

**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH  
TECHNOLOGY****EXPERIMENTAL STUDY ON THE EFFECT OF HEAT TREATMENT ON THE  
PROPERTIES OF DUCTILE IRON AFTER ALLOYING****Rajneesh Yadav<sup>\*1</sup>, Dr Lokendra Pal Singh<sup>2</sup> & Romiyo Mclin Jojowar<sup>3</sup>**<sup>\*1</sup>M.Tech Scholar, Dept. of Mechanical Engineering, SHUATS, Allahabad, U.P., India<sup>2</sup>Asst. Professor, Dept. of Mechanical Engineering, SHUATS Allahabad, U.P., India<sup>3</sup>M.Tech Scholar, Dept. of Mechanical Engineering, SHUATS, Allahabad, U.P., India

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**ABSTRACT**

Cast Iron, the first man – made composite, is at least 2500 year old. It remains the most important casting material, with over 70 % of the total world tonnage. The man for cast iron longevity are its wide range of mechanical and physical properties coupled with its competitive price. Ductile iron or popularly known as spherodized graphite iron (SGiron) is a special variety of cast iron having carbon content more than 3 % and has graphite present in compact, spherical shapes. These compact spheroid hamper the continuity of the matrix much less than graphite flakes which results in higher strength and toughness with a structure that resembles gray cast iron , thus imparting superior mechanical properties i.e. much higher than all other cast irons and which can be compared to steel .This unique property enables ductile iron to be used for numerous industrial applications .The excellent combination of mechanical properties obtained in S.G. iron can further be improved by the heat treatment . The most recent development in this regard is the production of Austempered Ductile Iron (ADI). It provides an excellent combination of high tensile strength, wear resistance along with good corrosion resistance and quite significant amount of ductility.

Due to these factors, S.G. or ductile iron is austempered when a very favourable combination of various properties is required. But this type of treatment is bit tricky, since it require controlled heating and isothermal holding of the material. So it is necessary to find some attractive methods for property development in S.G. iron.The present work is an attempt to study the properties enhancement of ductile iron by heat treatment. Normalizing, Austenitization, Quenching & Tempering, Austempering methods are applied to study the hardness, tensile strength, and impact strength of the material. The mechanical properties obtain by various technique have been compared to one another using two different grades of S.G. Iron (one with copper and another without copper). The effect of copper has been studied.

**KEYWORDS:** Ductile iron, Tempered iron, Austempered, tensile strength and elongation.**I. INTRODUCTION**

Ductile Iron is also commonly known as “**Nodular Iron**” or Spheriodial graphite (S.G) iron was patented in 1948. With a steep rise in development work in 1950 within a decade ductile iron was extensively used in Industries as an popular engineering material. Its use in commercial application is still relevant in todayscenario.

Graphite is present as flakes in grey iron while it is present as spheroids in the ducile iron which gives it unusual combination of properties. By adding a very small, but specific amount of Mg &Ce or both to molten iron of proper composition this mode of solidification is obtained. Like malleable iron, Ductile Iron exhibits a linear stress-strain ratio; a considerable rang of yield strengths and as its name implies ductility. A wide range of sizeswith sections which are very thin or very thick in the castings are made by ductile iron.

By controlling the matrix structure around the graphite as they are cast or by subsequent heat treatmentthe different grades are produced. Controlling of the matrix structure as-cast to provide response to heat treatment is done by alloy addition.

In present research work, areto determine the mechanical properties and microstructure of heat treated ductile iron with two different grades, and to compare these properties with different treatment conditions.

