EXPERIMENTAL DETERMINATION OF THE EFFECT OF WOOD CHARCOAL AS CARBURIZING MATERIAL ON HARDNESS, IMPACT AND TENSILE STRENGTHS OF MILD STEEL

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Abstract
This study investigated the effect of wood charcoal as carburizing material and time as a moderator variable on the hardness, impact and tensile strengths of mild steel. Wood charcoal was processed into carburizing material and used to pack carburize ten each of mild steel hardness, impact and tensile specimens for one, two, three, four and five hours each after which the specimens were case hardened. Independent measures were used to control for variability within the experiment. Direct measurement gave a mean hardness of 61.66HRC; mean impact strength of 7.43joules; and mean tensile strength of 659.282N/mm^2. Wood charcoal thus showed a considerable positive effect on hardness and tensile strength but a negative effect on the impact strength of mild steel. Carburizing time as a moderator variable had significant effect on only hardness of mild steel and the effect was ordinal. It was recommended among others that wood charcoal should be processed into carburizing material as substitute for imported carburizing compounds that are no longer readily available in Nigerian industrial markets.

Keywords: *Wood charcoal, hardness, carburizing, case hardening, impact and tensile strength*

Introduction
Locally fabricated gears, shafts, cams, pinions, sprockets, bearings, hand tools, and agricultural implements usually experience stresses that can cause them to fail when needed functional properties of hardness, impact and tensile strengths are lacking. The singular and combined effects of hardness, impact strength and tensile strength play significant roles in the enablement of steel engineering elements to withstand tensile, compressive, impact, abrasive, torsion, bending, and shear stresses and to serve satisfactorily (Ohize, 2007). Hardness is known to influence mechanical properties like tensile strength, impact strength and toughness of steel.

The essential compromise between hardness and toughness which results in case-hardened mild steel should promote the tensile and impact strengths of mild steel. Mild steel among the classes of steels possesses higher degree of machinability, malleability and ductility. The workability of mild steel coupled with its dominance in the world of steel accounts for its wide application in engineering. By its nature, however, it is often lacking in the degree of hardness that its function in most applications demands. It is in other to make for increased hardness of the outer case of mild steel that the pack carburization process is adopted.

In the pack carburization process, it is required that compounds that are rich in carbon be made to decompose and liberated carbon from them infused into mild steel. Carbonaceous industrial powders and substances like cascamite powder, kasenite powder, cyanide salt and a host of others have been developed for the purpose of carburization. Authors have reported that commercial pack carburizing compounds are formulated from materials like charcoal, bone dust, coke, beans, nuts, leather, and carbonates of barium, calcium and sodium (Shrager, 1961; Love, 1979; Repp and McCarthy, 1992; Bestow, 2000; Dempsey, 2002). Carbonates of barium, calcium and sodium are chemicals that simply serve as energizers to hasten the carburizing process. Quite a number of the carbonaceous materials mentioned above and some other ones are known to abound in Nigeria. Such forms of carbon as wood charcoal, lamp black, sugar charcoal and animal bone charcoal are reported to be in abundance in Nigeria (Ababio, 1990). These local carbonaceous materials may be suitable substitutes for commercial carburizers. The local carbonaceous material investigated in this study is wood charcoal.

Machinists, fabricators, blacksmiths, repair shop owners, and technical training institutions that were interviewed admitted that the non-treatment of their products was due to non-availability of carburizing compounds like cascamite and kasenite powders which they used to know. Some of the blacksmiths and apprenticeship-trained craftsmen in machine tool processes, fabrication and fitting skills who were interviewed claimed that they never heard of hardening process.

Statement of the Problem

As a result of the non-availability of conventional carburizing materials, heat treatment component of metalwork technology cannot be taught effectively. It is, therefore, common to teach only the theoretical aspect of pack carburization and case hardening. As a result, students are not able to master the process and skill of pack carburization and case hardening (Ohize, 2007). Graduates of metalwork technology programmes who go to take up jobs as mechanical craftsmen and technicians lack the skill of the essential treatments of carburizing and case hardening of parts that they produce or recondition. It is, therefore, imperative that substitutes be found for commercial carburizing compounds that have disappeared from Nigeria industrial markets. Whereas carbon rich mineral resources and other sources of carbon have been discovered in Nigeria, it still remains to be determined experimentally if these minerals and other local carbonaceous materials can be good carburizing materials for mild steel. This study was therefore designed to experimentally determine the effect of wood charcoal as carburizing material on such mechanical properties as hardness, impact and tensile strengths of mild steel.

Purpose of the Study

The purpose of this study was to determine the effect of wood charcoal as carburizing material on mild steel. Specifically, the study investigated:

(i) The hardness of mild steel pack carburized with wood charcoal and case-hardened;
(ii) The tensile strength of mild steel carburized with wood charcoal and case-hardened;
(iii) The impact strength of mild steel pact carburized with wood charcoal and case-hardened;
(iv) The timing effect on the case hardness of mild steel pack carburized with wood charcoal and case-hardened.

