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FATIGUE BEHAVIOR OF TOUGHENED AUSTEMPERED DUCTILE IRON

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ABSTRACT

Austempered ductile iron is a new engineering material which has a combination of good strength, toughness and wear resistance. The toughness can be further enhanced by employing special heat treatment to the ductile iron samples generally termed as QB^1 process. The resulting toughened austempered ductile iron samples have been found to possess superior toughness and wear resistance.The Fatigue behavior of toughened austempered ductile iron (TADI) samples have been studied and reported. The austempering temperature has been held constant at 350^0C and the austempering time has been varied from 15-210 minutes in steps of 15 minutes. The austempered samples were also tested for microhardness and the results analyzed. The results indicate that the fatigue strength increases as the holding time increases from 15 to 150 minutes. Samples austempered beyond 150 minutes shows a decrease in fatigue strength. The maximum hardness value reported with micro hardness test was at an austempering time of 150 minutes. Further, the retained austenite content and distribution of bainite in the matrix play a vital role on the fatigue properties of Toughened austempered ductile iron.

Keywords: *Toughened, Fatigue, Retained Austenite, Bainite, Microhardness.*

1. Introduction

Austempered Ductile Iron (ADI) is replacing steel forgings and castings with its excellent wear properties, relatively low manufacturing cost and recyclability. Rail road applications that have been produced in ADI include wheels, suspensions, covers, latches, tie bars and track hardware. Automotive applications include crankshafts, camshafts, brake components and pump components [1-3].

Austempered Ductile Iron (ADI) is currently used widely in the place of cast steel and weld components because of its high strength, wear resistance and toughness. The conventional austempering heat treatment process involves soaking the ductile iron above the upper critical temperature followed by a isothermal hold in the bainitic range to transform the austenite into bainite and retained austenite. It has been reported [4] that by employing special heat treatment process (QB^I process) the toughness of ADI can be further increased without sacrificing its strength. The toughened ADI produced by QB^I process shows higher fracture toughness compared with the ordinary ADI. Narasimha Murthy etal [5] have developed permanent molded Toughened ADI with superior abrasion resistance. Many researchers have reported that the presence of large amounts of retained austenite lead to better wear and fatigue resistance in ADI, due to the strain hardening nature of the austenite [5,6]. Mohamad H. Alaalam[8] has reported that fatigue strength of ADI depends on austenitising temperature and the soaking period. His observation is that the optimum fatigue strength occurs at 900°C held for 120 min. Gülcan Tokta etal [9] have observed that the lower ausferritic structure has the highest fatigue strength than when the structure was ferritic. They have reported that the value increased as the pearlite content increased.

Jen et al. [10] have observed that the estimated endurance limits were mainly dependant on the hardness of ADI. Krishnaranj et al. [11] have reported that among ductile irons with different matrix structures, the one with bainitic matrix possessed the highest fatigue limit. Shanmugam etal [12] have observed that the presence of feathery bainite and large amount of retained austenite have a pronounced effect on the fatigue behavior of ADI.

The matrix microstructure plays a major role on the fatigue behavior of ADI. Also, the matrix structure can be varied either by heat treatment or by alloying additions. It is also clear that there are further modifications in the matrix microstructure due to the

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samples being subjected to special austempering treatment in the development of Toughened ADI.

Though there has been published information on the fatigue behavior of ADI, the available literature on the fatigue behavior of Toughened austempered ductile iron is scanty. In the present work the role of austempering time on the fatigue behavior of TADI has been planned by having austempering temperature constant and varying austempering time. This work is a part of larger work aimed at developing a suitable alternate material to replace steel castings in automotive and power sectors

2. Experimental Details

2.1 Casting procedure (melting)

The charge material used was clean steel scrap, petroleum coke and ferro-silicon. Prior to starting the induction furnace for melting ductile iron, the furnace was lined with basic refractory and the crucible was sintered. The furnace was started after charging with mild steel scrap and the controller was slowly increased till the wattage attained was about 12 KW. Once the charge started melting, slag was removed and silicon additions were made into the melt in the form of ferro-silicon and the carbon content was built up to the required level by adding petroleum coke. Once the petroleum coke was fully dissolved and the other charge materials were added to the furnace, the metal was super heated to a temperature in the range of 1475-1500ºC and tapped. The temperature was monitored using dip type pyrometer. Prior to pouring the molten metal, de-slagging was done. The liquid metal was then tapped on to pre heated ladle (700ºC) and the melt was treated with magnesium in the form of Fe-Si-Mg. It was post inculcated using Fe-Si and poured into pre-heated sand mould of dimension 170 mm x 280mm x 30 mm.

