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RESEARCH ARTICLE

VARIATION OF MECHANICAL PROPERTIES OF AUSTEMPERED DUCTILE IRON WITH PROCESSING PARAMETERS

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ABSTRACT

Austempererd ductile iron is the most recent development in the area of ductile iron. This is formed by an isothermal heat treatment of the ductile iron. The newly developed austempered ductile iron is now replacing steel in many fields so it has becoming very important to various aspects of this material. In the present work the effect of copper along with the process variables (austempering temperature and austempering time) on the properties (Tensile strength and Elongation) and microstructure of ductile iron was studied. With increasing austempering time tensile strength and elongation were increasing but with increasing austempering temperature tensile strength was decreasing and elongation was increasing. Austempered ductile iron with copper was showing some higher strength and lower elongation than the austempered ductile iron without copper. In microstructure ferrite was increasing with increasing austempering time and austenite was increasing with increasing austempering temperature in both the grades.

INTRODUCTION

In recent years, there is a significant importance in energy saving which has led to the advancement of light weight, durable and cost effective materials. For this purpose, there is a requirement to continually formulate new materials and checkout those already in account. One such material is ductile iron. Research efforts on this material have mainly focused on possible improvements of mechanical properties by subjected it to appropriate heat treatment and by alloying elements (Refaey and Fatahalla, 2003; Sidjanin *et al.,* 1994; Franetovic *et al.,* 1987; Putatunda, 2001; Eric *et al.,* 2006; Ahmadabadi *et al.,* 1999).

A ductile iron which subjected to a peculiar isothermal heat treatment process i.e. heating to the austenitizing temperature, followed by quenching into a salt or oil bath at a temperature in the range of 445 ^{o}C to 200 ^{o}C and holding for the time required for transformation to occur at this temperature, is known as austempered ductile iron (ADI) and the process is known as austempering (Tanaka and Kage, 1992). Ductile Cast Iron undergoes a remarkable transformation when subjected to the austempering heat process. The resulting microstructure, known as "Ausferrite", which consist of fine acicular ferrite with carbon enriched stabilized austenite and gives its special attributes to ADI. The new microstructure (ADI) results with capability superior to many traditional, high performance, ferrous and aluminium alloys. Ausferrite exhibits twice the strength for a given level of ductility compared to the pearlitic, ferritic or martensitic structures formed by conventional heat treatments (Nofal and Jekova, 2009; El-Baradie *et al.,* 2004;Gür *et al.,* 2008;Valdes *et al.,* 2009; Campos-Cambranis *et al.,* 1999). In present research work, the effect of copper alloying as well as the effect of heat treatment parameters like austmpering time and austempering temperature on microstructure and properties of the ductile iron were studied.

MATERIALS AND METHODS

Two grades of ductile iron samples produced from commercial foundry, L&T Kansbhal,are used in the experiment. The difference between these two grades are one contains copper and another without copper. Chemical composition of the two grades of ductile iron samples are given in Table 1. For tensile test the solid block of ductile iron was cut to “Dog Bone Shape”, which were machined to 6 mm gauge diameter and 30 mm gauge length. 12 numbers ofsamples of each grade have taken and heated to 900^{o}C for one hour (austenisation) and then transferred quickly to a salt bath at austempering temperatures 250, 300 and 350^{o}C, held for 1/2, 1, 1 ½ and 2 h and then air- cooled to room temperature. Then tensile test was conducted by using Fuel Instruments & Engineers universal testing machine, model UTES-100as per ASTM standard. After that, from each specimen a slice of 4 mm is cut andstandard metallographic preparation techniques (mechanical grinding and polishing followed by etching in 2 %Nital solution) were applied for Scanning Electron Microscopy (SEM) analysis. X-Ray diffraction (XRD) analysis was performed for few selected samples. This technique was used to estimate the volume

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Table 1 Chemical compositions of alloyed/unalloyed ductile iron

Specimen	C %	Si %	Mn %	Cr %	Ni %	Mg %	Cu %	S %	P %
Copper Alloyed	3.55	2.1	0.18	0.03	0.22	0.038	0.49	0.009	0.024
Unalloyed	3.57	2.22	0.23	0.03	0.23	0.045	0.001	0.011	0.026

Table 2. Tensile strength, yield strength and elongation of Unalloyed and Copper alloyed ADI

