Wear Characteristics Of Carburised Mild Steel

O. I. Sekunowo, O. I. Nwagu

ABSTRACT: The growing concern about excessive wear of most plain carbon steel in applications involving friction continued to receive quality attention. In this study, the wear characteristics of carburized mild steel is carried out with a view to establish the suitability or otherwise of the processing method at combating the menace of wear in engineering components made from mild steel. The study methodology involves pack carburization of specially prepared mild steel specimens under a finely pulverised charcoal environment at 750^{0}C, 800^{0}C, 850^{0}C, 900^{0}C and 950^{0}C. This is followed by tempering at 500^{0}C for 30mins after which the specimens are tested for hardness, wear and flexural properties respectively. The results show significant improvement in all the properties evaluated. Thus, carburisation can be used to enhance the wear resistance of mild steel comparable to that achievable through conventional hardening process.

Keywords: Mild steel, pack-carburization, flexural strength, wear

INTRODUCTION

Among many failure modes associated with steel components, wear presents a unique challenge to the designer and developer of mechanical components. It is most seen in areas relating to the contact of two surfaces where friction occurs. Wear is commonly defined as the undesirable deterioration of a component through the removal of material from its surface (Rabinowicz, 1995). The mechanism involves displacement and detachment of particles from the material surface hence its mechanical properties are surreptiously compromised over time. However, wear phenomenon occurs in various forms which include abrasive (Ingrid, et al., 2004). Abrasive wear is quite common in mining, agriculture and cement industries (Kumar, 1994) while dry sliding wear according to Gupta, et al (2009) is oxidative in nature. Other modes of wear that are inimical to a reliable engineering component performance are described as erosive and corrosive (Williams, 2005). Erosive wear occurs due to a relative movement between a metal and liquid or gas. The typical incidence of material degradation at the surface with attendant seepage of corrodents into the material matrix is reffered to as corrosive wear. Jaykant (2009) also identified fatigue wear as removal of particles due to cyclic action. All the foregoing indicate the fact that many variables are involved in the occurrence of wear. These include loading regime, sliding speed, component geometry, composition and environment. It is common practice to use high carbon steels which are known to exhibit high hardenability, in particular for application where dead weight is of paramount importance. However, for application requiring a combination of hard surface and tough core, high carbon steel is unsuitable. Case hardening is one of the variety of techniques used to improve the mechanical properties and wear resistance of parts without affecting the softer interior (Sanjib, 2009). This combination of hard surface and inner toughness characteristics are useful in parts such as cam shaft, fasteners, automotive clutch plate, tools and dies. Usually, these parts require a very hard surface to resist wear due to prolonged hours of operation and a sufficiently tough interior to resist impact due to speed and power changes. Further, the surface hardening of steels has an advantage over intentional hardening because it is less expensive. Also, low-carbon and medium carbon steel surfaces can be modified without the problems of distortion and cracking associated with through hardening of thick sections. There is therefore the need to improve on the wear resistance of most engineering components for better performance and durability. These characteristics are equally desirable during operation in order to minimize damage and frequent replacement or outright failure which could be catastrophic. Carburising as a differential metal surface heat treatment process is a proven effective means of carbon absorption as steel is heated in a carbon bearing enviroment (Farlex, 2012). There are various methods with regard to the environment employed in carburising steels. These include pack, gas, liquid, salt and vacuum hardening environments respectively. However, the pack carburising method has some advantages over the other forms (Krauss, 1980). For example, pack carburisation is cheap, simple and a relatively large parts can be handled however, the contol of its case depth is usually a challenge. The process itself is accomplished by embedding the workpiece completely in pulverised charcoal treated with barium carbonate which induces the formation of carbon monoxide (CO) that aids diffusion of carbon atoms into the steel. The carburised part can then be quenched directly in a medium that provides the right cooling rate to produce a supersaturated solid solution to the desired depth. This process if carried out effectively is capable of improving the wear profile of the material as well as enhanced its durability.The usefulness of a material lies in its ability to perform effectively under the intended service conditions. Hence, the imperative for the production of engineering components with minima defects and better performance entails that production processes are continuosly improved upon and products perfomance characteristics promptly evaluated. This study therefore invetigates the wear propensity and other related mechanical properties of carburised mild steel with a view to determine its suitability as substitute for high carbon steel in certain applications.

