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Effect of Peening Intensity and Applied Load on Low Stress Abrasive Wear Response of Agricultural Grade SAE-6150 Steel

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ABSTRACT

The effect of shot peening on low stress abrasive wear behaviour of SAE-6150 steel was studied at various intensities varying from 0.17A to 0.47A. The abrasive wear test on un-peened and peened specimens by dry sand abrasion tester revealed that shot peening reduced abrasive wear considerably, when it was restricted up to 0.17A. But over peening led to higher abrasive wear rate. In the critical period, the peened and un-peened samples exhibited comparable wear rate, indicating that peening was required on regular interval to maximize the advantages. The technology would be useful for manufacturer of agricultural implements in India, due to its simplicity and cost effectiveness.

***Key words**: Peening, abrasive wear*

Medium carbon steels are used for various engineering and agricultural applications. In fact, these steels are used in high volume in tillage/soil working implements (Bliesener, 1953) like cultivator sweep, furrow opener of seed drill, ploughshare, etc. The rapid wear of these machine parts is responsible for most of idle time for maintenance as well as expenditure on repair and manufacturing of spare parts (Foley *et al.*, 1994). A large fraction of agricultural implements in India is fabricated by the small scale sector, which generally face problems of non availability of proper material, inadequate manufacturing process and quality improvement techniques. The Government of India in its report stressed for more research and development activities on the design and quality production of agricultural implements (Anon, 1986). To overcome the effects of these adverse factors (dynamic loads, abrasive wear and chemical action), various attempts have been made to improve the surface properties (specially hardness) of soil-engaging components such as diffusion coating, hardfacing (weld deposit) and enamel coating. Commonly used diffusion process by the investigators for life extension of fast wearing components of agricultural implements are carburizing (Rautaray,1997; Varshney, 2000; Saxena and Sharma, 2001; Moore,1975) nitriding, carbonitriding (Moore,1975) and boriding (Moore, 1975; Er and Par, 2006). The relative wear resistance of carbonized and nitrided materials used for soil working components of agricultural implements were found similar to that of a high carbon steel of same hardness. A regular cultivator sweep tested with five kinds of hardfaced sweeps indicated that the wear in all hardfaced sweeps were considerably less in comparison to regular sweep. But, the extents of wear are different in different kinds of hardfacing (Zhang and Kushwaha, 1995). The wear rate in soil working components of agricultural implements like tine point, subsoiler, plough land slide and mole plough with alumina protection are reported to be five times lower than that of conventional steel components (Foley et *al.*, 1994). Hardfacing by weld deposit on the surface of soil-engaging components is more useful in sliding wear in weak soils with low stone content (Moore, 1979). In hardsurfacing of cultivator shovel, a single-layer deposit is reported to be satisfactory. Hardsurfacing shovels with electrodes Modi 600, Lomet 304,Cromcarb N6006, Lomet 303 and ultimium N112 exhibited reduced wear in the order of electrodes listed (Raval and Kausal, 1990). Hardfacing is a very effective and techno-economic solution for wear problem (Kumar *et al.*, 1999; Kumar *et al.*, 2000). Various enamel coatings were also used in agricultural implements to reduce draft requirement, improving scoring and to minimize wear (Foley, 1988; Salokhe and Gee clough, 1988; Salokhe *et al*., 1989). Enamel coated plates have shown excellent non–stickiness to the soil in actual field conditions (Salokhe and Gee Clough , 1988). All these processes are cost and energy intensive, as new materials are deposited and considerable amount of electrical energy is required. Shot peening is reported to be an appropriate technique to improve the strength of metal, which indirectly improves wear resistance without using alloying or other processes that changes the bulk microstructures of materials due to surface work hardening (Yan *et al.,* 2007).

As shot peening is also a surface work-hardening process,

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it is expected that considerable improvement in wear resistance could be achieved due to application of the technique. Singh and Saxena (2008) examined the effect of heat-treatment and shot peening on 50B50 boron steel at 75N load, and found that heat-treatment cycles as well as shot peening intensity significantly affected the wear rate of 50B50 boron steel. Presently, boron steels are commonly used for manufacturing of agricultural implements only in developed countries, as its cost is higher and are not easily available in developing countries like India. Heat-treatment is again a costly process to alter the properties of a material. Keeping this in view, medium carbon steel (SAE-6150), commonly used for making fast-wearing components of agricultural implements in India, was selected to understand its wear behaviour in "as-received condition" (without heat-treatment) with and without shot peening process at three different loads of 75, 200 and 375N.

