

Impact-sliding wear behavior of shot-peened AISI 4340 steel

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Abstract: This study investigates the impact-sliding wear behavior of shot-peened AISI 4340 steels under severe loading conditions. Steels were shot-peened at intensities of 16, 20, and 24 A, and their structural and mechanical properties were analyzed using optical microscopy and microhardness testing. An inclined impact-sliding test, designed to simulate high dynamic loads, was conducted under Hertzian contact pressures of 1.59 and 2.88 GPa. Results revealed that increasing shot-peening intensity enhanced both surface hardness and impact-sliding wear resistance

Keywords: AISI 4340, Impact-sliding wear, Shot peening, Surface properties.

1. Introduction

Surface-environment interactions play a critical role in the failure of structural components. Enhancements in fatigue strength are closely linked to compressive residual stresses introduced by surface treatments such as shot peening, a mechanical process widely applied to improve the fatigue life of high-strength steels like AISI 4340 used in aircraft landing gear components (Voorwald et al., 2009; Trung et al., 2016; Karimbaev et al., 2020). These stresses act as barriers to crack propagation by shifting crack initiation from the surface to subsurface regions (Torres and Voorwald, 2002).

Given the demand for improved reliability of aircraft materials, this study examines the impact-sliding wear behavior of shot-peened AISI 4340 steel under severe dynamic conditions. Steels were treated at varying shot-peening intensities and tested using a custom-designed inclined impact-sliding wear apparatus (Chen et al., 2013), capable of simulating combined impact and sliding forces representative of extreme service conditions.

2. Materials and Methods

AISI 4340 steel, with a chemical composition of 0.41 C-0.73 Mn-0.80 Cr-1.75 Ni-0.24 Mo-0.25 Si (wt.%), was used for the shot peening treatments. Prior to peening, the steels were ground with 1200-grit SiC paper, polished with 0.05 μm alumina, and cleaned with ethanol. Shot peening was performed using an industrial air-blast system at Almen intensities of 16A, 20A, and 24A with S230 steel shots and 200% coverage, yielding three treatment groups. The 200% coverage was selected to ensure complete surface exposure, as recommended by AlSumait et al. (2019).

Cross-sectional morphologies were examined using a Nikon Eclipse LV150 light optical microscope (LOM). Surface roughness was measured with a Mitutoyo SurfTest SJ-400 profilometer. Microhardness profiles were obtained using a Shimadzu HMV tester under a 50 g load and 15 s dwell time.

Impact-sliding wear tests were performed to evaluate the effect of shot peening on wear resistance. The test rig was calibrated to apply maximum loads of 40 N and 240 N, corresponding to Hertzian contact pressures of 1.59 GPa and 2.88 GPa. Each steel

underwent 4297 impact cycles against a 10 mm AISI 52100 steel ball under dry conditions (25 ± 4 °C, 35 ± 5 % RH). Wear volume was measured using a 2D profilometer, and wear rates were calculated as volumetric loss per cycle (mm^3/cycle). Wear scars on both the steels and counter-bodies were analyzed using LOM equipped with NIS-Elements software.

3. Results and Discussion

Figure 1 illustrates the microhardness variation with depth for the steels. The untreated steel showed an average hardness of 229 ± 5.7 HV_{0.05}. Shot peening significantly increased the surface hardness, which gradually decreased toward the core. Higher Almen intensities produced greater hardness, with the 24A-treated steel exhibiting the highest surface value. This enhancement can primarily be ascribed to cold-work hardening and the formation of compressive residual stresses induced by the peening process. The plastically deformed surface layer, containing pores, cracks, and grain boundaries, effectively impeded dislocation mobility, thereby contributing to the observed increase in hardness (Kovacı et al., 2019).

