Distribution of Hardness, Surface Roughness and Wettability of AISI 316L Induced by Shot Peening with Different Duration and Shooting Distance

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Abstract. A research is conducted to analyze the effect of shot peening on distribution of hardness, surface roughness, and wettability of AISI 316L. The shot peening process was performed on the surface of a 316L stainless steel sample with a shooting duration of 2, 4, 15, and 30 minutes, using a 0.4 mm diameter steel ball with a hardness of 40-50 HRC, the pressure of compressor held constant at 8 bar with nozzle diameter 5 mm, and the distance between the nozzle and the surface sample is 6 cm and 12 cm for each shooting duration. The results show that the shot peening can change the surface roughness. The closer the distance and the longer the duration of shot peening will reduce the surface roughness. Surface hardness increase with increasing of shooting duration and hardness distribution rate declines as the farther the distance from the surface of the shot peening.

Keywords: Shot peening duration, shot peening distance, 316L stainless steel, surface roughness, hardness distribution, wettability.

1. Introduction
As one of the branches of science in the field of materials, biomaterial plays an important role in health problems. Currently, biomaterials continue to be developed as one of the healing methods in bone implant problems. Some materials that qualify as implant materials include austenitic stainless steel, titanium alloys, and cobalt alloys [1]. The material that is widely used for implanted materials is titanium and stainless steel, because it has high strength, good ductility, and can be received by the body [2]. Each year more than 2500 cases of implant failure occur in Canada [3]. Orthopedic bone plate implant fail in their application till 5.8% [4]. The most common cause of orthopedic bone plate implant failure is due to material fatigue and corrosion [5].

SS 316L is widely used as an implant material for making artificial joints, bone plates, stents, prostheses, as this material is corrosion resistant, has good mechanical properties and is relatively cheaper than other metal biomaterials [6]. There are several techniques for improving the physical and mechanical properties of materials by engineering the properties of the steel and its alloys. Austenitic stainless steel cannot use heat treatment so cold treatment is used, ie shot peening. The shot peening process is a process that is performed by firing high-speed steel balls on the surface of the work piece in order to provide a compressive residual stress on the surface of a component that can improve the
material properties of the dynamic load [7]. Surface treatment will be very effective in improving fatigue and corrosion properties [8].

Stainless steel 316L material has been widely observed for biomedical applications, preparation for feeding, structural and submarine [9]. Research on the surface characterization of the material with severe shot peening then performed plasma nitriding at 400°C for 4 hours was performed on 316L stainless steel [10]. The effect of severe shot peening on microstructures and mechanical properties on the 31L sample was studied. The result is that the structure morphology on the surface tends to narrow down to nano size, forming the compression residual stress[7]. Variations of ultrasonic shot peening parameters such as ball material and diameter, sonotrode amplitude and coverage were studied in AISI 316L [11]. The effect of the relationship between surface hardening and roughness due to ultrasonic damping of the padding was investigated in AISI 316L [12]. Local corrosion, such as pitting and crevice corrosion were evaluated on austenitic AISI 316L stainless steel [13]. Surface hardness enhancement and surface compressive residual stress after shot peening delay crack formation and suppress crack growth rate [14]. Roughness of surface layer and droplet angel are significantly affect bio-adhesion process of orthopedic implant. Roughness of surface layer and small droplet angel can increase adsorption of protein which initiates the bone improvement in human bone [15].

The aim of this experiment is focused on the effect of shot peening treatment with the shooting distance of 6 and 12 cm, 2, 4, 15, and 30 minutes duration at each distance against surface roughness, hardness distribution and wettability on 316L stainless steel material.