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METHODOLOGY

Materials and sample preparation

The materials used in this study include a commercial mild steel sheet of 2mm thickness with its chemical composition determined through a metal analyser model ARL 3460B. The result of the composition analysis is presented in Table 1. Barium carbonate ($BaCO_3$) being a suitable carbon inducing agent is procured from the chemical market and used as the energiser for the carburisation process. Pulverised wood charcoal is used as the main source of carbon

Table 1: Composition analysis result of the as-received mild steel sample

Element	C	Si	Mn	P	S	Cr	Ni	Cu	V	Co	Fe
Wt. %	0.057	0.012	0.372	0.010	0.007	0.019	0.007	0.028	0.007	0.004	99.467

The mild steel plate is mechanically cut at ambient temperature into 2cm x7cm dimension and treated with methylated spirit in order to remove contaminants such as oil, oxides and alkaline solutions which are capable of retarding diffusion of carbon. Similarly, the carburising medium is prepared by pulverising the charcoal and then mixed it thouroughly with 10% barium carbonate to serve as an energiser.

Heat treatment (Pack carburising)

Prior to carburising, the treated mild steel samples were immersed in a mixture of pulverized charcoal and Barium carbonate ($BaCO_3$) and placed in a stainless steel container. The stainless steel container was then introduced into the muffle furnace which is heated to different carburisation temperatures of 750^0C, 800^0C, 850^0C, 900^0C, 950^0C and soaked for 4 hours. The presence of barium carbonate in the carburising mixture actually aided sufficient formation of carbon atoms which diffused into the steel samples surfaces. Consequently, the carburised samples are then quenched in fuel-oil in oder to retain the carbon on the steel surfaces to a certain depth. The tempered samples are stress relived by heating them to 500^0C, held for 30 minutes and then cooled in air. This is done to reduce internal stresses within the samples which might influence subsequent properties analyses. The carburised and tempered mild steel specimens are then subjected to mechanical properties tests such as wear, hardness, flexural and microstructural analysis.

Properries evaluation tests

Wear

The carburised samples were sujected to abrasive wear test which was conducted on a Pin-on disc machine. Each sample was held perpendicular such that its flat surface is forced to press against a revolving disc. The disc is allowed to rotate for a predetermined period at a varying sliding moment for 60 seconds. After each test, the weight of the specimen is obtained as the mass loss which was then used to determine the wear rate and other related wear parameters such as wear volume and wear resistance. These parameters are evaluated through equations 1-3:

Wear volume, V (cm^3) $= w/\rho$ (1)

Where w is the weight-loss in (g) and ρ, specimen density which is 7.86 $g.cm^{-3}$

Wear rate, ω ($cm^2.s^{-1}$) $= V/d$ (2)

Where d is given by $2\frac{\pi RN}{60} \times t$ and d, the sliding wheel speed (cms^{-1}). For this experiment, R is the abrasive radius which is 8cm, N, is revoluton per minute of the pin-on disc which is 250, **t** time in second (60s) and π is 3.142.

Wear resistance, $\Delta = 1/wear\ rate,\ \omega^{-1}$ (3)

The test results data generated are substituted into the relevant equations and each wear parameter is computed and presented in Table 2 for 60seconds test duration.

Hardness

Gunt Brinell hardness testing machine was used for the test which involved both carburised and as-received test specimens of 2cm x 7cm dimension.
Using the standard ratio of the applied force to indenter ball diameter for steel (F/D^2), the specimens

prepared surfaces with the aid of a Φ2mm hardened steel ball were subjected to a constant load of 120kgf for 20seconds. The specimens hardness (*HB*) is determined by taken the mean diameter of the indentation and substituting it into equation 4.

Hardnes, $HB = \frac{2P}{\pi\Delta[\Delta - (\Delta^2 - \delta^2)^{1/2}]}$ (4)

Where ***P*** is load in kgf; ***D*** is indentation ball diameter in mm and **d** is the diameter of the indentation in mm while $\pi = 3.142$. The computed hardness values are presented in Table 3.