Austempering Temperature (^{o}C)	Time (min)	Unalloyed ADI			Copper alloyed ADI		
		Tensile strength, σ^{UTS}(MPa)	0.2% Yield strength, σ^{YS} (MPa)	Elongation (%)	Tensile strength, σ^{UTS}(MPa)	0.2% Yield strength, σ^{YS} (MPa)	Elongation (%)
250	30	997	795	1.9	1039	834	1.5
	60	1139	957	2.4	1181	995	2.1
	90	1124	927	2.8	1162	967	2.4
	120	1116	906	2.8	1168	978	2.3
300	30	831	693	3.7	873	685	3.1
	60	983	806	4.2	1017	825	3.5
	90	965	759	4.8	1034	858	3.7
	120	976	788	4.7	1030	851	3.8
350	30	724	539	5.9	778	591	5.2
	60	871	691	6.7	928	735	5.8
	90	849	673	7.2	921	733	5.9
	120	861	687	7.1	907	716	6

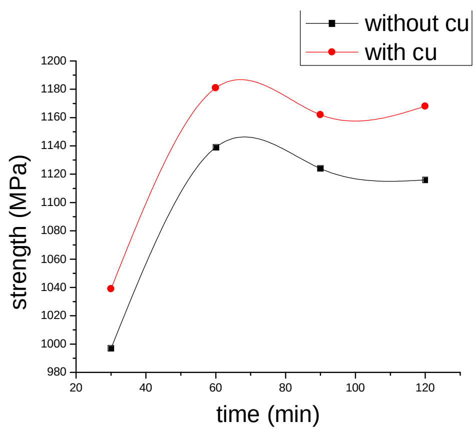

Fig. 1. Variation of tensile strength with respect to the austempering time at temperature 250^{o}C

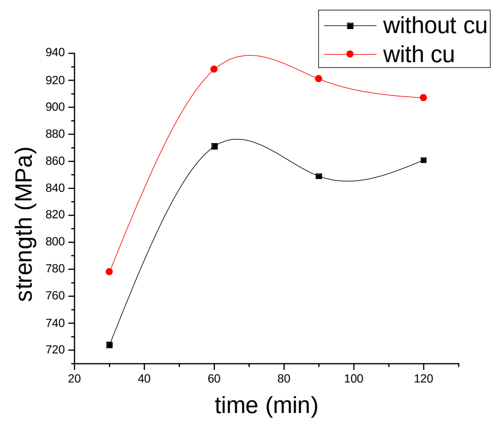

Fig. 3. Variation of tensile strength with respect to the austempering time at temperature 350 ^{o}C

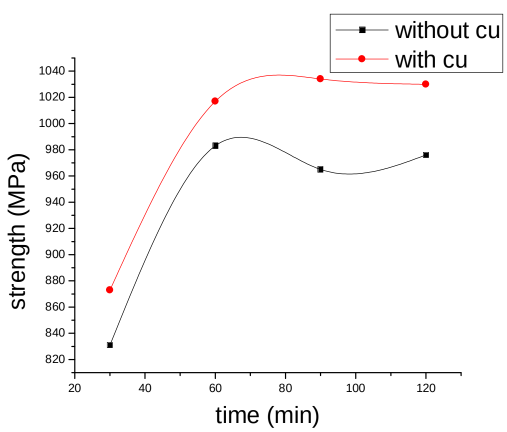

Fig. 2. Variation of tensile strength with respect to the austempering time at temperature 300 ^{o}C

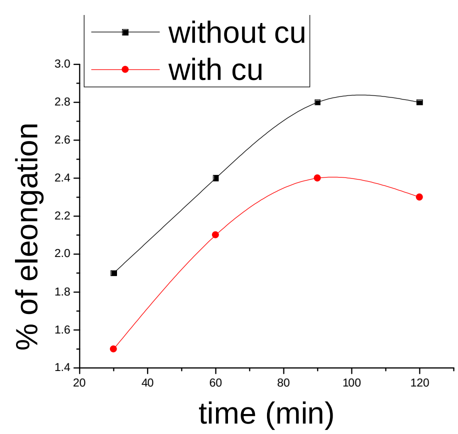

Fig. 4. Variation of elongation with respect to the austempering time at temperature 250 ^{o}C

fractions of retained austenite and ferrite in the material after treatment. XRD was performed 30 KV and 20 mA using a Cu-Kα target diffractometer. Scanning was done in angular range 2θ from 40° to 48° and 70° to 92° at a scanning speed of 1°/min.

