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Effect of Heat-Treatment and Shot Peening on Low Stress Abrasion Wear Behaviour of Medium Carbon Steel

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ABSTRACT

The soil working components of agricultural machinery faces serious problem of abrasive wear. The study was conducted to investigate synergic effect of heat-treatment and shot-peening on medium carbon steel with small percentage of Boron (50B50 steel). Three heat treatment cycles (annealing, inter critical annealing, quenching and tempering) were done to obtain different material property combinations. Shot peening was done at different intensities (0.17A to 0.47A) on heat-treated specimens. Low stress abrasion wear behaviour of these steel specimens was investigated by rubber wheel dry sand abrasion tester confirming to ASTM G-65 standards. The results indicated that shot peening operation decreased the wear rate of soft as well as hard surfaces and improved the wear resistance when the peening intensity was restricted to a critical value of 0.37A.

Abrasive wear of agricultural machine components is a major issue responsible for higher energy consumption and lower operational efficiency. Most components of agricultural machines have been subjected to dynamic loads, abrasive wear and chemical action of the external environment during operation (Severnev, 1984). The actual area of contact between two solid surfaces compared with the apparent area of contact has been invariably very small, limited to points of contact of the surface asperities. The loads applied to these implements get transferred through these points of contacts and thus, the localized force can be very large. Selection of proper materials and their appropriate treatment can provide solution to these problems of material failure to a significant extent. The selection of a material and treatment depends upon the various properties desired for specific application. These include chemical composition, mechanical as well as tribological properties and working environmental conditions such as pressure, relative speeds of the components etc.

Surface properties such as tribological (wear, friction), mechanical (fatigue, creep, rupture), thermo-mechanical (oxidation), electromechanical (aqueous hot corrosion), optical, electrical, magnetic etc can be improved by surface engineering techniques. Wear is a surface phenomena, and combination of three primary type wear such as abrasive wear, adhesive wear, erosive wear as well as some secondary wear like surface fatigue, fretting and cavitations erosion. Frequently more than one mechanism operates simultaneously, and it is difficult to separate the individual effects (Riney, 1997). Shot peening is a well known surface treatment to prevent crack initiation and its propagation in the components (Fridrici *et al.*, 2001). It has been one of the unique techniques used for surface treatment of the mechanical components like automobile leaf springs, aero engine blades, gears, bearings and other structural components (Sharma et at., 1983). It is also used for treatment of soil engaging agricultural components for improving their performance. Shot peening has beneficial effect in fretting, micro fatigue, resistance to crack initiation, crack propagation etc that are having similar mechanism. The plastic deformation induced due to shot peening is beneficial for both the hard as well as soft materials. Boron steels and cromium steel both exhibited better sliding and abrasion wear resistance properties than the high carbon steel (Bhagat 2004). The effect of shot peening on abrasive wear of Boron steel was thus studied.

Optimum shot peening has been found to improve the service life of metal part of agricultural machines. Rautary reported that surface properties of 0.18% Carbon steel shot peened after caburising, hardening and tempering were found to be comparable to that of bulk material properties of 0.78% carbon steel, giving better cost effectiveness.

MATERIALS AND METHODS

Material and Heat Treatment

The chemical composition of the steel used for the investigation (tested at National Metal Laboratory,

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Mumbai) is given in Table 1, and conformed to 50 B50 steel. In order to obtain different mechanical, microstructural and tribological properties, the steel specimens (80 mm wide, 8 mm thick) were heat treated at three different schedules as given in Table 2. The heat-treated as well as untreated samples were used for the study.

Hardness Testing and Metallography

The hardness of heat-treated as well as untreated metallographically polished samples were tested on Vicker's hardness (H_v) tester. The indentations were made randomly on the specimen surfaces at a distance more than twice of the diagonal length of previous indentation. The microstructure of untreated specimens as well as heat-treated specimens at various cycles were examined by a metallurgical microscope after being metallographically polished and etched with 2% of natal reagent.

Shot Peening

The specimens were polished up to 400 grade emery paper, prior to shotpeening. The peening intensities were calibrated using standard ALMEN 'A' strip. The strips were shot peened using selected parameters like flow rate, distance between nozzle and specimen surface, peening pressure and time and subsequently the deflection of the ALMEN strips 'A' were measured with ALMEN gauge. The shot peening intensities varies from 0.17A to 0.47A.

