International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Effect of Copper on Austempering Behavior of Ductile Iron

Abhishek Singh[1], Brijesh Ojha[2]

[1]M. Tech. (ME) Scholar, R.R. Institute of Technology and Management Lucknow, UP-India

[2]Professor, R.R. Institute of Technology and Management Lucknow, UP-India

Abstract: ***Even since its discovery in 1948, the use of ductile iron is increasing continuously, this is due to the combination of its various excellent mechanical properties. Excessive amount of research is being carried out to develop even better properties. Austempererd ductile iron is the most recent development in the area of ductile iron or S.G. 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 (Hardness, Tensile strength and Elongation) and microstructure of ductile iron is studied. With increasing austempering time hardness, tensile strength and elongation are increasing but with increasing austempering temperature hardness and tensile strength are decreasing and elongation increasing. Austempered ductile iron with copper is showing some higher strength, hardness and lower elongation than the austempered ductile iron without copper. In microstructure ferrite is increasing with increasing austempering time and austenite is increasing with increasing austempering temperature in both the grades.***

Keywords: S.G. Iron, Austempering, austempered ductile iron, austempering time and temperature, austenite and ferrite

1. Introduction

In recent years, there has been a significant importance in energy saving which has led to the advancement of light weight, durable and cost effective materials. For these 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.

A ductile iron which subjected to a peculiar isothermal heat treatment process austmpering is known as austempered ductile iron (ADI). The properties of Austempered ductile iron is produced by the particular heat treatment so the only essential for austempered ductile iron is better ductile iron.

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(2) and gives ADI its special attributes. 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.

The mechanical properties of the austempered ductile iron are depending on the ausferrite microstructure. The austepmered matrix is responcible for significantly better tensile strength to ductility ratio than is possible with any other grade of ductile iron (1).An unusual combination of properties is obtained in austempered ductile iron because of the ausferrite microstructure. These properties mainly depend on the heat treatment conditions and alloyed elements. Alloy additions may be made to austempered ductile iron with a view to control the matrix structure.

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 microsteucture and properties of the ductile iron were studied.

2. A Discussion of Previous Work-

Olivera Eric, Dragan Rajnovic, Slavica, Leposava Sidjanin, T.Jovanovic have studied on the macrostructure and fracture of two types of austempered ductile iron, one is alloyed with copper and another one is alloyed with copper and nickel and observed the effect of copper and copper plus nickel on the microstructure and impact properties of the two types austempred ductile irons. They told that addition of copper plus nickel delays the transformation kinetics of the residual austenite resulting in a shift of the maximum of volume fraction of retained austenite to 3 hours of austempering, compared to 2 hours in austempered ductile iron alloyed with copper. In the same time, they observed higher maximum value of the volume fraction of retained austenite in austempered ductile iron alloyed with copper plus nickel. In the same austempered ductile iron a substantial plastic deformation at the peak of impact energy is associated with the highest volume fraction of retained austenite. So they have been demonstrated that the volume fraction of retained austenite strongly effects impact energy of both irons, i.e. with content retained austenite up to maximum value impact energy increases, then a decrease occurs with the decrease of retained austenite [23].

J. Zimba, D.J. Simbi, E. Navara have studied the abrasive wear and mechanical properties of the austempered ductile iron and compared these properties with the quenched and tempered steel. In this work they have taken one type of ductile iron sample and two types of steel samples and austmpered the ductile iron sample at different temperatures and times, and steel samples were quenched & tempered at different temperatures. They observed that as the austempering temperature is increases so does the ferrite lath spacing and the volume fraction of retained austenite. In mechanical properties, the tensile strength and hardness decrease with austempering temperature while the elongation and impact toughness indicate significant increase as the austempering temperature is raised. The good wear resistance exhibited by austempered ductile iron despite the low initial hardness can be attributed to the surface transformation of retained austenite to martensite during abrasion, i.e. during abrasion; there is a surface transformation of retained austenite to martensite. Due to this the surface hardness and wear resistance of austempered ductile iron increase [24].

