Pack Carburization of Mild Steel, using Pulverized Bone as Carburizer: Optimizing Process Parameters

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Abstract

Investigation was conducted into the mechanical properties of mild steel subjected to packed carburization treatment using pulverized bone as the carburizer, carburized at 850°C, 900°C and 950°C, soaked at the carburizing temperature for 15 minutes and 30 minutes, quenched in oil and tempered at 550°C. Prior carburization process, standard test samples were prepared from the as received specimen for tensile and impact tests. After carburization process, the test samples were subjected to the standard test and from the data obtained, ultimate tensile strength, engineering strain, impact strength, Youngs' moduli were calculated. 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 strongly influenced by the process of carburization, carburizing temperature and soaking time at carburizing temperature. It was concluded that the sample carburized at 900°C soaked for 15 minutes and the one carburized at 850°C soaked for 30 minutes followed by oil quenching and tempering at 550°C were better because they showed a trend of hard case with softer core.

Keywords

Packed carburization; Carburizing temperature; Activated carbon; Hardness.

Introduction

Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures within the austenitic region of the steel concern, which generally is between 850°C and 950°C for mild steels. Within this temperature range austenite, which has high solubility for carbon, is the stable crystal structure. Hardening is accomplished 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 superimposed on a tough, low-carbon steel core [1].

Carbon diffusivity in austenite varies both with carbon concentration and carburizing temperature [2-5]. Considering that carbon concentration depends on its activity in austenite and that the finite repulsive interactions exist between neighboring carbon atoms in octahedral sites, Babu and Bhadeshia [6] modeled carbon diffusivity in accordance with kinetic and thermodynamic behavior of carbon in austenite. Siller and McLellan [7] suggested that the repulsive forces between the neighboring carbon atoms influence carbon diffusivity by reducing probability of interstitial sites occupancy in the vicinity of the site already occupied by carbon atom. Therefore, in a concentration gradient, carbon atom attempting random motion faces exaggerated difference in the number of available sites, which enhances carbon diffusion down the concentration gradient.

Interstitial carbon diffusivity is strongly affected by the atomic interactions with substitutional solute, i.e., alloying elements present in the steel [8]. If these interactions are positive, substitutional solute atoms tend to attract interstitial carbon atoms. Such deviation from randomness in the interstitial atoms distribution impedes long range diffusion of carbon in the austenite lattice, and therefore decreases the effective coefficient of carbon diffusion. Similar effect but of the opposite nature will be expected with solute components of negative interactions: as their binding energy decreases there will be localized volumes with increased carbon diffusivity. The study of process parameters in metals during heat treatment has been of considerable interest for some years [9-12] but there has been relatively little work on process variables during the surface hardening process [13] since controlling parameters in carburization is a complex problem. The major influencing parameters in carburization are the holding time, carburizing temperature, carbon potential and the quench time in oil [14].

The aim of research work is to improve the mechanical properties mild steels applicable for constructing farm implements and in automobiles, machines, gears, springs and high strength wires etc., by pack carburization using pulverized bone as a carburizer and by optimizing carburizing temperature and soaking time.

Material and Method

The materials used for this research work are Mild steel (with the chemical composition shown in Table 1. was sourced from Universal steel company, Ogba Industrial Estate, Ikeja, Lagos.), bone (purchased from the abattoir Araromi, Akure), Industrial engine oil as quenching medium.

Table 1. Chemical composition of the mild steel sample

Element	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu
Avg content	0.1999	0.1548	0.0594	0.0459	0.5826	0.131	0.1105	0.016	0.0013	0.384
Element	W	As	Sn	Co	Al	Pb	Ca	Zn	Fe	
Avg content	0.0076	0.0051	0.0377	0.0098	0.0028	0	0.0001	0.0048	98.2476	

Test Specimen Preparation

The mild steel was machined to standard test sample sizes of tensile and impact tests. This was done according to ASTM's specifications on standard tensile and impact sample dimensions.

