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# SHOT PEENING EFFECT ON SURFACE PROPERTIES AND PITTING CORROSION RESISTANCE OF BIOMEDICAL STRUCTURAL STEEL AISI 316L

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AISI 316L is used in biomedical engineering as bone implant materials. The mechanical properties and corrosion resistance of this material can be improved by shot peening. The aim of this research is to investigate the effect of shot peening on surface roughness, hardness, wettability, and pitting corrosion resistance of AISI 316L in 0,9 % NaCl solution. The shot-peening was performed on AISI 316L surfaces with duration of 0, 2, 4, 10, 20, 30 minutes using steel balls with a diameter of 0,6 mm and hardness of 40 - 50 HRC. The results show that shot peening increase roughness after 2 minutes then decrease the roughness with increasing time. The longer duration of shot peening will increase the pitting corrosion resistance.

*Keywords:* AISI 316L, shot peening, pitting corrosion, hardness, surface properties

## INTRODUCTION

AISI 316L medical grade austenitic stainless steel is commonly used as an implant material to make devices like artificial joints, bone plates, osteosynthesis plates, prothesis and stents [1 - 2]. AISI 316L stainless steel has good mechanical properties, easy to manufacture, low price and good corrosion resistance compared to other metal material [3]. The main elements of austenitic stainless steel are chromium, nickel, molybdenum, and iron. The combination of these elements makes stainless steels have good mechanical properties [4].

Corrosion is one of the phenomena that occurs in all alloys or metals used in corrosive environments [5]. The human body contains a high concentration of chloride ions with the temperature of 36,7 °C - 37,2 °C. The human body contains a high concentration of chloride ions with the temperature of 36,7 °C - 37,2 °C.

The chloride ion concentration and the working temperature lead to a corrosive fluid environment in the human body [2]. Body fluid as a corrosive environment in human body can decrease the corrosion and corrosion fatigue resistance of AISI 316L, because the body fluid can accelerate the rate of corrosion and propagation of fatigue cracks [6]. Therefore, after the stainless steel (especially AISI 316L) is implanted in the human body, there will be a dangerous state and may cause an inflammatory reaction in the human body.

Surface modification could increase mechanical properties and improve surface morphology of the stainless steel 316L [7]. The method of shot peening is the shooting of steel balls on materials with high speed and high pressure. Shot peening may improve the structure layer surface and the mechanical properties of materials such as hardness, roughness, and corrosion rate [8]. Azar et al have shown that the surface hardness can increase after shot peening [5].

The objective of this paper is to examine how shot peening process could improve the material properties of AISI 316L. The properties investigated in this paper are surface roughness, microhardness depth distribution, microstructure, wettability, and pitting corrosion behavior in 0,9 % sodium chloride. The processing parameter shot peening is variation duration. The surface properties and pitting corrosion rate result by shot peening compared with polished surface.

## EXPERIMENTAL PROCEDURES

The material is cut to 20 mm x 20 mm and 3 mm thick for research. The corrosion test specimen manufactured cylinders with a diameter of 14 mm and 3 mm thick. All specimens were grinded with silica grit paper # 400 to # 2 000 and polished with metal polish. After grinding and polishing, the specimen is cleaned with alcohol for about 10 to 20 minutes.

The shot peening process was carried out on all specimens with a 10 cm nozzle distance and perpendicular to the specimen, the pressure used was 8 bar constant, the average 0,6 mm steel ball size (S230 manufacturing code) and the hardness of the steel balls 45 – 50 HRC. The variation used process of shot peening are 2, 4, 10, 20, and 30 minutes and can be called SP2, SP4, SP10, SP20, and SP30. The material with duration

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of 0 minutes is a specimen without treatment can be called raw.

The surface roughness testing has been performed on the surface of the specimen by contact stylus profilometer (surfcorm 120 A, Advanced metrology system, UK). The surface roughness testing parameters use a cut of 8mm, the meas-mag 2 000 and the length of taken up 8 mm. Surface roughness can be indicated by the average roughness of arithmetic or Ra.

Furthermore, Vickers microhardness were performed on the cross section of specimen with 100 g load in 10 s (time to holding load), according to the ASTM E384 standard. The microhardness test has been done with 15 µm starting point from the surface. Each specimen will be taken 10 point after 15 µm from the surface with a range of 75 µm each point.

The droplet contact angle between the specimen and the liquid on the surface is drawn using high resolution camera tool. Before testing specimens should be cleaned by immersion to alcohol, then washed with distilled water and dried before testing. The droplets measurement used in wettability test is water. Liquid droplets are dropped at center of effect shot peening surface locations. The results of the droplet image measured the contact angle with image J. Wettability measurement method using snake-based method included in the plug-in image J software.

