Studies on Impact Toughness of Austempered Ductile Iron

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Abstract – The aim of the present investigation was to study the effect of austempering temperature and soaking periods on the impact strength of ductile iron samples poured in permanent moulds. ADI is an exciting alloy of iron which offers the design engineers the best combination of high strength-to weight ratio, low cost design flexibility, good toughness, along with fatigue strength. A part of the samples were annealed and the whole lot is then austempered at different temperatures and the above mentioned properties of these samples were investigated. The samples of ductile iron were austempered by single step Austempering process at temperatures 300^0C, 350^0C, 400^0C and 450^0C for 30, 60 and 120 minutes. Then respective tests were carried out and thus above mentioned properties were found out. From the results obtained we were able to conclude that the hardness of the material was maximum when austempered at 300^0C for a time period of 120 Minutes The surface hardness of the material reduced with increase in Austempering Temperature. The surface hardness of the material increased with increase in Austempering duration. The Microstructure of the samples was studied for different austempering temperatures and soaking times durations , showed graphite nodules of size varying from 6 to 7 with distribution of nodules/mm' varying from 75 to 250 depending on the Austempering Temperature and time duration.

Index Terms – Austempering, Temperature, Ratio.

1. INTRODUCTION

Ductile iron, also known as ductile cast iron, nodular cast iron, spheroidal graphite iron, spherulitic graphite cast iron, is a type of cast iron invented in 1943.Ductile iron is not a single material but is part of a group of materials which can be produced to have a wide range of properties through control of the microstructure. In ductile irons the graphite is in the form of spherical nodules rather than flakes (as in grey iron), thus inhibiting the creation of cracks and providing the enhanced ductility that gives the alloy its name.

Advantages: Ductile iron has the ability to be used as-cast and without heat treatments or other further refining. It has a tensile strength comparable to many steel alloys and a modulus of elasticity between that of gray iron and steel. It has a high degree of ductility. Because of the nominal and consistent influence of spheroidal graphite, the tensile properties and the Brinell hardness of ductile iron are well related.

Application: Automobile crankshafts and camshafts replacing steel forgings. Gear rings and drive rings replacing fabrications, castings and forgings. Shear pin housings and drive couplings replacing steel castings. Main shafts and rotors for machinery drives.

Austempered Ductile Iron (ADI) was invented in the 1950's but was commercialized and achieved success only some years later. Austempering is an isothermal heat treatment that, when applied to ferrous materials, produces a structure that is stronger and tougher than comparable structures produced with conventional heat treatments. The "aus" portion of the name refers to austenite. It possesses high strength to weight ratio, wear resistance, ductility coupled with excellent toughness machinability, and cast ability and design flexibility. 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. This provides an opportunity for dissolving the carbides formed in the as-cast condition. The microstructure condition produced in Austempered ductile iron is unique. Graphite nodules are surrounded by a matrix of bainite and ferrite with a high retention of austentite content.

2. LITERATURE SURVEY

Following are the survey done earlier on the properties of austempered ductile iron

2.1 Effects of heat treatment on the erosion behaviour of austempered ductile iron:

The normal-angle erosion behaviour of austempered ductile irons has been studied under various heat treatment parameters, including time and temperature for both austenitization and austempering process, and the results indicate that the erosion rate was in generally positively related to hardness and tensile strength. Two major models have been proposed to describe the erosion of single-phase ductile and brittle materials. The weight loss of ductile materials during erosion is considered by a micromachining mechanism. The model is capable to explain the angle of maximum erosion rate occurring at intermediate angles observed experimentally. For the erosion of brittle materials, the material loss is caused by crack propagation and chipping and has a maximum at normal impact. The cutting model is strictly valid for erosion at oblique angles and is modified with the inclusion of plastic deformation. The experimental material is melted in a furnace and then cut into appropriate shapes for studies. The samples were subjected to erosion wear test in a typical sand-blast type of test rig (Sio2 used as erodent)Which results , in at Austempering temperature Microstructure appearance of bainite morphology depends on its formation temperature and the thickness of bainitic ferrite became finer as reaction temperature decreases. And the Mechanical properties such as the ductility and mechanical energy density both first increased and then decreased as the austempering temperature increases. The strength data exhibits a monotonic decrease with temperature, Erosion rate Mechanical property is not the only controlling factor for the erosion behaviour of iron austempered at 450^0C compared to that below 360^0C. The latter exhibits better mechanical properties, including ductility, strength and mechanical energy density, but the former is more erosion resistant. When austempered at 450^0C, the formation of soft ferrite phase after the start of stage II reaction is highly beneficial to the normal-angle erosion resistance, though overall mechanical properties deteriorated we can conclude that For the austempered ductile iron to achieve good erosion resistance, the austempering process should stop within the process window and higher temp should be employed.

