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Paper on the Effect of Copper on Austempering Behavior of Ductile Iron: A Review

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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. Large 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 produced by an isothermal heat treatment of the ductile iron. The formed austempered ductile iron is now replacing steel in many fields so it has becoming very important to various aspects of this material. In this work the effect of copper along with the process changes the properties and microstructure of ductile iron is studied. With changing austempering time hardness, tensile strength and elongation are changes but with increasing austempering temperature hardness and tensile strength are decreasing and elongation increasing. Austempered ductile iron with copper is very hard and lower elongation than the austempered ductile iron without copper. In microstructure ferrite is change with change austempering time and austenite is increasing with increasing austempering temperature in both the grades.**

Index Terms:- Production of ductile iron by the austempering process and shows the important effect when copper is added on it.

INTRODUCTION

A ductile iron which undergoes heat treatment process austmpering is known as austempered ductile iron (ADI). These properties of Austempered ductile iron is formed by the particular heat treatment so the only necessity for austempered ductile iron is better ductile iron.Ductile Cast Iron undergoes a noticeable change when subjected to the austempering heat process. The change in microstructure grain size is known as "Ausferrite", which consist of fine acicular ferrite with carbon enriched stabilized austenite and gives ADI its special attributes. The new microstructure formed is superior to many traditional, high performance, ferrous and aluminium alloys. Ausferrite consist two times 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 based on the ausferrite microstructure size. The austepmered matrix is responcible for significantly better tensile strength to ductility ratio than is possible with any other grade of ductile iron.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.

REVIEW

Cast irons are basically alloys of iron and carbon like steels but contain greater amount of carbon. Cast irons contain between 2 and 6.67% of carbon. High carbon content tends to make the cast iron very brittle and most commercially Manufactured types are in the of 2.5 to 4% carbon. The ductility of cast iron is very low. They melt fastly and can be cast into typical shapes. Since casting is the process applied on these alloys, they are known as cast irons. By proper alloying as well as good foundry control and appropriate heat treatment, the properties of any type of cast iron may be varied over a wide range. The properties of the cast iron will greatly affected by the shape distribution of the free carbon particles. The cast irons are brittle, have lower strength properties and can be cast more rapidly than most steels. White cast iron, malleable cast iron, gray cast iron, nodular cast iron and alloyed cast iron are different type of cast irons.

1. Ductile iron

If the coke is not used for melting the iron and if high purity ores are used then ductile iron would have been accepted as normal form of iron. Ductile iron is also termed as nodular iron, spheroidal graphite iron and spherulitic iron in which graphite is present in tiny balls or spheroids. Because of the graphite is in the form of roughly spherical, which gives these materials their name and ductility significantly improved so alternative name is ductile cast iron. The properties like castability, corrosion resistance, machinability and abrasive resistance are similar to the flake graphite grades but tensile elongation as high as 17%.

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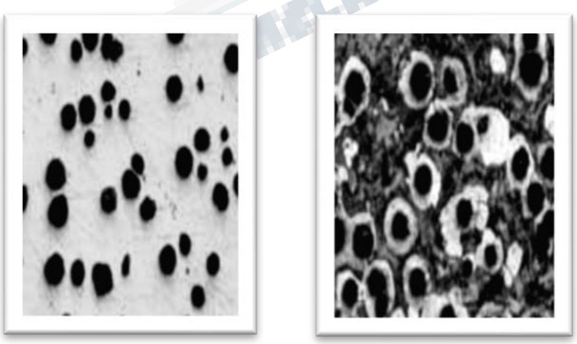
2. Production of SG Iron

