WEAR PROPERTIES OF PASTE BORONIZED 316 STAINLESS STEEL BEFORE AND AFTER SHOT BLASTING PROCESS

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ABSTRACT

This research investigates and analyzes wear properties of 316 stainless steel before and after applying paste boronizing process and to investigate the effect of shot blasting process in enhancing boron dispersion into the steel. In order to enhance the boron dispersion into 316 stainless steel, surface deformation method by shot blasting process was deployed. Boronizing treatment was conducted using paste medium for 8 hours under two different temperatures which were 850^{0}C and 950^{0}C. Wear behaviour was evaluated using pin-on-disc test for abrasion properties. The analysis on microstructure, X-ray Diffraction (XRD) and density were also carried out before and after applying boronizing treatment. Boronizing process that had been carried out on 316 stainless steel increases the wear resistance of the steel compared to the unboronized 316 stainless steel. The effect of boronizing treatment together with the shot blasting process give a greater impact in increasing the wear resistance of 316 stainless steel. This is mainly because shot blasted samples initiated surface deformation that helped more boron dispersion due to dislocation of atom on the deformed surface. Increasing the boronizing temperature also increases the wear resistance of 316 stainless steel. In industrial application, the usage of the components that have been fabricated using the improved 316 stainless steel can be maximized because repair and replacement of the components can be reduced as a result of improved wear resistance of the 316 stainless steel.

Keywords: *stainless steel, paste boronizing, shot blasting, wear*

1. INTRODUCTION

Stainless steel is mainly selected as engineering material due to its high corrosion resistance caused by high chromium content [1]. Stainless steel has been divided into four basic types which are martensitic stainless steel, ferritic stainless steel, austenitic stainless steel and precipitation-hardening stainless steel [2]. Austenitic stainless steel has the austenite structure with face centered cubic structure while ferritic stainless steel has the ferrite structure with body centered cubic structure [2]. Martensitic stainless steel has a more complex body centered tetragonal crystal structure due to a rapid-quench heat treatment [2]. Precipitation hardening stainless steel is formed from a heat treatment called precipitation hardening that this heat treatment produces a multiphase microstructure from a single-phase microstructure and this process increase the resistance of the stainless steel to dislocation motion thus raise its hardness or strength [2].

316 stainless steel is an austenitic stainless steel with nominal chemical compositions of 16-18% Chromium, 10-14% Nickel, 2-3% Molybdenum, 2% Manganese, 1% Silicon,

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0.08% Carbon, 0.045% Phosphorus, 0.03% Sulfur, 0.1% Nitrogen and the balance composition is ferum [2,3]. It contains alloying element that make it different from the low carbon steel or unalloyed steel. It has been widely used in industrial applications nowadays such as in automotive, food and oil and gas industries, and it also has been applied for medical and marine applications due to its high corrosion resistance [3,4]. However, the austenitic stainless steel has its own limitation which is it has poor wear resistance [5,6]. Basically, wear effect will reduce the thickness of the material when subjected to a heavy load [7]. This effect of wear is unfavourable in fabricating a product as it will affect the dimension and shape of the material that eventually lead to crack and surface deterioration. This situation can lead to the malfunction of the components or the worse is it can lead to an accident.

Thus, surface treatments that are paste boronizing and shot blasting processes were conducted in order to improve the wear resistance of the 316 stainless steel. Paste boronizing process is a process of diffusion of boron into the steel at elevated temperatures using paste medium that will form boride layers of FeB and Fe_2B [8-10]. Shot blasting is introduced in order to promote atom dislocation that allow for deeper boron dispersion, thus improving the wear resistance of 316 stainless steel. In this research, the effect of boronizing treatment with variation in the boronizing temperature together with the impact of shot blasting process were investigated on wear resistance of 316 stainless steel and the morphological and boronized layer of 316 stainless steel also were observed and analyzed.

