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Effect of Trace Elements (Boron and Lead) on the Properties of Grey Cast Iron

[1]Sanjeev Kumar [2]Anil Punia,
[1]Post graduate student, Department of Mechanical Engineering, Rao Pahlad Singh College of Engineering and Technology, Balana, Mohindergarh-123023
[2]Assistant professor, Department of Mechanical Engineering, Rao Pahlad Singh College of Engineering and Technology, Balana, Mohindergarh-123023
[1]Mechanical Engineering,
Mahendergarh, India

Abstract: In the current work an effort has been made to link the ''Effect of trace elements (B and Pb) on the tensile strength, hardness and microstructure of gray cast iron''. These elements have a important effect on the properties and microstructure of grey cast iron. These elements are intentionally added to study their effect on properties and microstructure. Boron up to 0.02 % in grey cast iron showed an enhancement in tensile strength and hardness values. While beyond this quantity it shows a declining trend, due to the formation of type B and type D graphitic formation. Lead in gray cast iron shows a declining trend in tensile strength and hardness ideals, even if present in trace amount, due to the formation of spiky or mesh type graphite.

***Index Terms* - Trace elements · Tensile strength · Microstructure · Hardness**

I. INTRODUCTION

Excellent cast ability, good combination of mechanical and physical properties, low cost and simplicity in production make grey CI an admirable foundation material for many engineering workings such as cylinder head, cylinder block oil coolers cover, brake drum etc. Grey CI is an alloy of iron, carbon, manganese, silicon, phosphorous and sulphur. In addition to these elements there are a number of trace elements present in the grey cast iron. The elements present in traces in gray cast iron have a important effect on properties and graphitic structure. Hence it is important to understand its property by the users and producers of such castings. Their effect on properties and graphitic structure becomes significant, when trace element levels are lower or higher than the normal value.

The source of trace elements in grey 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 charged materials, all bought in scrap should be examine earlier to the stock piling so that unde sirable charge materials can be distant. In the present work, the effect of boron and lead on the mechanical properties and graphitic formation at trace level on grey cast iron are considered. These elements are intentionally added to the grey cast iron to know its effect on the properties of grey cast iron

2. GREY CAST IRON COMPOSITION

The basis of element here in gray cast iron can bedivided into three categories [1- 4].

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

3. Major Elements

The three major elements in gray cast iron are iron, carbonand silicon.

Carbon

Carbon in grey CI constitute about 2.5 to 4 % by weight. It occur in two phases, elemental carbon in the form of graphite and collective carbon as iron carbide (Fe_3C). The degree of graphitization is assess by % Total Carbon = % Graphitic Carbon % Combined Carbon. If graphitization is full, the percentage of total carbon and the percentage of graphitic carbon are the same. If there is no graphitization occured, the percentage of graphitic carbon is zero. If about 0.5–0.8 % combined carbon exists in the grey iron, it usually indicate that the microstructure is mainly pearlitic.

Silicon

Silicon in grey iron constitute about 1.0 to 3.0 % by weight. The main effect of silicon is its effect ongraphitization. It is found that ever-increasing silicon percentageshifts the eutectic point of the iron carbon diagram to the left.

4. Minor Elements

The minor elements in grey iron are phosphorus and the two consistent elements manganese and sulphur.

Phosphorus

Phosphorus is found in all grey irons. It is hardly ever added intentionally, but tends to come from pig iron. To some amount it increase the fluidity of iron. Phosphorus forms a low melting point phase in grey iron that is normally referred as steadite (Fe_3P). At high levels it promote shrinkage porosity, while at low levels (below about 0.05 %) it increase metal penetration and finning defect.

Sulphur

In irons melted in acid cupola, sulphur is usually present within the range 0.08–0.18 %, and irons produced by electric melting usually contain 0.03–0.08 %. The influ- ence of sulphur requirements to be considered relative to its reaction with manganese in iron. Sulphur will form iron sulphide (FeS) and segregate on grain limitations during freezing and precipitates during final stage of freezing.

