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Effect of Carburization Time and Temperature on the Mechanical Properties of Mild Steel

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ABSTRACT

Mechanical properties of mild steel subjected to pack carburization process were investigated using rice husk as the carburizer. The samples were carburized at 850 ^{o}C, 900 ^{o}C and 950 ^{o}C, soaked for 20 minutes and 40 minutes, quenched in black seed oil and tempered at 550 ^{o}C. Prior to carburization, standard test samples were prepared from the as-received samples for tensile, impact and hardness tests. After carburization, the test samples were subjected to the standard tests and from the data obtained, hardness values, ultimate tensile strength, impact strength were recorded. The case and core hardness of the carburized tempered samples were measured. It was observed that the mechanical properties of mild steels were found to be influenced by the carburization process, carburization temperature and soaking time. The results obtained show that the samples carburized at 850 ^{o}C and soaked for 20 minutes and that of 950 ^{o}C and 40 minutes were better because they showed a trend of hard case with softer core. The impact strength, ultimate tensile strength and engineering strain were found to increase with increase in carburizing temperatures. However, the modulus of elasticity and hardness values for the case and core were decreasing as the temperature increased. A case-hardened steel sample that gives rise to a hard case and soft core was obtained through park carburization using rice husk as carburizer.

1. INTRODUCTION

Case hardening of mild steel is a common practice in engineering and it is geared towards improving the mechanical properties of the material (Linus and Ihom, 2013). They are utilized to produced cars body panels, tubes, domestic appliance, side panels, and other engineering applications because they are readily available, workable and weldable (Joseph *et al.,* 2015).

Heat treatment is an important operation in the manufacturing process of machine parts and tools. It may be defined as an operation of heating and cooling of metals in the solid state to induce certain desired properties in to them. Heat treatment can alter the mechanical properties of steel by changing the size and shape of the grains of which it is composed, or by changing its micro-constituents (Jain, 2011).

Carburizing is one of the most commonly performed steel heat treatment. Over long period of time, it was performed by packing the low carbon wrought iron parts in charcoal, then raising the temperature for hours. The entire pack, charcoal and all, was then dumped into water to quench it. Thus, the surface became very hard, while the interior or core of the part retained the toughness of low carbon steel (Fatai *et al.,* 2009). Carburizing is a process where carbon is added to the surface of low carbon steels at temperatures within the austenitic region of the steel and is generally within a range of 850ºC and 950ºC for mild steels. Within this range of temperature, austenite which has high solubility for carbon is the stable crystal structure. Hardening is attained when the subsequent high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is super imposed on a tough, low carbon steel core (Krauss, 1980). Low carbon steel has carbon content as 0.1% to 0.3% and cannot be hardened by direct heat treatment because of low strength of carbon content (Rajesh and Venkatesh, 2014). The work aimed to improve on the hardness and wear resistance of the mild steel through carburization since low carbon steels are readily machinable and can have their surface layers carburized and subsequently hardened.

2. MATERIALS AND METHODS

2.1. Materials

Mild steel was obtained from Universal Steel Company Limited, Lagos State, Nigeria. Rice husk was obtained from farm center in Osara, Okehi local government area, Kogi State, Nigeria. Black seed oil used as quenching medium was obtained from a vendor on shelf at Lokoja Kogi State, Nigeria.

2.2. Equipment

Mass Spectrographic Analyzer at Universal Steel Company, Ikeja, Lagos State, Nigeria was used for determining the chemical composition of the mild steel. Heat treatment furnace, Carbolite, Monsanto Tensometer were used for tensile test. Hardness and impact testing machine at the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria were used in carrying out the heat treatment. Lathe machine and grinding machine were used for cutting and grinding the samples.

2.3. Methods

The mild steel was machined to standard test samples sizes for tensile, impact and hardness tests. The prepared test samples were embedded in the pulverized rice husk inside a steel pot which was then tightly sealed with clay cover in order to prevent the carbon monoxide from escaping and prevent unwanted furnace gas from entering the steel pot during heating. The furnace temperature was adjusted to the required temperatures 850 ºC, 900 ºC, and 950 ºC for each stage respectively and the loaded steel pot was placed in the furnace. When the furnace temperature reached the required carburizing temperature, it was held at the temperature for the required time of 20 and 40 minutes. After this time, the steel pot was removed from the furnace and the material was quenched in black seed oil (Afolalu *et al.,* 2015).

2.3.1. Tempering of the carburized samples

The carburized test samples were then tempered at temperature of 550^{o}C, held for one hour and then cooled in air. After the heat treatment, the test samples were subjected to tensile test, impact test and hardness test and the procedure was similar to that reported by (Fatai *et al.,* 2009).

2.3.2. Mechanical test

2.3.2.1. *Tensile test*

The tensile test was performed on various samples using Monsanto tensometer. The fracture load for each sample were recorded as well as the diameter at the point of fracture and the final gauge length. The initial diameter and initial gauge length for each sample was noted before applying load. The sample was subjected to uniaxial loads, at a fixed crosshead speed of 10 mm/min. From the data obtained, the ultimate tensile strength, engineering strain and modulus of elasticity was calculated.

