ISSN: 2248-9622, Vol. 6, Issue 4, (Part - 4) April 2016, pp.68-73

RESEARCH ARTICLE OPEN ACCESS

Preparation Effect of Mould Systems on Microstructure and Mechanical Properties of Spheroidised Graphite Iron

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ABSTRACT

This study is based on evaluation of microstructure and mechanical properties such as tensile strength, Brinell hardness and Charpy impact test of as-cast spheroidal graphite iron using sandwich techniques in different mould systems viz. green sand mould, dry sand mould and CO^2 sand mould under varying cooling rates.

Keywords-Spheroidised graphite iron, mould, green sand, dry sand, CO^2 sand, microstructure, mechanical properties, sandwich technique, cooling rate.

I. INTRODUCTION

The gray cast iron in which graphite is present in the form of tiny spherulites rather than flakes in an evenly distributed matrix, which may be completely ferritic or pearlitic in the ductile grades, is called Spheroidised graphite iron (S.G. iron), Nodular iron or Ductile iron.

S.G. iron exhibits high ductility, good wear resistance, good fatigue properties [1] and shock resistance with relatively higher strength and thus used in various applications in automotive, heavy engineering and in railway industries [2]. The S.G. iron is now having an edge over cast iron (gray and white iron) as it possesses advantageous properties which include good castability, low manufacturing and material cost [3]. There are several factors which influence the structure of S.G. iron that include chemical composition, cooling rate, liquid metal treatment and heat treatment [4]. There are various researches indicate that varying cooling rate significantly influences the as-cast structure by refining the graphite size and matrix structure, thereby varying the chilling tendency resulting in a variation in hardness and strength [5].

There are several techniques which are recommended for adding the magnesium as nodulizing agent to the molten iron such as open ladle, the sandwich technique, the pressure ladle and plunging techniques, of which sandwich technique being the most commonly employed for small scale production. The technique has good control over deleterious elements, good inoculation and nodularisation which are necessary to achieve high nodule count and good spheroidality and to avoid carbide formation.

This paper aims to sperodising grey cast iron by the addition of Magnesium using the sandwich technique and observing the changes in the microstructure of the resultant S.G. iron under various cooling rates achieved by three different mould systems which include green sand mould, dry sand mould and CO^2 sand mould. The samples of as-cast S.G. iron were prepared for mechanical analysis and metallographic examinations. The mechanical tests were done to measure the tensile properties, Charpy impact toughness and Brinell hardness of the as-cast S.G. iron.

II. EXPERIMENTAL PROCEDURE

For the experiments, melting was done in induction furnace of intermediate frequency in 100kg capacity crucible as shown in Fig.1 below, and table 1 representing the composition of the charge materials.

For the chemical compositions mentioned in the table 1, charge calculation has to be done first. For the preparation of ductile iron. The furnace charge was composed of the following ratio – Pig iron: Foundry return: Steel scrap = 5:3:2.

Fig. 1: Induction furnace

Table 1: Composition of the charge materials.

Materials	C%	Si%	Mn%	S%	P%
Pig iron	4.3	0.60	0.57	0.074	0.11
Foundry return	3.3	1.80	0.81	0.043	0.16
Steel scrap	0.17	0.13	0.66	0.020	0.06

Charge calculation has been done for 25kg liquid metal. For that, 12.5kg of pig iron, 7.5kg of foundry return and 5 kg of mild steel scrap have been taken.

Charge calculation for Carbon:

Carbon from pig iron = $\frac{4.3}{100} \times 12.5 =$0.5375 kg
Carbon from steel scrap = $\frac{0.17}{100} \times 7.5 = 0.1275$ kg
Carbon from foundry return = $\frac{3.3}{100} \times 5 = 0.165$ kg
Total Carbon = 0.7152 kg
Assuming carbon loss in the furnace is 12%
Assuming carbon present in liquid metal -
= $\frac{3.53}{100} \times 25 = 0.8825$ kg

Then, recarborising element has been added to increase the percentage of Carbon. Suppose recarborising element is equal to X kg

∴ (0.7152 + X) - (0.7152 + X)×0.12 = 0.8825
⇒ X = 0.2875 kg or 287.5 gm

Further, petroleum coke has been added for recovery = 60% and loss = 12%, and suppose petroleum coke is equal to Y.

