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# Microstructure and Tensile Characteristics of 1% Mn Content on Austempered Ductile Iron

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Abstract. The effect of high Mn content on microstructure and tensile characteristics of ADI at 320, 370 and 420 $^0$C for 2 hours has been studied. Optical studies reveal acircular bainite structure at 320$^0$C. Higher Mn content resists carbon diffusion rate in the region of Mn, where in stage II carbides starts to precipitate near graphite nodules before the completion of ferrite laths growth in the region away from the nodules generates more unreacted austenite volume with lower carbon presence turns to martensite during cooling around the periperhal shape creating austenite-martensite zone at 370 $^0$C and much more observed at 420$^0$C. Austempering at 320 $^0$C results in improvement of tensile characteristics but the presence of stage II carbides and austenite-martensite zone in the intercellular regions and due to their embrittlement construct easy crack path for initiation and propogation detoriating the tensile properties at 370$^0$C and 420$^0$C.

Index Terms- Unreacted Austenite. Austenite-Martensite Zone, Intercellular Region, Tensile Characterstics, Higher Temperature, Austempered Ductile Iron, Carbon Content

## I INTRODUCTION

The ductile iron was another class of cast iron family. By integrating the characteritics of gray iron and steel [1] .Austempered ductile iron, where its characteristics can be specially made for requiring high tensile strength, wear properties[2,3]. Collectively it is required to add Mn, Mo, Ni and Cu for delivering eligible hardenability in ADI. Mn, Cu, Mo and Ni are used in to reduce the cost in automotive industry for gears [18] and wear resistance material [10], to enlarge the use of ADI , having favourable strain hardening of austenite [3,4]. In the immense great number of these reviews depend on the conventional lower manganese idea. Increasing the manganese level can simultaneously enhance the strength and hardness of ductile iron alongside increasing retained austenite content. From the former writing it is not clearly said about affect of higher manganese content on microstrucutre and tensile characteristics of ductile iron. Along these ,ductile iron with high Mn was concentrated their study on microstructure and tensile characteristics of austempered ductile iron.

## 2 EXPERIMENTAL PROCEDURE

The alloy choosen castings was prepared in Survail castings Mangaluru ,produced in the form of slabs of dimensions 150*200*40 mm$^3$ .Chemical composition was done by using Optical Emission Spectrometer, at Gwasf quality castings, Mangaluru, India. Composition range is shown in the table 1. Austempering heat treatment was followed by austenitization at 900 $^0$C for 45 minutes. Next step is austempering heat treatment at 320, 370 & 420 $^0$C, which was carried out in a salt bath. The salt mixture consists of 55% $KNO_3$ and 45% $NaNO_3$ by weight. Etcheing was done with 2% nital solution. The microstructural characterization was done using A1TM optical microscope. JEOL JSM-6380LA SEM was also used for fracture surface analysis of fatigue samples. X-ray diffractometry (XRD) analysis was carried out using JEOL-JDX-8P X-ray diffractometer. Scan range was in between 2θ- 420 to 50$^0$ at rate of 1$^0$/min. XRD profile consisted of two peaks within this angular range namely the (111) for austenite and (110) for ferrite. Direct comparison method suggested by B.D. Cullity [20] was used to identify the respective volume fractions of austenite and ferrite. Shimadzu HMV-G 20ST micro-vickers hardness tester was used to determine hardness. Tensile specimens were followed as per ASTM E8M standards [21] testing was done on Shimadzu AG-X plus™ 100kN universal testing machine with strain rate 1mm/min.

TABLE 1

CHEMICAL COMPOSITION IN WT%.

| *Element* | % ge |
|---|---|
| *C* | 3.4 |
| *Si* | 2.7 |
| *Mn* | 1 |
| *Ni* | 1.5 |
| *Cu* | 0.6 |
| *Mo* | 0.3 |
| *Mg* | 0.04 |

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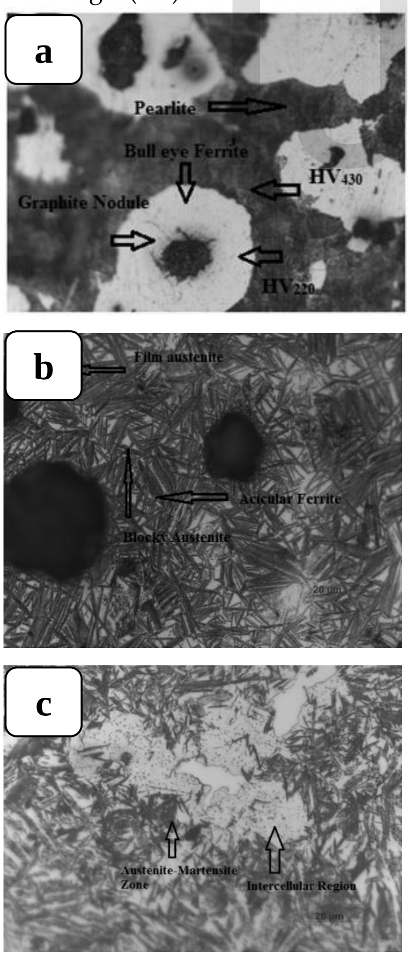
## 3 RESULTS AND ANALYSIS

