Effect Of Process Variables On The Mechanical Properties Of Surface Hardened Mild Steel Quenched In Different Media

Nwoke, V.U; Nnuka E.E; Odo, J.U, Obiorah S.M.O

Abstract: The effect of process variables on the mechanical properties of surface hardened mild steel quenched in water and brine was investigated. The process variables are treatment temperature and soaking time and the mechanical properties studied are impact strength, Rockwell hardness, ductility and micro-hardness. Pack carburization method of surface hardening was used. Standard tests and analytical methods were used for the research and results obtained showed that impact strength decreased by 82.14% and 96.43% when quenched in water and brine respectively, as compared to the control specimen, the impact strength of which was 84J. Rockwell hardness increased by 15.09% and 23.27% when quenched in water and brine respectively. Micro-hardness also increased by 120.55% and 45%.5%when quenched in water and brine respectively while ductility decreased significantly from 12.73% to 3%. The process variables investigated affected the mechanical properties as increase in treatment temperature and soaking time increased the surface hardness and decreased the impact strength and ductility of mild steel while micro-hardness and Rockwell hardness increased. Mild steel quenched in water was found to be harder than that quenched in brine.

Keywords: process variables, surface hardness, quenching media, carburization.

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1. INTRODUCTION

The failure of engineering materials is undesirable for several reasons, which include loss of human lives, injuries, economic losses and interference with availability of products and services. Even though the causes of failure and behavior of materials may be known, prevention of failure is difficult to guarantee. The usual causes are improper selection and processing of materials and inadequate design or misuse of component. It is the responsibility of the engineer to plan for possible failure and in the event that failure occurs, to assess the cause and take proper preventive measures against future occurrence. (Callister Jr., 2006) Many different types of heat treatment processes are used to modify the surface and structure sensitive properties of engineering components (Child, 1980) .The service condition of many steel components such as cams, gears and shafts demands that they possess both hard wear-resistant surfaces and tough shock-resistant cores. The set of properties exist only in steels of different carbon content. Low carbon steel containing approximately 0.1% carbon, will be tough but soft, while high carbon steel will be only hard. The desired set of properties can best be met by employing a low carbon steel with suitable core properties and surface hardening it with carbon or nitrogen to a regulated depth. Rapid penetration of the surface of steel can only be effective if the solute element dissolves interstitially. Once dissolved, the elements increase the hardness of the surface by forming interstitial carbides, nitrides or borides depending on the diffusing atoms (Higgins, 2004). Locally produced steel does not often meet the requirement for manufacturing spare parts due to their low carbon content. When there is need for high carbon steel case for special purposes, production of high carbon steel cases locally, using abundant local materials becomes imperative. This reduces the burden on foreign reserves and creates employment opportunities. (Oyetunji and Adeosun 2012). When the steel is cooled rapidly by quenching, the higher carbon content on the outer surface becomes hard via the transformation from austenite to martensite, while the core remains soft and tough as a ferrite and/or pearlitic structure (Oberg et al, 1989). The objective is to produce a hard, wear-resistant case which will be resistant to both bending and contact fatigue while still maintaining the toughness and ductility of the low carbon core (Stephen and Edward, 1991).

1.1: Mechanism of carburizing

When low carbon steel is brought in intimate contact at austenitic temperature range with solid, liquid or gaseous carburizing medium, which liberates free carbon by means of chemical reactions and might be catalyzed by iron, carburizing occurs. The process of carburizing takes place in two major steps. In the first step, the absorption of carbon takes place at first rapidly at the surface of the steel because there is large difference between carbon content of the steel surface and carbon potential atmosphere. As the surface carbon content increases, the rate at which additional carbon can be absorbed is decreased till equilibrium is established with the atmosphere. In the second step, carbon at the surface diffuses into the case. At first, the diffusion is slow as carbon gradient is small between the surface and the core. The concentration gradient of carbon increases as more free carbon is absorbed by the surface. Therefore, the depth of carburization depends on the diffusion rate of carbon from the surface to the interior (Higgins, 2004). Different cross

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sections may have different cooling rates which can cause excessive stresses in the material and result in breakage. It is virtually impossible to have a workpiece undergo carburization without having some dimensional changes. The amount of these changes varies based on the type of materials that is used, the carburizing process that the material undergoes and the original shape and sizes of the workpiece. However, changes are small compared to heat-treating operations (Robert et al, 1994). Quenching results in a martensitic structure which possesses super-saturated carbon in a deformed body-centered cubic (BCC) crystalline structure, properly termed body-centered tetragonal (BCT), with much internal stress. Thus quenched steel is extremely hard but too brittle for practical purposes, depending on the quenchant (Smith et al, 2006)

1.2: Mechanical properties

The mechanical properties of a material refers to the behavior or the reaction of the material to loading, pressure, impact, indentation, heat, etc. so in addition to the physical properties of conductivity, magnetism and melting point, the major usefulness of a metal depends on the mechanical properties such as strength, ductility, toughness, hardness, malleability, etc. Others include shear strength, compressive strength, fatigue strength, impact strength, bending and torsional strength. The properties cannot however be expressed in simple numerical terms, rather mechanical tests which are related to the properties can be used to compare numerical interpretation. Engineers are concerned with the forces which cause deformation in metals and not deformation itself. Tensile and hardness tests correlate the amounts of deformation produced with given forces in tension and compression respectively, while impact is a direct measurement of the energy the material can absorb before failure. The results of engineering designs are based on the measurement of force-deformation values obtained from the tests (Okeke, 2002). There are several techniques used in determining the hardness of a material. Most industrial methods measure the resistance to penetration using a small spherical cone or pyramid. The Brinell, Vickers and Rockwell are some tests used for hardness measurement. The Charpy and the Izod tests are some of the tests for impact measurement. A sound knowledge of mechanical properties is very essential to enable the selection of suitable materials for various structures or various components of machines. Most of the mechanical properties of metal are generally expressed in terms of stress or strain or both (Khurmi and Sedha, 2004).