SG Irons are produced directly by the solidification of a melt containing sufficient silicon to ensure graphite formation, after careful removal of sulphur and oxygen. Magnesium additions to the bath tie up sulphur and oxygen and radically change the graphite growth morphology. Magnesium reacts with the oxygen to form highly stable MgO, which floats to the surface and can be skimmed off. The oxygen content is reduced from typical levels of 90-135ppm to about15-35ppm. Magnesium also reacts with the sulphur to produce MgS which again floats to the bath surface, but less stable than the oxide. Since magnesium has low solubility in the metal and is volatile, the reactions can become reversible if losses are too great. Other elements from groups 1A, 11A and 111A can be also being employed to tie up oxygen and sulpher. In particular cerium forms highly stable oxides and sulphides and less volatile than magnesium, with which it is used in combination. Some of the inclusions formed by the inoculants act as nuclei for the graphite and are found at the center of the nodules. The simplest explanation of the spherodising effect of inoculants such as magnesium is that oxygen and sulphur are absorbed preferentially on the hexagonal planes of graphite, leading to the lamellar morphology. The removal of sulpher and oxygen by the inoculants allows more isotropic growth. A careful choice of alloying additions is used to appropriately adjust the deoxidation, graphitizing and nucleation effects.

3. Structure

The main difference between ductile iron and grey iron is the morphology of graphite particles which take on a nodular or almost spherical form after suitable treatments are made to the melt. The major micro structural constituents of ductile iron are: the chemical and morphological forms taken by carbon, and the continuous metal matrix in which the carbon and/or carbide are dispersed. The following important microstructural components are found in ductile iron.



(a) (b)

Fig 3.1.Mirostructure of ductile iron (a) unethed (b) nital etched

4. Austempered Ductile iron (ADI)

ADI, the most recent addition to the ductile iron family, is a sub-group of ductile iron produced by giving conventional ductile iron a special austempering heat treatment. Nearly twice as strong as pearlitic ductile iron, ADI still retains high elongation and toughness. This combination provides a material with superior wear resistance and fatigue strength.

5. Factor affects the properties of the ductile iron

Ductile iron is a special kind of material which exhibits a good combination of strength with ductility ensuring its huge application in heavy

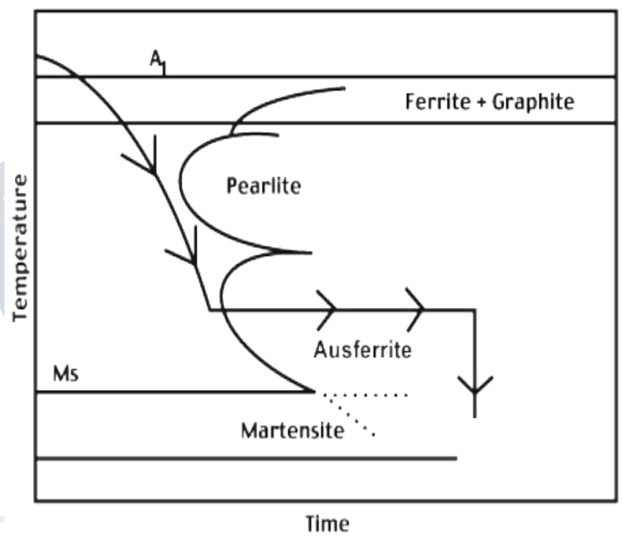


Fig.5.2. Control of time and temperature on the process.

engineering industries. This is due to very typical microstructure owing to its chemical composition, heat treatment practice and processing variables. Some lists of important constituents which are responsible for its typical mechanical properties are discussed below.

6. Effect of graphite shape

As would be expected from the dramatic differences in mechanical properties between Gray and Ductile Irons, that modularity plays a significant role in determining properties within the Ductile Iron family. The relationship between modularity and Dynamic Elastic Modulus not only emphasizes the strong influence of modularity on DEM, but also indicates that DEM values obtained by sonic testing can be used to measure modularity (graphite volume and nodule count should be relatively constant).

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7. Austempering

The austempering process was first developed in the early 1930‟s as a result of work that Bain, et al, was conducting on the isothermal transformation of steel. In the early 1940‟s Flinn applied this heat treatment to cast iron, namely gray iron. In the 1950‟s, both the material, ductile iron, and the austempering process had been developed.

8. Process

1) Heat castings in a molten salt bath to austenitizing temperature (815-927Oc)
2) Hold at austenitizing temperature to dissolve carbon in austenite.
3) Quench quickly to avoid pearlite.
4) Hold at austempering temperature (232-4000C) in molten salt bath for isothermal transformation to ausferrite.

