

Effect of Shot Peening in Different Shot Distance and Shot Angle on Surface Morphology, Surface Roughness and Surface Hardness of 316L Biomaterial

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Abstract. Shot peening is a mechanical surface treatment with a beneficial effect to generate compressive residual stress caused by plastic deformation on the surface of material. This plastic deformation can improve the surface characteristics of metallic materials, such as modification of surface morphology, surface roughness, and surface hardness. The objective of this study is to investigate the effect of shot peening in different shot distance and shot angle on surface morphology, surface roughness, and surface hardness of 316L biomaterial. Shot distance was varied at 6, 8, 10, and 12 cm and shot angle at 30, 60, and 90°, working pressure at 7 kg/cm², shot duration for 20 minutes, and using steel balls S-170 with diameter of 0.6 mm. The results present that the shot distance and shot angle of shot peening give the significant effect to improve the surface morphology, surface roughness, and surface hardness of 316 L biomaterial. Shot peening can increase the surface roughness by the increasing of shot distance and by the decreasing of shot angle. The nearest shot distance (6 cm) and the largest shot angle (90°) give the best results on the grain refinement with the surface roughness of 1.04 µm and surface hardness of 534 kg/mm².

1. Introduction

Metallic biomaterials continue to be used extensively for the fabrication of surgical implants. AISI 316L stainless steel is widely used in components of the oil and gas, food and beverage and chemical industries, as well as a biomaterial due to its outstanding corrosion resistance in aggressive environments [1, 2]. The biomaterial of 316L austenitic stainless steel is one of the most used materials for fracture fixation devices compared to the other mentioned alloys, due to its suitable mechanical properties and low cost [3]. The biomaterials of stainless steel 316L are self-protected by the spontaneous formation of a thin oxide film. The passive layer formed on surgical stainless steel. [4-7]. Shot-peening method is a cold-working process used to produce a layer containing huge compressive residual stresses, modifying the metal surface structure, and creating the ultrafine grain and nanostructure. It entails bombardment of the surface with shots inducing the sufficient force to create plastic deformation resulting in increased compressive residual stress on the metal surface [8-10]. The hardness increment resulted mainly from a significant increase in the strain-induced strain-hardening [11]. The increase in the peening coverage and the Almen intensity markedly improved the microhardness and compressive residual stresses in the



surface layer, while the peening intensity depends on the shot size [12]. Shot peening effectively changed the topography and removed the grinding marks, increase the surface roughness and initially increase the surface roughness [13]. The shot peening surface material was constrained by the surrounding material and suffered reaction force because the target surface is stable and remains plane [14]. The surface roughness increases with increase in the peening time. The hardness of surface layer increase with increasing shot-peening time [15, 16]. It is possible to generate not only a compressive residual stress state and an increase of hardness in the surface layer of material, but also a nanocrystalline layer of material. Roughness is strongly increased and is somehow comparable to the different treatments that were tested. It induces severe plastic deformation that causes crystallite refinement in the surface layers [17]. Grain diameter was adjusted by changing bright annealing temperature after cold working. It could be realized the effect on the decreasing of grain diameter [18]. Consistent reduction in grain size and enhancement in dislocation density with increase in strain, indicate that no dynamic recovery occurred during the shot peening process [19]. The references give the support statement that the shot peening is an appropriate mechanical surface treatment to be applied on surface of 316L to achieve the objective of this research to investigate the effect of shot peening in relation with shot distance and shot angle on surface morphology, surface roughness, and surface hardness of 316L biomaterial.

2. Experimental work

The biomaterial of 316L stainless steel was used as the specimen of shot peening (20 x 25 x 3 mm) with chemical composition as shown in table 1. This chemical composition was obtained by spectrometry (Hilger spectrometer E-9 OA701).

Table 1. Chemical composition of 316L.