## II. MATERIALS AND METHODS

For our work samples of ductile iron were procured from a commercial foundry, Two grades of ductile iron were used. The differences between these two grades are: one contains copper, while other was without copper. They were designated as Grade X1 and Grade X2. Chemical compositions of raw material obtained by weight chemical analysis method used in this study are given in Table 1

*Table 1 Chemical compositions of Specimens: X1 and X2*

Specimen	C %	Si %	Mn %	Cr %	Ni %	Mg %	Cu %	S %	P %
With Cu (X1)	3.53	2.0	0.17	0.02	0.23	0.036	0.47	0.008	0.021
Without Cu (X2)	3.56	2.19	0.21	0.02	0.29	0.042	0.002	0.012	0.025

14 samples from each grade were used for tensile .The specimen size should be compatible to the machine specifications: The sample that of length 120 mm and diameter 30 mm. According to the ASTM standards for a specimen the ratio of gauge diameter to gauge length should be 1:5, Hence the final shape after turning operation become as the following specifications: Gauge length -70 mm, Gauge diameter -14 mm, Total length - 90 mm, Grip diameter -20 mm.Next the sample was subjected to various heat treatment processes and was taken to a UTS machine for testing of various mechanical properties, For hardness test 14 samples from each grade were taken.The specimen of dimension 8×8×3 mm.

**Heat Treatment:**26 samples from each grade were taken in a group to homogenize the samples kept them in a muffle furnace for one hour at 900°C (austenization), afterthat, two samples from each grade were normalized by rapid cooling in still air for 30 minutes, and 2 samples from each grade quenched in oil for 20 minutes. For Temperingtreatment: After austenization, 6 samples from each grade were tempered at 300°C,450°C and 600°C for 1 hr, and for austempering, 16 of the samples from each grade were heated at 900°C for 1 hr for anstenzation and then 8 of this sample transferred quickly to a salt bath (salt combination was 50 wt % NaNO<sub>3</sub> and 50 wt % KNO<sub>3</sub>) maintained at 300°C, and the other samples to a bath of 350°C . The samples were kept in the salt baths for different times as: 0.5, 1hr, 1.5 hr, and 2.0hr.

### Tests Measurements:

**Hardness Measurement-**The heat treated samples were polished in emery 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 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.

**Tensile Testing Measurement-**Itwas carried out according to ASTM (A 370-2002). Test were conducted by using universal testing machine at room temperature (25 °C ) with strain rate of  $9 \times 10^{-3}$  up to fracture. The tensile load of 50 KN was applied to the specimen up to the breaking point.

## III. RESULTS AND DISCUSSION

**Mechanical Properties:**The mechanical properties measured by using Universal testing machine and dimensions of specimen was carried out according to ASTM (A 370-2002), are given in Table 2 and Table 3 , lists the mechanical properties of tensile strength, yield stress, elongation and hardness of ductile irons (with and without Cu)X1, X2 respectively.

**Table 2 Tensile strength, yield stress, elongation and hardness of Tempered ductile iron with and without Copper**

Treatment	Tempered ductile iron with Copper ( X1)				Tempered ductile iron without Copper (X2)			
	UTS (MPa)	Y.S (MPa)	%	H (RA)	UTS (MPa)	Y.S (MPa)	%	H (RA)
As Received	368	192	5.2	45	270	198	14.0	44
Normalized	378	195	4.3	60	275	202	7.7	68
Oil Quench	486	197	3.1	72	394	210	6.0	72
Tempered at 300 C°	426	204	7.1	69	325	215	8.8	67
Tempered at 450 C°	395	201	10.6	67	211	211	15.3	61
Tempered at 600 C°	384	198	11.1	64	279	204	14.7	59

**Table 3 Tensile strength, yield stress, elongation and hardness of Austempered ductile iron with and without Copper**

Treatment	Temp. C°	Austempered ductile iron with Copper ( X1)				Austempered ductile iron without Copper (X2)			
		UTS (MPa)	Y.S (MPa)	%	H (RA)	UTS (MPa)	Y.S (MPa)	%	H (RA)
As Received	.....	375	325	8.2	45	565	274	18	44
Austempered 0.5 Hour	300	870	648	6.1	73	822	631	6.8	71
	350	696	482	8.2	70	648	430	8.9	66
Austempered 1.0 Hour	300	1022	830	6.6	68	923	801	7.2	67
	350	881	620	8.8	63	821	571	9.6	60
Austempered 1.5 Hour	300	1017	811	6.9	63	895	722	7.7	59
	350	842	605	9.1	58	775	550	10.2	54
Austempered 2.0 Hour	300	1015	808	7.2	60	898	761	7.5	56
	350	833	590	9.3	52	790	567	10.1	50

