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Friction-wear behavior of shot peened aluminium 7075-T651 alloy

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The present study reports the friction-wear behavior of un-peened and shot peened aluminium 7075-T651 alloy against aluminium 7075-T651 alloy in dry sliding condition. Shot peening was done using CI steel ball (40-45 HRC) with 0.6 mm diameter. Phase Structure, hardness, compressive residual stress, surface morphology and surface features are characterized using X-ray diffractometer (XRD), Vickers hardness tester, noncontact-surface profile meter and scanning electron microscope (SEM). Sliding wear test were conducted against aluminium 7075-T651 alloy in dry sliding condition at room temperature using a pin on disc apparatus. A 25% increase in the hardness was seen for shot peened aluminium 7075-T651 alloy. Shot peened aluminium 7075-T651 alloy has induced maximum compressive residual stress of -188 MPa. No new phases were formed for the shot peened aluminium 7075-T651 alloy, however, the shift in the plane is observed. There was also a drastically increase in surface roughness in spite of the peening process. Adhesive wear was the dominant wear mechanism for the un-peened specimen, whereas, it was reduced for the shot peened surfaces.

Keywords: Aluminium-7075-T651, Shot peening, Friction, Wear

Aluminium 7000 series alloys find uses in the several applications like automotive, aircraft, construction industries and marine due to its better mechanical properties, light weight, good machining characteristics[1]. Despite their use in structural applications, their use in the wear applications is rather limited. Wear is the one important failure in the machine components caused by the interaction of two contacting surfaces. So many research works had concentrated on improving the wear property of the aluminium material. Wear properties could be improved through use of various surface treatments processes such as shot peening[2], laser shock peening[3], ultrasonic shot peening (USSP)[4] and sand blasting[5] etc. Shot peening process is used to induce a compressive residual stress and improve the mechanical properties of the metal surfaces by inducing severe plastic deformation on the surface of the material. Literature reports the severe plastic deformation leading to the formation of nano-crystallization on the surface of the material[6-10]. The surface of the metal is bombarded with high velocity hard balls for creation of dimples are created. These dimples are bounded by the plastic region and the elastic zone. This recovered elastic zone induces large compressive residual stress in the surfaces[11-13]. Cho *et al.*[10] applied shot peening process onto an aluminium alloy and reported increase in hardness. Mitrovic *et al.*[15] reported the domination of abrasive and adhesion wear mechanisms in the surface of shot peened 36NiCrMo16 and 36CrNiMo4 alloys in dry sliding conditions. Increase in wear resistance of aluminium alloy after shot peening process has been reported[15].

No investigation on the wear behavior of shot peened aluminium 7075-T651 alloy is seen. Hence, the present study reports the friction and wear behavior of un-peened and shot peened aluminium 7075-T651 in dry sliding condition.

Experimental Procedure

Materials and shot peening process

Aluminium 7075-T651 alloy is used as a substrate in the shot peening process. The chemical composition and mechanical properties of the aluminium 7075-T651 alloy are shown in Tables 1 and 2. The substrate was purchased from perfect metal works company, India and was cut to the required dimensions using EDM (electrical discharge machine). The shot peening process was done on the aluminium 7075-T651 alloy. CI steel ball (40-45 HRC) with 0.6 mm diameter was used for shot peening. Compressive air was passed through the nozzle for throwing CI steel balls on the surface of the material with 5 bars velocity. The schematic representation of shot peening process is shown in Fig. 1.

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Micro-hardness measurements

The surface hardness of peened and un-peened aluminium 7075-t651 was measured using Wilson Wolpert Vickers's micro hardness tester at a load of 3 N at 10 s dwell time. Five readings were taken randomly on the surface of each sample and average values were calculated. Also hardness was measured across the cross-section up to 500 μm depth in the scale of 100 μm from the surface and its five average readings were calculated and reported.