9. Consistent control of times and temperatures throughout the entire process

Initial austenitizing times and temperatures (1550° to 1700° F.) are controlled to ensure formation of fine grain austenite and uniform carbon content in the matrix. The precise temperature is grade dependant.

1. Quench time must be controlled within a few seconds, to avoid formation of pearlite around the carbon nodules, which would reduce mechanical properties. Quench temperatures (450° to 750° F.) must stay above the point of martensite formation.
2. The austempering step which follows austenitizing, the temperature of the final salt bath must also be closely controlled. The austempering step is also precisely time-controlled, to avoid over- or under-processing. By the end of this step, the desired ADI ausferrite structure has developed.

10. Austenitizing

The austenitizing temperature controls the carbon content of the austenite which, in turn, affects the structure and properties of the austempered casting. High austenitizing temperatures increase the carbon content of the austenite, increasing its hardenability, but making transformation during austempering more problematic and potentially reducing mechanical properties after austempering.

Ref. Grade	ASTM A897 Grade	Tensile Strength	Yield Strengths	Elongation	Brinell Hardness
1	130-90-09	130,000 p.s.i.	90,000 p.s.i.	9%	269 - 341
2	150-110-07	150,000 p.s.i	110,000 p.s.i	7%	302 - 375
3	175-125-04	175,000 p.s.i.	125,000 p.s.i.	4%	341 - 444
4	200-155-02	200,000 p.s.i	155,000 p.s.i.	2%	388 - 477
5	230-185-1	230,000 p.s.i.	185,000 p.s.i.	1%	402 - 512

Table2.1. Grades of austempered ductile iron

of the silicon content, which has a significant effect on the upper critical temperature of the Ductile Iron. Austenitizing time should be the minimum required to heat the entire part to the desired austenitizing temperature and to saturate the austenite with the equilibrium level of carbon, (typically about 1.1-1.3%). In addition to the casting section size and type, the austenitizing time is affected by the chemical composition, the austenitizing temperature and the nodule count.

11. Austempering

Austempering is fully effective only when the cooling rate of the quenching apparatus is sufficient for the section size and hardenability of the component. The minimum rate of cooling is that required avoid the formation of pearlite in the part during quenching to the austempering temperature. The critical characteristics are as follows:
• Transfer time from the austenitizing environment to the austempering environment
• The quench severity of the austempering bath
•The maximum section size and type of casting being quenched
• The hardenability of the castings
•The mass of the load relative to the quench bath.

The use of a correctly designed austempering system with a suitably high quench severity, and the correct loading of castings, can minimize hardenability requirements of the casting resulting in significant savings in alloy costs.

12. Austempered ductile iron

Austempered ductile iron is the most recent addition of the ductile iron family. It is produced by giving conventional ductile iron to austmepering heat treatment. Unlike conventional "as-cast" irons, its properties are achieved by heat treatment, not by specific addition. Therefore the only prerequisite for a good ADI is a quality ductile iron.

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12.1. Microstructure

Ductile Cast Iron undergoes a remarkable transformation when subjected to the austempering heat process. A new microstructure (ADI) results with capability superior to many traditional, high performance, ferrous and aluminum alloys.

12.2. Composition

In many cases, the composition of an ADI casting differs little from that of a conventional Ductile Iron casting. When selecting the composition, and hence the raw materials, for both conventional Ductile Iron and ADI, consideration should be given first to limiting elements which adversely affect casting quality through the production of non spheroidal graphite, or the formation of carbides and inclusions, or the promotion of shrinkage.

12.3. Properties of ADI Compared to Steel:

- ADI is much easier to cast than steel
- ADI is approximately 9% lighter than steel
- ADI has minimal draft requirements compare with steel forgings
- ADI loses less of its toughness than steel at sub-zero temperatures
- ADI work hardens when stressed
- ADI has more damping capacity than steel.