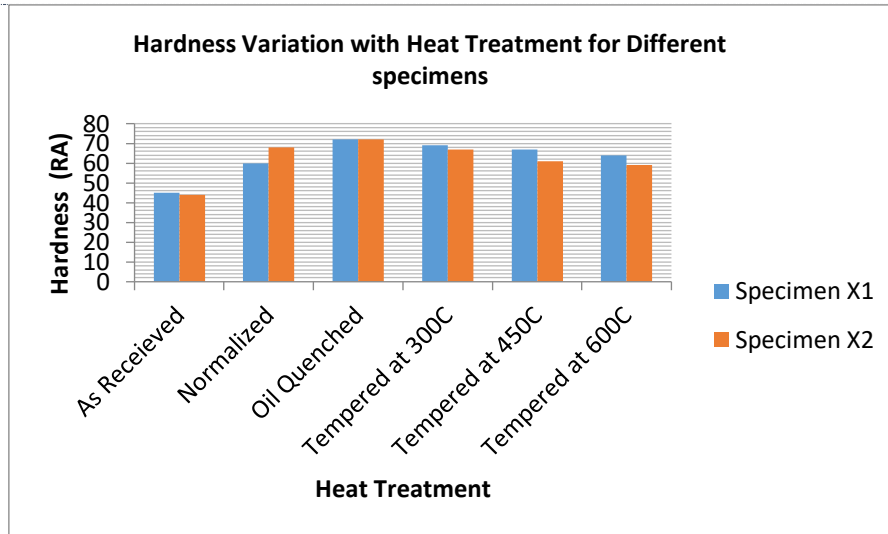
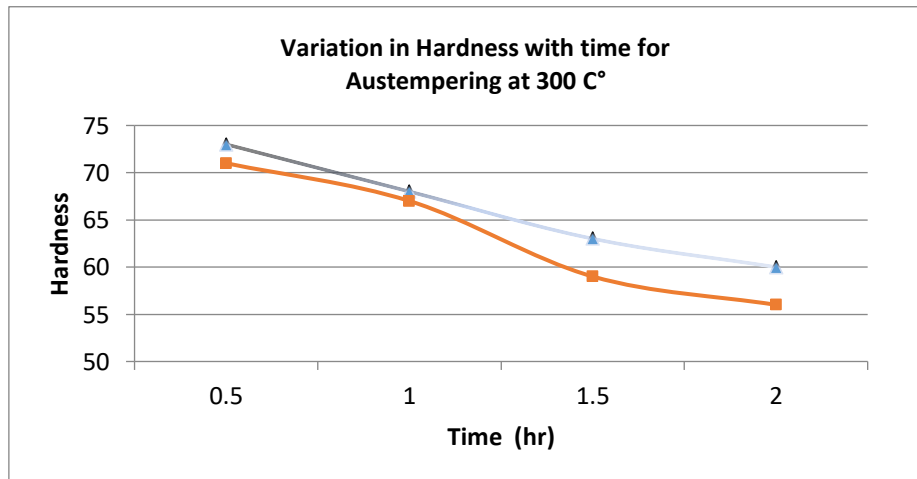
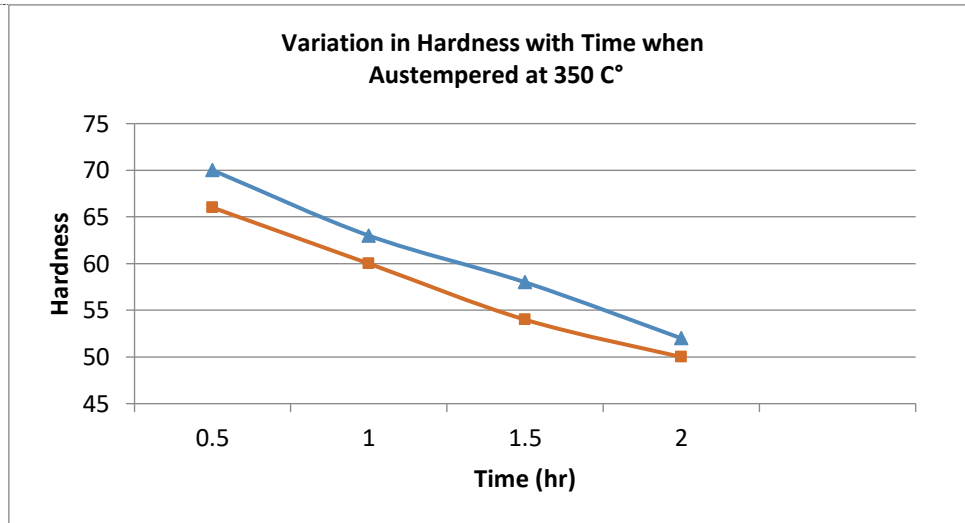


