Effect on the Mechanical Properties of Gray Cast Iron with Variation of Copper and Molybdenum as Alloying Elements

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***Abstract*— Unalloyed Gray cast iron is having very good compressive strength but poor tensile strength. Alloying elements are added to the gray cast iron to increase the mechanical, heat resistant and corrosion resistance. In this work copper and molybdenum added to study their effects on mechanical properties of gray cast iron. Copper is an austenite stabilizer and mild graphitizer while molybdenum is a ferrite stabilizer and carbide former elements. Therefore, their compositions have been varied in the base gray cast iron to study the combined effects. Mechanical properties like tensile strength and hardness increased due to addition of copper and molybdenum but toughness shows no improvement.**

Keywords—Gray Cast Iron, Alloying elements, microstructure, hardness, tensile strength, impact strength.

I. INTRODUCTION

Gray cast iron is the most castable material due to its castability, mechanical properties and simplicity of manufacturing. It appears gray because graphite is present as flakes in ferrous matrix. Basically, it is iron-carbon-silicon alloy containing small quantities of other elements. A typical chemical composition [1-3] to obtain a graphitic microstructure is 2.5 to 4.0 % carbon and 1 to 3 % silicon. Another factor affecting graphitization is the solidification rate, slower the rate greater the tendency for graphite to form.

Alloying elements like Mn, Cr, Ni, V, Mo, Cu, Al are used to enhance strength, hardness, hot hardness, electrical and magnetic characteristics and resistance to corrosion. The alloying elements addition depends upon the base composition and method of manufacturing to give the desired mechanical properties.

A. Effect of Copper in Gray Cast Iron:

Copper is mild graphitiser and it promotes pearlite formation [4, 5] besides, it also increases the strength of the pearlite formed. Bates [6] found that addition of copper in gray iron upto about 0.5% increase the yield strength and ultimate strength but higher concentrations produces almost negligible effect as the base iron became fully pearlitic. It is expected that, in a ferritic or ferritic plus pearlite base iron, copper has stronger effect. Tensile strength as well as hardness increases as the proportion of the copper increases.

B. Effect of Molybdenum on Gray Cast Iron

Molybdenum [4, 7, 8] is a carbide stabilizing element. Molybdenun is used for strengthening and hardening iron because of austenite transformation in fine pearlite to bainite. It is generally added in gray cast iron for refining pearlite. Molybdenum is not a pearlite promoter. Molybdenum is [9, 10] normally added as Ferromolybdenum containing 60 to 70% Mo.

C. Effect of Copper and Molybdenum in Gray Iron

Both of these [11-14] elements exhibited higher hardness and tensile strength than ordinary pearlitic grades of gray cast iron. Janowak and Gundlach [4] reports increase in the room temperature and higher temperature mechanical properties of gray iron alloyed with copper molybdenum.

K. L. Hugrynen, D. J. Moore and Kandman reports [15] an increase in mechanical properties of gray cast iron added small amount of alloyed with copper and molybdenum.

II. EXPERIMENTAL DETAILS

A. Charge Material:

Charge material used pig iron, foundry returns of gray cast iron and steel scrap. The carbon equivalent value of the melt was planned in the range of 3.9 to 4.0%. Following composition of the charge material was taken to achieve the above C.E value.

The final base composition desired is 3.2% C, 1.7 % Si, and 0.18% Mn. Ferrosilicon (0.3%) in the form of lumps is used for increasing the silicon content in the base iron for inoculation.

Charge Materials	% C	% Si	% Mn
Pig iron	4.25	1.57	0.55
Foundry return scrap	3.4	1.9	0.82
Steel scrap	0.18	0.15	0.65

B. Alloy Additions

Alloy additions made were copper and molybdenum. Pure copper electric wires were used for addition of copper. Recovery of the copper was assumed to be 90%. Ferromolybdenum in the form of granules were used for molybdenum alloy addition. The recovery of molybdenum from ferromolybdenum granules is assumed to be 60%. Fe-Si added to the furnace and Fe-Mo and copper addition were made to the ladle.

C. Charge Material and Alloys Addition for Composition Control

Pig iron 9 kg, foundry return scraps 3 kg and steel scraps 3 kg are charged along with the alloys given below. Copper added to the ladle containing 9 kg is 150 gram for achieving 1.5% Cu in the casting. Similarly 200 gram and 231 gram of copper were added for obtaining 2.0% and 2.3% copper in the casting. Molybdenum added to the ladle containing 9 kg is 84 gram for achieving 0.5% Mo in the casting. Similarly 100 gram, 134 gram, and 167 gram of Fe-Mo were added for obtaining 0.6%, 0.8%, and 1.0% molybdenum respectively in the casting.

D. Experimental Procedure

Green sand mould has been prepared for the casting of test bars. Electric arc furnace has been used for melting the materials. Just before completion of melting commercial grade lime stone in granular form was added for the purpose of fluxing.

Alloy composition of Cu and Mo is given below:

Base iron

After pouring the base iron, Copper and Molybdenum were added to the ladle.