X- ray diffraction analysis

The structural characterization of peened and un-peened surface was done using an X- ray diffractometer from a diffraction angle 2θ from 10° to 70° at a step size of 0.02. To discuss the microstructure changes, the crystallite size of un-peened and peened aluminium 7075-T651 alloy is calculated using Scherrer equation (Eq. 1).

$$D_P = \frac{0.94\lambda}{\beta \cos\Theta} \quad \ldots (1)$$

Table 1 — Chemical composition of aluminium 7075-T651 alloy

Elements	Composition
Silicon	0.03
Iron	0.14
Copper	1.3
Manganese	0.02
Magnesium	2.3
Titanium	0.05
Zinc	5.6
Chromium	0.9
Others	0.15
Aluminium	90.22

Table 2 — Mechanical properties of aluminium 7075-T651 alloy

Property	Values
Tensile strength, MPa	540
Yield strength (0.2% offset), MPa	499.87
Elongation, %	13
Hardness, HV	172.9
Poisson's ratio	0.33
Shear strength, MPa	330.94
Fatigue strength, MPa	158.58

Residual stress analysis

Compressive residual stress measurement was carried out using X-ray diffraction sin2Ψ method. X-pert Prosystem (Netherlands) was utilized for measuring the X-ray radiations of 4 mm^2 at the diffractive plane of (422) in an operating voltage of 45 kV and current of 40 mA using Cu-Kα radiation with a wavelength of 1.54 Å. The layer of each depth was removed by electrolyte polishing method. It was performed by applying the solution with composition of 87.5% methanol and 12.5% sulfuric acid, which is controlled by 18 V voltage with incessant electro polishing process.

Friction-wear test

Friction and wear were measured using a pin on disc apparatus (DUCOM) in dry sliding condition with a load of 5 N in 300 rpm for 20 min in room temperature. Pin of 6 mm diameter with the height of 6 mm was used as a substrate and a disc of 50 mm diameter with thickness of 10 mm was used as the counter face material. Prior to the measurement, all samples were weighted using electronic balance machine. The actual materials used in the friction and wear measurement are shown in Fig. 2

