P. T. ISWANTO, R. I. YAQIN, AKHYAR, H. M. SADIDA

ISSN 0543-5846
METABK 59(3) 309-312 (2020)
UDC – UDK 669.15.76.74.77.711:539.43:620.197.6:620.178.1:620.193=111

INFLUENCE OF SHOT PEENING ON SURFACE PROPERTIES AND CORROSION RESISTANCE OF IMPLANT MATERIAL AISI 316L

Received – Primljeno: 2019-11-05
Accepted – Prihvaćeno: 2020-03-05
Original Scientific Paper – Izvorni znanstveni rad

AISI 316L is one kind of implant materials due to its excellent mechanical properties and corrosion resistance. However, some of their mechanical and surface properties must be improved to a higher level of cobalt-based alloys and titanium properties. Shot peening is a surface treatment that improves properties on material surface. In this research, the effects of shot peening duration (0, 2, 4, 10, 20 and 30 min) on surface hardness, roughness, wettability, and corrosion in 0,9 % sodium chloride were investigated and discussed. According to the experimental results, it was found that shot peening increases both surface roughness and surface hardness compared to untreated sample. Furthermore, shot peening can reduce contact angle and corrosion rate after 2 minutes.

Keywords: AISI 316L, shot-peening, roughness, hardness, corrosion

INTRODUCTION

The most popular and commonly used materials as orthopedic implant are titanium and stainless steel. They have some advantage characteristics, for example, high strength, good ductility, good biocompatibility[1], and good corrosion resistance.

On the other hand, implant materials, which are mainly used to connect human bone, should not release their ions that are toxic and cryogenic to the body [2]. AISI 316L is one of the most extensive materials used for engineering, biomedical, and chemical industries. It has good corrosion and oxidation resistance [3] due to its high content of nickel and chromium [4-5].

In general, AISI 316L is utilized to produce artificial joints, bone plates, stent and prosthesis due to favorable combination of mechanical properties, resistance corrosion and relatively low cost compared to the other metallic biomaterials[6]. However, after its implantation in human bodies, some failures which can lead to the inflammation reaction are feasible [7]. Corrosion is one of natural phenomenon which is plausible for metals or alloy as implant materials in the human body[8]. Because of high concentration of Cl^- and the temperature range of 36,7 – 37,2 ^{o}C, the fluid in human body is considered as corrosive environment [7].

One of the available treatments for implant material is shooting the steel ball with air pressure at the material, a process called peening [9]. Shot peening is one of commonly used a mechanical surface treatment method in the automotive and aerospace industries[10]. The shot peening treatment produces a rough surface, increased surface hardness, and a developed profile of residual stress [8]. Rough surface and wettability are significant for implant materials, especially in bio-adhesion. A rough and hydrophilic surface can cause adsorption of protein which initiates the bone development in human bone [3]. Liu et al. concluded that after shot peening treatment, the surface roughness of Ti-6Al-V increases as time duration of treatment increases [11]. Ahmed et al. reported that the advantages of shot peening are not only to improve surface hardness and roughness, but also to reduce the contact angle of wettability. Thus, shot peening can also improve the corrosion resistance [12].

The main objective of this research is to investigate the effects of shot peening duration on the surface hardness, the surface roughness, the wettability and the corrosion resistance of AISI 316L.

P. T. Iswanto (priyotri@ugm.ac.id), R.I. Yaqin, H. M. Sadida: Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.
Akhyar, Department of Mechanical Engineering and Industrial Engineering, Syiah Kuala University, Darussalam, Banda Aceh, Indonesia

EXPERIMENTAL PROCEDURE

The commercial plate AISI 316L was a manufactured corrosion tested specimen with a 14 mm diameter and 3 mm thickness. The other tests are done with a specimen which has 20 mm length and 3mm thickness. All specimens are grinded by #320 till #2 000 SiC paper and polished with metal polish. After the specimens were grinded and polished, then the specimens were submerged in alcohol approximately 10 minutes before shot peening treatment.

The shot peening process was done on the AISI 316L steel plate using steel ball with average size of 0,6 mm (with code S230) with hardness number 40 - 45 HRC. The distance between nozzle and specimen surface was 100 mm. The compressor pressure for shot steel ball was 8 bar. The variable duration of shot peening treatment was done in 0, 2, 4, 10, 20 and 30 minutes.

The chemical composition test was performed using Metalscan analyzer 2500 series a metal analyzer tool. The surface roughness test was performed on the surface of specimen by contact stylus profilometer (Surfcorm 120A, Advanced metrology system, UK). The vickers microhardness test was performed on the surface of specimen by using a behler model with a 100grf in 15s time loading, according ASTM E384.