The corrosion testing has been performed in the direct current method with electrochemical system Ametek versastat 4. electrolyte or corrosive environment used is 0,9% Sodium Chloride OTSU-NS. the chemical composition of OTSU-NS is NaCl 4,5 g, Osmolarity 308 mOsm / L, $Na^+$ 154 mEq / L, $Cl^-$ 154 mEq / L, and sterile aquades 500ml. All potentials have been measured using reference electrodes (Ag/AgCl [KCl]) and carbon rods used as auxiliary electrode. Specimen clamped with plastic to effectively measure one side.

## RESULTS AND DISCUSSION

### Surface Roughness

The relation between surface roughness of the initial (non-treatment) and shot peening treatment is shown in Figure 1 and Table 1.

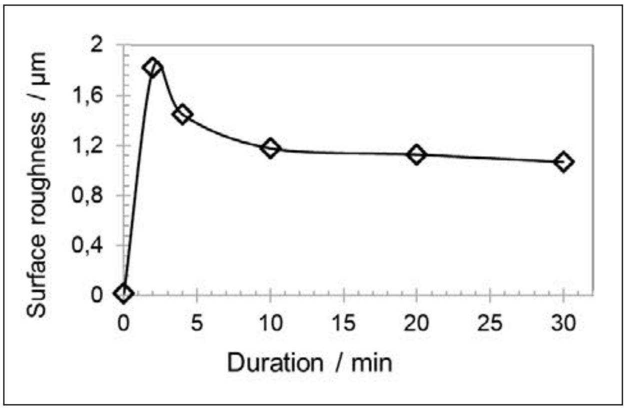


**Figure 1** Effect of shot peening on roughness

Table 1 **Result of surface roughness on shot peening parameters**

| Duration / min | 0 | 2 | 4 | 10 | 20 | 30 |
|---|---|---|---|---|---|---|
| Surface Roughness / µm | 0,02 | 1,82 | 1,45 | 1,18 | 1,13 | 1,07 |

The surface roughness test parameter with roughness average arithmetic (Ra). The surface roughness of the material increases from 0,02 µm to 1,82 µm on the materials with shot peening treatment. The shot peening process make roughness surface and the surface transform to heterogeneity [5]. Increased surface roughness and surface heterogeneity due to the impact of steel balls with high speed and pressure to the surface of 316L. Scratch on the surface leads to plastic deformation on the surface. Plastic deformation formed causes roughness and surface heterogeneity [10]. After the 10 minutes duration, the value of roughness is not significantly different.

The phase difference of the decline can be classified into 2 phases, phase 1 with significant decrease in roughness and phase 2 with a nearly constant roughness. The phase of this decrease in surface roughness is due to grain refinement on the surface of the material. The duration of shot peening increases the difference in peak height and the smaller the basin. This is because the energy obtained from the impact of steel balls is not able to change because each surface has been impacted by the impact of steel balls [5, 10]. Roughness will not change much after that.

### Microhardness distribution

A cross-sectional hardness distribution with variation in duration shown in Figure 2. The decreasing difference in the distribution of hardness values on the section area is also shown in Figure 2.

The effect of residual stresses and the hardening of the cold works resulted in the grain refinement of the uppermost layer region and the formation of the dislocation density which affect the hardness of material [6-10]. As it gets further away from the surface, the grain discharging effect will disappear and the grain will remain at the point before the shot peening process. This

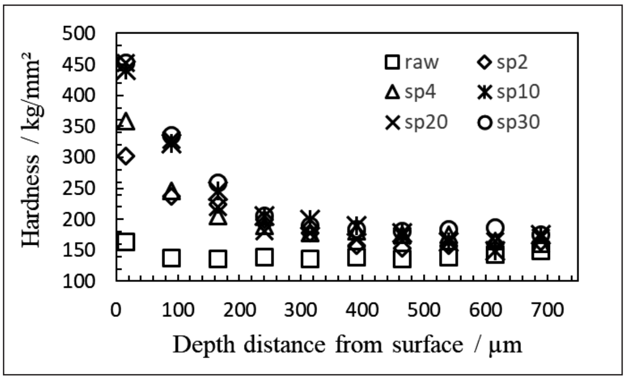


**Figure 2** Hardness Vickers depth profile of shot peening parameters

situation is identified in the gradual decline of violence and subsequently becomes a constant distribution of the value of hardness distribution.

## Microstructure

The 316L stainless steel commercial plate having a chemical composition in Table 2. Figure 3 shows the effect of shot peening's duration on changes in the microstructure of 316L material.