3. EXPERIMENTAL PROCEDURE

Moulding: Permanent mould was made out of gray cast iron having dimensions 150 mm X 125 mm X 25 mm. The gray cast iron moulds employed in this work, was coated with china clay to facilitate easy removal of castings from the mould after solidification. Mould was pre-heated to 400° C prior to pouring. Sketch of permanent mould employed is shown in fig.1.

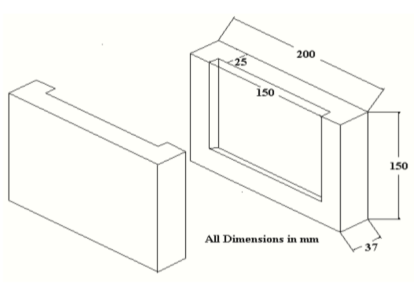

Fig.1: Gray cast iron permanent mould

Ductile iron castings were melted in a laboratory thyristor controlled coreless induction furnace of 15 kg capacity, 9.6 kHz, has been employed for the production of ductile iron castings (Figure 4.2). The charge material was low manganese carburized steel of low sulphur and low phosphorus content. Carbon additions were made using petroleum coke. Silicon content was built up to the required level using ferrosilicon. The furnace lining has been done prior to the melting operation. The charge calculations have been done based on weight of the casting to be produced in permanent moulds to achieve identical composition. The charge material i.e., mild steel is taken in the crucible and the power of the furnace is raised from 0.5 kW to 5 kW at an interval of 10 minutes and thereafter it is raised to 15 kW in steps of 2 kW at an interval of 10 minutes. The alloying elements and other charge materials (about 6 kg) are added to the molten metal. Details of the charge added to molten metal are in the following order.

The melt was superheated to 1500° C. Nickel-manganese alloy was used as spherodizer and post inoculation was done using ferrosilicon (inoculation grade). The melt was poured at 1400–1425° C into a preheated (400° C) grey cast iron mould. As shown in fig.2

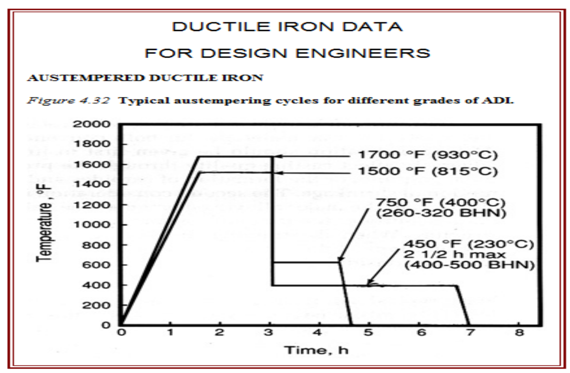

Fig.2 conventional Austempering process

Foundry process, Coating of the Metal Mould

The zircon or graphite paste is taken and mixed with a thinner to make it less dense, and then it is painted on the inner walls of the mould. The thinner is then ignited. Methanol alcohol is generally used as the thinner.