∴ (Y×0.6) – (Y×0.6)×(0.12)=287.5
⇒ Y = 5445 gm

Charge calculation for Silicon:

Silicon from pig iron = $\frac{0.6}{100} \times 12.5 = 0.075$ kg
Silicon from foundry return= $\frac{1.8}{100} \times 7.5 = 0.135$ kg
Silicon from steel scrap = $\frac{0.13}{100} \times 5 = 0.0065$ kg
Total silicon present in charge= 0.2165kg
Assuming, Silicon loss in furnace is equal to 12%, and Si present in liquid metal = $\frac{2.68}{100} \times 25 = 0.67$ kg
Amount of silicon added in melt is X kg, Therefore -
(0.2165+X) – (0.2165+X) × (0.12) = 0.67
⇒ X=0.544kg
Since, Fe-Si having 75% recovery and 12% loss, suppose amount of Fe-Si to be added is Y.
∴ 0.75Y-0.09Y=0.544
⇒ Y=0.824 kg or 824gm
So, 824 gm Fe-Si has been added during the time of melting.

Charge calculation for Manganese:

Mn from pig iron= $\frac{0.57}{100} \times 12.5 = 0.071$ kg
Mn from foundry return = $\frac{0.81}{100} \times 7.5 = 0.06$ kg
Mn from steel scrap= $\frac{0.66}{100} \times 100 = 0.033$ kg

Total Mn present in the charge material is equal to 0.164kg. Assuming, Mn loss in furnace is 15%. Therefore, Actual Mn in base melt-
= 0.164×(1-15%) = 0.1394 kg.
Therefore, % of Mn in the melt = $\frac{0.1394}{25} = 0.55\%$

Charge calculation for Sulphur:

S in pig iron = $\frac{0.074}{100} \times 12.5 = 0.0092$ kg
S in foundry return = $\frac{0.043}{100} \times 7.5 = 0.0032$ kg
S in steel scrap = $\frac{0.02}{100} \times 5 = 0.001$ kg
Total S in charge material= 0.0134 kg
Assuming S loss in furnace = 10%
∴ 0.0134×(1-10%)= 0.012 kg
So, % of S in the melt = $\frac{0.012}{25} \times 100 =$0.048 kg

Charge calculation for Phosphorous:

P in pig iron = $\frac{0.11}{100} \times 12.5 = 0.0137$ kg
P in foundry return = $\frac{0.16}{100} \times 7.5$= 0.012 kg
P in steel scrap = $\frac{0.06}{100} \times 5 = 0.003$ kg
Total P in charge material = 0.152 kg
Assuming P loss is 10% hence 0.152×(1-10%) which is equal to 0.1368 kg.
Therefore, % of P = $\frac{0.1368}{25} \times 100$= 0.54 %

The table 2 represents the chemical composition of product S.G. iron.

Table 2: Chemical composition of product S.G. iron

C	Si	Mn	P	S	Mg
3.53	2.68	0.55	0.54	0.048	0.05

The sandwich technique was used for obtaining a high magnesium recovery by holding down the magnesium alloy for some time and also producing a localized low temperature area. The depth and surface area of the sandwich pocket must be sufficient to contain magnesium alloy and steel scrap. The sandwich technique is often employed with a deep reaction ladle where the height-to-diameter ratio is 1.5 to 2.1. The extra metal depth increases recovery: for example values slightly in excess of 50% can be obtained when using 5% magnesium ferro-silicon alloy, at temperature as high as 1500^{0}C.