Table 2 **Composition of AISI 316L / wt. %**

| C | Mn | Si | Cr | Ni | Mo | Fe |
|---|---|---|---|---|---|---|
| 0,03 | 1,08 | 0,97 | 16,8 | 10,9 | 1,89 | Bal. |

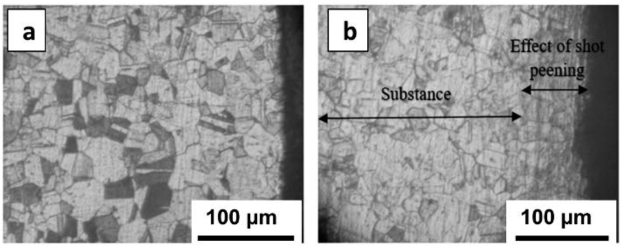


**Figure 3** Horizontal microstructure of a) non-treatment b) effect shot peening

Figure 3 a) shows that the state of the material with the grain size is evenly distributed. Figure 3 b) shows that the effect of shot peening could alter the grain size of the material. The microstructural image shows that there is no austenite phase change after the shot peening treatment. This phenomenon occurs because the nickel content in 316L material is quite a lot that stabilizes the austenite phase and is not transformed [8].

## Wettability

Figure 4 shows the effect of shot peening's duration on the contact angle of wettability. The decline starts from 82,55° to 63,47°.

The process of shot peening on 316L material can lower the contact angle on the material, so that the wettability of material will increase.

The condition shows that the material without treatment can be said to be less hydrophilic. The addition of shot peening duration will increase the contact angle. The value of the contact angle with the duration of 2, 4, 10, 20, and 30 minutes respectively are 63,47°; 66,09°; 70,49°; 73,68° and 75,15°. The increasing of contact angle is caused by surface roughness result of shot peening process. It can be said that the material after shot peening process considered as a material that has hydrophilic properties because it has a contact angle less than 90°.

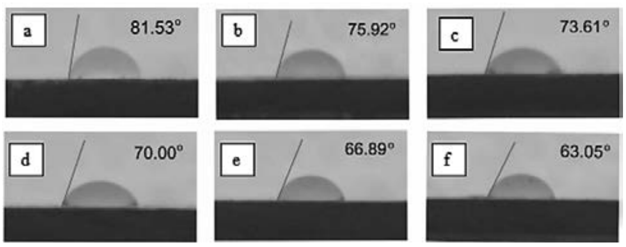


**Figure 4** Droplet contact angle of a) non-treatment, shot peening, b) 30 min, c) 20 min, d) 10 min, e) 4 min, f) 2 min

## Pitting corrosion behavior

The result of cyclic polarization method showed that the longer duration of shot peening then the corrosion resistance will also increase. The decrease in pitting corrosion rate is a result of residual compressive stress after shot peening. Table 3 shows the results of the cyclic polarization test on the 316L material with different shot peening duration.

Table 3 **Result of cyclic polarization**

| Sample | Raw | SP2 | SP4 | SP10 | SP20 | SP30 |
|---|---|---|---|---|---|---|
| $I_{corr}$ / mA/cm$^2$ | 1,37 | 1,34 | 1,3 | 1,19 | 1,17 | 1,15 |
| $E_{prot}$ / mV | -118 | -24 | 94 | 40,5 | -20,5 | 124 |
| $E_{pitt}$ / mV | 297 | 385 | 458 | 355,2 | 283,7 | 419 |
| $E_{pitt}$ - $E_{prot}$ / mV | 416 | 409 | 365 | 314,7 | 304,2 | 295 |

The very high compressive residual stress results better pitting corrosion resistance in surface. The pitting corrosion resistance increase with the lower $E_{prot}$ - $E_{pitt}$ value in Table 3. So that the area of the hysteresis loop shown in Figure 5 shows the reduction of the area. A good pitting corrosion resistance can be investigated by the existence of a passive layer formed on the surface [5]. The passive layer has greater durability caused by the formation of grain refinement on the surface layer effect of shot peening.

The addition of shot peening duration causes smoother roughness and grain refinement from a cold working effect would be better. This situation is caused by the roughness factor causing the hysteresis loop to be reduced. In addition, the grain refinement effect of peening shot residual stress can also determine the difference between $E_{prot}$ - $E_{pitt}$, then the resistance to pitting corrosion will increase.

