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Development of a New Route for Fe-C-Al Cast Iron Production

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Abstract: Fe-C-Al alloy system spheroidal graphite cast iron has enormous benefits such as higher strength and hardness, better wear and oxidation resistance etc. at room temperature as well as high temperature. However, its application is not still being popularized due to the production difficulties. In this investigation, a special type of design was developed to perform the magnesium (Mg) treatment in the melt. The raw materials were melted in an induction furnace and later liquid metal was treated using pure Mg foil for spherodization in special crucible. The microstructural study was performed using Scanning Electron Microscope (SEM). The chemical analysis shows a great breakthrough in Mg recovery of Fe-C-Al alloy system spheroidal graphite cast iron. It is also shown that the mechanical properties such as hardness, tensile strength and ductility are comparable to the previous research work.

Key words: Ductile cast iron, magnesium treatment, Fe-C-Al alloy, tensile strength

INTRODUCTION

Cast iron is an iron alloy consisting about 95% by weight iron, 2.1 to 4% by weight carbon and 1 to 3% by weight silicon. Ferrous alloys are the most important industrial alloy and among them 35% is cast iron (Rashid and Edmonds, 2002). The cast iron has multi directional properties depending on its graphite size, shape and the type of matrix. The gray cast iron contains flaky graphite in ferrite or pearlite or a mixture of these matrixes. These types of graphite act as crack initiator which reduces it's the tensile strength. So, the researchers try to modify the gray cast iron to change its graphite shape as well as its properties; because, if the graphite becomes spherical in shape, it will act as crack arrester which improves the properties of the cast iron (Qitfer, 1983). However, the later process flourishes very quickly for its convenience (Heine *et al*., 2002).

Aluminium and silicon have similar graphitization effect on Fe-C system. Ghoreshy and Kondic (1983) proposed Fe-C-Al cast iron with the eutectic solidification of cast iron. They proposed that solidification of Spheroidal Graphite (SG-Al) cast iron is more complex than SG-Si cast iron. In Fe-C-Al alloy system, there are two ranges of stabilizing effect corresponding to the formation of Fe_3AlC and Al_4C_3 compounds. Up to 4% of Al, its graphitizing effect is very strong (Fargues, 1985), whereas in the case of the silicon-bearing system, there is only one such range corresponding to SiC (Zhukov, 1978). Aluminium promotes graphite formation during eutectic solidification but it also stabilizes pearlite during eutectoid reaction. Aluminium reduces the solubility of carbon in liquid eutectic iron and increases the solubility of this element in austenite. Carlberg and Fredriksson (1977) showed that the liquidus temperature increases by 10°C for each per cent of Al whereas for each per cent of Si decreases by 30°C. They also found that the eutectic temperature increases by 20°C for same percent of Al whereas the temperature decreases by 7.5°C same percent of Si content.

The magnesium treatment has a great impact on the production of SG-Al cast iron. The use of magnesium alloy and its recovery is the crucial factor for the production of SG-Al cast iron. It is found that the consumption of magnesium containing alloy in the production of Fe-C-Al cast iron increases due to low recovery of magnesium which intern increase the production cost of SG-Al cast iron (Haque and Young, 1995; Rashid and Edmonds, 2002; Haque, 2007). In the present study, pure magnesium foil was used in specially designed ladle for liquid melt treatment and recovery of magnesium was very satisfactory.

EXPERIMENTAL DETAILS

Moulding materials: For ferrous casting hard sand mould is necessary. In this study, cold set resin bonded sand mould was prepared using synthetic silica sand (AFS grain fineness 60), cold set resin (Grade CS 1080) and hardener (Grade FC 200). The 18 kg silica sand was mixed

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Table 1: Detail of charge materials (wt. %)

Name of the materials	Fe-C-Al spheroidal graphite cast iron
Pig Iron (Sorel Metal, Grade RF10)	80.00
Mild Steel (0.2% C)	15.50
Ferrosilicon ($Fe_{20}Si_{70}$)	0.50
Commercially pure Al	3.00
Mg foil	0.055
Fluxing materials (commercially used)	0.20