The surface wettability equipment test was recorded using camera a high-resolution camera for measuring droplet contact angle between liquid and surface sample. The liquid droplet for wettability test is distilled water. The contact angle can be measured using Snake-based method by plug-in software image J.

The corrosion test was held using a direct current method with electrochemical system Amatek Versastat 4. This type of electrolyte corrosion process is a simulation of the human body 0,9% sodium chloride OTSU-NS. The chemical composition of OTSU-NS is NaCl 4.5 gr, Osmolaritas 308 mOsm/l, Na^+ 154 mEq/l, Cl^- 154 mEq/l, and sterile aquades 500ml. All of the potentials were measured with a reference electrode (Ag/AgCl[KCl]), and a carbon rod was used as an auxiliary electrode.

RESULT AND DISCUSSSION

Table 1 **Chemical composition wt./ %**

	C	Mn	Cr	Ni	Mo	Fe
AISI 316L	0,03	1,08	16,78	10,87	1,89	Bal.
ASTM A276	0,03	2,00	16,0-18,0	10,0-14,0	2,0-3,0	Bal.

The result of the composition test for AISI 316L is shown in Table 1. The test results were then compared with standard ASTM A276 [13]. According to the table, the specimen composition is still in range of standard composition of ASTM A276.

The surface roughness test was done on with and without shot peening treatment specimens. Figure 1 shows the surface roughness parameter Ra (hollow circle mark), Rmax (solid circle mark) and Rz (solid triangle mark) of the variety duration shot peening samples. All parameters decrease as the duration of shot peening increases. The specimen that underwent 2 minutes of shot peening has the highest surface roughness parameter. Figure 1 the increase of parameter surface roughness in our study shares a similar results with results of surface roughness from other research by azar et al [8]. The increasing surface roughness parameter due to the surface of specimen being plastic is deformed by impact steel ball [2]. The shorter duration of shot peening affects heterogeneity on the surface layer [8].

Figure 2 shows that as the duration of the shot peening process increases, the surface hardness increases. The highest surface hardness occurs when the duration of shot peening is 30 minutes with 517 HV. It is because the high dislocation density is built in sublayer the material during shot peening [6]. Moreover, induced residual stress can increase surface hardness [14]. Dislocation

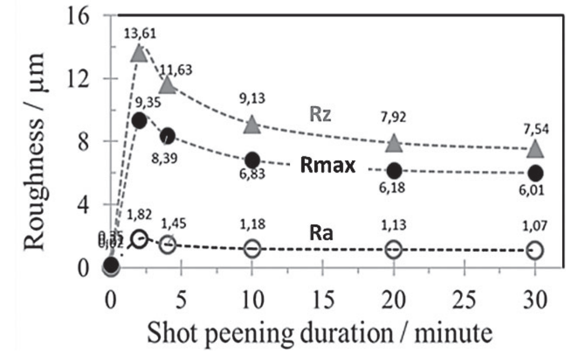

Figure 1 Surface roughness vs duration

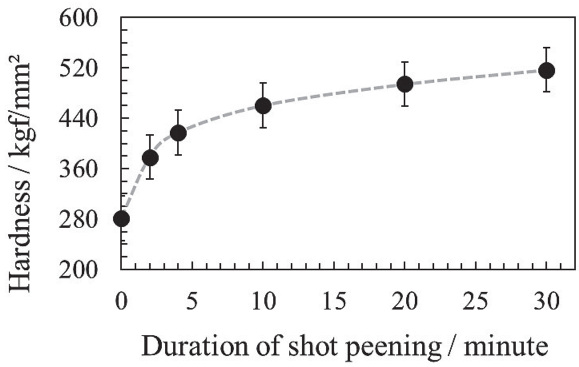

Figure 2 Surface hardness vs duration

density and residual stress affect the grain refinement become smoother. The grain refinement in the surface layer has the highest hardness than in the sub layer.

Figure 3 and 4 show the effect of duration shot peening with initial contact angle (by using distilled water). The surface wettability was enhanced by shot peening treatment as the contact angle decreases in all treated samples. The average contact angles of initial samples are 82,55 ° indicating less hydrophilic property due to very smooth specimen surface after it is polished. After initial samples, the contact angle of wettability was decreased from 82,55 ° until 63,47 °. The increased duration of shot peening caused an increase in the contact angle droplet from 63,47 ° until 75,15 °. It is due to the effect of surface roughness shot peening result [3,12]. Surface characteristic, surface chemistry, and surface