MATERIALS AND METHODS

Chemical Characterization of Steel and Shot Peening

Medium carbon low alloy SAE-6150 steel was used in the study. Its chemical composition is given in Table 1.

Table 1. Chemical composition of steel used

Specification	Chemical composition (weight, %)				
	C	Si	Mn	Cr	V
SAE-6150 steel	0.52	0.22	0.70	1.0	0.17

Shot peening

Shot peening was carried out at various peening intensities ranging between 0.17A and 0.47A by shot-peening (Mech Shot, Jodhpur, India) machine. Standard "A" type Almen strips were used to measure the peening intensity. The expose time was varied, keeping other parameters constant, for obtaining different peening intensities. The methodology of shot peening intensity measurement is given in Fig. 1. The peening intensity as a function of peening time is shown in Table 2.

Table 2. Peening intensity as a function of peening time

Peening intensity (A)	0.17	0.27	0.37	0.47
Expose time (s)	18	25	55	120

Measurements

Hardness, microhardness and microstructure of material

The hardness of test piece materials was measured before and after shot peening by a Vicker hardness tester. Polished

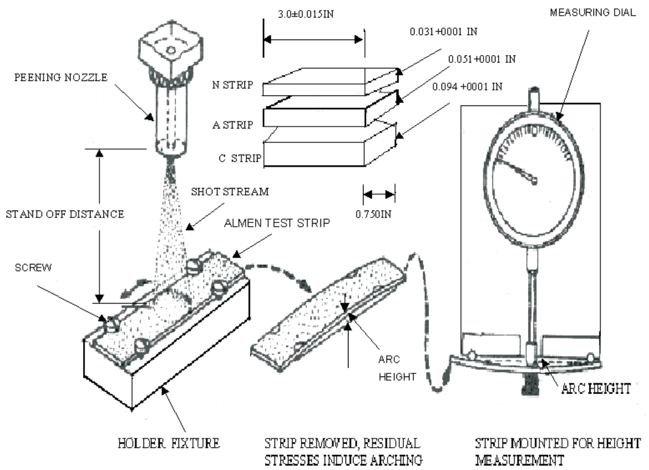


Fig.1: Measurement of shot peening intensity

samples were used for hardness measurement. Opposite surfaces of the samples were made parallel to each other prior to hardness measurement. As per standard procedure, a load of 294 N was used for making the indentations. Micro-hardness measurements were carried out on polished and etched surfaces of the samples with the help of a digital microhardness tester (LECO: Model DM-400). A Scanning Electron Microscope (SEM) was used to examine the microstructure of peened and un-peened specimens.

Low stress abrasive wear tests

Low stress abrasive wear tests were conducted using a dry sand abrasion tester as per ASTM-65 standard. Before starting the wear tests, the specimens were cleaned and polished according to standard metallographic techniques, weighed by an electronic balance, and then fitted in specimen holder. The test was started and as the machine stopped after completion of preset revaluations; the specimens were taken out, cleaned and weighed. This process was repeated for 18 times (200 revolutions, or 144m each time) to examine the wear trend of the specimen. The specimens ("as received" and shot peened) were tested at three loads (75N, 200N and 375 N). The wear rate was calculated from volume loss. This test methodology very well simulates with the working condition of fast wearing components of agricultural machinery as shown in Fig. 2. The test specimen was pressed against a rotating rubber wheel, while a controlled flow of abrasives was maintained at the test surface. The duration of the test and the applied load was varied as per the experiment requirements. Crushed silica sand particles (size 212-300mm) at the rate of 370 g.min^{-1} were applied for abrasive action. During the tests, a constant sliding speed of 1.86 m.s^{-1} was maintained.

