Effect of Processing Parameters on the Mechanical Properties of Alloyed/Unalloyed ADI

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ABSTRACT: Two types of Spheroidal Graphite (SG) cast iron samples with different weight percentage of copper were austempered at four different temperatures. The austempering temperatures were 200°C, 300°C, 350°C, 400°C. The effect of austempering parameters (i.e. time and temperature) on the mechanical properties of spheroidal graphite iron was investigated as a function of austempering time and temperature. XRD analysis was also carried out to study the formation of different phases during isothermal transformation at different austempering conditions. Graphite morphology was studied by SEM. It was found that both the austenite (111) and ferrite (110) lines could be identified nearly in all cases. The maximum intensity of the austenite (111) line is increasing with increasing temperature but ferrite (110) line is increasing with increasing austempering time and decreasing with austempering temperature. Hence austempering calls for very precise control of process variables (austempering time and temperature). It has been found from the result that ADI having the alloying element copper (grade N2) achieved significant mechanical properties as compared to other grade (N1) throughout the different austempering process adopted in this study.

Keywords: S G Iron, Austempering, XRD, SEM Analysis.

1. INTRODUCTION

In recent years, there has been an appreciable importance in energy saving which has led to the development of light weight, durable and cost effective materials. For these purposes, there is a requirement to continually generate new materials and checkout those already in account. One such material is ductile iron. Research efforts on this material, have mainly, focused on possible development of mechanical properties by subjecting it to appropriate heat treatment and by alloying. Ductile Cast Iron undergoes a remarkable transformation when subjected to the austempering process. The obtained microstructure, known as "Ausferrite", which consist of fine acicular ferrite with carbon enriched stabilized austenite[1] and gives ADI its special attributes. The new microstructure (ADI) results in properties superior to many traditional high performance ferrous and aluminium alloys. Ausferrite has strength twice the strength for a given level of ductility compared to the martensitic, pearlitic, or ferritic structures formed by conventional heat treatments. The mechanical properties of the austempered ductile iron are depending on the ausferrite microstructure. The austepmered matrix is responsible for significantly better tensile strength to ductility ratio and is more than any other grade of ductile iron.[2] The present investigation is to find out the effect of austempering process on the mechanical properties of the spheroidal graphite iron and to characterize the graphite morphology during different austempering process (i.e., different austempering temperature and time).

2. EXPERIMENTATION

Two different grades of nodular iron samples were used in the present investigation which was produced in a commercial foundry. The major difference between these two grades are copper i.e. one grade contains copper (0.56 wt %) and another almost without copper. The final chemistry of the two grades of nodular iron samples are listed below.

Table 1: Chemical Composition of the Nodular Iron (wt %)

Sample	*C*	*Si*	*Mn*	*S*	*P*	*Mg*	*Cu*
N1	3.67	2.32	0.22	0.018	0.029	0.048	0.002
N2	3.65	2.28	0.23	0.016	0.032	0.052	0.56

For different tests (Tensile, hardness and metallography), the solid Y block (as per ASTM A 397) of ductile iron was cut to thickness of 20–25 mm using power hacksaw. Then the samples were machined in a lathe machine to prepare exact dimension for tensile test (14 mm dia and 70 mm gauge length) and also for hardness (10 x 10 x 55 mm) as per EN1563 specification. Samples for XRD and SEM analysis were made as per standard. The heat treated samples were polished in emery papers of different grits for hardness measurement. Rockwell Hardness test was carried out at room temperature to measure the hardness of the nodular iron specimens in A scale.

3. RESULTS AND DISCUSSIONS

3.1 Effect of Austempering Temperature and Time on Hardness

The hardness values of the samples with Cu (N2) get increased as compared to the specimens without Cu (N1) in ADI by 6 to 10 Rockwell Hardness unit in A scale (R_A) for all the austempering process adopted.

