Experimental investigation of controlled single and repeated impact testing of shot peening on Ti-6Al-4V, 300M and AA7050-T7451

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Abstract

During the shot peening process, multiple spherical shots impact the component at high velocity, causing plastic deformation in the component surface. This plastic deformation introduces beneficial subsurface compressive residual stresses. The shot peening process is governed by several important parameters that determine the shot peening results. To better understand the shot peening process and peening results on different materials, it is critical to study the effect of individual process parameters for different target materials. This paper investigates the effects of individual shot peening parameters such as shot velocity, shot diameter, angle of impact, and material properties on the diameter of the indentation and the change of the coefficient of restitution (CoR) value after a single and three repeated impacts on aerospace alloys: Titanium Ti-6Al-4V, 300M Steel and Aluminum Alloy 7050-T7451, using a single shot peening cannon. For the three studied materials, the resulting indentation diameters increase with the increase of shot diameter and shot velocity. The CoR decreases with the increase of the impact velocity and the shot diameter has very limited effect on the CoR. For multiple impacts at the same location, the CoR value increases with the increase of the number of impacts due to the previous plastic deformation.

Keywords: shot peening, controlled single impact, indentation, coefficient of restitution.

Introduction

Shot peening is a cold working surface treatment to produce compressive residual stresses and to increase fatigue properties of the treated components by inducing plastic deformation on the surface of metallic components [1]. Many shot peening process parameters influence the shot peening results, which include the size, the velocity and the impacting angle of the shot, the mass flow and the air pressure of the media flow, the exposure time, the distance between the nozzle and the target surface, and the material properties of the target component, etc. Almen intensity is the most widely used method to control the impact energy [2]. Miao et al. [3] developed an analytical model to relate the shot peening process parameters to Almen intensity. More recently, sequentially coupled discrete element modeling (DEM) and finite element modeling (FEM) approach has been applied to simulate the complicated shot peening process [4]. The DEM model usually requires the knowledge of the shot/target coefficient of restitution, which is defined as the ratio of the final and initial relative speed between the two impacting objects [4].

Breumier et al. [6] performed an experimental single shot peening using an in-house developed shot peening canon. The authors developed a 3D trajectory reconstruction to analyze the impacting and rebound trajectories of the shot and obtain the impacting and rebounding velocities to compute the CoR. The impacting indentations and the CoR values on a copper specimen were measured and compared with the FEM simulation. Seifried et al. [7] computed the evolution of the CoR on aluminum 6060 specimens over multiple impacts using a pendulum dropped by a magnet. The simulation of repeated impacts on aluminum rods shows an increase of the CoR with the increase of the number of impacts, until a stationary value is reached.

In this paper, the same shot peening cannon used by Breumier et al. [6] is applied to perform single and repeated impact tests of shot peening on Ti-6Al-4V, 300M and AA7050-T7451. The diameters of the indentation on each material after different shot diameters, shot velocities were obtained and compared to the analytical predictions. The CoR after single impact and repeated impacts were analyzed.

Experimental Methods

A shot peening cannon set up as shown in Figure 1 was used to perform single and repeated impacts on Ti-6Al-4V, 300M and AA7050-T7451 specimens using bearing balls having diameters of 1.19 mm and 2.50 mm. Three impacting angles of 0º, 15º and 30º with respect to the normal direction were considered. Two highspeed Phantom V310 cameras positioned at the top and left of the specimens were used, together with specially built 3D-eye software, to compute the impact and rebound velocity of the shot [6]. A Keyence microscope was used to examine the indentation diameters due to its efficiency for large number of measurements. A Bruker's Contour GT-X 3D profiler was used to observe the 3D surface after repeated impacts. The GT Contour method can measure both the diameter and the depth of the indentations, which could be very useful for future validation of FEM simulation.

Experimental Results

Relationship between impact velocity and impact pressure.

Figure 2 shows the relationship between the cannon pressures and the computed impact velocities on the three tested materials for both 1.19 mm and 2.50 mm single shot peening with a total number of 183 tests. Shot having a diameter of 2.50 mm produce larger impact velocity compared to the shot having a diameter of 1.19 mm. The relationship between the impact velocity *V* and cannon pressure *P* can be fitted with equation:

$$V = \alpha \times P^{0.4}, \quad (1)$$

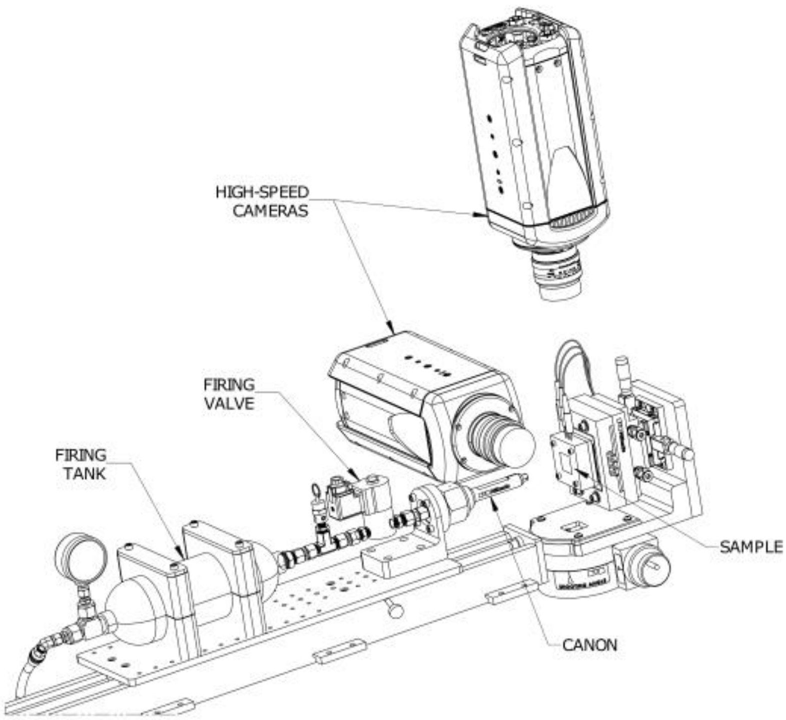

Figure 1. Shot peening cannon setup consisting of two high speed Phantom v310 cameras at top and left position to capture the 3D trajectory of the shot, nozzle, cannon and sample holding device [5].

where α is the fitting parameter, which equals to 76.28 for shot diameter of 1.19 mm and equals to 108.8 for shot diameter of 2.5 mm. This fitting equation shows that $v \propto P^{0.4}$ can be used to describe the relationship between the impact velocity and the pressure in this cannon setup.

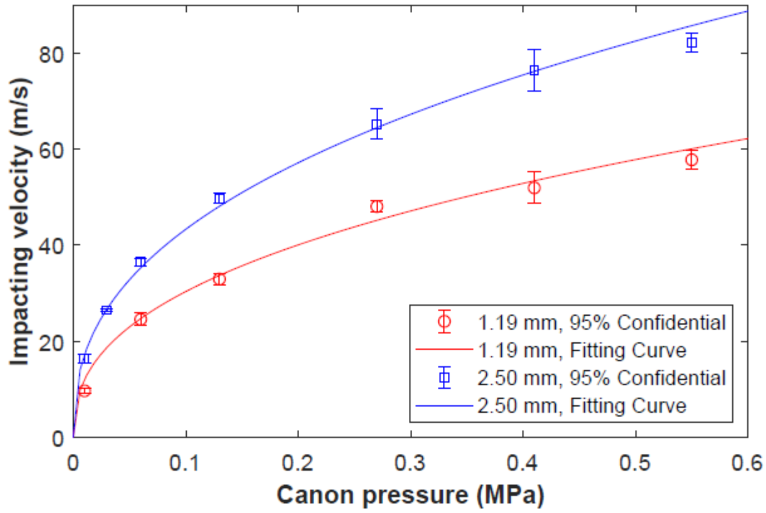

Figure 2. Relationship between the cannon pressures and the impacting velocities for two impact media having diameters of 1.19 mm and 2.50 mm.

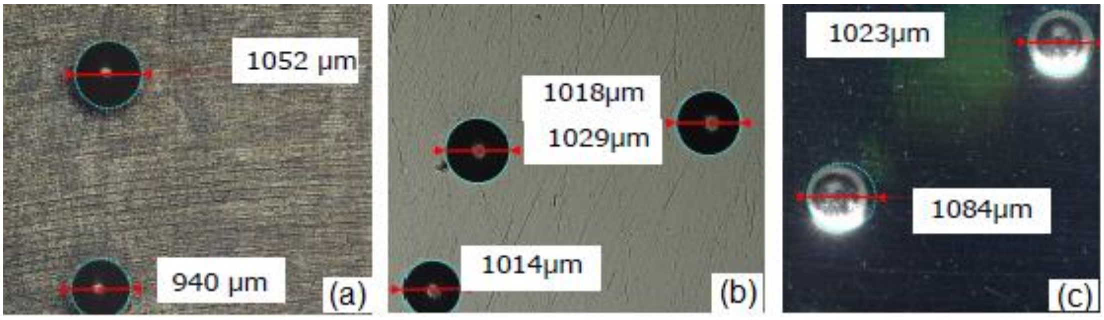

Figure 3 Surface indentation diameter measurement using Keyence microscope after one single impact for (a) Ti-6Al-4V, (b) 300M and (c) AA7050-T7451 with 2.50 mm media.

