MECHANICAL PROPERTIES AND CORROSION CHARACTERISTICS OF IS400/12 GRADE DUCTILE IRON

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ABSTRACT

In the present investigation, ductile iron castings conforming to IS400/12 grade were produced using green sand moulds. The castings were produced in a regular production foundry using 1.25T Induction Furnace. The molten metal was subjected to standard desulphurisation and modularisation to get graphite in the nodular form. The molten metal was poured into the sand mould and allowed to solidify. Based on the earlier investigation by the above group (1,4) the castings were austenitised at 900°C for 120m and quenched in a salt bath consisting of potassium nitrate and sodium nitrate in the ratio of 55:45 and maintained at 310°C for 120 minutes to bring about austempering treatment. The result in austempered ductile iron will consist of graphite nodules in a matrix of bainite.

The effect of austempering heat treatment on microstructure, mechanical properties and corrosion characteristics were studied and compared with the as-cast condition. Mechanical properties such as ultimate tensile strength, percentage elongation, hardness and impact strength were determined. Corrosion tests were carried out to determine the weight loss and corrosion rate of specimens; using salt spray fog type apparatus. Corrosion test was carried out for two different operating temperatures viz. 35°C and 45°C.

The results of the investigation indicate that the austempered castings show higher UTS values (34% increase), elongation values (24.2% increase) and hardness values (12.05% increases) as compared to the as-cast condition. From the corrosion studies, it is seen that austempered specimens exhibit lower weight loss (34% improvement), lower corrosion rate (33% improvement) compared to the as-cast specimens.

INTRODUCTION

Ductile Iron consists of graphite in the form of nodules or spheroids in a matrix[1,2] of either ferrite or pearlite. The properties of ductile iron combine the properties of cast iron and steel. Iron with varying microstructure can be obtained by varying the treatment conditions during melting, after treatment and also by heat-treating the castings. By altering any one of the parameters, a suitable iron as per requirements and application can be obtained. In order to improve the properties of ductile iron, the material can be treated with alloying elements or can be heat-treated to bring about change in the microstructure of the material. Commonly, austempering heat treatment is carried out on ductile iron; hence he name “Austempered Ductile Iron” or “ADI”. ADI has found its way in a wide range of components[5,6] for many engineering sectors as in gears, crank shafts, transmissions, suspensions, earth-moving and construction equipment, railways etc.

Wear is an important property, which is evaluated in materials to find out its response to undergo loss of material. It is a progressive, unintentional loss of material when two surfaces come in contact under normal load and there is relative motion between the surfaces. Wet abrasive wear test is one method for evaluating the material behaviour to wet abrasive action.

Different corrosion testing methods are available viz. Electrochemical test, salt spray test, total immersion test etc. The choice of the corrosion testing methods as reported[7,8] depends upon many factors such as nature of environment, nature of exposure, type of specimen etc.

Salt Spray Fog test[6] is one of the corrosion testing methods, which involves the exposure of the specimens to fine spray as mist of a solution of sodium chloride at a specified temperature. The spray particles settle upon the test surface (which is preferably inclined) and constantly replenish and replace the film of solution on the surface. The extent and nature of the corrosion of the metal or coated surface after a specified period of exposure serve as a measure of quality/corrosion resistance. To accelerate corrosion the temperature of the media or the pH of the media or the concentration of the media can be varied.

Many Indian foundries are producing ductile iron on a commercial scale since a few decades. However, the production of ADI in India is still in infant stages. Hence, in the present investigation ductile iron conforming to IS400/12 grade was produced and austempered for the best conditions hence, in the present investigation a systematic study was taken up for structure examination, assessment of mechanical properties, and corrosion properties for different time and temperature levels.