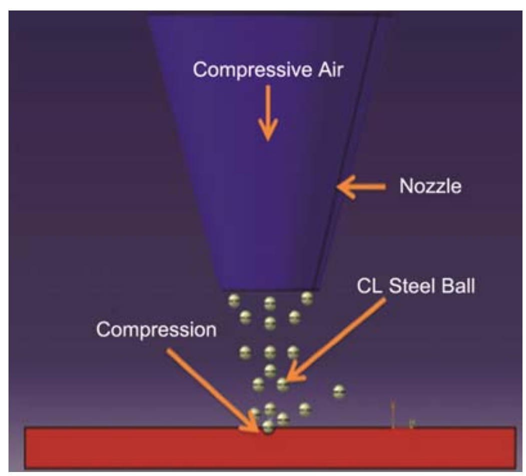

Fig. 1 — Schematic representation of shot peening process

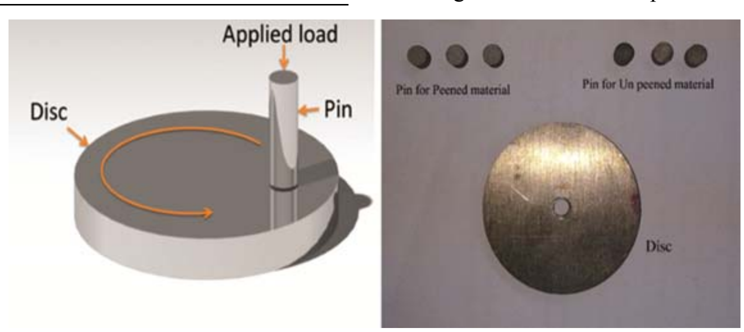

Fig. 2 — Specimens used for friction and wear measurement

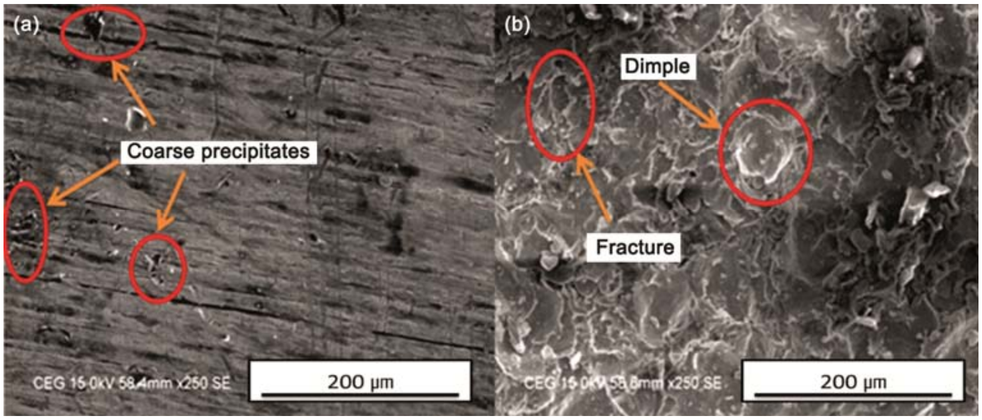

Fig. 3 — SEM image of (a) un-peened and (b) peened surface

Results and Discussion

Surface morphology study

Figure 3 shows the surface morphology of un-peened and shot peened aluminium 7075-T651 measured using scanning electron microscope. The un-peened surface (Fig. 3a) showed a smooth surface with coarser precipitates distributed randomly in the surface. In the case of the peened surface (Fig. 3b), dimples and fractures were presented. The existence of dimples and fractures evidenced that peened surface has undergone a severe plastic deformation during the shot peening process.

Hardness analysis

Figure 4 shows the surface hardness of un-peened and peened aluminium 7075-T651 alloy. It is clearly evident that there is an improvement in the hardness for peened aluminium 7075-T651 alloy after the peening process. Hardness value of peened aluminium 7075-T651 alloy surface is increased to 208.15 HV from 167.1 HV of un-peened aluminium 7075-T651 alloy. The increase in the hardness is due to the severe surface plastic deformation induced on the surface layer by shot peening. The severe plastic deformation increases the dislocation density and induces compressive residual stress, which impedes the dislocation motion of grain boundaries. This is the primary cause for the increase in the hardness of peened aluminium 7075-T651 alloy.

Figure 5 shows the hardness value measured across the cross-section of peened and un-peened aluminium 7075-T651 alloy. Hardness value is decreased considerably to the depth up to 300 μm from the surface. The decrease in the hardness to the depth is due to the low impact of the ball force across the surface. The influence of ball force is higher on the surface layer when compared to the cross-section. This

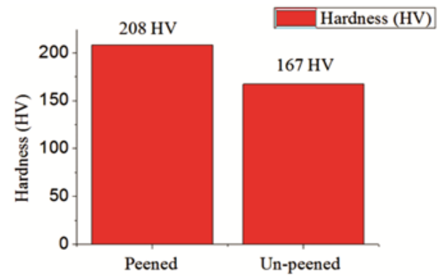

Fig. 4 — Hardness chart measured on the surface

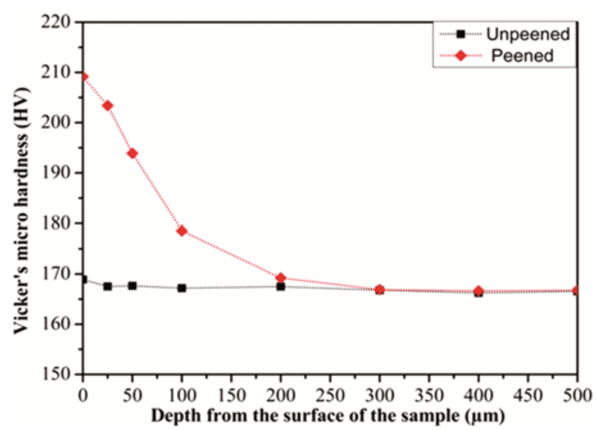

Fig. 5 — Hardness chart measured across the surface

low impact of ball force causes a low strain hardening across the surface, which could be the reason for the decrease in the hardness across the surface.

XRD analysis

The XRD peak of the un-peened and shot peened aluminium 7075-T651 alloy is shown in Fig. 6. Both samples exhibits a plane (111), (200), and (220) respectively, which indicates that aluminium is a face center cubic structure. No additional peak representing the new phases was formed for the short peened aluminium 7075- T651 alloy.