Melting, Moulding and Pouring procedure

To prepare the molten metal of right composition, initially the charge was melted in an induction furnace of capacity 15 kg, 9.6 KHz, 15 KW of maximum power, where Gradually the temperature was brought to 1600°C. During this time, coke, and sand were added to be melted in the specified percentages. The slag were removed at regular time periods. This was done by adding slag powder. Slag powder, used in this project, was slag sand (granulated Copper slag). The metals with the following composition were melted in the induction furnace at a temperature of 1559°C.Below shown the chemical compositon of test samples

carbon	3.8-3.95%
silicon	2.6-2.8%
manganese	0.8%
sulphur	0.002%
phosphorus	0.012%
magnesium	0.045%

Once the temperature was obtained the molten metal was poured into the die and the [mal casting was obtained of dimension 150mm*125mm*25mm which was cooled at room temperature and grade of 600/3 ISO STANDARDS was obtained.

Heat treatment Procedure: Test samples were heated to the austenitizing temperature of 950°C, and austempered at different temperatures(300°C, 350°C, 400°C, 450°C) and different soaking periods (30min,60min,90min,120min) for 2 hours and to saturate the austenite with carbon. Quenching (cooling) the part rapidly enough to avoid the formation of pearlite at four different austempering temperature namely 300°C, 350°C, 400°C, 450°C, Austempering the part for a time sufficient to produce a matrix of ausferrite ,Cooling the part to room temperature.

Temperature (°C)	Time (Minutes)		
300	30	60	120
350	30	60	120
400	30	60	120
450	30	60	120

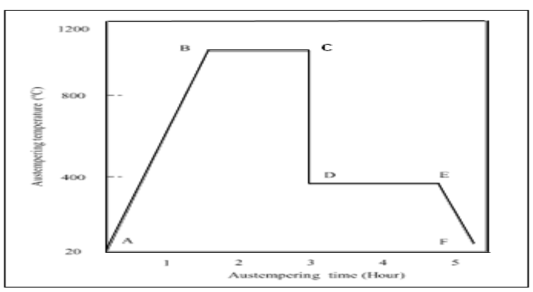

Fig: Schematic of the conventional single-step austempering process

A-B: heat up to the austenitizing temperature; B-C: hold at the austenitizing temperature (usually 2 h); C-D: quench to austenitizing temperature; D-E: hold at the austenitizing temperature (usually between 2–4 h); E-F: air cool to room temperature

Impact strength

The impact test is used to find out the energy required to rapture a material under sudden application of load. Different types of notched bar impact tests are carried out to determine the tendency of a material to behave in a brittle manner. Notch creates stress concentration which will ensure that fracture does occur evenly along the bar and causes it to plastically deform by breaking rather than bending. In this context Charpy test is conducted on an un notched bar which is held horizontally as it is hit by the pendulum.

Impact Energy = I =U - f

1) U = W * r * (Cos B - Cos A)

Where,

D = diameter

I = Energy consumed

f = frictional loss

Test conditions

a = 140^0 for Charpy test (angle of fall)

Weight of pendulum (W) =21.25 kg

Radius of the pendulum=0.825m

B =angle of rise

Procedure:

The dimension of the specimen and weight and length of the pendulum are noted. Using position gauge the specimen is positioned correctly on the anvil. The pendulum is lifted to its upper position and with no specimen on the anvil, it is released and the reading is noted. This reading gives the friction offered by bearings and air resistance of the Pendulum. Now the specimen was placed in the anvil and the pendulum is allowed to strike and rapture it. The pendulum by means of a hand brake and the angle of rise is calculated. The experiment is conducted for all the samples and the results are tabulated and calculated.