The chemical composition of the material poured is given in Table 1

Table 1: Chemical Composition

Elements	Composition (Wt %)
Carbon	3.5
Silicon	2.35
Manganese	0.45
Sulphur	0.015
Phosphorus	0.031
Magnesium	0.04

2.2 Test specimen preparation

The castings were removed from the moulds. The samples of required sizes for fatigue were taken from the bottom portion of these castings, by cutting and grinding operations. The top portion of the castings was discarded.

Fatigue samples were prepared according to ASTM designation E466-96 standards. Circular cross section with tangentially blended fillet between test section and the ends of diameter 7.5 mm were prepared. Fig. 1 shows the dimensions of the sample for fatigue test.

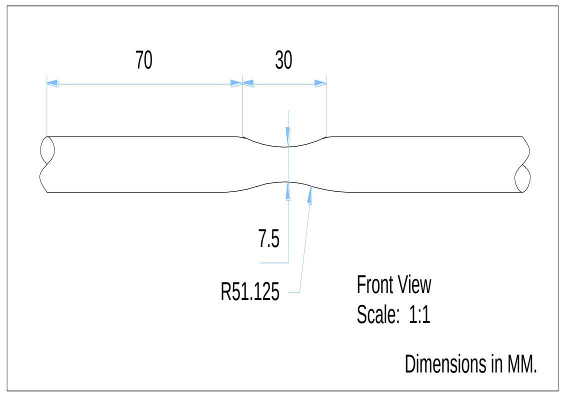

Fig. 1 Specification of the Fatigue Test Specimen

2.3 Special heat treatment procedure

2.3.1 QB[I] process

The test specimens taken from the castings were given the following heat treatment processes.

1. Austenitizing
2. Austempering

2.3.1.1 Austenitizing

The test specimens were heated to austenitizing temperature 950ºC and held at that temperature for 2 hours. Then the specimens were quenched immediately into an oil bath held at room temperature (Q Process).

2.3.1.2 Austempering

The samples were heated again to austenitizing temperature of 950°C and held at that temperature for 1 hour. Then the specimens were quenched immediately into a salt bath containing a mixture of sodium nitrate and potassium nitrate. The test specimens were held in the salt bath at 350ºC for 15, 30, 60, 90, 120, 150, 180, 210 minutes. The salt bath temperature was monitored using thermo couples placed very close to the specimens. The salt bath size was large enough compared with the size of the test specimen. The temperature of the bath remained constant during quenching.

The austempered specimens were air cooled and possible decarburized layers were removed (B Process). Fig. 2 shows the QB[1] process.

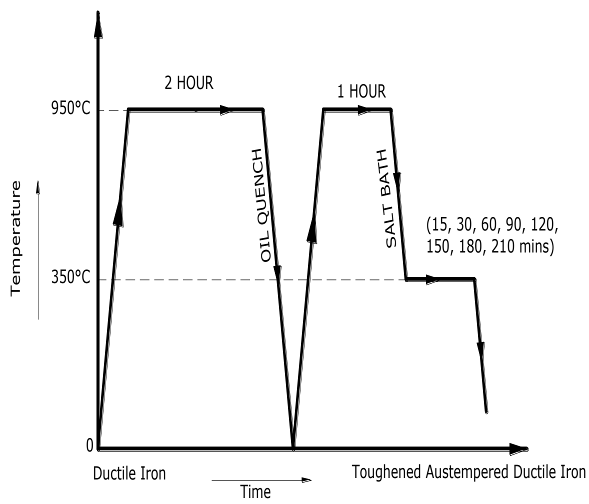

Fig. 2 Special Austempering Heat Treatment Cycle

3. RESULTS AND DISCUSSIONS

3.1 Fatigue test

The heat treated specimens are subjected to Fatigue test on a rotating bending machine. In this machine, cylindrical smooth specimens were mounted and loaded from both ends using rotating chucks. A weight is suspended from one side of the specimen to vary the bending stresses experienced by the specimen surface. Initially, the specimen will experience tensile stresses at its top surface and compressive stresses at its bottom. As the specimen rotates 180 degree, the stresses will be reversed and the top will be under compressive stresses while the bottom will be under tensile stresses. When the specimen completes one full rotation, the specimen surfaces would have experienced one full loading cycle.