Carburization of Mild Steel Samples

The prepared test samples were embedded in the activated carbon inside a steel pot which was then tightly sealed with clay cover to prevent the C° from escaping and prevent unwanted furnace gas from entering the steel pot during heating. The furnace temperature was adjusted to the required temperature (850°C, 900°C and 950°C for each stage respectively) and the loaded steel pot was charged into the furnace. When the furnace temperature reaches the required carburizing temperature, it was then held/soaked at the temperature for the required time (15 and 30 minutes). After the material was held at the specified time, the steel pot was removed from the furnace and the material was quenched in industrial engine oil.

Tempering of the Carburized Samples

The carburized test samples were then tempered at a temperature of 550°C, held for one hour, and then cooled in air. After the cycles of heat-treatment, the test samples were subjected to tensile test, impact test and hardness test.

Mechanical Test

Tensile Testing

The tensile tests were performed on various samples using Monsanto tensometer. The fracture load for each sample was noted 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 uniaxial load. From the generated data the ultimate tensile strength and percentage elongation of each sample was calculated.

Impact Test

The impact tests were performed on various sample determine the impact strengths by the "V-notch method using the Honsfield Balance Impact Testing Machine. Prior to mounting on the machine, the test sample is notched to a depth of 2mm with v-shaped hand file. The notched test sample was then mounted on the impact-testing machine, which is the operated to apply a (constant) impact force on the test sample. The impact strength (the amount of impact energy the specimen absorbed before yielding) was then read off the calibrated scale on the impact testing machine.

Hardness Test

In present experimental work Rockwell hardness was measured on carburized, tempered mild steel samples which are carburized under different temperature range of 850, 900 and 950°C. For each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case.

Results and Discussion

Table 2 shows the mechanical properties of the carburized, tempered samples: The relationships between these properties are depicted as follows in Figures 1, 2, 3, 4, 5 and 6, depict the effects of carburizing temperature on the impact energy, ultimate tensile strength, engineering strain, Young's modulus of elasticity, case hardness and core hardness of the test samples respectively.

Table 2. Mechanical Properties of the Carburized, Tempered Samples

Time (Min)	Temperature (°C)	Impact Strength (J)	Core harness (H_{RA})	Case hardness (H_{RA})	UTS (N/mm^2)	Engineering Strain	Modulus of Elasticity (N/mm^2)
15	850	31.23	67	68.3	689.60	0.01942	35,509.78
15	900	41.37	63.8	67.3	863.57	0.0652	13,244.94
15	950	60.43	63.1	62.1	900.25	0.08479	10,617.41
30	850	20.69	61.6	67.6	751.81	0.02421	31,053.7
30	900	34.61	71	62.5	655.97	0.15987	4,103.15
30	950	61.65	60.2	59.7	789.76	0.10977	7,194.68

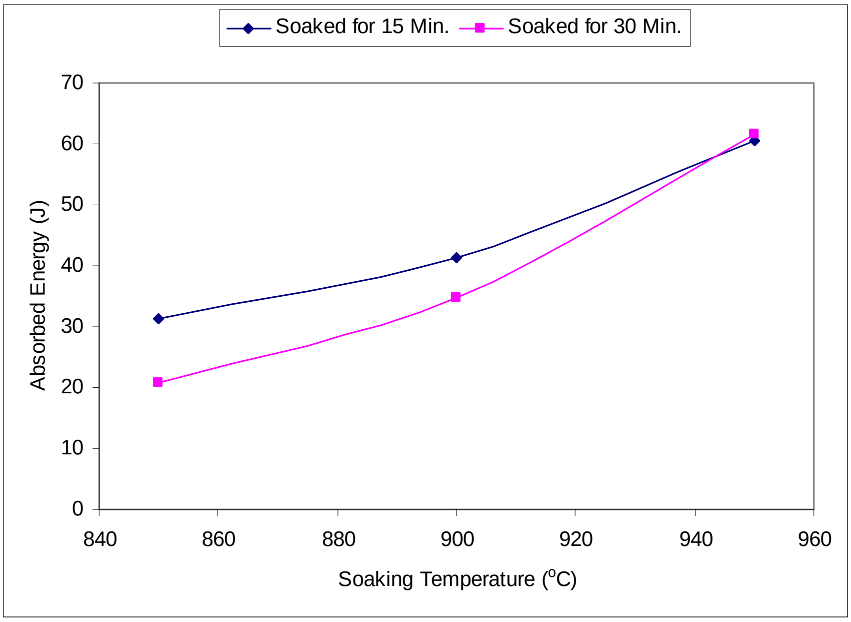

Figure 1. *The effect of carburizing temperature on the impact energy of the samples*

