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Effect of Bismuth in Trace Level on the Properties of Gray Cast Iron

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Abstract

In the present work an effort has been made to correlate the "Effect of Bismuth in trace level on the tensile strength, hardness and microstructure of gray cast iron". Bismuth in trace level have a significant effect on the properties and microstructure of gray cast iron. Bismuth is deliberately added to study its effect on properties and microstructure. The addition of bismuth in trace level shows a decreasing trend in tensile strength and hardness values for all additions.

Keywords: Trace elements, tensile strength, microstructure, hardness.

Introduction

Outstanding castability, good combination of mechanical and physical properties, low cost and simplicity in production made gray cast iron as an excellent founding material for many engineering components such as cylinder block, cylinder head, oil cooler cover, brake drum etc. Important mechanical properties for such castings are tensile strength, modulus of elasticity, impact strength and damping capacity. Gray cast iron is an alloy of iron, carbon, silicon, manganese, phosphorous and sulphur. In addition to these elements there are a number of trace elements present in the gray cast iron. The elements present in traces in gray cast iron have a significant effect on properties and graphitic structure. Hence it is important to understand its effects by the users and producers of such castings. Their effect on properties and graphitic structure becomes important, when trace element levels are lower or higher than the normal value.

The source of trace elements into gray cast iron are from pig iron, non-ferrous metal scrap, vitreous enameled scrap, leaded steel scrap, purchased scrap containing lead or coated with lead based paint. To avoid trace element contamination in charge materials, all bought in scrap should be examined prior to the stockpiling so that undesirable charge materials can be removed. In the present work, the effect of bismuth on the mechanical properties and graphitic structure at trace level on gray cast iron are studied. Bismuth is deliberately added to the gray cast iron to know its effect on the properties of gray cast iron.

Gray Cast iron Composition:

On the basis of elements present in gray cast iron can be divided into three categories [1-4].

1) Major elements,
2) Minor elements and
3) Trace elements.

Major elements: The three major elements in gray cast iron are iron, carbon and silicon.

Carbon: carbon in gray cast iron is present from 2.5 to 4% by weight. It occurs in two phases, elemental carbon in the form of graphite and combined carbon as iron carbide (Fe_3C). The degree of graphitization is assessed by % Total Carbon = % Graphitic Carbon + % Combined Carbon.

Silicon: silicon is present in gray iron from 1.0 to 3.0% by weight. The important effect of silicon is its effect on graphitization. It is found that increasing silicon percentage shifts the eutectic point of the iron carbon diagram to the left. The eutectic shift is often described by the following relationship. Eutectic carbon percentage = 4.3 – 1/3 x % Si.

Minor elements: The minor elements in gray iron are phosphorus and the two interrelated elements manganese and sulfur.

Phosphorus: Phosphorus is found in all gray irons. It is rarely added intentionally, but tends to come from pig iron. To some extent it increases the fluidity of iron. Phosphorus forms a low melting point phase in gray iron that is commonly referred as steadite (Fe_3P). At high levels it promotes shrinkage porosity, while at low levels (below about 0.05%) it increases metal penetration and finning defect.

Sulphur and Manganese: In irons melted in acid cupola, sulphur is normally present within the range 0.08 to 0.18%, and irons produced by electric melting usually contain 0.03% to 0.08%. The influence of sulphur needs to be considered relative to its reaction with manganese in iron. Sulphur will form iron sulphide (FeS) and segregates on grain boundaries during freezing and precipitates during final stage of freezing.

TRACE ELEMENTS: Elements normally present as trace amounts in gray cast iron can have a significant effect on properties and graphitic structure. The effect on properties and structure becomes important when trace element levels are lower or higher than normal values. Trace elements normally detected in gray cast iron are Boron, Lead, Bismuth, Titanium, Nitrogen, Arsenic, Aluminium, Tin, Tellurium, Antimony, Vanadium etc [5].

Bismuth: Bismuth content in gray iron can be <0.02 percent the sources of bismuth in gray cast iron are pig irons, bismuth containing mold and core coatings. The residual bismuth levels in excess of 0.0035 % in flake graphite irons cause a serious reduction in all mechanical properties, owing to the formation of free carbide, type D, spiky, mesh and widmanstatten graphite. Bismuth restricts eutectic cell growth, promotes under cooling, increases chill (carbide net work) and reduces the eutectic cell count. It has been reported in literature [6] that addition of about 0.10% percent cerium to the gray iron melt neutralizes the harmful effect of bismuth to the mechanical properties [6-11].