Experimental Details

i) Mould Material Used : Silica sand having a grain fineness of AFS61 was used for making the moulds. Greensand moulds were prepared using 5% bentonite and 3.5 % water. Cylindrical test bar castings of 30mm dia and 300mm length were produced using cope and drag moulds. Figure 1 shows the details of the cope and drag pattern used to prepare the test bar.

ii) Melting, Casting and Treatment : Charge consisting of Grey Cast Iron; foundry returns; ductile Iron, commercial pig iron (S<0.05%), mild steel punching was used. Conventional techniques of melt treatment and heat treatment were carried out as shown in the flowchart Fig.2 to produce ductile iron castings and ADI castings. The composition of IS400/12 was 3.6%C, 2.8%Si, 0.35%Mn, 0.03%P(max) and 0.03%S(max) with 0.03%Mg (min).

iii) Evaluation of Properties: Standard metallographic procedures like grinding and polishing were done for microstructure examination. Standard test procedures were employed for structure examination and mechanical property assessments.

iv) Dry Sliding Wear Test: The specimens in the form of 5mm pins were prepared in a lathe and used as a sample for dry wear test. A hardened circular disc having hardness of 64HRC was used as counterface. The testing was carried out by allowing the specimen to rub against hardened disc for a given normal load and speed condition. Making use of pin on disc machine test was carried out. The specimens were taken out at regular intervals and the weight was recorded. The experiment was conducted for different load, speeds and different conditions of metal (as-cast or heat treated). Figure 3a shows the details of wear testing machine used in the investigation.

Metal charge (PI,CI,Steel punching,Soral PI)

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Induction Furnace
1.25T, 200HZ

↓

Melt was superheated
155^{o} and Desulphurised with
1.9% CaC_2 to reduce S level to <0.05%

↓

Desulphurised Iron was poured into a Ladle
containing Fe-Si-Mg alloy using sandwich method

↓

Post inoculated with 0.3% FeSi & the melt was stirred.
Slag removed

↓

Molten metal poured into the moulds and cooled

↓

Castings were heat treated by first austenitising at 900^{o}C for 120 minutrs
Quenched in salt bath containing KNO_3: $NaNO_3$: : 55:45 maintained at a known temp. level and held at this temp. for 120 minutes

↓

Castings cooled

↓

The resulting Iron is ADI

Flow chart for ADI casting production.

v) Wet Abrasive Wear Test: The specimens in the form of bolts were subjected to abrasive action by making use of rotating disc dipt inside a slurry consisting of abrasive media and water maintained at given pH level. The specimens are rotated in the slurry for known duration of time and regular intervals of two hours the testing was stopped, specimens are taken off and cleaned well using alcohol and water and dry using a drier. The initial weight of the sample and the subsequent weight of the sample measure on continuous scale will give the wear of the specimen at a given time interval. It was carried out for 24hours and graphs are plotted. Figure 3b shows the details of wet abrasive wear testing machine used in the investigation.

vi) Impact Studies: Impact test was carried out using standard Izod (cantilever type) and standard Charpy (simply supported) specimens and evaluation of impact on specimen in as-cast condition and heat-treated condition. It is absorbed on heat treatment, the impact values will come down appreciably.

vii) Corrosion Studies: Corrosion studies were carried out using standard salt spray fog type testing machine. Corrosion testing apparatus conforming to ASTM standard B117 specification was used. The corrosion rate of the specimen was calculated using the formula

Corrosion Rate (mpy)= (534xW) / D A T

W = Weight loss in mg,
D = Density of the specimen in gm/cc,
A = Area in square mm,
T = Exposure time in hours
mpy = million parts per year

Weight loss method was employed to assess the corrosion of the specimen. At regular intervals, the specimen was taken out and the weight is determined for calculation of loss in weight or corrosion. Figure 3c shows the details of the fog type corrosion apparatus used in this investigation.

Steps involved

- Rectangular slab specimens of 50mm x 25mm x 6mm thick (after noting down the initial weight) was hung using a nylon wire inside the fog chamber..
- The corrosive media consisting of water and sodium chloride in the ratio 95:5 on weight basis was filled at the bottom of the chamber.
- The outlet of the compressor was connected to the nozzle and the heating coil was switched on; the corrosive solution gets heated and the temperature inside the cabinet was held constant (viz. 35^oC and 45^oC) throughout the duration of the test.
- Compressed air at a constant pressure of $2kg/cm^2$ was blown through the nozzle for the entire duration of the test to cause bubbling action in the salt bath and create fog in the chamber.
- The specimen was exposed to corrosive atmosphere was 24 hours, at the end of every 2 hours, the test was stopped, the specimens were removed and cleaned with distilled water. The specimens after the test were thoroughly cleaned as per ASTM G181 specifications and the corrosion rate was determined.

