Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 97 (2016) 42208-42213

ISSN: 2229-712X

Tensile Property Enhancement Austempered Ductile Cast Iron (ADI) by Novel Two Stepped Austempering Process

C. S. Wadager and R. V. Kurahatti
Belagavi, Karnataka, India.

ARTICLE INFO

Article history:
Received: 16 June 2016;
Received in revised form:
29 February 2016;
Accepted: 2 March 2016;

Keywords
ADI,
Two Stepped Ausempering Process,
Tensile Properties.

ABSTRACT
Two step austempering of ductile produces unique microstructure with excellent properties like high strength, toughness, good wear resistance, machinability at low cost. ADI primarily used in high stress machine parts, gears, crankshafts. Attempt is made to study the effect of austempering time and temperature on tensile behavior of ADI. ADI yielded from two step austempering process higher ultimate yield strength with almost no change in ductility. Mode of fracture changes from brittle to ductile with increased austempering time.

1.Introduction

Austempered Ductile Iron (ADI) possesses excellent properties, such as high strength, hardness, resistance to fatigue good wear resistance with good ductility and good machinability (Ravishankar K.S. et.al., 2010). Austempered ductile iron is more applied in high stress machine parts such as gears, crankshafts, mining car wheels, railway wagon wheels, chain links, and connecting rods. (J.L. Hernandez-Rivera et.al., 2011)

Austempering of ductile iron produces a unique ausferrite or banitic microstructure, which results in excellent combination of properties (Adel Nofal, 2013) and it has been recognized as an important engineering material because of its excellent properties (S. Laino et.al., 2007). At lower austempering temperatures fine ferritic needles with relatively less amount of retained austenite are produced. This is referred to as "lower bainite". At higher austempering temperatures broad plates of ferrite with relatively large amounts of retained austenite are produced. Lower bainitic structure has high fracture toughness and high wear resistance with less ductility, where as upper bainitic structure has high tensile toughness and good ductility with less strength, so the best mechanical properties cannot be obtained by conventional austempering (Alan vasko, 2009). Therefore stepped austempering was conceived to produce ·a mixture of lower bainite and upper bainite to optimize properties (Ravishankar K. S. et.al., 2008)

2. Ductile Iron

Ductile iron is also known 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 cast ability, corrosion resistance, machinability and abrasive resistance are similar to the flake graphite

Ductile cast irons represent a success in 20th century metallurgical research. These irons were developed independently in approximately 1948 at the International Nickel Company (INCO) in the United States and at the British Cast Iron Research Association (BCIRA) in England. Both groups discovered that by keeping the sulfur and phosphorus levels low and adding very small amounts of a key chemical element, the shape of the graphite could be changed from connected flakes of gray irons into isolated spheres (usually called spheroids) of graphite. 6 The INCO team showed that the effect was produced by the addition of only 0.02 to 0.1% Mg, and the BCIRA team by the addition of only 0.02 to 0.04% C_e (the rare earth metal of atomic number 58) (Verhoeven John D, 2007).

2.1.Production of Austempered Ductile Iron

Austenitizing

The austenitizing temperature controls the carbon composition of the austenite which, in turn, influence the structure and properties of the austempered casting. High austenitizing temperatures raise the carbon content of the austenite, increasing its hardenability, but building transformation during austempering more problematic and potentially reducing mechanical properties after austempering. (The higher carbon austenite requires a longer time to transform to ausferrite).Reduced austempering temperatures generally produce ADI with the best properties but this requires close control of the silicon content, which has a significant effect on the upper critical temperature of the Ductile Iron (A. G. F.Alabi et.al., 2013).

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, (typicallyabout1.1-1.3%).In addition to the casting section type and size, the austenitizing time is impacted by the chemical composition, the austenitizing temperature and the nodule count.

Tele:
E-mail address: wadageri1969@gmail.com

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 (Alan Vasko, 2009).