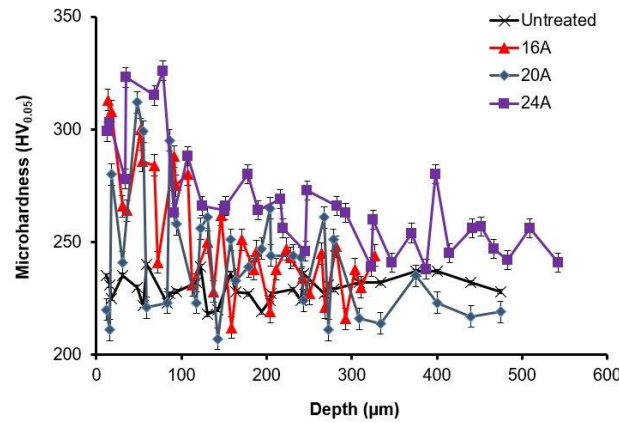


Figure 1. Microhardness-depth graph of steels

Figure 2 and Table 1 present the 2D surface morphologies and surface roughness values of the untreated and shot-peened steels. The shot-peened surfaces displayed non-uniform, crater-like topographies formed by the repeated impacts of steel shots during peening. The average roughness (R_a) values were $3.97 \mu\text{m}$, $5.14 \mu\text{m}$, and $5.48 \mu\text{m}$ for the 16A, 20A, and 24A conditions, respectively. Increasing Almen intensity led to greater plastic deformation and, consequently, higher peak-to-valley roughness, with the 24A condition exhibiting the highest R_a value.

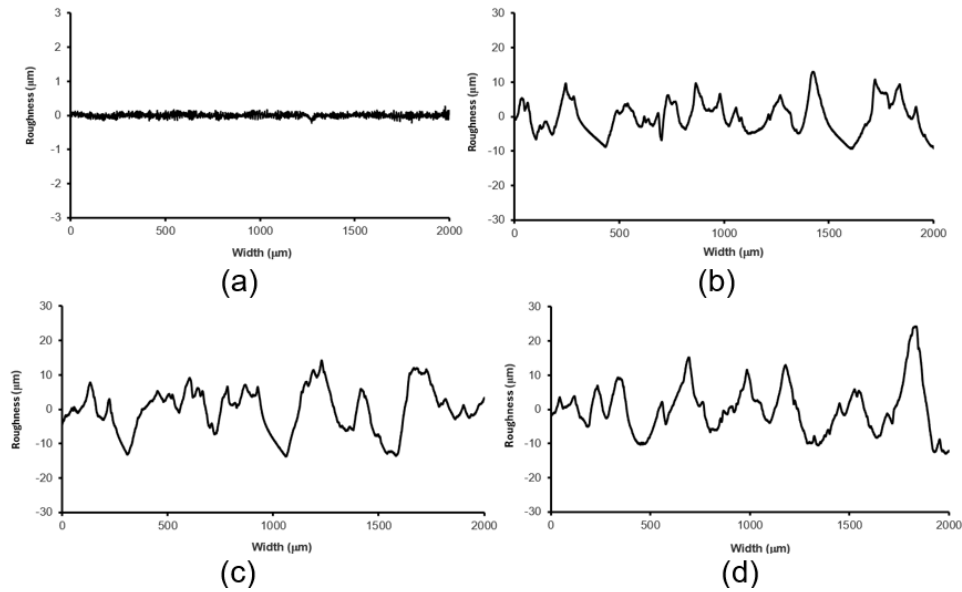


Figure 2. 2D surface images of (a) untreated steel and shot-peened steels at Almen intensities of (b) 16A, (c) 20A, and (d) 24A

Table 1 Surface roughness values of untreated and shot-peened steels

Steels	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
Untreated	0.05	0.4	0.06	0.5
16A	3.97	18.1	4.78	22.4
20A	5.14	20.8	6.39	27.9
24A	5.48	24.4	7.19	37.3

Figure 3 presents the LOM cross-sectional images of the shot-peened AISI 4340 steels. After etching with 2 % nital, ferrite (α) grains appear white and pearlite dark. All treated steels exhibited rough cross-sectional morphologies, with decreasing ferrite grain size as shot peening intensity increased. Since shot peening plastically deforms the surface and subsurface layers, increased surface roughness is a typical outcome of the process. The 16A-treated steel showed a relatively smoother surface, while the 20A condition revealed smashed regions, cavities, and plate-like cracks due to higher deformation. The 24A steel, subjected to the highest intensity, displayed more pronounced cracks and separated regions. These findings indicate that increasing shot peening intensity enhances subsurface crack formation and promotes the development of plate-like cracks within the deformed layer.

