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EFFECT OF IMMERSION SPEED ON MECHANICAL PROPERTIES AND MICROSTRUCRE OF WATER QUENCHED LOW CARBON STEEL AISI 1020

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Abstract: Steel is an important commodity in the engineering world as it has a wide range of application ranging from domestic (doors and burglaries) and many more to its industrial use in construction and manufacturing. Due to the wide application of steel, it is usually required in various forms which may not actually be available in its pure state. Steels are heat-treated under controlled sequence of heating and cooling operation to alter their physical and mechanical properties to meet desired engineering applications.This practice affects both the mechanical properties and microstructure of the steel. This work shows the effects of variations of in immersion speeds on the mechanical properties and microstructure of quenched AISI 1020 steel. The study revealed that low immersion speed yield higher mechanical properties. The empirical equation $Y = 49.71x^2 - 337.6x + 619.7$ with $R^2 = 0.998$ was obtained showing the relationship between the tensile strength and immersion speed.
Keywords: Heat treatment; Mechanical Properties; Microstructure; AISI 1020

1. INTRODUCTION

Steel is an alloy of iron with definite percentage of carbon ranges from 0.15-1.5% (John, 1980). Plain Carbon steels on the other hand, are those containing 0.1-0.25% (Brown, 2000). There are two main reasons for the popular use of steel: Firstly, it is abundant in the earth's crust in form of Fe_2O_3 and little energy is required to convert it to Fe, and secondly it can be made to exhibit great variety of microstructures and thus a wide range of mechanical properties. Its application is wider than any other metal, ranging from domestic use in the forms of utensils and many more to its use in construction and manufacturing industries.

According to Rajan *et al.,* (1988), steels with carbon content varying from 0.25 to 0.65% are classified as medium carbon, while those with carbon content less than 0.25% are termed low carbon. The carbon content of high carbon steels usually ranges within 0.65-1.5%. Low carbon steel which was employed in the course of this study has high malleability and ductility, good machinability, good surface finish, good formability, and general availability at low cost. Hardness and other mechanical properties of plain carbon steels increase with the increase in concentration of carbon dissolved in austenite prior to quenching during hardening heat-treatment (Rajan *et al.*, 1988; Thelning, 1984), which may be due to transformation of austenite into martensite (Feng and Tahir, 2008). The wide range of application of steel in engineering practices has prompted the desire to increase certain mechanical properties which can only be obtained through heat-treatment. Quenching is a heat-treatment process which involves heating a material to a very high temperature and then subjecting the heated material to rapid cooling in a cooling medium often referred to as quenchant.

The quenching of steel does not necessarily improve all the mechanical properties of the steel, the effect on the steel at different immersion speeds would be different, hence leading to variation in the mechanical properties. Understanding the varying effects on the mechanical properties caused by the difference in immersion speed is required for selection of steel in various applications, hence a reason to undertake this study. Although, many works have been done on the effects of cooling rate on hardness and microstructure of steels (Nagpal and Baker, 1990; Lu *et al.*, 2009, Calik, 2009). There has been little research work on the effects of immersion speed on mechanical properties and microstructure of quenched low carbon steel. Fadare *et al.*, (2011) discussed on the effects of heat-treatment on mechanical properties and microstructure of medium carbon steel. The objective of this paper is to study the effects of immersion speed on mechanical properties and microstructure of quenched low carbon steel.

2. MATERIALS & METHODS

Sample of Low Alloy steel bar with 25 mm diameter and 100 mm long was purchased from a local market located in Oyo Sate, South-Western, Nigeria. The chemical composition of the steel sample was carried out at the Federal Institute of Industrial Research, (FIIRO), Lagos state, Table1.

Table 1: Chemical Composition of mild carbon steel AISI 1020

C (%)	Si (%)	Mn (%)	S (%)	P (%)	Cr (%)	Ni (%)	Cu (%)
0.189	0.207	0.497	0.021	0.022	0.101	0.073	0.174
Nb (%)	Al (%)	B (%)	W (%)	Mo (%)	V (%)	Ti (%)	Fe (%)
0.0050	<0.0001	0.0011	<0.0001	0.0026	0.0018	0.0004	98.7
Co (%)	Pb (%)	Sn (%)	Zn (%)	As (%)	Bi (%)	Ca (%)	Ce (%)
0.0092	0.012	0.0069	0.0016	0.0014	0.0009	0.0003	0.0023

2.1. Test specimen preparation

A set of specimens was prepared for hardness tests and microstructural analyses. Tensile test specimens were also produced from the as-received low carbon steel samples of the same composition. The low Alloy steel was machined into a tensile test specimen, the steel obtained was machined at the Engineering Materials development Institute (EMDI, Akure) into a test piece specimen as shown in the Figure 1.