Wear Test

A rubber wheel dry sand abrasion test ring (DUCOM make) was used for low abrasion tests as per ASTM G-65 specifications, Fig 2. The test methodology very well simulates the working condition of soil engaging components of machines (Jha et al., 2003). In the tests, a rubber wheel (177.8mm diameter and 12.7mm width) was rotated against the stationary flat rectangular specimen (76.2mm x 25.4mm and 6mm thick) test surfaces flat within 0.125 mm. Crushed silica sand particles (size 212-300Fm) were fed between wheel and specimen at the rate of 370g/min. The applied load, sliding speed and test length were fixed at 75N, 1.86 m/s and 2154m (143.6m X15 nos.) respectively. The specimen was polished prior to the tests. Subsequently, the tests were conducted on pre-worn surfaces until the specimens in each case obtained steady state wear loss. Weight loss was measured after 143.6 m sliding distance.

RESULTS AND DISCUSSION

Material and Microstructure

Microstructure and hardness variation of medium carbon Boron steel (50 B50) steel before and after various heat-treatment processes is given in Table 3. Abrasive wear behaviour was dependent on the deformation behaviour of the material, which was a strong function of material hardness, ductility and fracture characteristics (Modi *et al.,* 2003). Various heat-treatment processes were done to alter the deformation behaviour of the medium carbon boron steel specimens. The hardness of the specimens strongly depended upon the microstructure or heat-treatment cycle. Maximum hardness (458 VHN) was found in quenched and tempered heat-treatment process (tempered martensite) followed by intercritical annealed specimens (20% ferrite 80 % martensite) 446 VHN, un-treated (near pearlitic structures 85% pearlite and 15% ferrite) 220 VHN and annealed specimens (80% pearlite and 20% ferrite)184 VHN.

Table 1. Chemical composition of the steel used

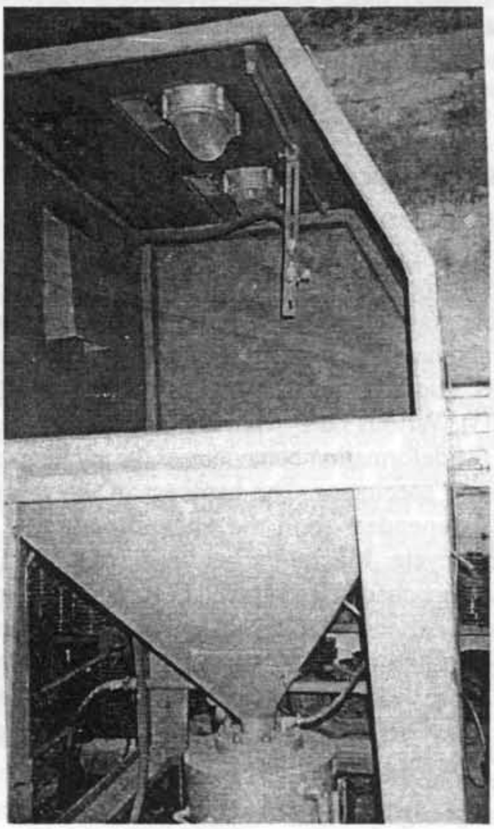
Name of element	C	Si	Mn	Cr	B
Quantity, %	0.50	0.21	0.78	0.95	0.005

Table 2. Heat-treatment schedules for steels used

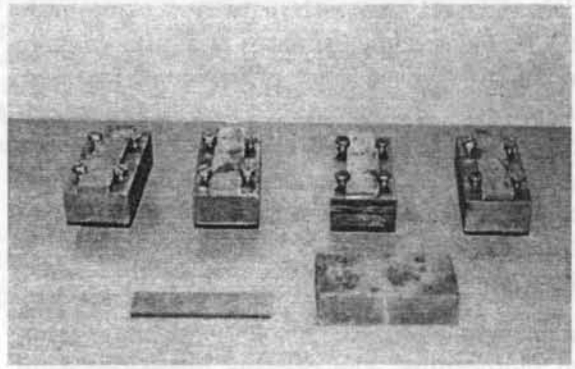
Name of Treatment /Schedule	Austenising temperature, °C	Socking time, min	Quenching media	Tempering temperature, °C	Tempering time, min
Annealing	870	60	Furnace cooling		
Intercritical annealing annealing	870 777	60 30	Water with 8 % NaCl	250 250	120 120
Quenching and tempering	870	60	Water 8%NaCl	250	120