Significance of the Study

The findings of this study are of great benefits to machinists, fabricators, blacksmiths, small and medium scale manufacturers engaged in production and reconditioning of engineering elements like shafts, cams, gears, pinions, sprockets hand tools and agricultural implements. Their products will gain increased operational life span and safety in operation as they adopt the treatment. These qualities will ensure greater patronage and hence increased business for the manufacturers.

The users of the products of these manufacturers are also expected to benefit from the findings of this study as they get value for their money by reason of longer service life of the parts. The safer and longer working life of the parts also guarantees increased turn over for the investors as shut down time due to breakdown will be reasonably reduced. Replacement of parts due to rapid wear is hoped to be minimized when the quality of such parts are improved by case hardening treatment. Consequently, productivity will be increased.

The findings of the study are also expected to open new lines of businesses in solid mineral development, which should be of advantage to potential entrepreneurs. Carbonaceous material found suitable for case hardening mild steel is expected to afford business opportunity in such material and thus expand trade base thereby promoting commercial activities. Alternative commercial uses of the material will diversify the market for such material and enhance healthy competition in the economic system of the nation.

The government also stands to benefit from the findings of the study by way of increased revenue generation. The development of such material found to be suitable will spare the government of foreign reserves that will otherwise go into the importation of commercial carburizing materials. International industrial markets may also open for alternative carburizing material. Such opportunities will increase the foreign reserve of the nation.

Students and teachers of metalwork technology will also benefit from the findings of the study. The basic science of wood charcoal and the technology of application as applied in the study can be built into technology curriculum. Metalwork technology students and teachers thus gain new knowledge and skill in carburizing mild steel with wood charcoal. Proven processes and techniques deriving from the study will further enhance the curriculum content of technical vocational education.

Research Questions

The following research questions were formulated to guide the study.

(i) What is the hardness of mild steel pack carburized with wood charcoal and case-hardened?

(ii) What is the tensile strength of mild steel pack carburized with wood charcoal and case-hardened?

(iii) What is the impact strength of mild steel pack carburized with wood charcoal and case-hardened?

(iv) What is the effect of carburizing time on the hardness of mild steel pack carburized with wood charcoal and case-hardened?

Research Design

This study adopted 1 x 5 factorial design to investigate the main and interactive effects of wood charcoal as independent variable and five levels of carburizing time as moderator variable on the hardness, impact and tensile strengths of mild steel. Thirty test specimens made up of ten each for hardness, tensile and impact strengths were used for the study. These provided two specimens randomly assigned to each test condition as shown in Table 1. The specimens were machined from 20mm diameter mild steel rods bought from steel marketers. The study used different sets of specimens for each test condition thereby generating independent measures. Independent measures helped to control variability within the experiment.

Table 1: Specimen distribution by carburizing time and test type

	Carburizing Time					
Test type	1hr	2hrs	3hrs	4hrs	5hrs	TOTALS
Hardness	2	2	2	2	2	10
Impact Strength	2	2	2	2	2	10
Tensile Strength	2	2	2	2	2	10
TOTAL	6	6	6	6	6	30

Experimental Procedure

Wood charcoal was procured from charcoal market in Kogi State, Nigeria and granulated using Jaw Crusher of the Department of Geology, Federal University of Technology, Minna. Fine powder was sieved off from the granulated material with number 3 sieve. Five 200mm by 100mm pack boxes with lids were fabricated from Standard Wire Gauge (SWG) 18 mild steel sheet bought from industrial stock market in Minna, Nigeria. The five pack boxes were stamped 'W1' 'W2' 'W3' 'W4' and 'W5' each to denote the carburizing times. Sets of six specimens for each test condition were also stamped 'W1' 'W2' 'W3' 'W4' and 'W5' respectively.

All the five boxes were packed carefully with wood charcoal and a set of six specimens as numbered were loaded into 1000^{o}C heat capacity Scandia Ovnenas of the National Metallurgical Development Centre, Jos, Nigeria. The boxes were sealed with clay and arranged carefully to allow for appropriate withdrawal of the boxes in accordance with carburizing time. The Oven was then shut, the temperature was preset to 900^{o}C and switched on. Carburizing time was started at the Oven's attainment of the preset temperature of 900^{o}C. At one hour of carburizing time, packed box marked W1 was withdrawn and the clay seal broken. The box and content were dumped into water tank for rapid cooling and hardening. Every one hour thereafter, the remaining pack boxes were withdrawn in the order of their carburizing time, the clay seals broken, and the boxes and contents rapidly cooled in water tanks. Different water tanks containing equal volume of water were used for each test condition. The specimens were then removed for their respective tests.

Results and Discussions

The detailed results for hardness, impact and tensile strengths in the order of measurements are contained in the Appendix. The summary of the results is presented in Table 2.