2. MATERIALS AND METHODS

2.1. Materials

The mild steel was sourced locally from Kenyetta building materials market, Enugu, Enugu State, Nigeria and analyzed using atomic absorption spectrometer (AAS). It was cut and machined to standard test sample sizes according to American Society for Testing and Materials (ASTM) standard specifications using lathe machine. Carburization was done using heat treatment furnace at Scientific Equipment Development Institute, Akwuke, Enugu, Enugu State. The tensile test was conducted using Computer Controlled Electro-Hydraulic Servo Universal Tensile Testing Machine (Model HLCS-600) at Linkso Nigeria Limited, Port-Harcourt, Rivers State, Nigeria. Metallurgical microscope (Model Olympus PMG-3) was used to study the microstructures while micro-hardness testing machine (Model UH930) was used to measure the micro-hardness while impact testing machine (Model UI820) was used to determine the impact strength.

Table 1: Chemical composition of mild steel rod

Element	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu	W	As	Sn	Co	Al	Pb	Ca	Zn	Fe
%Comp.	0.19	0.15	0.05	0.04	0.58	0.13	0.11	0.01	0.02	0.38	0.0	0.0	0.03	0.03	0.004	0.0	0.0	0.01	98.17

Source: DSC Aladja

2.2 :

2.3 Methods

Carbon powder was mixed properly with an energizer (barium carbonate) in the proportion of 7:3 after which the first set of samples was buried in the mixture inside a rectangular steel box. Clay mixed with bentonite and moderate water was used to seal the rectangular steel box tightly to prevent carbon (11) oxide from escaping and in turn not allowing unwanted furnace gas from re-entering the steel box. The steel box was then charged into the furnace and allowed to heat to temperatures of 700°C, 750°C, 800°C, 850°C and 900°C respectively. At each temperature the test specimen was soaked for one, two and three hours respectively. The steel box was removed from the furnace with the help of tongs at each temperature and then the specimens were quenched in water at ambient temperature. The load-extension graph was generated from the computer integrated to the tensile testing machine and the stiffness was calculated from the data obtained.

3: RESULTS AND DISCUSSION

The results of the tests are presented on figures 1 to 9.

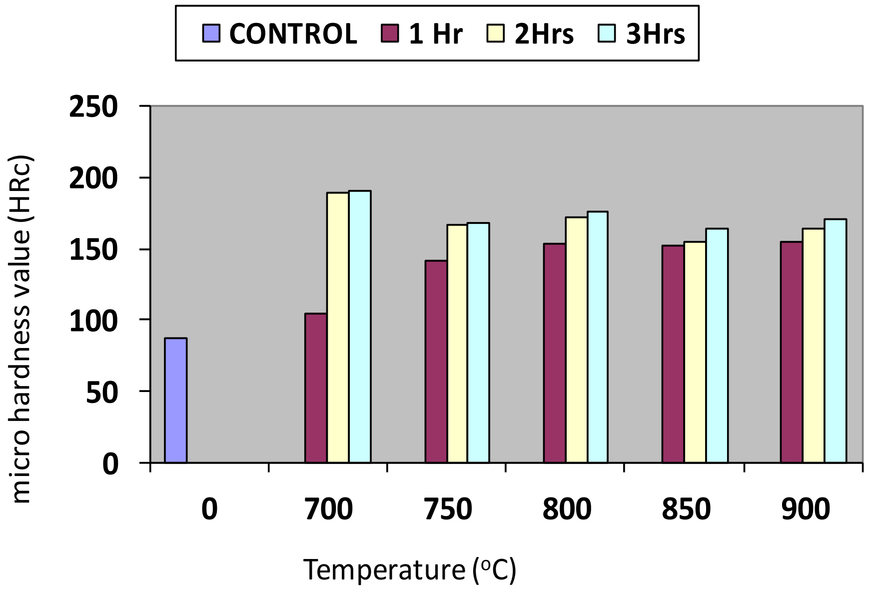

Fig. 1: Effect of temperature and soaking time on the micro-hardness of carburized mild steel quenched in water.

Figure 1 shows the effect of temperature and soaking time on the micro-hardness of carburized mild steel quenched in water. Due to the large difference in carbon potential between the rich carbon atmosphere and the surface of the alloy there was a rapid rate of absorption of diffusing carbon atoms into the alloy from room temperature to 700°C and soaking time of one hour. The decrease in micro-hardness at the temperature range of 700°C and 750°C was as a result of low rate of diffusion in ferrite and austenite at that temperature range (700°C-750°C). At 800°C and above, the rate of diffusion of carbon atoms was seen to be low but, increased with soaking time until 900°C. This shows that the lattices of the austenite phase were almost saturated and further increase in temperature and soaking time resulted in the formation of Fe_3C in the alloy.

