International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878 (UGC Approved, Sr. No. 48096)
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791

Effect of Shot Size and Peening Pressure on the Low Stress Abrasive Wear Behavior of Inter Critically Annealed Medium Carbon Steel

S. L. Ahirwar[1], D. P. Mondal[2, 3], Mukesh Pandey[1], Shyam Birla[2, 3]

[1]University Institute of Technology, RGPV, Bhopal 462036, India
[2]CSIR-Advanced Materials and Processes Research Institute, Bhopal 462026, India.
[3]Academy of Scientific and Innovative Research (AcSIR), India

Corresponding Author: S. L. Ahirwar, Tel.: 07552472360
University Institute of Technology, RGPV, Bhopal 462036, India
E-mail address: slahirwar.75[at]gmail.com

Abstract: ***The effect of shot size and peening pressure on abrasive wear of medium carbon steel after intercritical annealing has been studied. The peening pressure was varied between 3-5 bar and shot size in the range 0.6-1 mm. The steel samples were polished and then shot peened. The peening intensity was kept constant to 0.27A using varying peening parameters (shot size: between 0.6 to 1.0 mm and peening pressure: between 3 to 5 bar). The low stress abrasive wear test was conducted using dry abrasion test rig TR-38 at an applied load of 50 N. The wear tests were conducted up to 3000 m sliding distance and the wear rate was measured at every interval of 300 m. It was noted in general, that the wear rate decreases with increase in sliding distance. The minimum wear rate is observed at 0.8 mm shot size and 4 bar peening pressure. Further, decrease or increase in peening pressure or shot size leads to higher wear rate. This has been understood from the surface and the subsurface microstructures.***

Keywords: Shot Peening intensity; peening parameters; abrasion; wear rate; sliding distance; microstructure

1. Introduction

Steel is a widely used material for most of the engineering applications not only because of its availability in market but also because of its attaining a wide range of properties, such as hardness, strength, toughness, wear resistance etc., which is not found in any other family of materials [**1-2**]. Properties of dual phase steels, such as ferrite–martensite, suit the requirement of agricultural implements as it possess good combination of ductility, strength, toughness and better deformability than other high strength steels **[3-5]**. Based on survey of manufacturers of fast wearing components of agricultural implements, it is revealed that majority of manufacturers were using medium carbon steel (55%) followed by high carbon steel (27%), mild steel (12%) and high carbon tool steel (6%) **[6-8]**. Several researchers **[9-12]** have reported that the wear rate of soil moving, cutting and threshing equipment is very high. This is primarily due to wear, caused by abrasion, due to material surface and soil plant interaction.

Wear has been defined as the material removal from solid surfaces, which may cause failure of components. Wear mechanism and wear rate depend extensively on chemical composition, microstructure, surface properties of materials and experimental parameters like load, sliding distance, abrasive particle size and shape etc. It is reported that 80–90% of wear problem in agriculture sectors are due to abrasion **[13-16]**. As wear rate is primarily governed by hardness and strength, it is expected that quenched and tempered steel should give highest wear resistance in soil engaging components **[17, 18]**. The wear of material is also related to surface hardness and subsurface cracking. If the extent of cracks increases, the wear resistance will decrease. But the surface cracking can be reduced through generation of compressive residual stresses using shot peening **[19-22].** Shot peening also work hardened and modified microstructures of the subsurface of the peened specimen. Thus, shot peening should improve the wear resistance of steel, vary limited attempts have been made to examine the effect of shot peening on the low stress abrasive wear behavior of medium carbon agricultural grade steel **[23-25].** The martensitic steel suffers from low ductility and fracture toughness. However, ferrite-martensitic structure exhibits reasonably good strength as well as toughness. Thus, it is expected that the wear resistance of dual phase steel may be quite good. However, the peening parameters were not optimized for getting optimum wear resistance in peened steel. The present paper deals with optimization of peening pressure and shot size to get maximum wear resistance in Inter Critically Annealed steel. The present paper also compares the wear resistance of dual phase (ICA) steel with that of tempered martensitic steel.