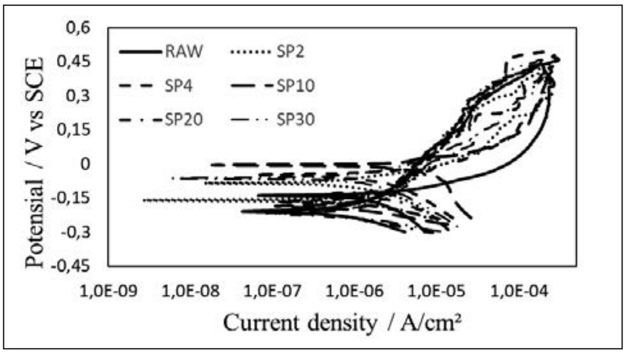


**Figure 5** Cyclic polarization curves for different duration shot peening in 0,9 % NaCl

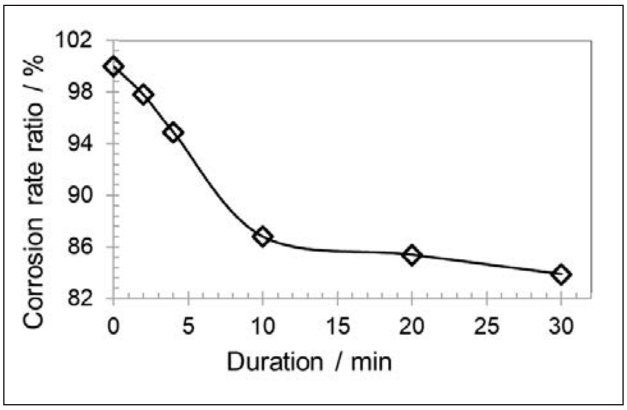


**Figure 6** Percentage reduction of pitting corrosion rate graph for duration shot peening AISI 316L

Figure 6 shows a decrease in the ratio of pitting corrosion rate with increasing duration of peening shot. This indicates that the shot peening can decrease the corrosion rate with a certain duration of treatment. Rising corrosion resistance due to roughness factor. The increasing shot peening duration causes the surface roughness to decrease, although its roughness value is higher than without peening shot treatment. The roughness also affects the pitting corrosion rate. The decrease in roughness value by shot peening causing corrosion resistance of pitting increased. The corrosion resistance of pitting increased due to comparison residual stress and surface roughness to be balance.

## CONCLUSIONS

The conclusion that can be drawn in this study is that the process of shot peening could increase the hardness and change the surface wettability of the material becomes more hydrophilic. The rate of corrosion of shot peening results increased in the initial duration or very short duration. Very short duration of shot peening causes roughness and high heterogeneity, these factors increase the rate of corrosion of the wells, roughness will initiate localized corrosion on the surface. Research has shown that the decrease in corrosion rate of wells can be lowered with a long duration of shot peening.

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## REFERENCES

[1] Mudali UK, Sridhar TM, Raj B. Corrosion of bio implants. Sadhana (2003) 28, 601– 637.
[2] Yang H, Yang K, Zhang B. Pitting corrosion resistance of La added 316L stainless steel in simulated body fluids. Mater. Lett. (2007) 61, 1154–1157.
[3] Disegi JA, EschbachL. Stainless steel in bone surgery. Injury. 2000;31:S-D2-6.
[4] Singh L, Khan RA, Aggarwal ML. Effect of shot peening on hardening and surface roughness of nitrogen austenitic stainless steel. Int. J. Eng. Sci. Technol. (2010) 2, 818–826.
[5] Azar V, Hashemi B, Yazdi R, et al. The effect of shot peening on fatigue and corrosion behavior of 316L stainless steel in Ringer's solution. Surf. Coatings Technol. (2010) 204, 3546–3551.
[6] Maliwemu EUK, Malau V, Iswanto PT, et al. Corrosion Fatigue Crack Propagation of AISI 316L by Nitrogen Ion Implantation in Simulated Body Fluid. Metalurgija 60 (2021) 1–2, 43–46.
[7] Arifvianto B, Suyitno, Mahardika M. Effects of surface mechanical attrition treatment (SMAT) on a rough surface of AISI 316L stainless steel. Appl. Surf. Sci. (2012) 258, 4538–4543.
[8] Ahmed AA, Mhaede M, Wollmann M, et al. Effect of surface and bulk plastic deformations on the corrosion resistance and corrosion fatigue performance of AISI 316L. Surf. Coatings Technol. (2014) 259, 448–455.
[9] Trdan U, Skarba M, Grum J. Laser shock peening effect on the dislocation transitions and grain refinement of Al-Mg-Si alloy. Mater. Charact. (2014) 97, 57– 68.
[10] Liu YG, Li MQ, Liu HJ. Nanostructure and surface roughness in the processed surface layer of Ti-6Al-4V via shot peening. Mater. Charact. (2017) 123, 83–90.

**Note:** The responsible translator for English language is Wihda Nadia Silcha, M.Pd