Flexural test

The imperative for the determination of the carburisation effectiveness necessitates that test specimens are subjected to bending integrity. Thus, flexural test was carried out to evaluate the permanence or otherwise of carbon atoms that diffused into the specimens surfaces. This is meant to prevent incipient cracks or flaking whenever the material is employed under bending moment. The test specimens (carburised and as-received) are placed on a three-point loading beam while the flexural jaw is mounted on the tensometer. The jaw was lowered steadily towards the centre of the specimen and allowed to exert bending force producing such deflection until a near u-shaped specimen ensued. The data and graphs generated during the test are presented in Fig. 5 and Fig. 6 for carburised and as-received specimens respectively.

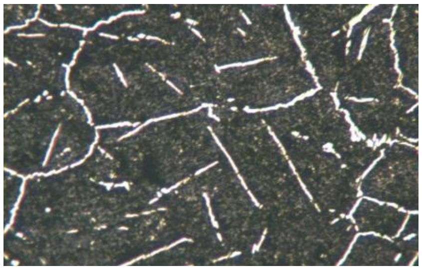
Microstructural analysis

The test specimens were ground on a water-lubricated grinding machine using silicon carbide abrasive papers grade 240, 320, 400 and 600 grits in succession. Final polishing of the specimens was carried out with 0.5 microns chromic oxide powders. The mirrow like surfaces obtained were etched in 2% Nital solution for 30 seconds and rinsed in water while the microstructural features were examined under an optical microscope at x 200 magnification and the micrographs presented in Plate 1(a and b).

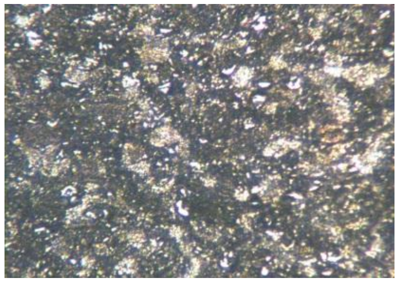
RESULTS AND DISCUSSION

Microstructure

Plate 1(a, b) shows the representative micrographs of test specimens under varying conditions. The carburised specimen exhibited complete coverage of its surface by combined carbon atoms which might have diffused to a certain case during carburisation. The carbon being in a combined form has a huge potential to impact positively on the material's surface hardness as well as its wear characteristics. The display of fine pearlitic structure by the as-received specimen is an indication that the carburised specimen core confers ductility and compliments the hard surface in applications desirous of such characteristics.



(a)



(b)

Plate 1: Micrographs of test specimens (a) Carburised (b) As-received mild steel The carburised steel shows its surface completely covered with cementite (Fe_3C) due to the cloud of carbon atoms released during carburisation. In contrast, the as-received microstructure displays the normal fine pearlite crystals with both ferrite and cementite evenly distributed.

Abrasive wear characteristics

Under applied load of 12N and varying sliding speed, the wear characteristics of the test specimens are evaluated to include parameters such as wear volume, wear rate and wear resistance. As shown in Figs. 1-3, the magnitude of these parameters increases slowly initially and then sharply as the sliding speed increases. This behaviour is due to the stratified structure that developed in the carburised specimens in which wear is observed to be very minimal on the surface but once the hard surface case has worn-out, the soft core begins to wear heavily. Further, the carburised specimens exhibited marked contrast with the as-received in terms of all the wear parameters investigated. This shows in the average wear volume of 0.24cm^3 for the carburised compared with 0.94cm^3 for the as-received which is 66% higher than the carburised (Fig. 1). Likewise in Fig. 2 the average wear rate of the carburised put at 13.0cm^2/s is quite lower than the huge 60.3cm^2/s for the as-received while the carburised specimens also exhibited better wear resistance of 9.4/s against the paltry 1.7/s of the as-received (Fig. 3). The behaviours of test specimens demonstrating lower wear characteristics as the hardness increases agree well with established principle of the higher the carbon content in steel the higher its wear resistance (Davies and Oelmann, 1983). Given this level of wear characteristic demonstrated by the carburised specimens, the material can be used to replace conventional materials as machine structural members (Oberg and Ryffel, 1989). This further validates the effectiveness of the process employed in this study and also underscores the significance of developing innovative processing method at a relatively competitive cost.