Dong Cherng WEN and Tien Shou LEI have studied the mechanical properties and microstructure of low alloyed ductile iron in the upper ausferrite region. For that they have taken the samples of ductile iron alloyed with 0.77% copper and 0.5% nickel and austenitized at 900oC and austempered at 400oC.they found from their work is that The martenslte content of ADI had a significant influence on Its mechanica] propertles. As martensite content Increased, ductility and toughness decreased obviously. The effect of martensite on reducing mechanical properties coud be eliminated after tempering at 2000 C. Ductility and toughness could be increased without Decreasing the previous strength, and these strengthening effects were particularly evident at 3- 50 % martensite content. Tempering at 200^0 C could shorten the austempering time in getting the samelevel as the peak values of mechanical properties of ADI treated with single austempering, and could extend the effective range of austempering time. From the observation of mechanical properties and microstructure changes, it was evident that the use of processing window defined by resisitivity curve in selecting the isothermal holding time in austempering was effective and direct. When ductile iron was austempered within this processing window the mechanical properties satisfied the standard requirement were obtained

3. Experiments

Two grades of ductile iron samples have used in the experiment which are produced commercial foundry known as L&T Kansbhal. The difference between these two grades were one contains copper and another without copper. Chemical composition of the two grades of ductile iron samples given below in the table.

Table 3.1: Composition of the samples

	C	Si	Mn	Cr	Ni	Mg	Cu	S	P
With Copper	3.55	2.1	0.18	0.03	0.22	0.038	0.49	0.009	0.024
Without Copper	3.57	2.22	0.23	0.03	0.32	0.045	0.001	0.011	0.026

3.1 Test Specimen Preparation:

For different tests the solid block of ductile iron was cut to thickness of 4-6 mm using power hacksaw. Then they are grinded, polished and machined to the dimension required for various experiments to be carried out.

3.2 Heat Treatment (Austempering):

No of samples of each grade have taken and heated to 900^0C for one hour (austenisation) and then transferred quickly to a salt bath (salt combination was 50 wt % NaNO3 and 50 wt % KNO3) maintained at different temperatures(250^0C,300^0C,350^0C) for half an hour, one hour, one and half an hour and two hours.

3.3 Hardness Measurement:

The heat treated samples of dimension 8×8×3 mm were polished in emery papers(or SiC papers) of different grades for hardness measurement. Rockwell Hardness test was performed at room temperature to measure the macro hardness of the ductile iron specimens in A scale. The load was applied through the square shaped diamond indenter for few seconds during testing of all the treated and untreated samples. Four measurements for each sample were taken covering the whole surface of the specimen and averaged to get final hardness results. A load of 60 kg was applied to the specimen for 30 seconds. Then the depth of indentation was automatically recorded on a dial gauge in terms of arbitrary hardness numbers. Then these values were converted to in terms of required hardness numbers (as Brielle"s or Vickers hardness numbers).

3.4 Tensile Testing

Tensile test were carried out according to ASTM (A 370-2002). A specimen of "Dog Bone Shape" shown in figure 3.2 was prepared for tensile test, which were machined to 6mm gauge diameter and 30 mm gauge length. Test was conducted by using universal testing machine (UTM100) as per ASTM standard.

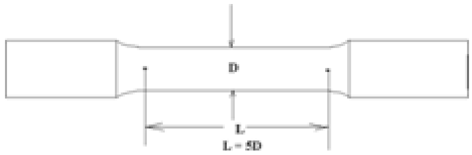


Figure 3.4: Specimen used for tensile properties

Advanced materials are used in a wide variety of enviournments and at different temperature and pressure. It is necessary to know the elastic and plastic behavior of these materials under such conditions. Such properties as tensile strength, creep strength, fatigue strength, fracture strength, fracture toughness, and hardness characterize that behavior. These properties can be measured by mechanical tests.

3.5 Scaning Electron Microscopy

3.5.1. Micro-structural observations

The samples were prepared for micro structural analysis. From each specimen a slice of 4 mm is cut to determine the microstructure. These slices are firstly mounted by using Bakelite powder then polished in SiC paper of different grades (or emery papers) then in 1 µm cloth coated with diamond paste. The samples were etched using 2% natal (2% conc. Nitric acid in methanol solution). Then the microstructures were taken for different heat treated specimen by using Scanning Electron Microscopy (SEM).

3.5.2 Fractoraography

Fracture surface or surface morphology of the samples which fractures in different manners (ductile, Brittle and mixed mode fracture) after tensile test for treated and untreated condition are analyzed by using Scanning Electron microscopy (SEM).For this samples were cleaned with Acetone to remove any dust or impurity on the surface of specimens before SEM.