Manganese

When manganese is present, manganese sulphide (MnS) is produced and neutralize the effect of sulphur. % Mn ¼ 1:7 × % *S* : Chemically equivalent sulphur and manganese percentages to make MnS % Mn ¼ 1:7 × % *S* þ 0:15 : The manganese percentagewhich will promote a utmost of ferrite and a minimum of pearlite % Mn ¼ 3 × % *S* 0:35 : The manganese percentage which will build up a pearlitic microstructure

Chromium

Chromium can be present in grey irons up to 0.3 %. It promotes chill and pearlitic structure in grey irons. It improve the strength due to the creation of carbides.The main source of chromium is from nickel plates, steel scrap and Ni–Mg alloys here in the initial charge materials.

Nickel

Nickel can be present in grey irons up to 0.5 %. It has least effect if it present in small amount (up to 0.1 %) but it promote graphitization when present in large quantities. The main resource of nickel is from steel scrap ,nickel plates and Ni-Mg alloys present in the initial charge materials.

Copper

Copper can be present in grey irons up to 0.5 %. It pro- motes pearlitic structure, improves strength and impairfertilization in ductile irons. The major source of copper is from copper wires, copper based alloys and steel scrap present in the initial charge materials.

Tin

Tin is a dominant pearlite promoting element and increasing the tin content of grey and nodular irons will make sure that structures required to be fully pearlitic or freeof ferrite. Tin is normally present in grey cast iron at levels below 0.02 %. Higher levels may effect from non- ferrous contamination or from the use of tin coated steels during melting. Where purposeful additions of tin are made, a maximum level of 0.1 % tin will ensure fullypearlitic matrix and increase the tensile strength ofboth grey and nodular irons. Additions in surplus of 0.1 % result in increased hardness and reduced tensile strength

4.1 Trace Elements

Elements usually present as trace amounts in grey cast iron can have a important effect on properties and graphitic structure. The effect on properties and structure becomes significant when trace element levels are lower or higher than normal values. Trace elements normally detected in grey cast iron are Boron, Lead, Bismuth, Titanium etc. [5].

Boron

Boron is an unwanted element in grey cast iron, because of its very powerful carbide stabilizing properties. It is usually recommended that gray cast iron should contain 0.005 % boron. Boron is usually not detected in pig iron, when boron is present above trace level; it is normally the result of the accidental inclusion of enameled scrap in the furnace charge. Typical examples of enamelled scrap are cast iron baths, cooker handles and sauce pans, which due to its thin sections gets broken into small pieces, making it not easy to estimate the enamel content. It is recommended that a maximum of 5 % enameled scrap be used in a furnace charge. When exceed, it is possible for boron to be present in the iron up to 0.055 %, with disastrous results in terms chill, cracking problems in thin sections, decrease in tensile strength and undesirable graphite forms such as formation of type D graphite in gray cast iron[5–9].

Lead

During melting of grey cast iron, the trace elements in charge materials, such as lead, build up to a level where the structure and the mechanical properties of castings are harshly affected. It has been reported by some investi- gators that the presence of trace amounts of lead in gray iron promote the development of abnormal graphites such as bayonet-shaped, widmanstatten, mesh or spiky. Development of irregular graphites causes a lessen in tensile strength, impact strength as well as thermal shock and crack resistance. Some lead bearing material charged into the melting furnace may be underpinning of lead contamination. The main source of lead in grey iron is mainly due to the scrapcontaining lead or coated with lead based paint, leadedsteel scrap, lead bearing fluxes [5, 10–15].

Lead contamination can be prohibited by investigative allbought in scrap, prior to stock piling, so that unwanted material can be avoided. Enameled scrap should not exceed 5 percent of the charge weight. It has been reported by Bates and Wallace [12, 15] that the adding of 0.10 % cerium, to the leaded iron can eliminate the harmful effect of lead.