2. Experimental Procedure

2.1 Material and heat treatment

Specimens for micro structural, mechanical and wear testing were made from medium carbon steel, which contain 0.51 wt% C, 1.00 wt% Cr, 0.61 wt% mn, 0.027 wt% P, 0.025 wt% S, 0.14 wt% Si, 0.17 wt V, and rest Fe. The steel was inter critically annealed (ICA). This heat-treatment schedule involves soaking the samples for 60 minutes at 875^0C.Then the samples are allowed for soaking time of 30 minutes at 780^0C and after that samples are water quenched. Finally, the samples were kept at 250^0C for two hours and allowed for air cooling. The hardness of these steels was measured using Vickers hardness tester at an applied load of 50 N. The tensile tests were conducted using Instron universal test machine (Model: 8801).The hardness and tensile properties of quenched and tempered steel are 293 HV and 1730 N/mm^2 respectively.

2.2 Shot peeing

The shot peening is carried out using Mec shot, Jodhpur make machine at varying shot size and peening pressure maintaining constant peening intensity of 0.27 A. the strips were shot peened, using selected parameters like pressure (bar) and diameter of steel shots of (45 HRC) for 20-120 s for obtaining fixed peening intensity (0.27A).

2.3 Micro-hardness measurement

The micro-hardness values from the surface towards the centre of the specimens are measured. The micro-hardness values are taken at an interval of 20 µm. In all the samples micro-hardness values are taken using applied load of 10 gmf. Therefore, in case of ferrite-martensitic steel micro-hardness values are taken in martensitic phase as these are the major phase constituent in these materials. The distributions of micro-hardness from the surface towards centers were examined in order to understand the stress distribution on the surface of the specimen.

2.4 Low stress abrasion wear tests

Three body abrasion tests were conducted on as pinned and unpinned samples under differently heat treated conditions. The tests were conducted following ASTM standard tests in a Test rig (Ducom Bangalore, India made). The schematic view of the test procedure is shown in Figure 1(a). The samples of dimensions 75mmx25mmx7mm were used. The sample is hold rigidly against the rubber wheel. The sand particles are feed between sample and rubber wheel. The average size of sand particles is 258.90 µm. The size distribution of these sand particles is shown in Figure 1(b).

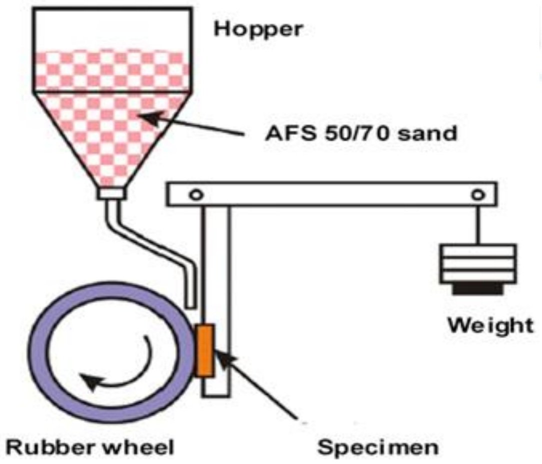


Figure 1(a) Schematic view of low stress

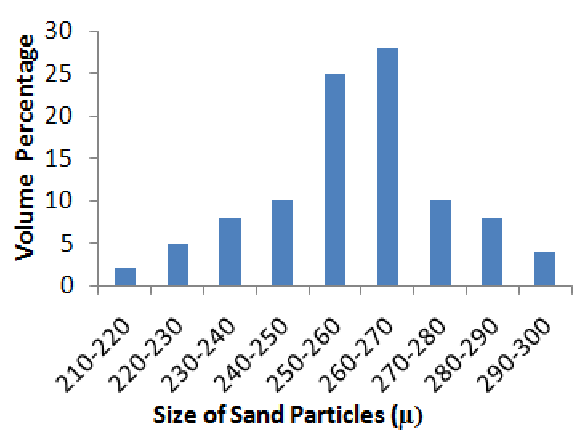


Figure 1(b) Size distribution of sand particles abrasion wear test

The wheel was rotated at a fixed speed of 1.86 m/s and moved up to a distance of 2.6 km and all these tests were conducted at a constant load of 50 N. The wear rate was measured from weight loss measurement using following relation:

$$W_R = \frac{W_i - W_f}{(\rho * D)} \quad \textbf{(1)}$$

Where, W_i is weight of specimen prior to the test, W_f is the final weight of specimen after the wear test, $(W_i - W_f)$ is the weight loss, ρ is density of test specimen and D is siding distance.

