EFFECT OF COPPER ON TENSILE STRENGTH OF DUCTILE IRON WITH AND WITHOUT AUSTEMPERING HEAT TREATMENT

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Abstract - Austempered Ductile Iron (ADI) is a relatively new material. The application of austempering heat treatment process to ductile iron produces Austempered Ductile Iron. The interest in ADI is increasing due to its advantageous properties over conventional ductile iron and steel. In this study ductile iron was produced by sandwich method using gas fired furnace installed at a local commercial foundry. A comparative study of the effects of copper varying from nil to 1.5 wt. % was made. Tensile samples were machined from Y Block castings. Tensile test was performed to find out the effect of copper addition on tensile strength of ductile iron having different compositions of copper. Effect of austempering heat treatment was also studied to find out the effect of copper on tensile strength. ADI was made by austenitized the samples at 900 ˚C for one hour and austempered at 270 ˚C and 370 ˚C for one hour. It was found that with the increase of copper in ductile iron, the tensile strength continued to increase up to 1.5 wt. % with & without austempering heat treatment.

Index Terms - Ductile iron, Copper addition, Tensile test, Austempering, Austentized.

I. INTRODUCTION

Ductile iron derives its name because in the as-cast form, it shows good ductility. By contrast, neither white iron nor grey iron reveals substantial ductility in tensile specimen [1]. Ductile iron is defined as a high carbon containing, iron-base alloy in which the graphite is present in a compacted, round shape [2]. Ductile iron is also known as nodular iron or spheroidal graphite iron. Unlike grey iron that contains graphite flakes; the ductile iron has as- cast structure containing graphite particles in the form of small, rounded round nodules in the matrix. Therefore, ductile iron has much higher strength than grey iron and a considerable degree of ductility. Ductile iron is very useful discovery. It offers the design engineers the option of selecting high ductility, more than 18% elongation, or high strength exceeding 825 MPa. Ductile iron, when compared to steel and malleable iron castings offer cost savings [3].

Like most commercial cast metals, steel and malleable irons decrease in volume during solidification, and as a result, require reservoirs (feeders or risers) of liquid metal to compensate shrinkage. The formation of graphite during solidification causes an internal expansion of ductile iron as it solidifies. As a result it may be cast free of significant shrinkage defects either with feeders that are much smaller than those used in malleable iron and steel. This reduced requirement for feed metal increases productivity of ductile iron and reduces its material and energy requirements resulting in substantial cost savings. The use of most common grades of ductile iron “as-cast” usually eliminates heat treatment cost, offering a further advantage.

Ductile iron castings are used for many structural applications, especially where strength and toughness are required with good machinability and low cost. Ductile iron is finding increasing applications in automobile parts e.g. crankshafts, piston rings and cylinder liners. The use of ductile iron in these applications offers increased strength and weight savings.

It is possible to achieve much higher ranges of tensile strength and elongation by adopting austempering heat treatment for ductile iron. For austempering treatment, defect free castings should be chosen. Any lapse in quality control of starting material will result in inferior end product. The process is simple. The first stage consists of soaking the castings at austenitizing temperature of 850-950 ˚C. The austenitized castings are then quickly transferred to a liquid bath (salt bath) maintained at temperature range of 235- 425 ˚C. The transformation is allowed to proceed for a period of up to four hours when austenite transforms to ausferrite. The castings are finally cooled to room temperature after transformation. By adopting austempering heat treatment process instead of conventional hardening and tempering treatment for ductile iron, the chances of cracking and distortion are reduced. Thus, it becomes possible to carry out rough and final machining before heat treatment. It is possible to achieve various combinations of high strength, high hardness, limited ductility or lower strength, lower hardness, high ductility by varying the temperature of austempering. The excellent properties of ADI are due to its unique structure known as ausferrite. This structure is obtained by controlled heat treatment. ADI has opened new prospects for cast iron to exchange steel castings and forgings in many applications in engineering with significant cost benefits [4].

Alloying elements are generally used in ductile iron to increase its hardenability. Only the minimum amount of alloys required should be used. Excessive alloying only increases the cost and difficulty in producing quality ductile iron necessary for ADI. Austempered Ductile Iron is normally alloyed with Mo, Ni, Cu and Mn in suitable combinations. These elements improve hardenability and assist in stabilizing austenite [5]. Heat treatment and alloying of ductile iron can attain various mechanical properties that are required.