2. EXPERIMENTAL DETAILS

2.1. Sample preparations.

Cylindrical 316 stainless steel specimens, with diameter of 10 mm, were prepared. These included untreated 316 stainless steel, shot blasted 316 stainless steel, unshot blasted and 850^0C boronized 316 stainless steel, shot blasted and 850^0C boronized 316 stainless steel, unshot blasted and 950^0C boronized 316 stainless steel, and shot blasted and 950^0C boronized 316 stainless steel. To prepare all the specimens, the raw material of cylindrical 316 stainless steel was cut into six specimens with 10 mm length for microstructure observation and it was cut into six specimens with 30 mm length for pin-on-disc test. For XRD analysis and density test, it was cut into twelve specimens with around 3-5 mm length. The specimens were cut using METASERV C180 Specimen Cut-Off Machine.

The specimens for microstructure observation were ground using VT GP2V Grinding Machine using Silicon Carbide, SiC sand paper up to 1200 grit and polished by using BUEHLER METASERV 2000 Polishing Machine using Alpha Alumina powder to obtain flat surfaces with an unscratched and mirror-finish surface while the specimens for pin-on-disc test, XRD analysis and density test were ground and polished using the same machines until the flat surfaces were obtained. For the specimens undergoing microstructure observation, they were shot blasted, boronized and hot mounted first before they were ground and polished. They were mounted using BUEHLER SIMPLIMET 2000 Automatic Mounting Press Machine to ease holding while carrying out the grinding and polishing processes. The shot blasting and boronizing processes were conducted on the specimens for pin-on-disc test, XRD analysis and density test after they were ground and polished.

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2.2. Shot blasting process.

Shot blasting process was implemented on the surfaces of the specimens with ceramics shots (100 µm size) using Finimac Shot Blasting Machine. Shot blasting process was performed until the surfaces of the specimens were deformed.

2.3. Paste boronizing process.

Boronizing process of the unshot blasted and shot blasted specimens were conducted on paste medium for 8 hours of holding time at temperature of 850^0C and 950^0C of each samples using Carbolite High Temperature Furnace. Samples were first coated with boron paste and immersed inside Ekabor powder before it was heated in an air tight steel box.

2.4. Microstructure observation.

Specimens were etched with Kalling's No 2 for around 15-20 seconds in order to reveal the grain size and grain boundary and microstructure of the specimens were observed under Optical Microscope (Olympus BX60).

2.5. XRD analysis.

XRD (X-ray Diffraction) analysis was carried out in Cu Kα radiation using Rigaku X-Ray Diffraction (XRD) Diffractometer (ULTIMA IV) with 2θ angle is $30\text{-}120^0$ at room temperature.

2.6. Pin-on-disc test.

Pin-on-disc test was carried out on the specimens using Pin-On-Disc Tester (DUCOM TR-20LE) at one hour duration with the rotation speed of 200 rpm, wear track radius of 80 mm and load of 20 N. Samples were weighted before and after the pin-on-disc test.

2.7. Density test.

The density of the specimens was obtained by using Analytical Balance Machine (GR-200) that the density of the specimens was obtained according to the specimen's weight in air and liquid. The density of the specimens indicates their mass per unit volume. This test uses the Archimedes concept.

$$\text{Density, } \rho = \frac{A}{A - B} \times (\rho_0 - d) + d \quad [11]$$

Where,

ρ = density

A = weight in air

B = weight in liquid

ρ_0 = density of liquid at room temperature

d = density of air

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3. EXPERIMENTAL RESULTS

3.1. Characterization of boronized layer.

The austenitic structure of 316 stainless steel can be seen clearly as in Fig. 1(a). The austenitic structure of 316 stainless steel which is Cr-Ni-Fe-C is verified through XRD analysis at 2Ɵ angle at 43 (1,1,1), 74 (2,2,0) and 90 (3,1,1) while ã-Fe is confirmed through XRD analysis at 2Ɵ angle at 42 (1,1,1) as shown in Fig. 2(a). For the shot blasted 316 stainless steel (Fig 1(b)), it can be observed that surface deformation occurs for the specimen that had been shot blasted compared to the untreated specimen. This shows that for the shot blasted specimen, the atoms had been dislocated after they had been shot blasted with the ceramic shot. For shot blasted 316 stainless steel, Cr-Ni-Fe-C is verified through XRD analysis at 2Ɵ angle at 43 (1,1,1) while ã-Fe is validated through XRD analysis at 2Ɵ angle at 42 (1,1,1) as presented in Fig. 2(b). From the graph of intensity versus 2Ɵ for shot blasted 316 stainless steel, it can be seen that the austenitic phase region peak decreased which shows that the effect of shot blasting process dislocates the atoms at the surface of the steel.

