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COMPARATIVE STUDY OF TENSILE STRENGTH OF DUCTILE IRON ALLOYED WITH AN EQUAL AMOUNT OF COPPER AND NICKEL SEPARATELY

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Abstract: There is a need to develop light weight, durable and cost effective material for use in various industries. Ductile iron is one such material. Researcher are working on this material to improve its mechanical properties by addition of alloying elements and by appropriate heat treatment. The objective this paper is to compare the tensile strength of ductile iron alloyed with copper and nickel separately. Three melts were made, one without any copper and nickel, the second with 1.0 Wt. % copper and third with 1.0 Wt. % nickel using sandwich method. Tensile test was performed to find out the effect of copper and nickel separately. It was found that the tensile strength increased in both the cases i.e. with the addition of copper and nickel in ductile iron. However, tensile strength increased more in case of copper addition than in case of nickel. Effect of austempering heat treatment was also studied to find out the effect of copper and nickel separately on tensile strength. The samples were austenitized at 900 ^{o}C for one hour and austempered at two temperatures; the low one at 270 ^{o}C and the high one at 370 ^{o}C for one hour. It showed an increase in tensile strength at both temperatures. It was observed that tensile strength was almost double at austempering temperature 270 ^{o}C than without austempering.

Key words: *Alloyed with copper, Heat treatment, Sandwich, Tensile strength, Austempering, Austentized.*

INTRODUCTION

These days, there is a great need of materials that consume less energy in their production and save energy when they are used. Production of per ton ductile iron consumes less energy than the production of steel. Ductile iron derives its name from the fact that, in the as-cast form, it exhibits measurable ductility. Ductile iron is defined as a high carbon containing, iron-base alloy in which the graphite is present in a compact, spheroidal shape [1]. Ductile iron has commercially replaced as-cast and forged steel in lower strength region [2]. Ductile iron castings are used for many structural applications, particularly those requiring strength and toughness combined with good machinability and low cost. Ductile iron is finding increasing applications in automobile parts e.g. crankshafts, piston rings and cylinder liners.

Most commercial cast metals, steel and malleable irons, decrease in volume during solidification. As a result these castings require reservoirs (feeders or risers) of liquid metal to compensate for the 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 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. It is possible to achieve much higher ranges of tensile strength and elongation by adopting austempering treatment for ductile iron. For austempering treatment, castings are first austenitized to dissolve carbon, and then quenched rapidly to avoid the formation of pearlite. The microstructure achieved with this process is unique. The resulting microstructure is known as “Ausferrite” which gives to Austempered Ductile Iron (ADI) special properties.

The austempering of ductile iron produces microstructure consisting of ferrite and high carbon austenite different from steel which is carbide in a ferritic matrix. The structure produced is stable at room temperature. By adopting austempering heat treatment, the chances of cracking and distortion are reduced. It is possible to achieve various combinations of high strength, high hardness, limited ductility or lower strength, lower hardness, high ductility by varying the austempering temperature. Austempering at low temperature produces acicular ferrite while austempering at higher temperature produces feathery type structure. Successful heat treatment of

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Austempered Ductile Iron depends on selection and control of austempering time, austempering temperature and austenitizing temperature [3]. Austempered Ductile Iron (ADI) is an important type of ductile iron which is produced by isothermal heat treatment of ductile iron. ADI production processes save around 50% of energy consumption compared to steel. Austempering is an isothermal heat treatment which when applied to ferrous materials produces a structure that is stronger and tougher than the comparable structure produced with commercial heat treatment [4]. ADI is produced by an isothermal heat treatment known as austempering. This consists of following steps:

1. Heating the samples to austenitizing temperature in the range of 810 ^{o}C - 930 ^{o}C than without austempering.
2. Holding the samples at austenitizing temperature for time sufficient to saturate the austenite with carbon
3. Cooling the samples rapidly to austempering temperature in the range of 230 ^{o}C - 400 ^{o}C
4. Austempering the samples at required temperature for a time enough to produce ausferrite structure
5. Cooling the samples to room temperature