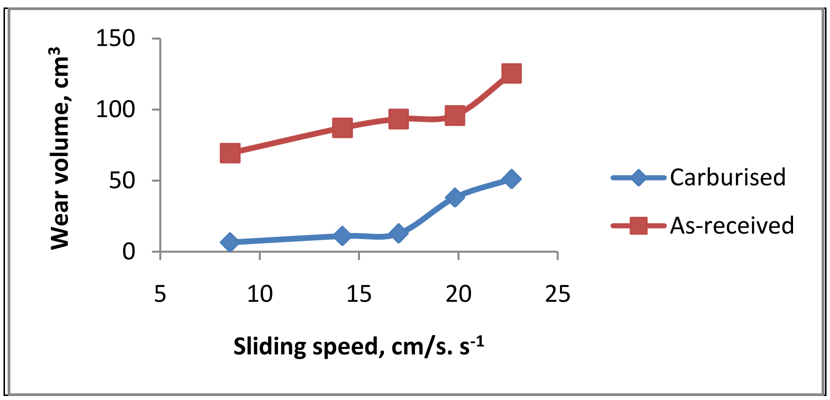


FIG.1: Wear volume at varying sliding speed

Table 2: Wear test results data of carburised and as-received mild steel specimens

Sliding speed, cm/s	Wear volume, cm^3		Wear rate, cm^3/s (10^{-2})		Wear resistance, $(cm^3/s)^{-1}$	
	Carburised	As-received	Carburised	As-received	Carburised	As-received
0.851	0.064	0.694	7.50	81.53	13.30	1.22
1.416	0.109	0.871	7.72	61.51	12.99	1.63
1.699	0.127	0.933	8.13	54.91	11.04	1.82
1.982	0.380	0.958	19.23	48.33	5.22	2.07
2.267	0.510	1.254	22.51	55.32	4.45	1.81
AVG. VAL.	**0.24**	**0.94**	**13.0**	**60.3**	**9.4**	**1.7**

Table 3: Hardness values (*HB*) of test specimens

Carburisation Temp; ^0C	Indentation diameter, mm	Hardness value, HB	Treatment condition
0	0.92	170.5	As-received
750	0.88	187.2	Carburised
800	0.81	223.3	
850	0.79	234.3	
900	0.75	261.6	
950	0.69	310.5	