Table 2: Hardness, Impact and Tensile Strengths of Mild Steel Carburized with Wood Charcoal and Hardened

	Carburizing Time					
	1hr	2hrs	3hrs	4hrs	5hrs	Mean
Hardness (HRC)	53.667	58.750	64.183	65.700	66.000	61.660
Impact Strength (joules)	6.000	6.950	7.400	6.800	10.000	7.430
Tensile Strength (N/mm^2)	591.110	671.710	659.745	668.665	705.180	659.282

Wood charcoal has proven to be an effective carburizing material in this study. Mean hardness of 28.33HRC was obtained for the control specimens whereas a range of 53.667HRC to 66HRC with mean of 61.66HRC was obtained for the experimental specimens within one to five hours of carburizing time. Results obtained with wood charcoal compare favorably with those quoted by Neely (1979), Repp, McCarthy and Ludwig (1982) and Oberg, Jones and Horton (2012) for the same class of mild steel. Neely reported values of 60HRC to 62HRC for mild steel carburized and quenched from 925^{0}C. Repp et al reported surface hardness of between 60HRC to 66HRC for case hardened mild steel. Oberg et al reporting in Brinell Hardness Number quoted a range of 400BHN to 700BHN. It is to be noted that values quoted by these authors were obtained with industrial carburizing materials which contain energizers, and that the carburizing temperature was 920^{o}C. With the addition of energizers to wood charcoal used in this study and increased carburizing time, better results may be obtained in shorter times.

Impact strength ranging from 6joules to 10joules was obtained for the experimental specimens within one to five hours of carburizing time. This gave mean impact strength of 7.43joules whereas the mean impact strength of the control specimen was 79joules. The results show that impact strength progressively decreased with increased hardness. This is in contrast to the report of Agbeeze (1979) that the fracture strength of a metal increases with its hardness. Improved impact strength is expected to result from the combined effect of case hardness and core toughness of case hardened mild steel. Impact test specimens used in this study were machined to a diameter of 11.4mm. This diameter might have been too small and/or the carburizing effect of wood charcoal is so high and rapid that carbon infiltrated too deep into the specimens. Thus the uncarburized core will be so small for an effective strength inducement into the specimens. An experiment with bigger diameter specimens or shorter carburizing time may help to verify this.

A range of 591.11N/mm^2 to 659.282N/mm^2 tensile strength resulting into mean of 659N/mm^2 was obtained for mild steel. Mean tensile strength for controlled specimen was 304.16N/mm^2. Results obtained in this study show that tensile strength of steel progressively increased with higher hardness values. The study showed a positive correlation between hardness and tensile strength of pack carburized and case hardened mild steel. The findings of this study agree with Weihsmann (1981) who reported that hardness measurement is known to correlate with the tensile strength of many metals, and that a definite relationship exists between tensile strength and hardness. Chapman (1978) also reported that there is a fairly definite relationship between Brinell hardness and tensile strength of steel.

Conclusion

The following conclusions were drawn based on the findings of this study;

(i) Hardness and tensile strength of mild steel specimen increased considerably but impact strength decreased when carburized with wood charcoal and hardened;
(ii) Carburizing time had an ordinal effect on the hardness of mild steel specimen when carburized with wood charcoal and hardened; and
(iii) There was significant interactive effect of wood charcoal as carburizing material and time only on the hardness of mild steel specimen.

Recommendations

The following recommendations were made as a result of the findings and implications of this study.

(iv) Wood charcoal should be processed into carburizing material;
(v) The process of pack carburizing with wood charcoal should be incorporated into metalwork technology curriculum;
(vi) Workshops on process of pack carburizing with wood charcoal should be organized for machinists, fabricators, blacksmiths and manufacturers engaged in the production and repair of steel parts like shafts, cams, gears, pinions, sprockets, hand tools and agricultural implements; and
(vii) Major steel product manufacturing industries should be encouraged to re-tool for the process of pack carburizing with wood charcoal.

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Appendix A: Hardness of Mild Steel Carburized with Wood Charcoal in the Other of Measurement

S/No	Specimen	Hardness (RC)		
		1	2	3
1	W_5	66.2	65.4	65.0
2	W_2	67.0	63.5	62.8
3	W_3	68.5	66.0	64.9
4	W_1	50.0	46.0	45.0
5	W_4	66.2	66.0	65.0
6	W_3	63.2	61.5	61.0
7	W_1	61.0	60.5	59.5
8	W_5	68.5	66.0	64.9
9	W_2	55.2	54.0	50.0
10	W_4	66.0	65.5	65.5

Appendix B: Impact Strengths of Mild Steel Carburized with Wood Charcoal in the Order of Measurement

S/N	Specimen	Energy Sbsorbed (J)
1	W_4	7.9
2	W_3	6.5
3	W_2	5.8
4	W_1	5.5
5	W_5	7.8
6	W_1	6.0
7	W_2	5.8
8	W_4	9.0
9	W_3	6.0
10	W_5	13.5

Appendix C: Tensile Strengths of mild Steel Carburized with Wood Charcoal in the Order of Measurement

S/N	Specimen	Tensile Strength(N/mm^2)
1	W_4	702.06
2	W_2	618.15
3	W_3	700.68
4	W_5	712.91
5	W_1	503.96
6	W_2	624.42
7	W_3	678.26
8	W_1	641.36
9	W_5	709.68
10	W_4	701.34