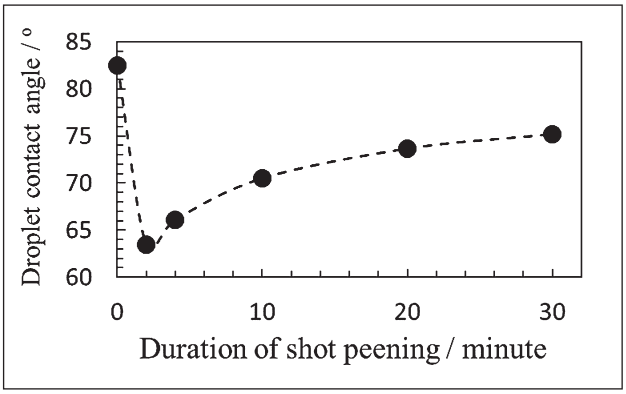

Figure 3 Effect of shot peening on wettability

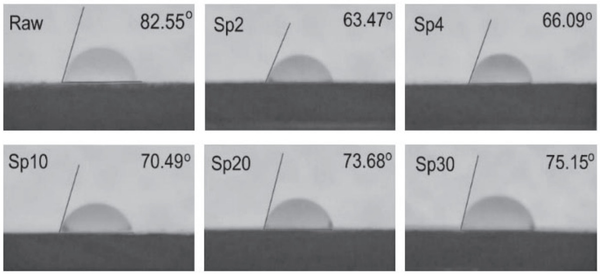

Figure 4 Surface condition contact angle

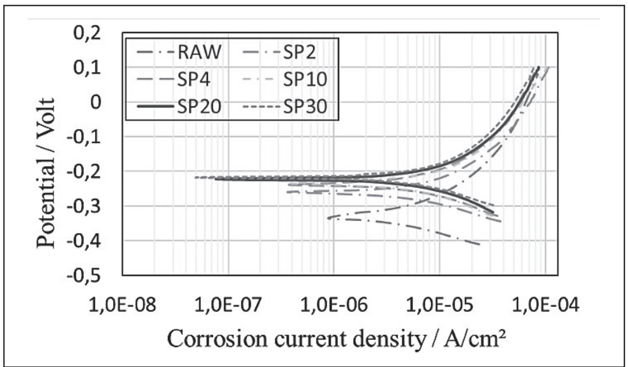

Figure 5 Potentiodynamic curves for different duration of shot peening

topography can affect the characteristic of surface wettability.

The characteristic of substrate surface (e.g. roughness, porous, coating, absorbed layer, etc.) cause spreading of droplet and wetting behavior of surface samples [3]. The spreading droplet reduce the contact angle surface. Generally, coarse surface roughness will be hydrophilic, and fine surface will be hydrophobic.

Figure 5 shows the potentiodynamic polarization initial of samples and duration of shot peening. The result of corrosion current density (i_{corr}), corrosion potential (E_{corr}), and corrosion rate each specimen from potentiodynamic polarization curves is shown in Table 2. Shot peening treatment cause increasing corrosion potential (E_{corr}) compared with the initial sample (non-treatment). The longer duration shot peening, the higher potential corrosion (E_{corr}) becomes. It will make sample with longer duration that becomes more catodic. This condition will be more electrochemically protected compared to non-treatment specimen. In this state, a higher potential corrosion specimen will form a passive layer in the surface [8]. The higher potential will have a better protection against corrosion. This investigation can be proven by a decrease in corrosion current density (i_{corr}). Thus, shot peening treatment affect to corrosion current density (i_{corr}) as well [2, 5, 8].

The comparison between higher surface roughness and heterogeneous of a surface specimen with lower residual compressive stress level would make ineffective passive layer. This condition makes pitting corrosion easy to attack surface samples. Figure 6. report ratio reduction of corrosion rate with initial sample (not treatment). After 2 minutes, ratio of corrosion rate decreases

Table 2 **E_{corr} i_{corr} and corrosion rate**

Specimen	Raw	Sp2	Sp4	Sp10	Sp20	Sp30
i_{corr} / μA/cm²	2,86	3,0	2,7	2,49	2,13	1,65
E_{corr} / mV	-333	-258	-238	-234	-221	-218
CR / mpy	1,29	1,4	1,2	1,13	0,97	0,75

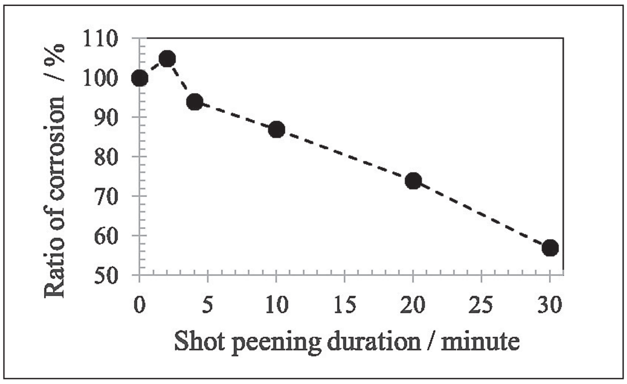

Figure 6 Corrosion rate ratio vs duration

as the increasing of shot peening duration. The increasing shot peening duration built grain refinement [11], that caused plastic deformation in surface layer. This condition allows with stronger passive layer can decrease corrosion rate [8].

