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CORROSION AND WEAR STUDIES ON AUSTEMPERED DUCTILE IRON

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ABSTRACT

ADI is an alloy of iron which offers the design engineers the best combination high strength-to-weight ratio, low cost design flexibility, good toughness, wear resistance along with fatigue strength. The aim of the present study is to characterize the corrosion, wear of Austempered Ductile Iron (ADI) developed by the single-step Austempering process.The samples were austempered at different temperatures and the above mentioned properties of these samples were investigated. Experiments were systematically planned to study the Corrosion properties. Wear and corrosion test was conducted on these specimens as per the standard ASTM 897M-90. The samples of Ductile Iron(DI) were first austenised at 925°c for 90 minutes and then austempered by the single-Step Austempering process at temperatures 300°C, 350°C, 400°C, 450°C. The results were found that the corrosion rate is maximum in basic medium and Wear has been observed that ADI Austempered at 350°C has high surface hardness and it is also observed that wear resistance was found to be maximum at 350^0C.

Key word: Permanent moulded austempered ductile iron, corrosion,wear.

INTRODUCTION

In recent years, austempered ductile irons (ADI) have been used for many critical components in automobiles, such as crank shafts, steering knuckles and hypoid rear axle gears. It is expected that the application of these irons will increase in the future, not only in the automobile industry, but also in many other fields**[1]**. The interest in these irons is due to the fact that they offer an exceptional combination of high strength, ductility and toughness. This unusual combination of properties results because of their unique microstructure, which consists of ferrite and austenite, rather than ferrite and carbide, as in austempered steels**[2]**. It is reported that Austempered ductile iron out performs proprietary abrasion resistant steels at similar bulk hardness levels. Austempered ductile iron is produced by subjecting a ductile iron casting to an austenitization soak followed by tempering in a salt bath**[3]**. This offers an opportunity for dissolving the carbides formed in the as-cast condition. The microstructure produced in Austempered ductile iron is unique. Graphite nodules are surrounded by a matrix of bainite and ferrite with a high retention of austenite content**[4]**. Recent studies**[5,6,7]** have shown that this new family of engineering materials also offers great potential for cast parts in application involving many critical components in automobiles, such as crank shafts, steering knuckles and hypoid rear axle gear. The application of these irons is expected to increase in the future, not only in the auto-mobile industry, but also in many other fields such as cast iron parts in application involving impact loads combined with wear, rail, and heavy engineering industry. The fatigue properties of ductile iron and ADI have been studied by many researchers. **Dr Mohamad H. Alaalam[8]** observed that fatigue strength of ADI depends on austenitising temperature and the soaking period. Increase in soaking period fatigue strength also increases. It was proved that optimum fatigue strength occurs at 900°C with soaking period 120 min. Fatigue strength drops with further holding in bath and increase in austenitising temperature. **Stanislav Věchet, Jan Kohout [9]** reported that Mechanical properties determined by tensile and fatigue tests of ADI transformed at the temperature of 400 °C during 11 various transformation dwells in the range from 2 minutes to 25 hours are confronted with obtained matrix structure. **Salman,F.Fındık,P.Topuz[10]** observered that the hardness of the specimens decreased with the increasing of austempering temperatures. However, cycles to failure increased with the rising of austempering temperatures due to upper bainite structure **Marrow and C¸ etinel [11]** investigated the growth of short fatigue cracks in ADI. It was proposed that the arrest and retardation of short crack nuclei was controlled by the austenite grain size and graphite nodule size. **Kim and Kim [12]** also examined influence of microstructure on fatigue limits of high strength ductile irons applying rotary bending fatigue test. Their result showed that in case of series B (bainite) the fatigue limit was higher than in case of series A (sorbite) and fatigue limits of series A, and B were improved compared with as cast specimens**.** **Bartosiewicz et al. [13]** studied the effect of microstructure on high-cycle fatigue properties of ADI. The results of this investigation demonstrated that the fatigue threshold of the material increased with the increase in volume fraction of carbon-saturated austenite. The fatigue strength of the material was found to increase with the decrease in austenite grain size**. Lin et al. [14]** performed another study which was about the effect of microstructure on fatigue properties of these materials. It was found that the mechanical properties and high cycle fatigue strength of ductile irons could be markedly improved by austempering heat treatment and the high cycle fatigue strength of ADI was increase with increasing nodularity and nodule count. **Lin and Lee[15]** exhibited the relationship between fatigue strength and highly stressed volume with various combinations of specimen configurations and loading modes for ADI. Lin and Fu, also investigated the relationship between low-cycle fatigue strength of ADI and cast section size and location. **Luo et al.[16]** determined fatigue behavior for ferritic, pearlitic irons, and ADI under tension–tension loading. **Bahmani and Elliott[17]** showed the relationship between fatigue strength and microstructure in ADI. The correlation between fatigue strength and austempered microstructure was evaluated depending on the amount of high austenite, Xc, and its carbon content, Cc. They observed that fatigue strength increased as Xc, and Cc increased. **Thomson et al.[18]** aimed to develop a generic model that would enable the producers of ADI to optimize their product in terms of microstructure and mechanical properties**. Jen et al.[19]** determined fatigue properties of ductile iron which were applied on four different grades of austempered heat treatment under bending fatigue test. They observed that the estimated endurance limits were mainly depended on the hardness of the ADI**. Krishnaranj et al.[20]** investigated fatigue behavior of ductile iron with different matrix structures. It was reported that among ductile iron with different matrix structures, the one with bainitic matrix possessed the highest fatigue limit. The utilization of permanent molds to produce ADI has several advantages in terms of finer graphite nodules, good surface finish, repeatability of castings, dimensional accuracy and environmental cleanliness. There have been few literatures which have reported beneficial effects of utilizing permanent moulds to produce ADI. The reported results have indicated that there is improvement in the mechanical and tribological properties of ADI produced from permanent moulds as compared to ADI produced from sand moulds. The presence of appreciable amounts of retained austenite should lead to better wear resistance and fatigue strength in these, due to the high work-hardening nature of the austenite. While considerable work has been reported in understanding the 'microstructural characteristics of a number of ADIs and their effect on tensile properties, impact toughness and fracture toughness. Information available on the effect on fatigue properties is scanty**.**