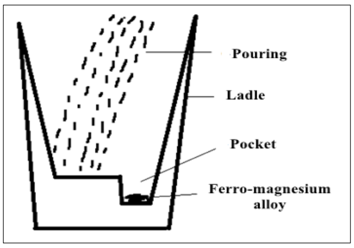

Fig. 2: Schematic diagram of sandwich technique

After melting to a temperature of 1450-1475 ^{0}C, the bath was held for 2.5 minutes and then it was poured immediately (Fig. 3 & Fig. 4) using sandwich technique spheroidisation and modification operation were performed in a ladle.

The foundry alloy Fe-Si was introduced by post inoculation method. Fe-Mg alloy is placed in a pocket in the bottom of an open heated ladle and then post inoculation was done while pouring as shown in figures below. The three moulds which are green sand mould, dry sand mould and CO^2 sand mould. The sand used for green sand mould and dry sand mould was properly mixed using sand Muller by varying composition of water, having 4% and 1.5% respectively. Measures were taken for the dry sand mould to remove moisture content by use of hot dryer. The moulding practice of the different mould system is as shown in Fig.5.

Fig. 3: Fe-Si alloy addition

Fig. 4: Pouring of molten metal

Fig. 5: Moulding practice

For making CO^2 sand mould, the sand was properly mixed in sand muller and additional ingredients were added such as dextrin (0.1%) and 4% sodium silicate as binder moisture content (2%). The CO^2 gas at about 1.3-1.6 kg/cm^2 pressure is then forged all around the mould surface to about 25 seconds using CO^2 probe. The above stated sands were used to make mould as shown in the Fig. 6, Fig. 7 and Fig. 8.

Fig. 6: Green sand mould

Fig. 7: Dry sand mould

Fig. 8: CO^2 sand mould

The carbon equivalent value (CEV) was calculated as below:

$$CEV = C\% + \frac{1}{3}\times(Si\% + P\%) \qquad \text{...…… (1)}$$

Careful precautions were taken to prevent formation of shrinkage cavities in the cast metal and to ensure homogeneity.

1) Metallographic Examination

a. Sample Preparation

The as-cast specimen has been cut into six similar small samples using hack saw machine as shown in the adjacent Fig. 9 of 15mm×15mm×2mm (L, B, T respectively).

Fig. 9: Hack saw machine

b. Grinding and Polishing

The samples were grounded progressively finer –SiC waterproof papers from 80–1200 grit, to produce a reasonably flat surface; it is lubricated with water to keep it cool and to remove grinding products. The sample should be moved forward and backward on the paper until the whole surface is covered with unidirectional scratches. It is then washed with running water to remove the debris after grinding. It is then ground on the next (finer) paper such that the scratches produced are at right angles to those formed by the previous paper. This will indicate the stage when the deeper scratches have been replaced by shallower ones, characteristic of the finer abrasive. This procedure is repeated through the range of papers available.

c. Etching

All the polished samples were then subjected to etching process in order to reveal the microstructure at the surface layer under the microscope. This was done using an etchant 2% Nital (2% nitric acid and 98% ethanol) conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

2) Tensile Test

The as-cast S.G. iron were machined using lathe machine with coolant into standard test specimens for tensile test according to standard tensile test ASTM (American Society for Testing and Materials) E370 [6]. The as-cast specimens are shown in Fig. 9 and Fig. 10. The machine was then operated at a constant crosshead velocity 2mm/s and the tensile test was performed in accordance with ASTM 809/E8M – 09 standards [7].

Fig. 10: As – cast specimen (from left) in green sand mold, dry sand mold and CO^2 mold

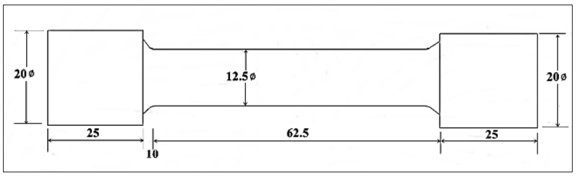

Fig. 11: Dimensions of tensile specimen (all dimensions are in mm)

3) Charpy Impact Testing

Charpy bar specimens which are most commonly used in the United States of America has a square cross-section (10mm×10mm) and contains a 45 V-notch, 2mm deep with a 0.25mm root radius. In the charpy impact, the velocity is 5m/s. the specimen is forced to bend and fracture.