Alloying elements are used in ductile iron to increase its hardenability. Only a minimum amount of alloys required should be used. Excessive alloying increases the cost and difficulty of producing quality ductile iron necessary for austempered ductile iron (ADI) [5]. The choice of elements to increase the hardenability of ductile iron are limited as compared to steel; however, copper and nickel also increase hardenability [6]. Extensive research is being made for new processing techniques for this prospective material (ADI) to acquire better combination of strength, toughness, wear resistance and machinability. Different alloying elements and different combination of alloying additions have been made to find out their effect on the properties of ductile iron. D. S. Padan [7] examined the effect of microalloying 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 [8] found that 1Wt % copper alloyed austempered ductile iron increased the impact toughness and fracture toughness due to the effect of retained austenite. It would be of considerable interest to determine whether the addition of copper in ductile iron can make any difference to ductile iron. Also ductile iron alloyed with nickel is significant in affecting tensile strength of ductile iron. It was a novel idea to add an equal amount of alloying addition i.e. 1 Wt % Cu and 1 Wt % Ni. Besides the alloying addition of copper and nickel separately, the samples would be austempered for high and low austempered temperatures i.e. 370 ^{o}C and 270 ^{o}C to observe the effect of heat treatment.

EXPERIMENTAL PROCEDURE

Ductile iron was made using local materials and local facilities. The melting was carried out in an induction furnace of commercial foundry. Materials used were pig iron & mild steel from the local market and ductile iron returns of the foundry. In order to get the required composition, ferro alloys and other alloying additions were made to the melt. Ductile iron was produced by sandwich method in which the spheroidizing and inoculant alloys are covered preferably with a steel sheet. Such a cover delays the reaction. Ferrosilicon was used as an inoculant. The inoculant is to provide the melt with seeds or nucleation on which the solid phases grow while freezing as nodules. After the melting, the metal was poured into a ladle with two pockets at the bottom. In one pocket spheroidizing alloy (ferrosilicon-magnesium) and inoculant (ferrosilicon) were placed while the other pocket was kept empty.

The melt was poured at about 1450ºC into standard Y block sand moulds. Tensile specimens of 15mm diameter and 250 mm long were machined from the Y blocks. The chemical analysis of ductile iron melts produced (a) without any copper & nickel, (b) with copper (c) with nickel addition is mentioned in the table 1. Following three melts were prepared to find out the effect of copper and nickel on ductile iron. The details of melts produced are as follows:

a) Heat No. H-0	without any Cu &Ni
b) Heat No. H-Cu	with 1.0 % Cu
c) Heat No. H-Ni	with 1.0 % Ni

EQUIPMENTS USED

Heat Treatment Furnaces.

Two types of furnaces were used for the heat treatment of tensile samples. The samples were austenitized in Carbonite Furnace, Type GPC 13/36 and the samples were austempered in salt-bath using vertical tube furnace, Carbonite Furnace Type VCF 12/10.

Tensile Testing Machine.

The universal tensile testing machine, Shimadzu UH-F-500 KNA was used for the tensile test of samples. The tensile samples were austempered using the above furnaces. The samples were first austenitized at 900 ^{o}C for one hour and austempered for one hour in salt bath maintained at 270 ^{o}C. After that salt bath temperature was increased to 370 ^{o}C for austempering at higher temperature. Then tensile test was performed using universal testing machine.

RESULTS AND DISCUSSIONS.

The tensile test samples (without any addition of copper and nickel) indicated that the tensile strength was 495.3 N/mm^2 as shown in table 2 and figure 1. However when nickel addition of 1.0 Wt. % was made the tensile strength increased to 552.4 N/mm^2. While adding 1.0 Wt. % copper to the ductile iron; the tensile strength increased to 581.7 N/mm^2 that was more than achieved by the addition of 1.0 Wt.% of nickel.

The ductile iron samples were then austeinitized at 900 ^{o}C for one hour and austempered in a salt bath at 270 ^{o}C for one hour. The tensile strength of ductile iron samples was 938.8 N/mm^2 without any addition of nickel and copper to the melt. With the nickel addition 1.0 Wt. % in the ductile iron, the tensile strength increased to 970.5 N/mm^2. The tensile strength was 1096.1 N/mm^2 with 1.0 Wt. % copper.