Bismuth

Bismuth content in grey iron can be 0.02 %. The source of bismuth in grey cast iron are pig irons, bismuth con- taining mould and core coatings. The remaining bismuth levels in excess of 0.0035 % in flake graphite irons causes a significant decrease in all mechanical properties, owing to the formation of free carbide, type D, spiky, mesh and widmanstatten graphite. Bismuth restrict eutectic cell growth, promotes under cooling, increases chill (carbide net work) and reduces the eutectic cell count. It has been reported in literature [15] that adding of about 0.10 % cerium to the gray iron melt neutralizes the harmful effect of bismuth on the mechanical properties [5, 7, 15].

Titanium

Titanium may be present in grey irons in the range of 0.005 to 0.05 %. The greater levels of titanium frequently result from intentional additions made to suppress the effect of nitrogen.Pig irons can contain up to 0.2 % titanium and are the natural sources of titanium in grey cast iron. The cause of nitrogen on structure and properties is of exacting significance in the case of grey cast iron. Nitrogen content in grey cast iron varies between 0.001 and 0.015 %. Above 0.01 % nitrogen change the graphite flakes manufacture it shorter and thicker and develop rounded ends. This compressed form of graphite causes an increase in tensile strength, but this graphitic structure is objectionable, since it lowers the thermal shock resistance. Very high nitrogen content can promote pearlite formation and may direct to white iron structure. The effect of nitrogen can be neutralize by the adding of nitride forming elements such astitanium and aluminium. The effect of nitrogen can beeliminated by the presence of titanium to the extent of 0.04 % in grey cast iron. Titanium combine with nitrogen in the melt by forming titanium nitride (TiN) and prevent formation of compacted graphite iron. High levels of titanium promotes the formation of objectionable graphite forms, such as under cooled graphite or type D graphitic structure [5, 15–18].

Table 1 Quantity of boron added to Grey cast iron

S. No	Boron weight (%)	Ferro boron for 1.2 kgmetal (g)
1	0.00	–
2	0.005	0.3
3	0.01	0.6
4	0.02	1.2
5	0.03	1.8
6	0.04	2.4

Table 2 Quantity of Lead added to Grey cast Iron

S. No	Lead weight (%)	Lead for 1.2 kgmetal (g)
1	0.00	–
2	0.005	75
3	0.01	150
4	0.025	375
5	0.05	750
6	0.1	1,500

5. Experimental Details

Moulding

This section explain the experimental procedure adopted during the analysis. Moulds for tensile test sample(30 mm round) are ready by using moulding sand of the following composition; High silica sand: 200 kg, Bentonite: 8 kg, Yellow dextrin: 2 kg, Iron oxide: 1 kg and unprocessed linseedOil: 6 l. High silica sand, Bentonite, Yellow dextrin and Ironoxide are mixe with reference to 30 s, in dry condition followed byenough water addition and mixing for another 30 s; finally linseed oil is further added and mixed for 90 s. The tensile sample mould are primed in the wooden moulding boxes to get amodel size of about 30 mm diameter and 300 mm length. The moulds are parched in a gas fired oven for about 3 hour at a temperature of 200 °C. Then the moulds are cooled to room temperature by insertion them in still air. The mould cavitiesare clean with high pressure air to avoid any sand and dirt inclusion in the sample.

Melting

The melting of grey cast iron was conceded out in induction melting heating system (coreless type of mains frequency) of capability 12 t and power of 2,400 kW. The furnace is ruled with acid refractory and the coils are water cooled (the pressure of circulate cooling water is maintained at a pressure of 0.343 MPa). The tap to tap time is 2 h and during tapping only 5 t of hot metal is tap andremaining 7 t is used to the next step.

Charging Sequence

The series of batch charging is Charge 1: Coke = 70 kg, Charge 2 Steel package = 900 kg, Pig Iron = 500 kg, Cha
1,000 kg, Charge 5: Steel particle = 1,000 kg. The incriminate ratio of steel scrap, foundry returns and pig iron is
coreless) furnace is move into the 42 t induction(Channel type) furnace, where it is held for some time to regu
the required temperature. Temperature of molten iron is calculated by using immersion pyrometer.

Inoculation

0.5 % ferro silicon is used for booster. The silicon content of Fe–Si is 50 %. The size of ferro silicon granule is in the range of 2–3 mm. The high temperature metal is tap into 400 kg preheated ladle, which contains 2 kg ferro silicon at the bottom.