However, there was a small shift in the plane (200), and (220) from higher angle to the lower angle. The shift of diffraction angle from higher to the lower angle indicated the existence of residual stress value[16,17]. This residual stress is the primary reason for the increase in the hardness of short peened aluminium 7075- T651 alloy as discussed earlier.

Table 3 shows the average crystallite size of unpeened and peened aluminium 7075-T651 alloy measures from the XRD data. It is evident that there is a reduction in the crystallite size for peened surface. This indicates the existence of finer microstructure for peened aluminium 7075-T651 alloy surface. Formation of finer microstructure was due to the severe plastic deformation caused during the shot peening process. This severe plastic deformation induces a compressive stress in the surface of peened aluminium 7075-T651 alloy, which is the primary reason for the peak shift for the aluminium 7075-T651 alloy.

Table 3 — The average crystallite size of un-peened and peened aluminium 7075-T651 alloy

2θ	Un-peened (nm)	2θ	Peened (nm)
38.3526	41.27	38.2341	25.37
44.5609	34.97	44.4043	22.89
64.9199	28.32	64.7809	17.86
Average crystallite size	34.85		22.04

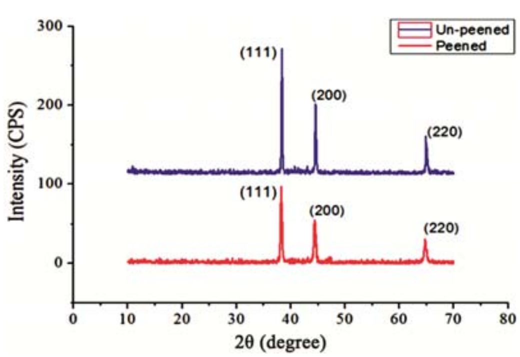

Fig. 6 — XRD of (a) peened and (b) un-peened

Residual stress study

The depth-wise compressive residual stress profile of un-peened and peened surfaces is shown in Fig. 7. Un-peened aluminium 7075-T651 alloy exhibited a compressive residual stress of 50 MPa, which is low when compared to the peened aluminium 7075-T651. There is an increase in the compressive residual stress to 276% for peened aluminium 7075-T651 and varies from 25 to 200 µm. Maximum residual stress was achieved on the surface of peened aluminium 7075-T651 alloy due to the high strain rate on the surface caused by the high impact ball force. The compressive residual stresses are decreased towards several hundred micrometer depth from the surface layer. The decrease in the residual stress across the depth of peened surface indicates that the impact of ball force is decreased across the surface.

Surface roughness

The roughness parameters (R_a, R_z, S_a, S_v, S_p) and 3D topography of the un-peened and shot peened surfaces are given in Figs 8 and 9. R_a is the arithmetic mean

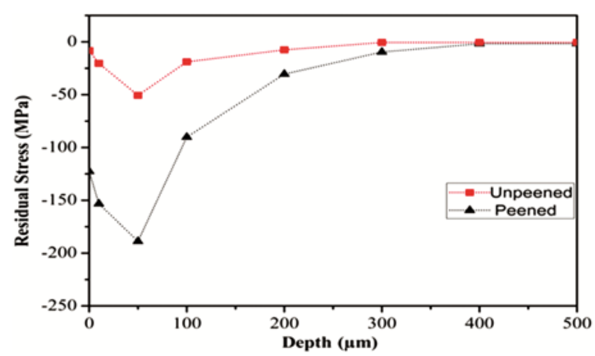

Fig. 7 — Depth-wise compressive residual stresses profile for the un-peened and peened aluminium 7075-T651 alloy