Scope of present investigation: ADI exhibits a favorable combination of strength and ductility, and has been used for variety of components in automobile, railroad and heavy engineering industries. The mechanical properties can be varied over a wide range by the correct choice of heat treatment variables and the composition of iron, austempered ductile iron can have tensile strength up to 1600 MPa with 1% elongation for application in which wear resistance is of primary importance. Extensive literature survey has been carried out, in the past, on ADI has revealed that its mechanical and wear behavior are dependent on heat treatment and alloy additions. In the present investigation, experiments have been systematically planned to study the corrosion, wear and the electrical conductivity of the samples and the results are interpreted . The samples have been subjected to initial austempering temperatures 300°C, 350°C, 400°C, 450°C . The results and conclusion have been measured in the forthcoming chapters.

EXPERIMENTAL SETUP,PROCEDURE

The ductile iron castings were made using a laboratory induction furnace of 15 kg capacity. The charge materials used were clean mild steel scrap, petroleum coke, Ferro-silicon and Nickel-magnesium. The melt was super heated to 1300-1350^{0}C and was subjected to spherodizing treatment using Ni-Mg alloy. Post inoculation was carried out using Ferro-silicon (inoculation grade) and stirred well prior to pouring. The liquid metal was then poured into the permanent gray iron and casting dimensions 110X25X75 mm.

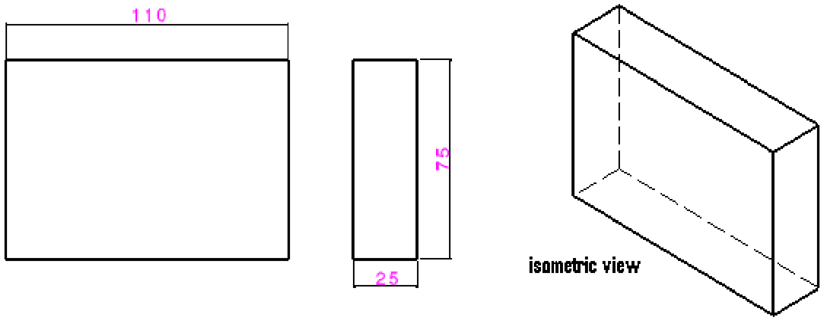


Figure 1: Permanent mould specification

Table1: Chemical composition

CHEMICAL ELEMENT	COMPOSITION (%)
Carbon	3.5
Silicon	2.35
Manganese	0.45
Sulphur	0.015
Phosphorus	0.031

Austempering heat treatment

The test specimens taken from the castings were given the following heat treatment processes. **1)**Austenitizing **2)** Austempering **3)**Austenitizing ,The test specimens were heated to austenitizing temperature 950°C and held at that temperature for 2hr.