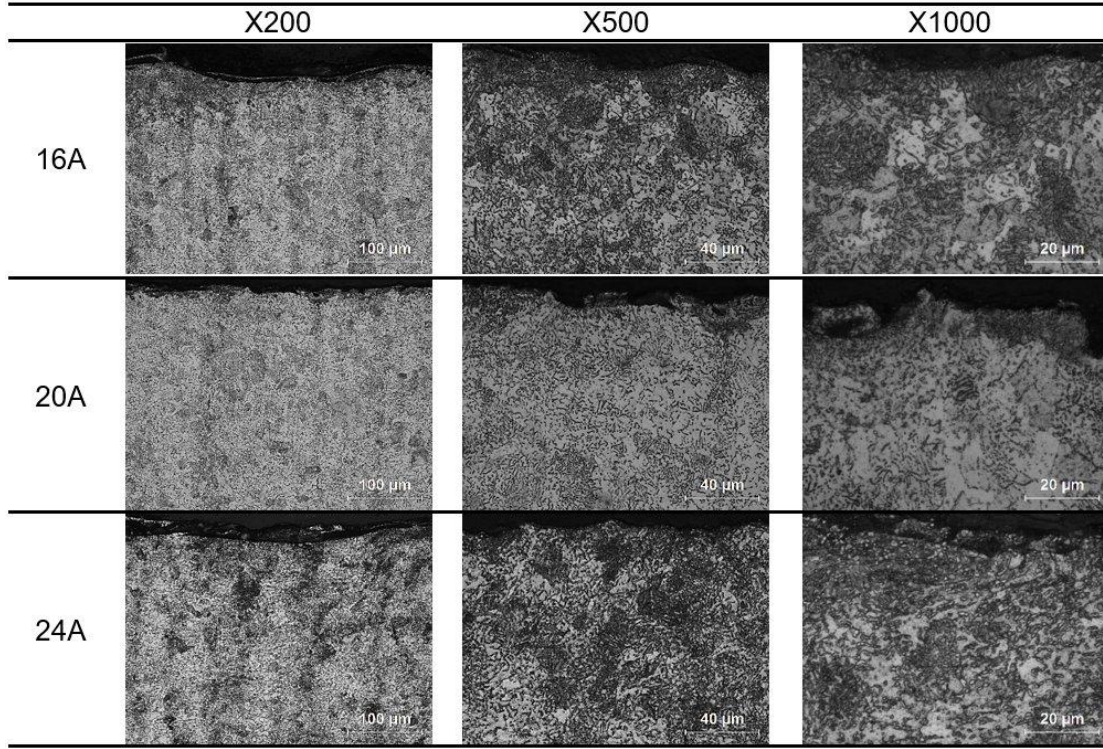


Figure 3. Cross-sectional LOM microstructures of the shot-peened steels at low and high magnifications

Figures 4 shows the 2D profiles of the impact and sliding zones of the wear tracks for the untreated and shot-peened steels after the impact-sliding wear tests. In all cases, the impact zone exhibited greater width and depth than the sliding zone, though the shot-peened steels displayed notably shallower wear tracks in the sliding region. The untreated steel, being softer, experienced severe plastic deformation under cyclic loading, leading to pronounced wear and the formation of shear lips at the zone edges. Conversely, the shot-peened steels, with their higher surface hardness and work-hardened subsurface layers, demonstrated enhanced load-bearing capacity and reduced damage, showing only minor shear lips after testing (Fig. 4).

