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Erosive Wear Characteristics of Carburized Mild Steel in Soil–Water Slurry

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Erosive wear characteristics in plain soil-water slurry of carburized mild steel samples were experimentally studied in an in-house designed and fabricated apparatus. The studied carburization technique greatly improved the hardness and wear resistance in the carburized steel. Both the hardness and wear resistance values of carburized products increased significantly with carburization temperature and time up to the range studied (900–950^{0}C, 2–3 h). The effectiveness of solid carburizers in improving these properties of steel decreased in the order: partially burnt char, char and coal. Majority of the carburized steel samples exhibited an improvement in their wear resistance with increase of rotation time in the slurry, and both the severe and mild wear were found to be operative. This study is expected to provide important information to the agro-industries on changes in hardness and wear properties of farm implements.

1. Introduction

Indian agro-industries/village artisans usually use abundantly available mild steels for manufacture of farm implements to suit poor farmers. These implements undergo erosion by the erodents like sand, stone, etc. present in the soil, which may be the major reason of their quick failure. Agro-industries/rural artisans are unable to substantially improve the mechanical and wear properties of these implements because of unavailability of economically feasible technology. The mechanical and wear properties of farm implements are approximately the same as those of as-received mild steel, indicating incapability of the manufacturers in imparting quality to the farm implements [1]. Hence, it was considered essential to do studies on minimization of wear in farm implement materials. Traditional carburization is most widely used for improving wear resistance of steel materials, but it is expensive and consumes lot of energy. Moreover, our previous studies [2, 3] have established that the mild steel, carburized in char followed by direct water quenching from carburization temperature, exhibits significantly higher hardness and abrasion resistance than the mild steel carburized by conventional technique. The objectives of the present work are mainly concerned with the carburization of mild steel samples under different conditions (temperature, time and medium) by this modified technology, and testing of their hardness and wear properties in plain soil–water slurry.

2. Experimental

2.1 Steel materials and carburizers

The wear test specimens were cut from the mild steels plates of 5mm thickness and finished by milling. Their chemical compositions, hardness and erosive wear resistance values are listed in Table 1.

Table 1. Chemical compositions, hardness and erosive wear resistance values of studied materials

Material	Elemental Analysis (wt. %)							Hard-ness (R_A)	Wear Resistance * ($m.m^{-3} \times 10^{13}$)
	C	Mn	Si	Cu	Al	S	P		
Mild Steel	0.160	0.730	0.330	0.120	0.015	0.035	0.038	41	0.430

* For two hours test duration in soil – water slurry

Fresh and once used coconut shell chars, non-coking coal and coal-tar pitch were used as carburizers in this study. Coconut shell char was prepared by carbonizing coconut shell pieces at a temperature of 800^{o}C (soak time: 1 h). The proximate analyses and CO_2 reactivity of these carburizers have been reported in Table 2.

Table 2. Proximate Analysis and Reactivity Values of Carburizing Mediums

Carburizer	Proximate Analysis (wt.%, air-dried basis				Reactivity ($mg.min^{-1}.mg^{-1}$)
	Moisture	Volatile matter	Ash	Fixed carbon	
Coconut Shell Char	4.00	5.96	2.14	87.90	0.0154
Non-coking Coal	7.54	36.55	39.76	16.15	0.0064
Used Coconut Shell Char	4.20	3.15	9.25	83.40	0.0420
Coaltar Pitch	Nil	79.50	5.40	15.10	Nil

2.2 Carburization and hardness measurement

The polished mild steel specimens were subjected to a number of pack carburization treatments in various carburizers, such as coconut shell char (size: 1-2 mm), non-coking coal (size: 1-2 mm), coconut shell char with a lapping of coal-tar pitch (3 mm thick layer approx.) on the steel surfaces, and used coconut shell char (partially burnt char remaining after completion of one carburization operation). Carburization was carried out at temperatures of 900, 930 and 950^{0}C for different time periods (2-3 h), followed by quenching in water. Hardness values of all these carburized steel samples were measured in a Rockwell hardness tester on C-scale under a load of 150 kg. The results have been listed in Table 3.

