Comparison of Structure and Properties of Semi-Solid Casting and Conventional Casting of Gray Cast Iron

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ABSTRACT

Semi-solid casting technique is one of the important casting methods for the production of metals and alloys to get non-dendritic structure of casting. Very few works have been carried out in the semi-solid processing of iron and steels although lot of works has been reported in the field of non-ferrous casting. In this study, an inclined channel was used to carry out the experimental work of semi-solid casting. The present study aims at finding out the effect of low shear stress while pouring the liquid metal into a mould on the microstructural morphology and mechanical properties of gray cast iron. To compare the effect of shear stress melts of same composition and from the same heat castings were made with shear and without shear, using a 20 kg arc furnace. Liquid metal was poured in green sand mould. Cylindrical test bars were cast using inclined channel and conventionally pouring of liquid metal under gravity in the sand moulds. Cylindrical test bars were cast to study the microstructure, tensile strength and hardness conditions. Microstructural study of the samples was conducted using a Leica optical microscope. The results obtained indicated that there was marked improvement in mechanical properties of low shear stress cast samples. Remarkably difference in microstructure was noticed from conventionally cast samples. Thus, low shear stress played a significant role in improving the mechanical properties and the modification of microstructure.

Keywords: Semi-Solid Casting, Low Shear Stress, Microstructure and Mechanical Properties.

INTRODUCTION

Gray cast iron is most commonly used material, with comparison to all other cast alloys in the world. Because of lesser ductility properties and brittle behaviour due to graphite flakes nature its usage has been constrained. Various methods are employed to optimise the properties so that to stretch the application of gray cast iron in metal processing and manufacturing sectors.

Many methods to control the morphology, size and distribution of graphite phase were used to improve the mechanical properties of GCI, such as modification, spheroiding and alloying, etc.[1–5]. The structure of GCI depends on chemical composition before the casting process, inoculants and cooling conditions[6]. The microstructure of GCI is characterised by graphite lamellae dispersed in the ferrous matrix. Foundry practice can influence nucleation and growth of graphite flakes. So that size and type of graphite flakes or both, enhance the desired properties. The amount of graphite, size, morphology and distribution of graphite lamelle are critical in determining the mechanical behaviour of GCI[6-8]. The as-cast microstructure is governed by the solidification process and solid-state transformation (eutectoid reaction). The matrix microstructure depends on the conditions under which the eutectoid reaction occurs. Among the variables that influence the mechanism of the eutectoid reaction are the chemical composition and the cooling rate through the eutectoid temperature range. The result of eutectoid transformation have key role in determining the mechanical properties of cast iron. Thus, the effect of alloying elements on mechanical properties of iron might be related to their influence on eutectoid transformation[9-11]. Although there is sufficient information available on microstructural characteristics of cast iron, effect of these on mechanical property (hardness) is not formulated. This has led to a series of experiments to find the effect of cooling rate on DAS and SDAS. Besides, the effect of these parameters on mechanical property (HB) is evaluated. The effect of high cooling rates in producing fine structures results in development of high-strength cast alloys. The undercooling of a melt to a lower temperature increases the number of effective nuclei relative to the growth rate, the latter being restricted by the rate at which the latent heat of crystallisation can be dissipated[12]. The microstructures of gray iron and ductile irons are determined by cooling rate, composition, nucleation and growth conditions existing during solidification and the transformation of austenite. DAS in alloys that solidified dendritically have been investigated by Zhang et al.[13]. Mechanical properties of cast in room temperature are more dependent to solidification microstructure and related phases in matrix, although different parameters such as chemical composition, size, shape and distribution of graphite, pearlite/ferrite ratio in matrix, have significant effects [14]. Venugopalan and Alagarsamy[15] evaluated the effect of alloy elements and suggested an equation for calculating mechanical properties (TS1 and YS2) vs. phase fraction. Yu and Loper [16] investigated the effect of pearlite amount on Hardness (Brinell) in ductile iron and suggested an equation:

$$HB = \text{ecp}\ (5.01 + \%\ \text{pearlite})$$

Simple equations were suggested by Svensson et al.[17] to correlate harness of iron to Si content (between 1.7 and 4.9). These equations are written below:

$$HB = HB_{\alpha}^{Si} \cdot f_{\alpha} + HB_{pe}^{Si} \cdot (1 - f_{\alpha})$$

$$HB_{\alpha}^{Si} = 54 + 37Si$$

$$HB_{pe}^{Si} = 167 + 31Si$$

Goodrich and Shaw's[18] investigations resulted an equation which calculate the ultimate tensile strength. Their formula includes not only composition of elements, but also cooling condition in the form of cast bar radius. Yang et al.[19] were the first ones who included the cooling rate of alloy in the formulation of mechanical property (Brinell hardness). This cooling rate (R) was in the special temperature (900°C). Their formula is summarised below:

$$HB = A + f(\%\text{alloy elements}) + f(R_{900})$$

In the present work the microstructure and hardness value obtained from different steps of stepped bar.

EXPERIMENT

Silica sand of AFS-GFN 68.6% bentonite and water were taken. The mixture was mulled for 7 minute. Two moulds were prepared having stepped pattern cavity and the moulds were allowed to dry for 3 hours. The 3D model of casting is shown in Fig. 1 and the dimension of the different steps of stepped bar is shown in the Table-1. Melting was done in a newly line electric arc furnace of capacity 20 kg. The molten metal pouring temperature was maintained at 1370°C. Metal was poured in the cavity by different methods, the metal was poured in both the mould box by different methods, in one mould box metal was poured conventionally and in the other mould box cavity was filled from metal following a slopped plate of 1 metre and inclined at approximately 10° hence giving a cooling rate of 60 Kelvin/second.

Table-1: Dimension of Steps of Stepped Bar

STEP NUMBER	LABEL	DIMENSION (mm)
1	S1	46 x 48 x 4
2	S2	52 x 48 x 7
3	S3	50x 48x 12
4	S4	50.5 x 48 x 18