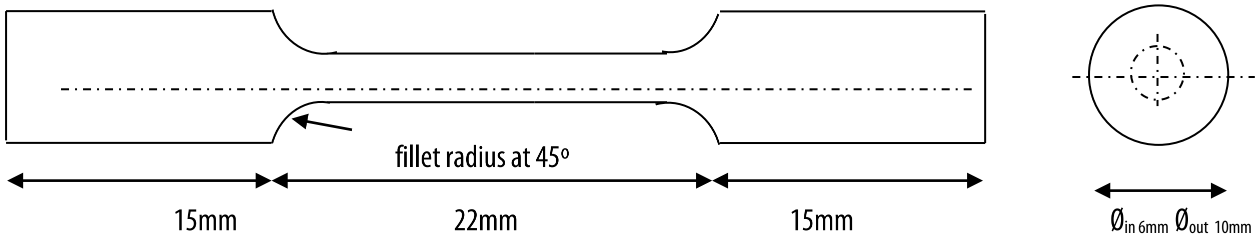

Figure 1: Machined Specimen For Tensile Test

2.2. Heating and Quenching Process

The second phase of the experiment was carried out at the metrology laboratory of the mechanical engineering department, Ladoke Akintola University of Technolgy, Nigeria. This involved heating of the tensile specimen to austenising temperature of 850 °C. The material was maintained at this temperature for one-hour and then quenched at various immersion speeds, speeds of 0.1, 0.2, 0.35, and 0.6 m/s respectively, using water as the quenchant.

At the third phase, the samples were returned to the Engineering Materials Development Institute (EMDI) Akure, where the effects of the quenching at the different immersion speeds on the physical and microstructural properties of the Steel were determined.

Prior to testing, specimens were mounted using phenolic powder, grinded and polished to obtain a smooth surface. A direct load of 490N was applied for a dwell time of 10seconds and hardness readings were evaluated following standard procedures, multiple hardness tests were performed on each sample and the average of the values was taken as a measure of the hardness of the each specimen. The microstructural analysis was obtained using an optical metallurgical microscope.

3. RESULT AND DISCUSSION

3.1. Effect of Heat Treatment on Mechanical Properties

The effects of immersion speed on the mechanical properties (ultimate tensile strength, hardness, toughness, percentage elongation, and percentage reduction) of the quenched steel were shown in Table 2.

Table 2: Mechanical Properties of Quenched Low Carbon Steel at different immersion speeds

Immersion speed (m/s)	Tensile Strength (N/mm^2)	%elongation	Modulus of Elasticity	Yield Strength (N/mm^2)	Hardness (Case)	Hardness (Core)
0.3102	333.62	37.40	6654.30	359.80	190.70	188.7
0.3241	137.86	39.20	5648.40	393.60	228.40	226.80
0.3384	59.65	29.80	9450.30	259.90	206.70	194.90
0.4167	62.75	28.50	25714.90	249.00	183.10	130.30

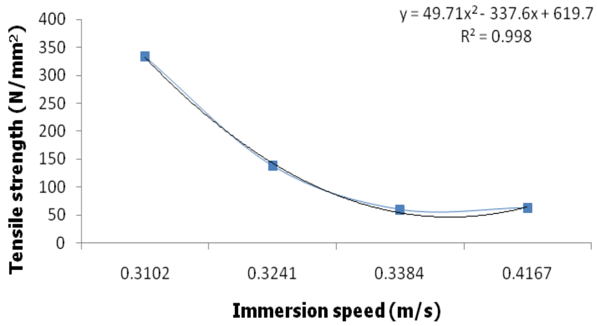

Figure 2: Graph of Immersion speed (m/s) against tensile strength (N/mm^2)