From Figure 1, it is observed that the absorbed (impact) energy increases with increase in the carburizing temperature, the impact energy of the samples soaked for 15 minutes (0.25 hours) were higher than those of the samples soaked for 30 minutes (0.50 hours).

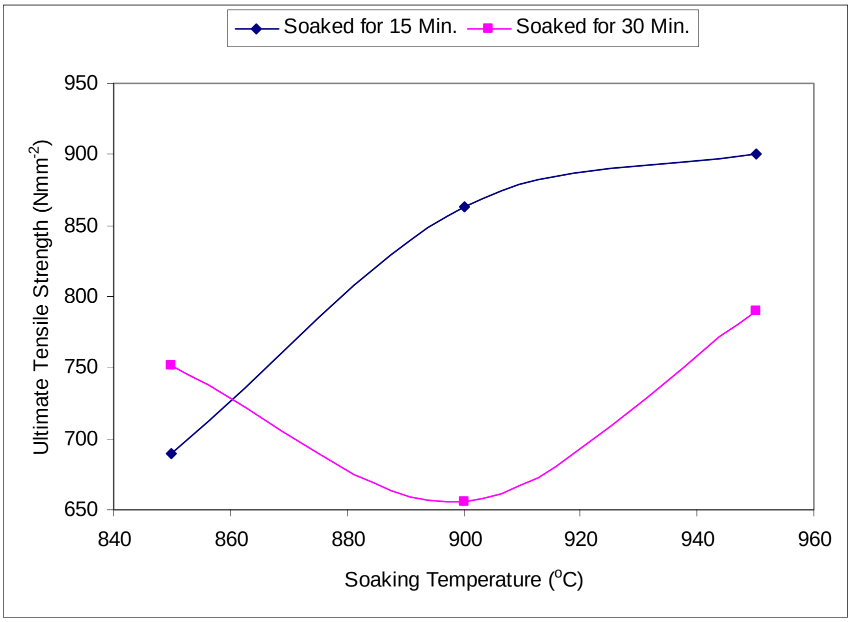

Figure 2. *The effect of carburizing temperature on the ultimate tensile strength of the samples*

In Figure 2, it is observed that for the samples soaked for 15 minutes, the ultimate tensile strength (UTS) increases with increase in the carburizing temperature and reached the maximum value of 900.25 Nmm^{-2} at 950°C. For the samples soaked for 30 minutes, the UTS initially decreased from 751.81 Nmm^{-2} (at the carburizing temperature of 850°C) to 655.97 Nmm^{-2} when the carburizing temperature increased to 900°C. It then increased to its maximum value of 789.76 Nmm^{-2} as the carburizing temperature increased to 950°C. This shows that the UTS of the samples soaked for 30 minutes was reduced by the carburization process, whereas the UTS of the samples soaked for 15 minutes improved as the carburizing temperature increased. Similarly, for both series the carburization process reduced the UTS of the treated samples at carburizing temperature of 850°C when compared with the UTS of the untreated as received sample which has a UTS of 800.07 Nmm^{-2} and impact energy of 61.25 J. For the samples soaked for 15 minutes, a similar result was arrived at by some researchers [15, 16] who studied the mechanical properties of cast 25Cr-20Ni steel subjected to pack carburization. This relationship of the UTS with the carburizing temperature is similar to its relationship with the percentage carbon content of steel in both annealed and tempered conditions [17,18], it can be reliably assumed that the amount of carbon that diffused into the samples increases with the carburizing temperature. The behaviour of the samples soaked for 30 minutes in Figure 2, is similar to the discoveries of Ward, (1981) [18] where he found that the UTS of carburized samples of some steel grades were some reduced.