0.5% Mo and 1.5% Cu

0.5% Mo and 2.0% Cu

0.5% Mo and 2.3% Cu

0.6% Mo and 2.0% Cu

0.8% Mo and 2.0% Cu

1.0% Mo and 2.0% Cu

Each mould consists of three cavities for test bars. Twenty one specimens (3 unalloyed and 18 alloyed) were prepared from the tensile test bar casting for these specimen of each composition.

III. Results and Discussions

A. Mechanical Properties

From the table no. 1 and 2 it is observed that as we increase the amount of copper both tensile strength and hardness increases, initially sharply and later slowly. It indicates that once matrix becomes fully pearlitic, further increase in copper content shows weaker effect. These types of results are also observed by Bates, but for a single composition of copper [12]. However, in present case study we have taken Mo (0.5%), while varying copper up to 2.0% copper significant effects are seen.

TABLE – 1: Effect of Cu variation keeping Mo-0.5% on Tensile strength

No. of Alloys	Composition		UTS (Mpa)			Average UTS (Mpa)
	% Mo	% Cu				
1 (base iron)	0.00	0.00	193.75	181.25	198.75	191.25
2	0.5	1.5	220.00	206.25	195.00	207.08
3	0.5	2.0	223.75	213.75	225.00	220.83
4	0.5	2.3	227.50	217.50	237.50	227.50

TABLE – 2: Effect of Cu variation keeping Mo-0.5% on Hardness

No. of Alloy	Composition		Hardness (BHN)			Average Hardness (BHN)
	% Mo	% Cu				
1 (base iron)	0.00	0.00	138	138	138	138
2	0.5	1.5	171	159	171	171
3	0.5	2.0	200	200	185	200
4	0.5	2.3	218	200	218	218

In the similar way, from table no. 4 and 5, it is observed that as we increase the amount of molybdenum both tensile strength and hardness increases, but intensity of increase is not similar as the case of previous case (increasing copper content). This is because once amount of molybdenum is increased keeping copper at 2%, the ferreto-pearlitic structure are formed. These types of results are also observed by Rosenthal [8], Walter [9], Janowak and Gundlach [4]. Since molybdenum retards the pearlitic reaction and no effects on ferritic reaction, the matrix in presence of molybdenum remains ferreto-pearlitic structure.

As per the results, it can be say that the tensile strength and hardness are directly related to pearlite content of the matrix. The increase in strength is probably due to the solid solution strengthening of copper and somewhat finer pearlite formed.

TABLE – 3: Effect of Cu variation keeping Mo-0.5% on Impact strength

No. of Alloys	Composition		Impact strength (Nm)			Average Impact strength (Nm)
	% Mo	% Cu				
1 (base iron)	0.00	0.00	4.41	3.92	3.92	4.08
2	0.5	1.5	3.92	3.43	-	3.675
3	0.5	2.0	3.43	4.41	3.43	3.756
4	0.5	2.3	3.92	2.94	2.94	3.266

TABLE – 4: Effect of Mo variation keeping Cu-2.0% on Tensile strength

No. of Alloys	Composition		UTS (Mpa)			Average UTS (Mpa)
	% Mo	% Cu				
1(base iron)	0.00	0.00	193.75	181.25	198.75	191.25
2	0.6	2.0	185.00	208.75	197.50	197.08
3	0.8	2.0	233.75	206.25	-	220.00
4	1.0	2.0	218.75	222.50	231.25	224.16

TABLE – 5: Effect of Mo variation keeping Cu-2.0% on Hardness

No. of Alloys	Composition		Hardness (BHN)			Average Hardness (BHN)
	% Mo	% Cu				
1(base iron)	0.00	0.00	138	138	138	138
2	0.6	2.0	159	148	159	159
3	0.8	2.0	171	171	171	171
4	1.0	2.0	185	185	185	185

TABLE – 6: Effect of Mo variation keeping Cu-2.0% on Impact strength

No. of Alloys	Composition		Impact strength (Nm)			Average Impact strength (Nm)
	% Mo	% Cu				
1(base iron)	0.00	0.00	4.41	3.92	3.92	4.08
2	0.6	2.0	4.41	3.92	2.94	3.756
3	0.8	2.0	3.43	3.92	2.94	3.43
4	1.0	2.0	2.94	2.94	3.43	3.103

From table No. 3 and 6 it is clear that gray iron shows poor impact strength. Even after addition of copper and molybdenum in gray cast iron, it does not show any considerable variation. Such alloyed gray iron is not recommended for high impact resistance application.

B. Graphite Morphology and Microstructure

Figure no.1 show the graphite distribution for base iron and alloyed iron with an increase in copper keeping molybdenum content at 0.5% fixed, while figure no. 2 show the graphite distribution for base iron and alloyed iron with an increase in molybdenum, keeping copper content at 2.0% fixed the no. of graphite flake is increased and the size of the graphite flake is reduced due to the graphitisation tendency of the copper. All photomicrographs shows refinement in pearlite with copper addition.