3. Result and Discussion

3.1 Material Characteristics

The microstructure of intercritically annealed steel is shown in figure 2. The microstructure indicates presence of ferrite grains and colonies of tempered martensite (Figure 2(a). In this steel, the ferrite contains is noted to be lower than in annealed steel. This is because the steel is quenched from the intercritical region and at this temperature range (780 °C) the ferrite content is lower. Higher magnification microstructure indicates clearly the ferrite grains and the tempered martensite regions (Figure 2(b)). The hardness and tensile properties of the steel are 293Hv and 1730 N/mm^2 respectively. The microstructure of shot peened specimen showed that the dents made through shot peening are uniformly distributed on specimen surface as shown in Figure 2(c). The higher magnification micrograph showed that fins within the dents are formed which get fractured (arrow marked) due to repeated peening action (Figure 2(d)). At higher peening pressure and coarser shot size, micro cracks are generated as shown in Figure 2(e).

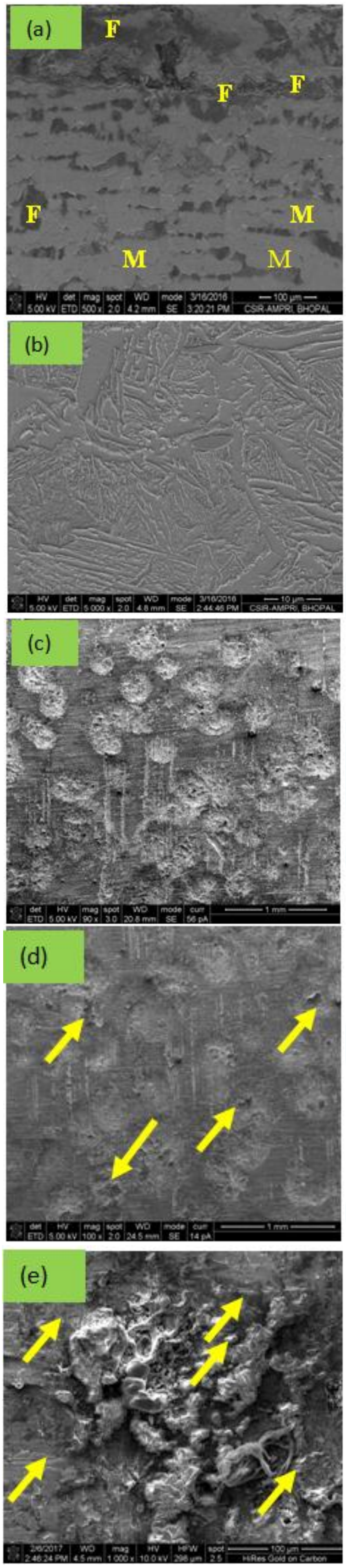


Figure 2 Microstructure of inter critically annealed steel (a) lower magnification and (b) higher magnification (c) shot peened specimen at lower magnification (d) shot peened specimen at higher magnification (e) at higher peening pressure and coarser shot size

3.2 Wear behavior of intercritically annealed steel

3.2.1 Effect of sliding distance

The wear rate of ICA samples as a function of sliding distance for the specimen which peened using different shot sizes under peening pressure of 4 bar, are shown in Figure 4 (a).

It is evident from this figure that the wear rate initially decreases with sliding distance and gradually reaches to a stable stage irrespective of shot sizes. It is further noted that at the very initial stage, the rate of reduction is much faster, which reduces also with sliding distance. This may be due to easy removal of lips generated around the shots and also a few micro cracks in the samples. The surface become smoother and the subsurface work hardening took place due surface deformation during wear.

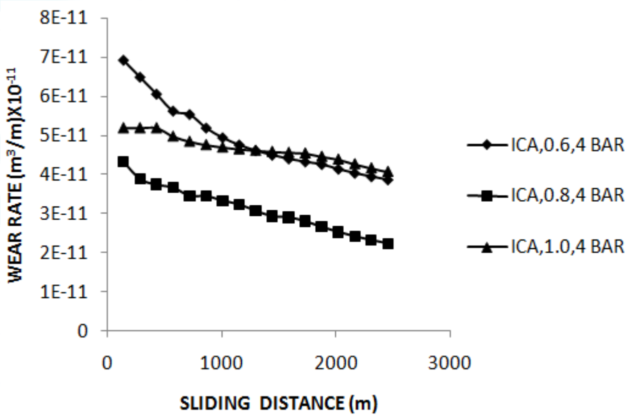


Figure 4(a) Comparision of wear rate with sliding distance for the specimen which peened using different shot sizes under peening pressure of 4 bar

3.2.2 Effect of shot size and peening pressure

The wear rate as a function of shot size for the materials tested at different shot pressures are shown in figure 4(b).It is evident from this figure that the wear rate initially reduced with size significantly and reaches to the minimum at 0.8 mm shot size and it increases again substantially with increase in shot size from 0.8 mm to 1.0 mm. This type of trend in variation of wear rate with shot size is observed at all peening pressures.