4) Hardness Testing

The Brinell hardness test was used for determining the hardness of the as-cast specimens. The setup consists of a 10mm diameter steel ball at a load of 3000 kg. The load is applied for a standard time (30 seconds) for correct measurement, the surface on which indentation is made should be relatively smooth and free from dirt.

$$\text{BHN} = \frac{P}{\left(\frac{\pi D}{2}\right)\left(D - \sqrt{D^2 - d^2}\right)} \quad \text{......... (2)}$$

Where, P = applied load (kg)
D = diameter of ball (mm)
d = diameter of indentation (mm)

III. RESULTS AND DISCUSSION

The sandwich process was beneficial in the perfect spherulisation of graphite flakes and has been implemented in the casting process. The mould hardness was found to be highest in CO^2 sand mould followed by dry sand mould and green sand mould, due to significant amount of moisture reduction and bonding between sand particles.

The microstructure of as-cast S.G. iron is presented in below figures (Fig. 12 to Fig. 14) which have been etched in 2% Nital and 500X.

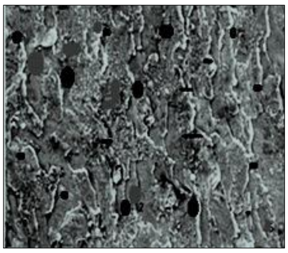

Fig. 12: Microstructure of green sand mould

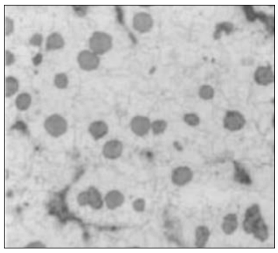

Fig. 13: Microstructure of dry sand mould

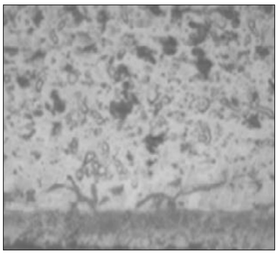

Fig. 14: Microstructure of CO^2 sand mould

The three different mould systems include green sand mould, dry sand mould and CO^2 sand mould with the thermal conductivities of the respective mould systems decreasing in magnitude. Hence, the cooling rate also decreases in the same order with CO^2 sand mould having the lowest cooling rate which facilitates proper spherulisation of graphite flakes by providing subsequent time for the same which can be observed from the microstructures of the specimens from the three mould systems. Proper spherulisation and fine microstructure results in an increase in tensile strength as compared to the other two mould systems having faster cooling rate. The values of tensile strength as noted from the tensile test of each specimen have been tabulated in the table 3.

Table 3: Tensile strength of different moulds

Sl. No	Specimen	Tensile Strength (MPa)	Mean UTS (MPa)
Green sand mould			
1	Green sand mould 1	560	579
2	Green sand mould 2	575	
3	Green sand mould 3	580	
4	Green sand mould 4	585	
5	Green sand mould 5	595	
Dry sand mould			
1	Dry sand mould 1	610	
2	Dry sand mould 2	618	

3	Dry sand mould 3	622	622
4	Dry sand mould 4	629	
5	Dry sand mould 5	632	
CO^2sand mould			
1	CO^2sand mould 1	633	643
2	CO^2 sand mould 2	637	
3	CO^2 sand mould 3	645	
4	CO^2 sand mould 4	648	
5	CO^2 sand mould 5	652	

The mean tensile strengths of the three mould systems are compared in a histogram below which shows the CO^2 sand mould producing the cast iron of highest tensile strength.

Moisture content in the mould systems bring about blow holes and pinholes in the as – cast samples. Moisture decreases from green sand to CO^2 sand mould and hence the highest mould hardness of CO^2 sand mould resulting in a higher possibility of these casting defects in the green sand mould. The hardness values for different sand moulds are tabulated data in the table 4 as given below.

