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Fabrication of forced air cool austempered ductile iron and exploring its corrosion behaviour in a simulated mine water

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Abstract

The production of austempered ductile iron (ADI) with uniform microstructure and properties is constrained by the austempering process vis-à-vis the quenching medium. This is as a result of the stringent operating parameters with costly facilities. This limitation has restricted the application of ADI, despite its inherent mechanical and chemical properties. An emerging technology of overcoming this limitation is by austempering with force air cooling equipment, which is accessible, available and cost-efficient. This work characterizes the behaviour of the forced air cool ADI in simulated mine water due to the strategic importance of the mining industry in the global economy. The study establishes the influence of sample section thickness on the corrosion performance. The sample's thickness were 5, 15, and 20 mm. Electrochemical experiments were performed on the forced air cool ADI at atmospheric pressure and room temperature with method such as open circuit potential (OCP). The post-corrosion analyses were performed using X-ray diffractometry (XRD) and field emission scanning electron microscopy (FESEM). The research highlighted that small section thickness has a more favourable performance compared with larger section. Consideration is also accorded to the capability of the ADI in the studied environment.

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Keywords: Austempering process; forced air cool quenching; austempered ductile iron; simulated mine water.

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1. Introduction

Production of austempered ductile iron leads to development of unique microstructure capable to offer excellent toughness and wear resistance and has been shown to have superior fatigue properties as well [1]. The production process consists of two different stages namely; casting and heat treatment. The latter is the dominant process which will determine the possibility of producing good engineering parts. The heat treatment facilities capacity, defects free casting, and optimization of heat treatment parameters are some of the limiting factors [1-2]. However, an emerging technology of overcoming this limitation is by austempering with force air cooling equipment [3], which is accessible, available and cost-efficient. The performance of tempered parts is a function of the section thickness which significantly affect its industrial applications. There is paucity of information on the corrosion behaviour of forced air austempered ductile iron in mining industry and this has prompted the attempt to explore the chemical stability of this material in this environment.

Hence, this study considered the corrosion behaviour of austempered ductile iron produced using forced air as quenching medium in simulated mine water with a view to assess the impact of the sample thickness. The goal does not capture the effect of austempering parameters such as temperature and time on the performance of the ADI in the studied environment.

2. Experimental procedures

This study involve production of austempered ductile iron (ADI) of various section thickness due to the limitation associated with thickness and microstructure during quenching process. The ADI was thereafter investigated for their corrosion resistance in simulated mine water. Ductile iron used as the starting material was manufactured at Nigerian Foundries Limited, Sango-Ota, Nigeria with production parameters and procedure as presented in Table 1.

Table 1: The production parameters for the austempered ductile iron

S/N	Furnace type and capacity	Medium frequency (3000 Hz) coreless induction furnace with melting capacity of 500 kg
1	Charge composition	15% pig iron, 20% ductile iron return and 65% steel scrap
2	Charge composition modifier	75 wt.% FeSi, 70 wt.% FeMn and graphite
3	Superheating	1550 °C to ensure homogenisation
4	Tapping temperature	1450 °C onto 5.5wt. % of Fe-Si-Mg
5	Post inoculation treatment	75 wt. % Fe-Si
6	Casting temperature	1440 °C
7	Casting method	Green sand mould
8	Casted shape	Y-blocks
9	Sample section thickness	5, 15, and 20 mm
10	Preheating temperature and time	300 °C; 1 h
11	Austenitising temperature	820 ^{o}C
12	Austenitising rate	180 ^{o}C/h
13	Soaking rate	1 h
14	Austempered temperature	300 °C
15	Austempered time	2 h
16	Quenching medium	air cool to room temperature.

Prior to corrosion tests , an electrical wire was fastened to a side of the samples with conductive aluminium tape to ensure electrical connection, then the samples were mounted into epoxy resin. The exposed samples surface were wet-ground with SiC grit sizes ranging from 240 to 1200, polished with 15 µm diamond suspensions, degreased with acetone, washed in a stream of water and dried in air. Simulated mine water with chemical composition as listed in Table 2 was prepared according to Masuku *et al.* and the measured pH was 6.0. The corrosion test was ppen circuit

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potential. The sample was the working electrode, graphite as the auxillary electrode, (AE) and a 3 M KCl saturated Silver/Silver Chloride electrode (Ag/AgCl) acted as reference electrode (RE) to complete the three electrode cell. The surfaces of the specimen was polarized from –1 V below OCP to +1.2 V above OCP at a scan rate of 0.25 mV/s and the test was carried out using AUTOLAB PGSTAT 304N at room temperature.