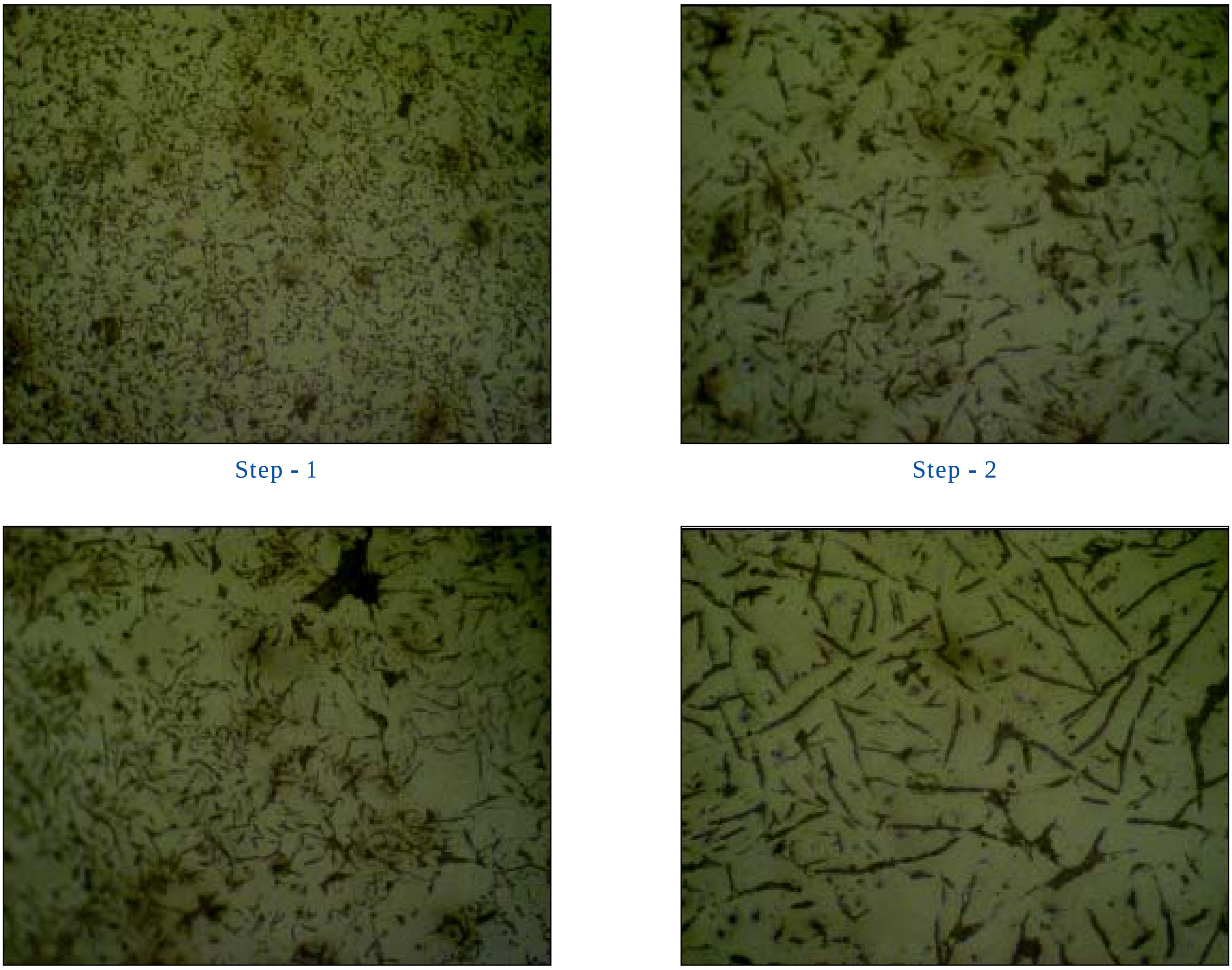
RESULT & DISCUSSION

Microstructure

The composition analysis of the cast metal test specimen was determined using an optical emission spectrometer. The obtained composition of the sample is given in the Table-2. The microstructure of different steps of the two cast samples each of semi solid condition and conventionally poured is shown below in Fig. 2 and Fig. 3 . Microstructures were seen in Leica optical microscope at 200 X. The microstructure of thinner section is much finer than that of thicker section in each case.