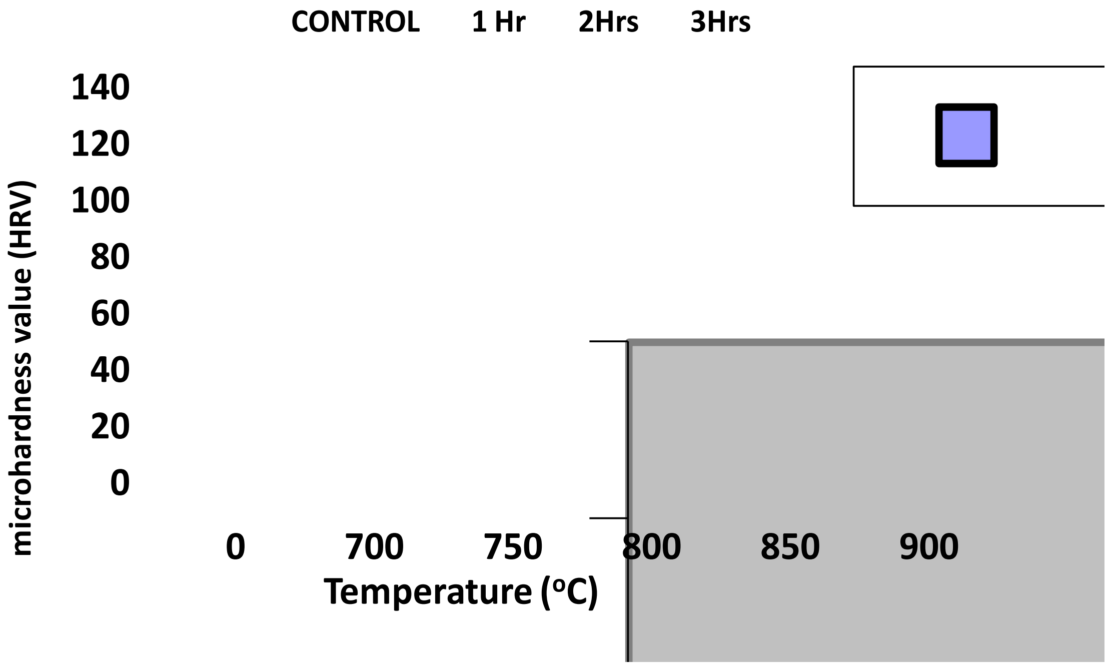

Fig. 2 Effect of temperature and soaking time on the micro-hardness of carburized mild steel quenched in brine.

Figure 2 shows the effect of temperature and soaking time on the micro-hardness of carburized mild steel quenched in brine. The micro-hardness of the control specimen was 86.6(HRV)µ, It was observed that the control specimen had a higher value than the specimens carburized at temperatures of 700°C, 750°C, 800°C, 850°C and 900°C quenched for one hour. The micro-hardness value increased at carburizing temperatures of 750°C, 800°C, 850°C and 900°C soaked for two and three hours except at 850°C soaked for two hours. The highest micro-hardness was recorded at the carburizing temperature of 800°C soaked for two hours which was 133(HRV)µ and 900°C soaked for three hours which was 126(HRV)µ. This was because of decrease in diffusion rate of carbon atoms as a result of saturation of the austenite lattice and emergence of Fe_3C phase.

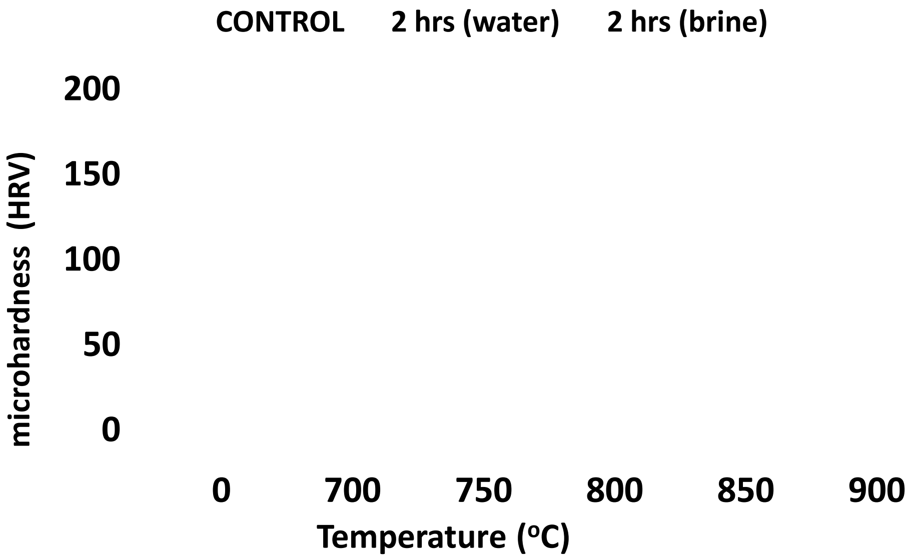

Fig. 3: Effect of temperature on the micro-hardness of carburized mild steel quenched in both water and brine.

Figure 3 shows the effect of temperature and soaking time on the micro-hardness of carburized mild steel quenched in both media. It was observed that except at carburizing temperature of 800°C and 900°C where the micro-hardness of the specimens quenched in brine was above that of the control sample, other specimens quenched in brine showed micro-hardness value below the control sample. This may be caused by defects such as segregation and may have also impacted on the property. The micro-hardness value of specimens quenched in water increased with carburizing temperature at soaking time of two hours as a result of diffusion of carbon atoms into the lattices of ferrite and austenite phases of the alloy thereby increasing the micro-hardness. The drop in micro-hardness value at the temperature range (800°C – 850°C) reduced the diffusion rate of carbon atoms into the alloy.

