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Effect of Austenising Temperature on the Tensile Property of AISI 1040 Steel

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Abstract

Every day, a lot of engineering materials experience failure as a result of stress. This has resulted in loss of life and property. This paper investigates the effect of varying austenising temperature on the tensile properties, microstructures and fractography of 0.4%C steel and how it affects the strength of steel. The samples were austenised at 8300C, 9300C, and 10300C respectively while some were not austenised. The austenised samples were quenched in water and tempered at 5000C. The samples were further machined into tensile test specimen and tested using the tensile test machine. Some of the fracture surfaces were examined using scanning electron microscope. The results showed a 47.6% increase of tensile strength at 10300C from the as received sample and a subsequent 36.7% decrease in the percentage enlongation. For the austenised samples, the result showed a 3.6% increase of tensile strength at 10300C from the sample austenised at 8300C and a subsequent 21.9% decrease in percentage enlongation, while there was a 2.5% increase of tensile strength at 10300C from the sample austenized at 9300C and a subsequent 16.2% decrease in percentage enlongation. This agrees with the fracture surfaces that likely show a gradual decrease in ductility as seen from the reduced dimples and tear rigdes in the fracture surfaces, as the austenising temperature increases.

1. Introduction

Medium carbon steel has between 0.25% to 0.5% carbon. Based on the percentage of carbon present in medium carbon steel, they are heat treatable to achieve desired property [1, 2]. Carbon steel, which include medium carbon steel are very important materials. Though many alloys have been developed, carbon steel still remains the most commonly used steel because of its cheapness, versatility in terms of mechanical properties, availability, and ease of protection [3]. Carriage bolts, machine screws, Crankshafts, couplings and cold – headed parts are often fabricated from AISI 1040 medium carbon steel. AISI 1040 steel is also suitable for machine, tie wire, u–bolts, and concrete reinforcing rods [4].

Austenitising is an inevitable occurrence during the heat treatment of steel. Despite this consideration, less attention has been paid so far to the study of the formation of austenite as compared to the vast amount of research on its decomposition. That is because the steel properties depend basically on the transformation process following austenisation. However, the initial autenitic condition is important to the development of the final microstructure and its mechanical properties. Ferrite can be transformed into the austenite phase by heating the steel to a temperature at which it changes crystal structure [5, 6]. When the austenite is cooled, it transforms into a mixture of ferrite and cementite. This transformation is as a result of carbon diffusion and if the rate of cooling is very fast, the steel may not produce pearlite [7]. This is a very important case in industries, where the carbon is not allowed to diffuse due to the cooling speed, which results in the formation of hard martensite [8]. To achieve martensitic transformation, quenching is done and some of the brittle martensite could be further transformed into tempered martensite, with

increased ductility [9-11].
The rate at which austenite decomposes to form pearlite has been reported to depend on the composition of the steel, as well as on other factors such as the austenite grain size [12, 13]. Hardenability is said to increase with increasing austenite grain size, because the grain boundary area is decreasing and this results in the reduction of the sites for the nucleation of ferrite and cementite. When this happens, transformations are slowed down and hardenability is increased [14-16].

When austenising temperature rises, the austenitic grain is coarsened, hardenability increases and the torsion strength and plastic torsion angle decreases remarkably after reaching their peaks at about 850^0C. Above about 950^0C, plasticity is almost lost and embrittlement occurs in these overheated steels [17]. Increase in austenising temperature result in increase in hardness of normalized steel because transformation temperature falls as the austenising temperature rises, so that transformed product becomes a finer and harder pearlite [17, 18]. This work investigates the effect of austenising temperature on tensile properties of 0.4%C medium carbon steel after tempering.

2. Methodology

2.1. Materials

The material used in this study was AISI 1040 steel. The medium carbon steel and its composition were obtained from Delta Steel Company Aladja, Delta State. The chemical composition is shown in Table 1.

Table. 1: Chemical composition of the AISI steel (heat no: 1043322)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Cu	Al
CONTENT (wt%)	0.4	0.58	0.17	0.044	0.043	0.16	0.10	0.27	0.002

2.2 Sample preparation

A total of twelve (12) samples were used for this experiment. Nine (9) of the samples were austenized in total, Three (3) each were austenitized at 830^0C, 930^0C and 1030^0C in the furnace respectively and then tempered at 500^0C. The remaining three (3) was not austenitized. Two (2) austenitized samples each from 830^0C, 930^0C and 1030^0C respectively and 2 non austenitized sampless were machined into tensile test samples. The tensile test samples were fractured using the tensile test machine and the average results obtained was recorded and tabulated using the

Equations 1 to 4 below for calculation. (Table 2) The fracture surfaces of some of the samples were examined using the scanning electron microscope. Three (3) from the remaining four (4) samples were taken for metallography. (i.e 1 non austenitized sample and 1 sample each, austenitized at 830^{0}C and 1030^{0}C respectively). The tensile test sample is shown in Figure 1.