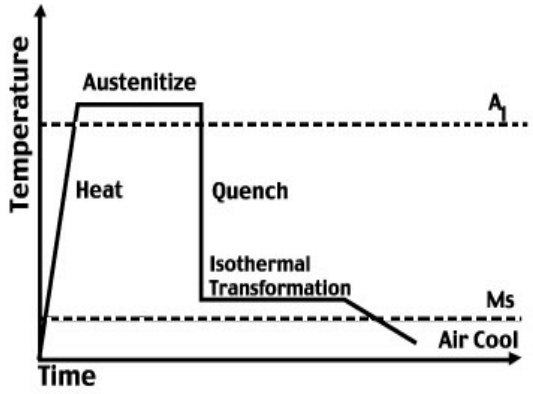

Figure Error! No text of specified style in document.**.1. Schematic representation of Austempering process.**

1) In a muffle furnace, heat the casting to austenitizing temperature (850°-900°C)

2) Maintained at austenitizing temperature to dissolve carbon in austenite.

3) Quench quickly to prevent pearlite.

4) Hold at austempering temperature (232-400oC)in molten salt bath for isothermal transformation to ausferrite (Yoon-Jun Kim et.al , 2008)

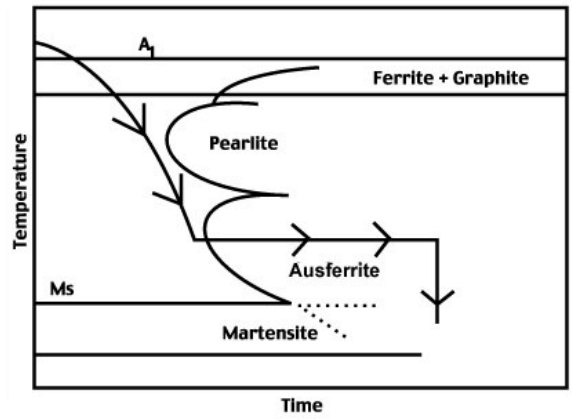

Figure Error! No text of specified style in document.**.2. Schematic representation of transformation during austempering process**

Consistent control of times and temperatures throughout the entire process was done by,

1)Initial austenitizing times and temperatures (850° to 900° C.) are controlled to ensure formation of very small grain austenite and uniform carbon composition in the matrix. The exact temperature is grade dependant.

2)Quench time should be controlled within a few seconds, top revent formation of pearlite around the carbon nodules, which would reduce mechanical properties. Quench temperature (232° to 400°C.) must stay above the point of marten site formation.

3)In the austempering stage which follows austenitizing, the temperature of the final salt bath must also be closely controlled. The austempering step is also exactly time-controlled, to prevent over-or under-processing. By the end of this step, the desired ADI ausferrite structure has developed (Darwish and R.Elliot, 1993).

4)Requires close control 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, (typicallyabout1.1-1.3%).In addition to the casting section type and size, the austenitizing time is impacted by the chemical composition, the austenitizing temperature and the nodule count (H. Bayati and Elliot, 1995). During Austempering ADI undergoes a two-stage transformation process, in the first stage, the initial austenite (γ) decomposes into ferrite (α) and high carbon austenite (γHC) If the samples are held at the austempering temperature for too long, a second stage reaction takes place and the high-carbon austenite can decompose further into ferrite(α) and carbide(ε) which is undesirable as the structure will contain carbide, which makes the material brittle ,so stage second reaction is avoided (L.C. Changa et.al., 2006)time period between the completion of the first reaction and the onset of the second reaction is termed as the process window. (Jiwang Zhang et.al., 2007).

3. Experimental Work

3.1. Material

The material used in the present investigation was ductile iron with pearlitic matrix as shown in figure 3.1 in the as cast condition. The chemical composition of the material is reported in table 3.1. The material was cast in the form of blocks of 150mm length and 125 mm width and 25mm thick.

The soundness of the casting was done by slicing the cast blocks for its porosity, nodule count, nodularity and the distribution of nodules in the matrix. The nodule count was measured using an image analyzer which resulted a nodule count of 100/mm^2 and the nodules were distributed in the matrix of the material. The porosity and other types of defects were at acceptable level.