Fig 1 Variation of hardness with tempering temperature

Figure 1 shows the variation of hardness values in Rockwell Hardness “A” scale with the treatment conditions. It shows that hardness decreases as the tempering temperature increases in both cases (with Cu and without Cu additions). This is due to the transformation of martensite to tempered martensite. The hardness of martensite is due to the tetragonal structure of the martensite where carbon occupies tetrahedral voids. This structure results from the diffusion less transformation which occurs by shear mechanism. So when martensite is tempered, diffusion of C from the tetrahedral sites of the BCT structure takes place and thus the tetragonality of martensite gets reduced. Alternatively, the structure of martensite becomes less strained after holding it at a higher temperature but less than the lower critical temperature because of carbon diffusion. and, the hardness of tempered martensite is lesser than quenched martensite in both cases (with Cu and without Cu additions).



(a) At 300 C°

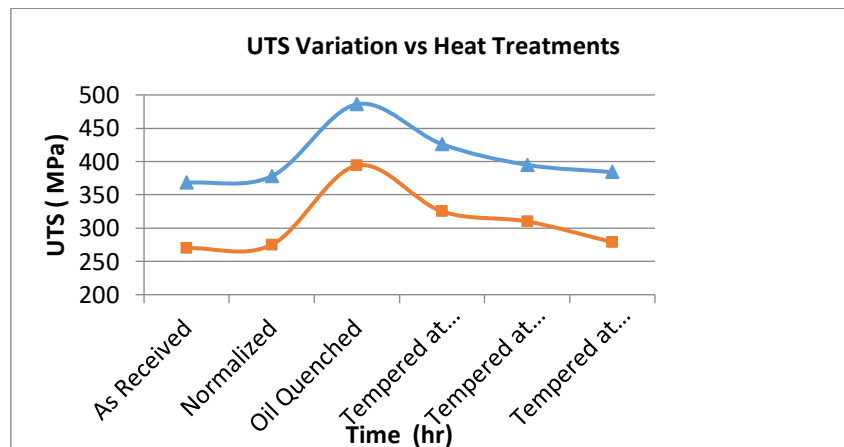


(b) at 350 C°  
 Fig 2 Variation of hardness with Austempering time

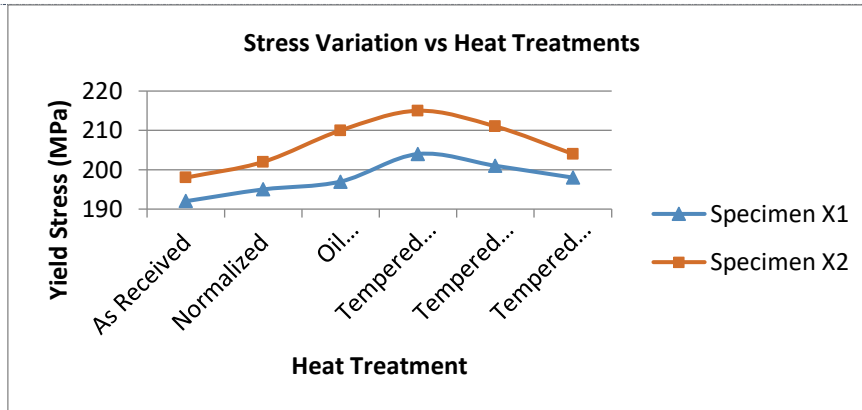
Hardness of plain ADI (X2specimen) is slightly lower than the Cu enriched ADI(X1specimen) , and hardness reduces proportionally with increase in austempering time. This decrease in hardness is due to the disappearance of martensite phase. Lower austempering time yield a finer structure and therefore higher hardness was obtained. But as the holding treatment time increased further, the hardness values were again decreased due to the occurrence of coarse plate-type structure (of bainitic) matrix phase.