3. Results and discussion

The possibility of the degradation process taking place is examined using open circuit potential, the corrosion rate was examined with the capability of the fabricated austempered ductile iron assessed using the hardness values and lastly, the microstructural behaviour were reported. Figure 1 presents the open circuit potential for the samples after two hours and there is no noticeable trend in the behaviour. For example, the OCP for 5, 15, and 20 mm are -0.684, -0.624 and -0.634 V respectively. The reason for this can not be explained but it may be adduced to the difficulties associated with production of good morphology during austempering process.

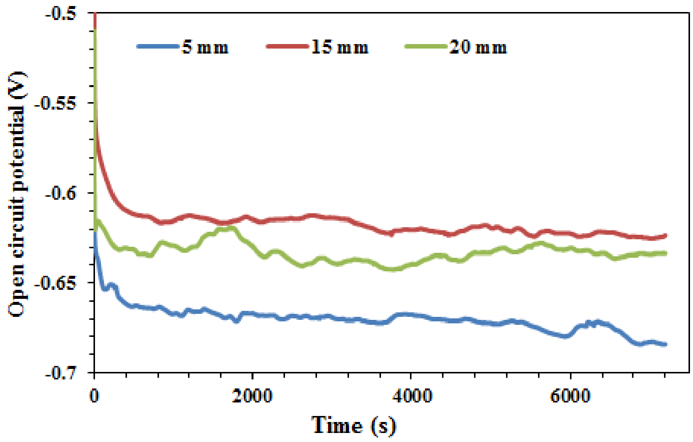

Fig. 1: Open circuit potential for the austempered ductile iron at various section thickness

The effect of the austempered ductile iron thickness on the corrosion rate in simulated mine water solution and the microhardness profile are shown in Figure 2. There is distinct increase in the corrosion rate as the section thickness was increasing and this can be attributed to the success or otherwise of the austempering process. It is suspected that as the thickness increases the effectiveness of the quenchant decreases. Hence the morphology was not well formed. Evidently, the microhardness values were inversely proportional to the corrosion rate as the section thickness increases and it was revealed that as the section thickness is increasing the microhardness values decreases parabolically. The highest microhardness value was obtained for sample with 5 mm thickness having an average of 365.89 HV whereas 329.22 HV were recorded for 20 mm thick sample. This could be attributed to the phases and microstructure present in the specimen which reinforced the earlier assertions that the microstructural transformations and varied retained austenite volume fractions affects the properties of austempered ductile iron [2].

In Table 3, the presence of austempered ductile iron alloying elements such as C, Si, and Fe are confirmed with the aid of EDS technique using mapping analysis. Comparative analysis of the alloying elements revealed that the elemental iron content decreased from 62.35 to 52.53% and there is little difference in the silicon composition. This is in contrast with an earlier report that concluded that there is silicon enrichment in the corrosion product [4].

Although it is considered that carbon content of retained austenite influenced the behaviour of ADI material, there is relatively no significant difference in the as-received and corroded samples carbon content. The presence of oxygen in the corroded coupon can be attributed to the oxidation products and the abundance of oxygen in the simulated mine water environment.

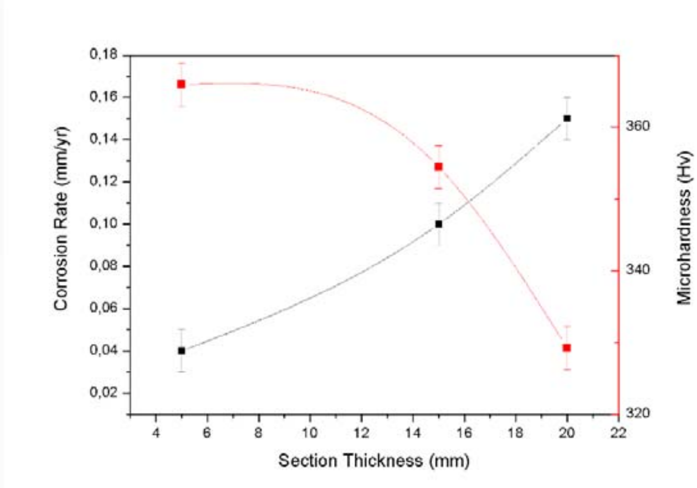

Fig. 2: The effects of section thickness on the corrosion rate and microhardness of the austempered ductile iron in simulated mine water.