Element	C	Si	S	P	Mn	Ni	Cr	Mo	Ti	Nb	Fe
%	0,031	0,969	0,003	0,037	1,079	10,866	16,782	1,894	0,005	0,014	67,78

The specimens were polished by abrasive paper and metal polish. Steel balls S-170 (diameter of 0.6 mm) were used in this research. Air blast machine was used as shot peening machine with 7 kg/cm² pressure of air compressor for 20 minutes. Surface morphology was investigated by an optical microscope, surface roughness was investigated by surface roughness machine Surfcom 120A and surface hardness was investigated by Micro-Vickers indentation using Buchler Micromet. Shot peening was applied on the surface of 316L by shot distance variations of 6, 8, 10, and 12 cm, and shot angle of 30, 60, and 90° as shown in figure 1.

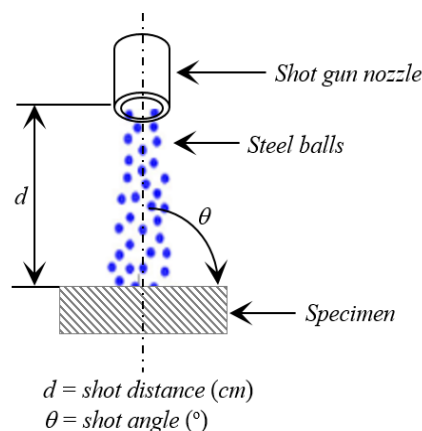


Figure 1. Scheme of shot peening.

The morphology modification on the surface of 316L was investigated by an optical microscope. The specimens were etched with HCl and HNO₃ and then specimen can be observed by an optical microscope. Surface roughness was investigated by contact stylus profilometer Surfcom 120A with setting parameter cut off of 0,800 mm, length of 5 mm, meas-mag of 2000 where the data can be used to get data of surface roughness (Ra). Surface hardness was investigated by micro-Vickers indentation using 100 grams indentation load for 10 seconds (ASTM standard E384). Hardness distribution for every specimen always takes in 10 points to get the hardness distribution be spread evenly on the surface of the specimen.

3. Result and discussion

3.1. Surface morphology

Shot peening gives a significant effect on surface modification in the form of plastic deformation characterized by the indentations formed on the surface of the specimen. The shot distances give a significant effect causing surface modification marked by the color change on the surface of the specimen, where the farther the shot distance, the color of the specimen becomes brighter as shown in figure 2, while the smaller the shot angle the specimen's color becomes brighter as shown in figure 3. This is due to the greater shot intensity at nearer distances, so the surface looks darker / gray.

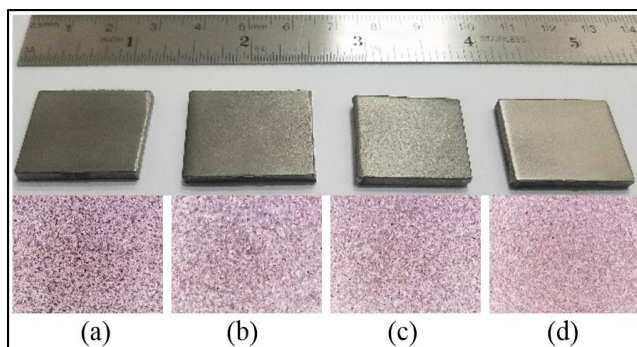


Figure 2. Surface modification on the surface of specimens at shot angle of 90°; (a) Shot distance of 6 cm, (b) Shot distance of 8 cm, (c) Shot distance of 10 cm, (d) Shot distance of 12 cm.

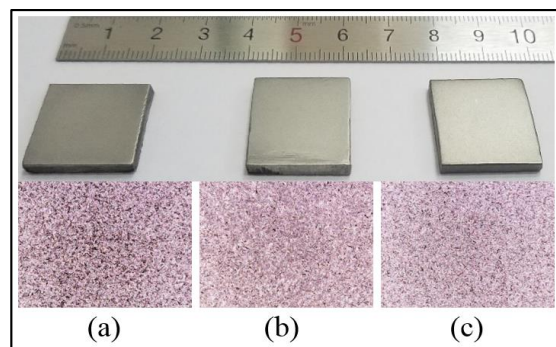


Figure 3. Surface modification on the surface of specimens shot distance of 6 cm; (a) Shot angle of 90°, (b) Shot angle of 60°, (c) Shot angle of 30°.