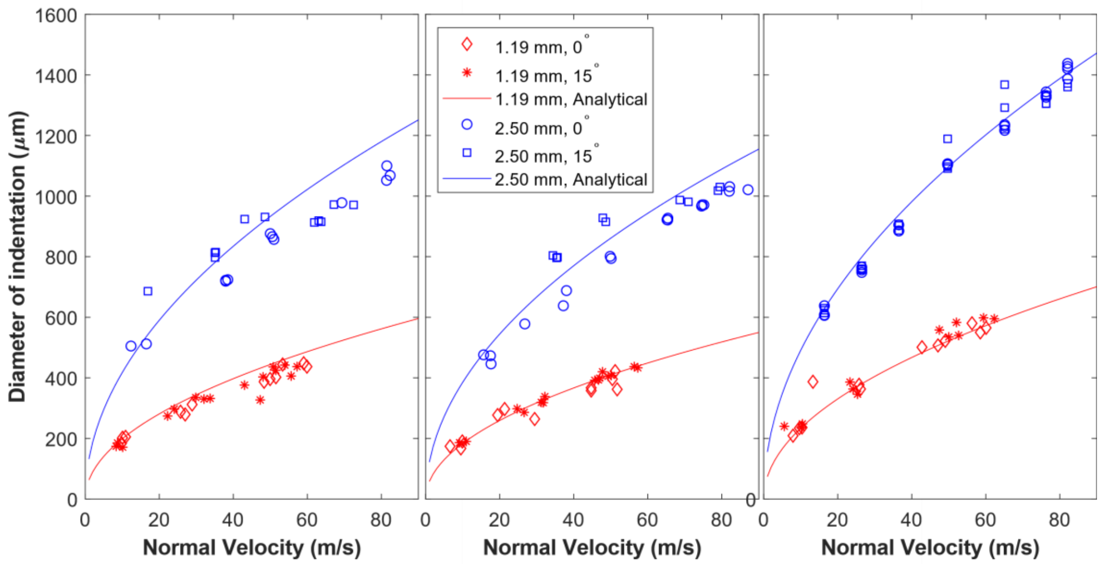

Figure 4. Relationship between the diameter of the indentations and the impact velocities for different impact shot size and angles. (a) Ti-6Al-4V, (b) 300M and (c) AA7050-T7451.

Diameter of the impact indentation.

Figure 3 shows an example of the indentation measurements using Keyence microscope for Ti-6Al-4V, 300M and AA7050-T7451 after impacts with shot diameter of 2.50 mm. The diameters of 183 indentations were measured for the two shot sizes with different impact velocities.

Error! Reference source not found. shows the relationship between the measured diameters of the indentation for the three tested materials with respect to the normal impact velocities, respectively.
An analytical model developed by Miao et al. [3] is used to compute the indentation diameter as:

$$D = 2R\left(8\rho V^2/9\sigma_s\right)^{1/4} \quad (2)$$

where D is the diameter of the indentation, R is the radius of the shot, ρ is the density of the shot, which equals to 7650 Kg/m^3, V is the normal impact velocity of the shot, σ_s is the yield stress of the target materials, which equals to 900 MPa for Ti-6Al-4V, equals to 1240 MPa for 300M, and equals to 470 MPa for AA7050-T7451 [8], respectively. The analytical prediction of the diameters of the indentation using equation (2) shows that the analytical model predicts well the relationship between the indentation diameters and the impact velocities for the single impact. Both experimental measurements and the analytical predictions show that the indentation diameters increase with the increase of the impact velocities and the shot diameters.

Influence of shot diameter and shot velocity on the Coefficient of restitution.