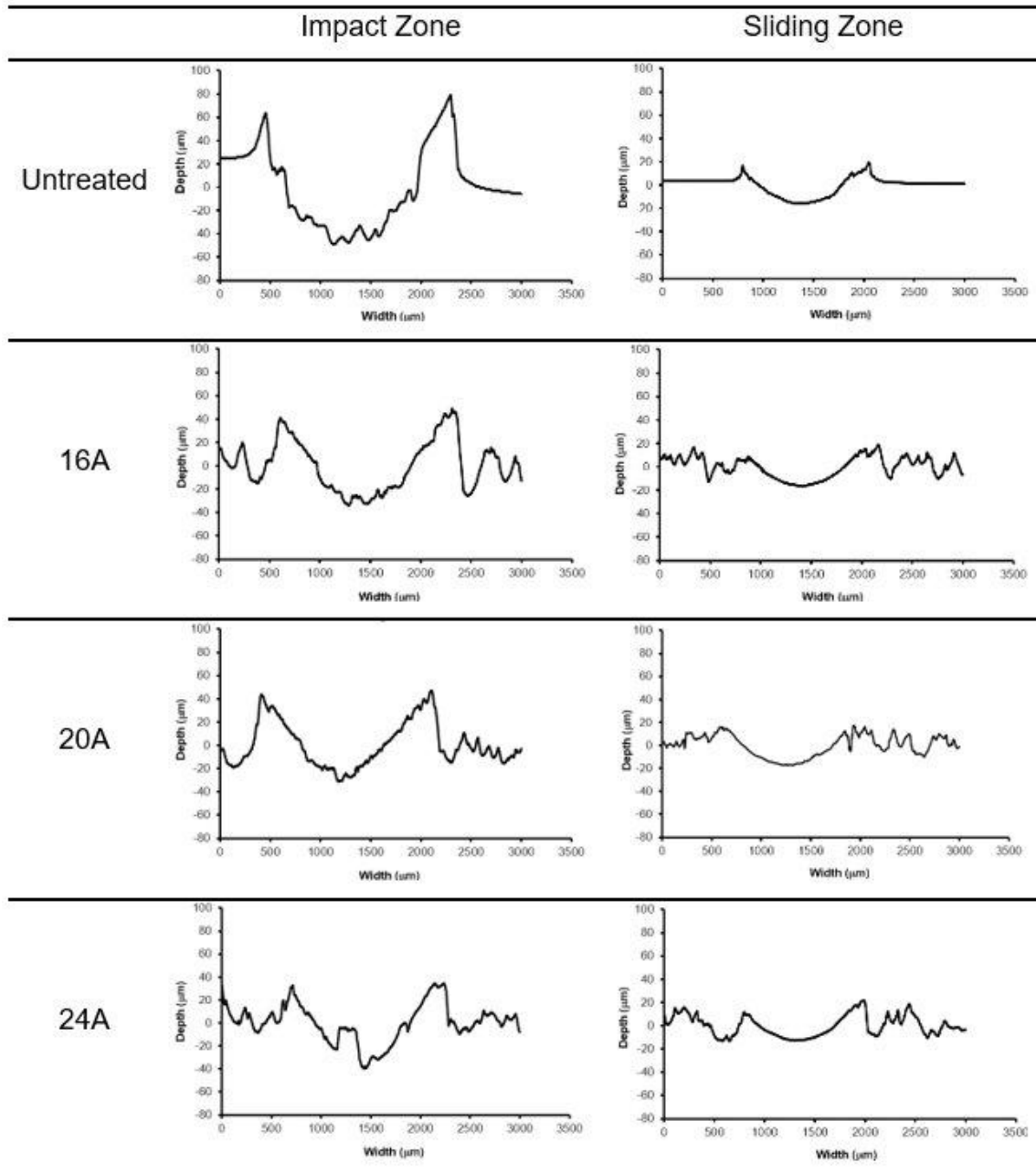


Figure 4. Typical 2D profiles of impact and sliding zones obtained from the steels

Figure 5 shows the average wear rates of untreated and shot-peened steels in the impact and sliding zones. In the impact zone, wear rates decreased by 44%, 55%, and 66% for the 16A, 20A, and 24A conditions, respectively, while the sliding zone showed reductions of about 17%, 27%, and 33%. The lowest total wear rate was obtained for the 24A shot-peened steel ($4.1 \times 10^{-5} \text{ mm}^3/\text{cycle}$), whereas the untreated steel exhibited the highest value ($7.43 \times 10^{-5} \text{ mm}^3/\text{cycle}$).