According to Table 2, a specimen with 2 minutes shot peening duration has increased corrosion current density and corrosion rate. This behavior may be caused by surface roughness, the surface heterogeneous and lower stress level lower after shot peening process [8]. The combination of higher surface roughness and heterogeneous of surface the specimen with a lower residual compressive stress level would make ineffective passive layer. This condition makes pitting corrosion easy to attack surface samples. Figure 6 reports the ratio of corrosion rate reduction with initial sample. After 2 minutes, ratio of corrosion rate decreases as the increasing of shot peening duration. The increased shot peening duration built grain refinement [11] that caused plastic deformation in surface layer. This condition allows with stronger passive layer in surface can decreases corrosion rate [8].

CONCLUSIONS

The research conclude that shot peening significantly increases hardness. The surface roughness first highly increases and then decreases with increasing of shot peening duration. Furthermore, shot peening reduce contact angle as hydrophilic and reduce corrosion rate after 2 minutes. Duration at 2 minutes has the highest of surface roughness with lower surface residual compressive stress which would make ineffective passive layer.

Acknowledgments

This work is supported by Hibah PDUPT - Universitas Gadjah Mada.

REFERENCES

[1] S. M. Perren, Mathys R, Pohler O. Principles of Fracture Management: Implants and Materials in Fracture Fixation. AO Publishing: New York 2000.

[2] P. T. Iswanto, V. Malau, B. H. Priyambodo, T. N. Wibowo, and N. Amin, Effect of Shot-Peening on Hardness and Pitting Corrosion Rate on Load-Bearing Implant Material AISI 304 MSF 901(2017), 91–96.

[3] B. Arifvianto, M. Mahardika, P. Dewo, P. T. Iswanto, and U. A. Salim, Effect of surface mechanical attrition treatment (SMAT) on microhardness, surface roughness and wettability of AISI 316L Mater. Chem. Phys. 125 (2011) 3, 418–426.

[4] J. Biehler, H. Hoche, and M. Oechsner, Corrosion properties of polished and shot-peened austenitic stainless steel 304L and 316L with and without plasma nitriding SCT 313(2017), 40–46.

[5] E. K. Brooks, R. P. Brooks, and M. T. Ehrensberger, Effects of simulated in fl ammation on the corrosion of 316L stainless steel Mater. Sci. Eng. C. 71(2017), 200–205.

[6] A. A. Ahmed, M. Mhaede, M. Wollmann, and L. Wagner, Surface & Coatings Technology Effect of surface and bulk plastic deformations on the corrosion resistance and corrosion fatigue performance of AISI 316L SCT 259(2014), 448–455.

[7] H. Yang, K. Yang, and B. Zhang, Pitting corrosion resistance of La added 316L stainless steel in simulated body fluids Materials Letters 61 (2007), 1154–1157.

[8] V. Azar, B. Hashemi, and M. R. Yazdi, The effect of shot peening on fatigue and corrosion behavior of 316L stainless steel in Ringer's solution SCT 204(2010) 21–22, 3546–3551.

[9] Suyitno, B. Arifvianto, T. D. Widodo, M. Mahardika, P. Dewo, and U. A. Salim, Effect of cold working and sandblasting on the microhardness, tensile strength and corrosion resistance of AISI 316L stainless steel Inter. Journal of Minerals, Metallurgy, and Materials 19 (2012) 12, 1093–1099.

[10] H. Lee, D. Kim, J. Jung, Y. Pyoun, and K. Shin, Influence of peening on the corrosion properties of AISI 304 stainless steel Corros. Sci. 51 (2009) 12, 2826–2830.

[11] G.Y. Liu, Li MQ, Liu HJ. Nanostructure and surface roughness in the processed surface layer of Ti-6Al-4V via shot peening. Materials Characterization 123(2017), 83-90.

[12] A.A. Ahmed, Mhaede M, Basha M, Wollmann M, Wagner L. The effect of shot peening parameters and hydroxyapatite coating on surface properties and corrosion behavior of medical grade AISI 316L stainless steel SCT 280(2015) 347-358.

[13] ASTM Standard A276-10, Standard spesification for stainless steel bars and shapes United States 2010.

[14] B. Hasemi, Yazdi R, Azar V. The wear and corrosion resistance of shot peened–nitrided 316L austenitic stainless steel. Material and Design 32(2010) 3287-3292.

Note: The responsible English translator is Emely Peterson, The Languange Center of Syiah Kuala Univ.