### 3.1 Opitcal Microscopy

Alloying with higher Mn resulted in constant rate growth of ferrite laths by rejecting carbon to the neighbouring austenite at 320 $^0$C during austempering. As represented in fig 1 (b-d) Coarser ausferrite laths was formed at (320 $^0$C) , ferrite laths was less effective after austempered at (370 $^0$C) and (420 $^0$C) [9].Mn reduces the bainitic transformation close the intercellular regions and the carbon content in austenite. Generally higher Mn increases their segregation and reduces carbon diffusion in the region away from graphite nodules at higher temperature resulting in lesser ferrite and more of untransformed austenite volume which is observed at 370 and 420 $^0$C .

During air-cooling, unreacted austenite with low carbon content will change to martensite forming austenite-martensite zone. Mn slow down the stage I reaction in the region away from the graphite nodules compare to the graphite nodules region,so much of untransformed austenite volume obsereved in the intercellular region which was observed at higher temperatures 370 and 420 $^0$C ,so as seen in micrographs large unreacted austenite which has not completed stage I due to high Mn content [5,6,10]. Mn carbides are formed in the intercellular region above 370 and 420$^0$C shown in fig 1 (c-d).



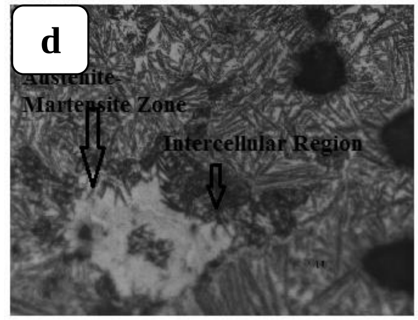




Fig. 1 Microstructure of sample (a) As-cast (b) Austempered at 320 $^0$C (c) 370 $^0$C (d) 420 $^0$C for constant duration of 120 minutes.(20µm)

### 3.2 Scanning Electron Microscopy

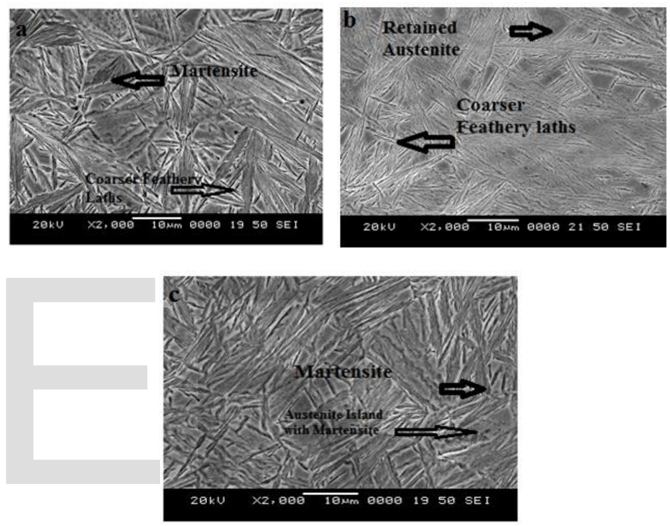



Fig. 2 SEM images of samples (a) Austempered at 320 b) 370 c) 420 $^0$C for constant duration of 120 minutes.

In fig 2 (a-c) SEM images shows the feathery ferrite laths is frequent occurance at all temperatures, with side ways growth during phase transformation. Twinned martensite is observed in figures 2 (b and c). Mn increased the retained austenite content due to their strong austenite-stabilizing effect, as well as blocky shape austenite [9]. Unreacted austenite volume carbon content decreases with increase in temperature

### 3.3 X-ray Diffraction (XRD) Studies

Table 2 shows decrease in carbon of austeinite at higher temperatures .At 320 $^0$C due to slower carbon diffusion and less effect of Mn segregation was less leading to the formation of high carbon stable austenite. Contrary situation was abound resulting in unstable/unreacted austenite with low carbon content at higher temperatures (i.e. 370 & 420 $^0$C). At 370 and 420 $^0$C the presence of more martensite on cooling at the intercellular region was confirmed with doublet peaks [11,12] .The energy for the transformation is with ($C^{-}_{\gamma}$ – $C^{0}_{\gamma}$ ). $C^{-}_{\gamma}$ concentration in austenite is estimated equations mentioned in [13]