4. RESULTS & DISCUSSION

4.1 Impact Energy (bar graphs)

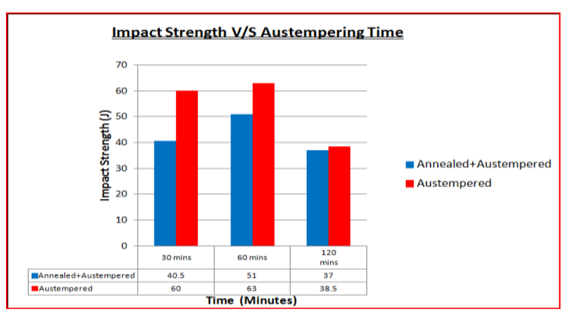

Fig. Impact energy of samples Austempered at 300°C

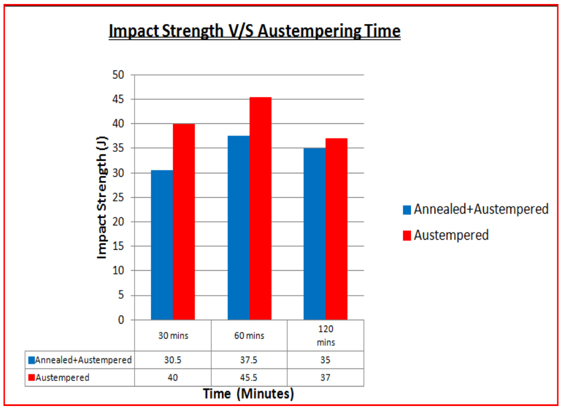

Fig. Impact energy of samples Austempered at 350°C

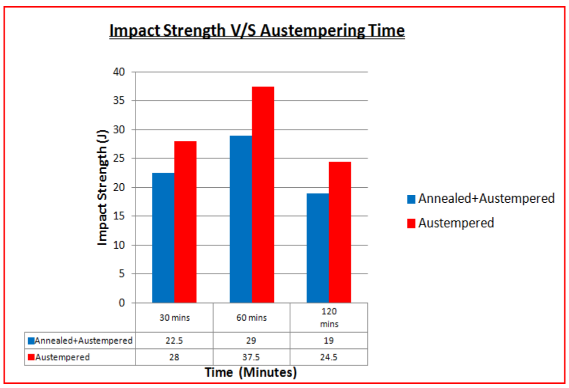

Fig. Impact energy of samples Austempered at 400°C

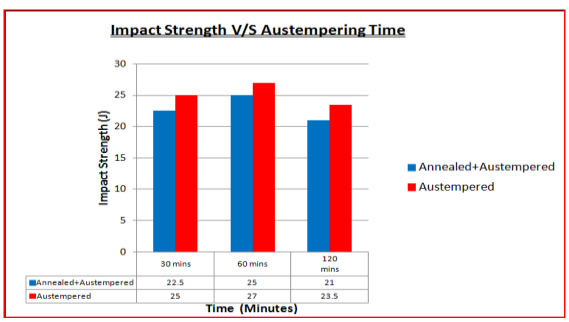

Fig. Impact energy of samples Austempered at 450°C

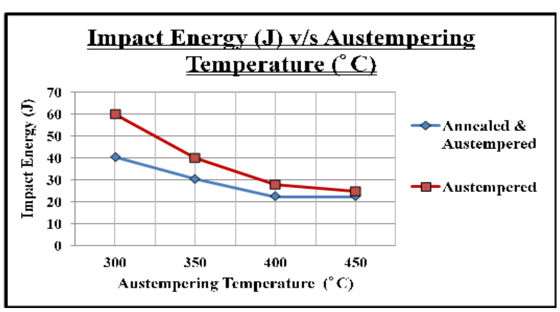

Fig. Impact energy of the samples Austempered for 30 mins

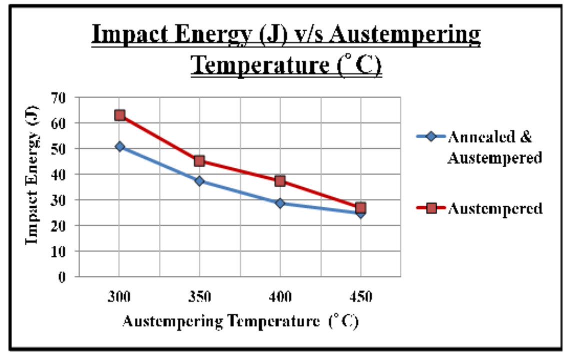

Fig. Impact energy of the samples Austempered for 60 mins

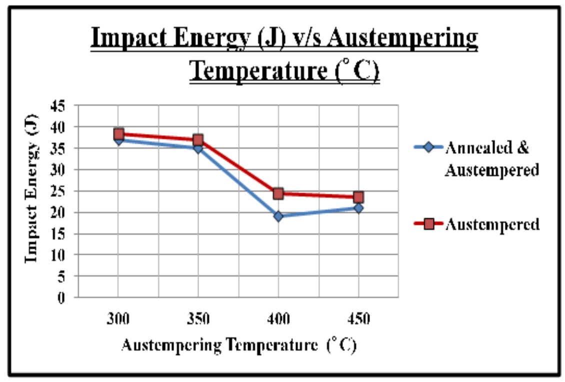

Fig.Impact energy of the samples Austempered for 120 mins

4.2 Table of Results, Impact energy for all the samples at different temperatures

	Impact Energy(J)	
Time(Minutes)	Annealed & Austempered	Austempered
30	40.5	60
60	51	63
120	37	38.5

Impact Energy for the Austempered samples at 300^{0}C

	Impact Energy(J)	
Time(Minutes)	Annealed & Austempered	Austempered
30	30.5	40
60	37.5	45.5
120	35	37

Impact Energy for the Austempered samples at 350^{0}C

5. MICROSTRUCTURE

5.1 Austempered ductile iron at 300^0C for 60 minutes *with etching*

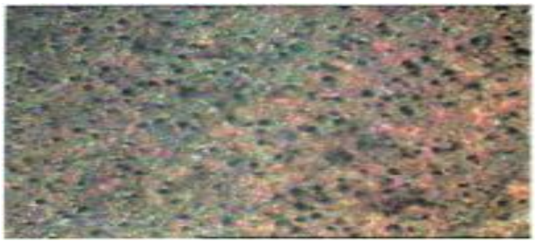

Fig.A Microstructure of ADI at 300^0C for 60 mins (with and without etching) with magnification 100X

5.2 Austempered Ductile Iron at 400^0C for 60 minutes with etching