Table 3 : Hardness Values of Carburized Steel Samples

Carburization Conditions *			Hardness (R_C)
Medium	Temperature (^{0}C)	Soak time (h)	
	Mild Steel		
Coconut Shell Char	900	02	63
	930	02	66
	930	03	67
	950	02	67
Used Char	930	02	63
Coal	930	02	61
Char with Coaltar Pitch	930	02	66

* Quenching in water was effected immediately after carburization

2.3 Erosive Wear Testing in Soil–Water Slurry

The erosive wear testing of as-received and carburized steel samples in soil – water slurry was carried out in a specially designed and fabricated apparatus consisting of sample holder connected through a belt and pulley system to a D.C. motor, stainless steel vessel to hold the slurry, etc.. Locally available red soil, consisting of silica sand and grits, was used to make the slurry. During the test, dried and weighed rectangular steel specimens, fitted at preset distance from the centre of the holding disc, were rotated within the slurry (soil:water – 1:2) at a constant speed of 700 rpm for a particular duration. In each test run, two steel specimens of a particular heat treatment were bolted in the holding disc at two diametrically opposite positions in order to avoid the biased results and obtain average data. At the end of each run, the specimens were taken out from the slurry, cleaned, dried, reweighed and further processed for the next run. Four consecutive runs (each of 2 h duration) were conducted for all the specimens and weight losses in them were noted. A fresh slurry was used for each specimen. The wear volumes of all the specimens were calculated and then their wear rates (wear volumes per unit distance traversed) were computed [4]. The wear resistance has been expressed as an inverse of wear rate.

3. Results and Discussion

3.1 Hardness Values of Carburized Mild Steel Specimens

As evident from Table 3, hardness of mild steel was strongly influenced by carburization and its magnitude increased from 41 R_A (as-received) to about 67 R_C at a carburization temperature in the range 900 – 950^{0}C. This indirectly indicated that the mild steel could be fully hardened (60–65 R_C) by the presently studied carburization technique.

The results presented in Table 3 show that the hardness of carburized mild steel increases considerably with rise of carburization temperature and time up to the range studied (900 – 950^{0}C; 2–3 h), which is believed to be due to the increased tendencies of carbon dissolution and formation of carbon-enriched martensitic structure in the surface of carburized layer. Mild steel samples, carburized in coal and used char, exhibited slightly lower hardness values than those carburized in fresh char under identical conditions. This is obviously due to relatively lower fixed carbon contents in coal and used char (Table 2), and thus less carbon pick-up in the carburized layer. It is also apparent from the results (Table 3) that coaltar pitch coating on steel surface could not contribute in improving hardness of carburized product. This is undoubtedly due to formation of high carbon structure in the carburized mild steel.

3.2 Wear Characteristics of Carburized Mild Steel Specimens in Plain Soil – Water Slurry

The variations in erosive wear characteristics with test duration of all the carburized mild steel samples, studied in plain soil–water slurry at a rotation speed of 700 rpm, have been presented graphically in Figs. 1–3. An analysis of the wear test results, generated in the present investigation, revealed that on carburization, wear resistance of mild steel improved greatly over that in the as-received state. It would be safe enough to suggest that these changes in wear properties of steel are being primarily controlled by alterations in its carbon content, hardness and microstructure.

3.3 Effect of rotation time

It can be seen in Figs. 1 – 4 that the first two hours test duration in plain soil – water slurry, in general, gives highest wear loss and rate. After that, the wear rate decreased with increase of test duration above 2 h. The severe wear rate in the first 2 h may be attributed to the (a) inclusion of run-in wear in this period and (b) removal of loose particles from the surfaces. The decrease in wear rate with increase of rotation time above 2 h is believed to be due to the strain hardening of surface layers caused by the impingement of erodents present in the soil. The two stage wear, i.e. primary severe wear followed by secondary mild wear, as observed in the present investigation, is in agreement with the works of Glascott et al. [5] and Pathak et al. [6].