RESULTS AND DISCUSSION

Microstructure Examination

Figures 4a & 4b show the details of the microstructure. In the as-cast condition, the graphite nodules, are more or less uniform and evenly distributed. In the heat-treated condition, the austempered specimens exhibit bainitic matrix.

Mechanical properties

The variation of ultimate tensile strength, percentage elongation and hardness values of the specimen are shown in Table-1. It can be seen that the UTS values, percentage elongation values and hardness values of the heat-treated specimen or higher than the as cast ones. This may be due to the formation of bainite in the heat-treated condition.

Table-1 details of Mechanical properties under as cast heat-reated condition.

Dry Sliding Wear

The variation of loss of weight at 3 different speeds and 3 different loads were evaluated Figs.5-8 consolidates the details of the test carried out for evaluating dry wear. Wear of, as cast specimen is higher than heat-treated condition for any given speed or any given normal load condition. Dry sliding wear increases with increase in time of testing. Decrease in wear for heat-treated specimen, varies from 15 to 20% with respect to as cast specimen.

Wet Abrasive Wear

Figs.9-11 shows the variation of wet abrasive wear as the function of time for different pH values and casting condition. Wear increases with time of testing for all the pH levels tested. Heat-treated specimen seems to show lower wear as compared to as cast specimen. Specimen under pH8 seems to show higher wear compared to other pH levels.

This behavior may be attributed to longer exposure of specimen to abrasive, heat treated specimens develop higher hardness and strengths and neutral media seems to wear specimens faster.

Table-2 shows the details of the wet abrasive wear for as cast and heat-treated condition for different pH values and at the end of 2 hrs & 24 hrs of testing.

Impact Test

The Izod impact results show that the impact energy decreases on heat treatment indicating that the specimen tends to become brittle. There is a decrease in energy level by nearly 29% as shown in Table-3.

Charpy result shows that the impact energy decreases on heat treatment. But there is a tendency to show sudden drop. The decrease is as high as 71% this may be attributed to the type of arrangement used for impact measurement and due to the specimen tending to become brittle.

CORROSION STUDIES

Corrosion

The weight loss of specimen in as-cast condition is more than heat-treated condition for any given temperature. The weight loss in specimens subjected to corrosion at higher temperature is more. This may be attributed to higher reaction involved at higher temperature of the fog mixture. The corrosion rate for specimen in as-cast condition is more than heat-treated condition for any given temperature. The corrosion rate is more at higher temperatures of the fog mixture. This may be attributed to more resistance offered by the heat-treated specimens and higher reaction rate involved at higher temperature. Figure 12 shows a representative graph of corrosion v/s time at 35^{o}C.

Corrosion Rate

The variation of corrosion rate (in mpy) versus time of testing (in hours) for as-cast and heat-treated conditions is shown in Fig.13. It can be seen from the graph that with increase in the duration of testing, the corrosion rate decreases. Corrosion rate is less in the heat-treated specimens compared to the as-cast ones. This may be due to presence of bainitic structure, which offers more resistance to corrosion; whereas in the as-cast condition the structure consists of ferrite.

Similar results were obtained for testing carried out at 45^oC.

Table-4 shows the variation of corrosion and corrosion rate for 35^oC & 45^oC of the fog.

CONCLUSIONS

The results of the investigation carried out on as-cast ductile iron and austempered ductile iron indicate the following :

- Graphite nodules are more or less uniform and are evenly distributed; upon austempering the structure shows bainitic matrix in the iron.
- Mechanical properties such as ultimate tensile strength, percentage elongation and hardness values are enhanced compared to the as-cast condition.
- Impact test shows that impact energy decreases on heat-treating of the specimen.
- Dry sliding wear shows that on heat treating the specimen shows higher resistance to wear
- Wet abrasive wear also shows higher resistance to wear in the heat-treated condition.
- Studies on corrosion shows that the weight loss is more in as-cast condition compared to heat-treated condition. It was also observed that corrosion is more at higher temperature of the bath.
- The corrosion (rate) of the heat-treated specimen is less/reduced compared to the as-cast conditions.

Hence, it is clear that by austempering the ductile iron castings, better mechanical properties and corrosion resistance properties are realised.

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