Erosive Wear Characteristics of Carburized and Tempered Mild Steel Samples in Plain Soil–Water Slurry for Application in Agro–Industries

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Abstract — Studies on erosive wear characteristics (in soil-water slurry) of carburized and tempered mild steel samples were carried out in a specially designed and fabricated apparatus, and the effects of tempering temperature and erosion time were determined. The objective was to provide information to the agro-industries on changes in hardness and wear properties in relation to these parameters. The studied carburization technique greatly improved the hardness (up to 67 R_C) and wear resistance in the resultant carburized steel. The effectiveness of solid carburizers in improving these properties of steel decreased in the order : partially burnt charcoal, charcoal and coal. Wear resistance of carburized and tempered steel increased with rise of tempering temperature up to the range studied (150 – 250^{0}C). Majority of the carburized and tempered steel samples exhibited an improvement in their wear resistance with increase of rotation time in the slurry, and both the severe and mild wears were found to be operative.

***Keywords* —** Agricultural implements, Carburization, Erosive wear, Mild steel, Soil-water slurry, Tempering.

I. INTRODUCTION

During wet agricultural operations, many of the farm implements undergo erosion by the erodents like sand, stone, etc. present in the soil, and it may be the major reason of their quick failure and damage. Due to limited resources, less technical know-how and unavailability of economically feasible technology, agro-industries / village artisans have not been able to substantially improve the mechanical properties and wear resistance of these implements. As reported in our previous paper [1], the hardness, tensile strength and abrasive wear loss of Indian farm implements are approximately the same to those of as-received mild steel, indicating incapability of the manufacturers in imparting quality to the farm implements. Numerous papers on the wear characteristics of metallic materials on pin-on-disc machines have been published, but very limited studies [1-5] were carried out on reducing the wear of farm implement materials in actual soil conditions. Therefore, it was considered essential to do studies on minimization of wear in farm implement materials.

Our studies here are mainly concerned with the carburization of mild steel samples by the modified technology, and testing of their hardness and erosive wear properties in plain soil–water slurry. The aim was to determine the effects of tempering temperature on erosive wear rate and resistance.

II. EXPERIMENTAL

A. Steel Materials

Mild steel was supplied in the form of plates of 5 mm thickness. Its chemical composition, hardness and erosive wear resistance values are given in Table 1. The wear test specimens were cut from this plate and furnished by milling.

Table 1. Properties of mild steel used

Elemental Analysis (wt. %)							Hard-ness (R_A)	Wear Resistance * ($m.m^{-3} \times 10^{13}$)
C	Mn	Si	Cu	Al	S	P		
.16	.73	.33	.12	.015	.035	.038	41	0.43

B. Carburizers – Their Proximate Analysis and Reactivity Measurements

The fresh coconut shell charcoals was used as carburizers for the above steel. Coconut shell charcoal was prepared by carbonizing coconut shell pieces at a temperature of 800^{o}C (soak time: 1 h), as per method outlined in our previous paper [6]. Proximate analyses of these carburizers were carried out as per Indian Standard methods [7]. CO_2 reactivities of these carburizers were measured (at 900^{o}C) thermo-gravimetrically by the method described elsewhere [8]. The results obtained have been reported in Table 2.

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C. *Carburization and Hardness Measurement*

The polished mild steel specimens were subjected to a number of pack carburization treatments in coconut shell charcoal (size: 1-2 mm) whose properties have been outlines in Table 2.

The steel specimens, fully surrounded from all sides with the thick layers of carburizer, were placed in a stainless steel container covered with a plate. The container was then introduced into the muffle furnace maintained at the required carburization temperature of 930^0C and kept there for 2 hours followed by quenching in water, i.e. the hardening was effected immediately after carburization. Mild steel samples, carburized at 930^0C (soak time : 2 hrs.), were tempered at three different temperatures of 150, 200 and 250^0C for one hour. Hardness values of all these carburized and tempered 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 2. Proximate analysis and reactivity values of charcoal

Proximate Analysis (wt.%, air-dried basis)				Reactivity ($mg.min^{-1}.mg^{-1}$)
Moisture	Volatile matter	Ash	Fixed carbon	
4.00	5.96	2.14	87.90	0.0154

Table 3. Hardness values of carburized and tempered steel samples in charcoal

Carburization Conditions *		Tempering Temperature (^{0}C)	Hardness (R_C)
Temperature (^{0}C)	Soak time (h)		
930	02	-	66
930	02	150	57
930	02	200	55
930	02	250	54