Table 2: Chemical composition of cast iron and sorel metal (wt.%)

Sample specification	Sorel metal	Fe-C-Al spheroidal graphite cast iron
C	4.06	2.94
Si	0.12	0.10
Al	--	2.99
Mn	0.013	0.28
P	0.03	0.021
S	0.012	0.026
Cr	--	0.047
Cu	--	0.132
Mg	--	0.033
Fe	Balance	Balance

with 2% cold set resin in the Muller (Hobert Muller, Model No A 200). After 5 minutes mixing, 1% hardener was added in the sand mixture and continued the mixing for another 1 minute. Finally, the sand mixture was used to prepare the mould using wooden pattern.

Charge materials: The raw materials were melted in a medium frequency induction furnace. For Fe-C-Al alloy system, pig iron (Sorel Metal), mild steel and commercially pure aluminium were melted together.

After melting, the fluxing material was added, stirred and the slag was removed. The details of charging raw materials and its chemical compositions are shown in the Table 1 and 2, respectively.

Magnesium treatment: A special type of crucible was design and prepared for Mg treatment in this investigation which is shown in Fig. 1. After melting all raw materials, the liquid iron was kept in the furnace and heated up to about 1550°C temperature. Then, the liquid metal was shifted into the special type of ladle for Mg treatment where the pure magnesium foil was covered with mild steel box. To protect the liquid metal splashing during reaction, the crucible was covered with mild steel lid with refractory lining. When the reaction completed the melt was poured into the mould at about 1450°C.

After casting, the chemical analysis was performed and calculated the magnesium recovery in the cast iron using the Eq. 1. The Metallographic sample was prepared by polishing and etched with 5% natal solution. Hardness was measured using Rockwell hardness tester, Model: 660RLD/T in B scale and converted to Brinell Hardness Number (BHN) using conversion table. Tensile test was performed using instron (Model -3360) universal testing machine and the fracture surface was observed under FESEM (JEOL JSM-6700F):

$$\frac{w_1 - w_2}{w_1}\times 100\% \tag{1}$$

where, w_1 is the initial weight of the magnesium which was added in the liquid metal and w_2 is final weight of magnesium which was remain in the solid cast iron.

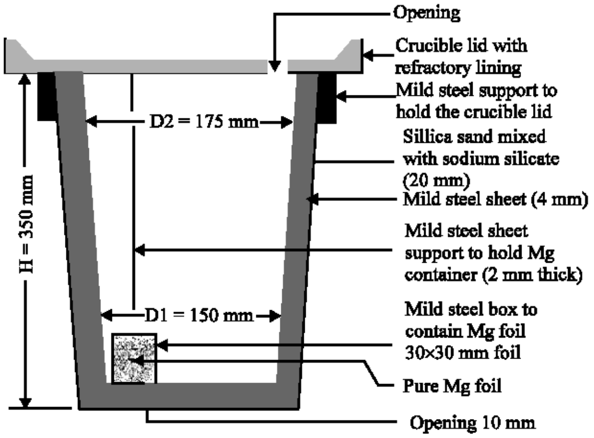

Fig. 1: Magnesium treatment crucible for preparing spheroidal graphite cast iron

RESULTS AND DISCUSSION

Microstructure and phases: Figure 2 shows the microstructure of ductile cast iron produced in the present study, it is noticed that graphite nodules are surrounded by ferrite which is known as bull's eye structure and beside the ferrite, pearlite also present as matrix. The nodularity of this cast iron was around 90% and is due to the diffusion of carbon from austenite. When the melt solidify from liquid to solid, it contains supersaturated austenite. However, at room temperature, the solubility of carbon in austenite is very low. Therefore, the carbon precipitated out in a free form which is known as graphitization and spherodized due to the presence of aluminium and magnesium, respectively. Since, the carbon diffuse out from the austenite, the near reason transformed to ferrite. The similar structure was also reported by Rashid and Edmonds (2002).