From Fig. 1 (c), 1(d), 1(e) and 1(f), it can be seen that the boronizing process form two layers which represent the boride layers that have been formed at the surface of the specimens after the specimens undergo paste boronizing process. The outermost layer shows the presence of FeB and the inner layer in which the colour is lighter than the outermost layer represents Fe_2B. FeB and Fe_2B are the boron iron. From the results of microstructure between the boronized specimens that were unshot blasted and were shot blasted, it can be seen that the boride layers for shot blasted and boronized specimen are thicker than the unshot blasted and boronized specimen. This is due to the atoms dislocation from the shot blasted boronized specimen that causes the boron to disperse more into the stainless steel. When comparing the difference in boronizing temperature, it can be seen that 950^0C of boronizing temperature produce thicker boride layers on the surface of the microstructure of the stainless steel compared to the 850^0C of boronizing temperature. Other researchers also observed that boride layers thickness increases with the increase in the boronizing temperature [8,12]. This shows that higher boronizing temperature raises the boron dispersion into the steel.

For unshot blasted and 850^0C boronized 316 stainless steel, FeB is validated through XRD analysis at 2Ɵ angle at 47 (2,1,0), 63 (0,0,1) and 82 (1,4,1) while Fe_2B is confirmed through XRD analysis at 2Ɵ angle at 42 (0,0,2), 45 (2,1,1) and 80 (4,1,1) (Fig. 2(c)). For shot blasted and 850^0C boronized 316 stainless steel, FeB is verified through XRD analysis at 2Ɵ angle at 39 (1,2,0), 57 (2,1,1) and 63 (0,0,1) while Fe_2B is confirmed through XRD analysis at 2Ɵ angle at 42 (0,0,2), 45 (2,1,1) and 80 (4,1,1) (Fig. 2 (d)). For unshot blasted and 950^0C boronized 316 stainless steel, FeB is confirmed through XRD analysis at 2Ɵ angle at 47 (2,1,0), 63 (0,0,1) and 72 (3,1,0), Fe_2B is verified through XRD analysis at 2Ɵ angle at 35 (2,0,0), 73 (3,1,2) and 80 (4,1,1) and ã-Fe is validated through XRD analysis at 2Ɵ angle at 42 (0,0,2) (Fig. 2(e)). For shot blasted and 950^0C boronized 316 stainless steel, FeB is verified through XRD analysis at 2Ɵ angle at 37 (1,0,1), 47 (2,1,0) and 63 (0,0,1) while Fe_2B is validated through XRD analysis at 2Ɵ angle at 42 (0,0,2), 45 (2,1,1) and 80 (4,1,1) (Fig. 2(f)). The graph of intensity versus 2Ɵ for boronized 316 stainless steel shows that the presence of boron iron which is FeB and Fe_2B. The presence of FeB and Fe_2B also have been observed by J.H. Yoon et. al. 1999 on boronized 304 stainless steel [9]. This is due to the boronizing effect that disperses boron into the surface of the steel to form the protective layer which is FeB and dispersion layer which is Fe_2B. From the XRD analysis, it can be seen that the combination of shot blasting process and boronizing treatment raise the amount of boron

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iron in the stainless steel and increasing the boronizing temperature gives a higher amount of the boron iron.