Addition of nickel, copper and molybdenum can change the microstructure of ductile iron and consequently hardenability is increased [6]. Austempered Ductile Iron components need less energy than for steel component. Hence it finds wide range of applications [7]. Different alloying elements and different combination of alloying addition have been made to find out its effect on the properties. D. S. Padan[5] examined the effect of microalloying elements of ductile iron. He found the tensile strength of cast ductile iron increased remarkably with the addition of V or Nb. Cheng-Hsun Hsu and Kuan-Ting Lin[6] found that impact toughness and fracture toughness is increased with 1wt % copper addition in ductile iron due to the effect of retained austenite. It would be of considerable interest to determine whether the addition of copper in ductile iron with varying weight percentage can make any difference in affecting tensile strength of ductile iron with or without austempering heat-treatment.

II. RESEARCH METHODOLOGY

During the present research, an attempt was made to observe the tensile strength of ductile iron by the addition of copper to metal samples. Different heats with and without copper were made. Samples for this study consisted of tensile test bars having different compositions of copper additions. Universal tensile testing machine was used to study the effect of copper on tensile strength of ductile iron with and without austempering heat treatment. Four heats were made to find out the effect of copper on the tensile strength of ductile iron. Copper content was varied from nil to 1.5 wt. %.

III. EXPERIMENTAL PROCEDURE

A. Production of Ductile Iron

Ductile iron was made using local materials and local facilities. The melting was carried out in a commercial gas fired furnace. Pig iron and mild steel were purchased from the local market. Ductile iron returns of the foundry was also used. In order to get the required composition ferroalloys and other alloying addition were added to the melt. Ductile iron was produced by sandwich method in which the spheroidizing and inoculant alloys are covered preferably with the steel sheet. Such a cover delays the reaction. Ferro-silicon was used as an inoculant. The inoculant is to provide the melt with seeds or nucleation on to which the solid phases grow during freezing as nodules. After melting the metal was poured into a ladle with two pockets at the bottom. In one pocket spheroidizing alloy (ferrosilicon-mangnesium) and inoculant (ferrosilicon) were placed while the other pocket was kept empty. The following raw materials for the production of ductile iron were used.

PIG IRON: Pig iron from local market was used for making ductile iron. The composition of the iron is given in table .1

C	Si	Mn	Fe
4.1	0.83	0.6	balance

Table 1. Chemical Composition of Pig iron in weightage

MILD STEEL: The mild steel with the composition mentioned in table 2 was used.

FERROSILICON MAGNESIUM: Ferrosilicon magnesium was used for the spheroidization with the composition shown in table.3

C	Si	Mn	Fe
0.2	0.3	0.4	balance

Table 2. Chemical Composition of Mild Steel in weightage

Si	Mg	Ca	Al	Fe
42	5.5	1.2	1.0	Balance

Table 3. Chemical Composition of Ferrosilicon Magnesium in weightage

The melt was poured from about 1450 ˚C into a standard Y block sand moulds. Tensile specimens of 15 mm diameter 250 mm long were machined from the Y blocks.

The chemical analysis of ductile iron produced without and with copper addition is mentioned in the table 4. Four heats were made to find out the effect of copper on ductile iron. The details of heats are as follows:

Heat No. C0 without any copper
Heat No. C5 with 0.5 % copper
Heat No. C10 with 1.0 % copper
Heat No. C15 with 1.5 % copper

Elements	Heat No C0	Heat No C5	Heat No C10	Heat No C15
C	3.6	3.5	3.7	3.9
Si	2.7	2.9	2.6	2.7
Mn	0.1	0.2	0.1	0.2
Cu	0.0	0.5	1.0	1.5
S	0.09	0.09	0.08	0.09
P	0.02	0.03	0.02	0.02

Table 4. Chemical Composition of Ductile Iron Produced with copper in weightage

B. Heat Treatment Furnaces Used

For austempering heat treatment, different types of furnaces were used for tensile samples. The details of furnaces are given below.

MUFFLE FURNACE: The austenitizing heat treatment of the samples were carried out in a muffle furnace. The samples were austenitized in Carbolite Furnace, Type GPC 13/36 with 9000 watts and its maximum temperature limit was 1300 ˚C.

VERTICAL TUBE FURNACE: Carbolite Vertical Furnace Type VCF 12/10 with 3000 watts was used for austempering. Its maximum temperature limit was 1200 ˚C.

The tensile samples were austempered in salt bath placed in the vertical furnace.

