Microstructure and Mechanical Characterization of Austempered AISI 1018 Steel

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Abstract- AISI 1018 mild steels are widely used for engineering applications in machine components and for structural purposes. These materials suffer mechanical damages especially when used under critical conditions of extreme load. In this study, the effect of austempering heat-treatment on the hardness, tensile strength, impact energy and the microstructure of AISI 1018 steels were evaluated. The steel specimens were subjected to austempering heat-treatment by austenitizing at a temperature of 830°C, maintained at this temperature for a period of 1 hour 30 minutes, before rapidly cooled down in a $NaNO_3$ salt bath maintained at 300°C for isothermal transformation for a further 50 minutes before finally cooled down to room temperature. Microstructural analysis using Scanning Electron Microscope (SEM) shows transformation from ferrite/pearlite to bainite microstructure. The tensile strengths of the specimen increased from 400 MPa to 500 MPa; hardness increased from an average value of 140Rc to 162Rc; while impact energy increased from 15.6 Joule to 30.6 Joule by the austempering heat-treatment.

Keywords- Austempering, hardness, tensile strength, impact energy, microstructure

1 INTRODUCTION

Steel is the general name for a broad family of Fe-C alloys containing at most 2.1 wt% C. Steels may contain little amounts of other alloy elements which could influence the properties. For instance, manganese in steels works as a deoxidizer and enhances hot working. Silicon, chromium, phosphorus, sulphur etc may also be present; either as a residual that are not added intentionally but released from raw materials during the steelmaking process, or as alloying elements purposefully added to modify the properties of the steel (Huyett, 2014; Lakhtin, 2000).

Machine components steels are required to have bainite microstructure. In a report presented by the Institution of Metallurgist, austempered bainitic steel had a mixture of bainitic ferrite and austenite phases and observed to have a superior wear resistance. The positive mechanical strength and ensuing corrosion resistance of bainite structure depend on number of factors such as bainite ferrite grain size, carbide dispersion, dislocation density and internal stress (Bodude, Ayoola, Esezobor, & Agbeleye, 2015).

Low carbon steels offer good balance of toughness, strength and ductility which are amenable by heat-treatment to suit applications. Austempering heat-treatment has been reported to produce bainitic microstructure in steel and the steel developed useful properties required for wide range of industrial application (Niazi, Nisar, & Shah, 2014). Austempering of steel at a temperature beyond 330 °C have been found to weaken mechanical properties (Wang et al., 2016; Xia, Zhang, & Yang, 2018). After austempering bainitic steel at a temperature of 400 °C Wang et al., 2016 found that the austempered bainitic steel had reduced strength and toughness compared to that austempered at 325 °C.

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The reduced strength and toughness is attributed to formation of wide bainitic ferrite lath and large blocky mantensite/austenite phases formed at high austempering temperature (Wang et al., 2016). In a related study, Xia et al., 2018 obtained finest mechanical properties (impact toughness, tensile strength, yield strength and elongation) in 18Mn3Si2CrMo steel austempered at a temperature of 205°C; but poorest mechanical properties were noticed after 330 °C (Xia et al., 2018). In this study, isothermal transformation temperature of 300 °C is selected for the AISI 1018 mild steel with a view to improving its mechanical properties.

Besides austempering temperature, the choice of austempering time could also influence material properties in ferrous metals. Studies have shown that increase in austempering time have led to improvements in properties like fatigue life, tensile strength, elongation, impact strength and yield strength while hardness of the ferrous metals studied have decreased with increase in austempering time (Akor & Tuleun, 2014; Felipe Dias, Ribeiro, Carmo, & Vilela, 2012; Han et al., 2012). Akor and Tuleun, (2014) observed austempered ductile iron specimens at different austempering time of 1, 2, 3, 4 and 5hrs over same austenitizing temperature of 950 °C and recorded increases in yield strength, tensile strength, elongation and impact energy (Akor & Tuleun, 2014).

While evaluating the effects of austempering time on the property (fatigue) of ductile iron, Felipe Dias et al., 2012 noticed that reducing austempering time also led to increase in fatigue life (Felipe Dias et al., 2012). 50 minutes have been chosen for the isothermal transformation of test specimen during the austempering process in this study. AISI 1018 mild carbon steel has useful applications in various engineering practices (AISI 1018, 2015) like bridges, beams, gears, machine parts etc. These materials however experience mechanical damages when used under critical conditions of extreme load. This work is aimed at studying the influence of austempering heat treatment on the microstructure and mechanical properties of AISI 1018 mild steel with a view to improving its performance.