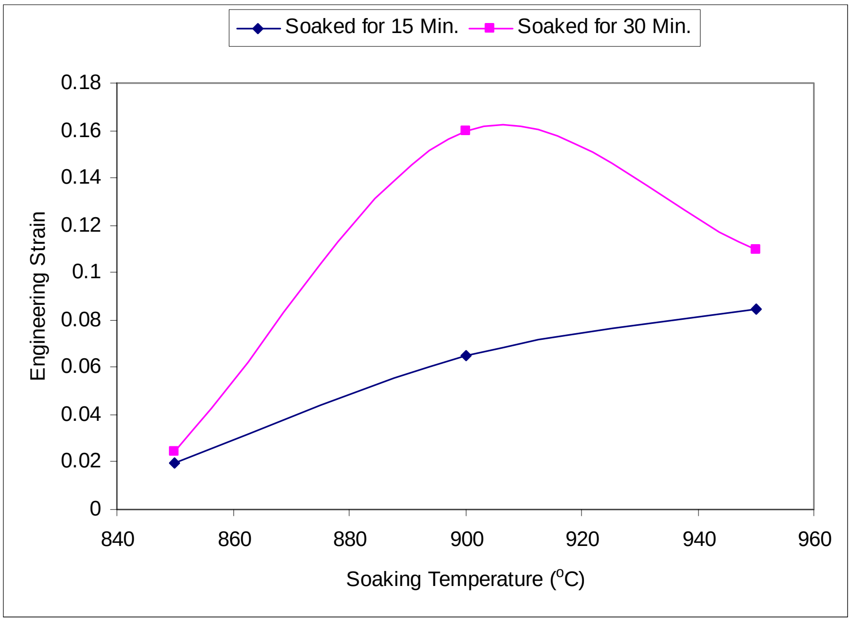

Figure 3. *The effect of carburizing temperature on the engineering strain of the samples*

In Figure 3, the strain for both series of samples initially increased. From its minimum level of 0.02421 (i.e. 2.421 % elongation) at 850°C, increased to its maximum of 0.15987 (i.e. 15.987 % elongation) as the carburizing temperature is increased to 900°C which then reduced to 0.10977 (i.e. 10.977 % elongation) with further increase in the carburizing temperature to 950°C for the samples soaked for 30 minutes. Similarly, the strain increase from its minimum level of 0.01942 (i.e. 1.942 % elongation) at 850°C, it further increased to a value 0.0652 (i.e. 6.52 % elongation) as the carburizing temperature is increased to 900°C which then increased slightly to 0.08479 (i.e. 8.479 % elongation) with further increase in the carburizing temperature to 950°C for the samples soaked for 15 minutes [19]. The reason for the initial increase in ductility as the carburizing temperature increases is due to an increased interface area produced by the carbide formation at grain boundaries which lead to the impurities (cavities and cracks) being redistributed, because their concentration is low the problem of embrittlement is negligible [20].

