

# Effects of Local Carbonaceous Materials on the Mechanical Properties of Mild Steel

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## Abstract

*This study experimentally determined the effect of coal, bone charcoal and wood charcoal on the hardness, tensile and impact strengths of mild steel. Sample pieces of mild steel machined to specifications were carburized with each of coal, bone charcoal and wood charcoal and case hardened. Direct testing and measurement of hardness, tensile and impact strengths were done on respective conventional testing machines. The study answered four research questions with means, and tested seven null hypotheses at .01 level of significance with 3 x 5 Analysis of Variance. Coal, bone charcoal and wood charcoal as carburizing materials each had considerable increasing effect on hardness and tensile strengths but a decreasing effect on impact strengths of mild steel. Wood charcoal had the greater effect while coal had the least effect on hardness and tensile strengths; and only the interactive effect of carburizing material with carburizing time was significant at .01 level of significance. Results obtained compared favourably with results of conventional energized pack carburizing materials.*

**Keywords:** Coal, bone charcoal, wood charcoal, hardness, tensile strength.

## Introduction

Mild steel, by reasons of its dominance and workability among the classes of steel (Jacob & Kilduff 1985), has found a very wide application in the production of engineering elements like gears, cams, shafts, pinions, keys, hand tools, agricultural equipment, etc. These elements require the mechanical properties of hardness, impact strength and tensile strength for their safe and durable functions. Mild steel with which fabricators and machinists easily produce the elements naturally lack these required mechanical properties. Such parts produced from mild steel thus require the heat treatments of carburizing and case-hardening in order to build-in these required mechanical properties (Neely 1979; Oberg, Jones & Horton 1984; Norwood 1996). Visits to giant steel industries like Ajaokuta Steel Company, Ajaokuta; Defense Industrial Corporation, Kaduna; and others at the inception of this study revealed that their high-tech equipment and facilities for carburizing treatments were broken down. A survey of Nigerian industrial

stock market revealed a dearth of commercial pack carburizing compounds that fabricators, machinists and blacksmiths who produce or recondition these vital engineering elements could conventionally use to carburize and case harden them. The resultant effect of this is the non-treatment of such produced parts with the consequent results of fast wear, tear and failure of mild steel parts, and the theoretical teaching of carburizing and case-hardening treatments in metalwork technology and other related programs.

Authors like Shrager (1961), Love (1979), Repp and McCarthy (1992), and Dempsey (2002) while writing on commercial pack carburizing compounds reported that they are formulated from materials that are rich in carbon element. Whereas many local materials have been identified to be rich in carbon compound, it had not been experimentally determined if these identified materials can serve as suitable substitutes for the commercial pack carburizing compounds that have disappeared from Nigerian industrial stock markets. This study was therefore designed to

experimentally determine the effects of locally sourced carbonaceous materials on the mechanical properties of mild steel. Specifically, the study investigated:

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

This study established a practice of case hardening mild steel with local carbonaceous materials and this should bring about:

- (i) New knowledge and skill in carburizing process for metalwork technology education students and teachers;
- (ii) Enhanced curriculum content of vocational technical education;
- (iii) Increased safe operational life of mild steel parts;
- (iv) Increased value for money for users of mild steel products;
- (v) New businesses in bone charcoal, coal and wood charcoal; and
- (vi) Increased revenue earnings for government.

### Research Questions

The following research questions were formulated to guide the study.

- (i) What are the hardness of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case-hardened?
- (ii) What are the tensile strengths [in Newton per square millimetre ( $N/mm^2$ )] of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case-hardened?
- (iii) What are the impact strengths [in joules] of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case-hardened?

- (iv) What is the effect of carburizing time on the hardness of mild steel carburized with each of coal, wood charcoal and bone charcoal?

### Hypotheses

For the purpose of this study and in accordance with the research questions, the following null hypotheses were formulated and they were tested at .01 level of significance. There is no significant difference in the hardness of mild steel pack carburized with each of coal, wood charcoal and bone charcoal and, case-hardened ( $p < .01$ ).

