EFFECT OF METAL-SPRAYING AND SHOT PEENING ON ABRASIVE WEAR OF CARBON STEEL

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ABSTRACT
Abrasive wear is a micro fatigue phenomena and it occurs in soil engaging tools. From cost consideration, these tools are made of cheaper steels (Carbon steels) [(1) & (2)]. To enhance wear resistance and tool life of such carbon steels we have studied the effect of shot peening, coating, and coating with post shot peening. Shot peening after coating has shown considerable improvement on abrasive wear resistance.

Test piece materials
Commercially available low carbon structural steel SAE-1022 and spring steel En42 were selected for study. En42 was through hardened and tempered. This was closely similar to the actual blade material of the rotavator. The chemical composition of test-specimen based on spectro-analysis was as follows

Range of elements	C	Si	Mn	P	S	Ni	Cr	Mo	Hardness HRc
SAE 1022	0.22	0.30	0.81	0.017	0.023	0.04	0.021	0.012	31.3
EN42 (HT)	0.78	1.29	0.89	0.029	0.027	0.16	0.74	0.013	51.8

Design of experiment
The following treatments were decided to be performed on the test specimens:

T1 = Virgin sample (SAE-1022) (T1 – stands for treatment one)
T2 = Virgin and shot peened
T3 = Virgin, and coated with material – 1 (i.e. self fluxing alloy of Ni-Cr-Fe-Si-B)
T4 = Virgin, and coated with material II (i.e. ceramic material which is a combination of $Al_2O_3 - TiO_2$)
T5 = Virgin, and coated with material III (i.e. super performance stainless steel)
T6 = Virgin, coated with material I and again shot peened.
T7 = Actual blade material sample (En42).

To make a comparative study of all the test specimens subjected to different treatments were tested (run) simultaneously in the wear test machine, so that all the sample could be subjected to same operating / environmental conditions.

Wear test set-up

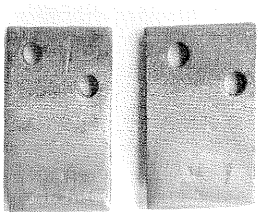
A wear testing set-up was developed from the available sand mixer to move the test pieces in circular sand path under controlled conditions. Two to three fixtures each having provision to hold two test pieces at a time, were fabricated and fitted to the unit. The mean radius of path followed by the test pieces was measured and corresponding to the rpm of the holders the speed of operation was determined. The average speed of operation was 2.30 km/h standard river sand being graded $\leq$2.36 mm was used in the test. Average depth of sand bed was kept 100 mm while average operating depth of test piece was 50 mm.

Specification of wear test set-up

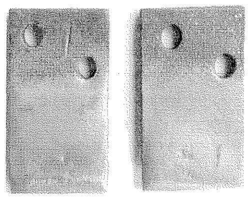
The wear test set-up consists of sand bath of circular shape. At the center of the sand bath there is a vertical shaft which carries two arms. On these arms fixtures carrying test pieces are clamped. These arms move in circular path as the vertical shaft is rotated by a reduction gear box worm wheel shaft coupled to it. Diameter of sand bath was 500mm and wall height 150mm. A 3-phase, 1hp, 1400rpm driving motor shaft is coupled with reduction gear box having reduction ratio 1:42 (worm and wheel). The wheel rotates at 34rpm.

Preparation of Test Specimens

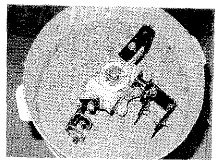
Test specimens were prepared from SAE 1022 Steel and En42 by normal machining operations. The specimens were cut to 48x32x5mm size to suit the sand/soil tank. Two holes (6 mm dia) were drilled for fixing them with the fixture. The cutting edges of the test pieces were beveled to 18 degree along 32 mm side at one end. The test pieces before and after wear, and the sand bed with rotary arm carrying test pieces on the fixture are as shown Fig 1. Specimen holding fixtures and outer view of abrasive wear set-up is shown more clearly in Fig. 2.



Test Specimen Before Wear
1. Coated with self fluxing alloy (alloy of Ni-Cr-Fe-Si-B)—T3
2. Coated with self fluxing alloy and again shot peened—T6

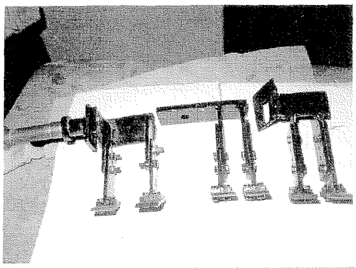


Test Specimen After Wear
1. Specimen—T3
2. Specimen—T6

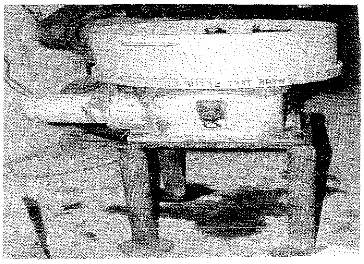


Operation of Test Pieces with fixture in sand bed

Fig. 1: Test pieces T3 and T6 before and after wear and sand bed with rotary arm and fixture.