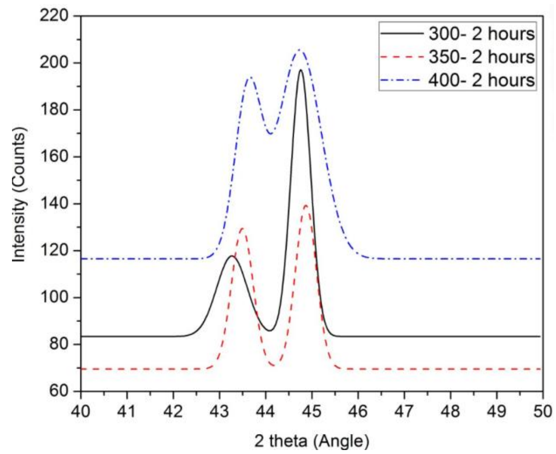



Fig. 3 Xrd profiles for sample (a) Austempered at 320 b) 370 c) 420 $^0$C for constant duration of 120 minutes.

### 3.4 Mechanical Properties

TABLE 2
Tensile properties, Retained austenite/Unreacted austenite & carbon content.

| *Temperature in $^0$C* | 320 | 370 | 420 | As-Cast |
|---|---|---|---|---|
| *Tensile Stress [MPa]* | 1100 | 790 | 545 | 780 |
| *YieldStress [MPa]* | 835 | 715 | 492 | 597 |
| *Strain [%]* | 9.3 | 3.4 | 2.6 | 4.6 |
| *Toughness [MPa]* | 95 | 24 | 15 | 35 |
| *UAV [%]* | 25 | 54 | 41 | -- |
| *Carbon Content* | 1.8 | 1.15 | 1.01 | -- |

Note: Retained austenite at 320 $^0$C, Unreacted austenite volume at 370 & 420 $^0$C.

Table 2 shows the experimentally calculate mechanical properties values i,e stress strain data's. The experimentation resultsfor as-cast condition is shown in table 2, same results were observed by [14]. High hardness was due to presence of pearlite content increased sharply when the manganese content reaches 0.9% which was due to some complex reaction occurred between Mn, Fe and C, hardness points $HV_{430}$ fig 1 (a) . The optimum toughness is obtained at temperature 320 $^0$C.

At lower temperature there is less variation in hardness value at different regions $HV_{530}$ and $HV_{503}$ measured as shown in fig 1 (b). The mechanical properties (strength and toughness) of the austemepred ductile iron structure mainly depend on the microstructure. At a lower transformation temperature at 320 $^0$C, the Feathery bainitic ferrite laths, stable austenite with higher carbon concentration and film martensite observed at 320 $^0$C in the microstrucutre in 1 (a) which showed a better strength and elongation resulted in table 2 i,e . The martensite containing ADI can be treated as fiber reinforced ductile material. Even if the fiber is brittle, it will not make the composite brittle, as a beneficiary and will improve the toughness of the ADI [18]. Stable austenite with higher carbon and coarsesr ferrite laths content act as crack resisting region giving more toughness for the microstructure
Increased austempering temperature to 370 $^0$C decreases tensile strength due to the variation in hardness of the matrix reduces elongation and toughness due to the presence of marrtensite and mechanically unstable austenite.Similarly at austempering temperature 420 $^0$C,gives bad combination of strength and ductility, which is due to strong Mn segregation and formation of much austenitic-martensitic zone during austemepring and carbide precipitation in eutectic cell and MnC $HV_{560, 660}$ in intercellular regions reduced the toughness and strength values due to brittleness nature of carbides $HV_{800}$ and austenite- martensitic zone[8] in 1 (c-d) [18] .

## 4 CONCLUSIONS

Alloy containing high Mn austempered at 320, 370 & 420 $^0$C for 120 min resulted in bainite morphology only at lower temperature 320$^0$C. At higher austemperature temperature 370 & 420 $^0$C, that the where in stage II carbides starts to precipitate near graphite nodules before the completion of ferrite laths growth in the region away from the nodules for austempering time 120 min. At higher temperatures 370 & 420 $^0$C, and the effect of slower kinetics for higher manganese, retarding the carbon diffusion which effects transformation rate resulted in formation of more untransformed austenite volume, turns to martensite upon cooling in the region away from the graphite nodules. Austenite-martensite zone was observed at austempering tempering 370 & much more pronounced surrounding the martensite at 420$^0$C. There was a improvement in tensile properties for austempering at 320$^0$C due to the mechanically stable austenite and due to the brittleness in nature of unstable austenite-martensite zone, stage 2 carbides ,MnC , and much variation in matrix hardness ,the mechanical properties (i,e Tensile strength, toughness decreases).

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