Table 4: BHN of different moulds

Sl. No	Specimen	BHN	Mean BHN
Green sand mould			
1	Green sand mould 1	155	161
2	Green sand mould 2	158	
3	Green sand mould 3	162	
4	Green sand mould 4	166	
5	Green sand mould 5	167	
Dry sand mould			
1	Dry sand mould 1	181	188
2	Dry sand mould 2	183	
3	Dry sand mould 3	189	
4	Dry sand mould 4	192	
5	Dry sand mould 5	194	
CO^2sand mould			
1	CO^2 sand mould 1	224	235
2	CO^2 sand mould 2	229	
3	CO^2 sand mould 3	233	
4	CO^2 sand mould 4	239	
5	CO^2 sand mould 5	248	

From the table 4 it is clear that the value of hardness decreased with the increase in cooling rate and thereby CO^2 sand mould producing the specimen of highest hardness among the three and green sand producing the least. It is because fine microstructure and greater amount of spherulisation and results into better Hardness value. The tabulated data for V-notch Charpy Impact toughness is as follows in the table 5.

Table 5: V-notch Charpy impact toughness of different sand moulds

Sl. No	Specimen	V-notch impact toughness (KJ/m^2)	Mean impact toughness
Green sand mould			
1	Green sand mould 1	206	210
2	Green sand mould 2	208	
3	Green sand mould 3	211	
4	Green sand mould 4	213	
5	Green sand mould 5	214	
Dry sand mould			
1	Dry sand mould 1	183	191
2	Dry sand mould 2	185	
3	Dry sand mould 3	193	
4	Dry sand mould 4	195	
5	Dry sand mould 5	201	
CO^2 sand mould			
1	CO^2sand mould 1	160	169
2	CO^2 sand mould 2	167	
3	CO^2 sand mould 3	171	
4	CO^2 sand mould 4	172	
5	CO^2 sand mould 5	177	

The table 5 shows that the Charpy impact toughness in the green sand mould cast specimen is the highest followed by dry sand and CO^2 sand mould respectively. This is the reason for the higher damping capacity as graphite structure tends to be flakier compared to other moulds as is evident from microstructure.

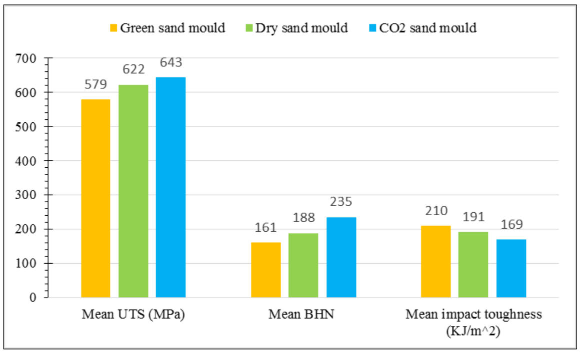

Fig. 15: Comparison among the different sand moulds

Fig. 15 shows the comparison among different sand moulds viz. green sand mould, dry sand mould and CO^2 sand moulds in terms of mean UTS, mean BHN and Mean V Charpy impact toughness. From the figure it is certain that CO^2 sand mould shows better results in terms of UTS and BHN, on the other hand green sand mould shows better results in terms of Charpy impact toughness.

IV. CONCLUSIONS

Based on this study, the following conclusions and recommendations were made:

i. The sandwich process was an efficient technique for significant spherulisation of graphite flakes.
ii. Micrographs method is required to provide a more thorough re-evaluation of the effect of cooling rate on tensile strength, BHN and impact toughness of as-cast specimen.
iii. The BHN value is maximum for CO^2 sand mould due to higher spherulisation and is minimum for Green sand mould due to lower spherulisation.
iv. The V-notch Charpy impact toughness value is highest for Green sand mould because of high damping due to flaky graphites.

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