Table 1: Chemical Composition of Ductile Iron Produced with CU & Ni in Wt %

Elements	Heat No H-0	Heat No H-Cu	Heat No H-Ni
C	3.60	3.70	3.70
Si	2.70	2.60	2.80
Mn	0.10	0.10	0.20
Cu	0.00	1.00	0.00
Ni	0.00	0.00	1.00
S	0.09	0.08	0.09
P	0.02	0.02	0.02

After that austempering temperature of salt bath was increased from 270 ^{o}C to 370 ^{o}C. The tensile samples were similarly austenitized at 900 ^{o}C for one hour and austempered at 370 ^{o}C for one hour. The tensile strength of ductile iron samples was 698.0 N/mm^2 without any addition of copper & nickel. With the nickel addition of 1.0 Wt % in the ductile iron the tensile strength increased to 721.1 N/mm^2 as shown in table 2. The tensile strength of ductile iron with 1.0 Wt % copper was 828.3 N/mm^2.

Table 2: Effect of Copper and Nickel on Tensile Strength of Ductile Iron.

UTS of Heat	H-0 0.0 Wt. %Cu & 0.0 Wt. % Ni UTS N/ mm²	H-Cu 1.0 Wt. % Cu UTS N/ mm²	H-Ni 1.0Wt. %Ni UTS N/ mm²
Without heat-treatment	495.3	581.7	552.4
Austempered at 270 ºC	938.8	1096.1	970.5
Austempered at370 ºC	698.0	828.3	721.1

The tensile strength increased with 1.0 Wt % copper in both cases with or without heat treatment. It was more than that of 1.0 Wt % nickel. The tensile strength was highest with 1.0 Wt % copper i.e. 1096.1 N/mm^2. The tensile strength is more than double if it is compared with ductile iron without any addition of copper and without any heat treatment which is 495.3 N/mm^2. Austempering at high temperature produces broad feathery ferrite structure and austempering at low temperature produces needle like lower ausferritic structure which gives higher tensile strength.

It was observed that there is still a need of research in the field of effect of elements and heat-treatment on the properties of ductile iron. This study about effect of copper and nickel on the tensile strength at lower and higher austmpering temperatures can make a small contribution towards the body of knowledge in this field.

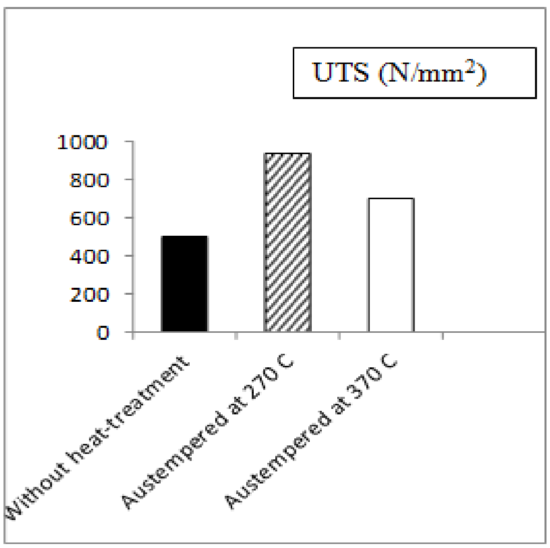

Figure 1: Effect of Nickel (1.0 Wt. %) on tensile strength of ductile iron when austenitized at 900 ºC and austempered at 270 ºC and 370 ºC.

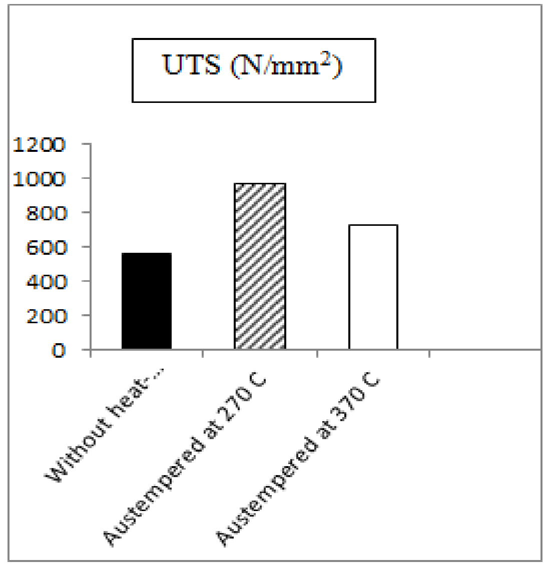

Figure 2: Effect of heat treatment on tensile strength of ductile iron without any addition of copper and nickel.