- (i) There is no significant difference in the tensile strength of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case-hardened ( $p < .01$ ).
- (ii) There is no significant difference in the impact strength of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case-hardened ( $p < .01$ ).
- (iii) There is no significant difference in hardness of mild steel due to carburizing time ( $p < .01$ ).
- (iv) There is no significant interactive effect of carburizing material and carburizing time on the mean hardness of pack carburized, and case-hardened mild steel ( $p < .01$ ).
- (v) There is no significant interactive effect of carburizing material and carburizing time on the mean impact strength of pack carburized, and case-hardened mild steel ( $p < .01$ ).
- (vi) There is no significant interactive effect of carburizing material and carburizing time on the mean tensile strength of pack carburized, and case-hardened mild steel ( $p < .01$ ).

### Methodology

The study adopted a 3 x 5 factorial design. 30 specimen pieces for each of hardness, impact and tensile strengths were machined to specifications from a 20mm diameter steel rod procured from Minna industrial stock market. Each of the three sets of specimens were randomly assigned in twos to fifteen groups and these provided six specimens for each test condition as shown in Table 1.

Table 1. Specimen distribution by carburizing time and material.

Carburizing Material	Carburizing Time					Total
	1hr	2hr	3hr	4hr	5hr	
Coal	6	6	6	6	6	30
Wood Charcoal	6	6	6	6	6	30
Bone Charcoal	6	6	6	6	6	30
<b>Total</b>	18	18	18	18	18	90

All six specimens carburized with coal for one hour were marked C1, those for two hours were marked C2 and so on to C5. Similarly, all specimens carburized with wood charcoal were marked W1 to W5 and those carburized with bone charcoal were marked B1 to B5 in accordance with carburizing material and carburizing time.

Animal bones were procured from butchers in Minna meat market and charred to produce bone charcoal. Coal from Okaba-Odigbo mining field and wood charcoal from farm market both in Kogi State were procured. The coal, wood charcoal and bone charcoal were granulated using Jaw Crusher of the Department of Geology, Federal University of Technology, Minna. Fine powders were sieved off from the granulated materials with number 3 sieve. Fifteen pack boxes measuring 200mm by 100mm by 100mm with lids were fabricated from Standard Wire Gauge (SWG) 18 mild steel sheets bought from Minna industrial stock market. Equal volumes of granulated coal, wood charcoal and bone charcoal were poured into five pack boxes each to fill them to about one-third full. The pack boxes were marked C1 to C5 for the five containing coal, W1 to W5 for the five containing wood charcoal and B1 to B5 for the five containing bone charcoal. Each set of six specimens was arranged into the pack boxes according to their numbering and it was ensured that the specimens neither touched each other nor the box. Equal volumes of the granulated coal, wood charcoal and bone charcoal were then poured into the respective boxes to fill them to about two-thirds full. It was ensured that the specimens were completely buried inside the carburizing materials. The lids of the boxes were placed on and sealed with clay to prevent oxygen infiltration. All the 15 packed carburizing boxes were loaded into Scandia Ovens of the National Metallurgical Development

Centre, Jos. The oven has a heating capacity of 1000°C. The boxes were arranged in threes according to their numbers. This was to allow for appropriate withdrawal of the boxes in accordance with the carburizing time. The Oven was then shut; the temperature was preset to 900°C and switched on. Carburizing timing was started on the Oven's attainment of the preset temperature. At one hour of carburizing time, the three packed boxes marked C1, W1 and B1 were withdrawn and rapidly cooled in water. Every one hour thereafter, sets of three pack boxes in the order of their numbering were withdrawn for rapid cooling in water. There were therefore, five sets of withdrawals corresponding to the five levels of carburizing time. On removal of the boxes from the furnace, the clay seals on them were broken off immediately and both boxes and contents were emptied into water tanks to effect rapid cooling. The specimens were then removed for their respective tests. This study used different sets of specimens for each test condition thereby generating independent measures. Independent measures helped to control variability within the experiment.

Direct testing and measuring of hardness, impact strength and tensile strength were done with appropriate machines duly validated and tested for reliability. Hardness data were obtained in Rockwell C (HRC) using Karl Frank GMBH Rockwell hardness testing machine. Tinius Olsen Universal Testing Machine of 300KN capacity was used to measure tensile strength in N/mm<sup>2</sup>. Avery-Denison Impact Testing Machine of 300joules capacity was used for the Charpy test to measure impact strength in joules. These machines were those of National Metallurgical Development Centre, Jos and Kaduna Polytechnic College, Kaduna. The data gathered in this study was analyzed using Mean and Analysis of Variance (ANOVA). Research

questions 1 to 4 were answered using means of the direct measurements obtained from the specimens of the respective tests. The hypotheses were tested using two-way ANOVA of 3 x 5 design. The tables of analysis are contained in the Appendix.

