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Research Paper

EFFECT OF COPPER ON THE PROPERTIES OF AUSTEMPERED DUCTILE IRON (ADI)

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ADI refers to heat treated Ductile Iron (DI). Austempering heat treatment is used to bring about changes in microstructure of ductile iron hence enhancement in the properties. ADI has the combined properties of cast iron and steel. Damping capacity, wear resistance combined with high strength are the key features of ADI. Development of ADI is a very challenging process, because lot of process variables are involved in the preparation of ADI. Attempt has been made in this work to evaluate the properties of the ADI and properties of DI are compared before and after heat treatment with addition of Cu in the range of 0.5 wt%, 1 wt%, 2 wt% in the DI matrix. The ductile iron preparation followed by the preparation of test specimens of each composition. The specimens were subjected to the austenization (900 °C), austempering (300 °C) in engine oil for the holding time of 1 hr. The heat treatment was carried in a conventional resistance furnace and electric oven. The prepared specimens were tested for tensile strength; microstructural analysis was carried out using optical microscope. Each test and analysis was carried out to specimen of each composition before and after the treatment for the purpose of comparing the properties.

Keywords: ADI, Austempering, Austenization

INTRODUCTION

The increasing interest in energy saving has led to the development of lightweight materials to reduce the weight of existing materials without compromising their properties. For example, in the automotive industries, attempts have been made to replace cast iron and steel components with aluminum and austempered ductile iron.

Austempered Ductile Iron (ADI) is a ductile iron that has undergone a special isothermal heat treatment called austempering. Unlike conventional "as-cast" irons, its properties are achieved by specific heat treatment. Therefore, the only prerequisite for good ADI is a good quality ductile iron (Olivera *et al.*, 2005).

ADI offers superior combination of properties because it can be cast, like any

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other member of the ductile iron family. It offers all production advantages of conventional ductile iron castings. The unique features of ADI are low cost, design flexibility, high strength to weight ratio, good toughness, wear and fatigue resistance (Najmeddin, 2011). Subsequently it is subjected to the austempering process to produce mechanical properties that are superior to conventional ductile iron, many cast and forged steels. The mechanical properties of ductile iron and Austempered Ductile Iron (ADI) are determined by the metal matrix (Myszka, 2007). In conventional ductile iron it is controlled by the mixture of pearlite and ferrite (Hasan and Almaida, 2009). However the properties of ADI are due to its unique matrix of acicular ferrite and carbon stabilized austenite called aus-ferritic (bainite). In many cases composition of ADI castings differs little from conventional Ductile Iron casting. When selecting the composition for both ADI and conventional Ductile Iron, consideration should be given first to limiting elements which adversely affect the casting quality through the production of non-spheroidal graphite, the formation of carbides and inclusions, and promoting the shrinkage. For this reason it's known from the previous research that the percentages of carbon, silicon and other major and minor alloying elements that control the mechanical properties are important (Anita, 2009; Nofal and Jekova, 2009; and Erfanian-Naziftoosi *et al.*, 2011).

In the present work, the effect of Copper with austempering heat treatment on the mechanical properties and hardness of ductile iron were studied. Austenization time, Austempering time (60 minutes) and temperature (900 °C-Austenization, Austempering-300 °C) are kept constant. Metallographic studies on DI and ADI are also conducted.

EXPERIMENT

Materials Selected: CRC scrap, Burnt Coconut shell for carbon, Ferro silicon Magnesium, Ferro silicon and pure copper (99%), engine oil as quenching medium.

Equipments Used: Resistance furnace, electric oven, miscellaneous equipments like quenching tube made of mild steel, graphite crucible etc.

Experimental Procedure

Experiment was conducted in a normal foundry located in Bangalore for the preparation of ADI. Melting of scrap was done in a induction furnace. Detail steps are explained below.

Material Selection: Cold Rolled Coil (CRC) scrap is used as the raw material for the preparation ductile iron. Carbon is added in the form of burnt coconut shell. Magnesium and silicon is added in the form of Ferro silicon magnesium and Ferro silicon as inoculants and graphite promoter respectively.

Melting: Melting was done in a induction furnace of capacity of 250 kg and 130 kW power. After melting the melt was transferred into the ladle for alloying purpose.