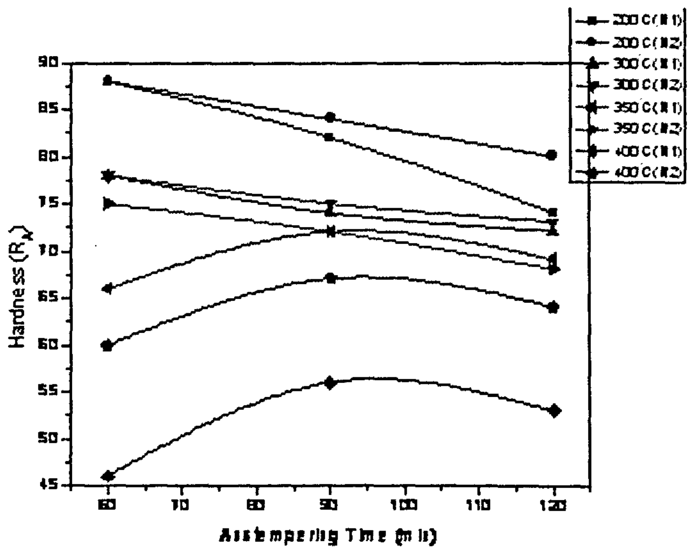

Fig. 1: Effect of Austempering Time and Temperature on Hardness

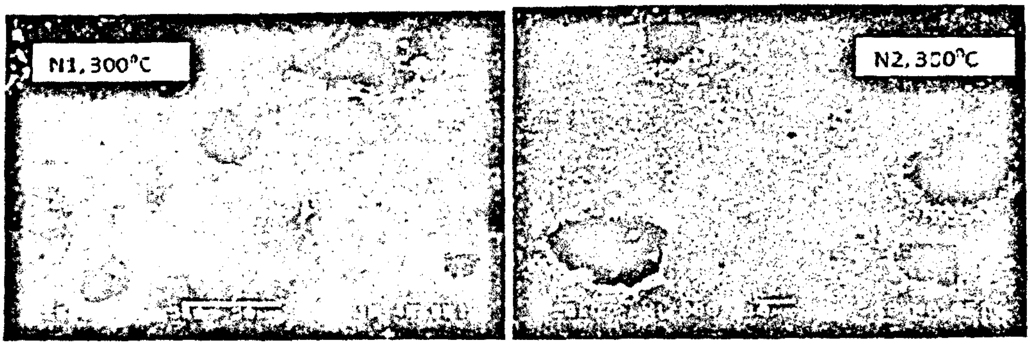

Fig. 2: SEM Micrographs of N1 and N2 austempered at 300°C for 1 hour

This enhancement in hardness over the specimen without Cu may be due to the presence of large amount of pearlite in the matrix of the specimen alloyed with Cu. Hardness is increasing up to one hour austempering time, from one hour to one and half an hour it starts decreasing and from one and half an hour to two hours sometimes increasing and sometimes increasing.

3.2 Effect of Austempering Time and Temperature on Tensile Strength

It is observed that tensile strength and yield strength of the samples with Cu (N2) gets increased as compared to the samples without Cu (N1), but Copper decreases ductility of ADI by some nominal value. As Cu is a pearlite promoter and the matrix of the ADI with Cu as the alloying element contains much large amount of pearlite but that without Cu contains large amount of ferrite. Tensile strength is decreasing with respect to the austempering temperature i.e. with increasing austmpering temperature tensile strength is decresing in both grades.