Figure 4 shows that the grain refinement occurs on the surface of specimen caused by multiple impacts of shot peening. Gariépy et al [18] report that shot peening gives an effect on the decreasing of grain diameter. The shot distances give a significant effect on the grain refinement on the surface of the specimen. The nearer of shot distance can create the smoother of the shape and size of the grain, because of the nearer of the shot distance, the greater of the shot intensity. The changes in shot angle also give an effect, the larger the shot angle the smoother the shape and size of the grain as shown in figure 5. According to Ranaware and Rathod [19], reduction in grain size and enhancement in dislocation density with increase in strain, indicate that no dynamic recovery occurred during the shot peening process. This grain refined will also increase the hardness properties of the material, due to the increasingly denser structure on the surface of the specimen.

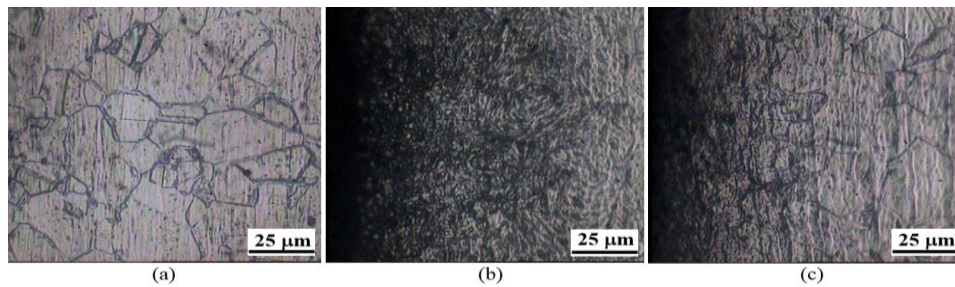


Figure 4. Cross-sectional microstructure of 316L at shot angle of 90°; (a) Non-Shot Peening, (b) Shot distance of 6 cm, (c) Shot distance of 12 cm.

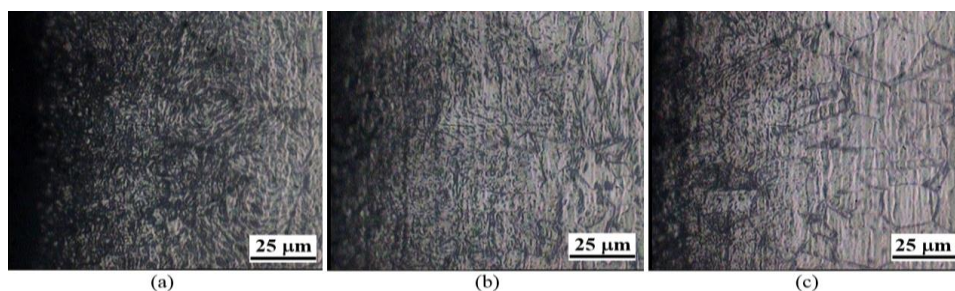


Figure 5. Cross-sectional microstructure of 316L at shot distance of 6 cm; (a) Shot angle of 90°, (b) Shot angle of 60°, (c) Shot angle of 30°.

3.2. Surface roughness

The surface of the specimen after the shot peening has a modification in surface roughness, where the steel ball impact has deformed the surface to become rougher than non-shot peening. Libor et al [17] report that roughness is strongly increased because it induces severe plastic deformation that causes crystallite refinement in the surface layers. The roughness value of the non-shot peening specimen increases significantly (133%) after shot peening in the different shot distance 6, 8, 10 and 12 cm (0.46, 1.07, 1.10 and 1.16 μm) at shot angle of 90°, but decreases in increasing of shot angle 30°, 60° and 90° (1.09, 1.07, and 1.04 μm) at shot distance of 6 cm. The farther the shot distance, the rougher the surface of the specimen, while the larger the shot angle, the roughness decreases as shown in figure 6.