TableError! No text of specified style in document.**.1. Composition of ductile iron specimen.**

Element	wt%
Carbon	3.48
Silicon	2.40
Manganese	0.31
Copper	0.03
Phosphorous	0.01
Sulphur	0.01
Magnesium	0.05

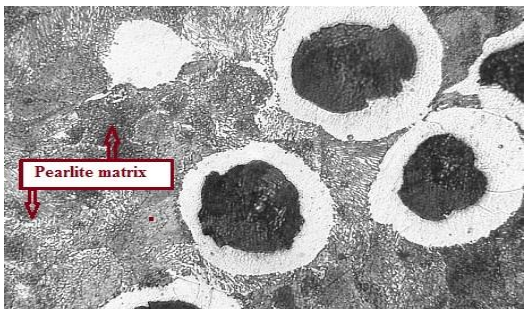

Figure Error! No text of specified style in document.**.1. Microstructure of ductile iron (optical microscopy, 500 x).**

3.2. Sample Preparation

Tensile specimens were machined from the above said cast block with a gauge length of 30mm and gauge diameter of

6mm (in accordance with ASTM-E8M standards) were prepared from the material.

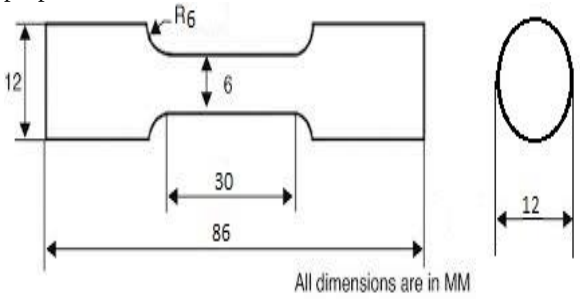

Figure Error! No text of specified style in document..**2.Tensile testing specimen.**

3.3. Heat Treatment

Tensile test specimens were initially austenitized at 900°C in an electric resistance muffle furnace for 60 minutes and subjected to two step austempering process. Two separate salt baths (containing potassium nitrate+sodium nitrate in the ratio 55:45) were maintained at temperatures 400°C and 320°C to carry out the two step austempering process. Two step austempering were carried out in different ways say two step austempering case-1 (TSA-1) and two step austempering case-2 (TSA-2). In TSA-1 austenitized specimens were initially austempered at 400°C for 30 minutes in one salt bath ,then immediately transferred to the other salt bath which was maintained at 320°C and held for 30,60 and 120 minutes. After that samples were water cooled to ambient temperature. Figure 3.3 shows the two step austempering process case-1. In TSA-2 austenitized samples were initially austempered at 320°C for 30 minutes in one salt bath, then immediately transferred to the other salt bath which was maintained at 400°C and held for 30,60 and 120 minutes. After that samples were water cooled to ambient temperature. Figure 3.4 shows the two step austempering process case-2.Table 3.2 shows the heat treatment process.

For comparison purpose, conventional austempering (CA) was done at two temperatures. In CA-1 specimens were austempered at 400 °C for 150 minutes and in (CA-2) specimens were austempered at 320°C for 150 minutes. Figure 3.5 shows CA-1 and CA-2 process. Table 3.2 shows the heat treatment process.

4. Results and Discussions

4.1. Tensile Properties

The variation of tensile properties under different austempering conditions ring (TSA-1 and TSA-2) and conventional austempering is shown in table 4.1. From the table it is clear that changing austempering conditions resulted in considerable variation in tensile properties and also the austempered samples wether conventional or twostep) showed tensile

Table Error! No text of specified style in document..**2: Heat treatment processes**

Sl.no	Austempering Process		Austenitizing		First step austempering		Second step austempering	
			Temp °C	Time min	Temp °C	Time Min	Temp °C	Time Min
1	TSA-1	1	900	60	400	30	320	30
		2	900	60	400	30	320	60
		3	900	60	400	30	320	120
2	TSA-2	4	900	60	320	30	400	30
		5	900	60	320	30	400	60
		6	900	60	320	30	400	120
3	CA-1	7	900	60	400	150	-	-
4	CA-2	8	900	60	320	150	-	-