It is also noted that at fixed shot size, the minimum wear rate is noted for the sample when peened at 4 bar and the maximum wear rate is noted for the one when peened at 5 bar pressure.

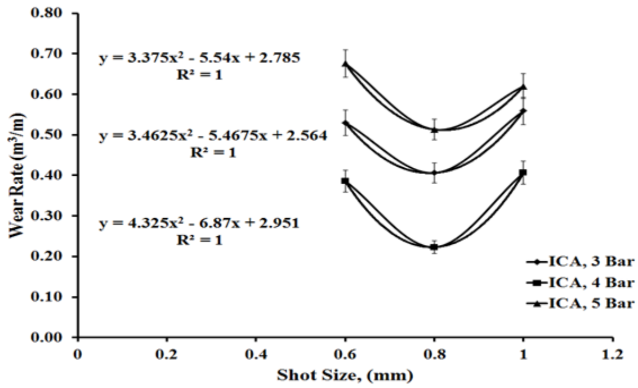
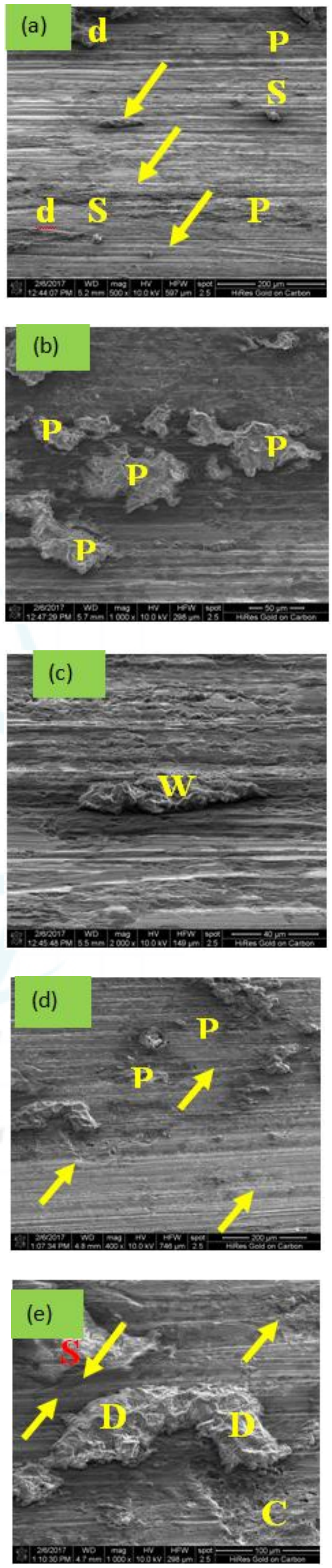


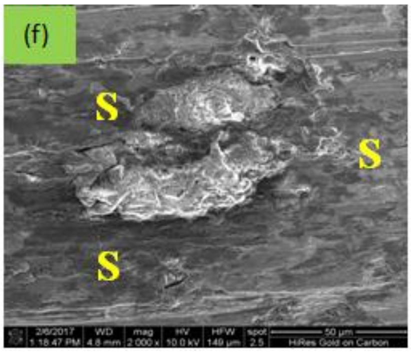
Figure 4(b) Effect of shot size on wear rate of ICA steel at different pressures applied