Figure 3 shows the X-ray diffraction of the ductile cast iron. The diffraction pattern showed graphite, ferrite, cementite and iron-aluminium-silicon complex phases. The XRD pattern indicated that the produced spheroidal graphitic cast iron contains higher ferrite content than pearlite. It was reported that aluminium has gamma loop closing property in iron-iron carbide equilibrium diagram

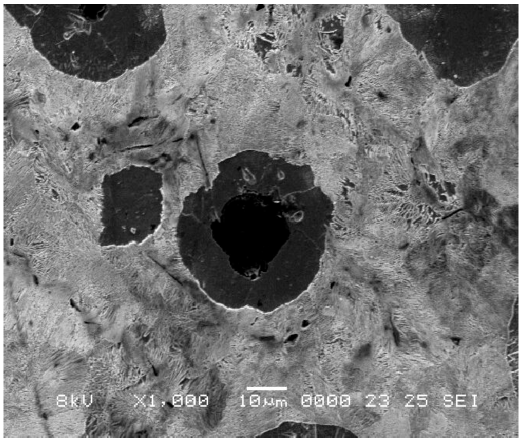

Fig. 2: Microstructure of spheroidal graphite cast iron (etched with 5% nital)

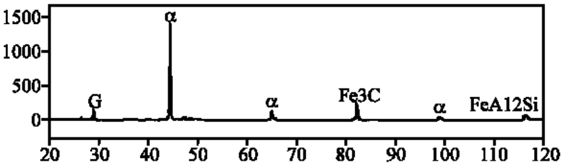

Fig. 3: X-ray diffraction pattern of spheroidal graphite cast iron

Table 3: Mechanical properties of Fe-C-Al SG cast iron

Hardness (Mpa)	UTS (Mpa)	0.2% YS (Mpa)	% of Elongation
240	478	313	3.50

and this property improves ferrite content in the matrix (Lancaster, 1993).

Tensile properties and fracture surface: The hardness and tensile properties of the cast iron is given in Table 3, it is clear that the Ultimate Tensile Strength (UTS) is 478 MPa and the percentage of elongation is 3.50%. It shows that it has nearly the same properties with other spheroidal graphite cast iron which is produced in different Mg treatment process (Haque and Young, 1995).

Figure 4 shows the fracture surface of the cast alloy. It was viaiable that Transgranular type fracture occurred in the developed cast iron fracture surface. It was reported by Batra (2005) that graphite nodules act as the discontinuities for crack propagation where the crack is arrested by graphite spheroids. Due to application of load, the matrix around the graphite deforms plastically, resulting in decohesion at the graphite/matrix and graphite/wrapped graphite interface. Thus, microvoids first form at the graphite nodules/matrix interface. These microvoids concentrate stresses and may later promote cracks in the matrix adjacent to the graphite nodules. The crack, which normally initiates near the graphite nodule, propagates through the matrix to reach the adjoining nodules.

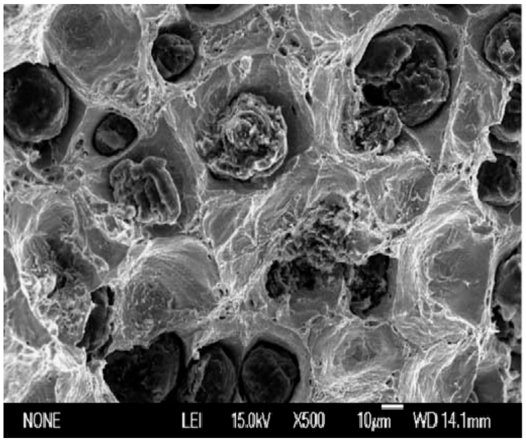

Fig. 4: Fracture surface of as-cast Fe-C-Al SG cast iron under tensile loading

CONCLUSIONS

The following conclusions can be drawn from the experiment of the present study:

- Fe-C-Al spheroidal graphite cast iron has been successfully developed with less difficulty with designing special type crucible for Mg treatment
- Magnesium recovery in this process is higher compared to other previous studies
- The cast iron shows satisfactory level of strength and hardness
- Transgranular type fracture occurred in the developed cast iron fracture surface

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