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To cite this article: M Pramudia *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **494** 012092

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The effect of steel ball diameter variation in dry shot peening process on surface roughness and corrosion rate of AISI 316L implant material

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Abstract. Stainless steel, or also called as inox steel is a material that has a resistivity to the oxide reaction in an oxygen-containing environment. This study uses AISI 316L stainless steel material which is a biomedical implant as a raw material that obtains surface modification technique to obtain new mechanical properties. Surface modification technique uses dry shot peening process by varying steel ball diameter as an abrasive material shot on the surface of steel ball at high speed. The steel ball used is AISI 440 C type with a hardness level of HRC 50-55. The results show that the level of material surface roughness will decrease along with the increasing (bigger) size of steel ball diameter used. The results of corrosion test on SBF solution (simulated body fluid) show an increase in corrosion resistance along with the decreasing (smaller) size of steel ball diameter used.

Keywords: steel ball diameter, dry shot peening, surface roughness, corrosion rate, AISI 316L

1. Introduction

Biomaterials are classified into four classifications based on their constituent materials, namely metals, polymers, ceramics, or composites that are used for interaction with living tissue. All of these materials are used in the human body with a variety of purposes, one of which is orthopedic application in the form of fracture fixation plates and artificial joints in hip bone, knee bone, shoulder bone, and ankle bone [1,2]. These materials are also used in the application of maxillofacial surgery, cardiovascular surgery, and dental implants. Biomaterials used in orthopedic application certainly have several requirements that must be met, namely these materials should have good physical, mechanical, chemical, corrosion resistance, and electrical properties. Therefore, several supporting scientific branches are needed as biomaterial references including biology, medicine, bio engineering and bio mechanics [3,4].

Over the past few decades, metallic biomaterials have a very important role in the scientific development of biomedical implants. In the modern era, metal has been used as a biomedical implant since more than 100 years ago, precisely in 1895 when for the first time metal plates were introduced



as human bone connector. Types of metals commonly used as implants include titanium alloys, CoCr alloys, and stainless steel [5,6]. Types of metals used in implant application include 316L stainless steel, CoCrMo, Ti6Al4V, TiNi, TiMo, 316 SS, and so on. Metal implants that are used to replace tissue in living things are required to have biocompatible properties/do not cause a reaction to the body of living things, have good corrosion resistance in order to minimize the risk of osteomyelitis or infection caused by bacteria so that it can cause bone swelling [7]. One of the most widely used alloy metals in almost all implants in cardiovascular science to otorhinology is 316L stainless steel.

AISI 316L is a type of resistant steel with a very low carbon content composition and has a high chromium and nickel composition. Very low carbon elements can reduce the risk of steel experiencing intergranular corrosion attacks, but if AISI 316L works in an environment with a high oxygen content and gain stress/load, then the material is at risk of corrosion attack in the form of SCC (Stress Corrosion Cracking) and pitting corrosion. AISI 316L stainless steel is included in austenitic steel with characteristics similar to ferritic steel type which cannot be hardened by heat treatment methods [8]. When given annealing heat treatment, stainless steel with austenitic phase which has characteristics will cause steel to be non-magnetic and can be hardened using the cold working method. The cold working method on the material experimentally is able to increase yield tensile strength, ultimate tensile strength, and fatigue strength [9]. One type of cold working method that is applied with the aim to increase mechanical strength, surface roughness and material service life is dry shot peening [10,11].

This study aims to determine the effect of steel ball diameter variation in dry shot peening process on surface roughness and corrosion rate of AISI 316L implant material.

2. Research methods

Specimen in the study is AISI 316L stainless steel made by cutting 50 cm x 50 cm of plate with 3 mm of plate thickness into small specimen of 2 cm x 2 cm for surface roughness testing and circle specimen with a diameter of 12 mm. This specimen has the chemical composition 67.56 % Fe, 1.76 % Mn, 16.8 % Cr, 11.44 % Ni, 2.42 % Mo, 0.68 % Si, and 0.56 % N. Furthermore, one of the specimen surfaces is smoothed using sandpaper with a size of 400, 600, 800, 1200 and 1500 and is polished using autosol so that the raw material specimen has the same initial condition. Another objective of polishing is to remove the impurities found in the material. After the polishing process is carried out, the next step is to do the shot peening process using steel balls as shown in Figure 1 below:

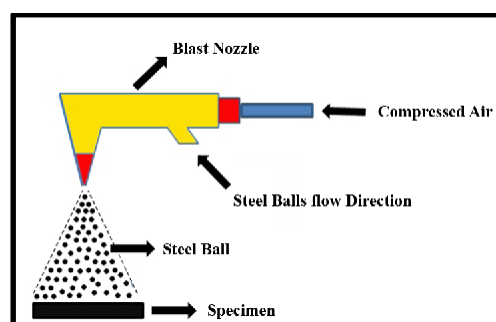


Figure 1. Shot Peening Process

The shot peening process is carried out using the principle of bombardment of AISI 440 C type steel balls through a 5 mm diameter nozzle/shot gun. The steel balls are fired with the help of high pressure air which is connected to a compressor with 250 liter of air capacity which has a working pressure of 7-8 kg/cm². Steel ball variations used are 0.5 mm, 1 mm, 2 mm, and 3 mm with a duration of shooting for 15 minutes. The results of the dry shot peening process are then tested for surface roughness using SE 1700 surfcode with *Fowler* brand with an M speed setting of 0.500 mm/s. The surface roughness data used is surface roughness average (Ra) with unit magnitude in micrometers

(μm). In addition to surface roughness test, dry shot peening material is also tested for corrosion using Potensiotate cells in simulated body fluid (SBF) media. The electrochemical process on corrosion test were performed using Galvanostat PGS 201T model with voltage in the range -20 mV to 20 mV and the electrical current in the range -2A to +2A. Simulated body fluid (SBF) is an intravenous fluid containing an ion concentration similar to human body fluids. Corrosion test data generated is in the form of corrosion current (I_{corr}) whose value is proportional to the corrosion rate of the specimen, the greater the I_{corr} value, the greater the tendency of the material to experience corrosion.

3. Results and discussion

3.1 Surface roughness test results

The results of the dry shot peening test on the surface roughness characteristics are shown on the graph with reference parameter of roughness average (Ra) value in each sample. The surface roughness value shows the configuration/surface profile of the test specimen. Figure 2 shows the significant differences between the materials that are subjected to dry shot peening treatment and the raw material that is not treated.

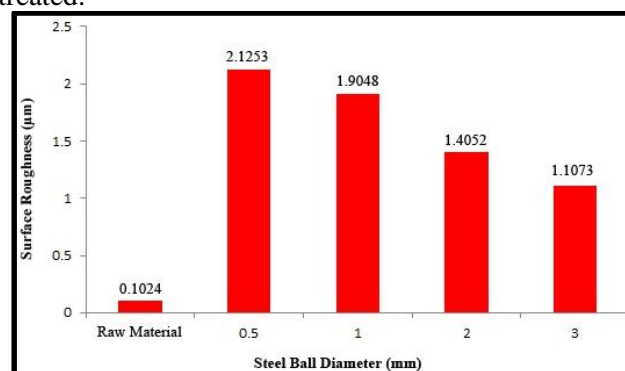


Figure 2. Surface roughness average (Ra)

Raw material has a roughness average (Ra) value of 0.1024 μm while materials with dry shot peening treatment using a variation of steel balls with diameters of 0.5 mm, 1 mm, 2 mm, and 3 mm have a roughness average (Ra) value of 2.1252 μm , 1.9048 μm , 1.4052 μm , and 1.1073 μm . The graph shows that the larger the steel balls used, the lower the roughness level (smooth) of the specimen surface. This is because the larger the size of the steel ball that is used as an abrasive material, it will result in a wider stretch of surface area compared to smaller steel balls. Steel balls that have a larger diameter will pound the surface of the specimen with a larger collision force resulting in a shallower/evenly distributed basin shape on the specimen surface. The broader but shallow form of the basin will cause the difference in height between the valley and the peak of the collision results to decrease so that this will result in refining the grain on the surface of the specimen and the lower level of surface roughness.

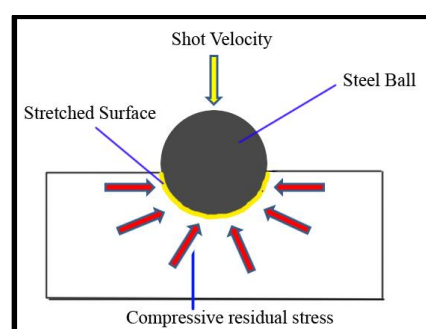


Figure 3. Schematic of shot peening bombardment on a surface

3.2. Corrosion Rate Test Results

Corrosion test is carried a solution of synthetic body fluid in the form of infusion liquid with the working principle of 3 cell electrodes. Determination of the corrosion rate is determined based on the corrosion current (I_{corr}) in each specimen. Test results data are shown in Figure 4 below:

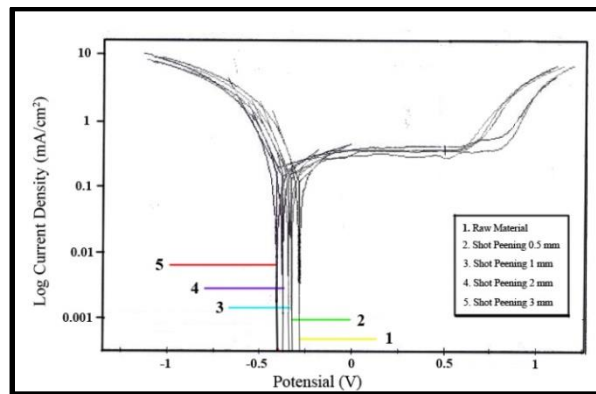
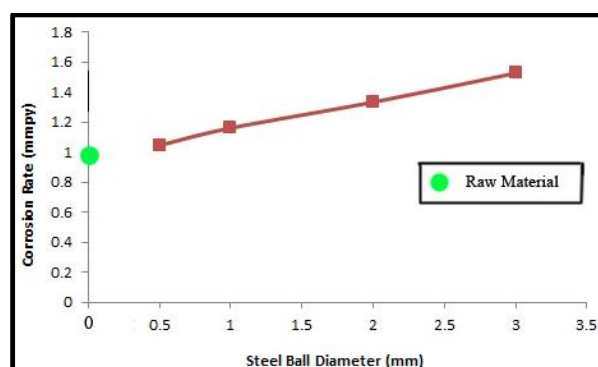


Table 1. Corrosion parameters obtained from Tafel fitting of potentiodynamic polarization curves.

Sample	E_{corr} (mV)	I_{corr} ($\mu\text{A}\cdot\text{cm}^{-2}$)
Raw Material	-0.263	0.251
Shot Peening 0.5 mm	-0.276	0.302
Shot Peening 1 mm	-0.281	0.357
Shot Peening 2 mm	-0.315	0.385
Shot Peening 3 mm	-0.382	0.413

(a)



(b)

Figure 4. (a) Polarization curves of AISI 316L immersed in infusion liquid
(b) Corrosion rate of AISI 316L testing material

Figure 4 (a) shows the difference in potential value (E_{corr}) and the corrosion rate between raw material and specimens that received shot peening treatment. The value of the corrosion rate is proportional to the magnitude of I_{corr} obtained by extrapolating the graph of the current density

measurement of the cathode and anode to the potential. The tafel chart shows that smaller the steel ball used, the potential value of the tafel chart will moved to a more positive direction. This will certainly have an impact on increasing the passivation of the test material on electrochemical reactions. The corrosion rate of AISI 316L material will decrease along with the change in diameter of the steel balls. The test results show that the corrosion rate of AISI 316L raw material is 1.036 mmpy. It is followed by materials that receive shot peening treatment with steel ball diameter of 0.5 mm, 1 mm, 2 mm, and 3 mm which have corrosion rate of 1.047 mmpy, 1.162 mmpy, 1.334 mmpy, and 1.528 mmpy. Based on these data, it can be concluded that the shot peening process can improve corrosion resistance of AISI 316L material. The shot peening process is able to produce layers that are passivated and free of porosity. The larger the diameter of the steel ball used, the greater the compressive residual stress resulting from the impact on the specimen surface. Compressive residual stress has a major effect on the process of forming passivation layers which aims to increase corrosion resistance. The greater the value of compressive residual stress will result in increased corrosion current density in the process of chemical polarization. This is because compressive residual stress affects the bonds between atoms in the granules. The higher the compressive residual stress on the material, the greater the bonding distance between atoms which results in a decrease in the quality of the passivation layer that forms on the surface of the specimen.

4. Conclusion

Based on the results of the study, it can be concluded that dry shot peening process with steel ball variation has an effect on the material roughness level and is able to improve the corrosion resistance of AISI 316L stainless steel. The larger the size of the steel ball used will cause the value of surface roughness of the test specimen to be lower and decrease the corrosion rate of the material. The highest surface roughness value is 2.1252 μm using a steel ball with a diameter of 0.5 mm and the smallest surface roughness value is 1.1073 μm using a steel ball with a diameter of 3 mm. Corrosion rate experiences an increase until reaching the highest value of 1.562 mmpy at a steel ball with a diameter of 3 mm. The minimum corrosion rate value is achieved at steel ball with a diameter of 0.5 mm with a value of 1.047 mmpy.

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