2 Materials and Method

The AISI 1018 steel used for this research work was obtained from a local steel market in Lagos, Nigeria. While the nitrate salt, (NaNO3) used for the austempering was also obtained from a scientific shop in Lagos, Nigeria. The chemical analysis of the steel was carried out at Midwal Engineering Services Limited, Lagos using Positive Material Identification (PMI) equipment. The Chemical results from the analysis are shown in Table 1.
Several samples with different dimensions were cut from the steel in accordance with the test standards. Samples were subjected to austempering heat-treatment by heating in a muffle furnace to a temperature of 830°C, maintained at this temperature for a period of 1 hour 30 minutes, before isothermally cooled down in a $NaNO_3$ salt bath at 300°C for transformation for 50 minutes before finally cooled down to room temperature (Figure 1). The austempered samples and control samples were then tested for various properties and microstructural examination. The samples were prepared, dimensioned and tested using ASTM A29 standard for tensile, ASTM E23 standard for impact, ASTM E110 standard for hardness, ASTM G83-96 standard for wear, and ASTM E3-01 standard for metallography.

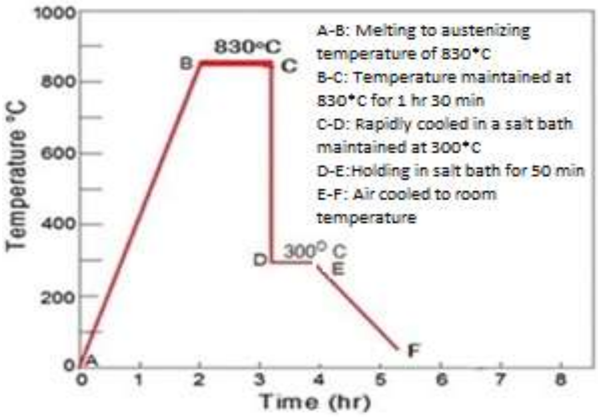

Fig. 1: Schematic diagram of the austempering heat-treatment procedure

The tensile test was conducted using Instron Universal Testing Machine model. The tensile test pieces were prepared from the as-received and austempered samples to ASTM A29 standard. From the tensile tests carried out, tensile strength and percentage elongations were determined.

The Impact test was carried out on the samples using the Avery- Denison Universal Impact –Testing Machine. The energy absorbed by the machined sample was measured and recorded when the machine pendulum was released from the maximum position corresponding to charpy test, striking the test piece with a load of 300 J. Macro-hardness test was carried out on the as received and heat-treated samples using the Briro V. A (D-7300) Universal hardness-testing machine while utilizing the Rockwell component. A diamond cone of 120^0 indenter was pressed on the sample with a load of 1411N maintained for about 15 minutes. The Rockwell hardness values were read from the digital meter attached to the machine.

The samples for the metallographic examinations were prepared by grinding using silicon carbide emery paper starting from 220, 320, 400 to 600 grits. The specimens are then polished with both 0.5 micron and 5-micron alumina polishing powders. This is followed by etching the samples with 2% Nital solution in readiness for microstructural examination in the scanning electron microscope (SEM). The sample is loaded in SEM with acceleration voltage of 20KV and magnifications of 1300X. The scan of various spots are made as well as the EDX of each of the samples one after the other.

3 Results and Discussion

Table 1 shows the chemical analysis of the AISI 1018 steel samples used for this study. The carbon (C) and Iron (Fe) content of the steel are 0.1870% and 98.4% respectively. While the Manganese (Mn), Nickel (Ni), Phosphorus (P), Silicon (Si) and Chromium (Cr) contents are 0.7190 %, 0.0723%, 0.0015%, 0.211% and 0.0634 % respectively as shown in Table 1. The elemental compositions of the test specimen conforms with that of AISI 1018 steel (AISI 1018, 2015). Basically, AISI 1080 steel should contain 98.00-99.00% Fe, 0.14-0.20% C, 0.60-0.90% Mn, ≤ 0.04% P and ≤ 0.05% Si (AZoM, 2012) and the chemical composition of the test sample falls within these range. The mechanical properties of steel are partly influenced by their chemical compositions and each of the elements mentioned above uniquely influence the behavior of the AISI 1018 steel (Bramfitt, Bethlehem Steel Corporation, & Homer Research Laboratories, 1998).