Trace Element Addition

Boron

Base Metal Composition The chemical investigation was done on a Quantovac unit in chemical laboratory at TELCO, Jamshedpur. The results obtained are given in Table 1.

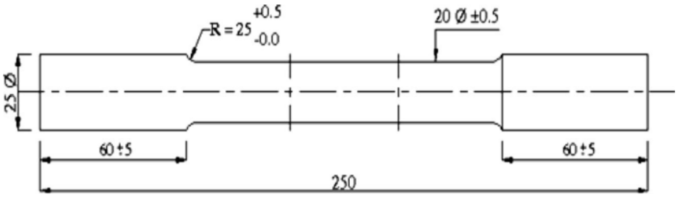

Fig. 1 Tensile test Specimen

Table 3 Effect of Boron additions on the tensile strength andhardness

S. No	Boron weight (%)	Tensile strength (Kg/mm^2)	Hardness (BHN)
1.	0.00	23.3	168
2.	0.005	23.4	174
3.	0.01	23.6	180
4.	0.02	25.0	185
5.	0.03	23.9	187
6.	0.04	23.3	188

Boron Addition

Boron is added in the form of ferro boron powder by placing it at the bottom of the moulds. The boron content in the ferro boron is 25 % and recovery is 80 %. This assumption is based on the previous study on industrial melt elemental losses. The quantity of ferro boron required for each composition was calculated using eqn (4):

Quantity of ferro boron to be added ¼ Quantity of metal × % added= Efficiency:

The boron is further added in the form of ferro boron and the estimated amount added to the melt is given in Table 1

Lead is added in the form of clean powder form by placing it at the bottom of the moulds. The recovery of lead is taken as 80 % based on the assessment carried out using quantovac unit available in the chemical laboratory at TELCO, Jamshedpur. The estimated amount of lead added to the melt is as given in Table 2.

Casting

The considered quantity of trace elements to be added are placed at the bottom of moulds and the high temperature molten iron is poured into the moulds to get test bars of dimension 30 9 300 mm. The samples are then cooled to room temperature by insertion them in still air. After cooling, the test bars are taken out from the mould and are cleaned with the wire brush. The samples are then sent to the machine shop to organize the tensile test bars of standard dimensions (IS: 2078-1979) as shown in Fig. 1. The specimens for metallography and hardness were cut from the fractured tensile test specimen.

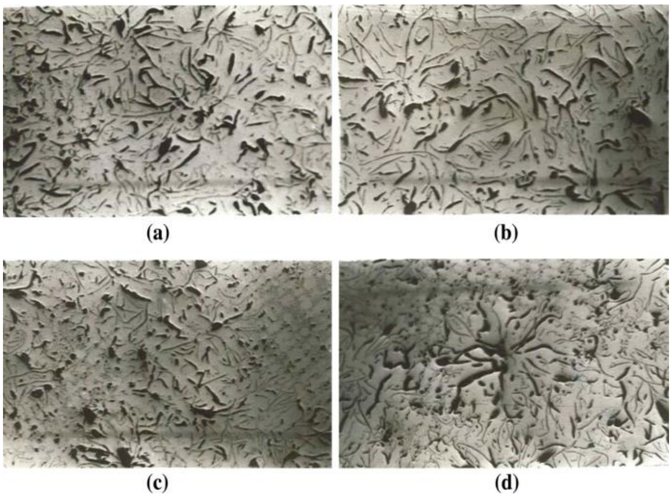

Fig 2 Effect of Boron additions on the microstructure of Gray Cast Iron a Base iron, b 0.02 % B, c 0.03 % B0.04 % B, 1009, Unetched