Experimental Details

Moulding: this chapter deals with the experimental details adopted during the investigation. Moulds for tensile test samples (30 mm round) are prepared using moulding sand of the following composition. High silica sand: 200 Kg, Bentonite: 8 Kg, Yellow dextrin: 2 Kg, Iron oxide: 1 Kg and Raw linceed Oil: 6 Lit. High silica sand, Bentonite, Yellow dextrin and Iron oxide are mixed for about 30 sec, in dry condition followed by sufficient water addition and mixing for another 30 sec, finally linseed oil is added and mixed for 90 seconds. The tensile sample moulds are prepared in the wooden moulding boxes to get a sample size of about 30mm diameter and 300mm length. The moulds are baked in a gas fired oven about 3 hrs at a temperature of 200 °C. Then the moulds are cooled to room temperature by placing them in still air. The mould cavities are cleaned with high pressure air to avoid any sand and dirt inclusion in the samples.

Melting: In TELCO, Jamshedpur the melting of gray cast iron is carried out in induction melting furnaces (coreless type of mains frequency) of capacity 12 tons and power of 2400Kw. The furnace is lined with acid refractory and the coils are water cooled (the pressure of circulating cooling water is maintained at a pressure of 3.5 Kg/cm^2). The tap to tap time is 2 hrs and during tapping only 5 tons of hot metal is tapped and remaining 7 tons is recycled in the next heat.

Charging Sequence: The sequence of batch charging is as below;
Charge 1: Coke = 70 Kg, Charge 2: Steel bundle = 900 Kg, Pig Iron = 500 Kg, Charge 3: Ferrosilicon = 30 kg, Charge 4: Steel (Heavy) = 1000Kg and Charge 5: Steel scrap = 1000Kg. The charge ratio of steel scrap, foundry returns and pig iron is maintained at 6:3:1. The molten iron from the 12 ton induction (coreless) furnace is transferred into the 42 ton Induction (Channel type) furnace, where it is held for some time to homogenize the composition and to superheat the gray iron to the required temperature. Temperature of molten iron is measured by using immersion pyrometer.

Inoculation: 0.5% Ferrosilicon is used for inoculation. The silicon content of Fe-Si: 50%. The size of ferrosilicon granules is in the range of 2 to 3 mm. The high temperature metal is tapped into 400 Kg preheated ladle, which contains 2 Kg ferrosilicon at the bottom.

Composition of Base metal :

The base metal sample composition is shown in Table 1.

Table 1: Base metal composition

Element	Total Carbon	Si	Mn	S	P	Cr	Cu	Sn
% Composition by weight	3.41	2.13	0.58	0.04	0.046	0.04	0.03	0.008

Bismuth addition: Bismuth is added in the form of pure powder form by placing it in the bottom of the moulds. The recovery of bismuth is taken as 60%. The estimated amount of bismuth added to the melt is as given in Table 2,

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Table 2: Amount of Bismuth addition to Base metal

S.No	Bismuth Weight, %	Bismuth for 1.2 Kg metal (grams)
1	0.00	----
2	0.01	200
3	0.025	500
4	0.05	1000
5	0.1	2000

The temperature of molten iron before pouring into the moulds is 1428 °C.

Casting

The calculated quantity of trace elements to be added are placed in the bottom of moulds and the high temperature molten iron is poured into the moulds to get the test bars of dimension 30x300 mm length. Then the samples are cooled to room temperature by putting in still air. After cooling, the test bars are taken out from the moulds and are cleaned with the wire brush. Then the samples are sent to the machine shop to prepare the tensile test bars of standard dimensions as per IS: 2078-1979.

Specimen Preparation:

Tensile test specimens were prepared from the tensile test bar castings for each composition. The specimens for metallography and hardness were cut from the fractured tensile test specimens.

Testing

- **Tensile strength test:** This test was carried out on a Universal testing machine of 60 ton capacity in mechanical testing laboratory at TELCO, Jamshedpur. The load on the test specimen was applied steadily till fracture occurs.
- **Hardness test:** Brinnels hardness test was carried out using a standard hardness testing machine. The steel ball diameter of the indenter is 10 mm and the load applied was 3000 Kg. hardness values are measured at three different places across the cross section of test piece and the average of three values are noted.
- **Metallography:** The samples for photo micro graphs are prepared according to the standard procedure. Around 20 mm thick sample was taken from the fractured tensile test bars. It is polished first on a belt grinder, emery papers of varying specifications from 01 to 03 and finally on a cloth grinder to get a mirror finish to the sample. The microstructure was observed using microscope at 100X magnification without etching and with etching with 2% Nital.

Results and Discussions

Effect of Bismuth addition: Data in Table 3 represents the effect of bismuth additions on the tensile strength and hardness values.