Table 1. Spectrometric Analysis

Elements	Ti	V	Cr	Mn	Ni	Cu	C	Co	P	Fe
Contents (%)	0.0006	0.0037	0.0723	0.7190	0.0634	0.1200	0.1870	0.0072	0.0150	98.4000
Elements	S	Al	Si	Ca	Sn	Nb	Sb	Se	Mo	Zn
Contents (%)	0.0445	0.0007	0.2110	0.0028	0.0076	0.0019	0.0014	0.0022	0.0143	0.0131

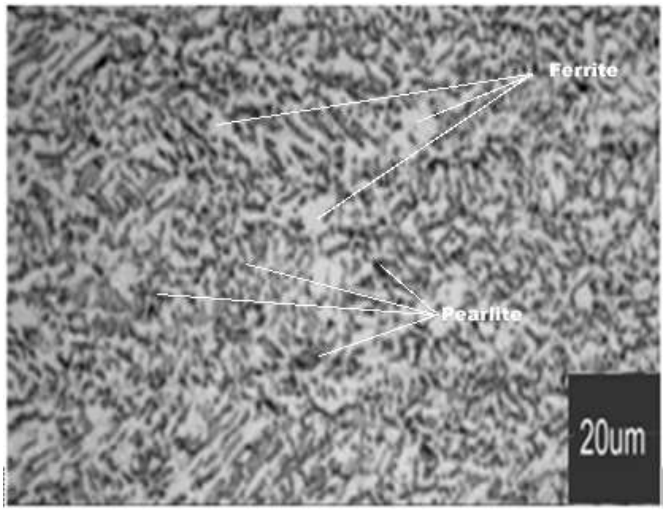

Fig. 2: Microstructure of as received AISI 1018 mild/low carbon steel

Figure 2 presents the microstructure of the as received AISI 1018 steel. The microstructure shows a combination of naturally soft ferrite (gray grains) and pearlite (black) (Nganbe, Khan, & and Glenesk, 2006). The distribution of the ferrite and bainite phases gives AISI 1018 low carbon steel excellent balance between ductility, strength and toughness which makes it suitable for various fabrication processes like heat treatment, cold drawing, forging and machining (AISI 1018, 2015).

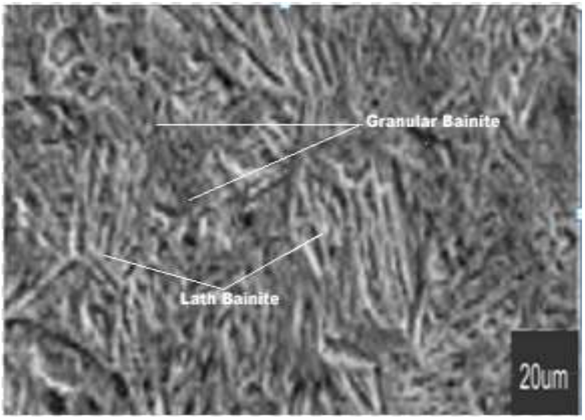

Fig. 3: Microstructure of austempered AISI 1018 mild/low carbon steel

Figure 3 shows the microstructure of the austempered steel sample and forms needle-like structure of bainites which is tougher and harder than the microstructure in Figure 2. The acicular distribution of bainite grains within the microstructure may have led to the resulting increase in the mechanical properties (hardness, tensile strength and impact energy) examined. This improvement in material properties is capable of enhancing the suitability of AISI 1018 steel for the various fabrication processes earlier mentioned

Table 2. Rockwell hardness test

Hardness Survey: ASTM E110			Scale: HRC		
Material	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
As received AISI 1018 mild/low carbon steel	148	144	141	153	146
Austempered AISI 1018 mild/low carbon steel	158	157	160	162	156

Table 3. Tensile strength test result

Material	Load at Break (Standard)	Tensile strain at Break (Standard)	Tensile extension at Break (Standard)	Energy at Break (Standard)	Tensile stress at Yield (Zero Slope)
Austempered low carbon steel specimen	7378.30475	0.27001	8.10037	67.33414	827.46824
As recieved low carbon steel specimen	5411.67185	0.28277	8.48312	53.15977	585.50559

Figure 4 shows the hardness values of both the austempered and as received AISI 1018 steel. The figure reveals that the austempered steel specimens have higher hardness values than the as received samples. The austempered steel samples have hardness values ranging from 155Rc to 162Rc as against 140Rc to 153Rc for the as received (see Table 2 and Figure 2). These hardness behaviors are due to the microstructural and isothermal transformation from ferrite/pearlite to bainite microstructures depicted in Figures 2 and 3.