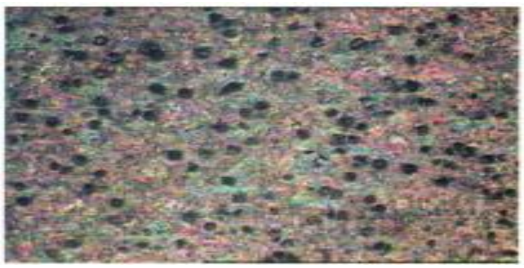

Fig.B Microstructure of ADI at 400^0C for 60 mins(with etching)with magnification 100X

5.3 Table of Nodular Size & Nodular Density

Material	Nodular size	Nodules / mm^2
Austempered at 300° C for 60 minutes	6 to 7	225 to 250
Austempered at 400° C for 60 minutes	6	75 to 100
Annealed & Austempered at 300° C for 60 minutes	6	150 to 180
Annealed & Austempered at 400° C for 60 minutes	6 to 7	175 to 200

6. CONCLUSION

In this research work, experiments have been carried out to study the influence of austemparing temperature and soaking time on the impact strength of austempered ductile iron casted in permanent molds. The Impact Energy was found to be maximum for test samples Austempered for a duration of 60 minutes. The Impact Energy was found to be maximum for an Austempering temperature of 300^0C. From the experimental results we can observed that the impact strength of the test samples is decreasing with increase in Austempering duration. The Microstructure of the samples was studied for different austempering temperatures and soaking times durations. From the microstructure photographs its was observed that Graphite nodules of size varying from 6 to 7 with distribution of nodules/mm' varying from 75 to 250 depending on the Austempering Temperature and time duration. Figures(fig5.1,5.2) shows representative micro photographs of the test samples.

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