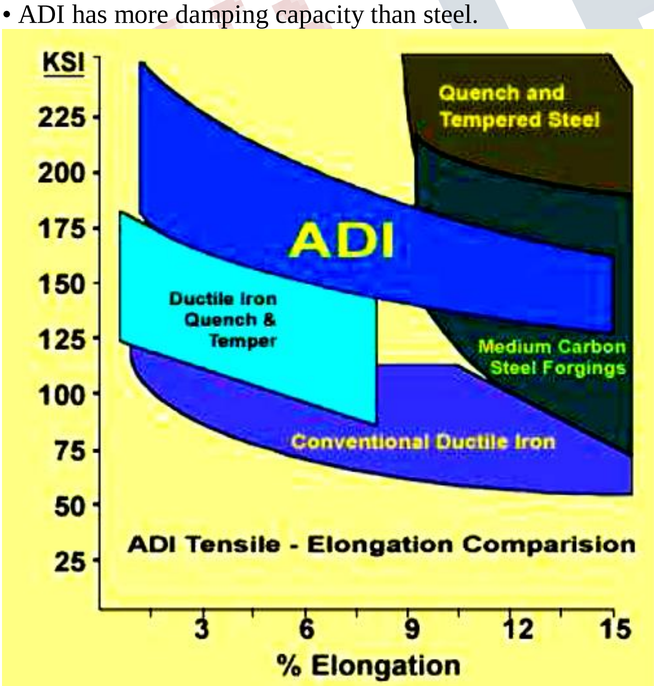

Fig12.1.Properties of ductile iron compared steels.

12.4. Disadvantages of ductile iron

Materials specifiers should look beyond limited mechanical property data when replacing steel parts with ADI. For example, welding is not recommended for ADI parts. In some instances, the stiffness of the design must be increased to compensate for ductile iron's lower modulus of elasticity. Also, larger fillet radii are required than for steel to avoid stress concentrations. To take maximum advantage of ADI when substituting for forgings, some designs should be modified.

12.5. Applications of austempered ductile iron

The development and commercialization of Austempered Ductile Iron (ADI) has provided the design engineer with a new group of cast ferrous materials which offer the exceptional combination of mechanical properties equivalent to cast and forged steels and production costs similar to those of conventional Ductile Iron. In addition to this attractive performance: cost ratio, ADI also provides the designer with a wide range of properties, all produced by varying the heat treatment of the same castings, ranging from 10-15% elongation with 125 ksi (870 MPa) tensile strength, to 250 ksi (1750 MPa) tensile strength with 1-3% elongation.

13. Heavy Truck and Bus Components

Economic growth drives the need to haul heavier loads over longer distances, resulting in more time between vehicle maintenance and some difficult engineering challenges. The Heavy Truck industry recognised the potential benefits of Austempering solutions many years ago.

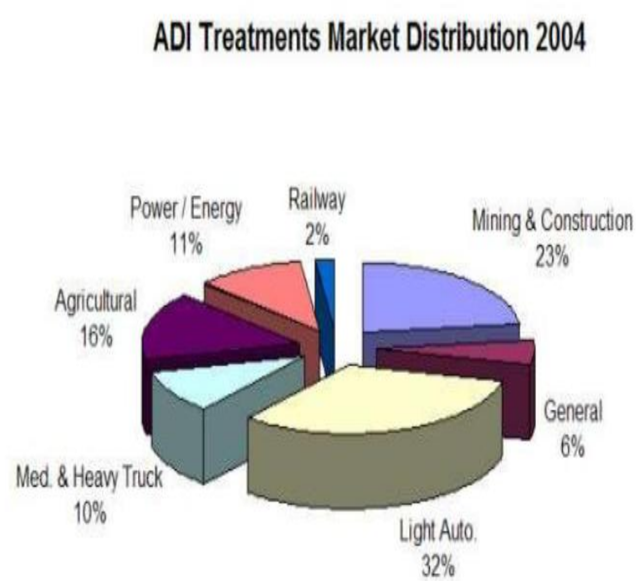

Fig 13.1. ADI market distribution.

14. Railway
The Railway industry is constantly looking to improve its products and the safety and efficiency of rail transport. The railroad industry uses ADI for suspension housings, top caps and friction wedges, track plates, repair vehicle wheels, nipper hooks, and car wheels.