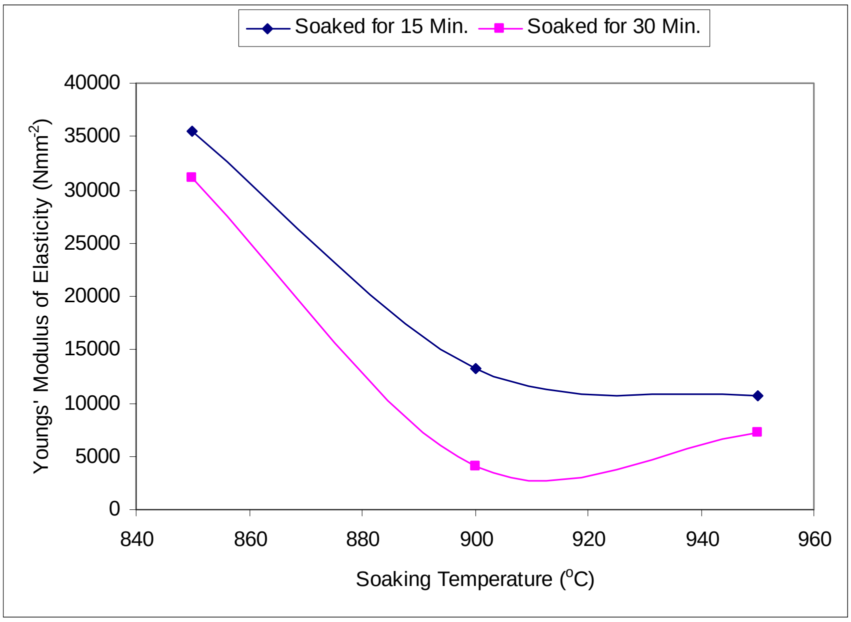

Figure 4. *The effect of carburizing temperature on the Young's modulus of elasticity of the samples*

From Figure 4 it is clearly seen that for the samples soaked for 15 minutes, the Youngs' modulus at carburizing temperature of 850°C reduced from its maximum value of 35,509.78 Nmm^{-2} to 13,244.94 Nmm^{-2} as the carburizing temperature is increased to 900°C and then reduced to minimum value of 10,617.41 Nmm^{-2} as the carburizing temperature is increased to 950°C. Similarly, for the samples soaked for 30 minutes, the Youngs' modulus at carburizing temperature of 850°C reduced from its maximum value of 31,053.7 Nmm^{-2} to the minimum value of 4,103.15 Nmm^{-2} as the carburizing temperature is increased to 900°C and then increased to 7,194.68 Nmm^{-2} as the carburizing temperature is increased to 950°C. Comparing these with the Youngs' modulus of the as received sample which has a value of 12,973.86 Nmm^{-2} show that the stiffness of the carburized samples were initially higher than the as received samples. This shows that the samples lost their stiffness with increase in the carburizing temperature.

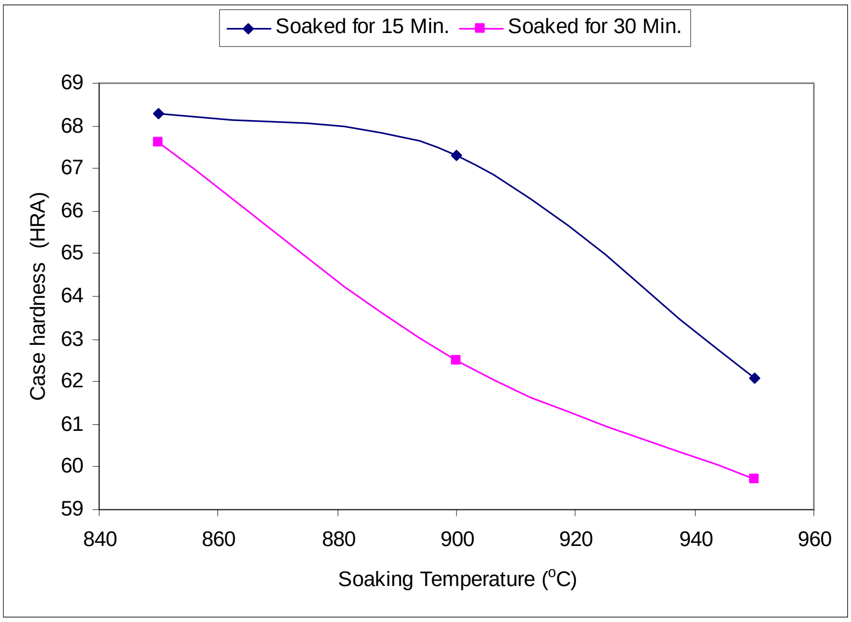

Figure 5. *The effect of carburizing temperature on the case hardness of the samples*

