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WEAR RESISTANCE ENHANCEMENT OF PERMANENT MOULDED AUSTEMPERED DUCTILE IRON BY TWO - STEP AUSTEMPERING PROCESS

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ABSTRACT

Austempered ductile iron (ADI) has attracted researchers and manufacturers alike mainly because of its immense properties and also at the same time cheaper to process and produce. Utilization of permanent moulds to produce ADI has many advantages such as very good dimensional stability, good nodule size and count, better surface finish and environmental cleanness. Extensive literature survey reported that the influence of novel two-step heat treatment which has resulted in significant improvement in yield and tensile strength and fracture toughness of the material over the conventional single step austempering process. In this investigation, ductile iron test samples were prepared in permanent moulds and are processed by a novel two step austempering process. Test samples were subjected to rubber wheel abrasion test and jet erosion test. The results show that two step austempering process has resulted in significant improvement in the wear resistance (abrasion and erosion). The results are analyzed based on the micro structural features.

Key words: *PMADI, Two-step Austempering Process and Wear*

1. Introduction

Austempered ductile iron (ADI) has attracted researchers and practicing engineers because of its good ductility, high strength, excellent wear resistance and high fracture and fatigue strength [1]. Major applications of ADI include automotive sector, mining, power plants, military and agricultural industries. ADI is conventionally cast in sand moulds. Utilization of permanent moulds for producing ADI have advantages such as fine graphite nodules, improved surface finish, less environmental pollution and better dimensional stability. Seetharamu et al [2] have reported that the permanent moulded austempered ductile iron (PMADI) castings have been found to possess better abrasion and erosion resistance compared to the sand moulded components.

The presence of appreciable amounts of retained austenite in ADI leads to better wear resistance and fatigue strength, due to high work hardening nature of the austenite [3]. Several researchers have studied the effect of alloying additions on the mechanical properties of ADI [4]. It has been reported that ADI possesses good wear resistance than steel castings and ductile iron [5-6].

ADI has a matrix which consists of a combination of acicular ferrite and stabilized austenite [7]. This structure results in an exceptional combination of strength and ductility [8-9]. Structure and properties of ADI depend on composition and heat treatment parameters. There is a lot scope for researchers to study the effect of variation in heat treatment parameters and resulting changes in the microstructure.

Conventional austempering process consists of austenitizing the castings in the temperature range of 871°C – 982°C for sufficient time to get a fully austenite (γ) matrix and then quenching to an intermediate temperature range of 260°C- 400°C. Mechanical properties of ADI depend on the bainitic matrix which consists of ferrite and higher volume of retained austenite.

Susil K. Putatunda et al [10] have developed ADI by a novel two step austempering process. They have reported that there is a significant improvement in mechanical properties and fracture toughness of the material as result of the two-step austempering process. Ayman et al [11] have studied fracture toughness as well as other mechanical properties of austempered ductile iron produced using both conventional and two-step austempering processes. There has been improvement in fracture toughness of the material, while maintaining the reasonable levels of strength. Gaston et al [12] have studied the effect of new two step austempering heat treatment process developed by Putatunda, on mechanical properties with the emphasis on the response to the abrasive behavior. Results have

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been reported that two-step austempering process has superior wear resistance compared to conventional ADI. Jianghuai Yang and Susil K Putatunda [13] have carried out investigations to examine the influence of novel two step austempering process on abrasion wear resistance and microstructural parameters of ADI. The results have indicated that this two step austempering process has resulted in significant improvement in abrasion wear resistance compared to conventional austempering process.

Since wear characteristics of ADI can be enhanced by casting in permananent moulds and also by utilizing two-step austempering process an attempt has been made to study abrasion and erosion behavior of PMADI developed using two step austempering processes.

2. Experimental Setup and Procedure

2.1 Melting and casting

The ductile iron castings were made using a laboratory induction furnace of 15kg capacity. The charge materials used were clean mild steel scrap, petroleum coke and Ferro-silicon alloy. The melt was super heated to 1500°C and treated with ferro-silicon magnesium alloy and post inoculated using Ferro-silicon (inoculation grade) and stirred well prior to pouring. The melt was poured at 1400°C-1425°C into a pre-heated (200°C) gray cast iron mould after de-slagging. The gray cast iron permanent moulds employed in this work are as shown in Fig.1. The chemical composition of the castings poured is shown in Table 1**.**