**Tensile Strength and Elongation Results:**

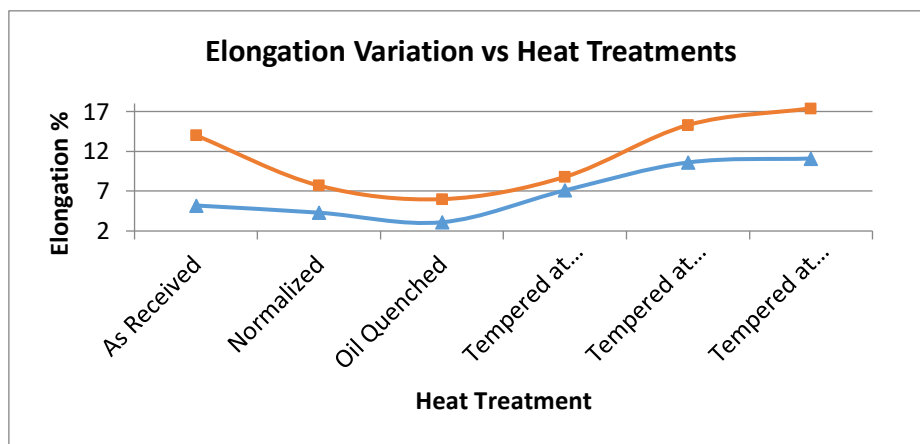
The variation of U.T.S., yield stress and elongation with temperature in the case of tempering, of two different grades are shown in figure 3 (a), (b), (c).