15. A BRIEF DISCUSSION
Form the available literatures, it is quite evident that many attempts were made to understand and predict the behaviors of austempered ductile iron that includes the study of ausferrite matrix structure and the response of matrix structure to heat treatment, structure and properties correlation, and its mechanical properties with different variables and possible applications. A brief review of some literatures in these areas is presented here under. 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.
Uma Batra, S.Ray and S.R.Prabhakar studied The effect of austempering temperature and time on tensile properties such as 0.2% proof stress, ultimate tensile strength (UTS), percentage of elongation, and quality index and these properties have correlated with the structural parameters of the austempered ductile iron microstructure. For that they have a ductile iron containing 0.6% copper as the main alloying element was austenitized at 850 °C for 120 min and was subsequently austempered for 60 min at austempering temperatures of 270, 330, and 380 °C. The samples were also austempered at 330 °C for austempering times of 30-150 min. They concluded from there is that, In Cu-alloyed ADI, when the austempering temperature increases from 270-380 °C, the proof stress and UTS decrease due to the change in morphology of the bainitic ferrite. However, the percentage of elongation and the QI increase monotonically. The proof stress, UTS, and the percentage of elongation, as well as the QI, are relatively low at short tAs, and these values increase as the austempering process progresses.The proof stress may decrease at longer tAs, while the UTS remains, more or less, constant. Austempering the Cu-alloyed ductile iron for 60 min at 270, 330, or 380 °C resulted in an ADI close to the 1200/4, 1050/7, and 850/10 grades of ASTMA 897. The UTS and the percentage of elongation of this ADI alloy that was austempered at 330 °C fall below those specified in the ASTM standard for tAs less than 30 min; however, these properties improve for tAs of 60-150 min.
U. Batra was studied the fracture behavior of copper-alloyed austempered ductile iron using metallography and fractography. She investigated the the effect of austempering temperature on the microstructure, mechanical properties, fracture behavior under tensile and impact loading, and fracture mechanism. She concluded from their work is that when the austempering temperature is increased from 270 to 380°C, the volume fraction of retained austenite, the carbon content of the austenite, and the size of the bainitic ferrite needle increase. The morphology of the bainitic ferrite changes from lower to upper. The hardness, 0.2% proof stress, and UTS of the ADI decrease, but the impact energy increases with the increase in austempering temperature from 270 to 380°C.

16. 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).

17. Tensile Testing:
Tensile test were carried out according to ASTM (A 370-2002). A specimen of “Dog Bone Shape” shown in figure 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 (UTM 100) as per ASTM standard.

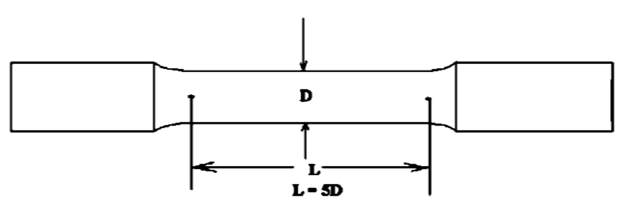

Fig.4.1. Specimen used for tensile properties

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Advanced materials are used in a wide variety of environments 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.

18. 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 methanolsolution). Then the microstructures were taken for different heat treated specimen by using Scanning Electron Microscopy (SEM).

19. 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.

20. RESULTS AND DISCUSSIONS

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.

21. Effect of autempering time on elongation

The variation of elongation with respect to the austempering time at temperature 2500C, 3000C &3500C respectively Elongation is increasing from half an hour austempering time to one hour, from.

22. Effect of austempering time on hardness

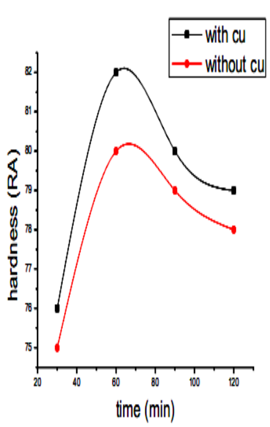

Fig 22.1

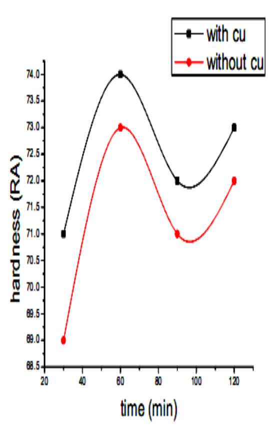

Fig22.2

Fig 22.1, 22.2& 22.3 are showing the variation of hardness with respect to the austempering time at temperature 2500C, 3000C &3500C respectively for two grades (one with copper and another without copper). Hardness 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