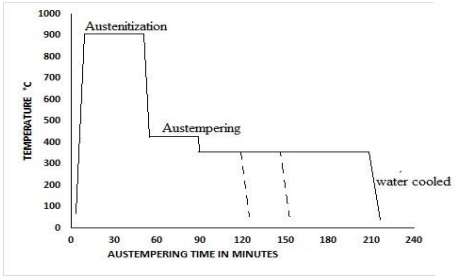

Figure Error! No text of specified style in document..**3. Schematic representation of two step austempering process case-1 (TSA-1).**

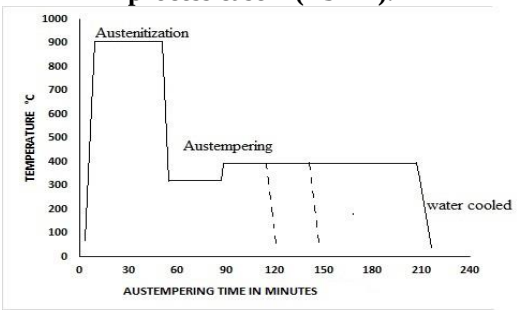

Figure Error! No text of specified style in document..**4. Schematic representation of two step austempering process case-2.**

Properties far better than as cast samples. Figure 4.1 shows the graphical representation of variation of ultimate tensile strength with austempering time.

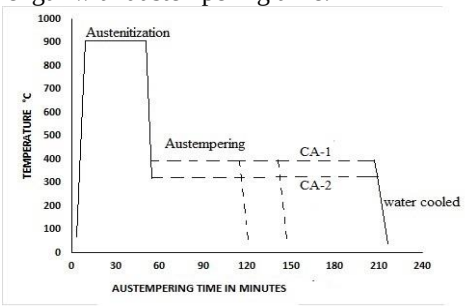

Figure Error! No text of specified style in document..**5. Schematic representation of conventional austempering process.**

Table *Error! No text of specified style in document.*.**1. Variation of tensile properties with different austempering process.**

Sl.no	Process/Material	Ultimate tensile strength Mpa	Yield Strength Mpa	Elongation %
1	Ductile iron(DI)	521	498	3.3
2	TSA-1,60 minutes	958	677	5.8
3	TSA-1,90 minutes	1072	816	4.7
4	TSA-1,150 minutes	1126	855	2.2
5	TSA-2,60 minutes	971	723	6.1
6	TSA-2,90 minutes	1018	786	5.2
7	TSA-2,150 minutes	1076	811	2.6
8	CA-1,150 minutes	976	618	5.2
9	CA-2,150 minutes	1092	822	2.1

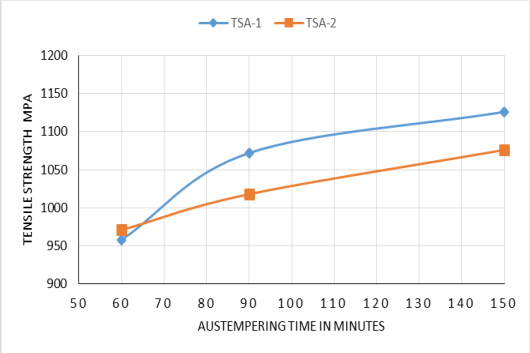

Figure Error! No text of specified style in document.**.1. Variation of ultimate tensile strength with austempering time.**

Ductile iron specimens subjected to two step austempering TSA-1 for 60 minutes contained more austenite and upper bainite which was responsible for low initial strength. After completion of the process, ultimate tensile strength of TSA-1 specimens were found to be superior to that of TSA-2 specimens. Strain hardening improved their tensile properties and strain induced martensite was observed in the microstructure of specimens subjected to both TSA-1 and TSA-2.Figure 4.2 and figure 4.3 shows SEM images of the microstructure of TSA-1 and TSA-2 specimens after tensile tests, strain induced martensite can be observed in the microstructures. Tensile propertes of specimens subjected to conventional austempering showed comparitievly lesser tensile strengths.