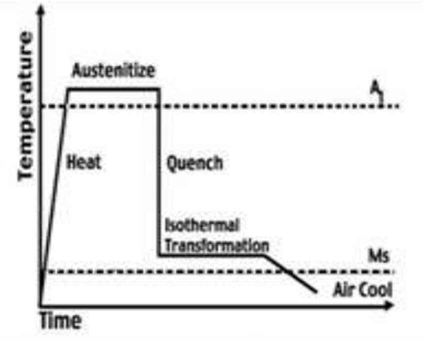


Figure:2 Production of ADI

Austempering

It is the process of quenching from a temperature above the transformation range to the upper limit of martensite formation, and holding at this temperature until the austenite is completely transformed to the desired intermediate structure, for the purpose of conferring certain mechanical properties, The austenitized 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 300^{0}C, 350^{0}C,400^{0}C,450^{0}C.The salt bath temperature was monitored using thermocouples 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.

Single step austempering process of SG iron

Specimen were heated up to 900^0C for 90 min. Then the specimen were quenched into a salt bath maintained at 300^0C, Similarly same process is repeated for second set at 350^0C, third set at 400^0C, fourth set at 450^0C. Later the specimen is taken out and cooled at room temperature in air medium. This process is done to increase the mechanical properties of ductile iron.

Corrosion Test Procedure

The corrosion set up consists of namely: Corrosion analysis software, Electrodes, Specimen holder, and power supply.

Electrodes: The specimen are completely insulated using insulating tape leaving square cm area. Exposed area then made to corrode in corrosive medium like (0.5N,0.75N and 1N) NaCl and H_2S0_4. Current is made to flow through specimen. Specimen is immersed in corrosive medium and allowed to corrode by flowing current for 60s. Using the analysis software, first find out the open circuit potential of the specimen for given conditions. Manually set the range of potential as well as current sensitivity. Later obtain the table plot for the given normality and temperature Find out density, no of electrons, area, and formula weight from pre-calculations. By entering these values, find results namely corrosion current, linear polar resistance and corrosion rates in terms of milli-inch per year. Similarly follow the same procedure for different normality's of NaCl and H_2S0_4. Thus results were analyzed and compared for different Austenizing temperatures.

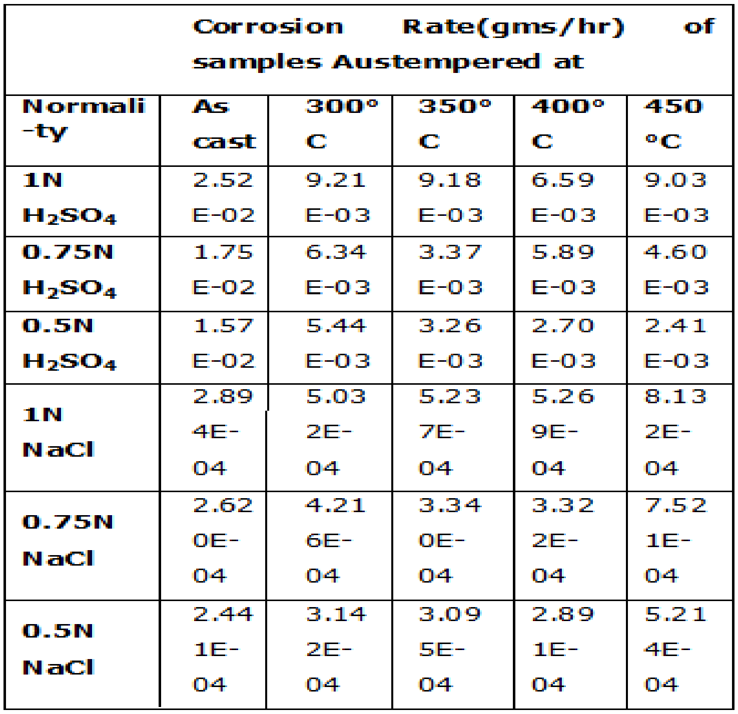
Figure 3: Permanent mould specification

Wear Test Procedure

Measure the dimensions and weight of the specimen. Insert the specimen into the holder and set it perpendicular to the disk. Add suitable weights to the lever. Start the motor and adjust the speed thus making the specimen in contact with the disc. Start the clock and note down the maximum frictional force for each 5 min at different weights. Stop the motor and remove the specimen remeasured the specimen dimension and weight. Repeat the test with other set of specimens.

