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Solidification Processing and Property Prediction of Ductile Iron.

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Abstract: *The study was carried out to predict the end properties of casting before pouring in the mould. To achieve this analysis of different cooling curves was carried out to predict Hardness of casting. The current work proposes thermal analysis system for analysis of ductile iron solidification processing. The solidification processing was carried out by changing the input parameters as Carbon Equivalent, Copper and inoculation. Even small change in processing can be monitored by thermal analysis and its effects on final mechanical properties i.e. hardness was predicted and validated. The predicted hardness values showed good agreement with that of actual measured values.*

Keywords- *Thermal analysis, Ductile Iron (DI), Hardness, Recalescence.*

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I. Introduction

Generally thermal analysis is a best method used in foundry for accurate, reliable and cost control of the casting. In recent times thermal analysis became an important tool to find the solidification behaviour of ductile iron. To save cost and materials, thermal analysis plays important role in industries. By adopting this new technology we can completely remove manual methods of predicting metallurgical properties. Many researchers have analyzed that the shape of a cooling curve measured by a thermocouple mounted in thermal analysis sample cup. It reflects the solidification processing of melt iron in the sample cup. [13]

Effects of key elements in nucleation processes such as Si, Ca, Al, Ba, Mg, S, O and N are described [1]. Castings with plate thicknesses from 1.5 to 8 mm have been investigated with the main focus on plate thicknesses from 2 to 4.3 mm. Both hypereutectic, near eutectic and hypoeutectic melts have been investigated with the main focus on the hypereutectic and near eutectic melts. The condition for nucleation and growth of the austenite and the graphite nodules was studied.[2]. With the help of cooling curves the study was carried out by focusing on pre liquids, Austenitic arrest, Nucleus growth, eutectic solidification, end of the freezing point and Austenitic transformation area .[3]. Inoculation process have strong effect on solidification of DI especially Ca-series and Sr-series bearing inoculants.[4] Early and late graphite content are calculated using thermal analysis which helps to predict the factor such as late graphite expansion.[5]. The effect of inoculation on microstructure and mechanical properties results in high quality DI.[6]Thermal analysis is used for to control chemical composition i.e. C equivalent, %C , %S and to define the pouring temperature which affects the end properties of DI castings .[7]

Thermal analysis is good technique to control carbides, shrinkage and micro-shrinkage formation.[8]CA-CCA (computer aided –cooling curves analysis) Can be used to calculate latent heat, solid fraction and dendrite coherency point from the cooling curves of multi compound alloys.[9]

To obtain best result use low inoculants addition i.e. 0.05% at pouring temperature is above 1390 degree Celsius.[10]

II. Nomenclature

Parameters	**Description**
TSEF	Temperature of the start of eutectic freezing (nucleation)
TEmin	Lowest eutectic temperature
TEmax	Highest eutectic Temperature
R	Recalescence

III. Experimentation

The variation in input process parameters is carried out by considering the following parameters from minimum to maximum:

1. CE- Carbon equivalent varies from 4.0%, 4.3%, 4.6%.
2. Cu- Copper varies from 0.3%, 0.6%, 0.9%.
3. Inoculants- Si based inoculant varies from 0.2%, 0.4%, 0.6%.

By using above combination of input process parameters, the L9 Orthogonal array of experiments was designed by Taguchi method as shown in table 3.1.

Experiment. No.	CE	Cu	Inoculants
1	4.0	0.3	0.2
2	4.0	0.6	0.4
3	4.0	0.9	0.6
4	4.3	0.3	0.4
5	4.3	0.6	0.6
6	4.3	0.9	0.2
7	4.6	0.3	0.6
8	4.6	0.6	0.2
9	4.6	0.9	0.4

Table No.3.1 Combination of parameter by using Minitab

Fig 3.1 shows the experimental setup used for thermal analysis. It shows the Quick Cup placed on Stand which is connected to the Data Logger by using the extension wire.

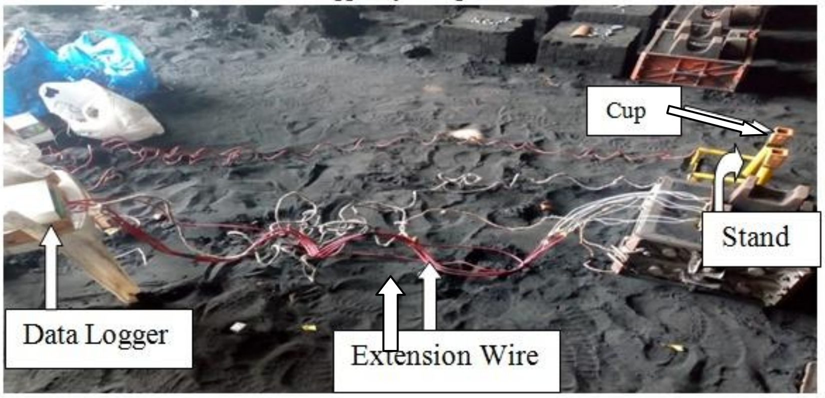

Fig 3.1 Experimental setup

Fig 3.2 shows the pouring of molten metal into the Quick cup. In the fig 3.3 shows Quick cup filled with molten metal.

