental conditions, the difference between the TEU temperatures of inoculated and uninoculated iron (ΔTEU) was observed in the range of 17-30oC. A higher ΔTEU value indicates that metal is more resistant to chill than with a lower ΔTEU value, which indicates that ΔTEU value for 0.6% and 0.8% inoculated melts is higher. The highest eutectic temperature (TER) is attained as a result of increase in temperature because of the release of inherent heat called

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 2, Issue 2, February 2017

latent heat. The recalescence (ΔTR = TER- TEU) reflects the amounts of austenite and graphite that precipitate during the first part of eutectic freezing. In the current experimental conditions, it is observed that as the amount of inoculant increases it decreases the recalescence ΔTR. The recalescence ΔTR was observed in the range of 6-2oC.

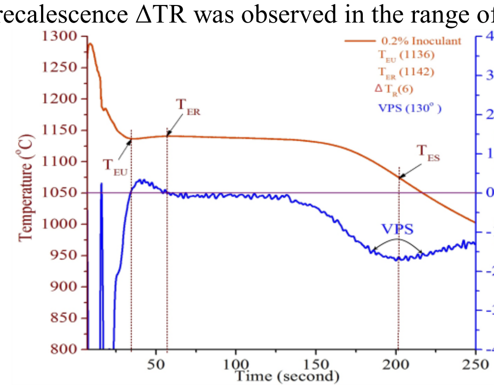

Fig. 3 Cooling curve for 0.2% inoculated metal.

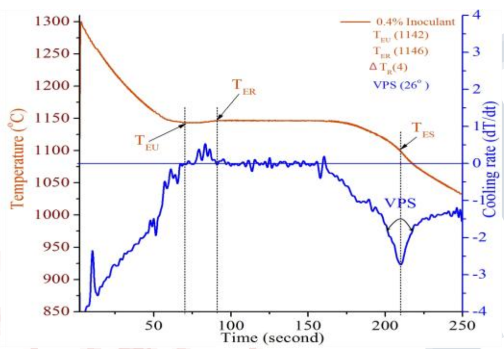

Fig.4 Cooling curve for 0.4% inoculated metal.

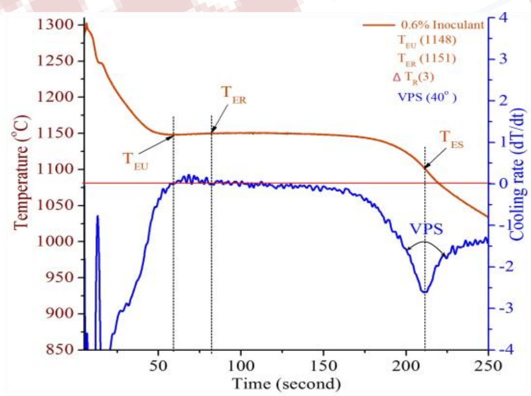

Fig.5 Cooling curve for 0.6% inoculated metal.

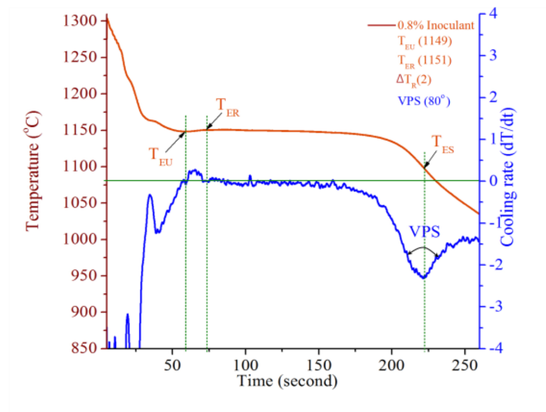

Fig.6 Cooling curve for 0.8% inoculated metal.

Table 3: Difference between inoculated and un-inoculated ductile irons for representative inoculants application.