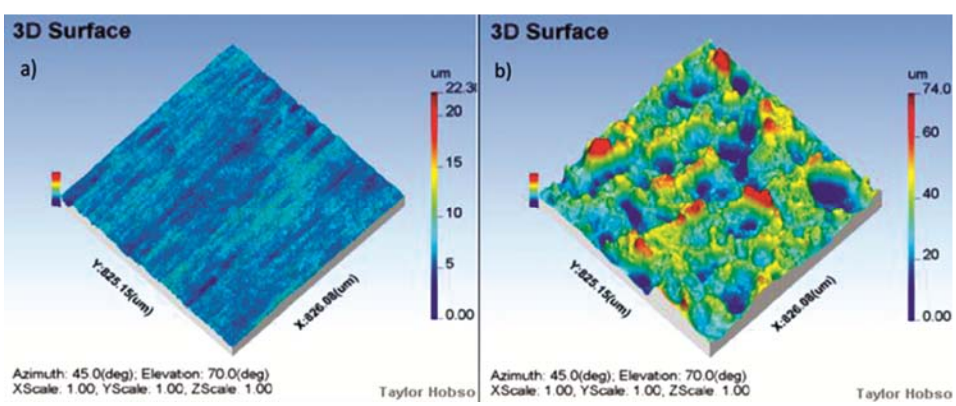

Fig. 8 — 3D Topographies of (a) un-peened and (b) Peened aluminium 7075-T651 alloy

deviation in the roughness profile, R_z represents the maximum height of roughness profile, S_a corresponds to the arithmetic mean height, S_v is the maximum pit height and S_p belongs to maximum peak height with respect to ISO 4287 and ISO 25178 standard.

There was a significant increase in the Ra, Rz, Sa, Sv and Sp parameters with peening process compared to the un-peened specimen. The increased roughness parameters are due to the high velocity of CI steel ball stroking the surface (Fig. 9). The high ball velocity increases the surface roughness as well as the severe plastic deformation on the surface. The uneven surface is clearly pictured in the surface texture of peened surface (Fig. 8b). The orange color marks in the surface texture clearly indicate the distribution of dimples.

Friction-wear behavior

Figure 10 shows the variations in the coefficient of friction of un-peened and shot peened aluminium 7075-T651 alloy with respect to sliding time. From the results obtained, it is clear that the average coefficient of friction is increased for shot peened specimen in contrast to the un-peened specimen. Coefficient of friction increases initially with high fluctuations for all specimens owing to the small contact per area which exerts greater force. The coefficient of friction stabilized with low fluctuations after a sliding time of 600 s for both peened and un-peened surfaces. Generally coefficient of friction is associated with the mechanical properties like shear strength and hardness. Hence, coefficient of friction generally decreases with increase in the hardness of the material. However, peened surface showed a higher coefficient of friction, though the hardness was high. This higher friction coefficient was due to the high surface roughness created during the shot peening process.

Mass loss of un-peened and peened aluminium 7075-T651 alloy is shown in Fig.11b. Peened surface showed a low mass loss when compared to un-peened surface. The low mass loss indicates the improvement in the wear resistance after the peening process.

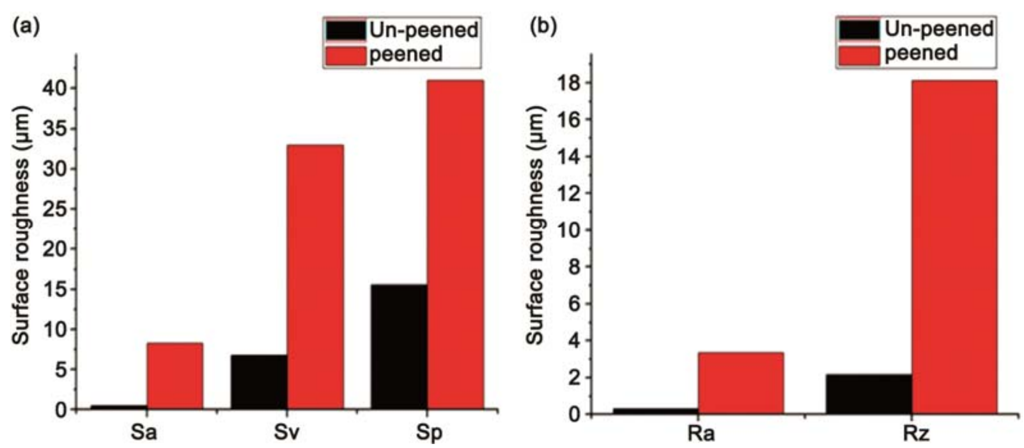

Fig. 9 — 3D Surface parameters of (a) un-peened and (b) peened aluminium 7075-T651 alloy