(a) U.T.S with treatment



(b) Yield Stress with treatment



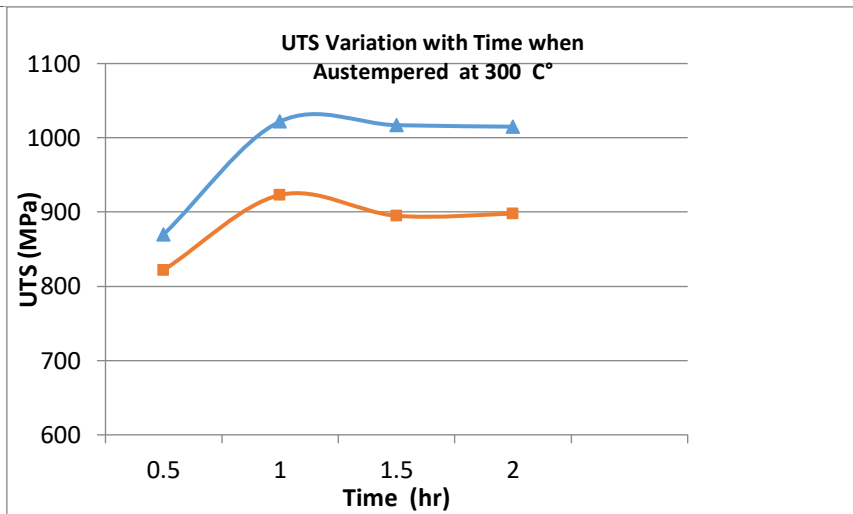
(c) Elongation with treatments

Fig 3 Variation of Tensile Properties of various grades with treatments

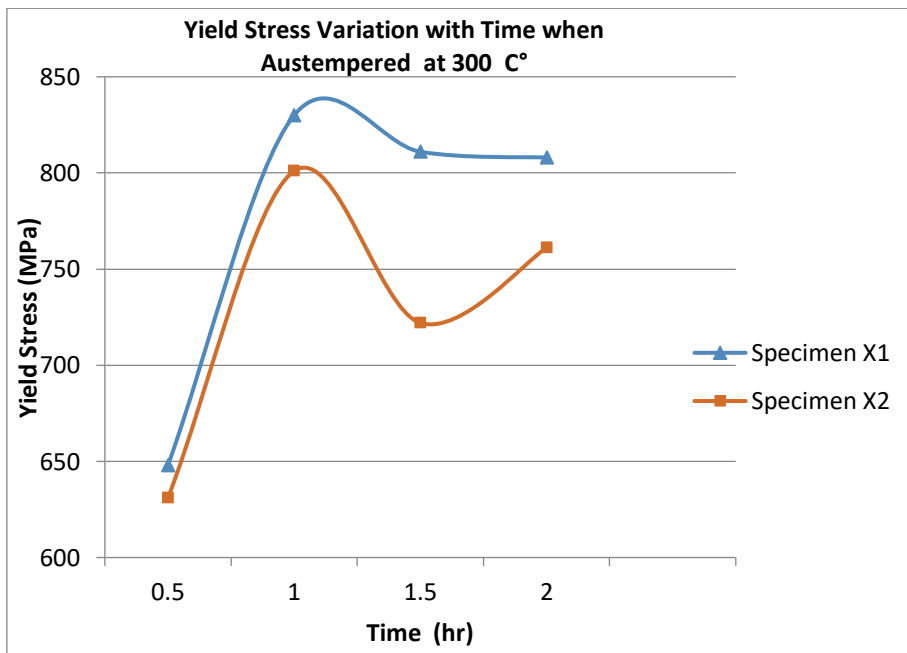
Comparing the tensile strength of two different grades of samples with different treatments, it is observed that, there is a slight change in their properties. The U.T.S of normalized samples was less than the tempered samples. The tensile properties vary with the matrix type, i.e. – pearlitic (in case of normalized samples), martensitic (in case of quenching and tempering) and bainite (in case of austempered samples) matrix. So U.T.S and yield stress for tempered treatment (from 300 C° to 600 C°) decreases but elongation increases depending on pearlite content of the matrix. Tempered samples have higher tensile properties than the normalized samples, but as the tempering temperature is increased there was a decrease in U.T.S and yield stress, as shown in fig 3 (a) and (b). The elongation of tempered samples is higher than normalized samples, because of the formation of martensite and temper martensite etc. on the other hand, the elongation increases with the tempering temperature as shown in figure 3 (c). Comparing the two grades of samples X1 and X2, shown that sample with copper (X1 grade) has higher UTS and Yield stress and lesser elongation than grade X2 for both Normalized and Tempering Treatment.

### Austempering Treatment

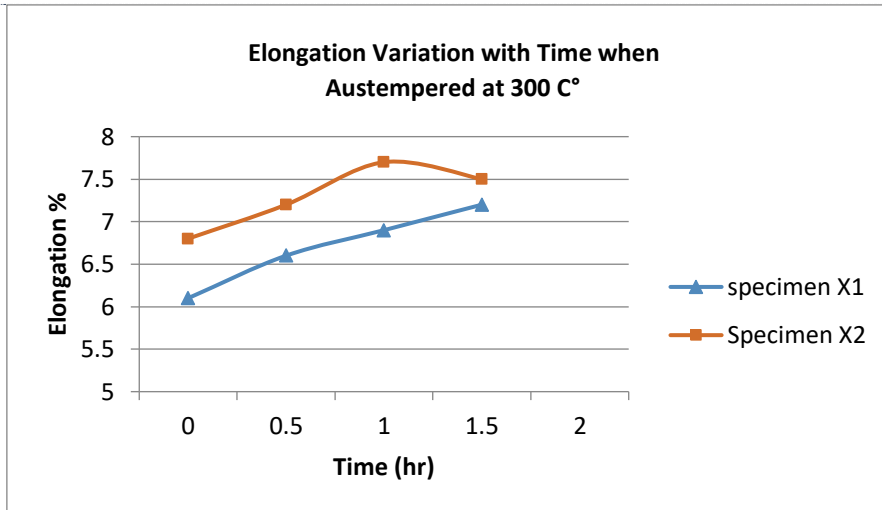
By austempering treatment, the variation of mechanical properties depends on the change in the nature and amount of transformation / formation of bainite phase. This properties summarized in Table 4.4 and Table 4.5, and figures : 4.4 (a),(b),(c) and 4.5 (a),(b),(c), which shows the variation of tensile strength with respect to the austempering time at temperature 300 C° & 350 C° respectively for grades X1 and X2.