The maximum bending stress acting on the specimen surface is given by $\sigma = 32M/\pi d^3$

Where, σ = the maximum bending stress

M = the bending moment at the specimen cross-section (weight * distance)

d = specimen diameter

The same tests were repeated for other specimens, each conducted at same stress level and the number of cycles it would take to fail is recorded. The S-N curve is a plot of the applied stresses versus the logarithm of the number of cycles to failure (N) for each specimen. The specimens were tested till fractured. The results of the fatigue tests have been depicted in the form of a bar chart as shown in fig. 3.

It is observed that as austempering time increases from 15 to 150 min there is an increase in fatigue value. However at austempering time beyond 150 min, the fatigue value shows a decreasing trend. It is clear from the above data that the optimum fatigue strength occurs at austempering time of 150 minutes. These results are well supported by earlier reported literature on fatigue of ADI [13, 14].

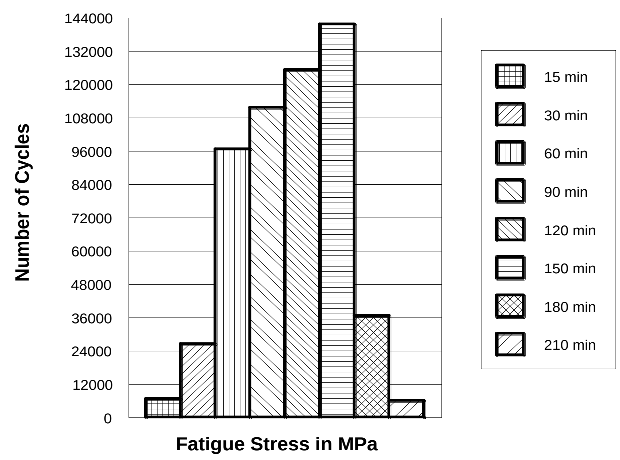

Fig. 3 Variation of Fatigue Value with Austempering Time of TADI

3.2 Micro hardness test

The polished specimens were taken for Vickers micro hardness test.

The micro hardness tests were conducted with Vickers diamond pyramid indenter under test load of 25 kg at room temperature. The load was applied for 15 second in order to have result with statistical significance; average of three values with different location was taken. Fig. 4 shows the variation of hardness with austempering time.

The observations indicate that the hardness value increases with austempering time up to 150 min and then decreases with increasing austempering time. The maximum hardness value is obtained at an austempering time of 150 minutes. The high initial hardness is due to some amount of martensite which is present in the microstructure. The gradual rise in hardness during later stages of austempering is due to carbide precipitation.

3.3 Microstructure

The micro structural features of the test samples prepared are examined using NIKON light (optical) microscope**.** The Ductile Iron samples as cast condition was observed for micro examination under optical microscope. The as cast photomicrograph of Ductile Iron samples has been shown in fig. 5. The graphite nodules are surrounded by ferrite.

Figures 6 to 9 show the representative photomicrographs of Toughened Austempered Ductile Iron samples.

The distribution of bainite and the densities of the bainite vary as the austempering time is increased. The retained austenite content in the matrix has changed significantly as the austempering time is increased. Samples austempered for 150 minutes had a retained austenite content of 42%.

