Effect of Deformation and Slag Ball Blasting on Micro Hardness, Micro Structure, and Surface Morphology of AISI 316LVM Stainless Steel

M. Crenata., Suyitno
Center for innovation of Medical Equipments and Devices (CIMEDs)
Jurusan teknik Mesin dan Industri, Universitas Gadjah Mada,
Jl. Grafika 2, Yogyakarta 55281, Indonesia
mercelliacrenata@gmail.com
Center for innovation of Medical Equipments and Devices (CIMEDs)
Jurusan teknik Mesin dan Industri, Universitas Gadjah Mada,
Jl. Grafika 2, Yogyakarta 55281, Indonesia
suyitno@ugm.ac.id

Abstract

Biomaterial is a synthetic material that has direct contact with human body. AISI 316LVM stainless steel is a type of metallic biomaterial that has a good combination in biocompatibility and mechanical properties. Concern of this research is to improve mechanical and physical properties of stainless steel AISI 316LVM. Samples was deformed and blasted with slag ball. Deformation was done by applied specific load to reach 10,15, and 25% of deformation. Slag ball blasting was done by blasted slag ball with diameter size : < 0,6mm, 0-1mm, 1-2mm, and 2-5mm from the surface of material that has been deformed. Micro hardness test was done by 100 gram load with 15s dwell time. The test was done in 0,05mm depth from surface of material that has been treated. Data was taken from range 0,05mm at first 3 point and 0,1mm at another point until 1,1mm depth from surface of material. Microstructure observation was done with optical microscope. Surface morphology observation was done by SEM. Results of this research are deformation and slag ball blasting increased the surface microhardness. The surface microhardness increased on area less than 15 micrometers from the surface. After treatment grain size turned into fine grain because of plastic deformation. Refinement grain size on surface area that produced by surface treatment can’t be observed clearly on photomicrograph. Surface morphology produced by slag ball blasting show that the microstructure change can occur up to 15 micrometers from the surface.

Keyword : deformation, slag ball, micro hardness, microstructure, AISI 316 LVM.

Introduction

Implant is medical device that consist of several biomaterials. Material that is used as biomaterial must fulfil certain functions such as strength, high resistance of corrosion and biocompatibility. Biomaterial can be metallic, polymer, ceramic or composite depends on its application.

Metallic material that was used first as biomaterial is vanadium. Vanadium was chosen because of its good mechanical properties, but in its application vanadium corroded quickly inside of human body. Stainless steel and Co-Cr alloy were used to replace vanadium at 1930 [3].

One kind of stainless steel that is used as biomaterial is AISI 316LVM stainless steel. This material can combined good mechanical properties with high biocompatibility [7].

Deformation is a change in dimension because of force that applied [8]. Plastic deformation is deformation that crossed its elastic boundary. Plastic deformation can increase strength of material and corrosion resistance so it can increase lifetime and efficiency [8].

Slag ball blasting is kind of surface treatment that blasted abrasive particle with high speed at surface of material. Slag ball blasting used slag ball with certain size of diameter as abrasive particle.

Both deformation and slag ball blasting in this research used as surface treatment in AISI 316LVM stainless steel to get plastic deformation. Then it will increase the mechanical properties of this material.

Materials and Experimental Methods

Samples were prepared from AISI 316LVM plate with a dimension of 200 x 140 x 40 mm. The samples chemical compositions (wt%) are 62.9 Fe, 0.0144 C, 0.4155 Si, 1.67 Mn, 17.3 Cr, 1.73 Mo, and 15.5 Ni. One sample is used as controlled variable. The other samples were used for deformation, slag ball blasting, and deformation that combined with slag ball blasting.

Deformation was performed with hydraulic pressure machine (Daichi Keiki) with 200 ton of maximum load.

The principle of the slag ball blasting has been introduced previously. During slag ball blasting, the sample was affixed on the bottom side of chamber then blasted perpendicular with abrasive particle used blaster gun whose distance 100 mm. Pressure at compressor kept at 5 – 7 kg/cm$^{2.}$

The parameter in this in this research are described below:

1. Variation on the treatment duration
   The samples were treated for 10, 15, and 20 min using SiO_2 slag ball as abrasive material.
2. Variation on the diameter size of abrasive material
   The samples were treated using SiO_2 slag ball with diameters <0.6, 0 – 1, 1 – 2, and 2 – 5 mm.
3. Variation on the degree of deformation
   The samples were treated with 10, 15, and 25% degree of deformation with loads of 445, 550, and 620 KPa.