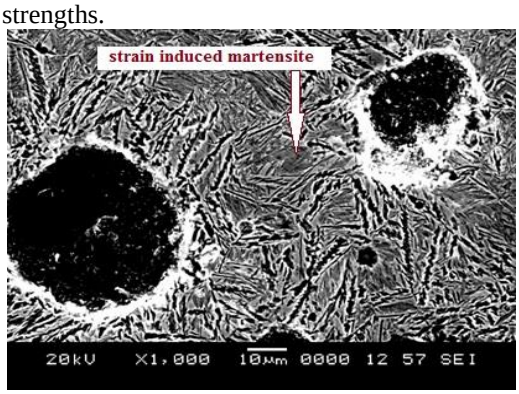

Figure Error! No text of specified style in document.**.2. SEM image of sample subjected toTSA-1 ,(400°C, 30 minutes-320°C, 30minutes)**

The trend of variation of yield strength with austempering time was shown in figure 4.4. Yield strength increased as austempering time increases this was because of the reduce of the softer austenite phase as austempering time increases. The yield strength values of the specimens subjected to TSA-1 for 150 minutes were found to be the highest.

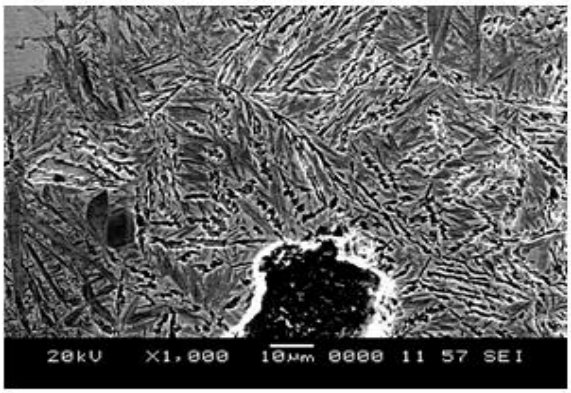

Figure Error! No text of specified style in document.**.3. SEM image of sample subjected to TSA-2,(320°C, 30 minutes-400°C, 30minutes).**

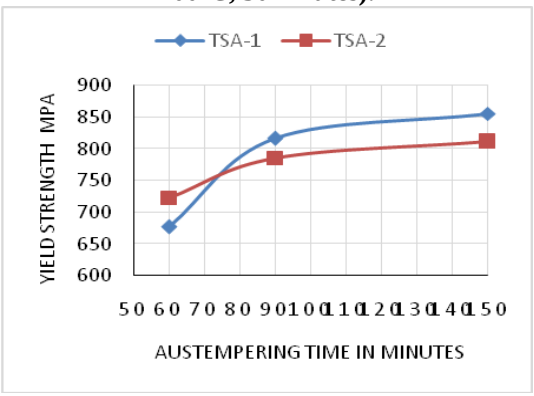

Figure Error! No text of specified style in document.**.4. Variation of yield strength with austempering time**.

Percentage elongations of the samples were calculated after tensile test and it was found to be decreasing as austempering time increases. Figure 4.5 shows the graphical representation. This was because of the reduction in austenite phase and increase of the ferrite phase and also because of the type of bainite present in it. Specimens with more of upper bainite in their microstructure possessed better elongation than that of specimens with more of lower bainite.TSA-1(60 minutes) specimens showed highest elongation of 6% .The values of elongation was 2% for the TSA-1 specimen austempered for 150 minutes.

Strain hardening exponent was calculated to determine the trend of strain hardening behavior of the specimens. Graphs of variation of log true stress with log true strain were plotted and slope of corresponding graphs gives the strain hardening exponent values. Strain hardening exponent indicates the strain hardening behavior of the heat treated samples subjected to tensile testing. Retained austenite get converted to martensite due to severe strain during tensile testing. Figure 4.6 shows variation of strain hardening exponent values with austempering time. Strain hardening exponent (n) found to be increasing as the content of retained austenite and upper bainite increases. Strain hardening exponent values decreases as lower bainite and retained austenite decreases because the retained austenite get converted into martensite during deformation. Strain induced martensite was observed in all the specimen, but more martensitic transformation was found in the TSA-1 specimens austempered for 60 minutes. In conventional austempering ,strain hardening was more for specimens austempered at 400°C.

