CHARACTERIZATION OF HEAT TREATED DUCTILE IRON THROUGH FRACTOGRAPHIC ANALYSIS

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Abstract:
Ductile iron specimens are subjected to different isothermal heat treatment processes and the properties obtained are studied to be used for spent nuclear fuel (SNF) cask application. Annealing treatment on the specimen yield to increase in ductility and impact strength and tempering of the specimen resulted in higher strength and hardness compromising ductility and impact resistance. Fractographic analysis confirmed the dominance of ductility over brittleness in annealed specimen and the case is reverse for normalized and tempered specimen. Both the normalized and tempered specimens are observed to have river markings whereas dimples are clearly seen in annealed specimen, which are the characteristics of brittle and ductile fracture respectively.

Keywords:
Heat treatment, mechanical properties, ductile fracture, river pattern

I. INTRODUCTION

Because of good mechanical properties ductile iron (DI), since its evolution has become most appropriate candidate for many structural as well as many other applications starting from automobile parts to spent nuclear fuel (SNF) storage cask. Although in as-cast condition DI gives good strength properties for any desired application, they can be improved by subjecting to suitable heat treatment process. Two stage or full annealing treatment is opted where high ductility and better impact resistance is required [1, 2]. A harder and brittle form of DI can be achieved by heating it above austenitizing temperature followed by rapid cooling to room temperature i.e., by subjecting to normalization treatment. A higher strength value of 1600MPa can be achieved by subjecting to austempering treatment in case of thin wall ductile iron specimen with uniform distribution of nodules and higher nodule count. Heat treatment of DI specimens leads to increase in strength properties at expense of ductility or vice versa. But when there is a need of combination of both strength and ductility tempering or austempering treatment is opted.

Practical industrial application of any material at a certain period of time fails due to many reasons. Finding the background story of failure can be carried using a very powerful tool i.e., fractographic analysis by observing the fracture surface under sophisticated microscopes. The failure phenomena of ductile materials characterized by presence of dimple patterns whereas the brittle ones are characterized by river pattern and cleavage facets. Reference [3] studied the behavior of DI with dual matrix structure subjecting to different austempering condition leading to formation of different ausferritic volume fractions. Result of their study showed increase in tensile strength with increase in austempering temperature and time. They have also reported the ductile nature of fracture featuring deboning of graphite nodules from the surrounding ferrite structure and a dimple pattern of fracture for fully ferritic matrix. Reference [5] has studied the fracture toughness behavior of copper alloyed austempered ductile iron (ADI) and reported existence of cleavage facets with river pattern in as-cast whereas dimples and ductile tearing in ADI for impact toughness specimen. Reference [6] has studied the nature of fracture on ADI samples and reported that with increasing austempering time the ductile mode of fracture is predominant while for a shorter period of austempering time mixed mode of fracture is exhibited.

The current study is focused to observe the behavior of heat treated DI specimens in terms of mechanical properties and to understand the fracture phenomena affected by different rate of cooling and cooling medium.

II. EXPERIMENTAL DETAILS

A. Specimen preparation

Chemical composition of the DI test block is given in Table 1. Prior to heat treatment Tensile and Charpy impact specimens are machined following ASTM E8 and ASTM E23 standards respectively from the test block brought from L&T Kansbahal, Odisha, India.
Table 1: Chemical composition of DI test block

<table>
<thead>
<tr>
<th>Elements</th>
<th>Wt %</th>
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<tbody>
<tr>
<td>C</td>
<td>3.45</td>
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<tr>
<td>Si</td>
<td>2.07</td>
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<tr>
<td>Mn</td>
<td>0.15</td>
</tr>
<tr>
<td>S</td>
<td>0.008</td>
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<tr>
<td>P</td>
<td>0.024</td>
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<tr>
<td>Cr</td>
<td>0.02</td>
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<tr>
<td>Ni</td>
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<tr>
<td>Mg</td>
<td>0.043</td>
</tr>
<tr>
<td>Fe</td>
<td>Balance</td>
</tr>
</tbody>
</table>