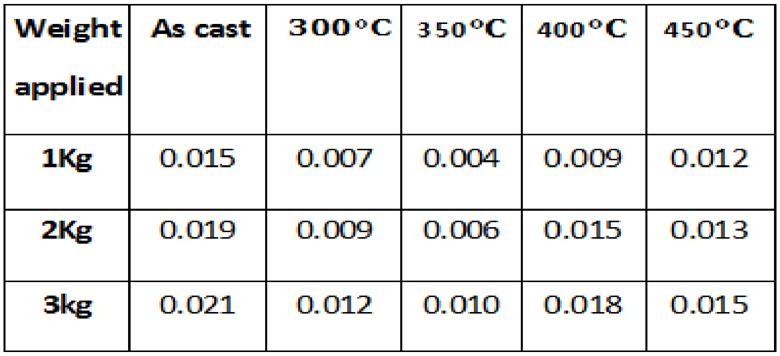
RESULTS AND DISCUSSIONS

Table2: Results for Corrosion



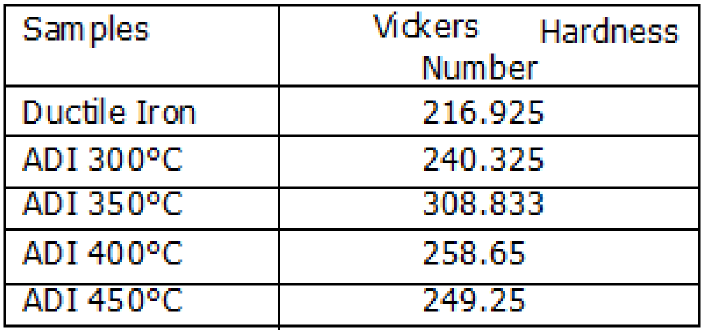
	Corrosion Rate(gms/hr) of samples Austempered at				
Normali-ty	As cast	300° C	350° C	400° C	450 °C
1N H_2SO_4	2.52 E-02	9.21 E-03	9.18 E-03	6.59 E-03	9.03 E-03
0.75N H_2SO_4	1.75 E-02	6.34 E-03	3.37 E-03	5.89 E-03	4.60 E-03
0.5N H_2SO_4	1.57 E-02	5.44 E-03	3.26 E-03	2.70 E-03	2.41 E-03
1N NaCl	2.894E-04	5.032E-04	5.237E-04	5.269E-04	8.132E-04
0.75N NaCl	2.620E-04	4.216E-04	3.340E-04	3.322E-04	7.521E-04
0.5N NaCl	2.441E-04	3.142E-04	3.095E-04	2.891E-04	5.214E-04