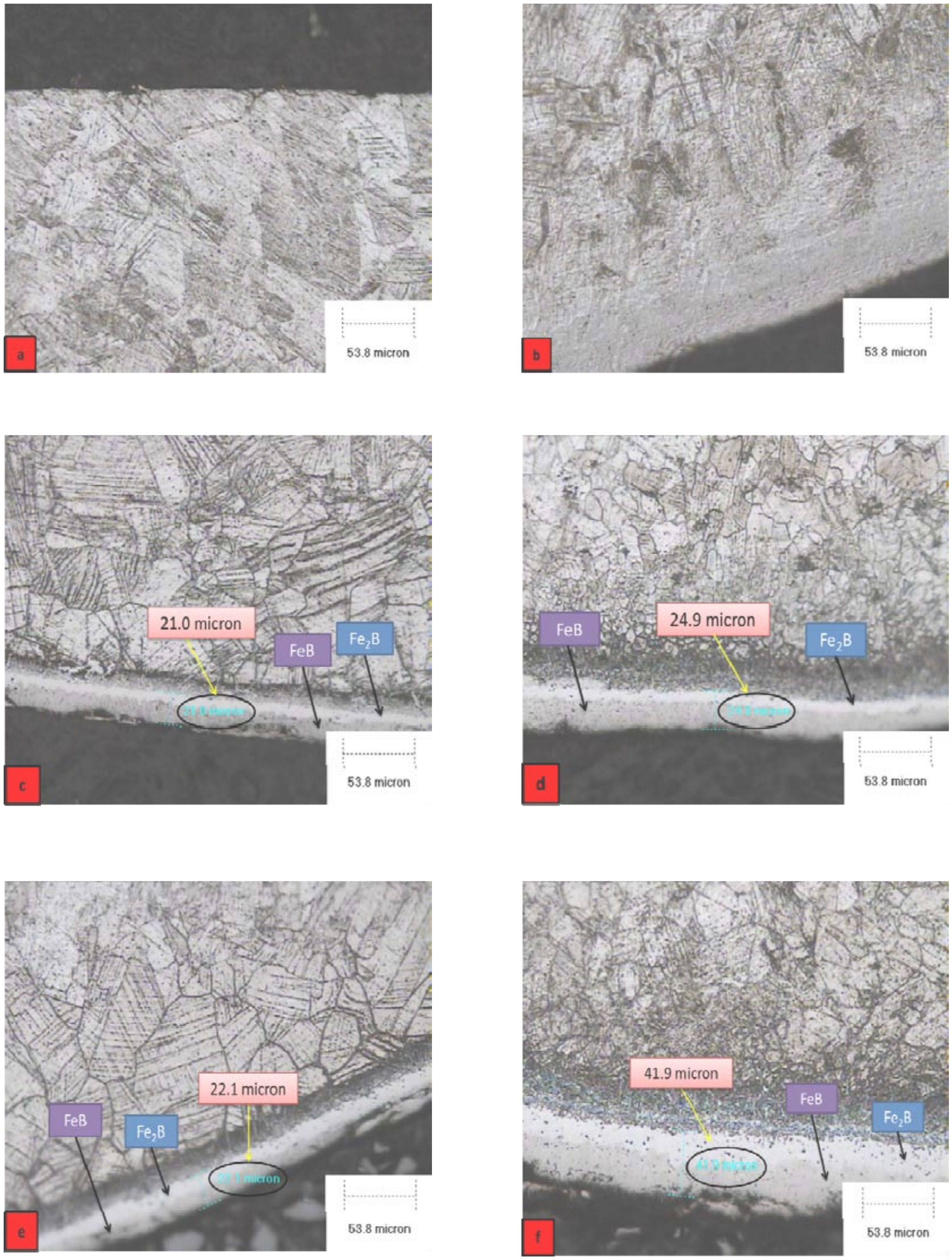

Fig. 1. Microstructure of (a) untreated (b) shot blasted (c) unshot blasted and 850^{0}C boronized (d) shot blasted and 850^{0}C boronized (e) unshot blasted and 950^{0}C boronized (f) shot blasted and 950^{0}C boronized 316 stainless steel.