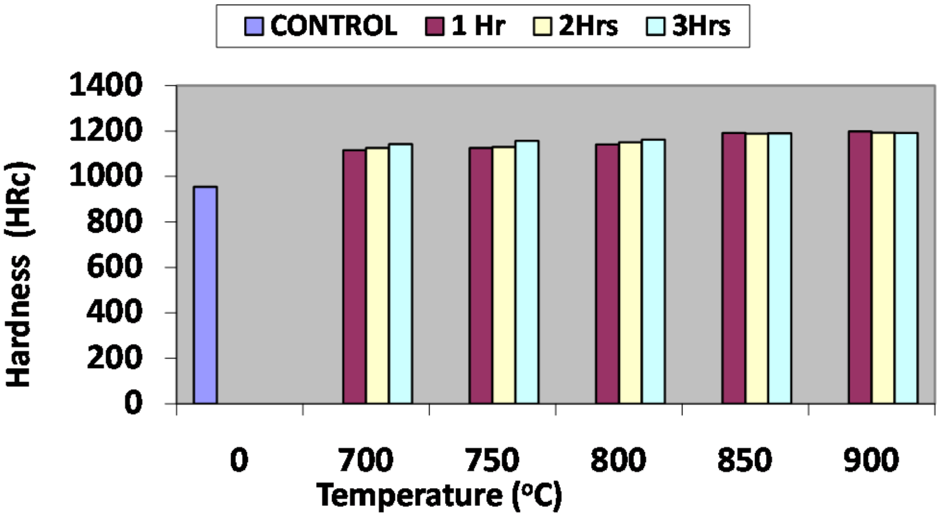

Fig. 4: Effect of temperature and soaking time on the Rockwell hardness of carburized mild steel quenched in water.

Figure 4 shows the effect of temperature and soaking time on the Rockwell hardness of carburized mild steel quenched in water. The increase in Rockwell hardness of the samples was as a result of the increasing carburizing temperature and soaking time which enabled the diffusion of carbon atoms into the ferrite and austenitic phases of the alloy. Water which was the quenchant contributed to increased hardness because it accounts for the martensitic phase which was formed in the alloy. Also, at carburizing temperature of 850°C the Rockwell hardness value of the specimens was not altered. This was because of the saturation of austenite lattice by diffusing carbon atoms.

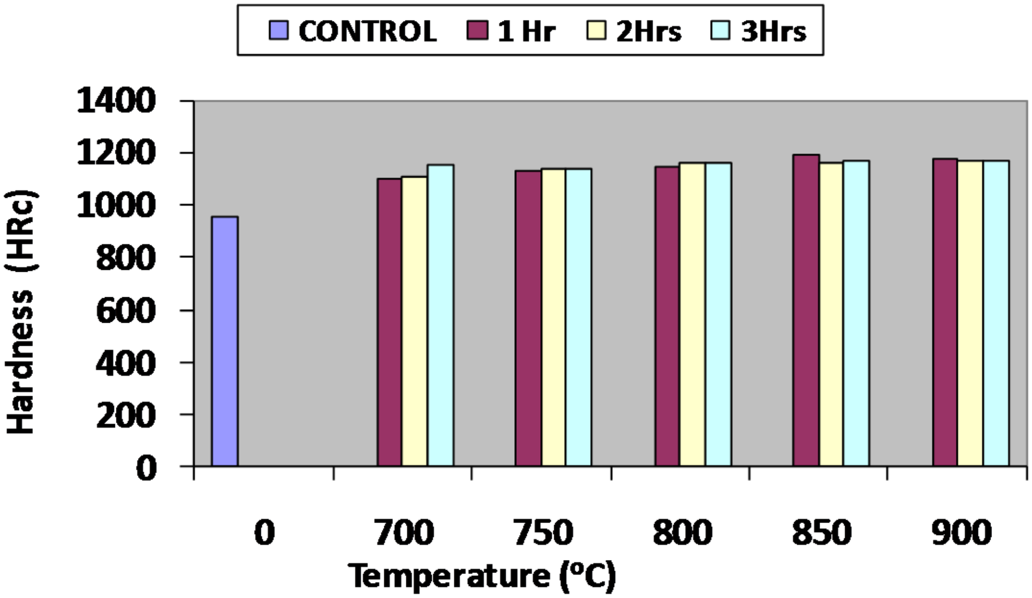

Fig. 5: Effect of temperature and soaking time on the Rockwell hardness of carburized mild steel quenched in brine.

Figure 5 shows the effect of temperature and soaking time on the Rockwell hardness of carburized mild steel quenched in brine. There was a significant increase in absorption of diffusing carbon atoms into the alloy at the carburizing temperature range of (25°C to 750°C). Above this temperature range, the absorption of carbon atoms increased at a slow rate because of saturation of austenite lattice by carbon atoms. Further increase in temperature and soaking time showed a slight decrease in Rockwell hardness. Appendix 1 shows the Rockwell hardness values of carburized mild steel specimen soaked for one, two and three hours and quenched in both media. It was observed that the Rockwell hardness value increased steadily as the carburizing temperature increased with soaking time, though the values of specimens quenched in water was higher. This was because of the severe quench caused by water. The Rockwell hardness of the control sample was 954HRc while the recorded values of Rockwell hardness for water and brine was 1198HRc at 900°C soaked for one hour and 1176HRc at 900°C soaked for one hour respectively.