Metal Treatment	Inoculation amount %	Pouring temperature °C	Lower eutectic temperature (T_{EU}) °C	Eutectic Recalescence temperature. (T_{ER}) °C	$\Delta T_{EU} = T_{EU}$ (Inoc.) – T_{EU} (Uninoc.)	$\Delta T_R = T_{ER} - T_{EU}$	VPS Angle
Base metal (uninoculated)	---	1380	1119	1132	---	13	130°
Ca-FeSi Inoculated	0.2	1375	1136	1142	17	6	130°
	0.4	1385	1142	1146	23	4	26°
	0.6	1355	1148	1151	29	3	40°
	0.8	1345	1149	1151	30	2	80°

Higher ΔTR values may indicate undesirable, early graphite expansion i.e. GF1 (Graphite Factor 1) and it is an indicator of eutectic graphite precipitation rate that increases the risk for wall expansion effects and primary shrinkage. Also, early graphite expansion may reduce the available carbon for later graphite expansion at the end of solidification and thus increase the risk for micro-shrinkage porosity formation.GF2(Graphite Factor 2) is determined from the first derivative of the cooling curve i.e. VPS angle and it describes the degree of late graphite formation which should be within 25-45o to avoid shrinkage.

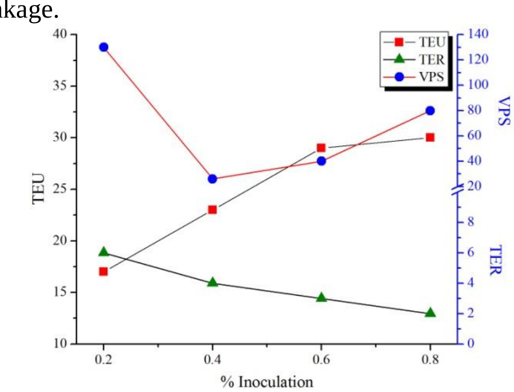

Fig.7 Variation of the parameters for different addition rates of inoculants

International Journal of Science, Engineering and Management (IJSEM)
Vol 2, Issue 2, February 2017

A lower GF2 is desirable and indicates late-forming graphite that counteracts shrinkage in the last metal to freeze..

IV. CONCLUSION

The experiments were conducted on ductile iron with varying amount of inoculant. The cup thermal analysis can be effectively used for measuring performance of amount of inoculant on solidification of ductile iron castings. Within the experiments conducted, the following conclusions were highlighted:

A higher ΔTEU value indicates that metal is more resistant to chill than with a lower ΔTEU value, which indicates that ΔTEU value for 0.6% and 0.8% inoculated melts is higher.

The experimental thermal analysis data indicates that a 0.6wt% addition rate of inoculant produces metal that is more resistant to shrinkage porosity formation than either lower or higher addition rates. These results confirm that the 0.6wt% addition rate of inoculant is the optimum for this specific foundry condition.

REFERENCES

[1]. O. SeiduS., I. Riposan, “Thermal analysis of inoculated ductile irons”, U.P.B. Sci. Bull., Series B, 73(2), (2011) pp. 241-253.

[2]. D. Sparkman, “Using thermal analysis practically in iron casting,” Modern casting. (1994).

[3]. S. Bockus, A. Dobrovolskis “Peculiarity of Producing Ferritic Ductile Iron Castings”, Materials Science (Medziagotyra), 10, 1, (2004) pp. 3-6.

[4]. Rio Tinto Iron and Titanium, “Ductile Iron Databook for Design Engineers”, Monreal, (1999), pp. 250.

[5]. J. Campbell in Castings Principles, the “New Metallurgy of Cast Metals Elsevier”, Amsterdam. (2004).

[6]. M. C. Flemings, in “Solidification Processing”, McGraw-Hill Book Company, New York, (1974) pp. 423.

[7]. T. Skaland, in proceedings of the AFS cast iron, schaumburg, Illinois, (2005) pp. 29-30.

[8]. G.L. Rivera, R.E. Boeri, and J.A. Sikora, AFS Transactions, (2003) pp. 111, 979.

[9]. J.D. Mullins, in manual of Sorelmetal, Technical services, Rio Tinto Iron and Titanium, (2006).

[10]. T. Skaland, Ø. Grong and, T. Grong, “Metallurgical and Materials Transactions” A, 24(A), (1993), pp. 2321.