Mild steel, carburized at 950^{0}C, exhibited somewhat different behaviour in the variations of its wear properties with rotation time. As shown in Figs. 1-2, the wear resistance decreased with increasing rotation time up to six hours in the slurry and thereafter started improving. This phenomenon appears to be due to the combined effects of presence of large volume fraction of coarse carbides in the surface layers, and lack of their coherency with the matrix. As referred by Stevenson and Hutchings [7], this can also be ascribed, at least in part, to the enhancement of strain in the surface layers by the high volume fraction of carbide inclusions.

3.4 Effects of carburization temperature and time

It is noteworthy here that despite different hardness values, the wear resistances of mild steel samples, carburized at 900 and 930^{0}C, are nearly the same (Fig. 1). This is most probably because of no appreciable change in the surface morphology of carburized layers. It is also clear from Fig. 1 that carburization of mild steel at 950^{0}C yielded carburized layers having considerably higher wear resistance than that of the steel samples carburized at 900 and 930^{0}C. This can be largely attributed to the combined effects of (a) accelerated formation of carbide particles, their interlocking and spread to the matrix, (b) formation of larger amount of carbon-enriched martensite in the carburized layer upon water cooling, and (c) higher dislocation density.

As evidenced by Fig. 2, the carburized steel showed an increase in its wear resistance as the soak time at a carburization temperature of 930^{0}C was raised from 2 to 3 hours, but the contribution of this parameter in improving wear resistance was relatively small in comparison to the effect of carburization temperature.

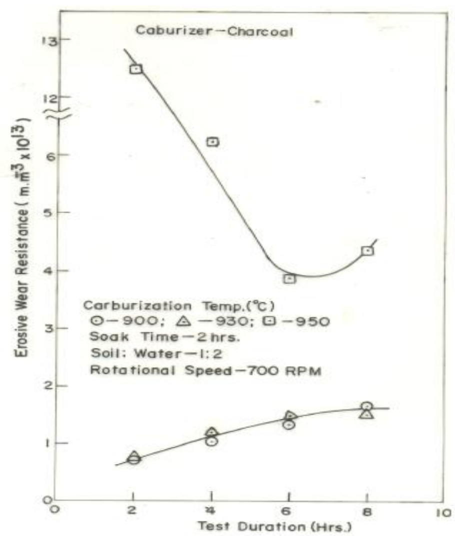

Figure 1. Wear resistance vs. rotation time : Effect of carburization temperature.

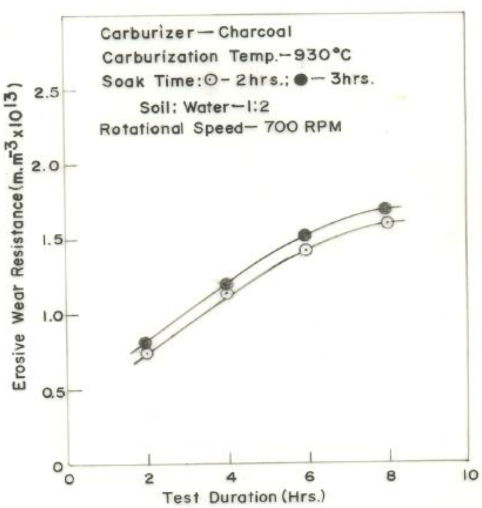

Figure 2. Wear resistance vs. rotation time: Effect of carburization soak time.

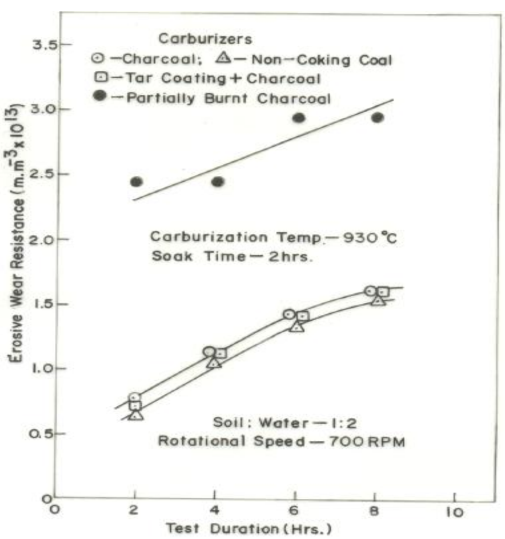

Figure 3. Wear resistance vs. rotation time for Mild Steel: Effect of carburizing medium.