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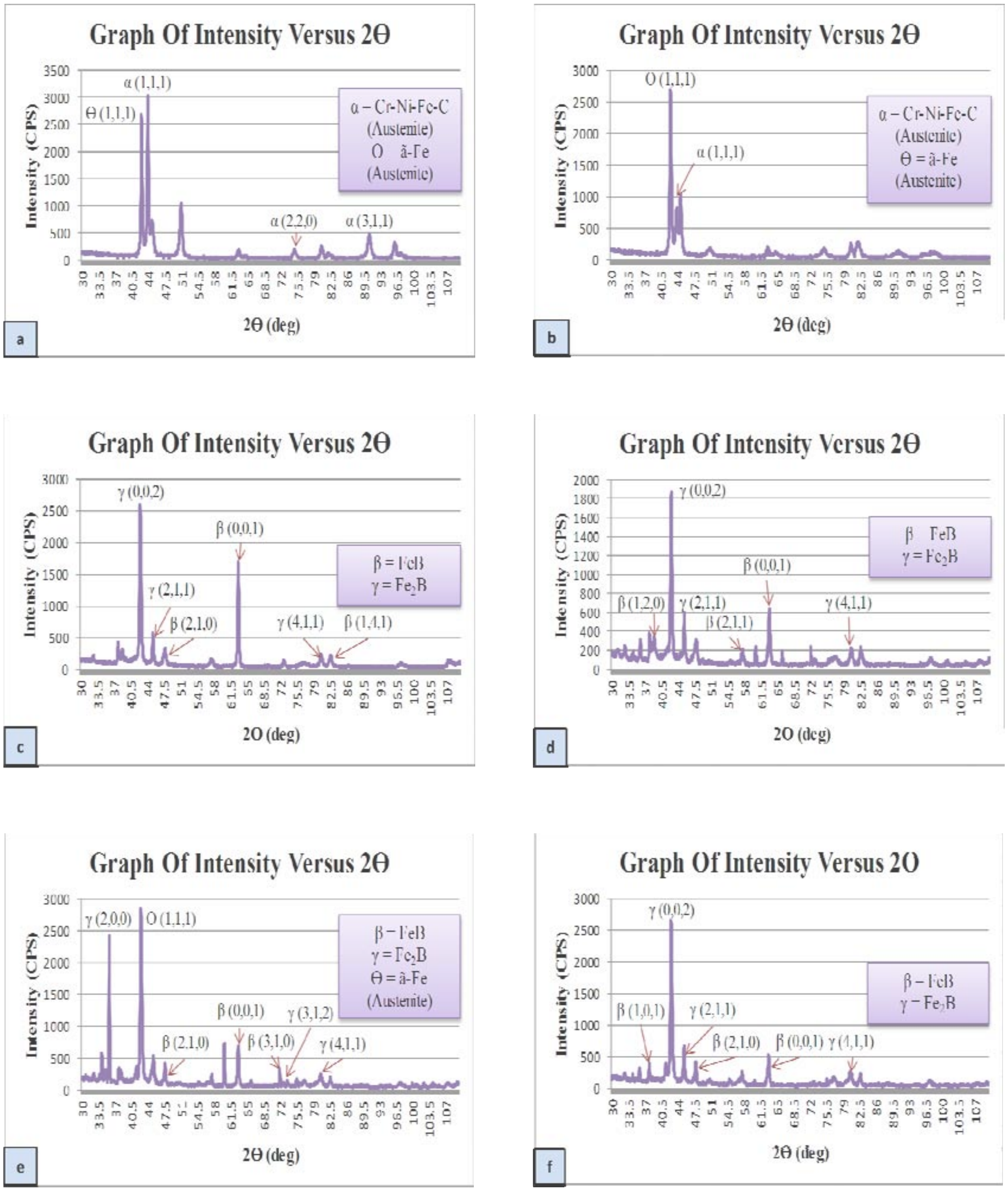

Fig. 2. Graph of intensity versus 2Θ of (a) untreated (b) shot blasted (c) unshot blasted and 850^0C boronized (d) shot blasted and 850^0C boronized (e) unshot blasted and 950^0C boronized (f) shot blasted and 950^0C boronized 316 stainless steel.