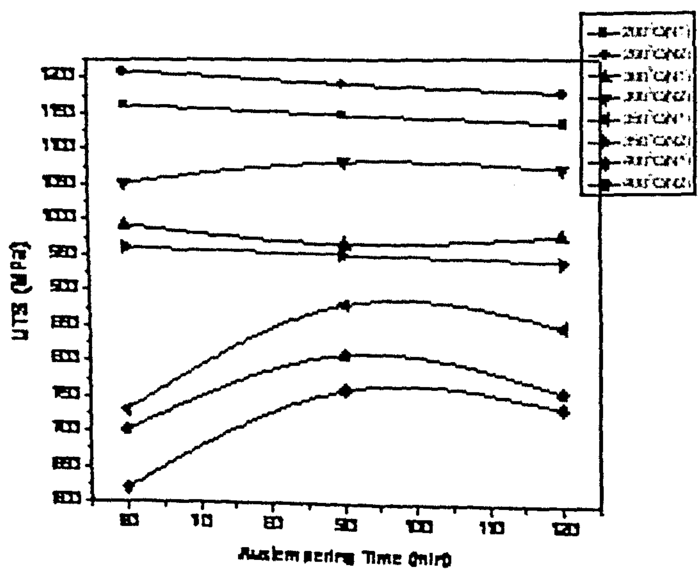

Fig. 3: Effect Austempering Temperature and Time on UTS

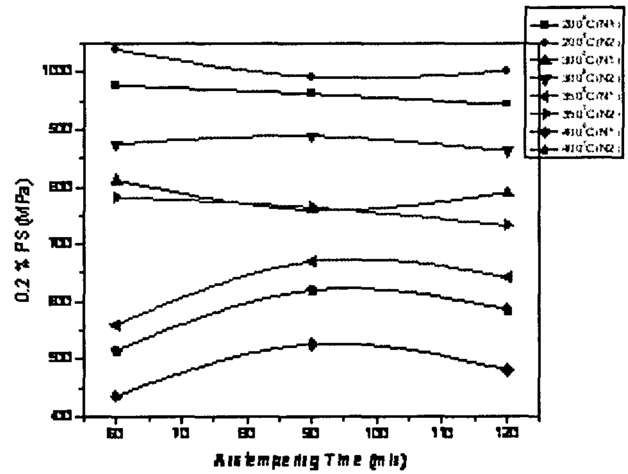

Fig. 4: Effect Austempering Temperature and Time on Yield Strength

Fig. 5: SEM Micrographs of N1 and N2 Austempered at 350°C for 60 Minutes

The hardness values, tensile strength and yield strength of Grade N2 are increased as compared to grade N1. During isothermal transformation both stage I and stage II reaction procees depending on both austempering time and temperature. The bainitic transformation in the austempered ductile iron occurs in a two stage phase transformation reaction. In the initial stage, primary austenite (γ) decomposed to ferrite (α) and high carbon-enriched stable austenite (γ_{HC}). This transformation is commonly known as the stage I reaction.[3] Mathematically it is written as,

Stage I: $\gamma \rightarrow \alpha + \gamma_{HC}$

If the specimen is hold for a longer austempering temperature, then stage II reaction proceeds, where high-carbon austenite further decomposed into ferrite and carbide.[3]

Stage II: $\gamma_{HC} \rightarrow \alpha$ + Carbide

Stage II reaction is not favorable for property enhancement of nodular iron, since it causes the embrittlement and the mechanical properties of ADI decreases. The c ε carbide is brittle which acts as a detrimental phase constituent, hence stage II reaction is always avoided in austempering process.[4]

3.3 Effect of Austempering Time and Temperature on Elongation

The lower elongation values for shorter austempering times may be attributed to the presence of martensite in the matrix of the bainitic structure. But as the austempering time increases, the amount of retained austenite increases as a result the elongation increases. This value reaches a maximum until and unless the completion of stage I reaction is completed and with the starting of stage II reaction, the ductility decreases leading to decrease in retained austenite.[5]

For smaller austempering times, as the stage I reaction proceeds, the amount of bainitic ferrite and high carbon austenite (γ_{HC}) gradually increases. But retained austenite is too less to make all the retained austenite stable at room temperature and some transformation of martensite is occured. With the increase in austempering time, the amount of retained austenite and bainitic ferrite increases till the bainitic transformation is completed, the tensile strength and yield strength and hardness is increased.[6] If austempering process is continued for longer duration, stage II reaction starts and retained austenite decomposes to bainitic ferrite and carbide which results in decrease of hardness, tensile strength and yield strength after reaching a maximum value.[7]

The increase in yield strength (YS) and tensile strength (UTS) for grade N2 (with Cu) in comparison to grade N1 (without Cu), for different austempering times(60, 90 and 120 minutes) initially increases rapidly with temperature, reaches a maximum value and then becomes constant, further increase in time and temperature, the vaues are decreasing.[8] It is observed that, above 60 minutes austempering times, the rate of increase in tensile strength initially increases with temperature and reaches some peak value at 350°C and then starts decreasing with further increase in austempering temperature. Due to the presence of coarser bainitic ferritic structure at higher austempering temperatures, the decreasing in strength may be more pronounced than the effect of pearlite matrix in in N2 grade.[4] It is observed that, at higher austempering time and temperature, the strength (YS and UTS) decreases for N2 grade specimens than N1 grade specimens.