Figure 5 presents the evolution of the CoR with respect to the impacting velocity for two shot diameters, three impacting angles and different impacting velocities for Ti-6Al-4V. Figure 5(a), (b) and (c) show the total CoR, normal CoR and tangential CoR, respectively. The total CoR includes the effect of both the normal and tangential components. Both the total CoR and the normal CoR decrease with the increase of the impact velocity. The diameter has very limited influence on the normal CoR. For the same initial impacting velocity, the total CoR increases with the increase of the impact angles. This is because during the angle impact, a smaller energy is absorbed by plastic deformation, when compared to normal impact. The impacting angle has no influence on the normal CoR. The tangential CoR shows a larger dispersion than the normal CoR in the lower range of the tangential velocity smaller than 10 m/s. For larger impact angle, the tangential CoR increases with the increase of the initial tangential velocity.

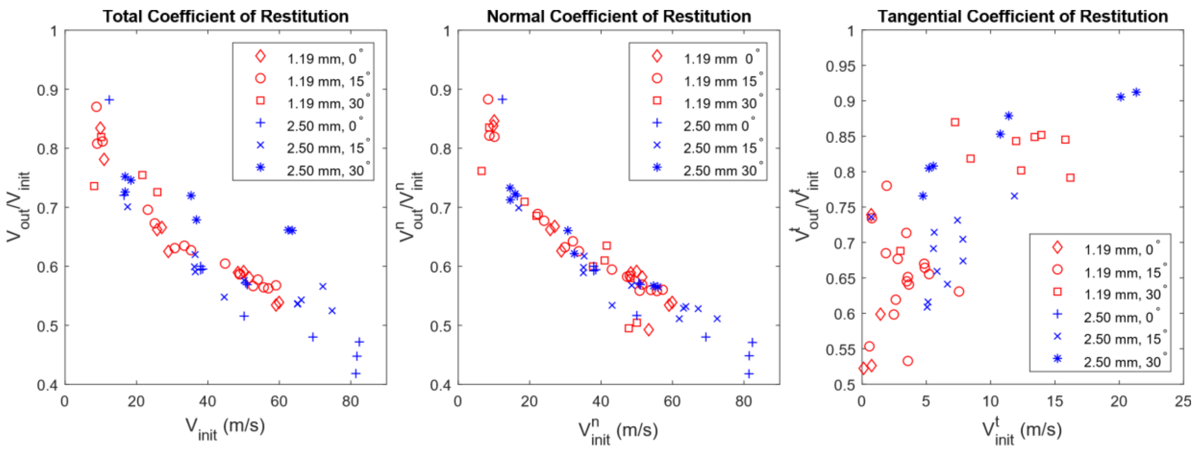

Figure 5 Relationship of CoR with the velocity before the impact for different shot diameters and impact angles for Ti-6Al-4V after single impact for: (a) Total CoR, (b) Normal CoR and (c) Tangential CoR.

It should be noted that only the values of Ti-6Al-4V are presented as examples, similar figures for 300M and AA7050-T7451 have been obtained in the test with different CoR ranges. In general, the CoR values on Ti-6Al-4V and 300M steel are higher than the values on AA7050-T7451 due to the lower yield stress value of the aluminum alloy component.