RESULTS AND DISCUSSION

Mechanical Properties

The mechanical properties (tensile strength, yield strength and elongation) of the Copper alloyed and unalloyed samples for various austempering time and temperature are summarized in

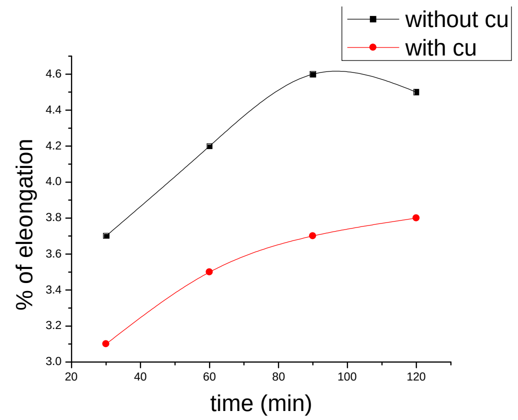

Fig. 5. Variation of elongation with respect to the austempering time at temperature 300 °C

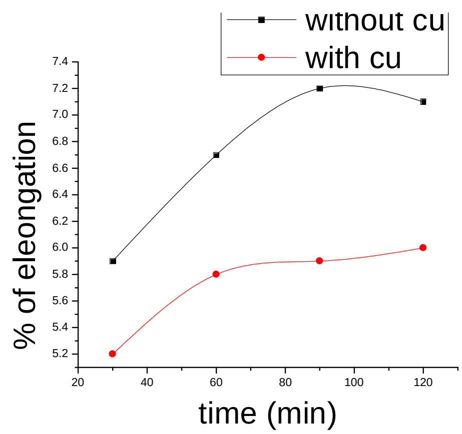

Fig. 6. Variation of elongation with respect to the austempering time at temperature 350 °C

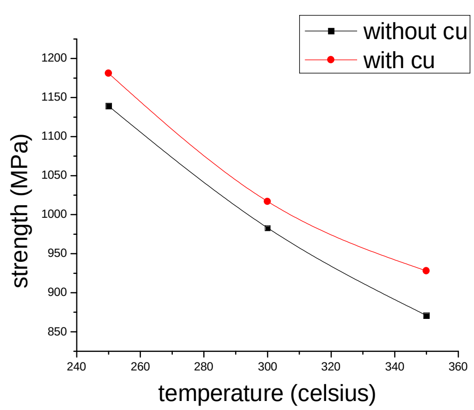

Fig. 7. Variation of tensile strength with respect to the austempering temperature for 60 min

Table 2. Fig 1, 2 & 3 show the variation of tensile strength with respect to the austempering time at temperature 250°C, 300°C &350°C respectively for two grades (one with copper and another without copper). Tensile strength is increasing from 30 min austempering time to 60 min but from 60 to 120 min there is no observable change for both the grades. Austempered ductile iron alloyed with cooper is showing little bit higher strengths than the unalloyed austempered ductile iron. Fig 4, 5 &6 show the variation of elongation with respect to the austempering time at temperature 250°C, 300°C &350°C respectively for two grades (one with copper and another

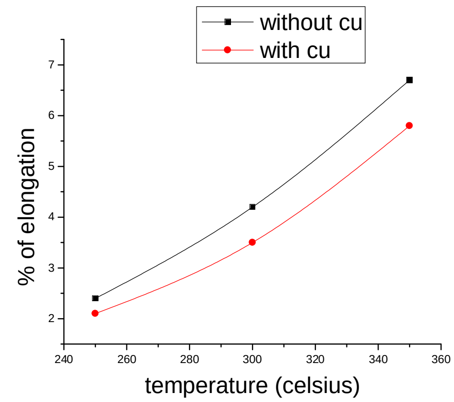

Fig. 8. Variation of elongation with respect to the austempering temperature for 60 min