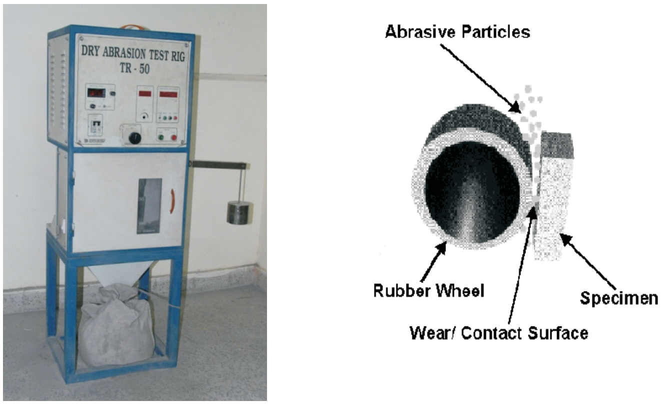


Fig.2: Abrasion tester (in conformity of ASTM G65)

RESULTS AND DISCUSSION

Materials and Microstructures

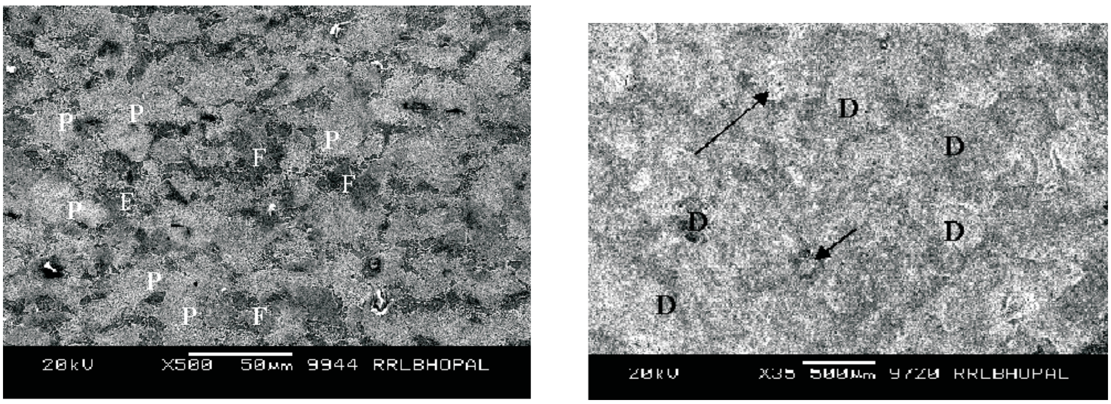
The microstructure of SAE-6150 steel exhibited two-phase structures of ferrite (F) and pearlite (P) in which the pearlite colonies were more or less surrounded with ferrite network as shown in Fig. 3 (a). In this ferro–pearlitic structure, the pearlite is a harder phase and the abrasive wear is controlled by the amount and distribution of this pearlitic phase. The volume fraction of ferrite and pearlite phases was found to be 20% and 80%, respectively. The hardness of steel was noted to be 150HV. The micro-hardness of steel at the subsurface after shot peening is given in Table 3. It revealed that the subsurface microhardness increased with increase in peening intensities, which indirectly suggested that work hardening of the surface took place due to shot peening. The microstructure of shot peened surface showed dents and leaps (marked 'D', Fig. 3(b)). The microstructure of heavily peened specimen at the surface showed extensive micro-cracking marked 'arrow' as depicted in Fig. 3(b).

Effect of sliding distance on abrasive wear

The variation of abrasive wear with sliding distance is depicted in Fig. 4, Fig. 5 and Fig. 6 at 75N, 200N and 375N, respectively. It could be noted that wear rates were decreasing with sliding distance, and obtained a steady state value. The initial wear rate was higher either due to presence of foreign material at the surface of un-peened specimens or presence of weaker leaps on the peened specimens, which were removed at faster rate during wear. The continuous plastic deformation caused surface work hardening and it could be expected that the wear rate would reduce monotonically with sliding distance. However, other phenomena like surface and subsurface cracking annihilated this effect after some time when the surface work hardened excessively. Under steady state condition, the wear rate of mild peened (0.17A) samples were found

Table 3. Micro-hardness (MH) of steel at the subsurface after shot peening

		Peening intensity, A															
Parameter	**unpeened**	**0.17**				**0.27**				**0.37**				**0.47**			
Depth, mm	-	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.3
MH, HV	150	190	172	154	150	215	183	169	152	240	203	182	156	270	232	194	159