3.5 Effect of carburizing medium

Comparison of data presented in Fig.3 indicates that amongst all the carburizers studied, carburization in partially burnt char resulted in highest wear resistance in the resultant carburized steel. This is most probably due to relatively higher reactivity and lower fixed carbon content in partially burnt char (Table 2) and as a result of which, the formation of carbon enriched martensite is expected. A hardness value of 63 R_C (Table 3) for the steel carburized in this medium clearly demonstrates this fact. As suggested by Patwardhan et al. [8], this type of structure ensures higher wear resistance. Next in series in order of their descending effectiveness are freshly prepared char and coal. The poor performance of coal in imparting wear resistance to resultant carburized steel is believed to be due to its lower reactivity and fixed carbon content (Table 2). The net result is that the use of more reactive carbon with optimum fixed carbon content yields carburized steel having highly wear resistant surfaces. As is clear from Fig.3, coaltar pitch coating on mild steel surfaces did not contribute in increasing its wear resistance during carburization in char. It seems to be due to rapid devolatilization of tar during the course of carburization at 930^{0}C, resulting in negligible pyrolytic carbon deposition on steel surfaces. The result is that the coaltar could not get an opportunity to utilize its carburization potential.

4. Conclusions

The main findings derived from the present experimental work are as follows :

1. Hardening effect immediately after carburization gave much higher hardness (60 – 67 R_C) and erosive wear resistance in the resultant carburized mild steel samples, and these results appear to be definitely superior than those obtained in mild steel by conventional carburization
2. Erosive wear resistance, in general, increased with increasing rotation (erosion) time in plain soil – water slurry irrespective of carburization conditions.
3. The carburized products from mild steel showed a progressive increase in their hardness and erosive wear resistance with increasing carburization temperature and soak time up to the range studied.
4. Among all the carburizers studied, partially burnt char proved itself to be most effective in imparting erosive wear resistance to the resultant carburized mild steel.
5. The coaltar pitch coating on steel surfaces had no effect on hardness and erosive wear resistance of carburized product.

References

[1] Kumar, M. and Gupta, R.C. Abrasive Wear Characteristics of Carbon and Low Alloy Steels for Better Performance of Farm Implements, Journal of Material Science Technology, 11, 1995, 91–96.

[2] Kumar, M. Studies on the Abrasive Wear of Carburized Mild Steel, *Trans. Ind. Inst. Met.*, 47(6), 1994, 417– 420.

[3] Kumar, M. and Gupta, R.C. Influence of Carburization Conditions on the Abrasive Wear of Mild Steel – An Approach for the Quality Upgradation of Farm Implements, *Tool & Alloy Steels*, October, 1996, 18–22.

[4] Pathak, J.P. and Tiwari, S.N. On the Mechanical and Wear Properties of Copper-Lead Bearing Alloys, *Wear*, 155(1), 1992, 37– 47.

[5] Glascott, J., Stott, F.H. and Wood, G.C. The Transition from Severe to Mild Sliding Wear fro Fe-12%Cr Base Alloys at Low Temperatures, *Wear*, 97(2), 1984,155–178.

[6] Pathak, J.P., Karimi, D. and Tiwari, S.N. Room Temperature Wear Characteristics of Al– Si – Cd Bearing Alloys, *Wear*, 170(1), 1993, 109 –117.

[7] Stevenson, A.N.J. and Hutchings, I.M. (1995), Wear of Hardfacing White Cast Irons by Solid Particle Erosion, *Wear*, 186-187(1), 1995, 150–158.

[8] Patwardhan, A.K., Kumar, S. and Singh, P. Controlled Graphitization as a Potential Option for Improving Wear Resistance of Unalloyed White Irons, *Metallurgical and Materials Transactions A*, 29A, August, 1998, 2147–2159.