Specimen Holding Fixture



Wear Test Setup

Fig. 2:Specimen holding fixtures and outer front view of wear test set-up.

Shot Peening Parameters

Shot peening was carried out on the test pieces using pressure peening system which was as shown in the Fig. 3. The peening system has one nozzle and a reciprocating arrangement for nozzle holder. The workpiece was fixed in front of the nozzle for shot exposure. Peening pressure was 0.589 MPa, nozzle bore 6.0 mm shot size S 330 (0.825 mm) shot hardness 45-50 HRC stand off 150 mm. Average mass flow was 0.4 t/h, angle of impingement was near to 90°, coverage 98%, peening intensity was 0.35 to 0.45 A.

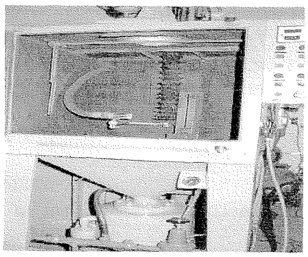


Fig. 3: Pressure Peening Setup

Results and Discussion

Percentage wear (mass basis) of test pieces after different treatments run in sand bed is given in table 1 and the corresponding dimension and volume wear is given in table 2. It was found that the mass wear of the virgin blade (SAE-1022) was the maximum of 6.25% followed by virgin – shot peened (5.84%), virgin – coated with stainless steel (0.9802%), virgin coated with ceramic material (0.07127%), virgin-coated with self fluxing alloy (0.06728%) and virgin-coated with self fluxing alloy and again shot peened (0.03217%). Similar trend was observed for mass wear per kilometer of test run.

The reduction in mass wear of treatment T3 over treatment T4 and T5 were found to be 5.58% and 93.13% respectively; this shows that performance wise the self fluxing alloy coating was best suited for wear prevention, followed by ceramic coating, and in the last stainless steel coating. Further comparing the results of T2 with T1 gives an idea that use of shot peening has also reduced mass wear by 6.56% to that of virgin sample (SAE-1022).

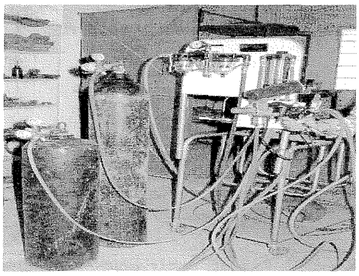
The use of shot peening after coating (T6) has further reduced the mass wear by 52.19% over the coated sample (T3). Further comparing the results of T6 with T7 it can be seen that the percentage mass wear has decreased by 99.32% which may be due to benefits of peening after metal coating of self fluxing alloy.

Effect of surface roughness on mass wear of test specimens

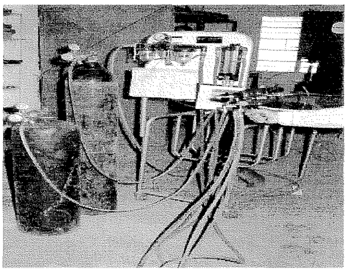
The Ra & Rpm: Ra (centre line average value of roughness) and RPM (height of the peak from the centre). The Ra & Rpm values of virgin (T1) sample were 3.76 µm and 10.30 µm before wear test, and 0.50 µm and 1.50 µm after wear test, this shows that all the peaks which were present before were shorned off by the abrasives and a near smooth surface was exposed having very low value of Ra (0.5 µm).

But the sample which was virgin – shot peened (T2), was having Ra & Rpm 4.76 µm and 12.40 µm respectively before wear test, but these values changed to 2.20 µm and 6.00 µm respectively, which shows the positive effect of peening against wear, due to development of comparatively harder and stronger exterior.

The actual blade material (T7) showed the same behaviour and the Ra & Rpm values changed from 0.67 µm and 2.90 µm to 0.22 µm and 1.96 µm respectively, here the percentage changes in the values of Ra and Rpm is less as compared to virgin (T1) sample, because this is a high carbon steel having high hardness. Similarly the percentage change in the values of Ra and Rpm for the self fluxed alloy coated sample (T3) is high as compared to self fluxed alloy coated and again shot peened sample (T6). This may be because of the plastically stretched dimples on the shot peened surface, were having high hardness and could not be shorned off by the abrasives (soil / silica) and a higher value of surface roughness is maintained.