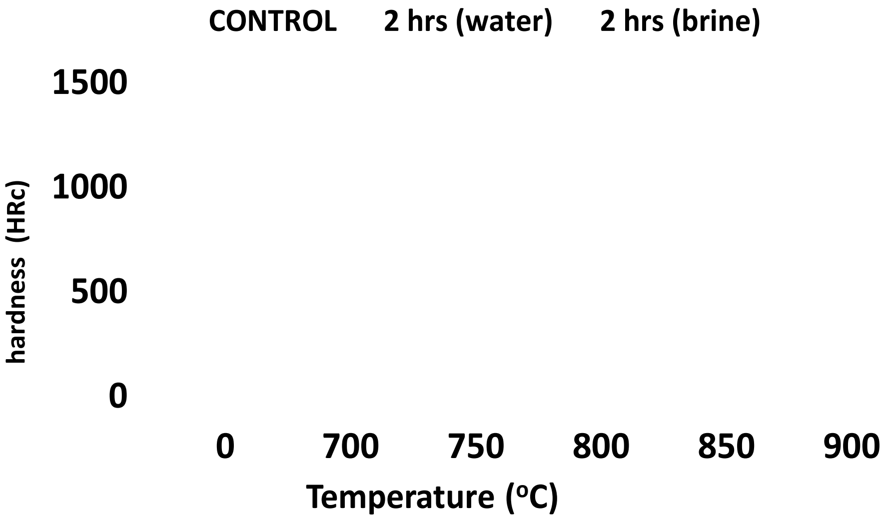

Fig. 6: Effect of temperature on the Rockwell hardness of carburized mild steel quenched in water and brine for two hours.

Figure 6 shows the effect of temperature on the Rockwell hardness of carburized mild steel quenched in water and brine. It was observed that there was an increase in Rockwell hardness of the specimens but, specimens quenched in water absorbed more carbon atoms as the carburizing temperature increased. At 750^{o}C, it was noted that specimens quenched in both media had the same Rockwell hardness value of 1130HRc and afterwards increased from the temperature of 800^{o}C until 900^{o}C as a result of carbon atom absorption by austenite lattice of the alloy. The specimens quenched in brine were saturated at carburizing temperature of 800^{o}C after which there was no further absorption of diffusing carbon atoms.

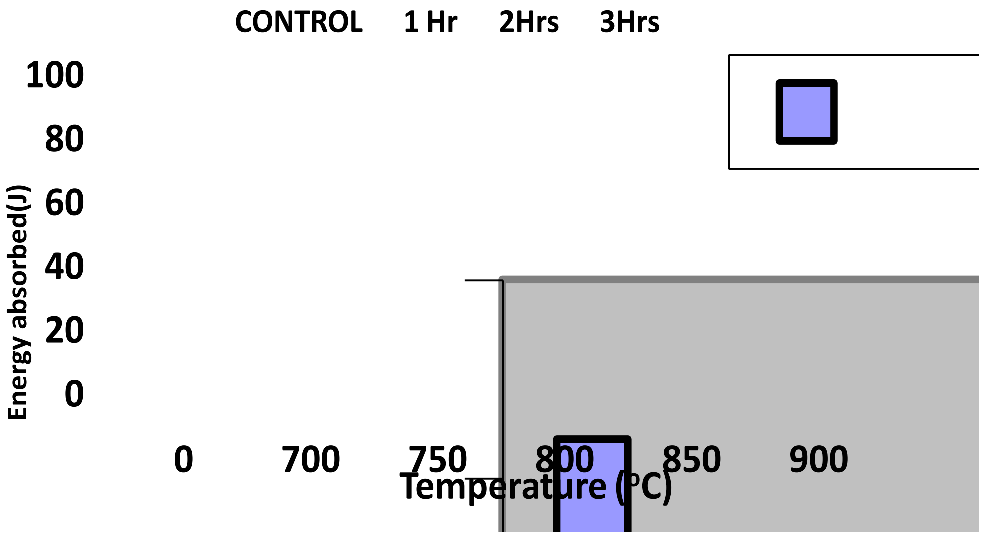

Fig. 7: Effect of temperature and soaking time on the impact strength of carburized mild steel quenched in water.

Figure 7 shows the effect of temperature and soaking time on the impact strength of carburized mild steel quenched in water. It was observed that the energy absorption by the specimens decreased with increase in carburizing temperature and soaking time. The energy absorbed by the control sample was the highest (84J) while the least absorption recorded was at a carburizing temperature of 900^{o}C and soaking time of three hours. The general reduction in energy absorption was as a result of increased diffusion rate and saturation of carbon atoms in the alloy thereby causing strengthening.

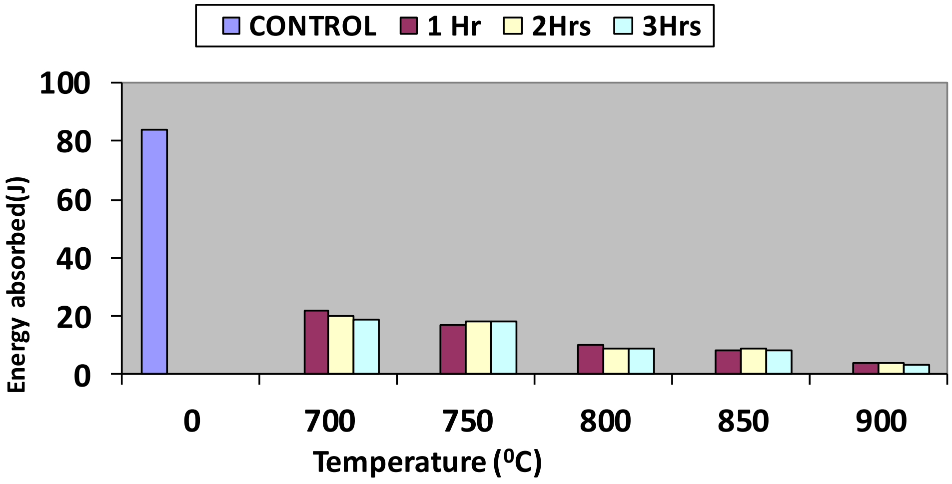

Fig. 8: Effect of temperature and soaking time on the impact strength of carburized mild steel quenched in brine.