* Quenching in water was effected immediately after carburization

D. *Erosive Wear Testing in Soil–Water Slurry*

The erosive wear testing of as-received, carburized and tempered steel samples in soil-water slurry was carried out in a specially designed and fabricated apparatus, as shown in Fig. 1, consisting of rotating steel shaft with one end connected through a belt and pulley system to a D.C. motor capable of rotation up to1450 rpm, means to control and measure the rotational speed, pH meter, stainless steel vessel to hold the slurry, etc.. Locally available red soil, consisting of silica sand and grits (size : –250 µm), was used to make the slurry. During the test, cleaned, dried and weighed rectangular steel specimens (size: 6.7 cm × 2.6 cm), fitted at preset distance from the centre of the holding disc, were rotated within the slurry (soil : water – 1:2, temperature : 28^0C, pH value : 8.1) 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 experimental run, the specimens were taken out from the slurry, thoroughly cleaned, dried, reweighed and further processed for the next run. Four consecutive runs (each of 2 hours duration) were conducted for all the specimens and weight losses in them were noted after each run by using an analytical balance. Fresh slurry was used for each specimen. The wear volumes (weight loss divided by density) in all the specimens were calculated and then their wear rates (wear volumes per unit distance traversed) were computed [9]. The wear resistance has been expressed as an inverse of wear rate.

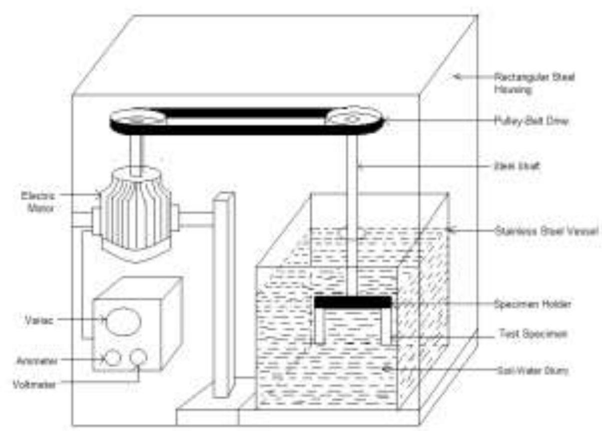

Fig. 1 Schematic diagram of experimental set-up for wear testing in soil-water slurry

III. RESULTS AND DISCUSSION

A. *Hardness Values of Carburized and Tempered 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 66 R_C at a carburization temperature of 930^0C. This indirectly indicated that the mild steel could be fully hardened (60–65 R_C) by the presently studied carburization technique.

This 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, as reported in the literature [4, 10, 11]. Carburization (temperature: 930^0C) followed by immediate water quenching leads to the formation of martensite in the case of the carburized steel [10, 11]. As outlined in the literature [12], the hardness of martensite is a function of its carbon content and increases from $44R_C$ at 0.2%C to $65R_C$ at 0.8%C (Table 4). It is evident from Table 3 that the carburized (at 930^0C) mild steel showed a progressive decrease in its hardness with increasing tempering temperature up to the range studied (i.e. 150 – 250^0C). As is clear from the literature [12], this is related to the relieve of internal stresses and decomposition of martensite.

Table 4. Relationship between hardness of martensite and its carbon content[12]

Carbon (wt. %)	0.2	0.3	0.4	0.5	0.6	0.8
Hardness (R_C)	44	50	57	60	63	65

B. Wear Characteristics of Carburized and Tempered Mild Steel Specimens in Plain Soil – Water Slurry

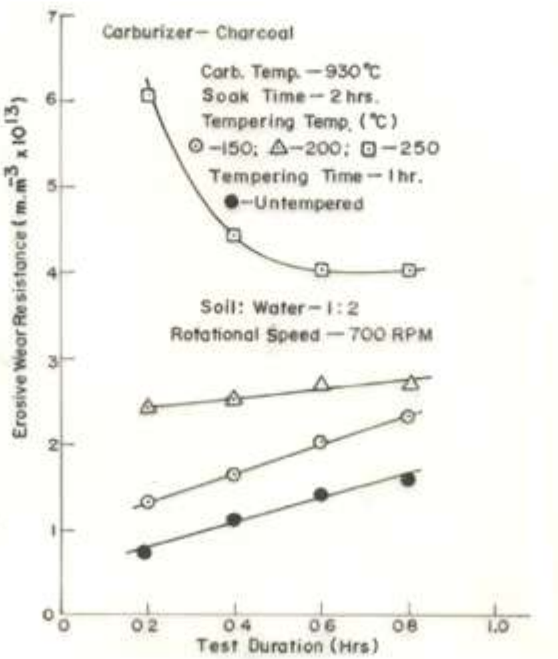

Fig. 2 Variation of erosive wear resistance with rotation time in soil–water slurry for carburized and tempered mild steel : Effect of tempering temperature.