Oxy-Fuel Wire Spray Installation



Oxy-Fuel Powder Spray Installation

Fig. 4: Oxy fuel wire spray and powder spray installation.

Table 1: Percentage wear (Mass-basis) of blades in sand bed

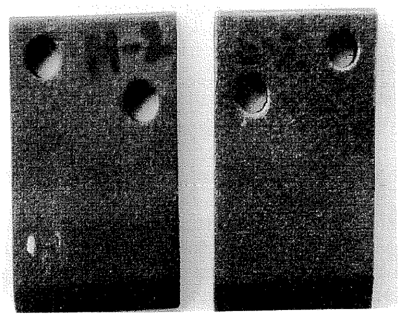
Sl.No.	Treatment / operation	Mass of blades before wear test (gms)	Mass of blades after 50 hrs of operation (gms)	% wear
1	T1: Virgin (SAE1022)	55.23	51.78	6.25% (0.054)
2	T2: Virgin Shot peened	55.14	51.92	5.84% (0.051)
3	T3: Virgin coating of material I (alloy of Ni-Cr-Fe-Si-B)	56.467	56.433	0.06021% (0.000406)
4	T4: Virgin coating of material II (alloy of $Al_2O_3 - TiO_2$)	49.104	49.069	0.07127% (0.000458)
5	T5: Virgin coating of material III (stainless steel)	48.867	48.388	0.9802% (0.005727
6	T6: Virgin coating of material I (alloy of NI-Cr-Fe-Si-B) shot peened	52.838	52.821	0.03217% (0.000138)
7	T7: Actual blade material (En42)	70.87	67.49	4.77% (0.041)

Table 2: Wear of specimens on dimension basis

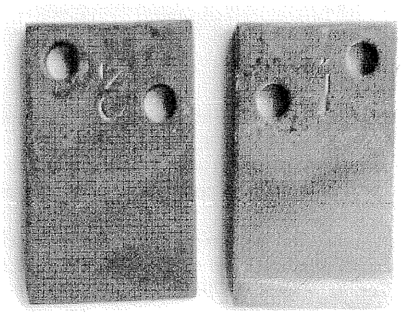
Treatment / operation	Initial dimensions {prior to wear test (in mm)}			Dimensions after 50 hrs of operation (in mm)			% Dimensional wear			% Volume wear (mm^3)
	L	W	T	L	W	T	L	W	T	
T1: Virgin (SAE1022)	48.60	31.10	5.40	42.80	28.46	4.46	11.93	8.49	17.41	33.44
T2: Virgin Shot peened	48.65	31.14	5.42	42.44	28.32	4.63	12.76	9.05	14.57	32.23
T3: Virgin coating of material I (alloy of Ni-Cr-Fe-Si-B)	48.70	31.0	5.75	48.35	30.09	5.7	0.718	0.322	0.869	1.899
T4: Virgin coating of material II (alloy of $Al_2O_3 - TiO_2$)	47.85	32.15	4.80	47.49	32.01	4.75	0.752	0.412	0.910	2.068
T5: Virgin coating of material III (stainless steel)	48.12	32.15	4.80	47.68	32.01	4.75	0.913	0.414	1.012	2.334
T6: Virgin coating of material I (alloy of NI-Cr-Fe-Si-B) shot peened	47.1	32.6	5.65	46.95	32.55	5.62	0.318	0.127	0.402	0.8765
T7: Actual blade material (En42)	46.70	36.00	6.48	43.86	34.42	5.74	6.08	4.39	11.42	20.46

Analysis of the volume wear show that loss in volume was the least with T_6 (0.8765%) and it was found to be very advantageous even over the volume wear (20.46%) of the actual blade specimen (En-42). Comparing the results of T6 with T7 it was found that the percentage volume wear has decreased by 95.71%. Similarly comparing T3, T4, T5 with T2. It can be concluded that the percentage volume wear has reduced to a very low value.

The improved performance of shot peened surface, comparison of (T2 over T1), may be attributed due to the fact that the peening action induced work hardened layer and residual compressive stresses, by which the micro crack origins on the surface was blocked, which resulted in improved strength and stability of the surface and there by reduced microchipping (as in abrasive wear phenomena material is removed from the surface by scratching and micro-chipping). It may there fore be inferred that shot peened surfaces offered more wear resistance as compared to unpeened surfaces [(3) & (4)].