Fig 3.2 Pouring of Metal

Fig 3.3 Metal poured into Cup

The charge mix for all the experiments is shown in table.3.2.

Experiment No.	**CRCA Kg**	**R/R Kg**	**Other Metal Kg**	**C Kg**	**Si Kg**	**Mn Kg**	**Cu Kg**
1	35	35	5	1.4	0.5	0.1	0.17
2	35	35	5	1.4	0.5	0.1	0.14
3	35	35	5	1.2	0.3	0.1	0.18
4	35	35	5	1.3	0.3	0.1	0.17
5	35	35	5	1.3	0.3	0.1	0.18
6	35	35	5	1.4	0.5	0.1	0.14
7	35	35	5	1.2	0.3	0.1	0.18
8	35	35	5	1.2	0.3	0.1	0.18
9	35	35	5	1.4	0.5	0.1	0.14

Table No 3.2 Charge mix for experiments

IV. Observation

The final compositions obtained from the Spectrometer are as shown in table 4.1. From the readings in table.4.1 the final composition related to CE, Cu, and Inoculants is shown in table 4.2. The CE calculated by CE = C + 1/3 Si.

Elements		**Experiment No.**							
	1	2	3	4	5	6	7	8	9
C (%)	3.5330	3.4230	3.6020	3.4560	3.7630	3.3590	3.3140	3.2040	3.0570
Si (%)	2.5710	2.6090	2.5830	2.6270	2.6990	2.7330	2.4730	2.6910	2.8400
Mn (%)	0.3460	0.3480	0.2310	0.2330	0.3610	0.3620	0.3150	0.3360	0.3610
P (%)	<0.008	0.0110	0.0130	0.0240	0.0310	0.0200	0.0080	0.0170	0.0110
S (%)	0.0260	0.0250	0.0210	0.0280	0.0310	0.0270	0.0230	0.0250	0.0240
Cr (%)	0.0260	0.0250	0.0250	0.0230	0.0230	0.0340	0.0270	0.0250	0.0280
Mo (%)	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Ni (%)	0.0250	0.0240	0.0210	0.0250	0.0330	0.0270	0.0260	0.0260	0.0250
Al (%)	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Cu (%)	0.2870	0.3260	0.6940	0.7190	0.8090	0.7050	0.3500	0.5870	0.7010
Ti (%)	0.0140	0.0140	0.0140	0.0120	0.0130	0.0130	0.0110	0.0140	0.0110
V (%)	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Nb (%)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
W (%)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.0260	<0.020
Mg (%)	0.0370	0.0340	0.0340	0.0340	0.0420	0.0280	0.0370	0.0340	0.0350
Co (%)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
B (%)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sn (%)	0.0131	0.0128	0.0127	0.0124	0.0149	0.0125	0.0117	0.0106	0.0101
As (%)	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200
Pb (%)	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200
Fe (%)	93.0752	93.1083	92.7185	92.7801	92.1366	92.6444	93.3642	92.9887	92.8623

Table No.4.1 Final composition obtained from spectrometer.

Sr. No.	**CE = C + 1/3 Si**	**Cu**	**Inoculants**
1	4.13	0.350	0.2
2	4.10	0.587	0.4
3	4.00	0.70	0.6
4	4.28	0.326	0.4
5	4.27	0.705	0.6
6	4.33	0.719	0.2
7	4.39	0.287	0.6
8	4.46	0.694	0.2
9	4.65	0.809	0.4

Table No.4.2 Final composition of input process parameters.

V. Result

5.1 Cooling Curves

From the experiment carried out, the cooling curves are shown in figures 5.1. The Recalescence is calculated as R = TEmax - TEmin. TEmax and TEmin from different experiments are used to calculate Recalescence (R).