From the above discussions and literature reports it is clear that addition of single element to produce high strength gray iron is usually inefficient. Alloying elements perform different strengthening functions and therefore alloys can complement each other when combined appropriately.

a) Complimentary alloying is accomplished through:

b) Addition of elements that retard free ferrite formation for producing fully pearlitic structure

c) Use of potent hardenability elements which strongly refine pearlite once a fully pearlitic structure is ensured, and

d) Use of elements which have synergistic hardenability effects in terms of strengthening by pearlite refinement.

A higher degree of complimentary action is possible with copper and molybdenum because of copper interacts synergistically with molybdenum to refine pearlite.

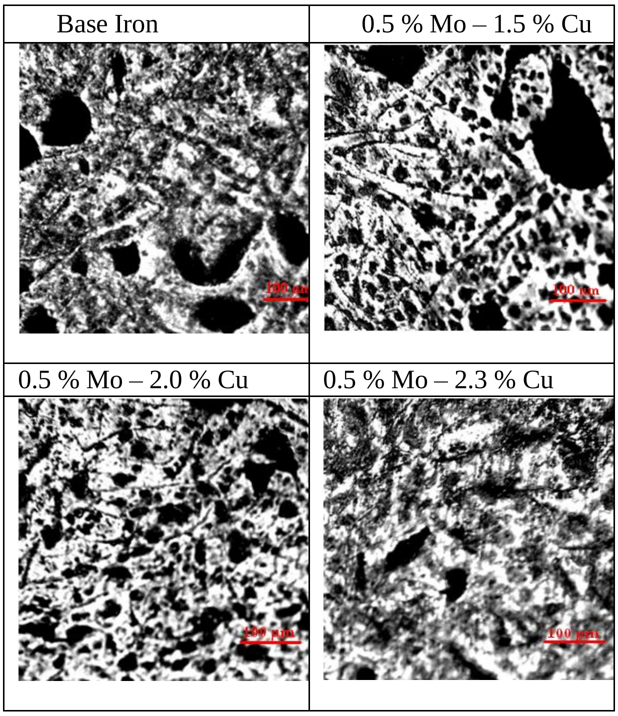

Fig.1. Microstructure for base iron and alloyed iron with an increase in copper keeping molybdenum content at 0.5% fixed

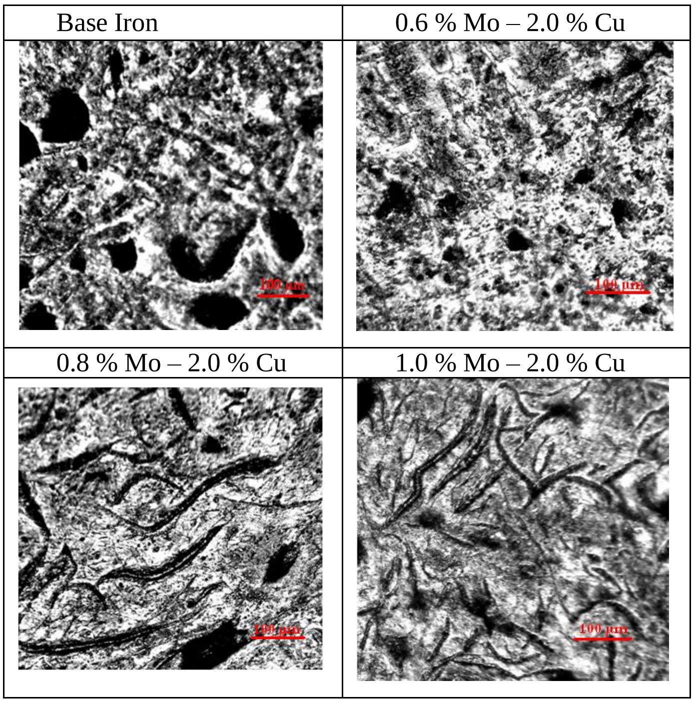

Fig.2. Microstructure for base iron and alloyed iron with an increase in molybdenum, keeping copper content at 2.0% fixed

IV. CONCLUSION

In light of the above discussion, the following broad conclusion can be made:

A. Copper affects the graphite shape and distribution of gray iron. With an increase in Copper content, the tendency of graphitisation increases and size of the graphite flake also becomes smaller.

B. Copper is strong pearlite promoter.

C. Addition of Copper increases both tensile strength and hardness of gray iron.

D. The base iron has a largely pearlitic matrix to Copper addition.

E. Molybdenum does not affect the graphite shape and distribution of gray iron.

F. Molybdenum refines the pearlite in gray iron.

G. Molybdenum increases the strength and hardness of gray iron.

H. Addition of Copper and Molybdenum both increase the amount of the ferreto-pearlitic structure.

I. Increasing cooling rate promote the formation of the acicular and ferreto-pearlitic structure.

J. The presence of ferreto-pearlitic structure increases the hardness of tensile strength of these gray irons.

K. Gray iron shows poor impact strength.

L. Addition of Copper and Molybdenum in gray iron shows negligible variation.

M. Finer grained structures have higher hardness and lower toughness. Coarser grained structures have lower hardness and higher ductility and consequently better toughness.

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