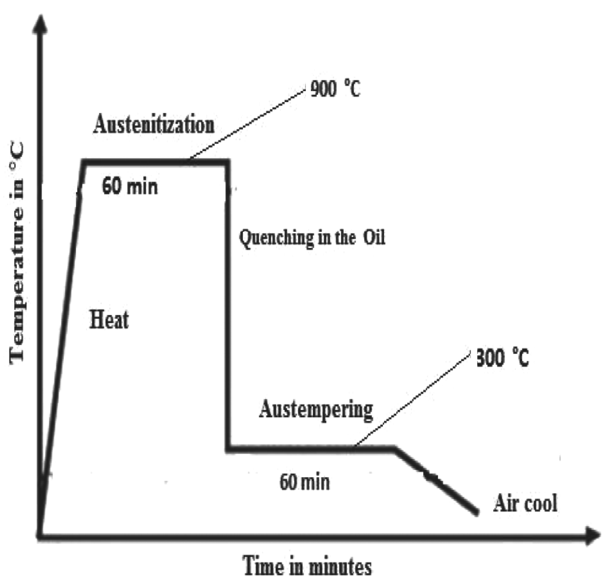
- Melted material was poured into the prepared sand mold and it is allowed for solidification.
- The specimens for tensile test were machined from the test bar casted and then specimens were subjected to austempering heat treatment.

- Two sets of specimens were prepared for each composition for the purpose of comparing the properties between the DI before and after heat treatment.

Heat Treatment

The prepared specimen was subjected to austempering process. Before austempering the specimen was subjected to austenization in a resistance furnace. Program was done in the furnace in such a way that to maintain 900 °C where the specimen is kept for 1 hour. Then the specimen is transferred to the oven where the quenching media was maintained at 300 °C in a cylindrical tube. The oven chamber was enclosed and specimen kept for 1hour and it is allowed for cooling slowly to room temperature. The quenching media selected for austempering was engine oil (Servo Max 4T grade). Figure 1 show the heat treatment cycle used in this experiment.

Figure 1: Typical Heat Treatment Cycle



Equipments Used for Heat Treatment

The following are the equipments used for heat treatment cycle:

- Resistance furnace: for Austenization at 900 °C.
- Electric oven: for Austempering at 300 °C.

After heat treatment specimens were tested for tensile property, hardness, and microstructural study using optical microscopy.