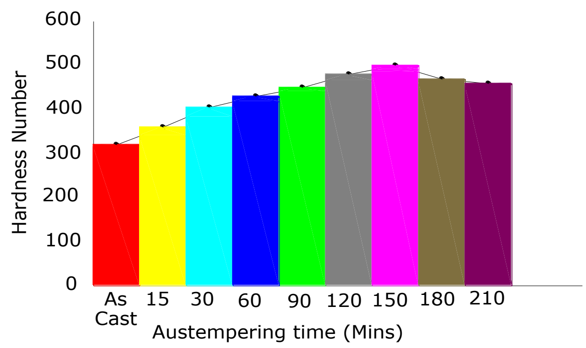

Fig. 4 Variation of Micro Hardness Value with Austempering Time of TADI

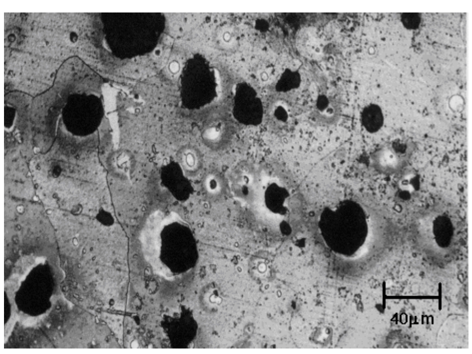

Fig. 5 Photomicrograph of as Cast Ductile Iron

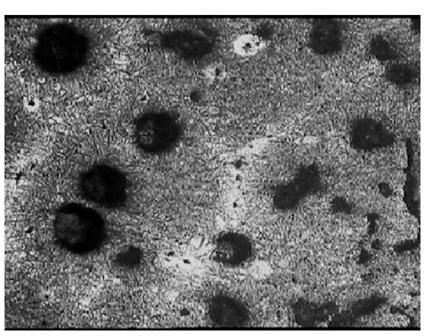

Fig. 6 Representative Photomicrographs of TADI for Austempering Time 60 min

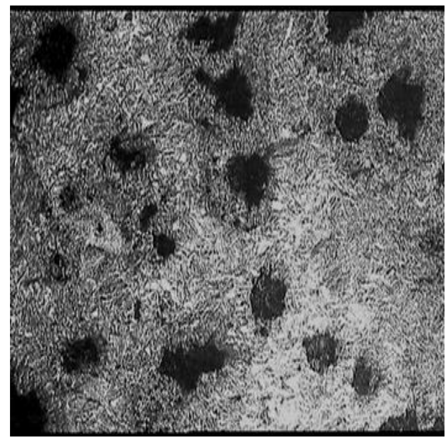

Fig. 7 Representative Photomicrographs of TADI for Austempering Time 120 min

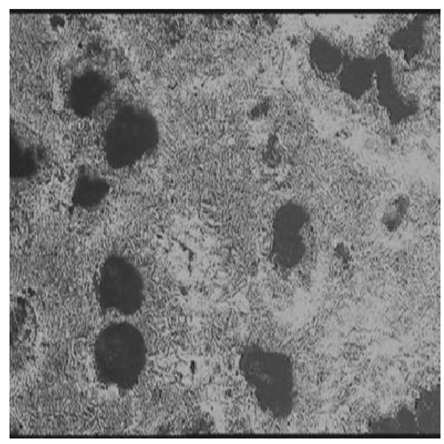

Fig. 8 Representative Photomicrographs of TADI for Austempering Time 150 min

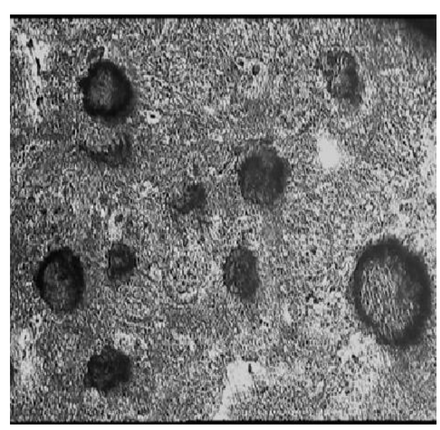

Fig. 9 Representative Photomicrographs of TADI for Austempering Time 180 min

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4. Conclusion

In this investigation, systematic study has been carried out on fatigue behavior of Toughened Austempered Ductile Iron. Experiments have been carried out on the influence of Austempering time on fatigue behavior and micro structure analysis of Austempered Ductile Iron. The results of study indicate the following;

i. Fatigue strength increases as the austempering time increases up to 150 minutes. Austempering beyond 150 minutes shows a decrease in fatigue strength of TADI samples.
ii. The austempering time which gives optimum fatigue strength was found to be at 150 minutes.
iii. The distribution of bainite and retained austenite which gives best fatigue strength was found at austempering time of 150 minutes.
iv. The micro hardness increased with increase in austempering time up to 150 minutes. The highest hardness was found to be at 150 minutes of austempering.
v. There is 56.25% increase in hardness of TADI samples, as compared to as-cast ductile iron samples.

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