The variations in erosive wear resistance with test duration of all the carburized and tempered mild steel samples, studied in plain soil–water slurry at a rotation speed of 700 rpm, have been presented graphically in Fig. 2. An analysis of the wear test results, generated in the present investigation, revealed that on carburization (followed by water quenching) and tempering, wear resistance of mild steel improved greatly (up to 12.5 $m.m^{-3} \times 10^{13}$) over that in the as-received state (0.43 $m.m^{-3} \times 10^{13}$). 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. The wear of carburized steel in aqueous slurry involved erosion by soil constituents (silica sand and grits, etc.) only and no wear loss due to corrosion was recorded up to two months.

C. Effect of Rotation Time

It can be seen in Fig. 2 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. The severe wear rate in the first two hours may be attributed to the (a) inclusion of run-in wear in this period and (b) removal of loose particles from the surfaces. As suggested by Chakraborty et al [3], the decrease in wear rate with increase of rotation time above two hours is probably due to the strain hardening of surface layers caused by the impingement of erodents present in the slurry. 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 [13] and Pathak et al [14].

D. Effect of Tempering Temperature

As shown in this Fig. 2, an appreciable improvement in wear resistance was noted with an increase in tempering temperature up to the range studied (150 – 250^{0}C), even though the hardness decreased. Hardness values listed in Table 3 and their correlation with carbon contents in Table 4 indicate the gradual depletion of carbon in martensite with increase of tempering temperature up to the range studied (i.e. 250^{0}C). This is in good agreement with the literature [12] which also suggests the gradual decrease in carbon content with the precipitation of fine ϵ- carbide (HCP, $Fe_{2.4}C$) during this stage of tempering. As reported by Basak and Chakraborty [4], the coherency of this type of carbide with tempered martensite increases with tempering temperature up to 200^{0}C and hence the wear resistance improves.

Fig. 2 also indicates that unlike tempering temperatures of 150 and 200^{0}C, a carburized steel tempered at 250^{0}C exhibited a decrease in its wear resistance with increase of rotation time up to six hours, and thereafter a reverse trend was observed. From the literature [10], it appears that the coherency of precipitated carbide particles with the tempered martensite lattice has got disturbed to some extent at a tempering temperature of 250^{0}C and is expected to go on further decrease with impact of erodents up to six hours, which is most probably the reason for decrease in wear resistance. Later in the test duration of 6–8 hours, the strain hardening of tempered martensite seems to start, which contributes to the wear resistance.

IV. FEATURES OF THE PRESENT INVESTIGATION

The present experimental work more or less simulates the actual agricultural operation and the observations derived are of considerable technological significance for the socio-economic development of farmers, village-artisans and small agro-industries. The basic groundwork for increasing the life and serviceability of mild steel farm implements has been prepared in this investigation, and it would now be pertinent to examine the structural changes that occur on carburization followed by immediate water quenching and tempering. From the results of this study, it appears that the carburization of mild steel in charcoal followed by its immediate water quenching and low temperature tempering is the potential, most effective and less energy consuming technique for improving the mechanical and wear properties of farm implements made of low carbon and mild steels. In addition to these, the present study has some other advantages, such as (a) saving of carburization time and elimination of rehardening treatment (as in conventional carburization), (b) utilization of waste material and reduction in the requirement of charcoal, and (c) no need of energizer (viz. $BaCO_3$, etc.).

V. Conclusion

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

1. Hardening effect immediately after carburization gave much higher hardness (60 – 66 R_C) and erosive wear resistance (in soil-water slurry) in the resultant carburized mild steel samples, and these results appear to be definitely superior than those obtained by conventional carburization.
2. Erosive wear resistance, in general, increased with increasing rotation (erosion) time in plain soil-water slurry irrespective of carburization and tempering conditions.
3. Both the severe and mild wear losses were operative in the present study.
4. With increasing tempering temperature up to 250^0C, the hardness declined but the erosive wear resistance improved.
5. From the point of view of commercial utilization, the carburization treatment involving 930^0C, 2 hours, water quenching and tempering at 200^0C appear most promising.

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