3.3 Wear surface and Subsurface

3.3.1 Wear surface

The wear surface of ICA steel peened at 4 bar peening pressure and shot size of 0.6 mm is shown in Figure 5(a). It is evident from the figure that the wear grooves are mostly continuous. Somewhere, the track direction changes (marked ‘arrow‘). In addition pitting (marked ’P’) as well as entrapment of sand particles (marked ‘S’) worn out steel flacks (marked‘d’) are observed. Sand particles roll over the steel surface. Because of peening these particles get accommodate in the dense and in due course get stick to the rubber wheel cause continuous wear through cutting and plaguing. Pitting is due to rolling of sand particles. These pits (marked ’P’) are clearer at higher magnification in Figure 5(b). Damage of wear surface and entrapment of wear debris (marked ‘w’) on the surface is clearer at higher magnification which is shown in Figure 5(c). when the peening pressure increases to 5 bar and shot size 0.6mm, the wear grooves again noted to be continuous along with pits (marked ‘arrow’) (Figure 5(d)). At higher magnification the entrapment of sand particles (marked ’S’) and wear debris (marked ‘D’) along with surface cracks (marked ‘arrow’) and decohesive region (marked ‘C’) are observed (Figure 5(e)). Surface micro-cracks and the entrapment of larger particles are due to higher peening pressure. The entrapped sand particles and surface cracking cause severely damage regions on wear surface (Figure 5(f)). At higher magnification smearing of surface(s) is also noted, indicating considerable temperature rise. This may be due to the fact that at higher peening pressure and coarser shot size, surface gets cracked and the deeper lips are formed. These get easily removed and stick to the surface. The wear surface of ICA steel when peened using 4 bar pressure and 1.0 mm shot size, showed (marked ‘C’) severe wear (Figure 5(g)). The surface is associated with micro cracks, deep cracks and damaged region (marked ‘D’).





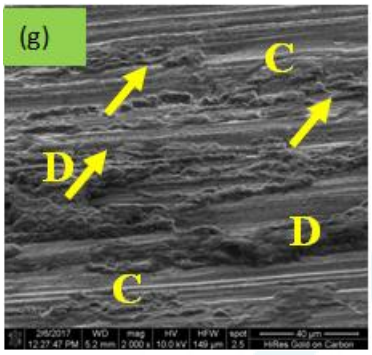
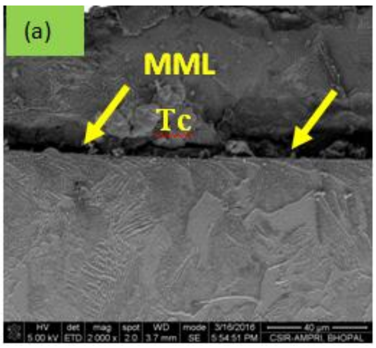


Figure 5: Micrograph of wear surface of ICA steel after wear test (a) peening pressure is 4 bar and shot size is 0.6mm (b) higher magnifications (c) peening pressure is 4 bar and shot size is 0.6 mm(d) higher magnification (e) shot size 1.0mm at peening pressure of 4 bar (f)higher magnifications (g) severe wear at 4 bar pressure and 1.0 mm shot size.