(a) UTS with Austempered Time

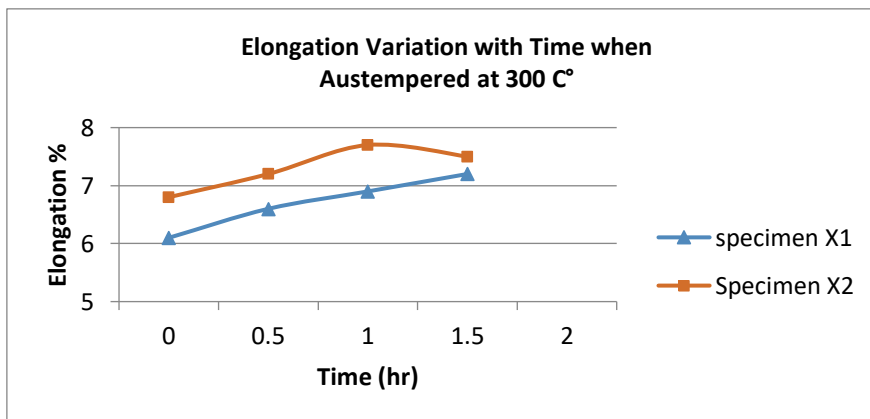


(b) Yield Stress with Austempered Time

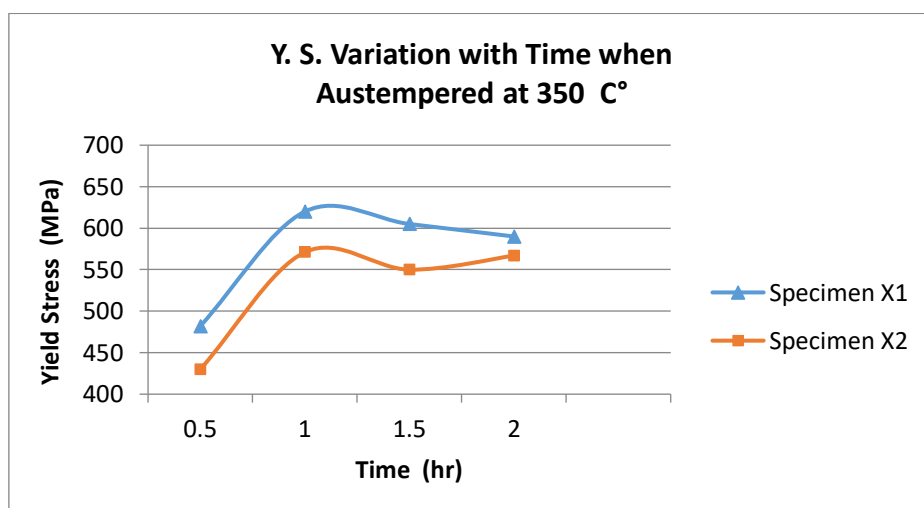


(c) Elongation with Austempered Time

Fig 4 Variation of Tensile Properties of various grades with Austempering time at 300 C°