From figure 8 the decrease in energy absorption of the specimens quenched in brine as the carburizing temperature and soaking time increased could be clearly observed. The decrease can be seen to be more defined than that of the specimens quenched in water. This was as a result of the quenchant (brine) used which does not allow rapid cooling thereby minimizing the chances of formation of martensite. The specimens quenched in brine have a superior impact property because they have the least value of energy absorption of 3J at carburizing temperature of 900^{o}C and soaking time of three hours.

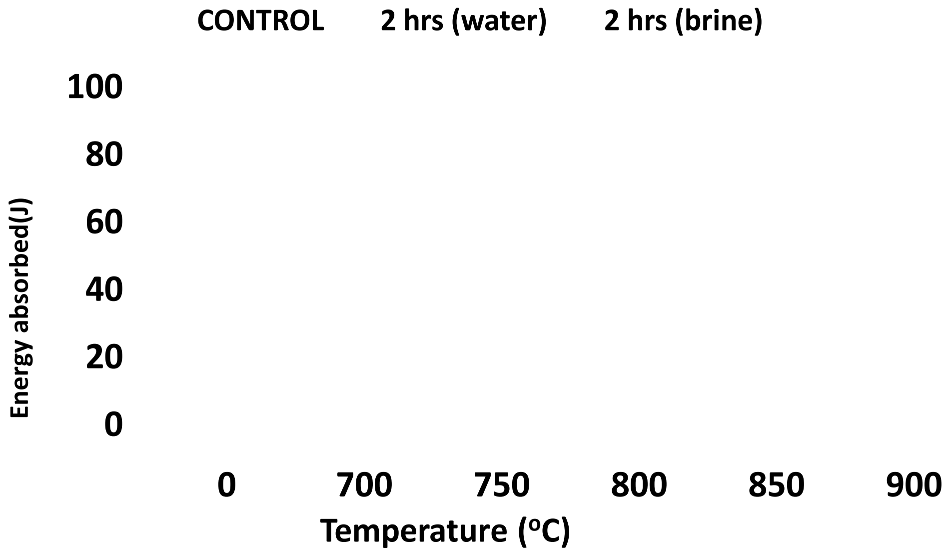

Fig. 9: Effect of temperature the impact strength by carburized mild steel quenched in water and brine.

Figure 9 shows the effect of temperature on the impact strength of carburized mild steel quenched in both media. It was observed that the specimens quenched in water had higher impact strength than those specimens quenched in brine due to the formation of Fe_3C phase as a result of saturation of the alloy with diffused carbon atoms as the carburizing temperature and soaking time increased.

4. CONCLUSION

From the results obtained, the following conclusions are drawn;

- The mild steel was successfully surface hardened using pack carburizing method.
- The specific application and service condition of the carburized mild steel will determine the range of carburizing temperature to be adopted to maximize the ductile-to-brittle behaviour of the material.
- Increase in carburizing temperature and soaking time resulted to reduction of impact strength.
- Mild steel quenched in brine looses hardness and stiffness more than the one quenched in water.
- The process variables affected the mechanical properties investigated.

5. RECOMMENDATION

When properly surface hardened, mild steel could be used in place of carbon steel for automobile body components and structural shapes like I-beams, sheets that are used in pipelines and buildings, iron hoes and shovels.

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Appendix 1:

Rockwell hardness of carburized mild steel quenched in water and brine

S/N	Soaking Time (hrs)	T.T (^oC)	Hardness value (HR_C) (for water)	Hardness value (HR_C) (for brine)
1.		700	1115	1102
2.		750	1125	1132
3.	1hr	800	1141	1151
4.		850	1191	1172
5.		900	1198	1176
1.		700	1126	1112
2.		750	1130	1142
3.	2hrs	800	1151	1162
4.		850	1189	1165
5.		900	1192	1170
1.		700	1142	1155
2.		750	1156	1138
3.	3hrs	800	1162	1166
4.		850	1190	1174
5.		900	1191	1169

Rockwell hardness value of control specimen was 954(HR_C)
Load used was 60kg
T.T- Treating temperature.

MICROGRAPH OF STUDIED MILD STEEL SPECIMENS (800X)