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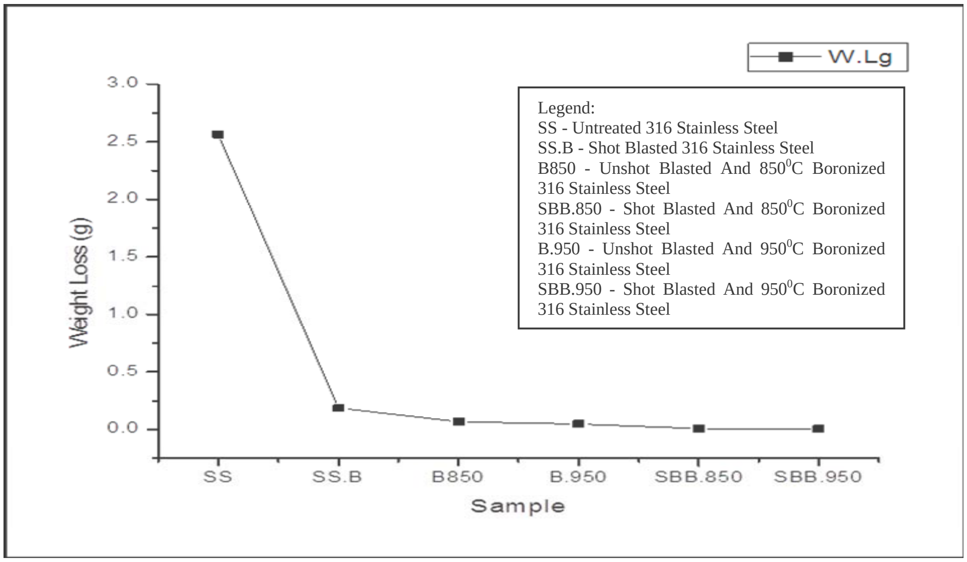

Fig. 3. Weight loss versus different types of sample of 316 stainless steel.