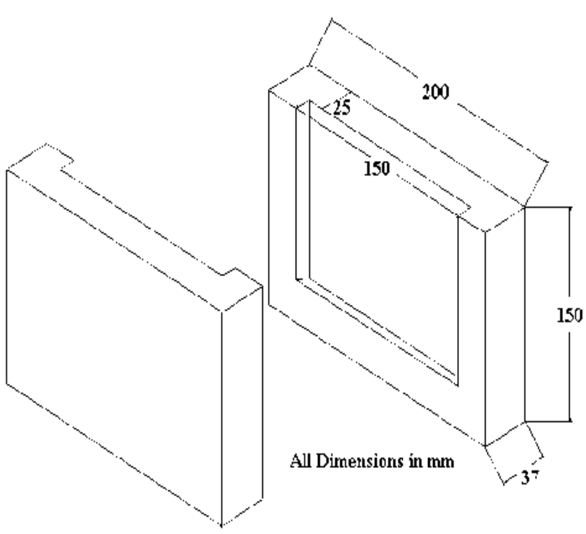

Fig. 1 Cast Iron Metal Mould

Table 1: Chemical Composition

Chemical element	Composition (%)
Carbon	3.3 to 3.4
Silicon	2.2 to 2.3
Manganese	0.1 to 0.2
Sulphur	0.005 to 0.02
Phosphorus	0.005 to 0.04
Magnesium	0.04

2.2 Two step austempering heat treatment

The test specimen of size 75mm x 25mm x 6mm taken from the castings were given an austenitizing soak of 950°C for 2 hours. These samples were initially quenched for about 5 min. in a salt bath maintained at 250°C. The salt bath temperature was raised to 280°C at a heating rate of 28°C-30°C per hour. Similarly, samples were quenched in the salt bath maintained at temperatures 310°C, 340°C, 370°C and 400°C. A schematic diagram of two step austempering treatment is as shown in Fig.2

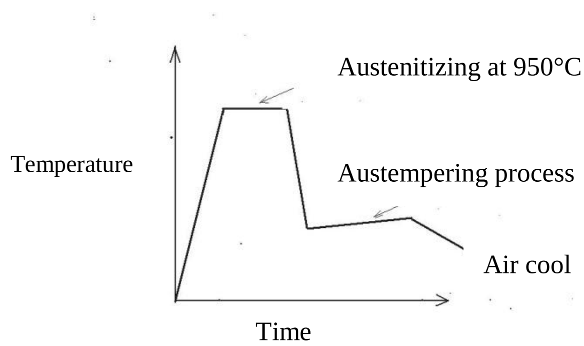

Fig. 2 Two-step Austempering Heat Treatment Cycle

2.3 Rubber wheel abrasion test

The test specimen of size 75mm x 25mm x 6mm was made flat on either surface by grinding it on belt emery and the test was carried out as per ASTM G76 standards.

The test equipment consists of a wheel with rubber beading around the circumferential periphery of the wheel. Test samples were suitably held in the specimen holder and were held in position against the rubber wheel by means of lever arrangement. The rubber wheel was rotated and the pressure was applied by means of loads suspended over the lever arrangement. Sand at a constant flow rate held in the top of the reservoir was allowed to fall between the rotating rubber wheel and the specimen through a nozzle. The test was conducted for 30 minutes or 6000 revolutions of the rubber wheel, which was rotated at 200 rpm. The rubbing of the abrasive sand particles against the test samples lead to physical wear of samples. The initial and final weights of the test samples before and after the test respectively were measured. The results of rubber wheel abrasion test have been tabulated in the Table 3.

The conditions used are as follows:

1. Dimension of the specimen: 75x25x6mm.
2. Erodant : Silica Sand AFS55
3. Mass flow rate : 0.25kg/min.
4. Duration : 30 min (6000 revolutions)

2.4 Jet erosion test

Erosion tests were conducted using a jet erosion test setup. Silica sand (AFS 60) with compressed air at a particle velocity of 40 ms^{-1} and flow rate of 600-650 g/min was made to impinge at an angle through a ceramic jet nozzle of 5mm diameter on the test sample of dimension 75x25x6mm. The test sample was cleaned and weighed in a digital balance before and after the test. The result was expressed in terms of volume loss (cm^3) divided by the weight of the abrasive (in kg). The tests were conducted at particle impact angles of 30°, 45°, 60°, 75° and 90° with test duration of 30 seconds.

2.5 Micro-structural analysis

The microstructures of heat treated samples were examined under an optical microscope.

3. Results and Discussions

3.1 Microstructure

i. Figure 3, 4 and 5 shows the photo micrographs of samples subjected to two-step austempering process in the range of (i) 310°C -340°C (ii) 340°C -370°C (iii) 370°C -400°C.
ii. It is observed that for the samples austempered in the range of 310°C -340°C long bainitic fibres with a retained austenite of 32% were observed. As the austempering temperature increases (temperature range of 340°C-370°C) the bainitic fibres appears shorter and finer and equally distributed. Further increase in the austempering temperature (temperature range of 370°C -400°C) the bainite appears scattered with carbides present in the matrix.