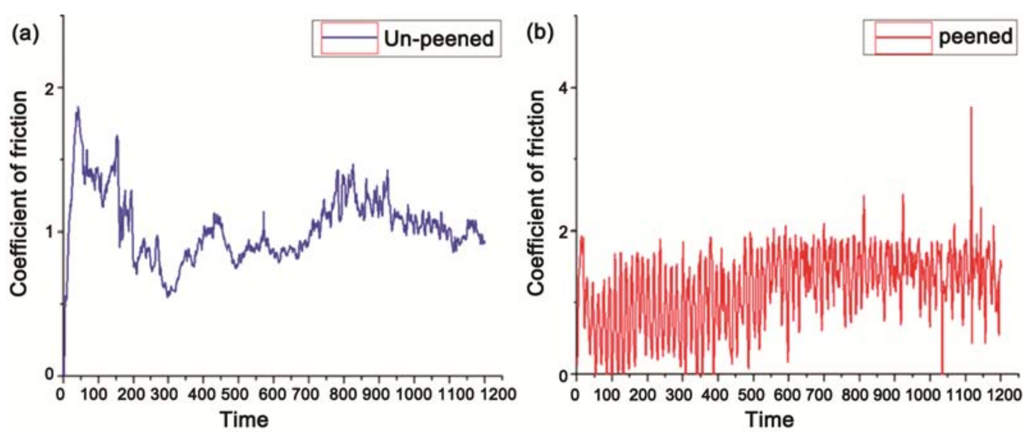

Fig. 10 — Coefficient of friction of (a) un-peened surface and (b) peened surface

In the case of un-peened surfaces, counter face and substrate material were the same. As a result, the local material transfer between the two contacting surfaces was high, leading to the high adhesive wear mechanism. To discuss the wear mechanism, the SEM image of the wear track obtained using scanning electron microscope is shown in Fig.12. From Fig.12a, delamination and oxidation marks are clearly observed in un-peened alloys. The delamination marks indicate that the surface has undergone a severe adhesive wear mechanism during the sliding. There is no delamination and oxidation marks in the wear track of peened aluminium 7075-T651 alloy surface. This indicates the reduction of adhesive wear after the peening process. However, deep grooves and Scratches were observed in the wear track of peened surfaces of aluminium 7075-T651 alloy. The existence of grooves and scratches are due to the three-body abrasion created by the hard debris particles removed during the sliding. The removed wear debris tends to act as abrasive and produces grooves and scratches in the wear track. Also, detachment and fracture were also the prime cause by the hard debris particles removed from the surface of aluminium 7075-T651 alloy.

Furthermore, oxidation can affect the dry sliding wear performance. The oxide layers (Fig. 12c) formed