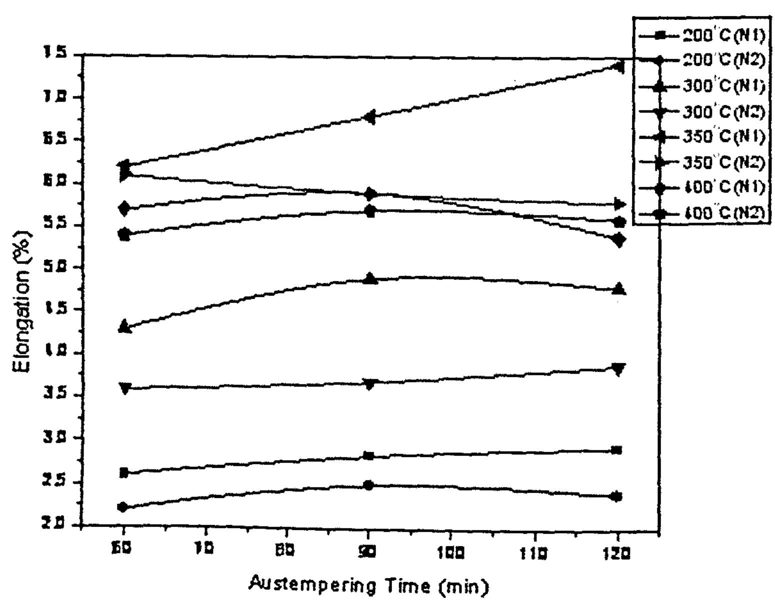

Fig. 6: Effect of Austempering Temperature and Time on Elongation

3.3 X-Ray Diffraction Analysis

The XRD pattern for ADI, which were austempered at 300°C and 350°C for 60 minutes and 120 minutes are listed below. It is observed that in both the Figures 7 (A& B), 8 and 9 the austenite (111) and ferrite (110) lines are common and easily identified. But in figure 8 both ferrite (110) and austenite (111) lines are more prominent and increases with increase in austempering temperatures.[9] The maximum intensity of the austenite (111) line increases with increasing temperature but ferrite (110) line increases with increasing austempering time and decreases with increasing temperature. It may be observed that both the austenite (111) and ferrite (110) lines are identified nearly in all cases.

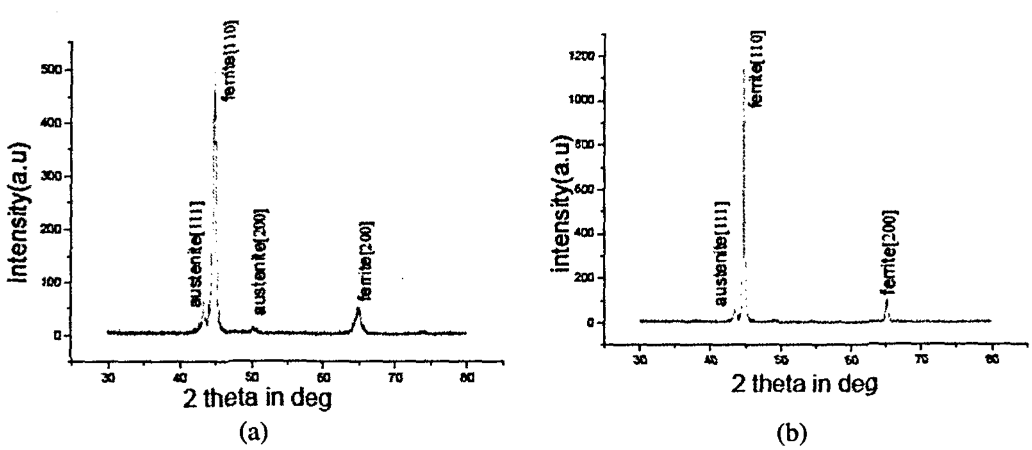

Fig. 7: XRD Pattern of ADI Austempered at 300°C for (A) 60 Minutes and (B) for 120 Minutes for Grade N1

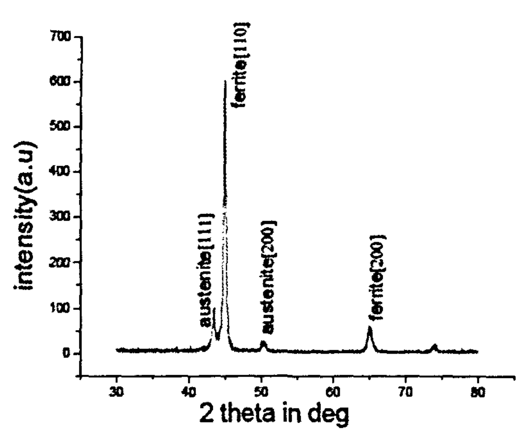

Fig. 8: XRD Pattern of ADI Austempered at 350°C for 60 Minutes

The maximum intensity of the austenite (111) line is increasing with increasing temperature but ferrite (110) line is increasing with increasing austempering time and decreasing with austempering temperature. Hence austempering calls for very precise control of process variables (austempering time and temperature).[9-10]

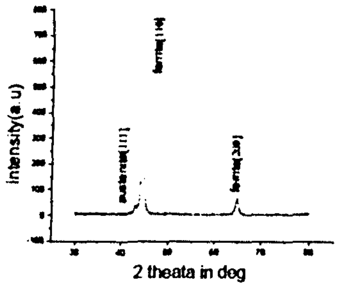

Fig. 9: XRD Pattern of ADI Austempered at 350°C for 120 Minutes

4. CONCLUSIONS

The following conclusions are made from the investigation

1. Alloying element (Cu) improves the mechanical properties (UTS, YS and Hardness) of spheroidal graphite iron after austempering. The increasing is constant with austempering time but with increasing austempering temperature it initially increases and then gradually becomes constant.
2. The ductility of ADI initially increases with austempering temperature and then after reaching some maximum value at around 350°C, it starts decreasing with further rise in temperature.

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