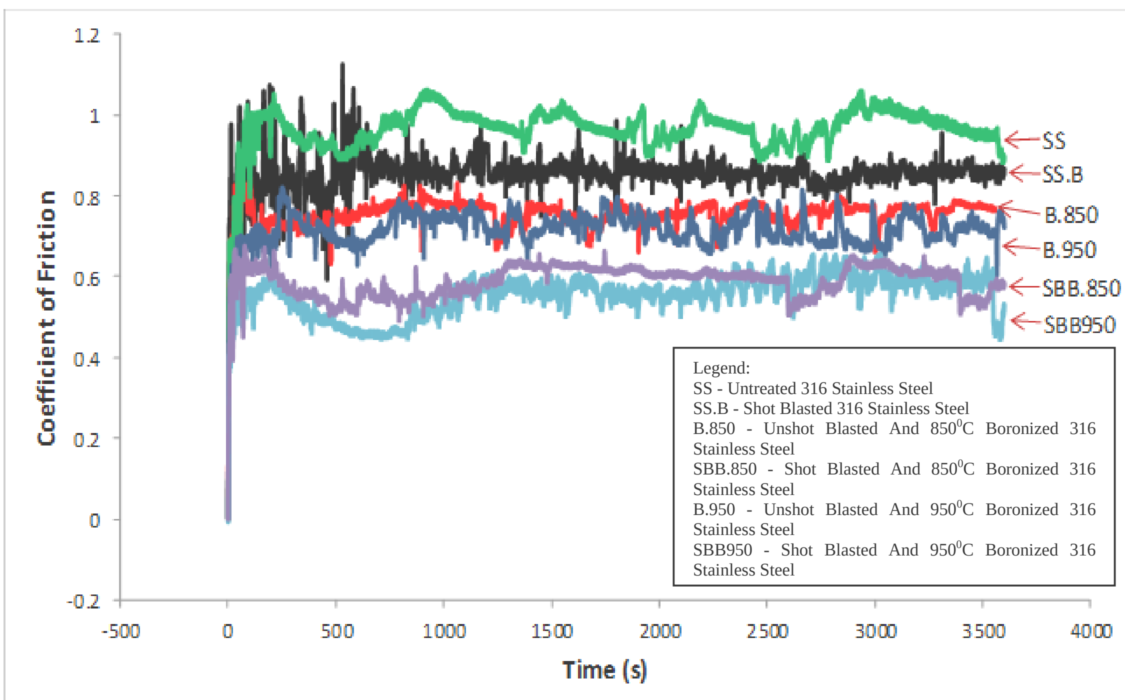

Fig. 4. Coeffient of friction versus time for the samples of 316 stainless steel.

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3.2. Wear properties.

Higher weight loss indicating low resistance to friction and wear and higher coefficient of friction determines less resistance to wear. From Fig. 3 and Fig. 4, it can be seen that the impact of shot blasting process and boronizing process increases the wear resistance of 316 stainless steel. On the other hand, combining the process of shot blasting and boronizing on 316 stainless steel raise its wear resistance greater than the same type of steel that has been treated with a single treatment. This statement also has been supported by the research on the wear and corrosion resistance of shot peened-nitrided 316L austenitic stainless steel that has been conducted by B. Hashemi et. al. 2011 [13]. Increasing the boronizing temperature also resulted in raising the wear resistance of 316 stainless steel. This is due to more boron dispersion to form the boride layers that consists of protective layer which is FeB and dispersion layer which is Fe_2B is occur. These layers will protect the 316 stainless steel from suffering a greater weight loss that resulted from the low wear resistance. Shot blasting process increases grain refinement and dislocations density at the specimen's surface layers that makes the diffusivity of boron is increases.

3.3. Density measurement.

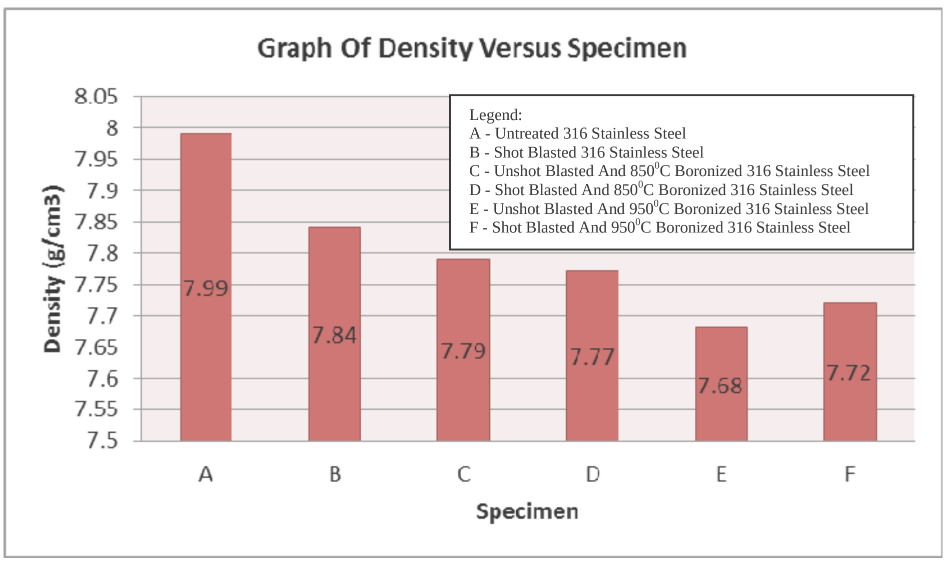

Fig. 5. Density versus different types of specimen.

The result of density of all of the specimens shows that the effect of shot blasting and boronizing slightly decreases the density of the 316 stainless steel. This is due to the effect of the atoms dislocation and heating that increases the volume of the steel and decreases the density of it. Increasing the boronizing temperature also reduces the density of the metal. Shot-blasted and 950^0C boronized specimen showed an increase in density from that of the unshot blasted specimen; compared to the reduction between 'C' and 'D' but it does not matter as the difference of density of all of the specimens is too small. Although the effect of shot blasting process and boronizing treatment seem to decrease the density of the 316

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stainless steel, the values do not differ too much when compared to the value of density of the 316 stainless steel.