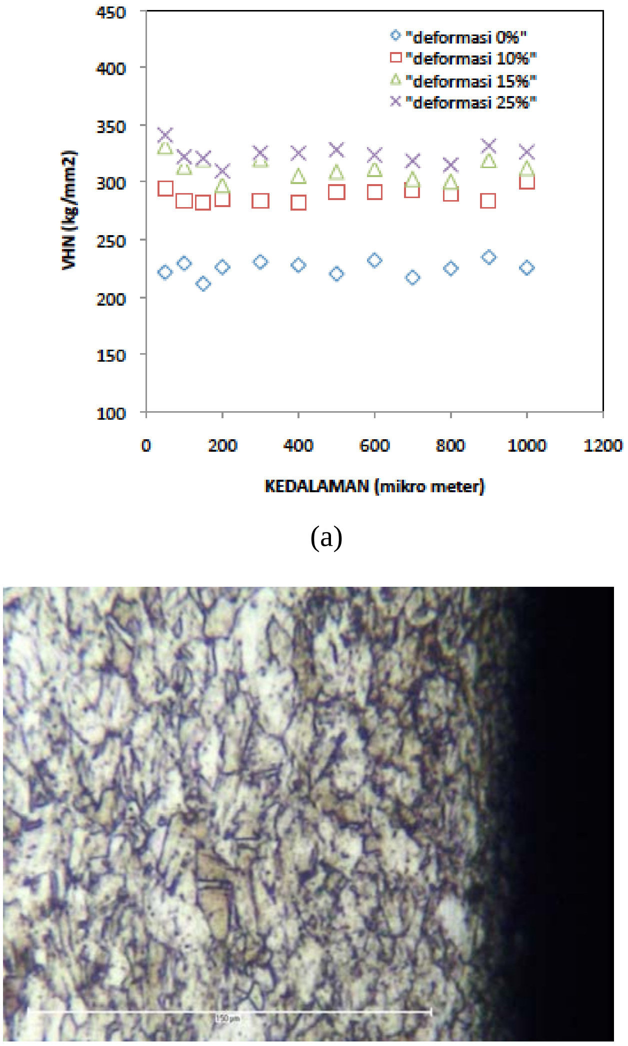
Microhardness measurement was measured using a microhardness tester (Buehler, USA) with an indenting load 100 gr with 15s dwell time. Each sample was cut laterally after treatment to expose its cross sectional area at which measurements was conducted. After treatment each sample was mounted with resin and polished. The data of microhardness value measured at 0.05 mm from the surface of material for first three points and at 0.1 mm at the next point until 1.1 mm from the surface of material.

Microstructure observation was characterized by using an optical microscope (Olympus, Japan) that connected with Optilab at the cross section area of the samples that treated before. Before the observation, the samples polished and etched with HCl and HNO_3.

Surface morphology observation was performed by the use of scanning electron microscope (JEOL, JSM-6510LA Analytical Scanning Electron Microscope) with 750 and 2500x magnification. Samples that observed with scanning electron microscope were treated by slag ball blasting whose < 0.6 and 1 – 2 mm diameter of abrasive material with 20s duration. Observation was performed at the surface and cross sectional area of the samples that treated.

Result and Discussion

The microhardness distribution at 0, 10, 15, and 25% degree of deformation are shown in Fig.1.



(a)

(b)

Figure.1. Deformation. Fig. (a). Effect of deformation degree on the microhardness, (b) microstructure observation at 10% deformation degree.

Microhardness value increased dependent on deformation degree or cold work degree. Deformation degree defined in Equation.1 :

$$\%CW = [(Ao-Ad)/Ao] \times 100\% \qquad (1)$$

Where:

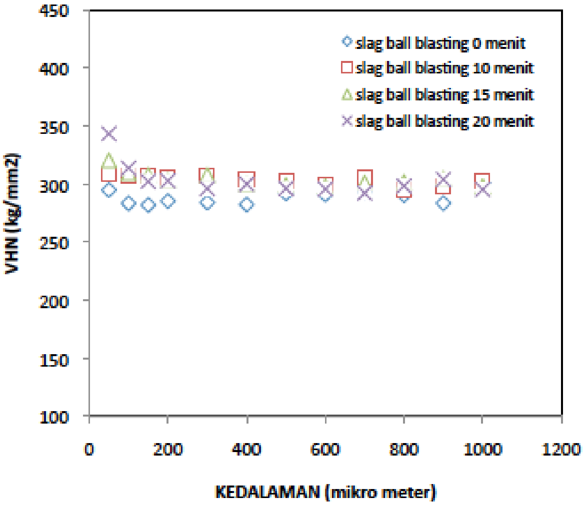
%CW : percent cold work/ deformation degree
Ao : the original area of cross section that experiences deformation
Ad : area after deformation.