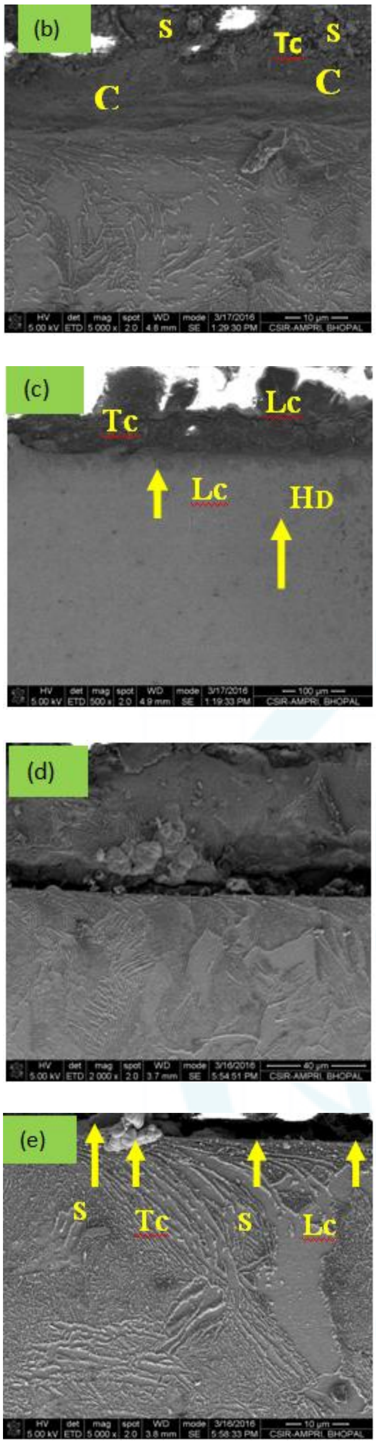
3.3.2 Wear subsurface

The subsurface wear of the ICA steel peened at 4 bar pressure using 1.0 mm shots are shown in Figure 6(a). It reveals that the MML at the top is relatively thin and associated with huge lateral cracks (marked 'arrow') and fine transverse cracks (marked 'Tc'). Even the top of MML is associated with 'hills' and 'valley' type structure and a missed layer of fine crashed sand, steel debris and the micro structurally refined steel structure. A large transverse crack is also noted. The lateral crack below the MML is almost continuous, which was subjected to removal of materials from specimen surface. Below the lateral crack, the surface is subjected to plastically deform and the micro constituents get aligned along the sliding direction. Severe cracking in MML due to the higher shot size which also causes surface cracking during peening. Even though the peening pressure is moderate. The subsurface become more severely damage when the peening pressure is increased to 5 bar, Figure 6(b). It clearly shows the large number of transverse cracks (marked as 'Tc') in addition to continuous subsurface longitudinal cracks (marked 'c') below the MML. A large number of fine sand particles generated due to abrasion (shearing action) of sand get entrapped (marked 'S') in the subsurface which make the surface more unstable as these particles facilitate formation and growth of cracks in the surface and subsurface. It is further noted that the martensite needles align themselves strongly along the sliding direction, indicating large subsurface deformation. Similarly, when the subsurface of wear specimen of ICA steels when peened at 4 bar pressure using 0.6 mm shots are shown in Figure 6(c). The MML is also noted to be very unstable due to formation of more transverse cracks (marked 'Tc') and lateral cracks (marked 'Lc'). Even within MML also lateral cracks are noted unlike in this case. A thin layer below MML is a subjected to deform (marked 'HD'). But the deformed layer is also subjected transverse and longitudinal cracking, Figure 6(d). These are due to soft surfaces and entrapment of fine particles on the softer specimen surface. This is again due to less surface hardening, lesser compressive residual stress under finer shot size and less pressure used during peening. The entrap particles over the worm surface causes more wear of specimen. When the shot peening pressure increased to 5 bar and the specimen is subjected to wear, the subsurface shows a very thin deformed layer below MML and highly damaged MML containing large size lateral (marked 'Lc') and transverse cracking (marked 'Tc'), Figure 6(e). A large number of fine sand particles are also entrapped when the subsurface and the longitudinal cracks (marked 'Lc') are quite wider. The MML is very unstable. This indicates relatively severe wear.

The subsurface of the peened and wear out specimen, which peened using 0.8 mm shots and 4 bar peening pressure, exhibits more stable MML, Figure 6(f). The relatively more stable MML consists of finer sand particles (marked'S') and finely surface materials (marked'd') of specimen. The crack between MML and deformed layer is less. Hence, the subsurface deformation is quite significant leading to alignment of martensite phase or other phase constituent in sliding direction, Figure 6(g). When the sample peened at 0.8 mm shot size and 3 bar peening pressure, the MML shows finer subsurface cracks (marked 'c') and also transverse cracks at the MML, Figure 6(h). It exhibits that the subsurface is relatively more unstable as compared to that in Figure 6(i) (0.8 mm shot size, 5 bar peening pressure). These microstructures, as a whole demonstrate that the subsurface is the most stable for the case when specimen are peened at 4 bar peening pressure and 0.8 mm shot size. In case of 0.8 mm shot size or 4 bar peening pressure, the subsurface layer is relatively stable than other condition, but more unstable than the condition of 0.8 mm shot size and 5 bar peening pressure. The microhardness measurements were also taken at the subsurface of all wear out samples as a function of shot size and peening pressure upto a depth of 100µm below are shown in Table 5. It is noted that the specimens, which were subjected to peening at 4 bar peening pressure and 0.8 mm shot size have the maximum microhardness. Similarly, the specimen peened at 0.8 mm shot size or 4 bar peening pressure exhibits more microhardness.