3.5.3 X-Ray Diffraction studies:

The XRay diffraction (XRD) analysis was performed for few selected samples. This technique was used to estimate the volume fractions of retained austenite and ferrite in the material after treatment. XRD was performed 30 KV and 20 mA using a Cu- Kα target diffractmeter. Scanning was done in angular range 2θ from 40° to 48° and 70° to 92° at a scanning speed of 1°/min. The profile were analyzed on computer by using X‟ Pert High Score Software to obtain the peak position and integrated intensities of the autenite and ferrite. By comparing these intensities the volume fractions of retained austenite and ferrite were estimated.

4. Result & Discussion

In the present research work effect of different variables like austempering time, austempering temperature and alloying of copper on properties and microstructure of ductile iron have been studied.

4.1 The mechanical properties

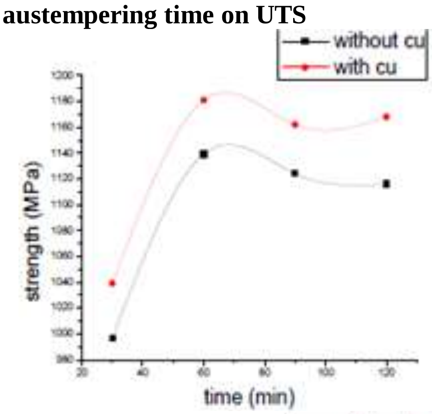
Table 4.1: Mechanicle properties of ADI without copper

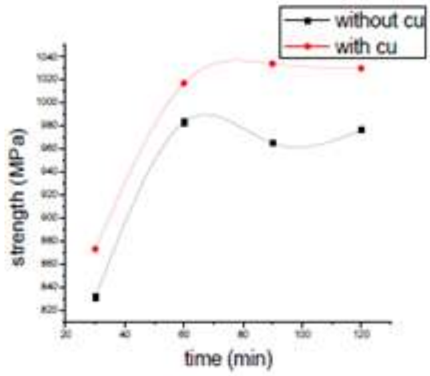
	Time (min)	UTS (MPa)	YS (MPa)	% Elongation	Hardness (RA)
250	30	997	795	1.9	75
	60	1139	957	2.4	80
	90	1124	927	2.8	79
	120	1116	906	2.8	78
300	30	831	639	3.7	69
	60	983	806	4.2	73
	90	965	759	4.8	71
	120	976	788	4.7	72
350	30	724	539	5.9	65
	60	871	691	6.7	69
	90	849	673	7.2	68
	120	861	687	7.1	67

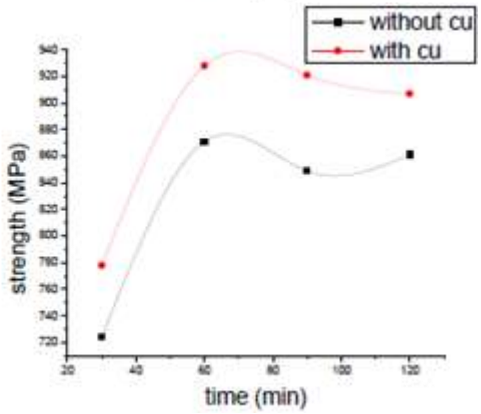
Table 4.2: Mechanicle properties of ADI with copper

Temperature (°C)	Time (min)	UTS (MPa)	YS (MPa)	% Elongation	Hardness (RA)
250	30	1039	834	1.5	76
	60	1181	995	2.1	82
	90	1162	967	2.4	80
	120	1168	978	2.3	79
300	30	873	685	3.1	71
	60	1017	825	3.5	74
	90	1034	858	3.7	72
	120	1030	851	3.8	73
350	30	778	591	5.2	68
	60	928	735	5.8	72
	90	921	733	5.9	70
	120	907	716	6	69

Effect of austempering time on UTS







Figures are showing 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 half an hour austempering time to one hour, from one hour to one and half an hour it is decreasing and from one and half an hour to two hours sometimes increasing and sometimes increasing. Overall it is observed that tensile strength is increasing from half an hour to one hour and for one hour, one and half an hour and two hours tensile strength almost same i.e. not showing significance difference for both the grades. Austempered ductile iron alloyed with cooper is showing little bit higher strengths than the unalloyed austempered ductile iron.

4.2 Scanning electron microscopy

4.2.1 Microstructure

The microstructures of unalloyed and alloyed ductile iron samples were observed under the scanning electron microscope and are shown in following fig.