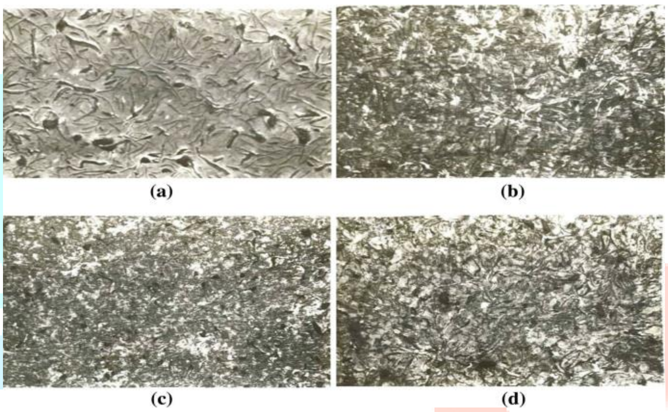

Fig 3 Effect of Boron additions on the microstructure of Gray Cast Iron a Base iron, b 0.02 % B, c 0.03 % B, d 0.04 % B, 1009, Etched with2 % Nital.

Table 5 Effect of Lead addition on the tensile strength and hardness

S. No	Lead weight (%)	Tensile strength (kg/mm^2)	Hardness (BHN)
1.	0.00	23.3	174
2.	0.005	19.7	172
3.	0.01	19.6	170
4.	0.025	16.9	161
5.	0.05	15.9	154
6.	0.10	15.3	154

6. *Testing*

1. Tensile strength test: This test was carried out on an UTM (Universal Testing Machine) of 60 t capacity inmechanical testing laboratory at RPS COLLEGE. The load on the test sample was applied steadily till fracture occurs.
2. Hardness test: Brinels hardness test was approved by using a standard hardness testing machine. The steel balls diameter of the indenter was 10 mm and load apply was 3,000 kg. Hardness value was calculate at three dissimilar places across the cross section of test piece and the average of three values were eminent.
3. Metallography: The sample for photo micro graphs were ready according to the standard procedure. Around 20 mm thick sample was taken from the cracked tensile test bars. It was polished first on a belt grinder, emery papers of changeable specifications from 01 to 03 and finally on a cloth grinder to provide a mirror finish to the sample.

The micro structure was examined using microscope at 1009 magnification without etching and also with etching using 2 % Nital.

7. Results and Discussions

Effect of Boron Addition

Table 3 shows the effect of boron addition on the tensile strength and hardness values.

The result are also represent in a graphical form as shown in Fig. 2. Figures 3 and 4 show the effect of boron addition on the micro structure of grey cast iron. Micro- structure of base grey cast iron consists of type A graphitic structure, with pearlitic matrix. With increase in addition ofboron to the extent of 0.02 %, both the tensile strength and hardness values enhance. This is recognized to carbide forming abality of the boron. The tensile strength increase from 23.3 to 25.0 kg/mm^2, and hardness value increase from 168 to 185 BHN, with 0.02 % boron addi- tion. Boron addition beyond 0.02 % decrease the tensile strength while hardness values show a mild increase trend. The reducion in tensile strength is due to the creation of type B and type D graphites. The increasein hardness is due to the carbide creation as shown in fig 2 . In this case the tensile strength decrease from 25.0 to 23.3 kg/mm^2, and hardness value increase from 185 to 188 BHN.

Effect of Lead Addition

Table 4 represent the effect of lead addition on the tensile strength and hardness values. A graphitic structure, with pearlitic matrix, and therefore a high tensile strength and hardness value. Reduction in tensile strength is more radical when compared with hardness. Though, as the lead quantity increase, the decreasing trend is mild. The tensile strength decrease from 23.3 to 15.3 kg/mm^2, while hard- ness value decrease from 174 to 154 BHN. This can be recognized to the creation of spiky microstructure.

8. Conclusions

The existence of boron and lead in trace quantity results in serious decrease in mechanical properties. Boron addition up to 0.02 % result in development in tensile strength andhardness values, while beyond this it shows a declining trend. Lead in grey cast iron reduces tensile strength and hardness values, even if nearby in trace amount. Care should be taken to keep away from the contamination from boron andlead in trace level in grey cast iron obtained from pig iron, non-ferrous metal scrap, vitreous enameled fragment, leaded steel fragment, 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 stock piling so that unwanted charge materials can be removed.

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