B. Heat treatment

The tensile and impact specimens are austenitized to 1000°C and allowed to soak there for 90mins. Specimens are then cooled to 700°C and held there for 5hrs 30mins followed by furnace cooling to room temperature in case of two stage or full annealing heat treatment. Normalizing heat treatment is conducted by austenitizing the specimen to 1000°C and soaked for 90mins followed by air quenching to room temperature. Same austenitization process is followed for tempering of specimens and quenched in paraffin oil (0.86-0.89 kg/m3) maintained at 100°C followed by tempering at 500°C for 2 hrs. The respective heat treatment processes are presented in Fig. 2.

C. Mechanical testing

Tensile test is performed on each of the respective specimen using INSTRON 1195 by application of 60KN load at a crosshead speed of 1mm/min at room temperature. UTS, 0.2% YS, ductility along with stress vs. strain curve has been determined and plotted with help of computer interface and printer. Charpy impact test is carried out with a Charpy impact tester with 30Kg hammer and striking angle of 150°. The energy absorbed by each type of specimen was recorded. Macro hardness test was obtained by applying a load of 20Kg using Vickers hardness tester.

D. Fractographic analysis

Specimens after each type of fracture have been observed under scanning electron microscope to identify the nature of fracture.

III. RESULTS AND DISCUSSION

A. Mechanical properties

Mechanical properties of respective specimens are presented in Table 2. Annealing of DI specimens has increased the ductility and impact strength, whereas the tempered specimen has highest UTS and hardness value. However an ambiguous behaviour is seen by tempered specimen that it has lower 0.2% YS than the normalized specimen though it has higher UTS value. The result obtained may be due to some errors while conducting the test or during heat treatment.

B. Fractographic analysis

The fractographic images for respective specimens after tensile and Charpy impact test are shown in Fig. 3 and Fig. 4 respectively. Presence of dimples which are due to formation of microvoids and coalescence phenomena is clearly observed in annealed specimen Fig. 3(a). These dimples are result of intensive local strain in the fully ferritic matrix around the nodules and internal necking [4]. Microvoids initiated at the graphite matrix interface and grow under triaxial state of stress until they coalesce to leave behind the large cavities called dimples are observed s reported in [3, 4]. It is evident that ductile fracture characterized by these dimples is dominating over brittle fracture, also showing a cup & cone type failure. On the other hand in Fig. 3(b) the normalized specimen appears to be dominated by brittle fracture over ductile showing river markings in the matrix around the nodules. Unlike the annealed and normalized specimens which have either ductile or brittle failure dominant, the tempered specimen is not dominated by any of these two failure mechanism. Rather it has both river patterns and dimples when observed under higher magnification Fig. 3(c) & Fig. 3(d) respectively and appeared to have a mixed type nature of failure. Similar type phenomena are observed for impact specimens in respective heat treated cases. Annealed specimen Fig. 4(a) appears to be fail in ductile manner whereas normalized and tempered Fig. 4(b) & Fig. 4(c) respectively specimens appeared to have brittle fracture characteristics. Specimen with higher impact strength i.e., specimen AN, dimples patterns are found to be the only operative mode of failure and for the case of minimum impact strength i.e., specimen NO river patterns and cleavage facets are the only characteristic that plays important role in fracture, which is also reported in [7].
IV. CONCLUSION

Ductile iron specimens are subjected to three different types of heat treatment processes and mechanical properties are obtained for each type of process. Results obtained are summarized below.

1. Full annealing lead to increase in ductility and impact strength at the expense of strength and hardness.

2. Cup & cone type fracture phenomena are observed for annealed specimen which is the characteristics of ductile fracture.

3. On the other hand normalized specimen showing brittle fracture characteristics in the form of river markings & cleavage planes.

4. The tempered specimen shows both river markings and dimples at higher magnification, concluding a mixed mode of failure.

5. Fracture surfaces of respective specimens after impact testing shows ductile failure for annealed specimen and brittle failure for normalized and tempered specimen.

V. Acknowledgement

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References