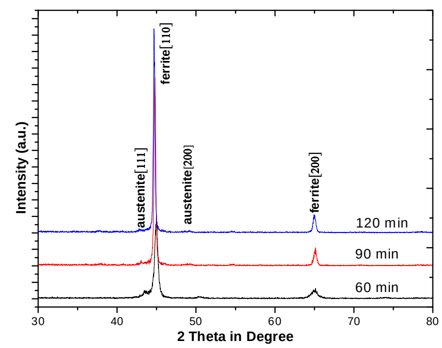

Fig. 9. XRD pattern of unalloyed ductile iron austempered at 250°C

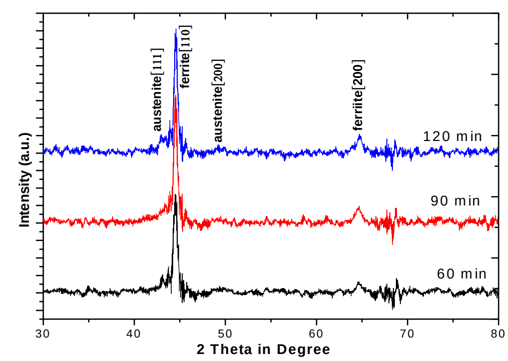

Fig. 10. XRD pattern of Cu alloyed ductile iron austempered at 250°C

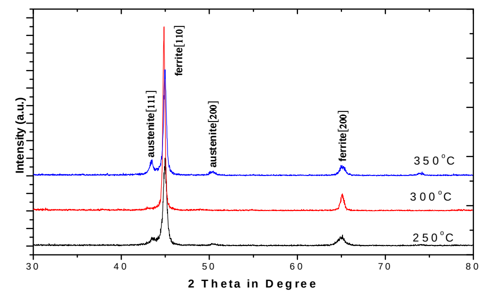

Fig.11. XRD pattern of unalloyed ductile iron austempered for 60 min

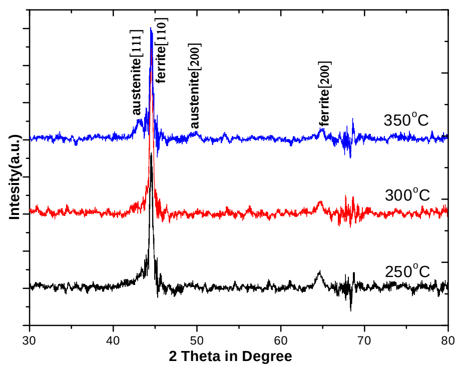

Fig. 12. XRD pattern of Cu alloyed ductile iron austempered for 60 min

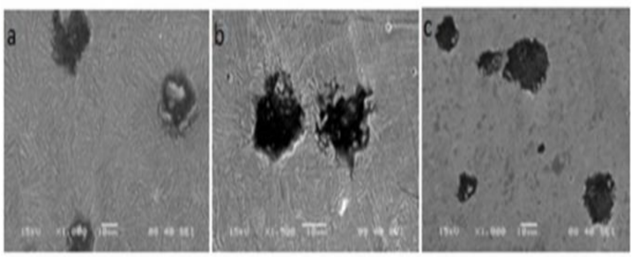

Fig.13. Microstructure of the autsmpered ductile iron (without copper) austempered for 60 min at a) 250°C (b) 300°C (c) 350 °C

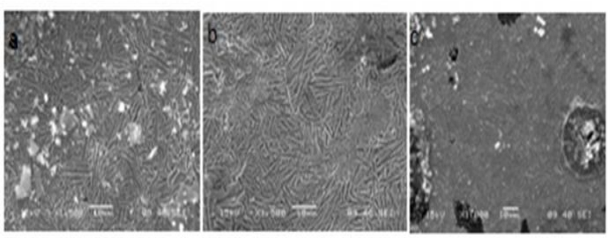

Fig. 14. Microstructure of the autsmpered ductile iron (with copper) austempered for 60 min at a) 250°C (b) 300°C (c) 350°C

without copper). Elongation is increasing from 30 min austempering time to 60 min but from 60 to 120 min there is no observable change for both the grades. Austempered ductile iron alloyed with cooper is showing little bit lower elongation than the unalloyed austempered ductile iron. Fig 7 & 8 show the variation of tensile strength and elongation with respect to the austempering temperature for 60 min for both the grades (one with copper and another without copper). From the graph, it is found that tensile strength is decreasing with increasing austmpering temperature but elongation is increasing.

X-ray diffraction analysis

The XRD pattern of austempered ductile iron (with and without copper) austempered at different temperatures and different times are shown in fig 9 to 12. In the XRD pattern it is observed that the austenite (111) peaks and ferrite (110) peaks are identified nearly in all cases. The maximum intensity of the austenite (111) peak is increasing with increasing temperature but ferrite (110) peak is increasing with increasing austempering time and decreasing with increasing temperature.

Microstructure

The microstructures of unalloyed and alloyed ductile iron samples were observed under the scanning electron microscope and are shown in figure 13 and 14. In the above microstructure it is observed that the samples which are autempered at higher temperatures having upper bainitic structure and the samples which are austempered at lower temperatures are having lower bainitic structure. When the austempering temperature increasing the morphology of bainite also changing from acicular to plate like. The amount of retained austenite is increasing at higher temperature. At lower austempering temperatures the strength is higher. There is no significance difference between copper alloyed ductile iron and ductile iron without copper.

Conclusions

Mechanical properties and microstructure of alloyed and unalloyed ADI were studied by means of tensile test, scanning electron microscopy and X-ray diffraction analysis. It was shown that:

- As the austempering temperature is increasing tensile strength is decreasing and elongation is increasing in both the alloyed and unalloyed ductile iron.
- As the austempering time is increasing tensile strength and elongation are increasing in both the grades.
- The ductile iron alloyed with copper is showing little bit high tensile strength but lower elongation compared with unalloyed ductile iron.
- In microstructure austenite is increasing with increasing austempering temperature and ferrite is increasing with increasing austempering time in both the grades.

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