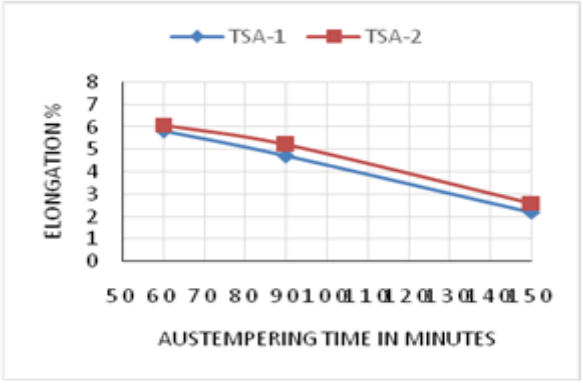

Figure Error! No text of specified style in document.**.5. Variation of % elongation with austempering time**.

From the micro structural study also, it was observed that more strain hardening occurred in the specimens with more amount of retained austenite which transformed to martensite due to severe deformation during the tension test.

The hardness values of the specimens were found to be increasing with increase in austempering time. Figure 4.7 and 4.8 shows graphical representation of variation of hardness before tension test and after tension test with austempering time.

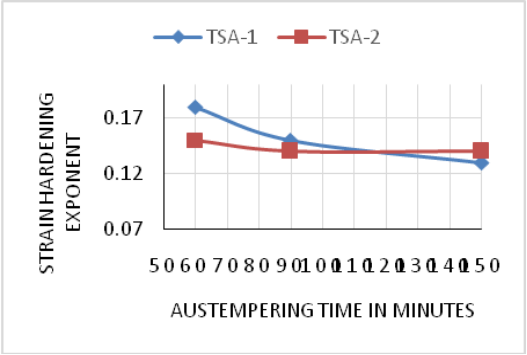

Figure Error! No text of specified style in document.**.6. Variation of strain hardening exponent with Austempering time.**

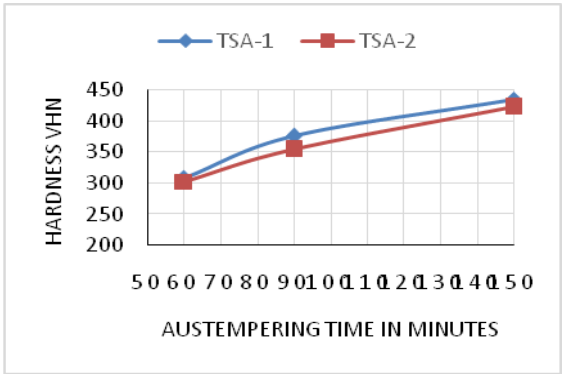

Figure Error! No text of specified style in document.**.7. Variation of hardness values with austempering time (before tension test).**

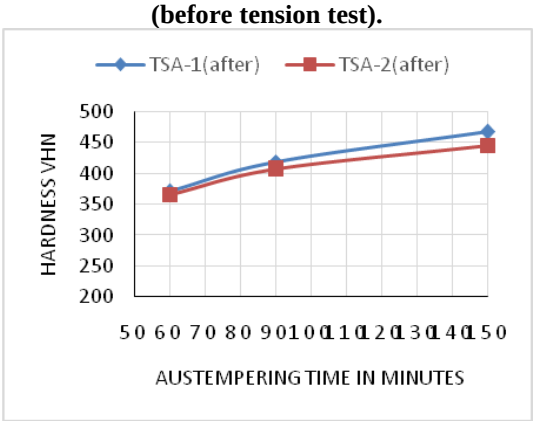

Figure Error! No text of specified style in document.**.8. Variation of hardness values with austempering time (before tension test).**

TSA-1 specimens showed higher hardness compared to TSA-2, this is because of the presence of more of lower bainite in samples. Conventionally austempered samples at 300°C showed slightly more hardness than TSA samples as it contains only lower bainite and retained austenite. The increase in hardness values was upto 21% for the specimens austempered for 60 minutes, and up to 7 % for the specimens austempered for 150 minutes. This indicates that after tensile test was strain induced martensitic formation was more for specimens austempered for 60 minutes which contained more retained austenite.

