Corrosion Resistance of 316L Biomaterial in Simulated Body Fluid by Modification of Shot Distance and Shot Angle of Shot Peening

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Abstract. Corrosion resistance of 316L biomaterial can be improved by mechanical surface treatment such as shot peening. Shot peening can create plastic deformation as a nanocrystal surface layer on the metal surface to protect the material from corrosion attack. This study aims to investigate the effect of shot peening on the corrosion resistance of 316L to reach the best rate of corrosion. The shot peening parameters in this research are shot distance (6, 8, 10, and 12 cm), shot angle (30, 60, and 90°), compressor pressure (7 kg/cm²), shot duration (20 minutes), and steel balls S-170 (diameter of 0.6 mm). Simulated Body Fluid (SBF) was used as a corrosion media with ion concentrations nearly equal to human blood plasma. Corrosion tests were used versaSTAT, and the data were analyzed by VersaStudio. The result shows that the shot peening can decrease the corrosion rate of the 316L biomaterial. The larger the shot angle, the lower the corrosion rate and the nearer the shot distance, the lower the corrosion rate. The nearest shot distance (6 cm) and the largest shot angle (90°) give the best result to decrease the corrosion rate from 0.8617 mpy to 0.1096 mpy.

Keywords: Biomaterial, corrosion resistance, shot peening, simulated body fluid

1. Introduction
Medical science and improvement in biomedical materials have an outstanding increase in advanced year population and quality of life. Medical implants can fail due to wear, fatigue, chemical destruction, and corrosion. Metallic biomaterials are used extensively for implants fabrication. The surface of the implant must be accepting the ability for long-term usage contact to biological connection with tissue. The corroible metals must be accepting the ability for long-term usage contact to biological connection with tissue. The corroible metals are used to minimize the corrosion of metallic biomaterials in medical device applications [1-3]. AISI 316L stainless steel is generally used as components of biomaterial due to its outstanding corrosion resistance in corrosion environments such as in the human body as an orthopedic implant, cardiovascular, and dental devices [4].

Shot-peening is a cold-working treatment that creates a layer with compressive residual stress by plastic deformation, modifying the surface and forming the ultrafine grain and nanostructure with high productivity [5-7]. Austenitic stainless steel has excellent corrosion resistance because it contains high chromium contents. Metastable austenitic stainless steels have a phase transformation
to induce martensitic by cold working such as shot peening. The corrosion rate of AISI 304L with shot-peening is lower than AISI 316L without shot-peening. It means that the AISI 304 with shot-peening has better than non-treated AISI 316L [8-10]. Shot size is important to decrease the corrosion rate. The coverage and Almen intensity markedly improved the micro-hardness and compressive residual stresses on the surface layer. Shot peening increases the surface roughness by modifying the different shot peening parameters. Shot peening can increase the surface roughness and hardness by changing the shot distance and shot angle of shot peening [11, 12].

High corrosion, wear resistance and biocompatibility are good properties for biomedical materials. Corrosion was commonly deeper in the cold-drawn steels than in the solution-annealed [13, 14]. Chloride ions in simulated body fluid can cause severe pitting corrosion on the surface of a metal. The pitting potential ($E_{pit}$) as a critical parameter can evaluate the pitting response at a critical voltage under a corrosive media [15]. Simulated Body Fluid (SBF) and Bovine Serum Albumin (BSA) are general methods to create apatite interface layer. Hank solution can also be used as SBF. The simulated abiotic sulfide solution is not able to create a corrosive environment with the biotic sulfate-reducing bacteria culturing medium. In vivo apatite formation can be applied in SBF with ion concentrations nearly equal to human blood plasma. The in vivo bone bioactivity can be predicted by the apatite formation on the surface in SBF [16-19]. In the human body fluids, inorganic salts such as organic compounds like amino acids and proteins have an important role. The effects of the composition and buffering ability of immersion solutions are commonly used in evaluations of in-vitro corrosion [20].

This research aims to investigate the effect of shot peening as a suitable mechanical surface treatment by investigating the modification of shot distance and shot angle of shot peening to enhance the corrosion resistance of 316L biomaterial.

2. Experimental method

Stainless steel of 316L was used as the corrosion specimen with chemical composition as shown in Table 1. This chemical composition was gained by spectrometry measurement.

| Element | C  | Si | P  | Mn | Ni | Cr | Mo | Fe  |
|---------|----|----|----|----|----|----|----|-----|
| wt.%    | 0.030 | 0.969 | 0.037 | 1.078 | 10.867 | 16.782 | 1.894 | 67.78 |

This research used steel balls S-170 with a diameter of 0.6 mm. Compressor pressure was kept constant at 7 kg/cm$^2$ for 20 minutes. Shot peening was applied by steel balls impact on the surface of 316L by modifying the shot distance at 6, 8, 10, and 12 cm, and shot angle at 30, 60, and 90°.

Figure 1. The scheme of shot peening [12].
SBF was used in this research because the ion concentration of SBF nearly equal to human blood plasma with composition as shown in Table 2.

**Table 2.** The composition of Simulated Body Fluid [19].

| Reagent                  | Amount  | Purity (%) | Formula weight |
|--------------------------|---------|------------|----------------|
| NaCl                     | 8.035 g | 99.5       | 58.4430        |
| NaHCO₃                   | 0.355 g | 99.5       | 84.0068        |
| KCl                      | 0.225 g | 99.5       | 74.5515        |
| K₂HPO₄ 3H₂O              | 0.231 g | 99.0       | 228.2220       |
| MgCl₂ 6H₂O               | 0.311 g | 98.0       | 203.3034       |
| 1.0M-HCl                 | 39 ml   | -          | -              |
| CaCl₂                    | 0.292 g | 95.0       | 110.9848       |
| Na₂SO₄                   | 0.072 g | 99.0       | 142.0428       |
| Tris (HOCH₂)₃CNH₂        | 6.118 g | 99.0       | 121.1356       |
| 1.0M-HCl                 | 0.5 ml  | -          | -              |

Corrosion tests were used versaSTAT, and the data were analyzed by VersaStudio with parameters as shown in Table 3.