ISSN (Online): 2347-3878 (UGC Approved, Sr. No. 48096)
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791



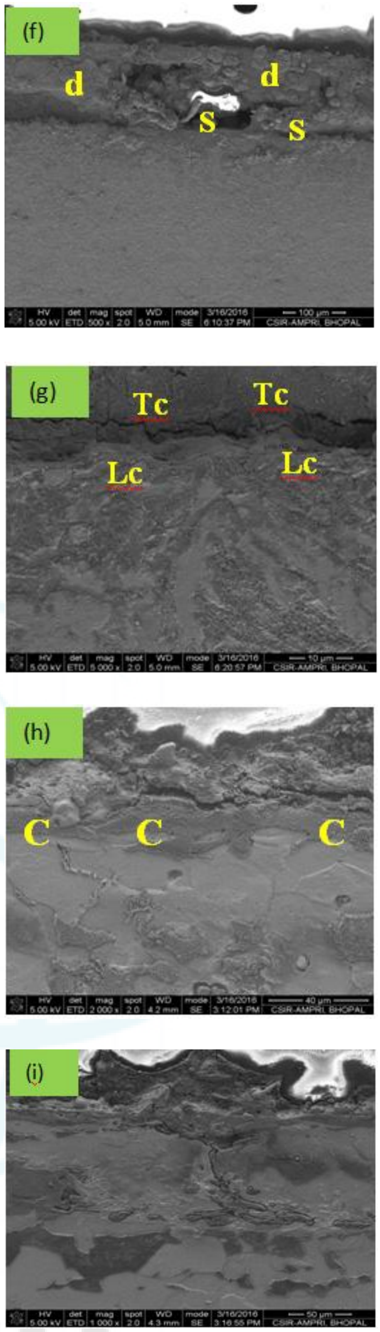


Figure 6: The subsurface of peened sample of ICA s after wear test (a) peened with 0.6mm shots at 3 bar pressure (b) higher magnification (c) peening pressure 4 bar with 0.6mm shots (d) peening pressure 3 bar and shot size 1.0 mm (e) higher magnification (f) MML is full of cracks (g) peening pressure 4 bar at 1.0 mm shot size (h) peening pressure is 4 bar (i) 5 bar pressure at 1.0 mm shot size.

Table 5: Micro hardness values of ICA steel at the subsurface

Shot Size (mm)	Peening Pressure (Bar)	Depth below wear surface					
		25µm	50µm	75µm	100µm	125µm	150µm
0.6	3	379±18.95	360±18.00	340±17.00	310±15.50	300±15.00	295±14.75
	4	400±20.00	350±17.50	345±17.25	330±16.50	301±15.05	298±14.90
	5	390±19.50	365±18.25	341±17.05	310±15.50	302±15.10	293±14.65
0.8	3	393±19.65	369±18.45	351±17.55	320±16.00	305±15.25	300±15.00
	4	450±22.50	405±20.25	378±18.90	360±18.00	305±15.25	300±15.00
	5	410±20.50	380±19.00	368±18.40	360±18.00	300±15.00	300±15.00
1.0	3	385±19.25	360±18.00	345±17.25	305±15.25	299±14.95	299±14.95
	4	420±21.00	380±19.00	348±17.40	309±15.45	309±15.45	298±14.90
	5	395±19.75	355±17.75	340±17.00	302±15.10	295±14.75	295±14.75

4. Conclusions

1. The wear rate of ICA steel decreases with increase in sliding distance. This is due to reduction in lips, increasing surface smoothness and work hardening with sliding distance.
2. The wear rate is a strong function of peening pressure and shot size. The minimum wear rate is at 0.8 mm shot size and 4 bar peening pressure, irrespective of all shot size and peening pressures.
3. This is due to changes in surface and subsurface characteristics. At higher peening pressure and coarser shot size, there is a tendency of micro crack formation and creation of longer lips.
4. The subsurface micro hardness also changes during wear. The maximum work hardening during wear is noted under shot size of 0.8 mm and peening pressure of 4 bar.
5. The surface work hardening is measured through micro hardness values.
6. The wear surface and subsurface also showed surface micro cracks, relatively unstable MML and severe wear under coarser shots and higher peening pressure.