2. Experimental method

2.1. Materials

The material used in this study was SS 316L which has chemical composition presented in Table 1.

| C   | Mn  | Si  | Cr   | Ni   | Mo   | S    | P    | Fe   |
|-----|-----|-----|------|------|------|------|------|------|
| 0.03| 1.08| 0.97| 16.78| 10.87| 1.89 | 0.003| 0.04 | Balance |

2.2. Sample Preparation

The 3 mm SS 316L samples were cut into 37.5 x 20 mm sizes of 8 samples. The plate is then smoothed with sandpaper that has been set in the sander orbital sander or gradually polishing machine with mesh size 100-5000 and polished with auto sol. The shot peening process is performed on the shot peening tool shown in Figure 1. The tool consists of components such as a 3HP 120L 10bar 380V compressor, a nozzle diameter of a 5 mm, a steel ball with a 0.4 mm diameter and hardness 40-50 HRC, rubber hose, container box for steel ball tank on top of the table, sample clamp, and container box as the place to put sample that will be given shot peening treatment. The samples were given treatment with a distance of 6 cm and 12 cm, and the duration at each distance was 2, 4, 15, and 30 minutes. Pressure on the compressor was maintained at 8 bar during the shot peening process.
Figure 1. Shot peening apparatus.

Surface roughness testing was performed with Surfcom 120A ver 2.2 with stylus profilometer type with cut off setting of 0.8 mm, length 8 mm, and meas-mag 2000. Samples that have been given shot peening treatment, cleaned first with alcohol to remove impurities which may affect the accuracy of roughness data retrieval.

Surface hardness testing conducted to determine the hardness distribution on a cross-section sample of shot peening process. The test is done by using micro Vickers tool with Buchler micro met 2100 series. The hardness test begins by cutting the material transversely then indented with 25 grams of the load for 10 seconds to get a small indentation at a narrow distance. The indentation was performed 10 times starting with a distance of 15 μm from the surface of the shot peening result and continued to the next indentation in the material with a distance of 15 μm each. Therefore, the total distance measured in inner hardness is 150 μm. Then the indentation diagonal is measured and calculated to obtain the hardness distribution value on the piece of material.

The wettability test is carried out by using a wettability test instrument consisting of a holder for the material site, measuring cups for the liquid site, and dropper drops. Prior to testing, the surface of the sample is first cleaned with alcohol. This test is done by measuring the contact angle between the droplet and the sample surface. Testing of wettability is done by dripping water as much as 4 points on the surface of the sample, which is then taken 3 nearest data and taken the average of the three angles of contact. After dropping on the surface of the sample, the droplet is then shot with the camera at 5 seconds after the water drip. The droplet image is then processed with image software, resulting in an average contact angle from each sample.

3. Results and discussion

3.1. Surface roughness
The surface roughness test result is the mean surface roughness value (Ra) obtained from the test on each sample. The shot peening treatment has an effect on the surface roughness of SS 316L as shown in Figure 2. The shot peening treatment makes the surface roughness of the material increasing compared to the surface roughness of raw material or non-treatment (NT). This provides information that the surface of the material changes to be rougher. The shot peening process provides a scar or indentation resulting from the impact of steel balls shot at high speed and pressure on the surface of the material. Thus, on the surface of the material will form an indentation pit which will make the surface of the material becomes rougher.
The duration of the shot peening process also gives effect to the surface roughness of the material. The subjects given a shot treatment for 4 minutes had a lower surface roughness than the material with shot peening treatment for 2 minutes. This decline in roughness values occurs with the longer duration of shot peening. The shot peening treatment causes an irreversible plastic deformation. From these data, there was an increase in roughness at 2-minute duration for both shooting distance. This increase occurs because of the formation of the pit at several locations on the surface of the sample. Unlike the case when the duration of 4, 15, and 30 minutes, the value of roughness tends to fall. This is because the entire surface of the test sample begins to be covered by a new pit due to the impact of steel balls over and over again. Thus, the height of the mound to the pit is reduced and the depth of the pit is no longer affected by repeated collisions. The longer the duration of shot peening, the more the number of steel balls are hit and hit the surface of the material, so that the surface area that has not been hit by steel balls will be shot by the impact of steel balls as well as causing the surface of the material to become flattered and smoother.