(a) Un-peened (b) Peened at high intensity

Fig. 3: Microstructure of as received un-peened and peened SAE-6150

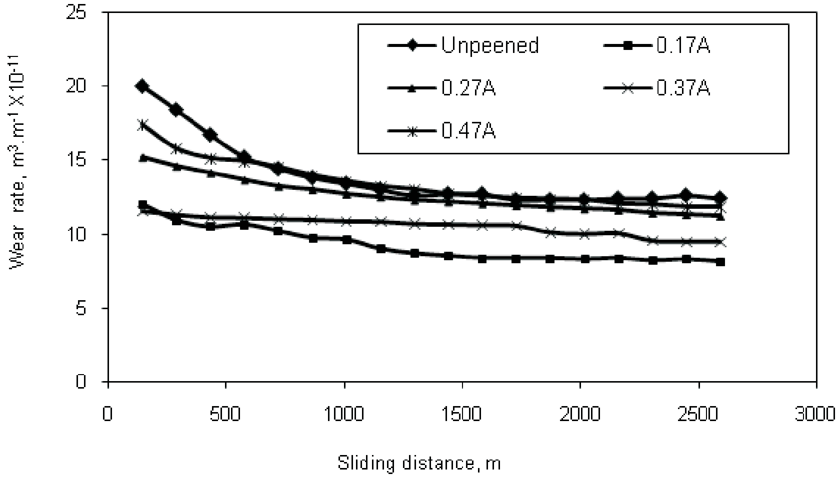


Fig.4: Effect of sliding distance on wear rate of SAE-6150 steel at 75N

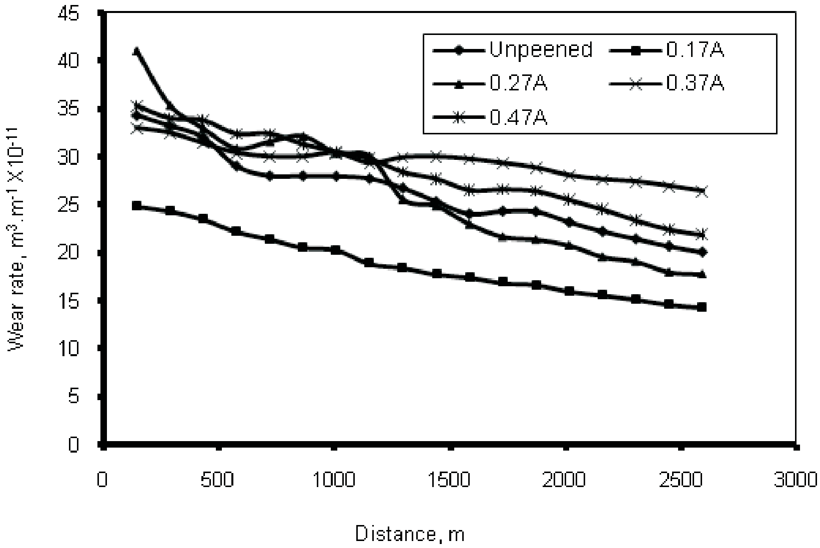


Fig.5: Effect of sliding distance on wear rate of SAE-6150 steel at 200N

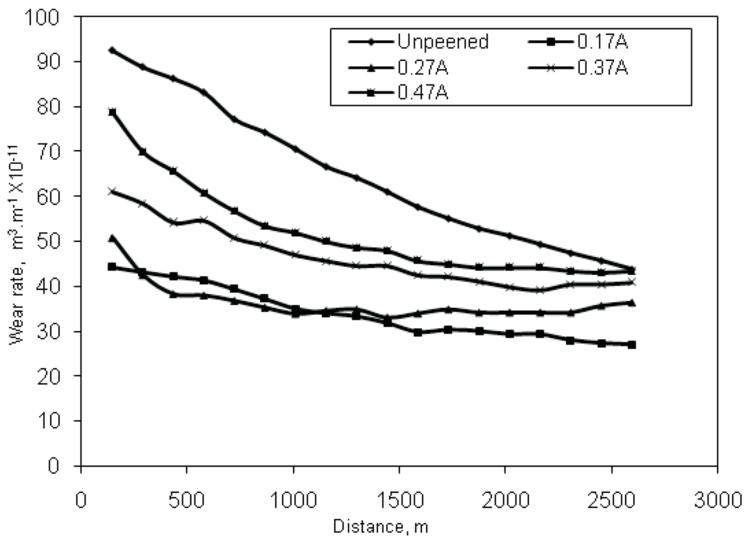


Fig.6: Effect of sliding distance on wear rate of SAE-6150 steel at 375N

to be about 35 %, 28.83% and 38.39% less in comparison to un-peened specimens at 75N, 200N and 375N loads, respectively. The wear behaviour of SAE-6150 steel is almost similar under varying applied loads. The reduction in wear rate due to mild peening occurred due to improvement in surface hardness (Table 3). This resisted the penetration of sand particles and development of residual compressive stresses at the surface and sub-surfaces that resisted crack formation and crack initiation at the surface and subsurface level during peening. Further increase in peening intensity led to crack formation and increased brittleness at the surface and subsurface level, which led to more severe wear.