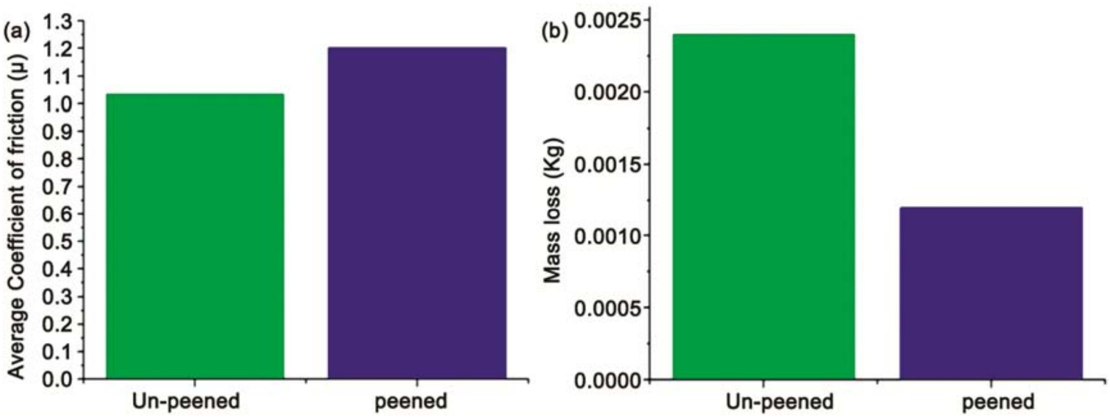

Fig. 11 — Images of (a) average coefficient of friction and (b) mass loss

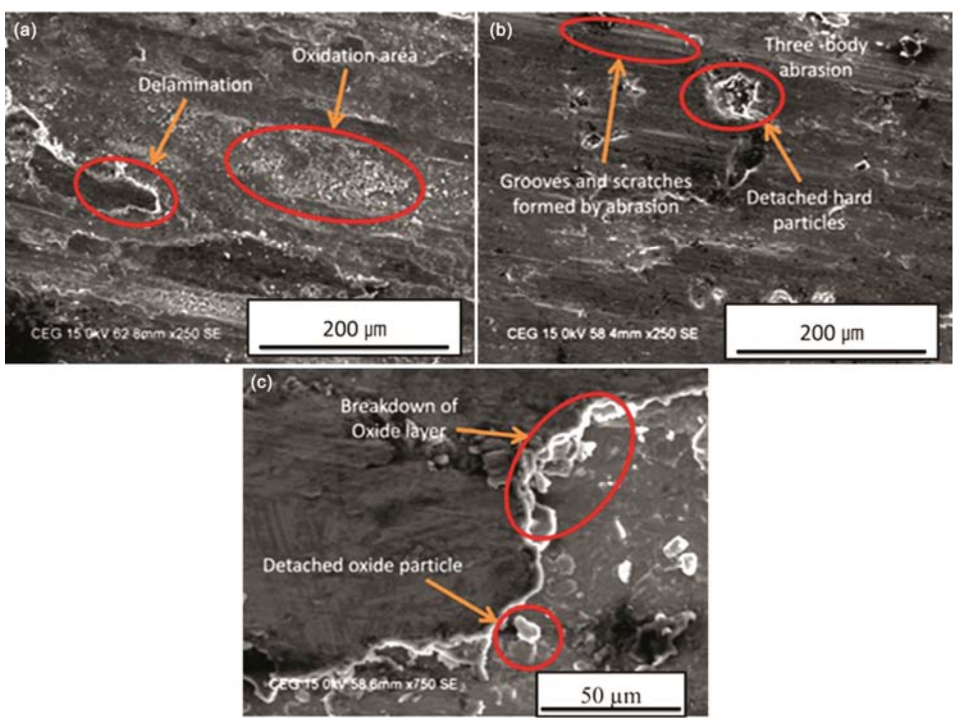

Fig. 12 — SEM image of wear track of (a) un-peened and (b & c) peened aluminium 7075-T651 alloy

as a result of oxidation had a great influence on increasing the coefficient of friction during the dry sliding. Hence, the coefficient of friction was high for the peened aluminium 7075-T651 alloy. On continuous sliding, the oxidation layers had a tendency to break into the oxide particles. These oxide particles causes a three body abrasion wear mechanism for peened aluminium 7075-T651 alloy. So abrasion wear was increased in peened aluminium 7075-T651 alloy surface when compared to the un-peened aluminium 7075-T651 alloy.

Conclusions

Shot peening process was successfully processed on aluminium 7075-T651 alloy and the following conclusions on its structural, surface features and friction-wear characterization have been drawn,

(i) There is no change in the phase structure of aluminium 7075-T651 alloy following the shot peening process.

(ii) Harness of peened aluminium 7075-T651 alloy is increased to 208.15 HV from 167.1 HV of un-peened aluminium 7075-T651 alloy.

(iii) Maximum compressive residual stresses were achieved for the peened aluminium 7075-T651 alloy. It is 276% greater than un-peened aluminium 7075-T651 alloy.

(iv) There is an increase in the surface roughness of peened aluminium 7075-T651 alloy when compared to the un-peened surface.

(v) Friction coefficient of peened aluminium 7075-T651 alloy was increased after the peening process due to increased surface roughness. However, wear resistance is better in contrast to the un-peened surface. Adhesive wear mechanism was dominant for un-peened surface, whereas, peened aluminium 7075-T651 alloy exhibited an abrasive wear mechanism.

(vi) There is no sign of adhesive wear in the wear track of peened aluminium 7075-T651 alloy, which indicates the control of adhesive wear after the peening process.

(vii) The overall conclusion is that peened aluminium 7075-T651 alloy exhibits a better wear property than un-peened surface.

Acknowledgment

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