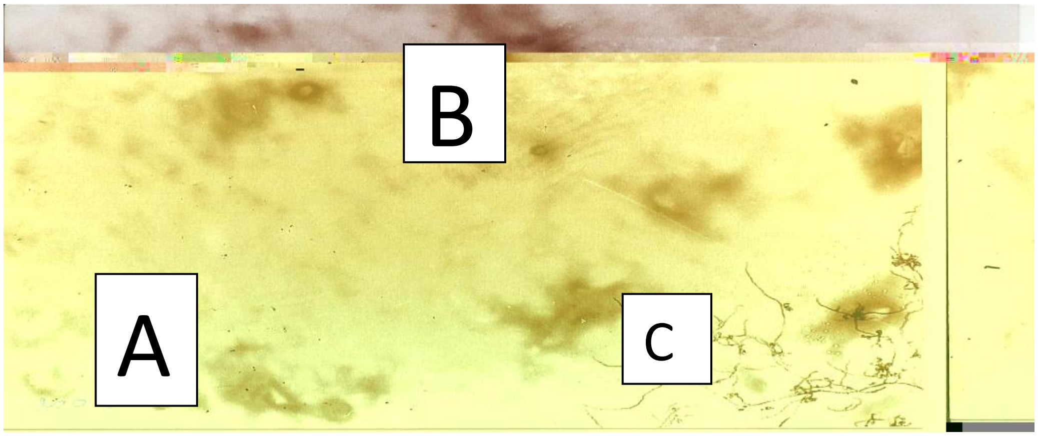

Plate 1: Control sample

A-Ferrite; B-Pearlite; C- grain boundary, D-Cementite

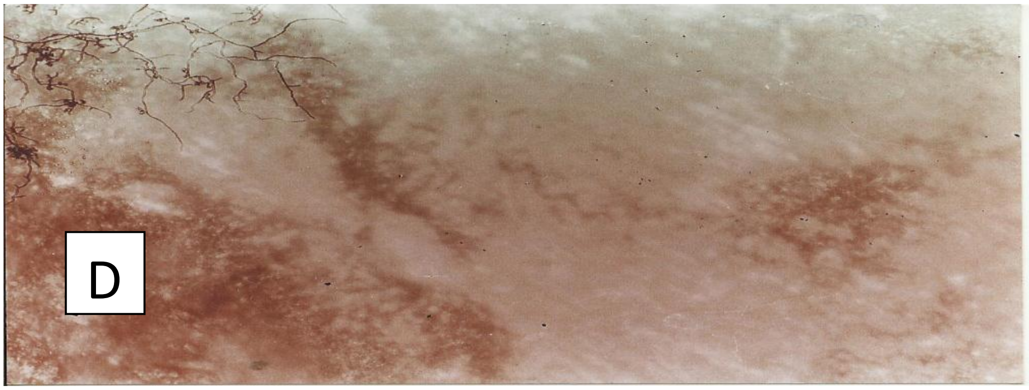

Plate 2: Quenched in water $700^{0}C$

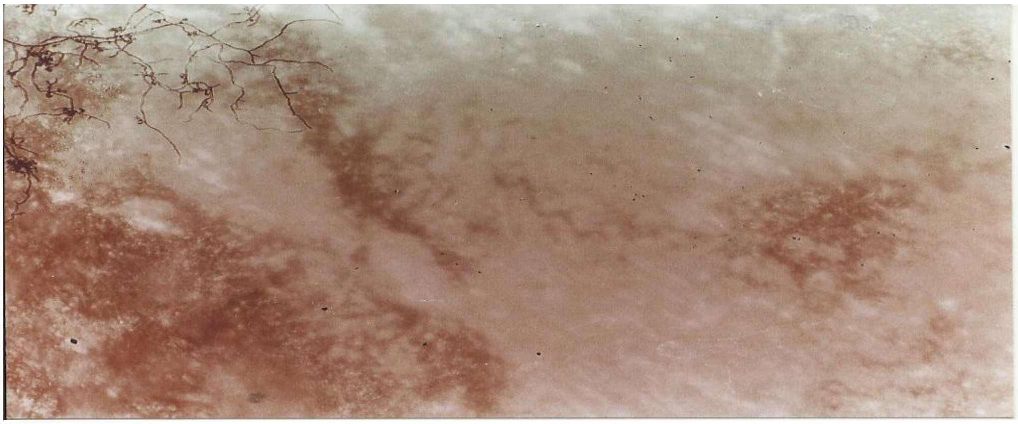

Plate 3: Quenched in brine at $700^{O}C$

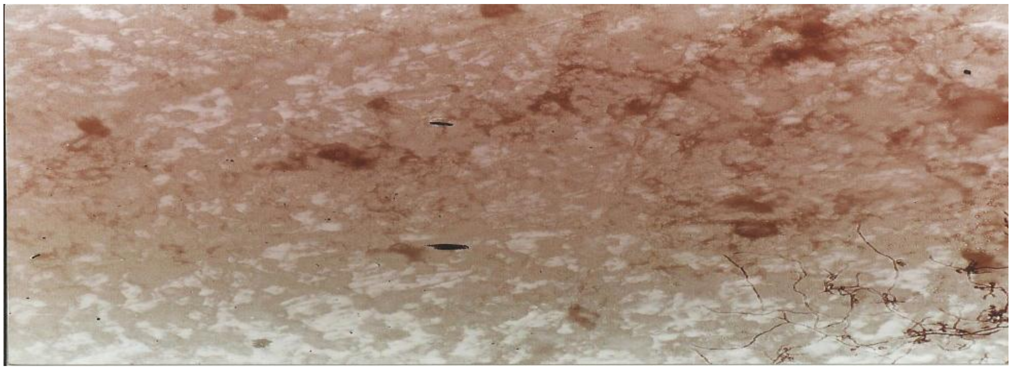

Plate 4: Quenched in water at $750^{0}C$

Plate 5: Quenched in brine at $750^{0}C$