From Figures 5 and 6, it is observed that the for the samples soaked for 15 minutes case hardness was 68.3 HRA (while the core hardness was 67 HRA), at the carburizing temperature of 850°C; when the sample was carburized at 900°C, the case hardness reduced to 67.3 HRA (while core hardness reduced to 63.8 HRA); when the sample was carburized at 950°C, the case hardness then reduced to 62.1 HRA (while the core hardness reduced slightly to 63.1 HRA). Comparing these with the hardness of as received samples of 51.2 HRA it is glaring that there was actually carbon enrichment in the carburized samples. Moreover, for those samples soaked for 30 minutes at different carburizing temperatures the case hardness was 67.6 HRA (while the core hardness was 61.6 HRA), at the carburizing temperature of 850°C; when the sample was carburized at 900°C, the case hardness reduced to 62.5 HRA (while core hardness increased to 71 HRA); when the sample was carburized at 950°C, the case hardness then reduced to 59.7 HRA (while the core hardness reduced to 60.2 HRA).

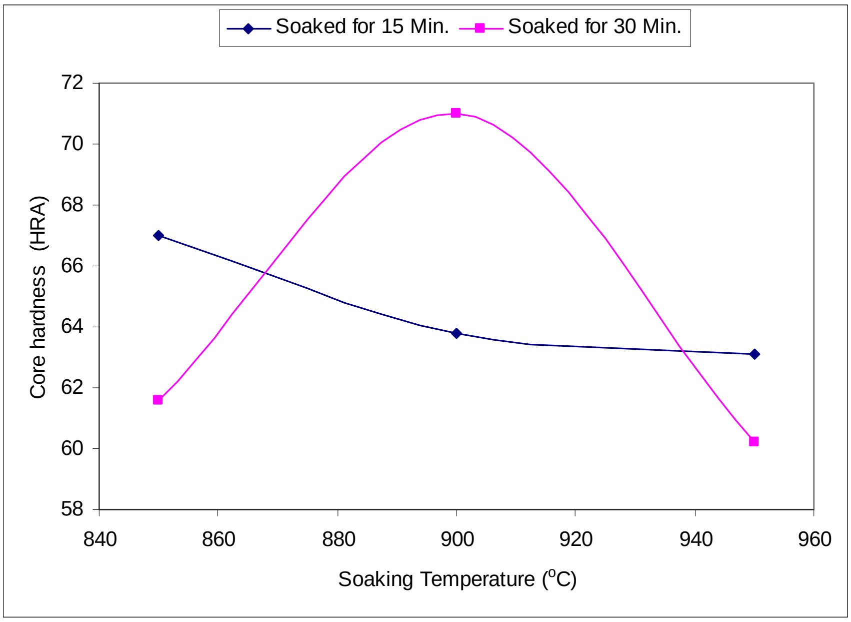

Figure 6. *The effect of carburizing temperature on the core hardness of the samples*

Summarily, looking at the hardness profile of the carburized samples, for those soaked for 15 minutes, the sample carburized at 900°C is considered the best, while for the samples soaked for 30 minutes, the sample carburized at 850°C is considered the best because they showed a trend of hard case with softer core.

Conclusions

From the discussions so far it can be concluded that:

1. Carburization process reduced the impact toughness of mild steels, but contrary to the trend observed where activated carbon is the carburizer the impact toughness increases with the carburizing temperature where pulverized bone is used as the carburizer.
2. The stiffness of the mild steel is increased by the carburization process, but it decreases with increasing carburizing temperature.
3. The carburization treatment followed by the oil quenching and tempering at 550°C strongly influence the hardness and tensile strength of mild steels.
4. The carburization process decreases the impact energy (toughness) of the mild steels. And the toughness is decreases with increase in the carburization temperature.

5. The mechanical properties of mild steels were found to be strongly influenced by the process of carburization, carburizing temperature soaking time at carburizing temperature.
6. The sample carburized at 900°C soaked for 15 minutes and the one carburized at 850°C soaked for 30 minutes followed by oil quenching and tempering at 550°C are considered better because they showed a trend of hard case with softer core.

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