RESULTS AND DISCUSSION

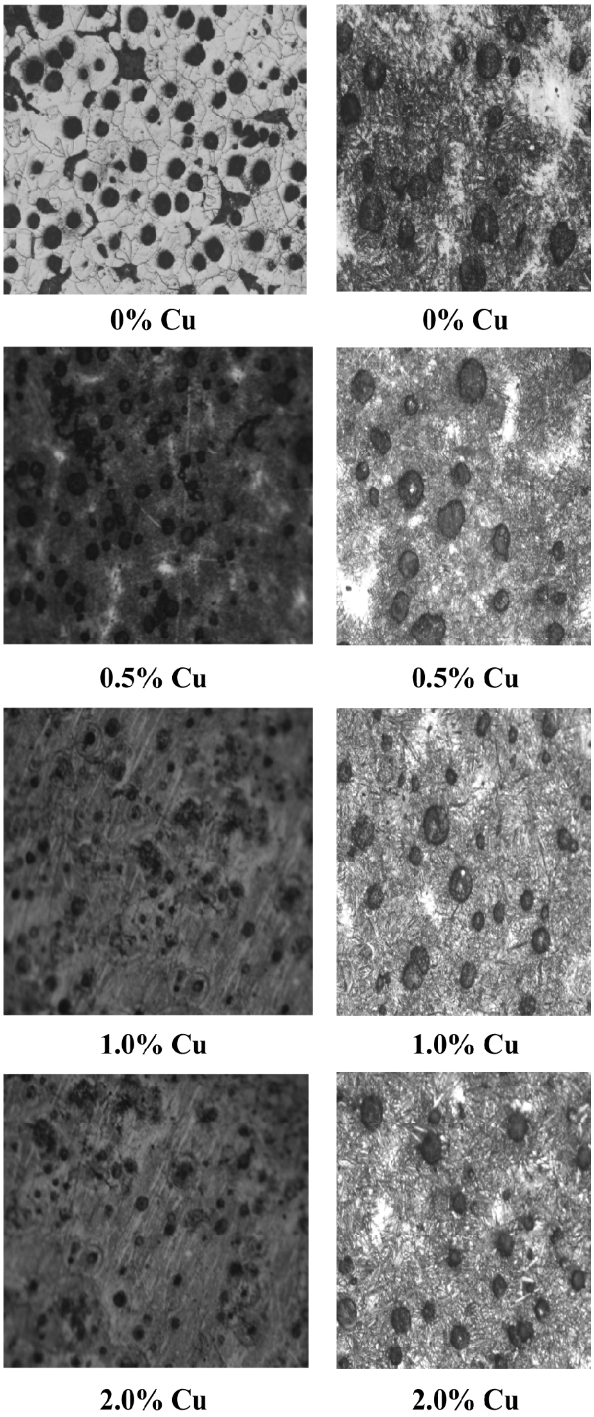
Microstructure of DI and ADI

From all the groups microstructural examination specimens were prepared. The photographs taken from these specimens are given at the Figure 2. The specimens are examined both before and after the heat treatment. At the microstructural examination before the heat treatment the percent of spherodisation is controlled. To determine the success of austempering microstructures are checked after heat treatment.

The microstructure of ductile iron in as cast condition is mostly pearlitic. After different heat treatments there is a change in matrix/phase structure, number of nodules and their spheroidicity. These cause changes in the mechanical properties of ductile iron. The microstructures after different types of treatments of two different grades are shown.

Bainitic matrix structure can be seen at photographs. The amount of stabilized austenite increases with the increasing temperature. In addition to this by the decrease of the transformation temperature a

Figure 2: Microstructure of DI Before and After Heattreatment



Effect of Copper on the Tensile Strength of Ductile Iron

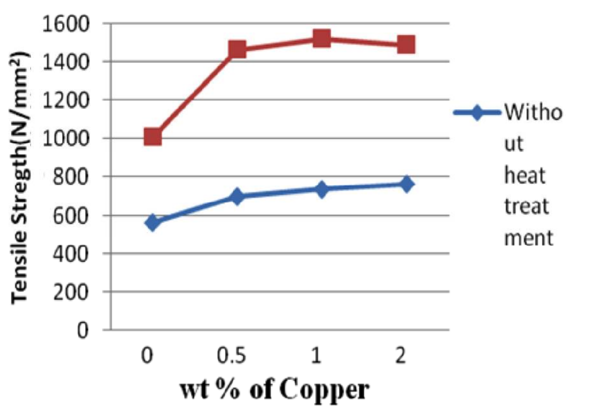
To find out effect of copper, four samples were made with 0.0 wt%, 0.5 wt%, 1.0 wt% and 2.0 wt%. The tensile samples were machined from the castings. The samples were austenitized in a Resistance furnace at a temperature of 900 °C for one hour and austempered in a Resistance oven at 300 ºC for one hour. Then the tensile test was performed. The results are tabulated in Table 1.

Table 1: Effect of Copper on Tensile Strength of Ductile Iron

Copper	Ultimate Tensile Strength (N/mm²)			
	0 wt%	0.5 wt%	1.0 wt%	2.0 wt%
Without heat treatment	561.5	696.1	734.3	762.2
With heat treatment	1009.4	1468.1	1523.6	1491.2

From the Table 1 and Figure 3 it can be said that addition of Cu in the Ductile Iron increases the strength of the Ductile Iron. This is because of the grain refinement takes place after the addition of Cu. When it is subjected to austempering process the presence of retained austenite matrix-ferrite decrease at the grain size is observed. This is possibly a cause of increase in hardness values and tensile strength.

Figure 3: Comparision of Tensile Strength Before and After Heattreatment of DI



matrix around the graphite nodules increases the tensile strength very high. But it is limited up to 1% of Cu, because after 1% there is decrease in the amount of retained austenite phase. But compare to Ductile Iron before heat treatment, tensile strength of ductile iron after heat treatment is very high.

CONCLUSION

Based on the experiment carried out and results obtained the following conclusions were made.

- Servo engine oil used for the austempering process helps in obtaining the ADI with good strength and ductility with compare to that of salt bath quenching from previous literature.
- The tensile strength of the DI before heat treatment was increased gradually with the addition of Cu (0.5, 1 and 2 in wt %) without decrease. Therefore the addition of Cu helps in improving the tensile strength of the material. The maximum tensile strength obtained was 762 N/mm^2 at 2 wt%.
- The tensile strength of the DI after heat treatment was increased up to the 1 wt% of the Cu addition, after it tends to decrease. The austempering helps in improvement of tensile strength compare to specimens of without heat treatment. The maximum tensile strength obtained was 1523.6 N/mm^2 at 1 wt%.

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