References

[1] Klocke, F., & Krieg, T. Coated tools for metal cutting–features and applications. CIRP Annals-Manufacturing Technology, 48(2), 1999, 515-525.
[2] Rosso, M. Ceramic and metal matrix composites: Routes and properties. Journal of Materials Processing Technology, 175(1), 2006, 364-375.
[3] Grainger, S., Blunt, J. Engineering coatings: design and application. Edition 2, Edited by Stan Grainger and Jane Blunt, Published by Abington publishing, Cambridge, 1998.
[4] Thurston, Richard, C.A. The Notch Toughness of Ultrahigh-Strength Steels in Relation to Design Considerations. DMIC Report, 210, 1964, 105.
[5] Rudnev, Valery, I., et al. Induction Heat Treatment: Basic Principles, Computation, Coil Construction, and Design Considerations. Steel Heat Treatment: Equipment and Process Design, 2006, 277.
[6] Davis, Joseph R., ed. Surface engineering for corrosion and wear resistance. ASM international, 2001.
[7] Saini, S., Ahuja, I. S., Sharma, V. S. Residual stresses, surface roughness, and tool wear in hard turning: a comprehensive review. Materials and Manufacturing Processes, 27(6), 2012, 583-598.
[8] Sharma, P. C. Production Technology (Manufacturing Processes): Manufacturing Processes. S. Chand Publishing, 2007.
[9] Briggs, D. E. Production and harvesting machinery. Barley. Springer Netherlands, 1978. 320-338.
[10] Faivre, Stephen, M., David, W., Larson, and James H. Bassett. Apparatus for measuring agricultural yield. U.S. Patent No. 5, 282, 389. 1 Feb. 1994
[11] Samuel, David Hillas, and William Kidd John. Harvesting machine. U.S. Patent No. 1, 930, 647. 17 Oct. 1933.
[12] Bachman, T. Improved Cereal Production Technology» FAO Project on Conservation Agriculture in Mongolia. Conservation Agriculture. Springer Netherlands, 2003. 235-242.
[13] Kruth, J. P., Froyen, L., Van Vaerenbergh, J., Mercelis, P., Rombouts, M., & Lauwers, B. Selective laser melting of iron-based powder. Journal of Materials Processing Technology, 149(1), 2004, 616-622.
[14] Withers, P. J., & Bhadeshia, H. K. D. H. Residual stress. Part 1–measurement techniques. Materials science and Technology, 17(4), 2001, 355-365.
[15] Burwell, J. T. Survey of possible wear mechanisms. Wear, 1(2), 1957, 119-141.
[16] Ko, P. L. Metallic wear—a review with special references to vibration-induced wear in power plant components. Tribology International, 20(2), 1987, 66-78.
[17] Bhakat, A. K., Mishra, A. K., Mishra, N. S., & Jha, S. Metallurgical life cycle assessment through prediction of wear for agricultural grade steel. Wear, 257(3), 2004, 338-346.
[18] Barwell, F. T. Theories of wear and their significance for engineering practice. Treatise on Materials Science & Technology, 13, 1979, 1-83.
[19] Jawahir, I. S., et al. Surface integrity in material removal processes: Recent advances. CIRP Annals-Manufacturing Technology, 60(2), 2011, 603-626.
[20] Harwell, F. T. Surface contact in theory and practice. Proceedings of the Institution of Mechanical Engineers, 175(1), 1961, 853-879.
[21] Chong, M. S. K., Y. E. Teo, and S. H. Teoh. Fatigue Failure of Materials for Medical Devices. Degradation of Implant Materials. Springer New York, 2012. 303-328.
[22] Gujba, A. K., & Medraj, M. Laser peening process and its impact on materials properties in comparison with shot peening and ultrasonic impact peening. Materials, 7(12), 2014, 7925-7974.
[23] Montross, C. S., Wei, T., Ye, L., Clark, G., & Mai, Y. W. Laser shock processing and its effects on microstructure and properties of metal alloys: a review. International Journal of Fatigue, 24(10), 2002, 1021-1036.
[24] Tushinsky, Leonid I., et al. Fatigue Failure of the Base Metal-Coating Composition. Coated Metal. Springer Berlin Heidelberg, 2002. 363-395.
[25] Avery, Howard, S. Work Hardening in Relation to. In Materials for the mining industry: symposium: Vail, Colorado, July 30 & 31, 1974, 43.
[26] Hochhalter, J. D., Veilleux, M. G., Bozek, J. E., Glaessgen, E. H., & Ingraffea, A. R. (2008). Multiscale Modeling of Damage Processes in Aluminum Alloys: Grain-Scale Mechanisms