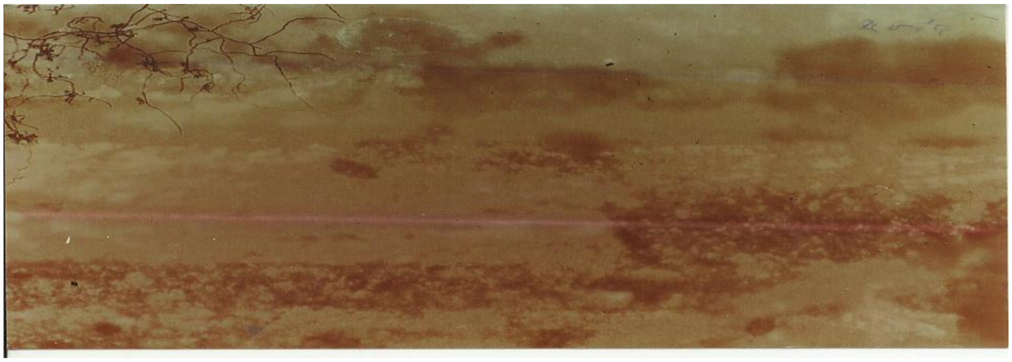

Plate 6: Quenched in water at 800^{0}C

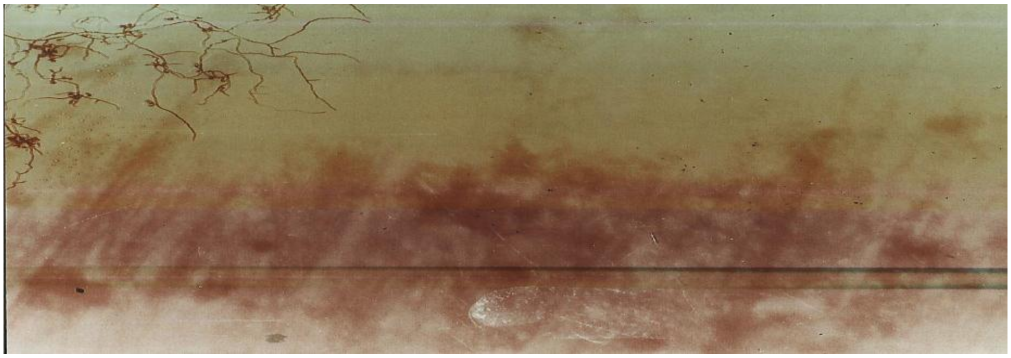

Plate 7: Quenched in brine at 800^{0}C

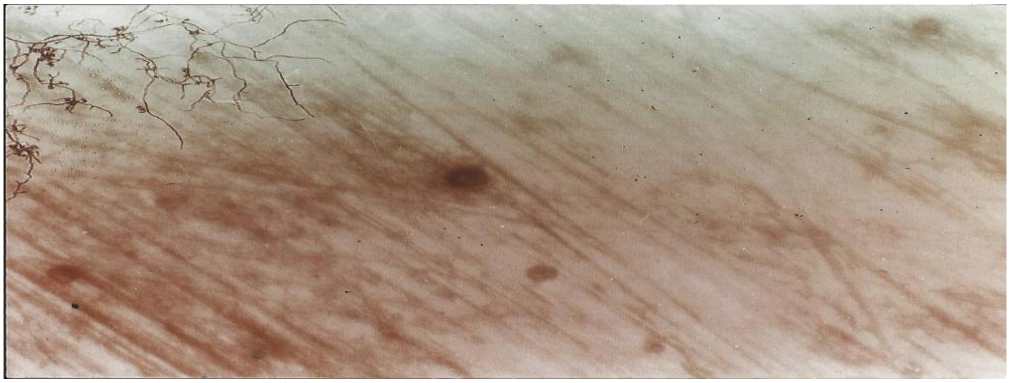

Plate 8: Quenched in water at 850^{0}C

Plate 9: Quenched in brine at 850^{0}C

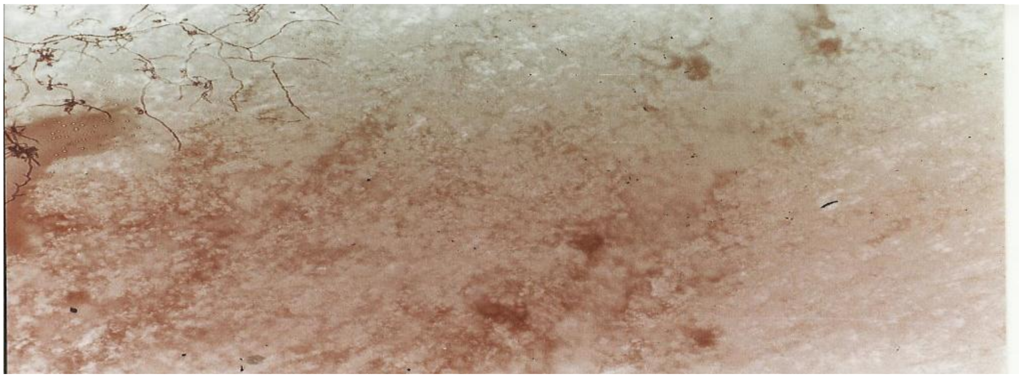

Plate 10: Quenched in water at 900^{0}C

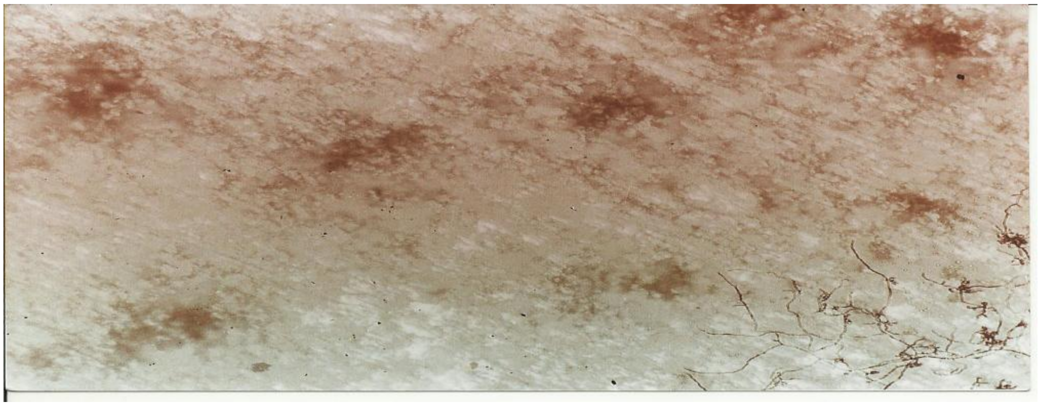

Plate 11: Quenched in brine at 900^{0}C