C. Tensile Testing Machines

The Universal Tensile Testing Machine Shimadzu UH-F-500 KNA was used for the tensile testing of samples.

IV. RESULTS AND DISCUSSION

A. Effect of Copper on Ductile Iron

To find out effect of copper, four melts were made with copper addition of 0.0wt%, 0.5wt%, 1.0wt% and 1.5wt% in a commercial foundry. The tensile samples were machined from Y block sand castings. The tensile samples were subjected to austemering heat treatment process. The samples were austenitized in a Carbolite muffle furnace at a temperature of 900 ˚C for one hour and austempered at 270 ˚C and 370 ˚C for one hour. Then the tensile test was performed on the samples. The test results are tabulated in Table 5.

Copper	UTSN/ mm^2 0.0 wt %	UTSN/ mm^2 0.5 wt %	UTSN/ mm^2 1.0 wt %	UTSN/ mm^2 1.5wt%
Without heat-treatment	495.3	517.6	581.7	705.7
Austempered at 270 ˚C	938.8	988.8	1096.1	1222.4
Austempered at 370 ˚C	698.0	861.7	828.3	911.6

Table 5. Effect of Copper on Tensile Strength of Ductile Iron

The tensile strength of ductile iron samples was 495.3 N/mm^2 without any addition of copper to the heat. When copper addition of 0.5wt % was made in the ductile iron the tensile strength was increased to 517.6 N/mm^2. With the copper addition of 1.0wt % in the ductile iron, the tensile strength was increased to 581.7 N/mm^2. When the copper addition was further increased to 1.5wt %, the tensile strength again increased to 705.7 N/mm^2.

The samples were then austenitized at 900 °C for one hour and austempered at 270 ˚C for one hour. The tensile strength of ductile iron samples was 938.8 N/mm^2 without any addition of copper to the melt. With the copper addition of 0.5wt% in the ductile iron the tensile strength was increased to 988.8 N/mm^2. When the copper addition was increased to 1.0wt % in the ductile iron, the tensile strength was also increased to 1096.1 N/mm^2. When the copper addition was further increased to 1.5wt %, the tensile strength showed the similar pattern and it increased to 1222.4 N/mm^2.

Now the higher austempering temperature was selected to find to find out its effect on higher austemering temperature i.e. 370 ˚C. After austenitizing at 900 ˚C for one hour, the samples were transferred quickly to salt bath maintained at 370 ˚C for time period of one hour. The tensile strength of ductile iron samples was 698.0 N/mm^2 without any addition of copper. With the copper addition of 0.5wt % in the ductile iron the tensile strength was increased to 816.7 N/mm^2. When the copper addition was further increased to 1.0wt % in the ductile iron, the tensile strength was also increased to 828.3 N/mm^2. When the copper addition was further increased to 1.5wt %, the tensile strength again increased to 911.6 N/mm^2. The figure1 shows the gradual increase of tensile strength with the increase of copper content without any heat treatment.

Figure 2 shows a similar increase of tensile strength with the increase of copper when the samples were austenitizes at 900 ˚C for one hour and austempered at 270 ˚C for one hour.

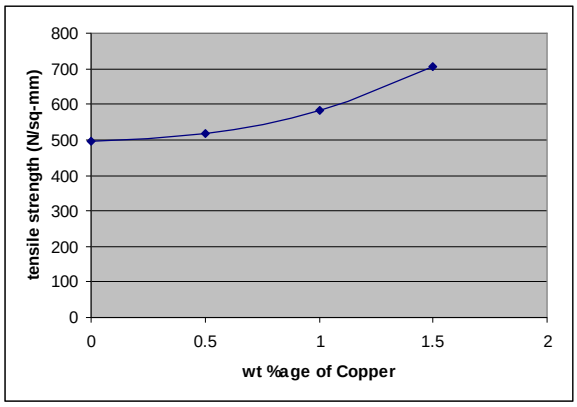

Figure 1 Effect of copper on tensile strength without any heat treatment

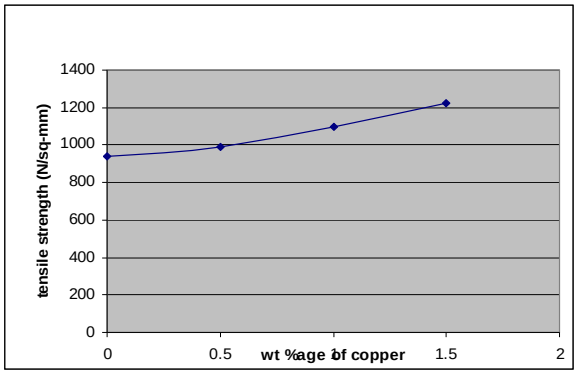

Figure 2 Effect of copper on tensile strength when austenitized at 900 ˚C and austempered at 270 ˚C.