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

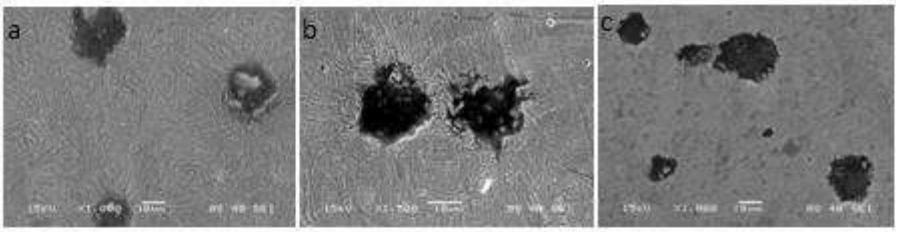


Figure 4.1: Microstructure of the autsmpered ductile iron (without copper) austempered at (a) 250^{o}C for ½ hour (b) 350^{0}C for 1 hour (c) 300^{o}C for 1 ½ hour.

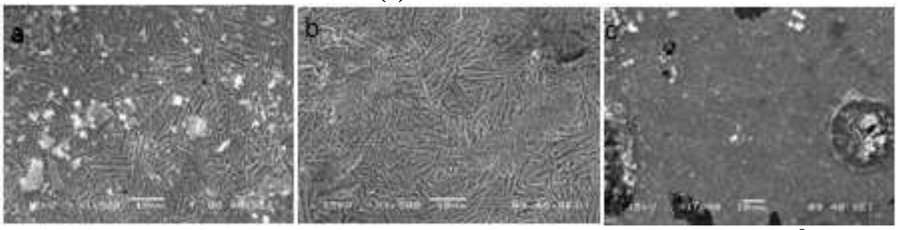


Figure 4.2: Microstructure of the autsmpered ductile iron (with copper) austempered at (a) 350^{o}C for 1 hour (b) 250^{0}C for ½ hour (c) 250^{o}C for 2 hours

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.

4.2.2. Fracrography

The morphology of fracture surfaces are analyzed by scanning electron microscopy and pictures are given bellow.

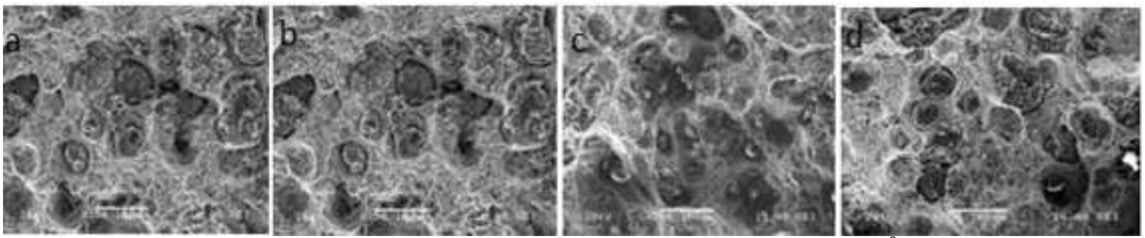


Figure 4.3: Fracture surfaces of the copper alloyed ductile iron which is austempered at 250^{0}C for a) 2hrs (b) 1 ½ hrs(c) ½ hr (d) 1hr.

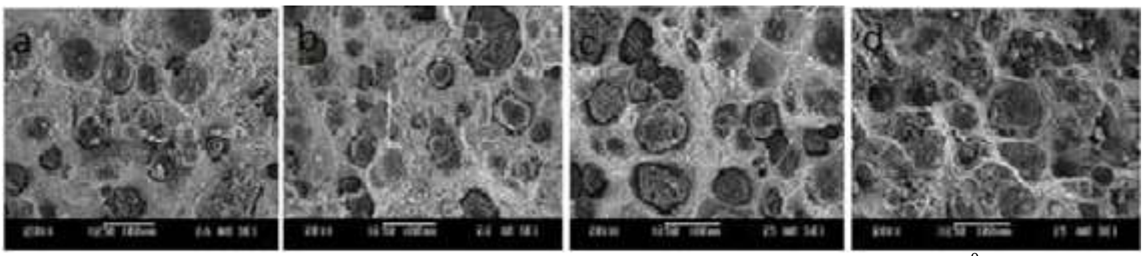


Figure 4.4: Fracture surfaces of the austemered ductile (without copper) which austmpered at 250^{0}C for (a) ½ hours (b) 1 hours, (c) 1 ½ hour and (d) 2 hours

In the above pictures it is observed that, at lower treatment times, the fracture pattern (in both the grades) shows a mixed mode of fracture (ductile and brittle), because of the presence of retained austenite and some amount of martensite. But as austempering time is increased, the fracture bears a dimple type appearance because of the disappearance of martensite phase. It is observed that the dimple size increases but the number of dimples decreases with increasing austempering temperature. Dimple size increased with increasing austempering temperature, which indicates improvement in ductility.