5. Conclusions

The following conclusions were drawn from the present study on the basis of micro structural studies and tensile behavior of ductile iron subjected to two step austempering and conventional austempering.

- The TSA processes show mixture of bainitic ferrite (feathery and acicular) with varying amount of retained austenite with austempering time and temperature.
- The retained austenite initially increases with increase in austempering time but reduces thereafter with TSA-1 and the same trend is true for the TSA-2 also.
- The carbon content of the retained austenite from CA2 to CA1 decreases from 1.75 wt% to 1.64 wt%. This increasing trend is true for TSA1 and TSA2.
- The hardness value is found to be higher for CA1 compared to CA2; but for TSA 1 and 2, it increases with increasing austempeting time.
- For the TSA1 and TSA2, the material possesses still higher ultimate and yield strength with almost no change in ductility.
- The mode of fracture is brittle for the lower austempering times during TSA where as it ductile for the longer austempering time during TSA
- In case of TSA, The tensile toughness was found to more or less a constant in both 1 and 2.
- The strain hardening exponent value is the indicative of the stability of austenite in the microstructure. The stability of austenite was found to be low in the microstructure where its presence is high with respect to a particular austempering process.

6. References

- A.G. F.Alabi, F. I Aluko, (2013) “Production of austempered ductile iron with optimum sulphur level for effective mechanical properties”. The International Journal of Engineering and Science (IJES), Volume 2, Issue 12, (2013), pp. 67- 71.
- Adel Nofal, (2013) “Advances in the Metallurgy and Applications of ADI” Journal of Metallurgical Engineering (ME) Volume 21.
- Alan Vasko, “Chosen factors influencing microstructure and Mechanical properties of austempered ductile iron”,(2009) Journal of Materials engineering, Vol. 16, PP 138-142
- Darwish and R. Elliot, “Austempering of low manganese ductile iron part 1 processing window and part 2 influence of austempering temperature”, (1993) Journal of material science and technology, Vol 9, PP 118-129
- H. Bayati and Elliot, “Austempering process in high manganese alloyed ductile cast iron”, (1995) Journal of material science and technology, Vol-11, PP 118-129
- JiwangZhang, NingZhang, Mintang Zhang, Liantao Lu, Dongfang Zeng and Qingpeng Song, “Microstructure and mechanical properties of austempered ductile iron with different strength grades”, (2007)Journal of Materials engineering, Vol. 23, PP 111-117
- K. S. Ravishankar, P. P. Rao and K. R. Udupa, “Improvement in fracture toughness of austempered ductile iron by two-step austempering process”, (2010)International Journal of Cast Metals Research , vol 23 no 6.
- Kathy L. Hayrynen, “The Production of Austempered Ductile Iron (ADI)”, (2002) World Conference on ADI.

- L.C. Changa, I.C. Hsui, L.H. Chen, T.S. Lui, "Effects of heat treatment on the erosion behavior of austempered ductile irons", (2006) Wear 260 , pp. 783–793.
- Ravishankar K.S, K.Rajendra Udupa and P.Prasad Rao,"Development of austempered ductile iron for high tensile and fracture toughness by two step austempering process", (2008)World Foundry Congress, pp. 35-40.
- Susil K. Putatunda, "Development of austempered ductile cast iron (ADI) with simultaneous high yield strength and fracture toughness by a novel two-step austempering process", (2001)Materials Science and Engineering A315, pp70–80.
- Verhoeven John d.,, Steel metallurgyfor the non metallurgist, (2007) p175-188
- Yoon-Jun Kim, Hocheol Shin, Hyounsoo Park, Jong Dae Lim, "Investigation into mechanical properties of austempered ductile cast iron (ADI) in accordance with austempering temperature", (2008) Materials Letters 62 , 357–360.