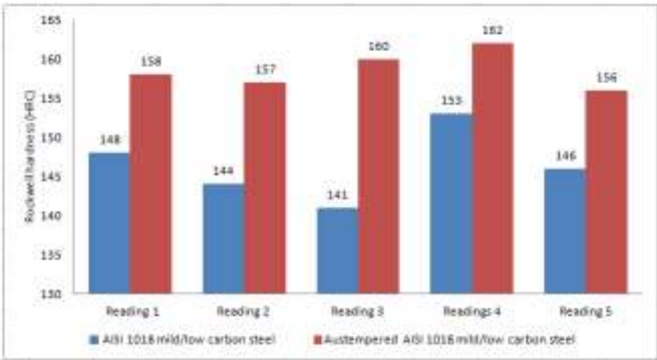

Fig. 4: Analysis of Rockwell hardness test

Figure 5 shows the impact energy for both the as received and the austempered low carbon steel Figure 6 shows the stress versus strain curves for the two materials. In both cases the mechanical properties of the austempered samples are higher than those of the as received samples. The impact energy of the austempered sample is 30.6 Joules while that of the as received sample is 15.6 Joules. Also, the ultimate tensile strength of the austempered sample is 500MPa while that of the as received sample is 400MPa. These are tremendous improvement by the austempering heat treatment. These behaviours are also due to the bainitic microstructure developed in the austempered samples as against ferrite and pearlite that exist in the as received sample.

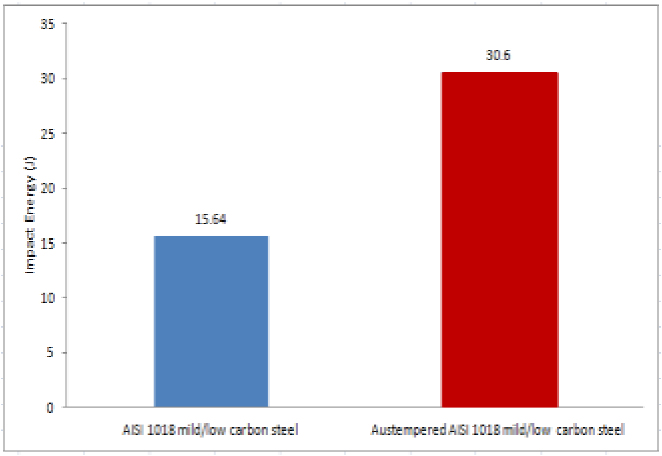

Fig. 5: Analysis of impact energy

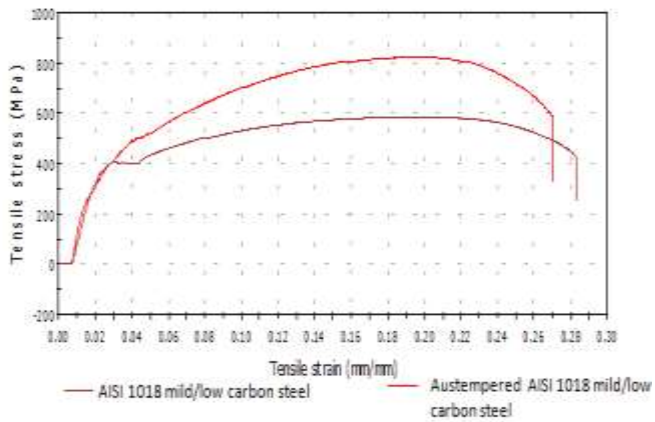

Fig. 6: Stress Strain Curves for the as received and austempered AISI 1018 steel sample

4 Conclusion

Austempering heat treatment of AISI mild carbon steel lead to isothermal transformation from ferrite/pearlite to bainite microstructures. Due to the isothermal transformation and changes in microstructure observed, percentage increases of 25%, 15.71% and 96.15% in tensile strength, hardness and impact energy respectively were characterized; which shows remarkable improvement in mechanical properties of the austempered AISI 1018 steel. The improvement in mechanical properties recorded after the austempering process is capable of enhancing the suitability of AISI 1018 steel for various fabrication processes like cold drawing, forging, weldability and machining.

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