Both copper and nickel increase the hardenability; however information of these two elements on the mechanical properties are limited and little work has been done on the effects of copper and nickel elements on the tensile strength of ductile iron. Figure 4 shows the comparison of effect of copper and nickel on tensile strength with and without heat treatment. The results are more or less similar to the research conducted by Cheng-Hsun Hsu et al [9] who studied the mechanical properties of cobalt & nickel alloyed ductile irons. They found an increase in strength after alloying the ductile iron and the highest strength was achieved with the addition of 4.0 % nickel. In another study Yan Mi [10] 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 [11] also found that the influence of copper on micro-structure and mechanical properties of ductile iron reaches maximum at about 1.0Wt. %. He suggested that properties may be further increased by other alloying elements. In the present study tensile strength property increased with alloying addition of copper and nickel.

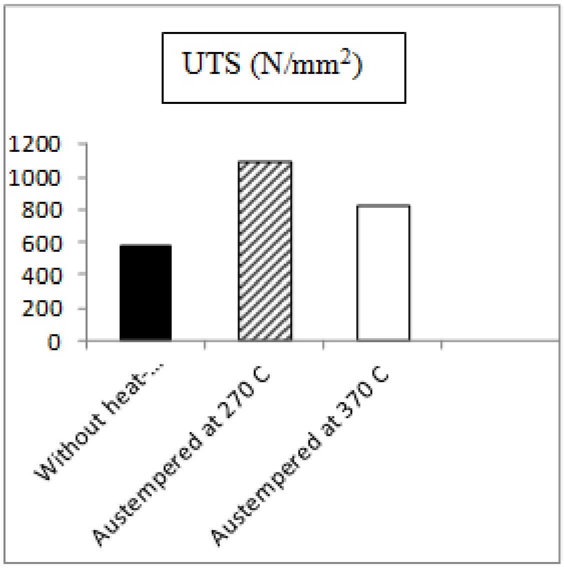

Figure 3: Effect of copper (1.0 wt %) on tensile strength of ductile iron when austenitized at 900 ºC and austempered at 270 ºC and 370 ºC.

This study will give the choice to engineers to choose either copper or nickel as alloying element to increase the tensile strength. Copper is much cheaper than nickel so production of ductile iron using copper will be cost effective.

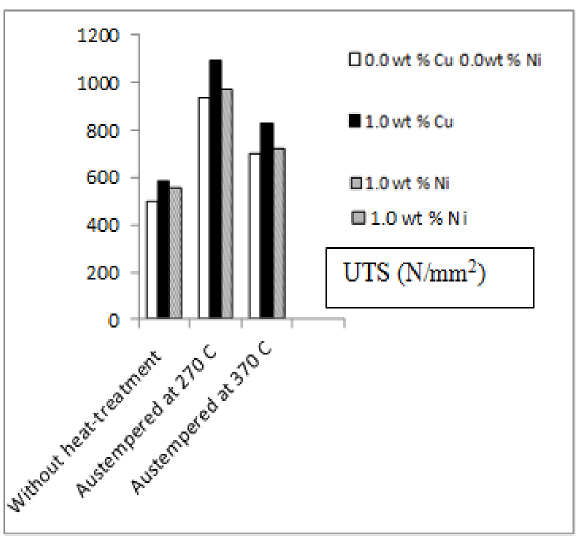

Figure 2: Comparison of Effect of Copper and Nickel on Tensile Strength of Ductile Iron when austenitized at 900 ºC and austempered at 270 ºC and 370 ºC.

CONCLUSION

1. It was found that with the addition of 1.0 Wt. % copper the tensile strength was more than ductile iron alloyed with 1.0 Wt. % nickel.
2. Austempering at lower temperature (270 ^{o}C) produced higher tensile strength than austempering at higher temperature (370 ^{o}C).
3. With the application of austempering heat treatment, the tensile strength was almost doubled as compared to that without heat treatment.

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