Figure 3 shows the same pattern of increase of tensile strength when the samples were austenitized at 900 ˚C for one hour and austempered at 370 ˚C for one hour.

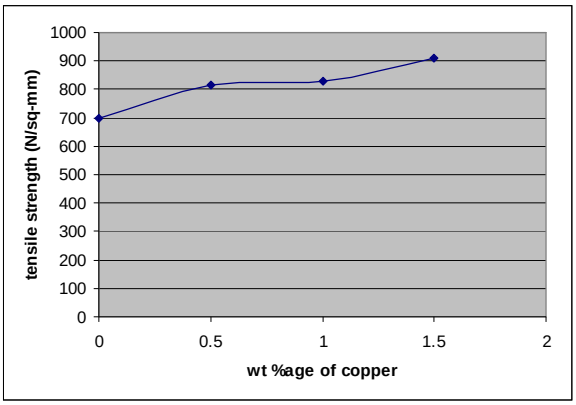

Figure 3 Effect of copper on tensile strength when austenitized at 900 ˚C and austemperd at 370 ˚C.

The results are more or less similar to the research conducted by Yoon-Jun Kim et al, [8]. In their study the samples were alloyed with copper and molybdenum and austenitized at 910 ˚C for 90 minutes and subsequently austempered in salt bath for 90 minutes. They found that with addition of copper and molybdenum ausferrite structure is formed and mechanical properties such as tensile strength and hardenability were enhanced.

Another study by A.A. Cushway [9] found that copper addition up to 1.5 percent increased the hardenability of ductile iron. He further found that the addition of copper above 1.5 percent resulted in no further increase in hardenability. In the present study the tensile strength also went on increasing up to 1.5 percent of copper addition.

Guerin and Gagne [10] made alloying addition of copper, tin and a combination of manganese and copper to ductile iron. They found that the use manganese (% Mn > 0.4 %) or tin (% Sn > 0.07 %) caused the formation of embritlling intercellular phases. The best mechanical properties were obtained with 1.48 wt. per cent of copper. As compared to an unalloyed heat, the addition of copper improved strength and hardness. He further found that manganese and tin were less effective than copper to harden and strengthen ductile iron.

P.W. Sheton and A. A. Bonner [11] in their experiments found that copper in quantities exceeding the limits of solid solubility in ferrous alloys (0.7 %), the strength and toughness improved considerably. These results are in agreement of the present study.

In another study Yan Mi [12] states that with the increase of copper content, the volume fraction of retained austenite increases. So the mechanical properties will also be enhanced with the addition of copper. In this study the mechanical property of tensile strength has increased with the addition of copper.

J. Sikora and Boeri[13] also found that the influence of copper on micro structure and mechanical properties reaches max at about 1.0 %. He suggested that properties may further be increased by other alloying elements. In present study tensile strength property increased when copper addition was made and it was maximum with 1.5 wt. % copper.

B. Future Work

1. Most of the studies quoted above have alloying additions in combination but when alloying elements are combined in an experiment, it is difficult to identify the effect of a single element, so it is suggested that the addition of single element may be made to ascertain the effect of the element.
2. Most of researchers have found the effect of alloying elements on mechanical properties like impact, hardness and toughness. The study was undertaken to find out the effect of copper on tensile strength. The tensile test gives a lot of information about mechanical behavior of a material. There is still room for more research work to find out the effect of different alloying additions on ductile iron.

C. Conclusions

1. With the increase of copper content the tensile strength went on increasing up to 1.5wt %. Ductile iron alloyed with 1.5 % copper had the highest tensile strength i.e. 705 N/mm^2 without heat treatment.
2. Austempering heat treatment at lower temperature i.e. at 270 ˚C produced higher tensile strength in comparison with austempering at higher temperature i.e.370 ˚C which resulted in lower tensile strength.
3. The tensile strength was almost doubled with the application of austempering heat treatment process. The tensile strength without any heat treatment was 495.3 N/mm^2 and when austempering heat treatment was performed at 270 ˚C for one hour; the tensile strength rose to 938.8 N/mm^2.

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