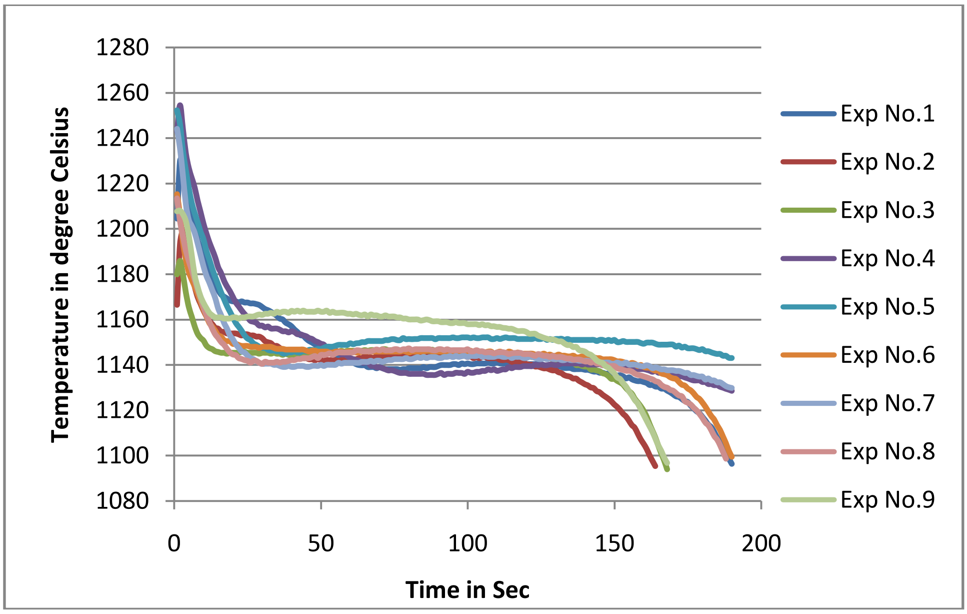

Fig No. 5.1 Cooling Curves

5.2 Recalescence and hardness values:-

The various Recalescence values and their corresponding Hardness values measured are shown below

Experiment No	Recalescence	Hardness (HR_B)
1	0.8	87.66
2	2.9	91.33
3	3.2	93.3
4	3.3	92.66
5	3.5	99.66
6	4.8	89.33
7	5.1	91.33
8	6.3	92.66
9	7.1	82

Table No. 5.1 Recalescence and their hardness values

5.3 Co-relation of Hardness and Recalescence

Fig 5.2 shows the correlation of hardness values from table 5.1 and Recalscence. The equation 5.1 shows the correlation between hardness and Recalescence.

$H = -0.212\times R^5 + 4.71\times R^4 - 28.38\times R^3 + 87.63\times R^2 - 115.4\times R + 136.9$ ….(Eq^n No. 5.1)

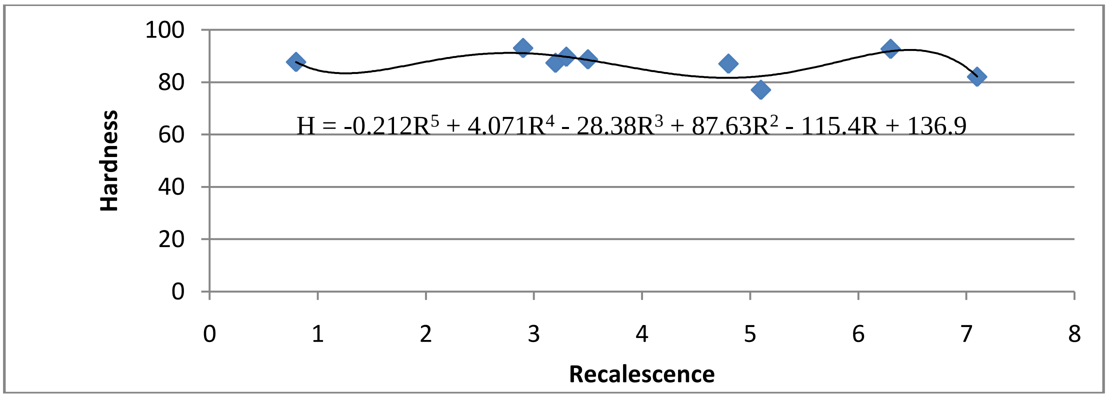

Fig.5.2 Graph of Hardness Vs Recalescence.

5.4 Validation:- For validation five experiment were performed. The predicted Hardness (from equation 5.1 and measured hardness are shown in table 5.2.

Sr. No.	Predicted Hardness(HR_B)	Measured Hardness(HR_B)	Error	% Error
1	89.79	92	2.21	2.4
2	85.64	87	1.36	1.56
3	89.79	89.33	0.46	0.52
4	89.79	93	3.21	3.45
5	91.5	88.66	2.84	3.2

Table No. 5.2 Measured and predicted Hardness values.

VI. Conclusion

New solidification model based on experimental cooling curves has been developed by co-relating Recalescence with Hardness values. The model shows good agreement between predicted and measured Hardness values. Also percentage error obtained is maximum 3.45% which shows that predicted values are close to the measured Hardness values. Thus Hardness values can be predicted before pouring liquid metal into mould.

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