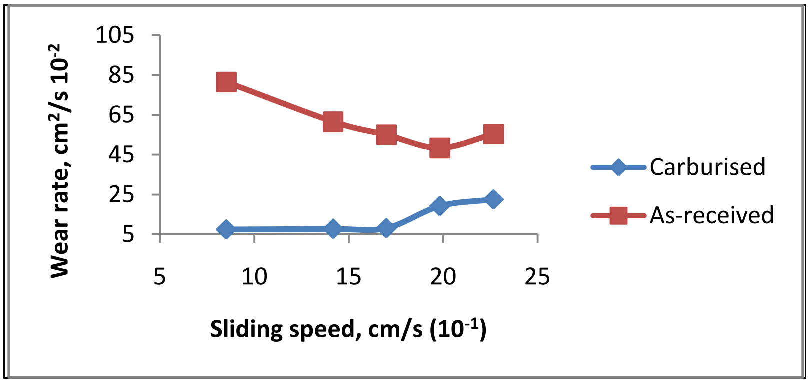


FIG. 2: Abrasive wear rate at varying sliding speed

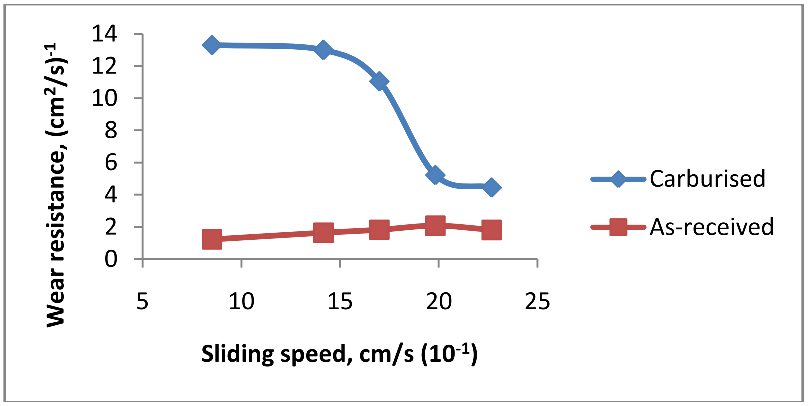


FIG. 3: Abrasive wear resistance at varying sliding speed

Hardness

Table 3 shows the hardness test result of the material which is illustrated by a chart in Fig. 4. The carburised specimens exhibited a huge difference in hardness values at varying carburisation temperatures compared with the as-received specimen. While hardness values averaged at 243.4 *HB* for carburised specimens that of uncarburised is 170.5 *HB* representing 30 percent increase in hardness due to carburisation. This can be attributed to the impart of the large volume of cementite formed on the specimens' surfaces during carburisation which strenghtened the relatively soft ferrite matrix. This results in increased resistance to indentation by the carburised specimens. The temperature effect also shows that hardness increases with increase in carburisation temperatures (see Fig. 4) apparently due to increase in volume of carbon released and the ease of its diffusion into the specimens surfaces as temperature increases. This accounts for the gradual increase in hardness from 223.3 *HB* at 800^{0}C and culminated in 310.5 *HB* at 950^{0}C being the highest carburising temperature.

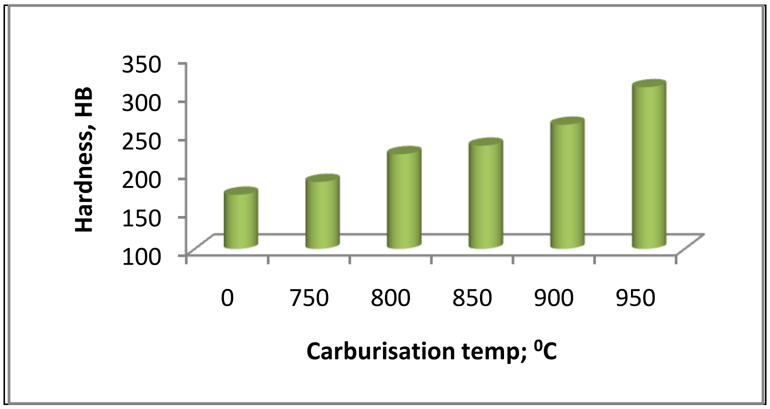


FIG. 4: Effect of carburisation temperature on hardness

Flexural strength

Flexural strength test was perfomed on the specimens in order to evaluate the tenacity of carbon atoms that diffussed into the steel surfaces under bending moment. The test involved two specimens (A and B) and the results are illustrated in Figs. 5 and 6 for the carburised and as-received respectively. As shown in Fig. 5, the differences in response to the applied force by the carburised specimens A and B show varied impact of carburisation on the specimens. This is likely due to variations in the volume of carbon atoms that diffused into the specimens body. In order to ensure homogeneity in carburisation there must be a thorough mixing of the carburising substances and the arrangement of specimens inside the carburising box should be such that enables equal access to the carbon atoms released into the carburising environment. On the average, the peak force required to accomplish 3mm deflection is 110N for the treated (Fig. 5) while the same level of deflection occurred on the application of just 40N for the as-received (Fig. 6). This translates to 2.59 kN/mm^2 and 2.17 kN/mm^2 flexural strength for carburised and as-received respectively representing 19.2% increase in resistance to deformation by the carburised specimens. Further, the carburised specimen curves (see Fig. 5) shows a monotonic increase in the amount of force required in tandem with increase in deflection presumably due to strain hardening.