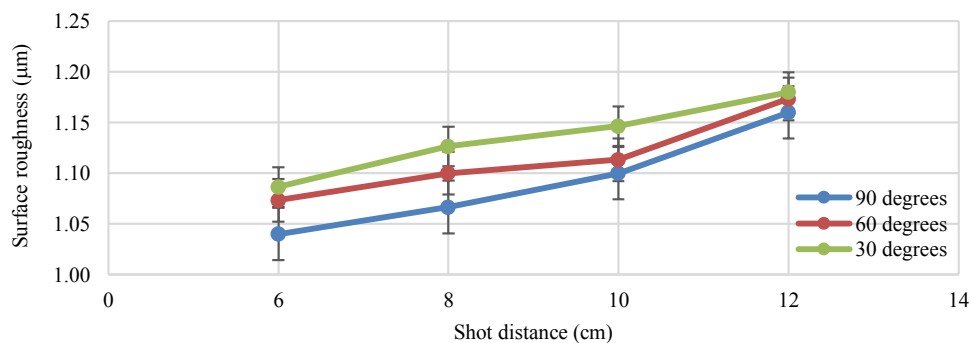


Figure 6. Effect of Shot Distance and Shot Angle of Shot Peening on Surface Roughness of 316L.

Nordin and Alfredsson [13] report that the surface roughness increased with increasing intensity of a given coverage. For a given intensity shot peening initially increase the surface roughness. This is due to the greater intensity of the shot at a distance of 6 cm so that the roughness decreases, while the shot intensity decreases at shot angle of 30° because the angle formed between the surface of the specimen with the shot direction is smaller so the tendency of the number of shot impact on the surface decrease.

3.3. Surface hardness

The shot distance and shot angle of shot peening also give the effect of enhancement in microhardness on the surface of the specimen. Nordin and Alfredsson [13] report that the largest hardness increases at the surface of the target. Hardness increases significantly (115%) at a distance of 6 cm with a shot angle of 90° (from 248 kg/mm² to 534 kg/mm²). Hardness decreases at the farthest of the shot distance, respectively at 6, 8, 10 and 12 cm (534, 489, 441 and 391 kg/mm²) at shot angle of 90°, but increases in increasing of shot angle at 30°, 60° and 90° (516 kg/mm², 532 kg/mm², 534 kg/mm²) at shot distance of 6 cm. According to Natori et al [11], the shot peening gives the hardness increment resulted mainly from a significant increase in the strain-induced strain-hardening. Figure 7 shows the best distance is the nearest distance (6 cm) and the best angle is the largest angle (90°). The farther the shot distance causes the lower the shot intensity because the required distance of the steel balls to reach the specimen surface farther away and the smaller the shot angle, the hardness decreases. This corresponds to the influence of the area of contact between the surface of the specimen and the shot direction so that the smaller shot angle causes the affected area of specimen getting smaller too.

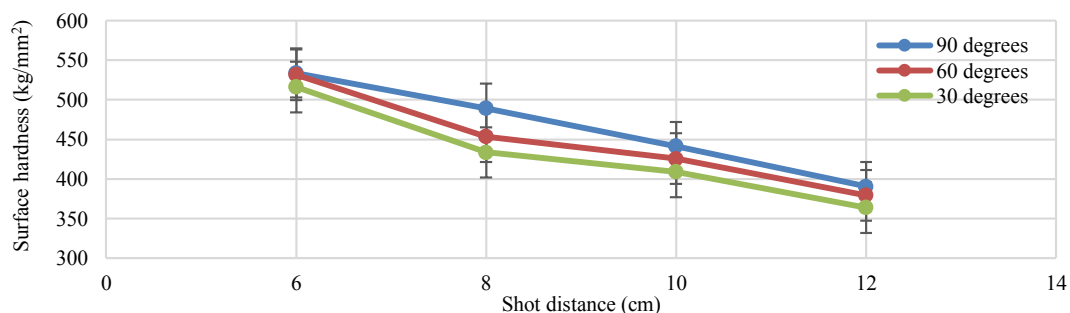


Figure 7. Effect of Shot Distance and Shot Angle of Shot Peening on Surface Hardness of 316L.

4. Conclusion

Shot peening presents the effect of the modification on surface morphology, surface roughness and surface hardness by different shot distance and shot angle. Shot peening can increase the surface roughness by the increasing of shot distance and by the decreasing of shot angle. Shot peening can increase the surface hardness by the decreasing of shot distance and by the increasing of shot angle. The nearest shot distance (6 cm) and the largest shot angle (90°) give the best results on the grain refinement with the surface roughness of 1.04 µm and surface hardness of 534 kg/mm².

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