Yield point stress $\sigma_y = \frac{Yield\ Load}{A_0}$ (1)

Utimate tensile strength (UTS) = $\frac{Maximum\ Load}{A_0}$ (2)

% Elongation = $\frac{\Delta L}{L_0} \times 100$ (3)

% Reduction in area = $\frac{\Delta A}{A_0} \times 100$ (4)

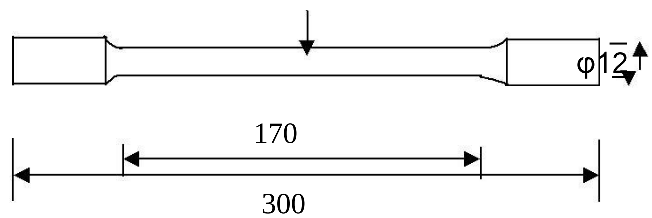

Figure 1. Tensile test sample

3. Results and Discussion

The carbon content from table 1 falls within the range of 0.25% – 0.5% and this qualifies it to be a medium carbon steel. The 1 in the 1040 steel denotes it is a carbon steel, while the 040 denotes the carbon content of the steel. [4]

Table 2: Tensile test result

TEMP. ( )	**YS (N/mm^2)**	**UTS (N/mm^2)**	**FS (N/mm^2)**	**%EL**	**%RIA**
As Received °C	446	547	458	9.0	30.0
830	968	1006	974	7.3	24.3
930	980	1018	993	6.8	22.6
1030	1018	1044	1024	5.7	19.0

Table 2 shows the average tensile test result of the samples. There was a 47.6% increase of tensile strength at 1030^{0}C from the as received sample and a subsequent 36.7% decrease in the percentage enlongation. For the austenised samples, the result showed a 3.6% increase of tensile strength at 1030^{0}C from the sample austenised at 830^{0}C and a subsequent 21.9% decrease in percentage enlongation, while there was a 2.5% increase of tensile strength at

1030^0C from the sample austenized at 930^0C and a subsequent 16.2% decrease in percentage enlongation.

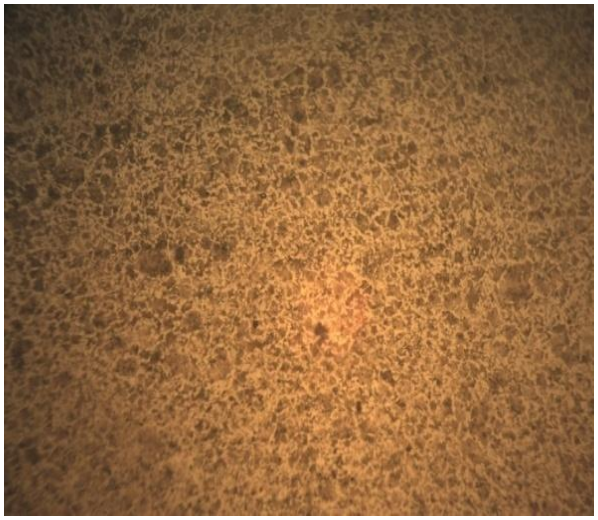

Figure.2: Microstructure of AISI 1040 steel that was not austenised

Figure 2 shows fine dispersion of cementite particle in equi-axed ferrite grain. The golden colour represents the ferrite grain, while the dark patches are the cementite. The fine dispersion of cementite particle in the ferrite grain indicates low strength, high ductility and cannot be used in load bearing application [10, 11].

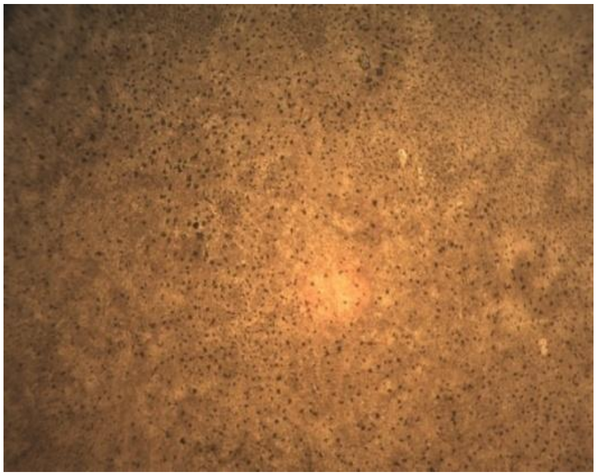

Figure 3: Microstructure of AISI 1040 steel austenised at 830^0C

Figure 3 shows less visible and larger dark patches representing cementite and probably second phase precipitate, while the golden colour represents ferrite. This indicates good strength but low ductility [10, 11]