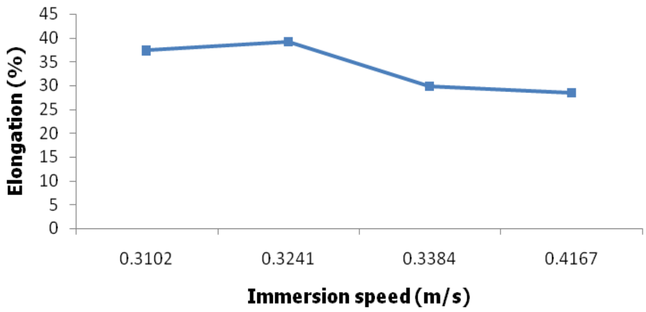

Figure 3: Graph of Immersion speed (m/s) against percentage elongation

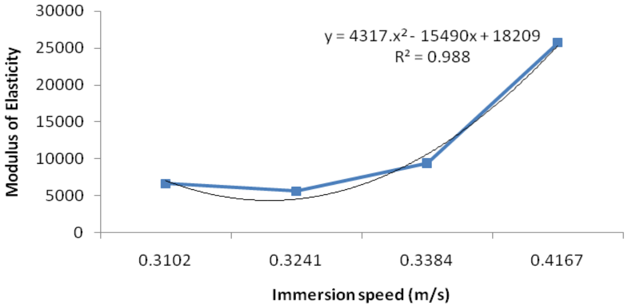

Figure 4: Graph of immersion speed (m/s) against Modulus of Elasticity

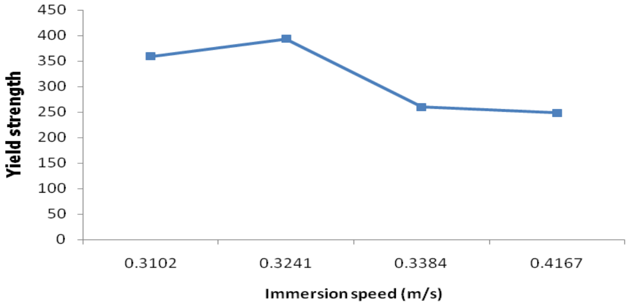

Figure 5: Graph of Immersion speed (m/s) against yield strength

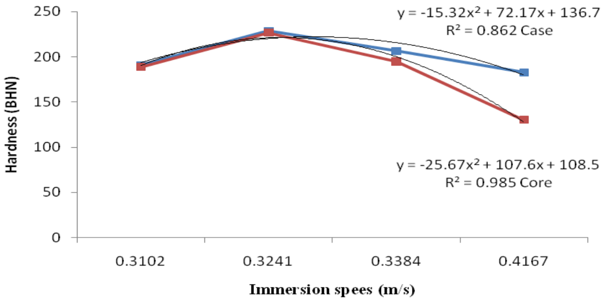

Figure 6: Graph of Immersion speed (m/s) against Hardness Value (BHN; Case and core)

3.2. Effect on Tensile Strength

Figure 2 shows the effect of immersion speed on tensile strength of the water quenched samples. It was observed that as the immersion speed increases, the tensile strength of the steel samples decreases given an inverse relation between the tensile strength and speed of immersion; $Y = 49.71x^2 - 337.6x + 619.7$ ($R^2 = 0.998$). At low immersion speed however, the final strength of the quenched steel is high, showing that low immersion speed may favour the growth of both pearlite and martensite formation. At higher speed of immersion, the final strength of the quenched steel is relatively reduced. At low immersion speed of 0.3102m/s, the corresponding tensile strength was 333.62 N/mm^2 and at a higher immersion speed of 0.4167m/s, the tensile strength reduced to 62.72 N/mm^2.Hence, it can be concluded that for the mild steel being analysed, the higher the immersion speed, the lower the tensile strength.

3.3. Effect on Percentage elongation

Figure 3 shows that as immersion speed increases, the percentage elongation also increases up to 0.3241m/s and decreases with increase immersion speed. At low immersion speed of 0.3241m/s, the % elongation was 39.20 and at a higher immersion speed of 0.4167m/s, the % elongation reduced to 28.5%.

3.4. Effect on Modulus of Elasticity

The elasticity of the quenched mild steel increases with an increase in immersion speed, at lower immersion speeds there was lower modulus of elasticity, and at higher speeds of immersion, the modulus of elasticity increases rapidly Figure 4. Thus, the empirical equation showing the correlation between the modulus of elasticity and the immersion speed is $Y = 4317x^2 - 15490x + 18209$ with $R^2 = 0.988$.

3.5. Effect on Yield Strength

The yield strength of the materials also decreases with increase immersion rate Figure 5, following the same trend as percentage elongation.However, at low immersion speed of 0.3102m/s, the yield strength was 359.80N/mm^2 and at a higher immersion speed of 0.4167, the yield strength is 249.00 N/mm^2.

3.6. Effect on Hardness

There is a notable difference between the hardness of the steel at the case and in the core, although. Moreover, there is good correlation between the values of hardness for the case and core. As observed in Figure 6, R2 = 0.862 for case and 0.985 for core. This is an indication that it will take the centre (core) parts of the specimens more time to cool to room temperature given a higher value of 0.985 compared to case (surface) parts.