Load that applied at the samples generated plastic deformation. Plastic deformation corresponds to the motion of large numbers of dislocations. The dislocation density in a metal increases with deformation, due to dislocation multiplication or the forming of new dislocations. The higher deformation degree generated higher plastic deformation that increased microhardness. Deformation also generated grain refinement at the samples. The grains flattened and turn into fine grain. Since the grains are of different orientations, a dislocation passing into other grain will have to change its direction of motion, this becomes more difficult as the crystallographic misorientation increased[4].

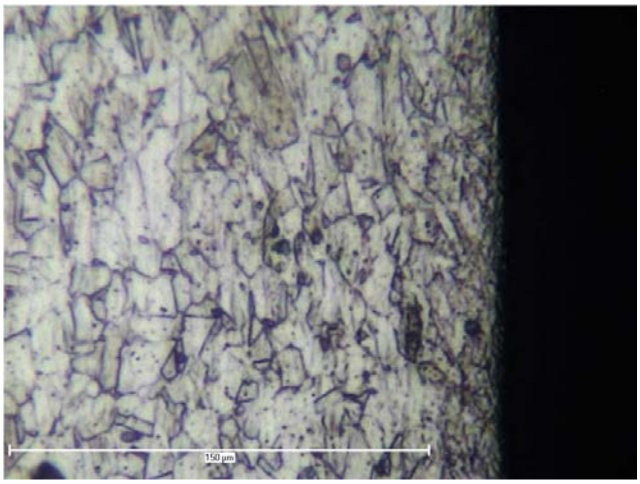
Consequently, the average distance of separation between dislocations decreased, the dislocations are positioned closer together. On the average, dislocation-dislocation strain interactions are repulsive. The result is that the motion of a dislocation is hindered by the presence of other dislocations. As the dislocation density increases, this resistance to dislocation motion by other dislocation becomes more pronounced [4][9][10].

Deformation that combined with slag ball blasting generated the highest surface microhardness. The highest Vickers Hardness Number in this treatment is obtained at the samples that deformed with 25% degree then blasted by slag ball with 2 – 5 mm size of diameter at 20 minutes duration. Figure.2(a). shows microhardness distribution across the samples sectional areas that deformed than blasted at the various duration of time.

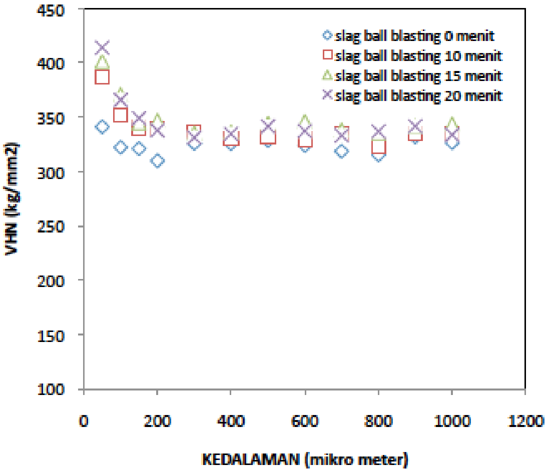
Micro structure observation shown in Fig.2(b). The shot impact creates a rough surface. The rough and irregular shape particles cause severe crack on the surface. The treatment duration also influence the sample’s roughness and the grain refinement. After treatment the grain size flattened and turn into fine grain.