Effect of applied load on abrasive wear

The effect of applied load in abrasive wear of SAE-6150 steel is depicted in Fig. 7. The increase in wear rate with applied load was expected. However, Fig. 7 demonstrated that the trend in variation in wear rate with applied load was almost invariant to peening intensity. With increase in applied load, the depth of penetration increased which led to more material removal. The figure also indicated that the steel exhibited minimum wear rate when subjected to peening at intensity of 0.17A, irrespective of the applied load. Further increase in peening intensity led to more wear, which is discussed in later section.

Effect of peening intensity on abrasive wear

The effect of peening intensity on abrasive wear of SAE-6150 steel at three loads of 75N, 200N and 375N are shown in Fig. 8. It is evident from the figure that wear rate decreased initially with increase of peening intensity up to 0.17A.

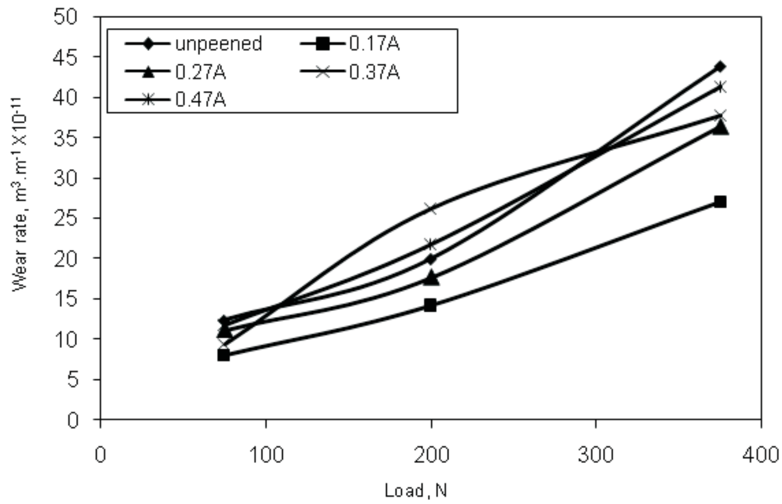


Fig.7: Effect of applied load on abrasive wear of "as received" SAE-6150 steel

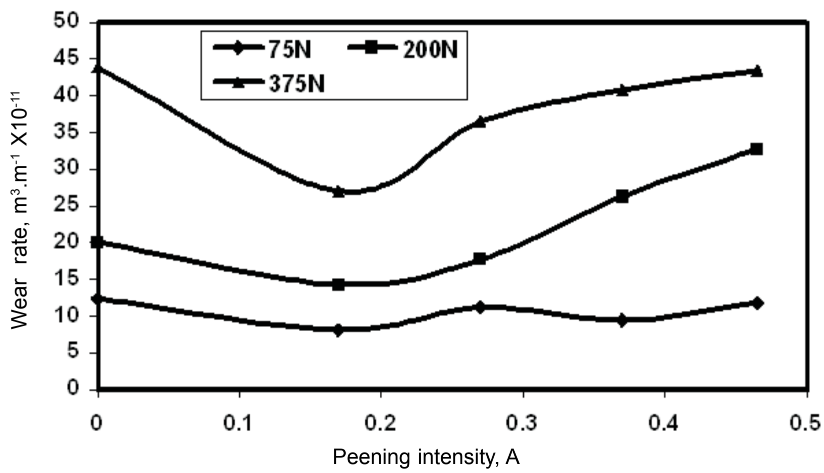


Fig.8: Effect of peening intensity on abrasive wear of "as received" SAE-6150 steel