Table 3: Effect of Bismuth additions on the tensile strength and hardness

S.No	Bismuth Weight, %	Tensile strength (Kg/mm^2)	Hardness (BHN)
1.	0.00	21.3	171
2.	0.01	20.6	168
3.	0.025	15.9	157
4.	0.05	16.2	157
5.	0.10	15.8	154

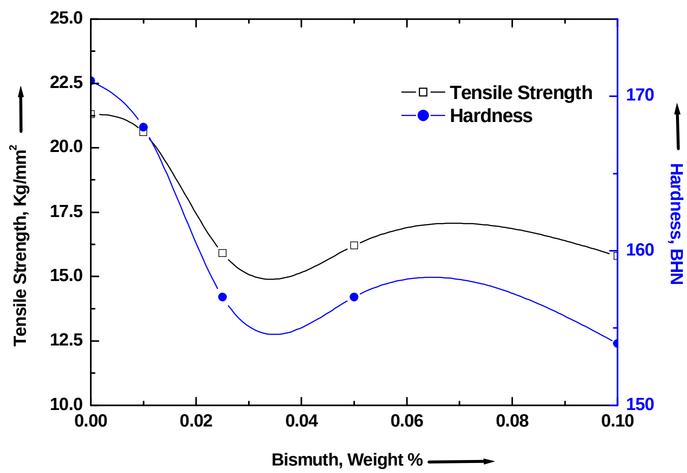

Fig. 1: Effect of Bismuth additions on the tensile strength and hardness

Fig. 2 and 3 shows the effect of bismuth additions on the microstructure of gray cast iron. Microstructure of base gray cast iron consists of type A graphitic structure. With increasing additions of bismuth, both the tensile strength and hardness values decrease drastically upto 0.025% bismuth, beyond which the change is only marginal. The tensile strength decreased from 21.3 Kg/mm^2 to 15.8 Kg/mm^2, while hardness value decreased from 171 to 154 BHN, with the increasing addition of bismuth. The drastic fall in the properties is due to the undesirable type D graphite. Further additions do not reveal any appreciable change in the microstructure and hence properties also do not change much.

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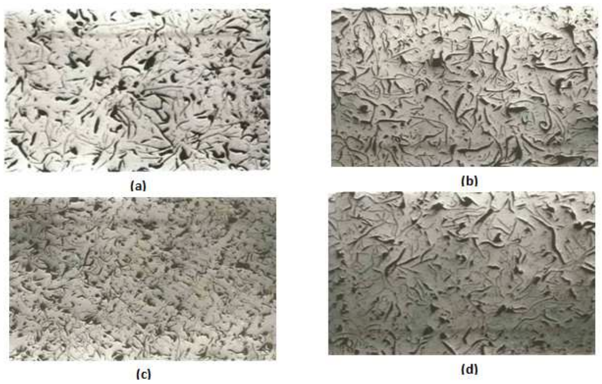

Fig. 3: Effect of Bismuth additions on the microstructure of Gray Cast Iron (a) Base iron (b) 0.025% Bi (c) 0.05% Bi (d) 0.1% Bi, 100X, Unetched

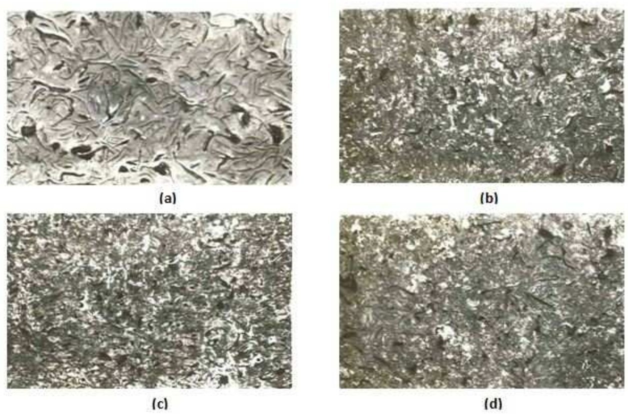

Fig. 4: Effect of Bismuth additions on the microstructure of Gray Cast Iron (a) Base iron (b) 0.025% Bi (c) 0.05% Bi (d) 0.1% Bi, 100X, Etched with 2% Nital

Conclusion

The presence of bismuth in trace level shows serious reduction in mechanical properties. It shows a decreasing trend in tensile strength from 21.3 Kg/mm^2 to 15.8 Kg/mm^2 with an addition of 0.1% bismuth. It also shows the decreasing trend in hardness values from 171 to 154. From the microstructural study, it is found that it is due to the formation of undesirable type D graphite. So, Bismuth in gray cast iron also shows a decreasing trend in tensile strength and hardness values at all additions. So care should be taken to avoid the contamination of bismuth in trace level from pig iron, non-ferrous metal scrap, vitreous enameled scrap, leaded steel scrap, purchased scrap containing lead or coated with lead based paint. To avoid trace element contamination in charge materials, all bought in scrap should be examined prior to the stockpiling so that undesirable charge materials can be removed

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