Table3: Results for Wear test

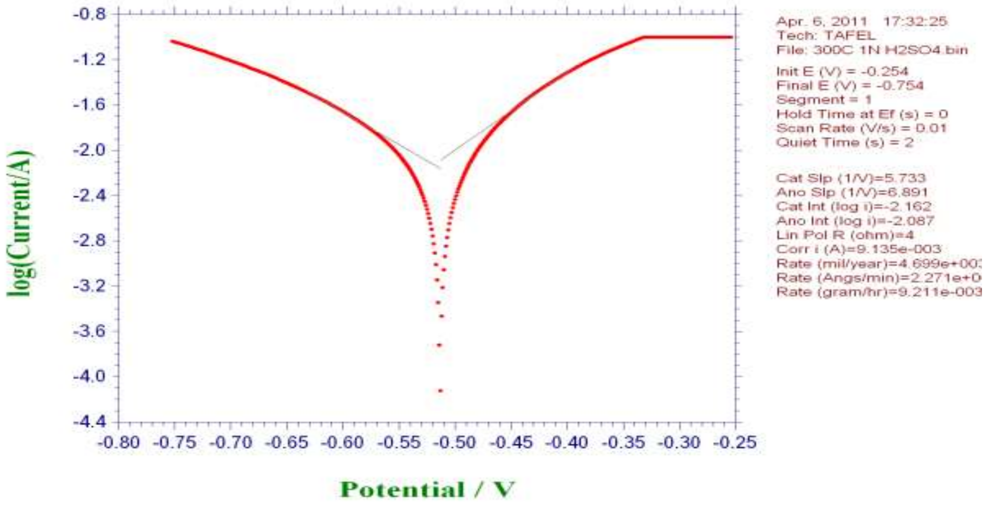


Weight applied	As cast	300°C	350°C	400°C	450°C
1Kg	0.015	0.007	0.004	0.009	0.012
2Kg	0.019	0.009	0.006	0.015	0.013
3kg	0.021	0.012	0.010	0.018	0.015

Table3: Surface Hardness (VHN)



Samples	Vickers Hardness Number
Ductile Iron	216.925
ADI 300°C	240.325
ADI 350°C	308.833
ADI 400°C	258.65
ADI 450°C	249.25



Graphs1: Table Plot (300°C 1N H_2S0_4)

Microstructures of permanent moulded austempered ductile iron, The distribution of banite and the densities of the banite vary as the austempering time is increased. The retained austenite content in the matrix has changed significantly as the austempering time is increased

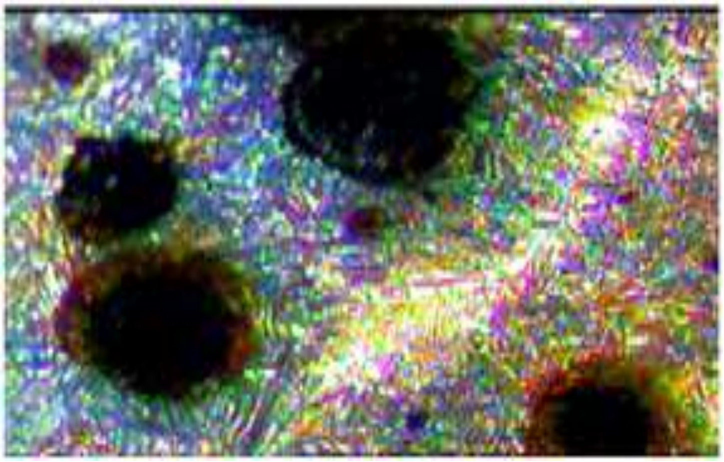


Figure 4: Microstructure of PMADI samples austempered at 350°C.60 min.

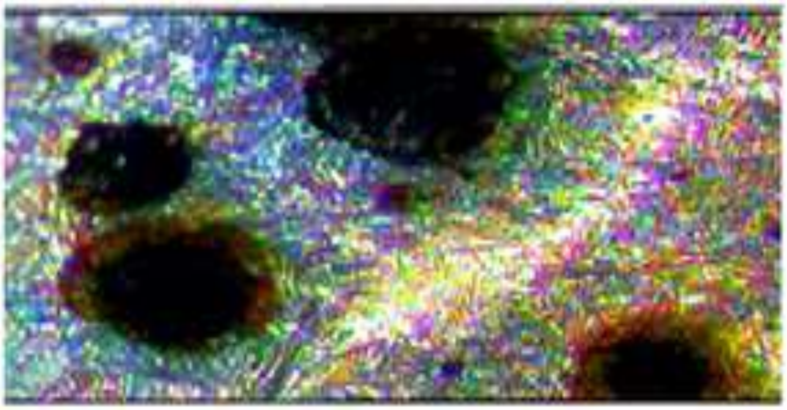


Figure 5: Microstructure of PMADI samples austempered at 300°C.60 min.

CONCLUSION

Corrosion: In acidic medium, Austempered ductile iron at 350°C and 400°C are showing better corrosion resistance property. In basic medium, ADI Austempered at 450°C is showing lower corrosion resistance. Ductile iron has the least corrosion resistance as compared to Austempered Ductile iron in acidic medium. Ductile iron is showing good corrosion resistance in basic medium. In acidic medium (H_2SO_4),the conventional ductile iron is showing an increase in corrosion rate as compared to the austempered samples.The corrosion rate is more in case of basic medium . ADI Austempered at 350°C has highest surface hardness and wear resistance . It has been observed from the wear test that ADI Austempered at 350°C is showing better Wear resistance compared to ductile iron. As seen from the results of Vickers hardness test, the heat treated samples are giving high hardness when compared to Ductile Iron.

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