Table 3. Microstructure and hardness of medium carbon boron steel

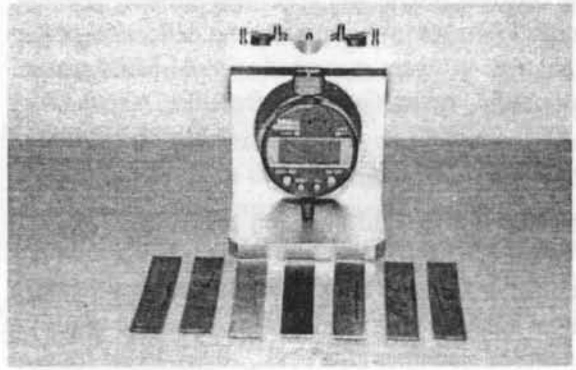
Treatment	Microstructure	Hardness
As received	Near pearlitic structures 85% pearlite and 15% ferrite	220 VHN
Annealing	80% pearlite and 20% ferrite	184 VHN
Inter critical annealing and tempering	20% ferrite 80 % martensite	446 VHN
Quenching and Tempering	Tempered martensite	458 VHN



(a) Almen block for holding Almen strip



(b) Almen gauge with Almen strip 'A'



(c) Shot peening machine

Fig.1: Almen block, Almen gauge with Almen strips 'A', and shot peening machine

Abrasive Wear

In low stress abrasion test, the abrasive (falling sand) removed the material from the specimen surface by cutting or plough action. The wear rate of the specimens at varying heat-treatment cycles and peening intensities could be considered as a function of sliding distance, Fig 3-7. It was noted that the wear rate decreased with sliding distance up to certain sliding distance and then approached to steady state condition. The wear of specimens strongly depended upon the heat treatment process (Fig. 3). The final wear rate in case of intercritical annealing and quenching and tempering was almost same (8.1% more in case of intercritically annealed compared to quenched and tempered specimens) as the hardness of the specimens did not vary much. In case of un-treated and annealed specimens the wear rate was significantly higher (117.8% and 64.4 % respectively) than quenched and tempered steel specimens.

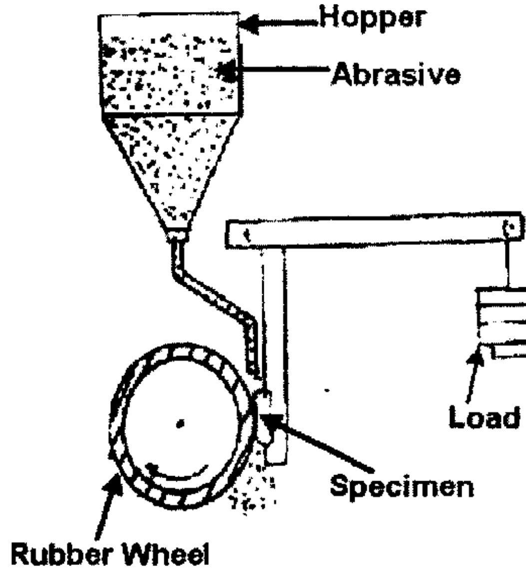


Fig. 2: Schematic representation of the rubber wheel / dry sand abrasion test apparatus in conformity ASTM G65

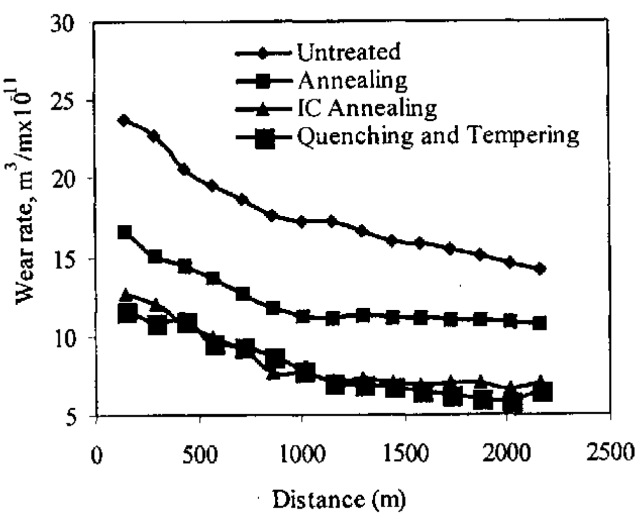


Fig.3: Wear rate as a function sliding distance (for heat-treated specimens)

The wear is a surface phenomena and shot peening is a very effective operation for increasing the surface hardness of the specimens. The effect of shot peening at 0.17A intensity on heat-treated specimens is shown in Fig. 4. As the surface hardness of shot peened specimens increased, the difference of wear rate between soft (un-treated and annealed) specimens and hard (intercriticaly annealed and quenched and tempered) steel specimens narrowed down. Wear rates after mild peening were found to be 72.2%, 48.7% and 17% higher in case of un-treated, annealed and intercritically annealed specimens respectively as compared to the quenched and tempered specimens (117.8% and 64.4 % respectively) in case of without peened specimens.