2.3.2.2. *Hardness test*

Rockwell hardness was measured on carburized, tempered mild steel samples carburized at 850^{o}C, 900^{o}C and 950 ^{o}C. Each test on each sample was repeated 3 times and the average of all the reading were recorded in each case.

2.3.2.3. *Impact test*

V-notch method was used to carry out the impact test on various samples. Hounsfield balance impact testing machine was used in this research before the mounting of the sample on the machine, the sample was notched to a depth of 2 mm with V-shaped hand file. The notched test sample was then mounted on the impact testing machine, which was operated to apply a constant impact force on the test sample. The impact strength (i.e. the amount of impact energy the specimen absorbed before yielding) was read off the calibrated scale on the impact testing machine.

3. RESULTS AND DISCUSSION

The composition of the mild steel used in this study is presented in Table 1. The most abundant element present in the mild steel was iron (Fe) with a composition of 97.75%.

Table 1: Chemical composition of the mild steel used

Element	Fe	C	Si	Mn	S	P	Cr	Ni	Cu	Al	Mo	V	Ti
Composition (%)	97.75	0.21	0.25	0.77	0.03	0.02	0.13	0.13	0.33	0.29	0.02	0.003	0.009

The results for the carburized samples which include the impact strength, hardness values for the case and core, ultimate tensile strength, engineering strain and young modulus of elasticity are shown in Table 2. In Table 2, it shows that the impact energy absorbed by the sample increases with increase in the carburizing temperature. The impact energy of the samples soaked for 20 minutes was higher than those of 40 minutes though these values are lower than the result obtained from the control sample with 70.29J. It was observed that the ultimate tensile strength increased (UTS) with increase in the carburizing temperatures. The UTS result for the samples soaked for 20 minutes was higher than the samples soaked for 40 minutes which has UTS values decreasing with increase in temperature. This indicates that the UTS of such samples was reduced by the carburization process, whereas the UTS of the samples soaked for 20 minutes improved as the carburizing temperature increased. Similar result was reported by (Singh, 2005; Fatai *et al.,* 2009), where in this case the UTS value of the control was 821.72 N/mm^2.

Table 2: Mechanical properties of the carburized tempered samples

Time (min)	Temperature (°C)	Impact strength (J)	Core Hardness (H_{RA})	Case hardness (H_{RA})	UTS (N/mm^2)	Engineering strain	Modulus of Elasticity (N/mm^2)
20	850	33.27	70.16	72.4	692.42	0.0194	35586.31
20	900	45.5	66.5	70.3	893.75	0.0649	13293.81
20	950	58.63	64.3	66.1	914.18	0.0848	10616.15
40	850	30.09	68.4	70.9	743.6	0.0241	31117.96
40	900	42.14	65.2	68.2	684.68	0.1598	4103.89
40	950	56.64	63.9	65.7	669.14	0.1064	7195.33
Control		70.29	58.9	60.1	821.72	0.0512	14691.05

The relationship between UTS values with the carburizing temperature is related to the carbon content of the steel in both annealed and tempered conditions (Ward, 1981). It may be that the amount of carbon diffusing in to the steel samples increases with increase in carburizing temperature. The results of the hardness test of the carburized samples for both core and case hardness revealed that the samples soaked for 20 minutes had a case hardness of 72.4 H_{RA} and the core has 70.1 H_{RA} at the carburizing temperature of 850°C. When the carburizing temperature was increased to 900°C, the case hardness reduced to 70.3 H_{RA} with the core having 66.5 H_{RA}. The same trend was noticed at a temperature of 950°C with a decrease in the hardness values of both the core and the case. Comparing these results with the hardness of the control sample, having a case hardness of 60.1 H_{RA} and the core with 58.9 H_{RA} respectively, indicating that there was carbon enrichment in the carburized samples. The same result was obtained at a soaking time of 40 minutes with the hardness increasing compared to the control sample. The engineering strain values were found to increase with increase in carburizing temperatures for both samples soaked for 20 and 40 minutes. This increase in ductility with increase in carburizing temperature can be linked to an increased interface area produced by the carbide formation at the grain boundaries which lead to the impurities being redistributed (Ward, 1981). The Young's modulus of the carburized samples soaked for 20 minutes at 850°C has the maximum modulus of elasticity of 35,586.31 N/mm^2. The Young's modulus of elasticity was found to reduce as the carburizing temperature increases and the same trend was noticed at a soaking period of 40 minutes. . When compared with the control having 14,691.05 N/mm^2, it shows that some of the samples lost their stiffness as the temperature of carburizing increases.

4. CONCLUSION

The following conclusions were drawn from the study.

1. Generally, the carburization process increased the impact strength of the samples
2. The carburization treatment has influence on the mechanical properties of the mild steel as the ultimate tensile strength increased with increase in temperature of carburization.
3. Samples carburized at 950 °C and soaked for 40 minutes followed by quenching in oil and then tempered at 550°C was the best as it showed a trend of hard case with soft core.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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