4. CONCLUSIONS

From the results of the pin-on-disc abrasion test, boronizing process increases wear resistance of 316 stainless steel and increasing the boronizing temperature and with the aid of shot blasting process improves its wear resistance greatly. The density of 316 stainless steel seems to decrease slightly with the variation of boronizing temperature and shot blasting process. From the result of microstructure observation and XRD analysis, it can be observed that the addition of boride layers which is FeB and Fe_2B occurred at the surface of the 316 stainless steel after it has been boronized rather than the unboronized specimen which has only the austenite phase region. It was also observed that the thickness of boride layers increases with increasing boronizing temperature and with the aid of shot blasting process. To put it laconically, it can be seen that the effect of boronizing treatment and shot blasting process increase wear resistance of 316 stainless steel and combining these effects together with increasing the boronizing temperature raise its wear resistance greater.

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REFERENCES

[1] William F. Smith. Foundations Of Materials Science And Engineering (Second Edition). McGraw-Hill, Inc., 1993
[2] James F. Shackelford. Introduction To Materials Science For Engineers (Sixth Edition). Pearson Prentice Hall, 2004
[3] Y. Ait Albrimi, A. Eddib, J. Douch, Y. Berghoute, M. Hamdani and R.M. Souto. Electrochemical Behaviour of AISI 316 Austenitic Stainless Steel in Acidic Media Containing Chloride Ions. International Journal of Electrochemical Science Vol. 6 (2011), p. 4614-4627
[4] L. Ceschini, C. Chiavari, E. Lanzoni and C. Martini. Low-Temperature Carburised AISI 316L Austenitic Stainless Steel: Wear and Corrosion Behaviour. Materials and Design Vol. 38 (2012), p. 154-160
[5] H.R. Abedi, M. Salehi, M. Yazdkhasti and A. Hemmasian-E. Effect of High Temperature Post-Oxidizing on Tribological and Corrosion Behavior of Plasma Nitrided AISI 316 Austenitic Stainless Steel. Vacuum Vol. 85 (2010), p. 443-447
[6] N. Karimzadeh, E.G. Moghaddam, M. Mirjani and K. Raeissi. The Effect of Gas Mixture of Post-Oxidation on Structure and Corrosion Behavior of Plasma Nitrided AISI 316 Stainless Steel. Applied Surface Science Vol. 283 (2013), p. 584-589
[7] Munir, M. K. (2010). Improvement on Wear Resistance of 316 Austenitic Stainless Steel by High Temperature Nitriding Technique.
[8] I. Gunes, S. Ulker and S. Taktak. Plasma Paste Boronizing of AISI 8620, 52100 and 440C Steels. Materials and Design Vol. 32 (2011), p. 2380-2386

ISSN 1675-7009

[9] J.H. Yoon, Y.K. Jee and S.Y. Lee. Plasma Paste Boronizing Treatment of the Stainless Steel AISI 304. Surface and Coatings Technology Vol. 112 (1999), p. 71-75

[10] Siti Khadijah Alias, Bulan Abdullah, Ahmed Jaffar, Syazuan Abdul Latip, Salmiah Kasolang, Mohd Faizul Izham and Muhd Azimin Abd Ghani. Mechanical Properties of Paste Carburized ASTM A516 Steel. Procedia Engineering Vol. 68 (2013), p. 525-530

[11] AD-1653 Specific Gravity Measuring Kit: Instruction Manual. Japan: A&D Company, Limited., 1998

[12] M. Tabur, M. Izciler, F. Gul and I. Karacan. Abrasive Wear Behavior of Boronized AISI 8620 Steel. Wear Vol. 266 (2009), p. 1106-1112

[13] B. Hashemi, M. Rezaee Yazdi and V. Azar. The Wear and Corrosion Resistance of Shot Peened-Nitrided 316L Austenitic Stainless Steel. Materials and Design Vol. 32 (2011), p. 3287-3292

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