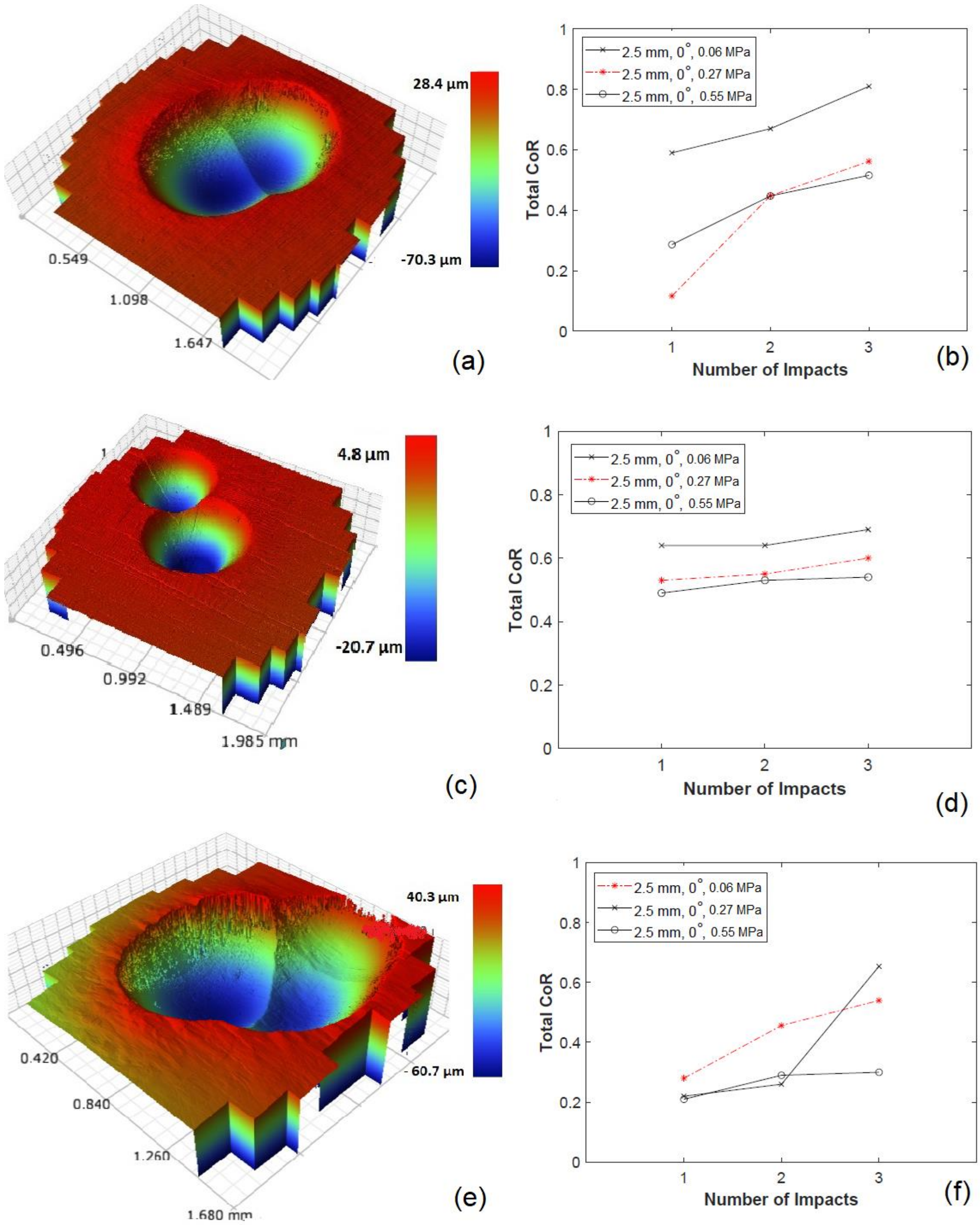

Figure 6 Contour analysis and CoR for shot diameter of 2.5 mm and impact angle of 0º, pressure of 0.27 MPa after multiple impacts, (a), (c) and (e) are for Ti-6Al-4V, 300M and AA7050-T7451 after the third impact, respectively. (b), (d) and (f) are for the relationships between the Total CoR value with respect to the number of impacts for Ti-6Al-4V, 300M and AA7050-T7451, respectively. The red curves in (b), (d) and (f) are corresponding to the indentation images in the left side for each material.

CoR after repeated impact.

Figure 6(a), (c) and (e) show the 3D surface contour measurements after three repeated impacts with 2.5 mm shot, impact angle of 0º and pressure of 0.27 MPa on Ti-6Al-4V, 300M and AA7050-T7451 specimens, respectively. Figure 6(b), (d) and (f) present the normal CoR values after one, two and three repeated impacts at the same location for shot diameter of 2.5 mm, impact angle of 0º, and pressure of 0.06, 0.27 and 0.55 MPa on Ti-6Al-4V, 300M and AA7050-T7451 specimens, respectively. In these figures, the dashed red lines are consistent with the impacting images by the contour 3D measurements in their left side, the other two cases have not been measured by the 3D contour profiler. In Figure 6(a) and (e), the three are almost coincident. Therefore, the measured CoR increases significantly with the increase of the number of impacts, as shown in Figure 6(b) and (f). This increase of the CoR is due to the plastic deformation of the previous impact which is hardening the material. However, in Figure 6(c), the repeated impacts did not completely coincide, resulting in a slightly increase of the CoR as shown in Figure 6(d).

Conclusions

For the current shot peening cannon set up, a quantitative relationship between the shot impacting velocity and the pressure were obtained for shot media having diameters of 1.19 mm and 2.50 mm. The diameter of indentations of a single impact after different shot diameters, shot velocities, and impact angles have been measured by Keyence microscope and compared with analytical predictions. Both experimental measurements and analytical predictions show that with the increase of the shot diameters and shot velocities, the indentation diameters increase. For the three studied materials, the total and normal CoR increase with the increase of the impact velocities. Shot diameter and impact angle have no influence on the normal CoR. The increase of the impact angles increases the total CoR and the tangential CoR. For repeated impact at the same location, with the increase of the number of impacts, the CoR increases due to the hardening effect of the previous impact.

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