Table 2: Elemental composition of the austempered ductile iron as received and after immersion in simulated mine water as obtained from EDS

S/N	Elements	Weight (%)	
		Before	After
1	C	35.03	36.45
2	Si	2.62	1.85
3	O	-	9.7
4	Fe	62.35	52.53

The morphologies of austempered ductile iron is characteriterized with the presence of ausferrite which is a unique structure consisting of a mixture of acicular ferrite and carbon-enriched stabilized austenite [2]. This feature were clearly shown in Figures 3 (a and b) where the structure have graphite nodules dispersed in ausferrite matrix. The ausferrite matrix becomes coarse and its acicular ferrite becomes longer as the sample section thickness increases and this is attributed to the effect of the quenching process on the austempering quenching process. Typical SEM images of corroded ADI in simulated mine water are presented in Figures 3 (c and d). It is obvious that the microstructure is still graphite nodules been dispersed in the ausferrite matrix. However, the nodules have been attacked and its nodularity affected; there is also the deposit of corrosion products on the ausferrite matrix. It has been proposed that the matrix acts as anode around the graphite (cathode) and as such the graphite peeled off. There is a mixed type of graphitic corrosion and uniform attack and it is expected that the corrosion rate is reduced due to the occurrence of retained austenite in the matrix [5].

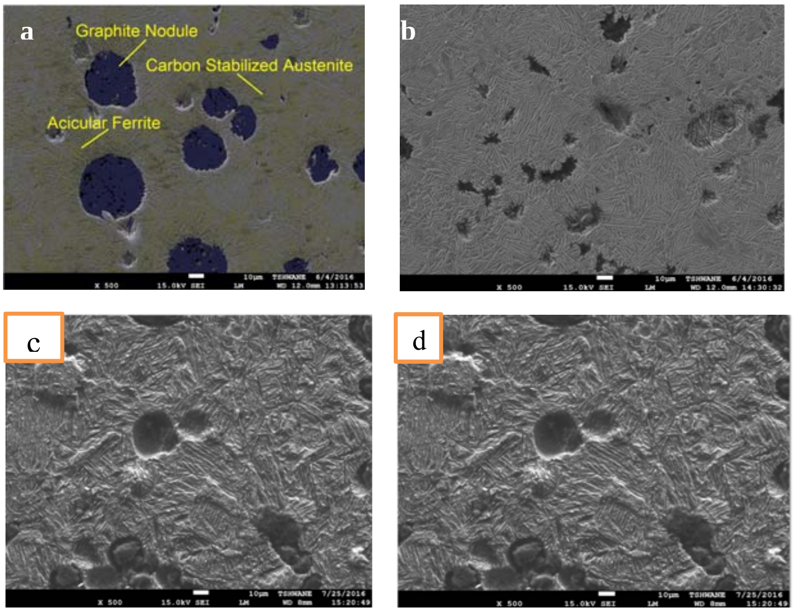

Fig. 3. SEM images of the austempered ductile iron (a) as received – 5 mm (b) as received – 15 mm (c) corroded – 5 mm and (d) corroded 20 mm

4. Conclusion

The corrosion characteristics of fabricated austempered ductile iron by forced air cool quenching medium was achieved with the aim of assessing the section thickness in simulated mine water. The produced ADI performance revealed that the corrosion rate is a function of the thickness which is due to the grain growth and nucleation and the hardness values were inversely related to the section thickness. The effect of austempering temperature and time on the corrosion behaviour of the forced air cool austempered ductile iron is currently under investigation. Attempt is in progress to examine the phases with the aid of XRD so as to correlate it with the microstructural evaluation in order to have a complete understanding of the material performance under the studied conditions.

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