## Findings and Discussion

The followings are the findings after carefully analyzing the data collected in this study.

(i) Each of coal, wood charcoal and bone charcoal increased the hardness of mild steel considerably over time.

(ii) Coal, wood charcoal and bone charcoal had increasing effect on the tensile strength of mild steel over time.

(iii) Coal, wood charcoal and bone charcoal had decreasing effect on the impact strength of mild steel over time.

(iv) Carburizing time had an effect on the hardness of mild steel. The longer the time the harder the mild steel.

(v) There is a significant difference in the mean hardness of mild steel based on carburizing material.

(vi) There is no significant difference in the mean tensile strength of mild steel based on carburizing material.

(vii) There is no significant difference in the mean impact strength of mild steel based on carburizing material.

(viii) Carburizing time made significant difference in mean hardness of mild steel.

(ix) Carburizing material and carburizing time interaction had significant effect at alpha level of .01 on hardness of mild steel.

(x) Carburizing material and carburizing time interaction had no significant effect on impact strength of mild steel.

(xi) Carburizing material and carburizing time interaction had no significant effect on tensile strength of mild steel.

Coal, wood charcoal and bone charcoal have proven to be effective carburizing materials in this experimental study. The range of 28.2RC to 28.5RC was obtained for the control specimens whereas a range of 51.177RC to 61.66HRC was obtained for the experimental specimens. This range of hardness was obtained within one to five hours

of carburizing time. It is probable that higher hardness values may be obtained with longer carburizing time.

Results obtained with the carburizing materials that were investigated compare favourably with those quoted by Neely (1979); Repp *et al.* (1982); and Oberg *et al.* (1984) for the same class of mild steel. Neely reported values of 60HRC to 62HRC for mild steel carburized and quenched from 925°C. Repp *et al.* (1982) reported surface hardness of between 60HRC to 66HRC for case hardened mild steel. Oberg *et al.* (1984) 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. These materials contain energizers that hasten carburization process. With the addition of energizers to the local carbonaceous materials used in this study, better results may be obtained in shorter times.

Hardness measurement is known to correlate with tensile strength of many metals (Tabor 1951). Chapman (1978) also reported that there is a fairly definite relationship between Brinell hardness and tensile strength of steel. Results obtained in this study showed that tensile strength of mild steel progressively increased with higher hardness values. The findings of this study agree with these views. The study showed a positive correlation between hardness and tensile strength of pack carburized and case hardened mild steel.

Impact strength, however, progressively decreased with increased hardness. This is in contrast with the report of Agbeezee (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 effects of coal, wood charcoal and bone charcoal so high and rapid that carbon infiltrated too deep into the specimens. Thus, the un-carburized 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 significant difference between the mean hardness of mild steel carburized with each of coal, bone charcoal and wood charcoal was detected from analysis. A post hoc test showed non-homogeneity of paired comparison of coal, bone charcoal and wood charcoal effects. This is indicative of significant different effects of each carburizing material from the other. The mean hardness for each was 51.1767RC for coal, 54.8133RC for bone charcoal and 61.660RC for wood charcoal.

Carburizing times of two hours and three hours showed homogeneity in hardening effect. Three hours, four hours and five hours carburizing times also showed homogeneity of effect. The value obtained for one hour carburizing time was not homogeneous with any other and was far lower than the rest. This may indicate that at one hour carburizing time, either enough carbon had not been liberated from the carburizing materials, or that the mild steel had not attained enough affinity for carbon absorption. It therefore, suggests that pack carburizing of mild steel must always be done in more than one hour whenever maximum hardness is desired.

Homogeneity of carburizing times of three hours to five hours as recorded in this study may require further investigation to determine whether carbon was completely used up, or the mild steel had reached its carbon saturation point. Such investigation may require bigger boxes packed with more carburizing materials.

### Recommendations

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

(i) Coal, wood charcoal and bone charcoal should be processed into carburizing materials.

(ii) The process of pack carburizing with coal, wood charcoal and bone charcoal should be incorporated into metalwork technology curriculum.