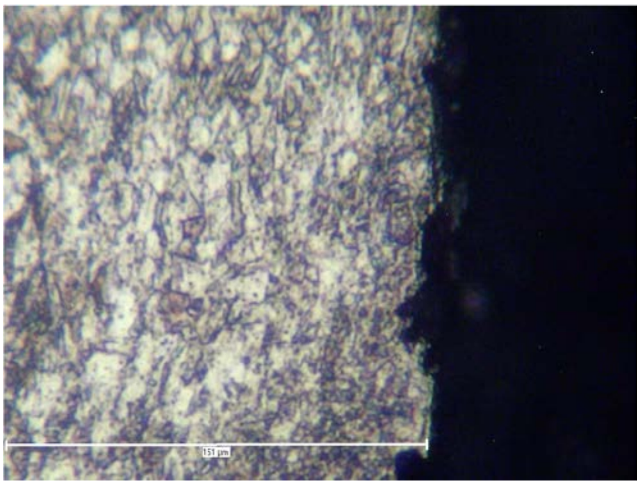
(a)



(b)



(c)



(d)

Figure.2. Effect of duration treatment at samples. Fig.(a). deformed by 10 % degree of deformation and <0.6 mm size of slag ball diameter, (b) micro structure observation at samples that deformed by 10 % degree of deformation, 20 minutes and <0.6 mm size of slag ball diameter, (c) deformed by 25% degree of deformation and 2 – 5mm size of slag ball diameter, (d) micro structure observation at samples that deformed by 25 % degree of deformation, 20 minutes and 2 - 5 mm size of slag ball diameter.

The research shown that deformation and slag ball blasting increases the microhardness value at the surface of AISI 316LVM stainless steel. The value at the area that is closer to the blasted surface is higher that the further area. The enhancement is attributed by presence of residual stress. The residual stress is formed by deformation and impact between surface samples with the abrasive material. The microhardness value of the treated samples approaches values that similar to the untreated sample at the depth of up tp 0.15mm. The microhardness value at the untreated sample has relatively constant at all measure points. Decrease in microhardness value after specific length caused by decrease in the effect of plastic deformation [5].

Besides of increases in microhardness value, deformation and slag ball blasting made the surface grains refinement at the samples. According to Hall-Petch theory, grain size affects the microhardness value. The smaller the grain size will give the higher microhardness value [4]. Equation.2. shows that yield strength is depend on the grain size of the material. Smaller grain size will increase yield strength consequently microhardness will increase.

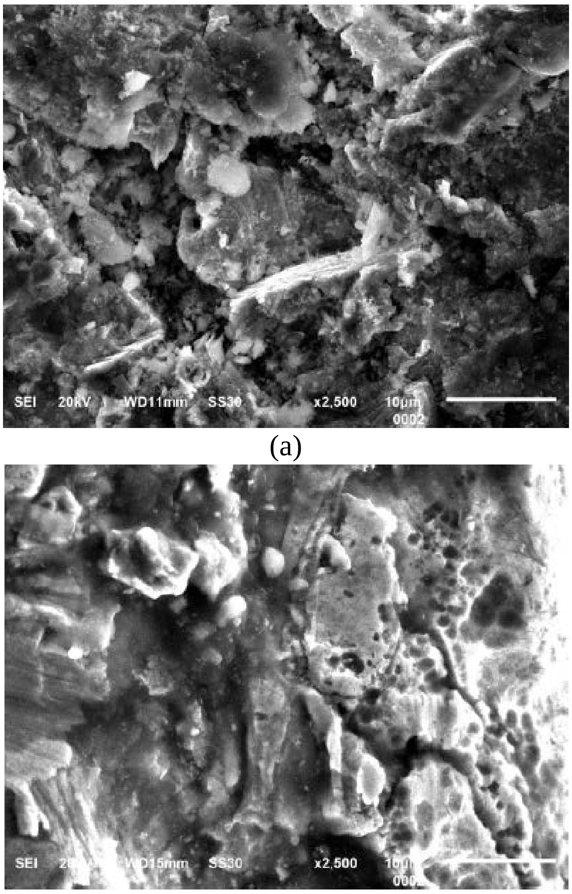
$$\boldsymbol{\sigma}y = \boldsymbol{\sigma}0 + kyd\text{-}1/2 \quad (2)$$

Where:
Σy : yield strength (N/mm2)
σi, k : constants depend on material (N/mm2)
d : diameter grain (mm)

This result in good agreement with the previous studies in shot peening and sandblasting. The previous study in titanium and AISI 316L stainless steel shown, that the treatment generated grain refinement at the treated surface [2][7].