**Table 3.** The parameters of the corrosion test.

| Endpoint properties | Scan properties | Threshold properties |
|---------------------|-----------------|----------------------|
| Initial potential (V) | Vertex potential (V) | Final potential (V) | Step high (mV) | Step time (s) | Scan rate (mV/s) | Start level (V) | Threshold (mA) |
| -0.1                | 1.2             | -0.1                 | 2              | 1             | 2               | 0.2            | 1              |

**3. Result and discussion**

The corrosion test has a purpose to investigate the corrosion properties of 316L as a non-treatment specimen and shot peening specimen as shown in Figure 2.

![Figure 2](image)

**Figure 2.** The corrosion test specimens of 316L; (a) Non-treatment specimen, (b) Specimens after shot-peening in different shot distance.

Figure 2 shows the different color between non-treatment specimen and specimens after shot peening. This is the effect of shot peening on the surface of the specimen that makes surface darker than the non-treatment specimen. It can happen because the shot intensity gives a significant effect of changing the morphology on the surface of the specimen. The reduction in corrosion resistance has a correlation with the morphology on the surface of the treated specimens [11]. The distance of the shot peening has a significant impact that causes surface modification which is marked by discoloration on the surface of the specimen, where the color of the specimen becomes brighter at the farthest of the shot distance, while the smaller the shot angle, the specimen becomes brighter. This is due to the greater shot intensity at nearer distances, so the surface looks darker/gray [12].
Figure 3. SEM photograph of the specimen after corrosion test; (a) Non-treatment specimen, (b) Specimen with shot peening.

Figure 3 shows that uniform corrosion attacks the surface of the specimen. A specimen without shot peening (non-treatment) has more oxide on the surface as the effect of corrosion because the specimens without shot peening are more easily oxidized. Thin layer on the surface of the specimen as the effect of shot peening can protect the substrate of material from corrosion attack. This phenomenon can happen because shot peening can produce a layer containing huge compressive residual stresses, modifying the metal surface structure, and creating the ultrafine grain and nanostructure [5].

Corrosion test can produce the polarization curve that can be used to determine the parameters of corrosion potential ($E_{corr}$) and corrosion current density ($I_{corr}$) as a result of the intersection between Tafel lines of anodic and cathodic. Both of these parameters are used to determine the corrosion rate.

Figure 4. The polarization curve of 316L by shot distance modification of shot peening.

Figure 4 shows that the shot distance can reduce the corrosion current density of 316L from 2.059 µA/cm² (non-treatment) to 0.262 µA/cm² (shot distance of 6 cm), 0.468 µA/cm² (shot distance of 8 cm), 1.040 µA/cm² (shot distance of 10 cm), and 1.589 µA/cm² (shot distance of 12 cm). The
nearest distance at 6 cm has a good corrosion current density. The shot angle of shot peening also affects the corrosion resistance of 316L. The shot angle can reduce the corrosion current density from 2.059 \( \mu \text{A/cm}^2 \) (non-treatment) to 1.331 \( \mu \text{A/cm}^2 \) (shot angle of 30°), 0.573 \( \mu \text{A/cm}^2 \) (shot angle of 60°), and 0.262 \( \mu \text{A/cm}^2 \) (shot angle of 90°) as shown in Figure 5. The largest shot angle gives the best result of corrosion resistance indicated by the lowest corrosion current density. The corrosion current density has a directly proportional relation with corrosion rate. The low corrosion current density indicates that the specimen has a low corrosion rate.

![Polarization curve of 316L by shot angle modification of shot peening.](image)

**Figure 5.** The polarization curve of 316L by shot angle modification of shot peening.

The effect of shot peening on corrosion resistance was indicated by a reduction in corrosion rate after shot peening. Figure 6 and 7 show that the shot peening can affect the corrosion resistance by decreasing the corrosion rate from 0.8617 mpy to 0.1096 mpy at the shot distance of 6 cm and shot angle of 90°.

![Corrosion rate of 316L by shot distance modification of shot peening.](image)

**Figure 6.** The corrosion rate of 316L by shot distance modification of shot peening.
The shot distance of shot peening can affect the corrosion rate as shown in Figure 6. The nearest shot distance gives the best result of corrosion rate because the shot intensity of the nearest distance is higher than the farthest distance. Multi-impact at the nearest distance is higher than the farthest distance so that the surface of the specimen will be denser than the farthest distance and can cover the area of the surface of the specimen.

![Figure 7. The corrosion rate of 316L by shot angle modification of shot peening.](image)

Shot angle also can affect the decreasing of corrosion rate of the 316L biomaterial as shown in Figure 7. The larger the shot angle, the lower the corrosion rate. The largest shot angle is the best result of corrosion rate because the area of the contact angle between the position of shot nozzle and surface of the specimen is larger than the smallest shot angle, so the shot intensity increased too and centered on the surface of the specimen. These effects can cover the surface of the specimen from corrosion attack.

4. Conclusion
The shot peening can improve the corrosion resistance of the 316L biomaterial by decreasing the corrosion rate. The larger the shot angle, the lower the corrosion rate and the nearer the shot distance, the lower the corrosion rate. The nearest shot distance (6 cm) and the largest shot angle (90°) give the best result to decrease the corrosion rate from 0.8617 mpy to 0.1096 mpy.

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