3.2. Hardness Distribution

Hardness distribution is resulted from hardness testing at cross-section. This test is carried out using a small load of 10 gf with a duration of 10 seconds indentation to obtain a small indentation and distance as close as possible between indents. To obtain cross-sectional hardness test data, indented 10 times with each distance 15 μm. The hardness distribution in cross-section of the sample which has been subjected to shot peening. Figure 3 shows that the further distance from the surface of the hardness value decreases. Indentation point with distance 15 μm from surface treatment of shot peening, has high hardness value. While, the indent point with a distance of 150 μm from the surface of the shot peening treatment results, has a low hardness. A decrease in the value of hardness occurs as the distance from the surface of the shot peening results. This indicates that the hardening effect of the shot peening sample occurs only on the surface of the material up to a certain depth. This decrease occurs because the effect of the dislocation density cannot reach into the larger material.

Figure 3(a) shows cross-sectional hardness distribution data on shot peening material with 6 cm range. While the hardness cross-section data distribution on shot peening material with 12 cm shot
distance is shown in Figure 3(b). Both shot distance, it showed that the cross-sectional distribution of hardness are identical or resemble each other, as the distance from the shot peening surface further decreases the hardness. However, the two graphs have the difference that the slope of the graph line in Figure 3(a) is more sloping than the slope of the graph in Figure 3(b). This occurs because the difference in the distribution of indented hardness values at each point provides a smaller difference for the shot peening material with a distance of 6 cm. With close proximity, then the intensity of the collision will be more and more so that the dislocation density is formed greater. In contrast to the peak shot material with a distance of 12 cm, the intensity of the shot impact is smaller so as to provide a greater difference in the distribution of hardness values at each indentation point. This shows that shot peening by using a smaller firing range will have a deeper effect of hardness.

![Graphs showing hardness distribution on shot peened material](image)

**Figure 3.** Hardness distribution on shot peened material with a shooting distance 6 cm (a) and a shooting distance 12 cm (b).

### 3.3. Wettability
Shot peening affects the surface properties of SS 316L, so it can change the wetting properties of the implantable material. The wettability test is done by dripping water onto the surface of NT samples and shot peening results on 316L stainless steel material. Water droplets above the surface of the sample are
drawn so that they can be analyzed and determined by the wetting properties of the sample. The result of the wettability test to distance and duration of shot peening can be seen in Figure 4.

![Figure 4. Droplet Contact Angle of Shot Peening SS 316 L.](image)

It was found that the shot peening process decrease the droplet contact angle from the original 92.42° for the NT as the control sample, then decrease to 82.13° for the sample with a 6 cm shot peening distance and dropped to 85.29° for the sample with distance shoot 12 cm. Droplet contact angle after shot peening process with duration of 2 minutes in both shooting distance decrease angle which is inversely proportional to the increase of it roughness. The shot peening reduces the droplet contact angle from ± 92° (control sample) to a droplet angle of approximately 68-85°. From the data, we can know that NT 316L stainless steel classified as having hydrophobic properties (θ > 90°). Meanwhile, the sample shot peening results differ from the wetting character of the NT where the roughness value is different. Shot peening's material has droplet contact angles ranging from 68-85° (θ < 90°) so they have hydrophilic properties.

4. Conclusion
The effect of shot peening treatment with the shooting distance of 6, and 12 cm, then 2, 4, 15, and 30 minutes duration at each distance against surface roughness, hardness distribution and wettability on 316L stainless steel material was observed. The conclusion of this experiment is increased of surface roughness by shot peening process on AISI 316L. Moreover, the longer the shooting duration and the closer the shooting distance will reduce the roughness of the surface of the material, so it obtains a low roughness value or a smoother surface. Shot peening on AISI 316L gives a deepening effect of hardness. Surface hardness significantly increase with increasing of shooting duration and hardness distribution rate declines as the farther the distance from the surface of the shot peening. Shot peening on AISI 316L causes a decrease in droplet contact angle and causes a change in the properties of hydrophobic to hydrophilic.

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