Further increase in peening intensity led to increase in wear rate. It could be observed from Fig. 8 that minimum wear rate could be achieved with peening intensity limited to 0.17A. At considerable higher peening intensity, the wear rates of material were considerably higher, and sometimes even higher than that of un-peened specimens. The extent of improvement in wear resistance due to mild peening was due to higher surface and subsurface hardness (Mondal *et al.*, 2008; Singh *et al.*, 2010), which might have been achieved due to work-hardening and micro-structural refinement. Compressive residual stress developed on the surface due to shot peening reduced micro-cracking tendency during wear on the surface (Lida, 1996; Yan *et al.,* 2007). Higher peening intensity made the surface saturated with work-hardening and caused surface and subsurface micro-cracking either during peening or wear test due to application of load. The dents and leaps formed during peening got damaged during severe peening, and thus easily removed. Furthermore, surface and subsurface cracks developed during peening started growing further and interacted with each other, leading to delaminating wear in addition to the abrasive type wear. The subsurface being significantly work-hardened during peening, only minimum amount of energy was spent on the surface and subsurface deformation, and major extent of energy was consumed for abrasion. All these facts led to increase in the wear rate at higher peening intensity. Thus, it could be recommended that higher peening intensity should be avoided for obtaining improved wear resistance.

Peening leads to microstructural refinement and surface work-hardening up to limited depth. As a result, it is expected that after removal of material up to this depth, even the shot peening material would behave similar to that of un-peened material. In this context, comparison of wear rate of un-peened and peened (0.17A) specimens of SAE-6150 at different intervals was examined, and shown in Fig. 9. It is exhibited from the figure that the wear rate of peened (0.17A) specimen in the initial intervals were significantly less than that of un-peened samples. In later intervals, the difference in the wear rate amongst the peened and un-peened samples reduced and after a critical distance of about 1700 m, both the peened and un-peened samples exhibited almost similar wear rate at each proceeding intervals. This demonstrated that the effective depth of peening got removed after sliding up to 1700 m. The effect of shot peening towards wear behaviour became inactive after a sliding distance of about 1700 m. This further suggested that the overall improvement in the wear rate in shot peened and un-peened samples was due to significant influence of peening in the initial stages of the wear behaviour, which caused considerable decrease in wear rate in the initial sliding period. In fact, a critical depth from the peening surface of the specimen got subjected to plastic deformation during peening and the influence of peening was limited to this depth only. After a certain distance (about 1700 m in the present study) the layer influenced by shot peening got completely removed and thus, beyond this sliding distance, even the shot peened samples behaved similar to the un-peened samples. This further suggested that in order to have continuous improvement in the wear resistance, the material could be shot peened intermediately during its operation.

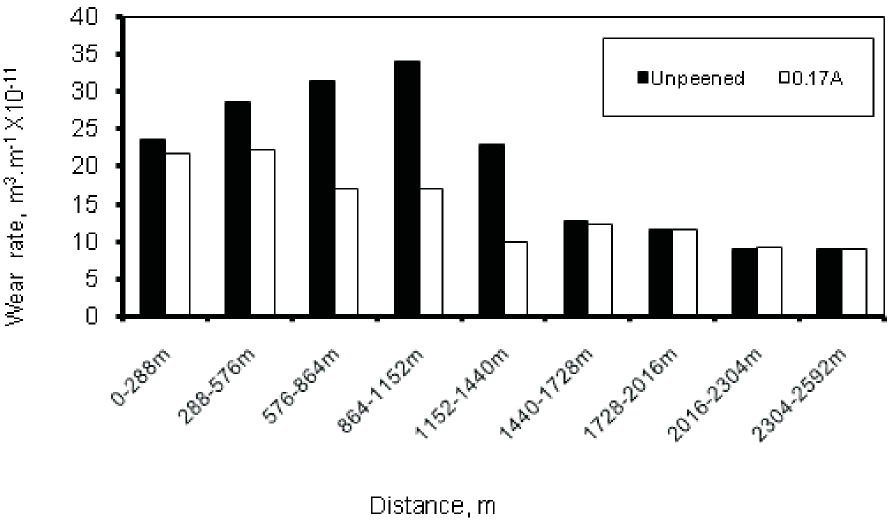


Fig.9: Comparison of wear rate of "as received" SAE-6150 steel peened and un-peened condition (at 200N load) at different intervals

CONCLUSIONS

i. Wear rate decreased with sliding distance irrespective of peening intensities and applied loads. Wear rate increased monotonically with increase in applied load, irrespective of peening intensity.

ii. Shot peening was found to be a suitable surface treatment technology to improve abrasive wear resistance to a great extent.

iii. Peening up to 0.17A (in this case) was beneficial. Over peening had adverse effect on abrasive wear.

iv. Fast wearing components of agricultural implements would require to be shot peened after about 1700 m of travel, as soon as the effected depth from surface gets worn out.

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