It was noted that the increase in peening intensity from 0.17A to 0.27A led to only marginal decrease in wear rate in all specimens, Fig. 5. This marginal decrease in wear rate differed for all the specimens and depended upon the changes in micro structural properties of the specimens. When the peening intensity was increased further to 0.37A, the wear rate further decreased in all cases except quenched and tempered specimens, Fig. 6. The wear rate slightly increased in this case, possibly due to increased brittleness of microstructure at the surface of the specimens. When the specimens were peened at higher intensity of 0.47A, the wear rate started increasing drastically irrespective of heat treatment cycle, Fig. 7.

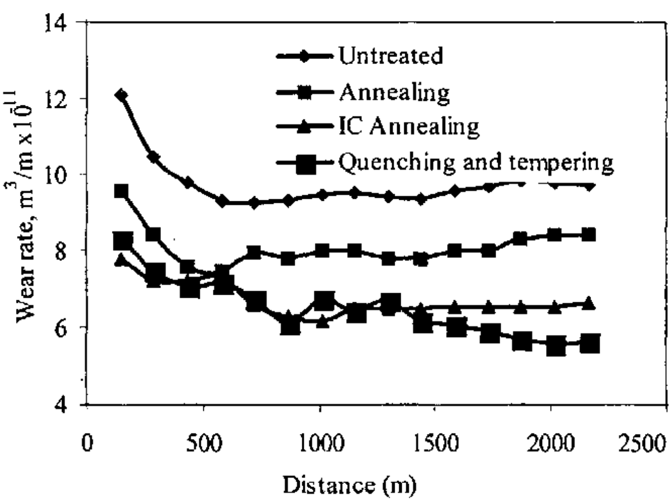


Fig.4: Wear rate as a function sliding distance (for 0.17A peening intensity)

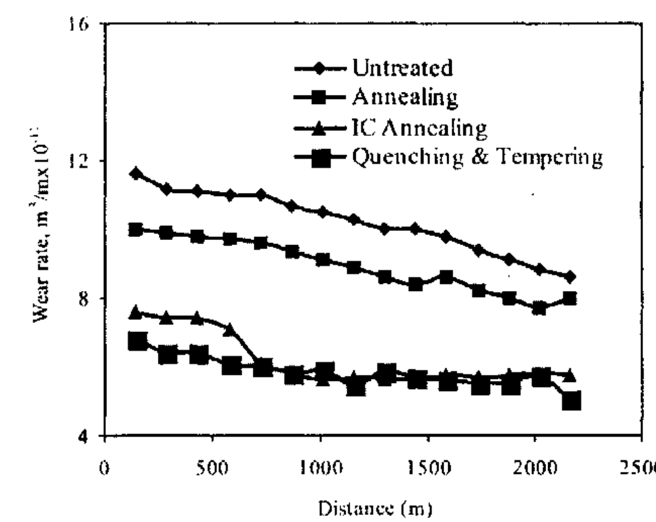


Fig.5: Wear rate as a function sliding distance (for 0.27A peening intensity)

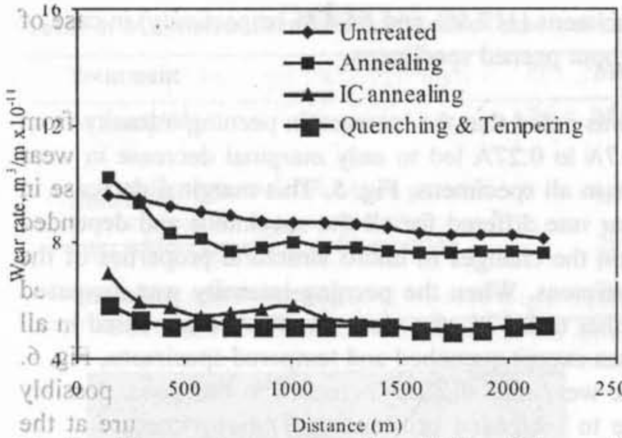


Fig.6: Wear rate as a function sliding distance (for 0.37A peening intensity)