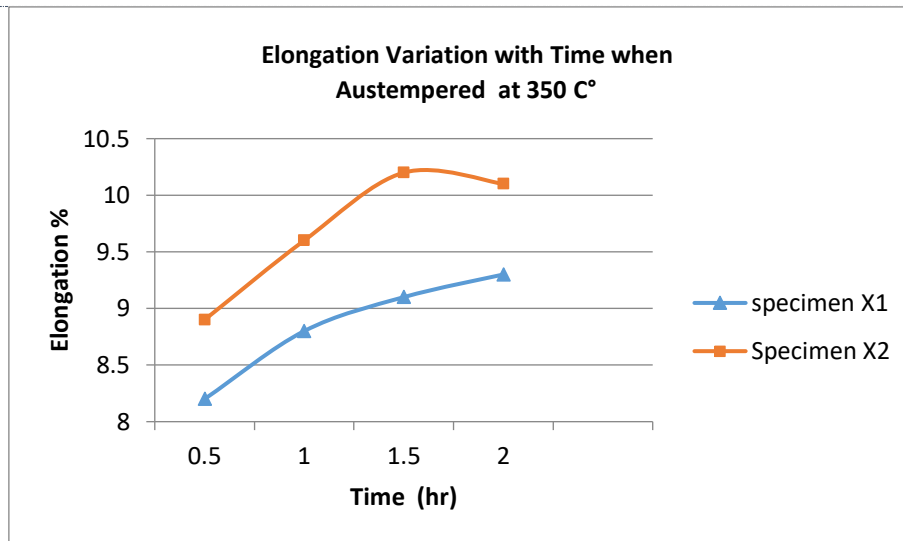


(a) UTS with Austempered Time



(b) Yield Stress with Austempered Time





(c) Elongation with Austempered Time

Fig 5 Variation of Tensile Properties of various grades with Austempering time at 350 C°

At lower austempering times, the Tensile strength is increasing initially from 0.5 hr to 1 hr, then from 1 hr to 2 hr decreases slightly for both grade, and with further increase in treatment time attains a steady state, as shown in fig4(a) and (b). The increase in strength initially at low time interval is due to the high amount of martensite derived from the unreacted austenite, but as the time increase above one hour the first stage reaction commences in the intercellular regions for which strength decreases. And as the time increases further, the retained austenite reduces, and ductility again increases with time. So ductility increases further to a maximum value; that indicates the tolerable amount of martensite. The sample alloyed with copper(X1) has increased ductility and lesser strength than that sample without copper content(X2)

Elongation for Austempered Ductile Iron (ADI) is increasing from 0.5 hr. to 1.0 hr. but with slight decreased from 1.0 hr. to 2.0 hr. as shown in figure 4.c and 5.c, which also shows that (ADI) with copper (X1) is lower of that grade without copper (X2) with small amount. Comparing the tensile strength with respect the austempering temperature for both grades from table 3, it is found that tensile strength is decreasing with increasing austempering temperature but elongation is Increasing. Also the sample with copper (X1) has higher ductility and lesser strength than that sample without copper content(X2).

#### IV. CONCLUSION

The effect of three different heat treatment processes: Normalizing, Quenching - Tempering and Austempering on hardness, tensile properties and Microstructure of Ductile Iron were studied in this thesis, also, the effect of copper on the microstructures and mechanical properties.

**For Quenching and Tempering heat treatment cycle**, we observed the following Experimental Observation:

1. Ductility of the both samples (with and without copper) increase with increase in tempering temperatures but the hardness and strength were decreasing.
2. Samples with copper were having more values of strength and hardness, while ductility was found to be more for the sample without copper.
3. The microstructure in as cast condition shows the pearlitic matrix with graphite nodules in both grades of samples, while after quenching and tempering the matrix converted into the martensite and tempered martensite. Thus, the strength and elongation was increased in tempered samples, but hardness decreases.

**For Austempering heat treatment cycle**, we observed the following Experimental Observation:

1. For both samples, the tensile strength initially increases and then decreases with the increase of time in Austempering Process.
2. With the increase of time in Austempering Process (for both samples), elongation first decreases and then increases.

3. The hardness values normally decreases with the increase of time in austempering process for both samples.
4. The strength and hardness values for the sample with copper are more while ductility was found to be more for the sample without copper.
5. The microstructure was ausferrite or bainitic ferrite and retained austenite with graphite

Nodules embedded in it for all periods of time. But, the morphology of bainite was changed from needles to plate like structure as the austempering time increases. So, the strength and hardness decreases with time and ductility.

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