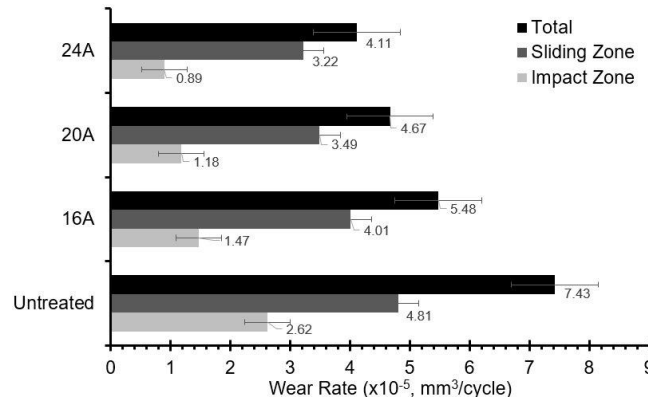


Figure 5. Wear rates of the wear tracks formed on the steels' surfaces

Figure 6 shows detailed LOM images of the worn surfaces of untreated and shot-peened steels. The 2D profiles (Fig. 4) indicate that shot-peened steels exhibited shallower wear tracks in both zones, suggesting that the work-hardened layer remained largely intact despite noticeable plastic deformation under impact loading. The untreated steel showed clear abrasive wear with parallel grooves along the sliding direction, while the shot-peened steels displayed smoother sliding zones with visible dimples from the peening process. These dimples, deeper than the material removed by sliding, persisted even after wear. The counter-bodies also exhibited material transfer, cracks, and wear debris, implying that increased surface hardness and roughness from shot peening intensified crack formation on the opposing surface.