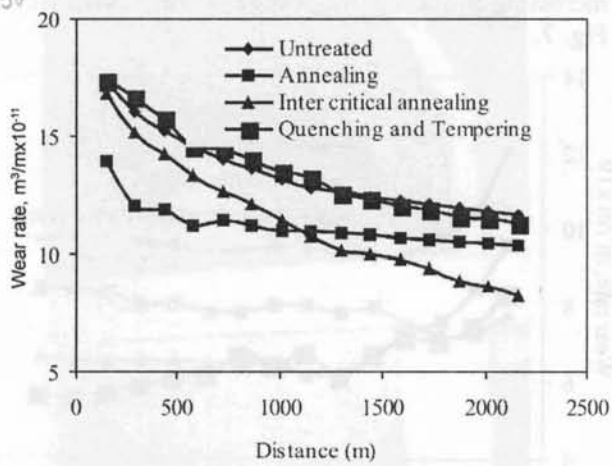


Fig.7: Wear rate as a function sliding distance (for 0.47A peening intensity)

The wear rates of heat-treated shot peened specimens at different intensities were compared Fig.8. It exhibited that with peening intensity of 0.17A, the wear rate decreased by almost 30.3%, 21.6%, 6.5% and 13.3 % in case of un-treated, annealed, intercritically annealed and quenched and tempered specimens. Further increase in peening intensity did not lead to any significant improvement in wear resistance.

After reaching a critical value of peening intensity of 0.37A, the wear rate increased drastically (44.2%, 37%, 63% and 118%) in case of un-treated, annealed, intercrtically annealed and quenched and tempered specimens of medium carbon boron steel. This may be because of greater possibility of surface and sub surface cracking due to higher peening intensity, Fig. 9. The harder material showed more severe effect in this case.

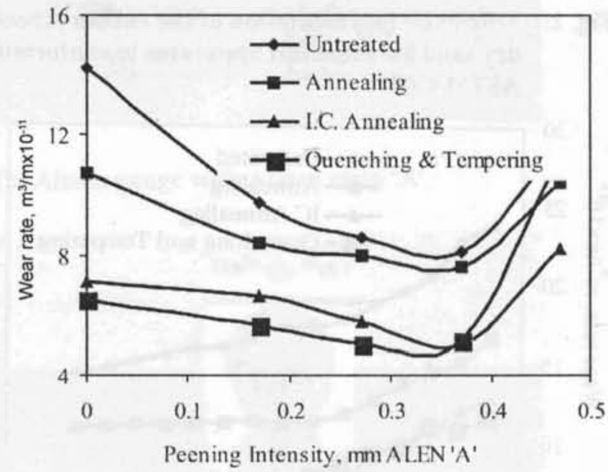
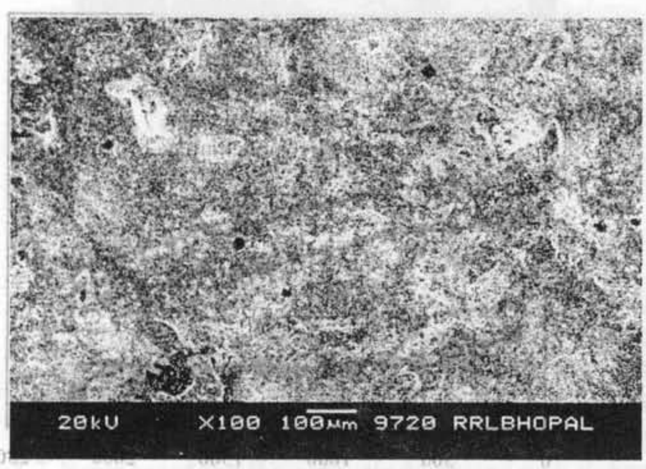


Fig. 8: Variation of wear rate with peening intensity



Microstructure at 0.17A

Microstructure at 0.47A (Cracks are visible at high peening intensity)

Fig.9: Typical microstructure of un-treated 50B50 steel at lower and higher peening intensity

CONCLUSIONS

i. Heat treatment cycles significantly affected the wear rate of medium carbon boron steel. The wear rates (117.8% and 64.4%) were significantly higher in case of un-treated and annealed specimens where as in case of inter-critical annealing it was 8.1% higher in comparison to quenched and tempered specimens.
ii. Peening operation narrowed down the difference in wear rate of soft and hard surfaces. The wear rates after mild peening (0.17A) were 72.2%, 48.7%, and 17% higher in case of un-treated, annealed and intercritically annealed specimens respectively as compared to quenched and tempered specimens.
iii. Mild shot peening intensity (0.17A) decreased the wear rates significantly to 30.3%, 21.6%, 6.5% and 13.3 % in case of un-treated, annealed, intercritically annealed and quenched and tempered specimens. Further increase in peening intensity did not lead to any significant improvement in the wear resistance.
iv. After reaching a critical value of peening intensity, the wear rate increased drastically to 44.2%, 37%, 63% and 118% respectively in case of un-treated, annealed, intercrtically annealed and quenched and tempered specimens of medium carbon boron steel.

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