5. Conclusions

1) As the austempering temperature is increasing hardness and tensile strength are decreasing and elongation is increasing in both the copper alloyed ductile iron and un alloyed ductile iron.
2) As the austempering time is increasing tensile strength, hardness and elongation are increasing in both the grades.
3) The ductile iron alloyed with copper is showing little bit high tensile strength and hardness but lower elongation compared with unalloyed ductile iron.

4) In microstructure austenite is increasing with increasing austempering temperature and ferrite is increasing with increasing austempering time in both the grades.
5) 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 in both the grades.
6) The fracture surfaces showed a mixed mode of fracture for shorter austempering time. The percentage of dimple fracture (ductile) then increased with time and with increasing temperature also size of dimple is increasing which indicates improvement in ductility.

6. Scope for Future Work

Austempered ductile iron has found enormous applications in recent years due to its high strength and hardness, with ductility and toughness. It has started to replace steel in some structural applications. Engineering applications of ductile iron in as cast and different heat treated conditions are growing day by day. More work is needed to improve the properties of ductile iron through find out the effect of different alloying elements and heat treatment process on the ductile iron.

References

[1] Chandler Harry , Heat treaters guide: practices and procedures for irons and steels, ASM International; 2 Sub edition (December 1995)
[2] Nofal A.A., jakova L., Journal of the university of chemical technology and metallurgy,44, 3, 209, 213-228, review.
[3] Avnor, Introduction to physical metallurgy, john willey publications.
[4] Dividson James h., Microstructure of steels and cast irons, Springer publications.
[5] verhoeven John d., Steel metallurgy for the non metallurgist, 2007, p175-188.
[6] Ductile iron, http://www.rastgar.com/rec/papers/paper-2.pdf.
[7] Swine S., Effect of Chemistry and Processing Variables on the Mechanical Properties of Thin-wall Ductile iron castings, M.Tech thesis.
[8] Ductile Iron society, ductile Iron Data for Design Engineers. http://www.ductile.org/didata/pdf/didata2.pdf, 9.
[9] A guide to the mechanical properties of ductile iron, mid Atlantic casing service, http://www.mid-atlanticcasting.com/ductile-iron_casting-guide_FEB05.pdf
[10] Ductile iron society, ductile iron data for engineers. http://www.ductile.org/didata/Section5/5intro.htm
[11] Hayrynen Kathy L., The Production of Austempered Ductile Iron (ADI), 2002 World Conference on ADI.
[12] Advanced cast products, http://www.advancedcast.com/austempering-process.htm
[13] DuctileIron Data for Design Engineers, http://www.ductile.org/didata/section4/4intro.htm
[14] Durhamfoundary,austempered ductile iron castins, http://www.durhamfoundry.com/austempered_ductile_iron.htm.
[15] Ashraf Sheikh Muhammad, Effect of heat treatment and alloying elements on characteristics of austempered ductile iron, Ph.D thesis, 2008.
[16] Smith foundry, austempered ductile iron, http://www.smithfoundry.com/adi.asp.
[17] Benton foundry, Austempered ductile iron castings, http://bentonfoundry.thomasnet.com/item/all-categories/austempered-ductile-iron- castings/item-1003.
[18] Austempered ductile iron, http://www.aditreatments.com/microstructure.php Advanced cast products, http://www.advancedcast.com/adi-advantages.htm
[19] Metal technologies, ductile iron, http://www.metal-technologies.com/DuctileIron.aspx.
[20] Austempered ductile iron, http://www.ctiparts.com/austempered.htm
[21] Ductile iron data for engineer, http://www.ductile.org/didata/section4/4intro.htm#Applications.
[22]) eric Olivera, Draganrajnovi, Sidjanin Leposava, zec Slavica and Jovanovi Milant., An austempering study of ductile iron alloyed with copper, *J.* Serb. *Chem.Soc. vol.70* (7)(2005) pp1015–1022.
[23] Zimba J., Simbi D.J., Navara E., Austempered ductile iron: An alternative material for earth moving components, Cement & Concrete Composites, vol. 25 (2003) pp. 643–649.
[24] Fan Z.K. and Smallman R.E., some observations on the fracture of austempered ductile iron, Scripta Mctallurgica *et* Materialia, Vol. 31(1994) pp. 137-142.