The used of slag ball with larger diameter size in slag ball blasting increases the surface microhardness. Larger diameter size of slag ball in slag ball blasting delivers a greater impact load and yields a higher surface microhardness than the smaller one. This is caused by the magnitude of impact load (F) of single slag ball varies with its mass (m). Since the material of all slag balls in every various slag ball blasting treatment is mostly identical, their mass corresponds to its diameter [2].

Fig.4. (a – b) shows SEM photographs of the surface and cross sectional area of samples that treated by 20 minutes slag ball blasting with 1 – 2 mm diameter slag ball.



(a)

(b)

Figure.4. Surface morphology observation using SEM at samples that blasted 20 minutes with magnification 2500x. Fig.(a). surface sample that blasted with 1 – 2 mm slag ball diameter, (b) cross sectional sample that blasted with 1 - 2 mm slag ball diameter.

Scanning electron microscope shown, that slag ball blasting causes plastic deformation, resulting in an irregular rough surface morphology. Observation at the surface of material shows distribution of grain refinement and roughness at the sample's surface. Slag ball blasting generated heterogeneous craters at the surface. It may be caused by unsteady velocity and slag ball impact when sample treated by slag ball blasting [1]. This impact also generate crack at the surface of the treated sample [6].

At the cross sectional of the sample, SEM shown that slag ball blasting changed micro structure and generated grain refinement. This phenomenon only happened about 0.15 mm from the surface. This is appropriate with increases in surface microhardness that only happened about 0.15 mm from the surface then decrease to the untreated microhardness value. It indicates that effect of plastic deformation only happened in the surface of the samples.

Conclusion

Deformation and slag ball blasting increased the surface microhardness. The values increased on area less than 15 micrometers from the surface. After treatment grain size turned into fine grain because of plastic deformation. Surface morphology produced by slagball blasting show that the microstructure change can occur up to 15 micro meters from the surface.

References

[1] Aparicio, Conrado., Gil, F. Javier., Fonseca, Carlos., Barbosa, Mario., Planell, Josep Anton., 2003, Corrosion Behaviour of Commercially Pure Titanium Shot Blasted with Different Materials and Sizes of Shot Particles for Dental Implant Applications, Biomaterials, Volume 24, 30-35

[2] Arifvianto, B., Suyitno., Mahardika, M., 2010, The Effect of Sandblasting and Surface Mechanical Attrition Treatment on Surface Roughness, Wettability, and Microhardness of AISI 316L, International

[3] Bronzino, Joseph D., Park, Joon B., 2000, Biomaterials Principles and Applications, CRC Press LCC,Boca Raton, Florida

[4] Callister, W.D. Jr., 2001, Fundamentals of Materials Science and Engineering, 5th edition, John Wiley and Sons, Inc., USA

[5] Gil, F.J., Planel, J.A., Padros, A., Aparicio, C., 2007, The effect of Shot Blasting and Heat Treatment on the Fatigue Behavior of Titanium for Dental Implant Applications, Dental Material, Volume 23, 486-491

[6] Jiang, X.P., Wang, X.Y., Li, J.X., Li, D.Y., Man, C.S., Shepard, M.J., Zhai, T., 2006, Enhancement of Fatigue and Corrosion Properties of Pure Ti by Sandblasing, Material Science and Engineering A, Volume 429, 30-35

[7] Multigner, M., Frutos, E., Carrasco, G.J.L., Jimenez, J.A., Marin, P., Ibanez, J., 2009, Influence of the Sandblasting on the Subsurface microstructure of 316LVM Stainless Steel: Implications on the Magnetic and Mechanical Properties, Material Science and Engineering C, Volume 29, 1357-1360

[8] Singh, U.K., Dwivedi, Manish., 2009, Manufacturing Processes, New Age International (P) Limited, New Delhi

[9] Takahashi, Seiki., Echigoya, Junichi., Ueda, Terushige., Li, Xingguo., Hatafuku, Hiroshi., 2001, Martensitik Transformation due to Plastic Deformation and Magnetic Properties in SUS 304 Stainless Steel, Journal of Material Processing Technology, Volume 108, 213-216

[10] Tavares, S.S.M., Da Silva, M.R., Pardal, J.M., Abreu, H.F.G., Gomes, A.M., 2006, Microstructural Changes Produced by Plastic Deformation in the UNS S31803 Duplex Stainless Steel, Journal of Materials Processing Technology, Volume 180, 318-322

[11] B.N. Mordyuk, G.I. Prokopenko, J. Sound Vibr. 308 (2007) 855