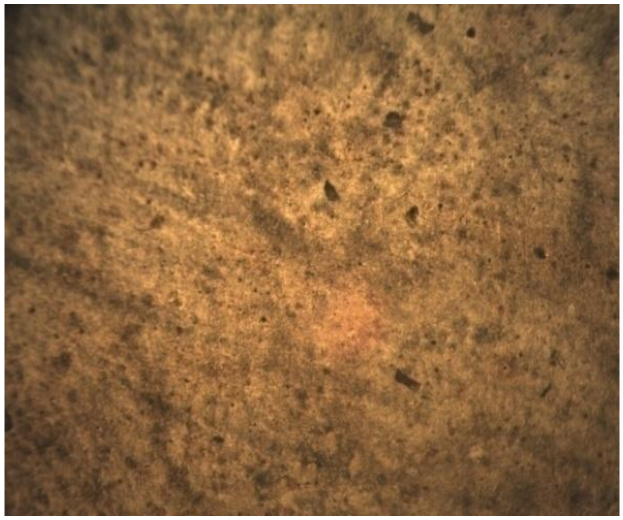

Figure 4: Microstructure of AISI 1040 steel austenised at 1030^{0}C

Figure 4 shows larger dark patches representing cementite and probably directional aligned second phase precipitate and some retained austenite.

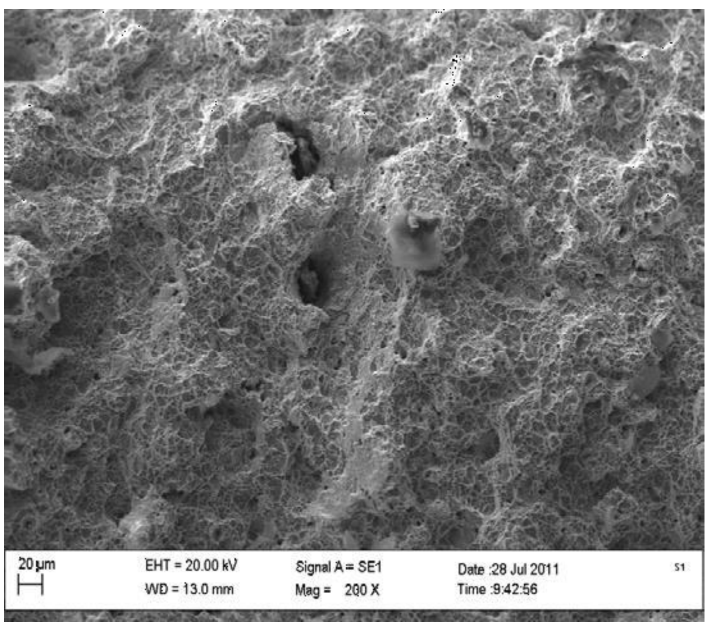

Figure 5: Fracture surface of AISI Steel that was not austenised

Figure 5 shows a fracture surface that is fibrous in nature, giving rise to many tear ridges and micro-void dimples. indicating good ductility.