3.7. Effect of Heat Treatment on Microstructure

The varied immersion speed has different effects on the final structure of the each specimen. These effects on the microstructure as obtained from the scanning electron microscope are shown in the Figures 7 – 8. It can be observed that at the case, the cooling is more rapid and there are more martensitic formations than in the core. Little pearlite is noticed in the case when compared to the core, this can also be observed in Figure 9 and 10 respectively. Therefore, there could be massive martensitic structure of hardened sample, when low carbon steels are rapidly quenched from its austenite temperature to room temperature. The austenite will decompose into a mixture of some medium carbon martensite and fewer pearlite as a result of the microstructure which is hard, thus increase the tensile strength and hardness, and reduces the ductility of the material. The high martensitic composition can make the material very hard and brittle.

4. CONCLUSIONS

The following conclusion can be drawn from the above discussion;

- » The speeds of immersion have varying effects on individual mechanical properties of low carbon steel and that the individual properties have a certain speed at which its value is highest.
- » Mechanical properties such as young modulus, yield strength and %elongation increases as the material is quenched, while the tensile strength reduces due to quenching of the mild steel.
- » The effect of the speed of immersion on the hardness of the steel differs at the case and at the core.
- » As the immersion speed increases, the hardness at the case increases as compared to the hardness value at the core of the mild steel.

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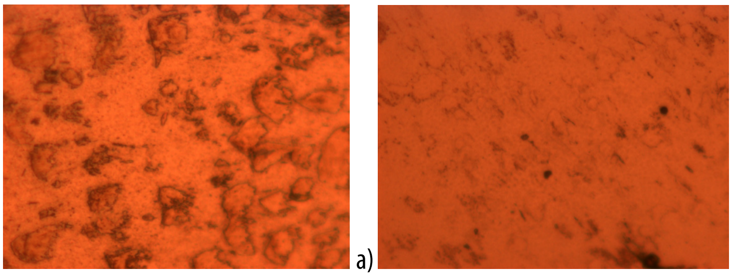
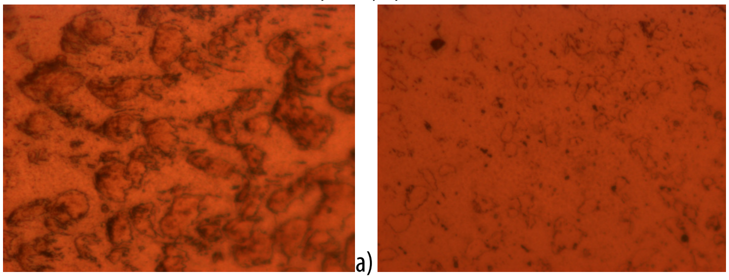


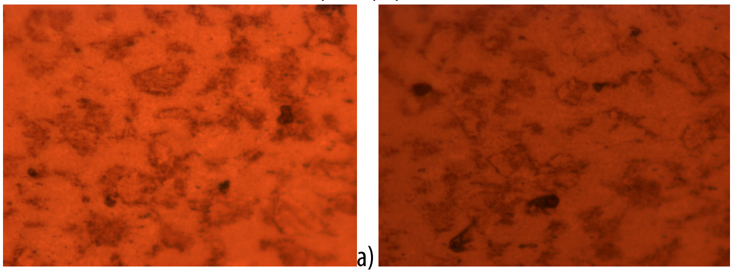
a) b)

Figure 7: Microstructure of water quenched Steel at immersion rate of 0.3102m/s. a) Core; b)Case



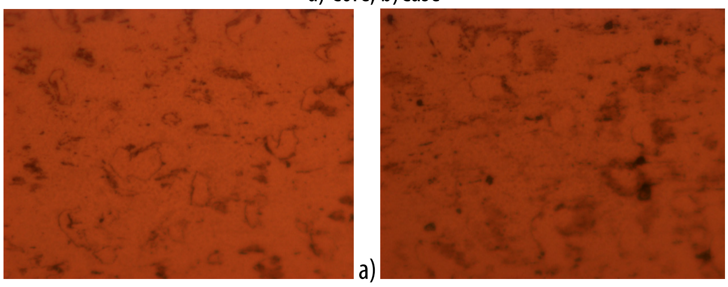
a) b)

Figure 8: Microstructure of water quenched Steel at immersion rate of 0.3241 m/s. a) Core; b)Case



a) b)

Figure 9: Microstructure of water quenched Steel at immersion rate of 0.3384 m/s. a) Core; b)Case



a) b)

Figure 10: Microstructure of water quenched Steel at immersion rate of 0.4167 m/s. a) Core; b)Case

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