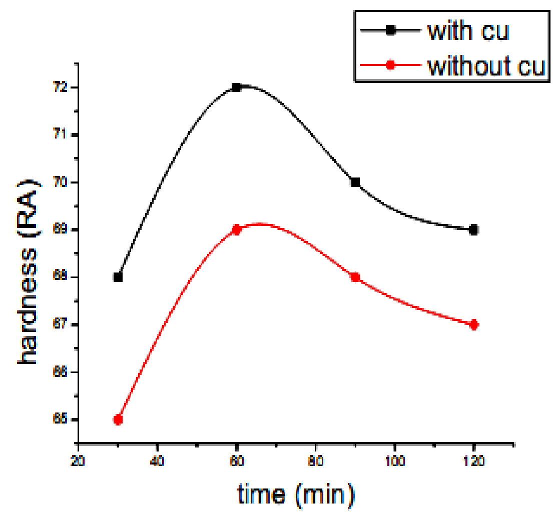

Fig 22.3

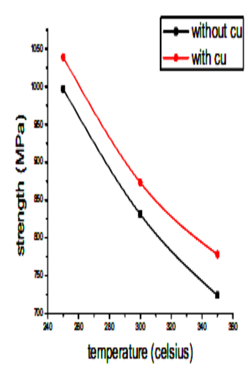

Fig22.3

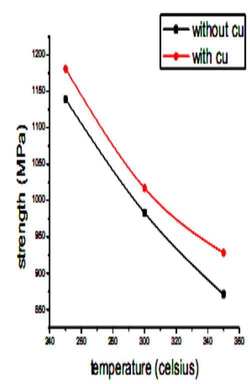

Fig 22.4

Fig 22.3, 22.4 are showing the variation of tensile strength with respect to the austempering temperature for ½ hour, 1 hour, 1 ½ and two hours respectively for both the grades (one with copper and another without copper). Tensile strength is

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decreasing with respect to the austempering temperature. i.e with increasing austmpering temperature tensile strength is decresing in both grades.

23. Effect of austempering temperature on hardness

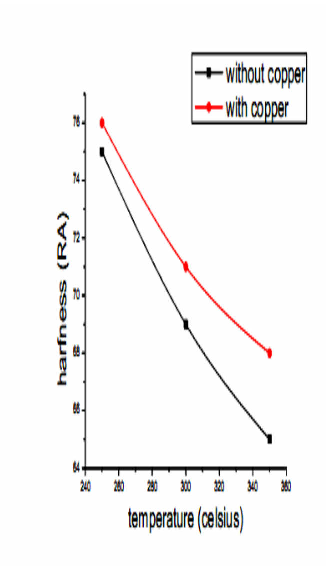

Fig 23.1

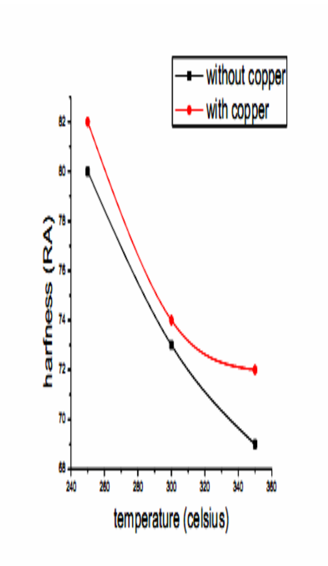

Fig 23.2

24. CONCLUSION

• 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.
• As the austempering time is increasing tensile strength, hardness and elongation are increasing in both the grades.
• The ductile iron alloyed with copper is showing little bit high tensile strength and hardness 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.
• 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.
• The fracture surfaces showed a mixed mode of fracture for shorter austempering time.

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