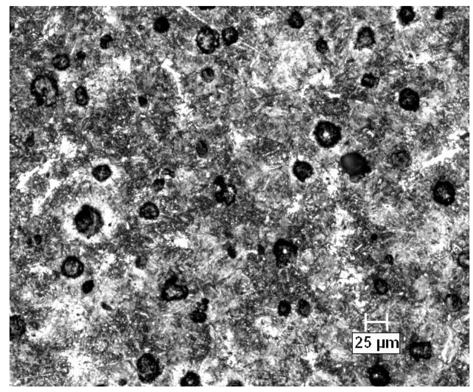

Fig. 3 (100X-Nital etched): Micro-Structure for the Sample Maintained at Temperature: 310°C -340°C

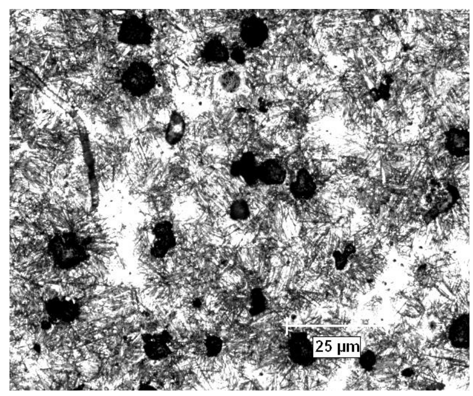

Fig. 4 (100X-Nital etched): Micro-Structure for the Sample Maintained at Temperature: 340°C -370°C

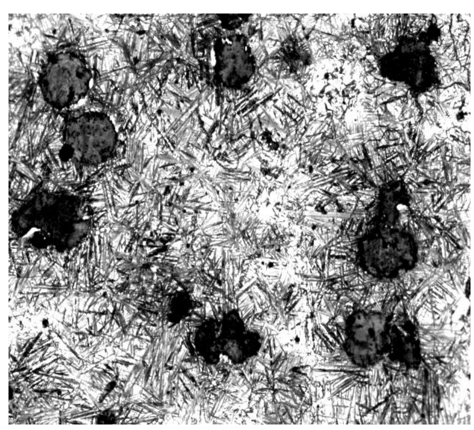

Fig. 5 (100X-Nital etched): Micro-Structure for the Sample Maintained at Temperature: 370°C -400°C

3.2 Rubber wheel abrasion

The results of the rubber wheel abrasion test on PMADI subjected to two step austempering process has been are tabulated in Table. 3.

i. Superior wear resistance was observed in the samples austempered in the temperature range of 340°C - 370°C
ii. Permanent moulded ADI heat treated by novel two step heat treatment process has shown 18-20% improvement in the abrasion resistance compared samples subjected to conventional austempering heat treatment.

Table 3: Rubber Wheel Abrasion Volume Loss of Permanent Moulded ADI, Heat Treated Samples by Two-step Austempering Process

Casting Designation	Casting Sample Austempered at	Abrasion Volume Loss (cc kg^{-1})$x10^{-3}$
T1	250°C - 280°C	115
T2	280°C - 310°C	120
T3	310°C - 340°C	113
T4	340°C - 370°C	67
T5	370°C - 400°C	77

3.3 Jet erosion test

Fig. 4 gives the variation in the erosion volume loss in cc/kgx10^{-3} of samples subjected to two-step austempering treatment with impact angles.

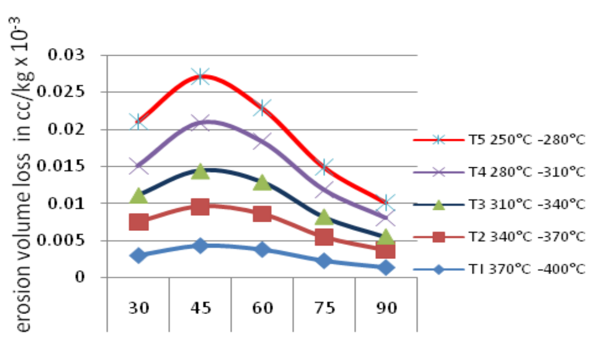

Fig 4: Effect of Impact Angle on the Erosion Volume Loss

Following are the salient features that emerge on the erosion behavior.

i. The erosion volume loss increases with the increase in impact angle from 30° to 45° and then it shows a downward trend up to normal impact angle for all the three categories of samples.
ii. The samples austempered in the temperature range of 370°C - 400°C has shown the lowest erosion loss at all impact angles.
iii. Permanent moulded ADI heat treated by novel two step heat treatment process has shown 8-10% improvement in the erosion resistance compared samples subjected to conventional austempering heat treatment.

4. Conclusions

The systematic study conducted on Permanent moulded ADI subjected to novel two step heat treatment process indicates the following.

i. Test samples show superior abrasion resistance in the temperature range of 340°C - 370°C when compared to other temperature ranges.
ii. The samples austempered in the temperature range of 370°C - 400°C has shown the lowest erosion loss at all impact angles.
iii. PMADI samples heat treated by novel two step heat treatment process has shown 18-20% improvement in the abrasion resistance and 8-10% improvement in the erosion resistance compared to samples subjected to conventional austempering heat treatment.
iv. Test samples treated by novel two step austempering process resulted in good nodular count and size. Finer austenite and ferrite as well as higher austenitic carbon in the matrix are accountable for the improvement of wear resistance (abrasion and erosion).

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