(iii) Workshops on process of pack carburizing with coal, wood charcoal and bone

charcoal should be organized for machinists, fabricators, blacksmiths and manufacturers engaged in the production and re-conditioning of steel parts like shafts, cams, gears, pinions, sprockets, hand tools and agricultural implements.

(iv) Major steel product manufacturing industries should be encouraged to re-tool for the process of carburizing with coal, wood charcoal and bone charcoal.

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### Appendix

Table A1. Mean hardness of mild steel pack carburized with each of coal, wood charcoal and bone charcoal and case hardened.

	Hardness in Rockwell C (RC)					
	1hr	2hrs	3hrs	4hrs	5hrs	Mean
Coal	48.450	48.450	48.583	54.933	55.467	51.177
Bone charcoal	37.650	53.300	60.033	60.167	60.917	54.813
Wood charcoal	53.667	58.750	64.183	65.700	66.000	61.660

Table A2. Mean tensile strengths of mild steel pack carburized with each of coal, wood charcoal and bone charcoal and case hardened.

	Tensile strengths in N/mm <sup>2</sup>					
	1hr	2hrs	3hrs	4hrs	5hrs	Mean
Coal	517.270	585.665	583.910	588.050	586.075	572.314
Bone charcoal	512.930	517.315	591.910	621.435	652.690	579.256
Wood charcoal	591.110	671.710	659.745	668.665	705.180	659.282

Table A3. Mean impact strengths of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case hardened.

	Mean impact strengths in joules					
	1hr	2hrs	3hrs	4hrs	5hrs	Mean
Wood charcoal	6.000	6.950	7.400	6.800	10.000	7.430
Bone charcoal	7.500	8.250	11.850	10.750	12.300	10.130
Coal	9.650	13.400	7.500	14.250	9.400	10.840

Table A4. Mean hardness of mild steel pack carburized with each of coal, wood charcoal and bone charcoal, and case hardened based on carburizing time.

	Hardness in Rockwell C (HRC)			
	Coal	Wood charcoal	Bone charcoal	Mean
1hr	48.450	53.667	37.650	46.589
2hrs	48.450	58.750	55.300	54.167
3hrs	48.583	64.183	60.033	57.600
4hrs	54.933	65.700	50.167	60.267
5hrs	55.467	66.000	60.917	60.794

Table A5. Summary of analysis of variance for main and interactive effects of carburizing material and carburizing time on hardness of mild steel.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5,054.440 <sup>a</sup>	15	336.963	14.974	.000
Intercept	281,065.225	1	281,065.225	12,490.101	.000
Rep 1	18.587	1	18.587	.826	.366
Time	2,441.038	4	610.259	27.119	.000
Material	1,700.025	2	850.012	37.773	.000
Time*Material	894.791	8	111.849	4.970	.000
Error	1,665.225	74	22.503		
Total	287,784.890	90			
Corrected Total	6,719.665	89			

<sup>a</sup>. R Squared = .752 (Adjusted R Squared = .702)

Table A6. Summary of analysis of variance for main and interactive effects of carburizing material and carburizing time on tensile strength of mild steel.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	100,791.413 <sup>a</sup>	15	6,719.428	.913	.570
Intercept	10,930,616.6	1	10,930,616.55	1,485.964	.000
Rep	1,345.896	1	1,345.896	.183	.675
Cmaterial	40,112.038	4	10,028.080	1.363	.296
Time	46,719.284	2	23,359.642	3.176	.073
Time*Cmaterial	12,613.915	8	1,576.739	.214	.983
Error	102,982.716	14	7,355.908		
Total	11,134,390.7	30			
Corrected Total	203,774.128	29			

<sup>a</sup>. R Squared = .495 (Adjusted R Squared = .047)

Table A7. Summary of analysis of variance for main and interactive effects of carburizing material and carburizing time on impact strength of mild steel.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	186.065 <sup>a</sup>	15	12.404	.557	.864
Intercept	2,688.533	1	2,688.533	120.747	.000
Rep	.108	1	.108	.005	.945
Time	35.183	4	8.796	.395	.809
Cmaterial	64.741	2	32.370	1.454	.267
Time*Cmaterial	86.003	8	10.754	.483	.849
Error	311.722	14	22.266		
Total	3,186.320	30			
Corrected Total	497.787	29			

<sup>a</sup>. R Squared = .374 (Adjusted R Squared = .297)