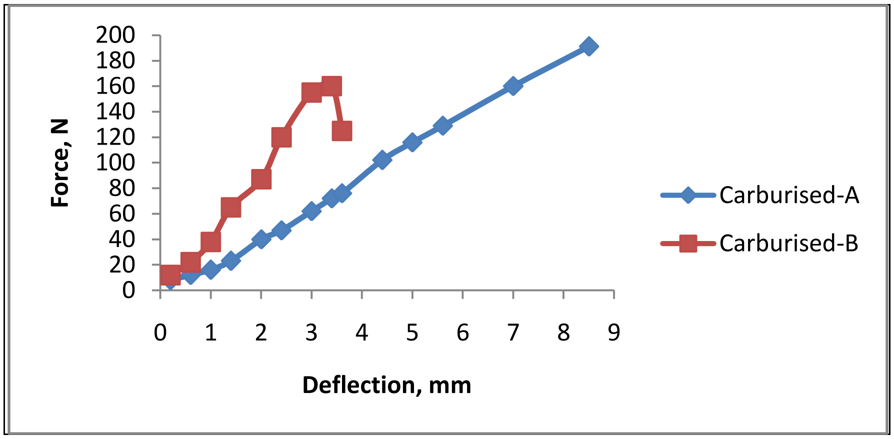


FIG. 5: Variation of force (at peak) and corresponding deflection of carburised specimens

The preponderance of increase in carbon content to a certain depth in the specimen may have given rise to strain hardening hence, the continuous increase in force. In contrast, the as-received specimens response (Fig. 6) illustrates the conventional elastic-plastic deformation behaviour typcal of plain carbon steel devoid of any work hardening phenmenon (Dieter, 1988). Both specimens A and B exhibited almost the same response to the applied force indicating homogeneity in their microstructures. On macro examination of the specimens after the test, there are no incipient cracks observed in particular on the carburised speciens. However, it is observed that higher energy, 4.8J was expended on the as-received to fracture compared with 3.6J of the carburised. The basic inference that can be drawn from this behaviour is that the as-received specimens are 25% tougher than the carburised specimens.

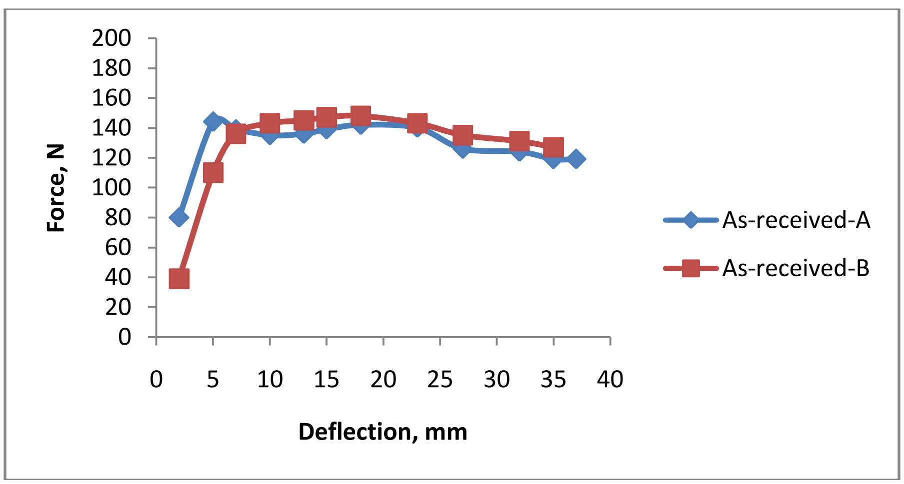


FIG. 6: Variation of force at peak and corresponding deflection of as-received specimens

CONCLUSION

The wear characteristics of carburised mild steel sheet has been investigated and from the analyses of results, the following conclusions are drawn:

1. The hardness, abrasive wear rate and flexural strength of the test specimens improved significantly by 30%, 22% and 19.2% respectively. By these results the material is suitable partcularly for applications as machine-bed and medium-arm weapon housing.
2. The improved properties developed stemm from effectiveness of the carburisation process
3. Appropriate carburisation temperature regime (850^0C-950^0C) coupled with homogenous mixture of carburising agents (charcoal and barium-carbonate) are key factors in the process effectiveness.

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