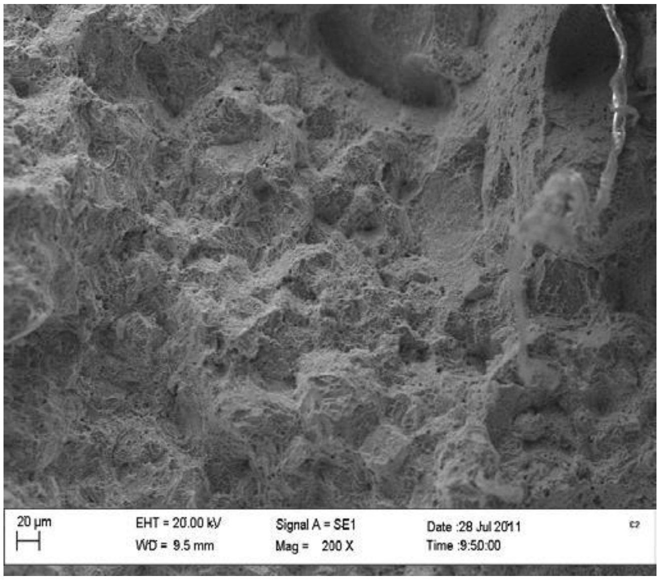

Figure 6: Fracture surface of AISI 1040 steel austenised at 830^0 C

Figure 6 shows lesser tear rigdes and micro-void dimples near the fracture plane

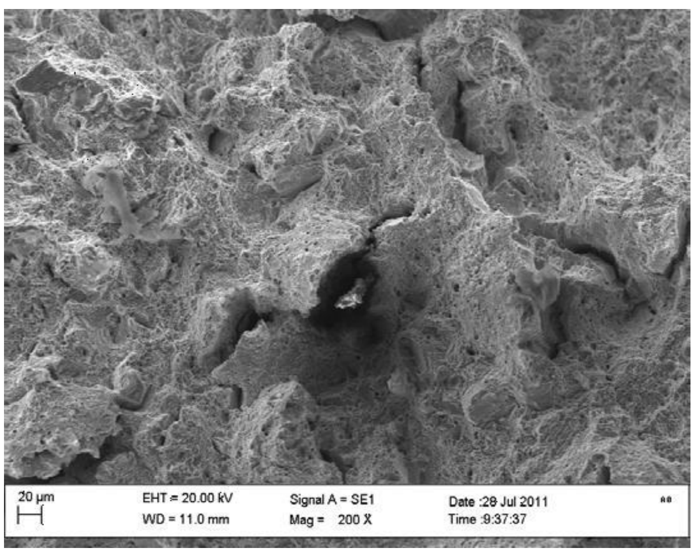

Figure 7: Fracture surface of AISI 1040 steel austenised at 1030^0 C

Figure7 shows some dimples and tear rigdes joining the final fracture plane and the emergence of some fracture cracks.

From Table 2 the ultimate tensile strength, yield strength, and fracture strength, of the specimens, increased respectively with increasing austenising temperature but with a gradual decrease in ductility. This is in agreement with Kazuaki [17], who observed that as austenising temperature rises, the austenitic grain is coarsened and hardenability increases. He also observed that for normalized steel, increase in the austenising temperature results in increased hardness of the steel because transformation temperature falls as the austenising temperature rises, such that the transformed product becomes a finer and harder pearlite. Also Honeycomb and oblak e tal [14, 15, 16] observed increased hardenability with increasing austenite grain size. He explained his observation by grain boundary area decrease. With decrease in the grain boundary area, the sites for the nucleation of ferrite and cementite are being reduced in number and therefore these transformations are slowed down and the hardenability increases.

These observations can be used to explain the findings in the tempered AISI 1040 steel investigated. At 830^0C, the grains were fully in the austenite region. Increase in the austenising temperature (930^0C), produced the same austenite, but earlier grains produced had grown by coarsening. At further increase in the austenising temperature (1030^0C), there was more grain growth, thus making it coarser. The coarser the austenite, the more the trapped-in carbon, on quenching and the less the reaction sites, which resulted in increase in hardenability observed in the tempered steel.

The increase in the tensile property with increasing austenising temperature can also be deduced from the microstructures of the sample that was not austenised in Figure 2 and the austenised samples at 830^0C and 1030^0C in Figure 3 and 4 respectively. Figure 2 shows fine dispersion of cementite particle in the ferrite grain, indicating low strength, high ductility and cannot be used in load bearing application [10, 11]. Figure 3 shows less visible and larger dark patches representing cementite and probably second phase precipitate, while the golden colour represents ferrite. This indicates good strength and low ductility and therefore good in load bearing application [10, 11]. Figure 4 shows directional aligned second phase precipitates and some retained austenite. This indicates better strength and lower ductility as compared to the samples austenized at 830^0C. This retained austenite are probably due to the fact that at increasing austenising temperature, there is less reaction site which could have resulted in some austenite being retained, even after tempering. This agrees with Honeycomb, oblak e tal and also with Lewandowski e tal [14, 15, 16] The findings is further confirmed by the corresponding fracture surfaces in Figure 6 and 7 respectively. Figure 6 showed slightly more ductility with many tear ridges and micro-void dimples, while Figure 7 shows less ductility with a fracture surface showing some dimples and tear ridges joining the final fracture plane. The emergence of some fracture crack could likely be due to the presence of some impurities in the steel as seen in the microstructure [10, 11].

4. Conclusion

Based on the results of our study the following conclusions were achieved; Austenising temperature affects tensile property.The samples austenised at 1030^0C showed greater tensile strength, with a 47.6% increment. The fracture surfaces showed gradual reduction in dimples with increasing austenising temperature.

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