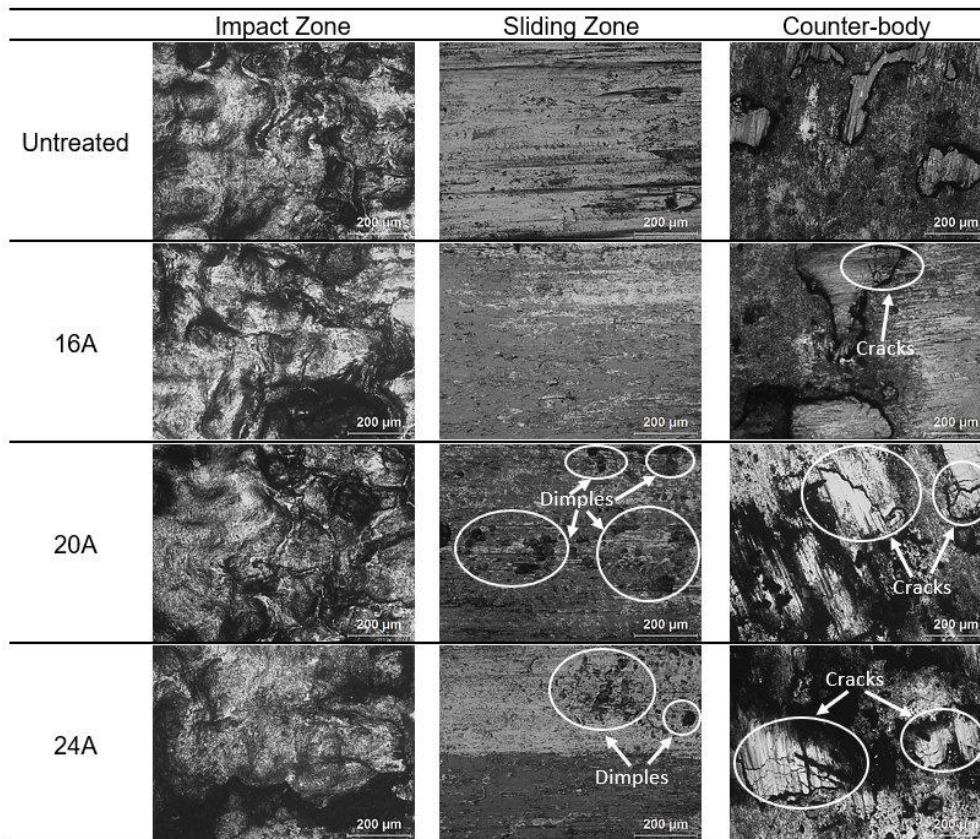


Figure 6. LOM images of the wear tracks formed on the surfaces of the untreated and shot-peened steels, and LOM images of their corresponding testing balls after the wear test.

4. Results

In this study, AISI 4340 steels were shot-peened at intensities of 16A, 20A, and 24A, and their surface plastic deformation was evaluated through impact-sliding wear tests. The main findings are as follows:

- Surface plastic deformation and roughness increased with Almen intensity, reaching a maximum at 24A, where deeper and wider dimples formed.
- Higher peening intensity refined the steel's grain structure.
- Wear rates decreased markedly with increasing intensity by up to 66% in the impact zone and 33% in the sliding zone with the 24A condition exhibiting the lowest total wear rate ($4.1 \times 10^{-5} \text{ mm}^3/\text{cycle}$) compared to the untreated steel ($7.43 \times 10^{-5} \text{ mm}^3/\text{cycle}$).

Acknowledgement

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References

- AlSumait, A., Li, Y., Weaser, M., Niji, K., Battel, G., Toal, R., and Es-Said, O. S. (2019). Comparison of the Fatigue Life of Shot-Peened 4340M Steel with 100%, 200%, and 300% Coverage. *Journal of Materials Engineering and Performance*, 28, pp. 1780-1789.
- Chen, Y., Cheng, T., and Nie, X. (2013). Wear Failure Behavior of Titanium-Based Oxide Coatings on a Titanium Alloy under Impact and Sliding Forces. *Journal of Alloys and Compounds*, 578, pp. 336–344.
- Karimbaev, R., Pyun, Y. S., Maleki, E., Unal, O., and Amanov, A. (2020). Improvement in Fatigue Behavior of AISI 4340 Steel by Shot Peening and Ultrasonic Nanocrystal Surface Modification. *Materials Science and Engineering: A*, 791, p. 139752.
- Kovacı, H., Bozkurt, Y. B., Yetim, A. F., Aslan, M., and Çelik, A. (2019). The Effect of Surface Plastic Deformation Produced by Shot Peening on the Corrosion Behavior of a Low-Alloy Steel. *Surface and Coatings Technology*, 360, pp. 78–86.
- Torres, M. A. S., and Voorwald, H. J. C. (2002). An Evaluation of Shot Peening, Residual Stress, and Stress Relaxation on the Fatigue Life of AISI 4340 Steel. *International Journal of Fatigue*, 24(8), pp. 877–886.
- Trung, P. Q., Khun, N. W., and Butler, D. L. (2016). Effects of Shot Peening Pressure, Media Type, and Double Shot Peening on the Microstructure, Mechanical, and Tribological Properties of Low-Alloy Steel. *Surface Topography: Metrology and Properties*, 4(4), pp. 045001.
- Voorwald, H. J. C., Silva, M. P., Costa, M. Y. P., and Cioffi, M. O. H. (2009). Improvement in the Fatigue Strength of Chromium Electroplated AISI 4340 Steel by Shot Peening. *Fatigue & Fracture of Engineering Materials & Structures*, 32(2), pp. 97-104.