Table-2: Chemical Composition of Gray Iron

Elements	C	Si	P	S	Mn	Cu
Amount (wt%)	3.46	1.6-2.0	0.11-0.18	0.08	0.52	0.37



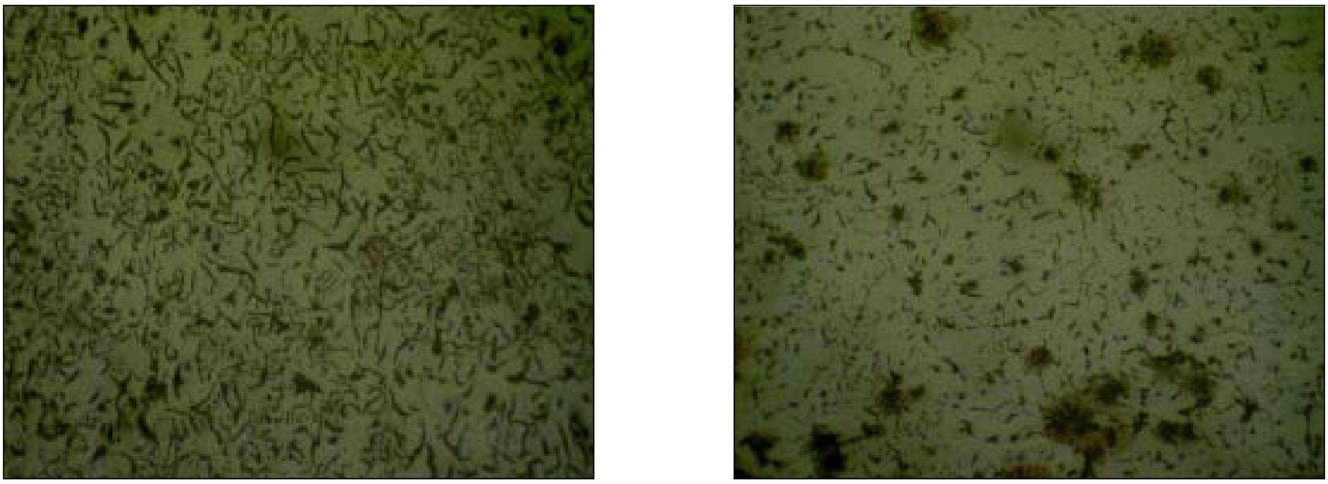
Step - 1

Step - 2

Step - 3

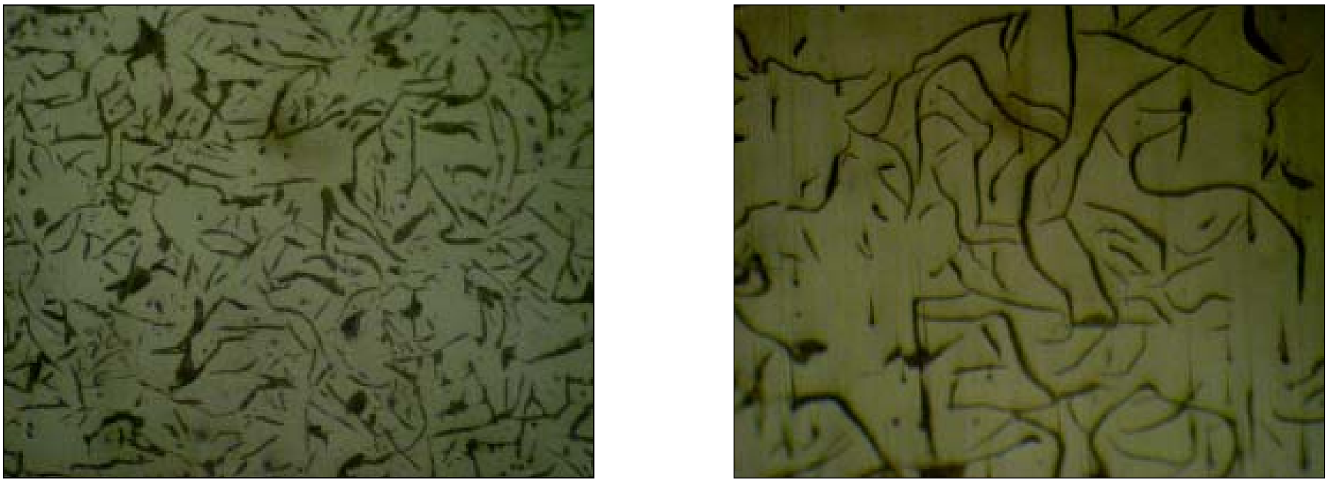
Step - 4

Fig. 2: Microstructure of different steps of semi-solid cast stepped bar at 200X.



Step - 1

Step - 2



Step - 3

Step - 4

Fig. 3: Microstructure of different steps of conventionally cast stepped bar at 200X.

Hardness

The test was performed on steps of different thickness and from the result it was concluded that the hardness value of semi-solid processed steps were having higher value than that of conventionally cast stepped bar. The hardness of different steps in BHN of the two-test sample is shown in the Table-3.

Table-3: Brinell Hardness Number of Steps.

	STEP	DENT DIAMETER (mm)	BHN
SEMI SOLID	S1	2.54	194
	S2	2.8	171
	S3	3.1	129
	S4	3.5	107
CONVENTIONAL	S1	2.59	187
	S2	3.1	138
	S3	3.4	107
	S4	3.5	101

CONCLUDING REMARKS

Investigation of gray cast iron with different cooling rate shows that the cooling rate has remarkable influence on microstructure and Brinell hardness. The Brinell hardness however, decreases as the cool-ing rate decreases, showing a direct relationship. But this behaviour becomes reverse in a special cooling rate range (50-67 Kelvin/second) because of change in graphite type in the structure. The acceptable range is 40-80 Kelvin/second and the hardness value in this range for proposed formula is in better agree-ment with experimental data in literature. Hence, these formulae can be used in industrial scales. In addition, the presented experimental method can be used for other commercial alloys.

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As a consequence, semi-solid cast parts are almost free of gas porosity.Â Semi-solid processing guarantees higher performance than die-casting, while maintaining a number of the advantages of die-casting, such as good dimensional tolerances, high production rates, high surface quality, complex near-net-shape parts, and thin sections with very limited need of any finishing operations [6]. In addition, when compared to conventional die-casting, SSM processing increases die life because of the.Â In Figure 10a, the comparison between the properties of semi-solid, casting, and forging Alâ€“Si alloys summarized by Brochu et al. [70] is shown, further supporting the above-mentioned advantages. Semi-solid metal casting (SSM) is a near net shape variant of die casting. The process is used today with non-ferrous metals, such as aluminium, copper, and magnesium, but also can work with higher temperature alloys for which no currently suitable die materials are available. The process combines the advantages of casting and forging. The process is named after the fluid property thixotropy, which is the phenomenon that allows this process to work. Simply, thixotropic fluids flow when sheared, but