Specimen T4 and T2 before Wear Test



Specimen T4 and T2 after Wear Test

Fig. 5: Specimens before and after wear test.

Coating

The use of coating has tremendously improved wear resistance of the surface, because these coatings are harder than the abrasives in the soil. The use of self fluxing alloy (alloy of Ni-Cr-Fe-Si-B) has shown the highest improvement in the wear resistance among the used coating material. This coating was fused after the spray, this fusing had caused the metallurgic bonding of the coating with the base. This coating was also suited for impact loads as encountered in soil.

The use of ceramic materials (alloy of $Al_2O_3 - TiO_2$) for coating has also improved surface hardness and reduced wear considerably. It is best suited for use in abrasive soils containing few stones and on cultivated land, especially at shallow working depths, where the risk of impact damage will be minimized, such as in case of sliding wear. As this coating is brittle in nature so its wear is more as compared to self fluxing alloy coating due to impact loads.

Similarly the use of stainless steel coating has also increased the surface hardness and improved wear resistance. But it was not as harder as the other coating material so its wear is pronounced than other coating materials.

The use of shot peening after the coating on the test specimen has further improved the wear resistant characteristic of the surface. The shot peening after the coating would have overcome those residual tensile stresses which were resulted from contraction during cooling and solidification. Another benefit of shot peening which improved the performance of the coated sample was the induction of work hardened layer, so the dislocation density could possibly be increased which resulted in hardening effect; this increase in hardness further improved wear resistance of surface.

Table 3 gives the cost of coated material lost due to wear (in 50 hrs of test operation) per kilometer of run. It is found that this value is minimum for ceramic coated (T4) sample, and highest for self fluxed alloy coated (T3) sample. Hence it shows that the ceramic – coating is the most economic coating, and its use for rotavator blades is highly suitable both from service life and cost effectiveness point of view.

Table 3 : Cost analysis for 50 hrs of test run

Sl. No.	Treatment	% Mass wear in 50 hrs of test run	Total loss of coated material (powder / wire) due to wear test (gms)	Cost of lost coated material due to wear, Rs.	Cost of material spent / lost per km. of run (Rs./km)	Total cost in units
1	T3	0.06021	0.034 gms	0.1377	0.001646	28.742
2	T4	0.07127	0.040	0.06	0.0007174	21.727
3	T5	0.9802	0.553	0.1299	0.001553	18.340

Conclusions

1. Wear rates with shot peened blades were found to be lower than virgin steel blades due to formation of surface work hardened layer included and residual compressive stresses, reducing RPM (height of the peak from the centerline).
2. Coatings of wear resistant materials on tillage equipment offered great potential for reducing severity of wear.
3. Among the self fluxing alloy (alloy at Ni-Cr-Fe-SI-B ceramic material (combination of Al_2O_3-TiO_2) and stainless steel coating materials, percentage wear (mass and volume basis) of self fluxing alloy (alloy of Ni-Cr-Fe-Si-B) was minimum with higher initial cost, while ceramic material coating gave lowest cost per kilometer run with higher wear rates. The stainless steel coating was cheapest among the three coatings but has shown highest wear rate.
4. Percentage wear (mass and volume basis) of shot peened self fluxed alloy coated blade was found to be low as compared to actual blade specimens.
5. Shot peening after coating has great potential in further improving wear resistant properties of coating, due to residual compressive stresses and surface work hardened layer. These residual compressive stresses are also beneficial in over-coming residual tensile stresses created by coating.
6. Plastically stretched dimple peaks on the surface of self flux alloy coated and again shot peened samples offered higher resistance to abrasion and there by took longer time to vanish.
7. Improved surface performance of shot peened samples, coated samples and coated and again shot peened samples indicated for an appropriate smaller section of blade than being conventionally used. With smaller sections, the blades would be lighter and would reduce the size and number of inclusions, and being coated and shot peened would give improved surface performance with better cost effectiveness.

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References

1. M.C. Sharma & S.K. Rautaray. "Shot peening to reduce wear of soil engaging components of tillage machinery". International conference on shot peening and blast cleaning, 1996, MACT, Bhopal, India.
2. S. Petrov, S. Bisonvaty. "Repair of farming machinery", Mir-Publication, 1996, p. 10-11.
3. V.N. Kashcheev, & G Ya, Yampolsky. "Abrasive-wear", Friction, Wear and Lubrication Tribology Handbook Vol.2, 1981, p. 28-48.
4 Moore MA and King FS, "Abrasive wear of brittle solids" , wear -60, 123- 140, 1980.