The Effect of Slurry Erosion Wear on Boronized Alloyed Ductile Iron (0.019 % Niobium and 0.145 % Vanadium)

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ABSTRACT

In this study, the effect on microstructure, hardness and slurry erosion wear of alloyed ductile iron (DI) with addition of 0.019 % of Niobium and 0.145 % of Vanadium before and after boronizing process will be discussed. The specimens of ductile iron (DI) and Nb-V alloyed DI were produced through CO_2 sand casting method. Specimens were fully coated with boronizing paste in estimation about 3-5mm thickness and heated using Carbolite furnace at 850 ^{0}C and 900 ^{0}C for 8 hours holding time. The observations of Microstructures were conducted by using Olympus BX 41M Optical Microscope. Vickers Micro Hardness Tester was used to determine the hardness of the specimens while Slurry erosion wear test was conducted to measure the weight loss of each specimen. Diffusing boron into the iron crystalline lattice leads to the formation of two kinds of iron borides (FeB and Fe2B). The thickest boride layer was detected at sample with temperature of 900 ^{0}C. The samples of 900 ^{0}C give higher hardness than temperature of 850 ^{0}C which are 2500 HV and 2209 HV respectively. Referring to slurry erosion test, samples boronized at 900 ºC had greater wear resistance compared to sample boronized at 850 ºC and as cast. This was attributed by the value of weight losses and surface roughness for the materials. This study had proven that, by increasing the boronizing temperature from 850 ^{0}C to 900 ^{0}C at 8 hours holding time has a significance effect to the boride layer thickness, hardness and wear resistance of alloyed ductile iron.

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Introduction

Ductile iron is widely used in various industrial applications, such as automotive and machine parts, tubes and the nuclear waste containers. Ductile iron is not only having excellent fluidity, workability and castability, but it also possesses to better toughness, ductility and also the strength than gray cast iron. In addition, The processing costs of ductile iron also lower than malleable iron [1]. However, the ductile iron cannot stand for a long time regarding the wear and surface properties.

Moreover, the base iron chemistry and alloy additions to ductile iron play important roles in steel technology. The addition of alloying elements during the production of heat-treated DI is often considerably higher than the levels used in the production of conventional grades of ductile irons. For example, the material of 4 % Ni-DI has the highest hardness and strength but the lowest ductility and toughness among all the ductile irons, Niobium is used predominantly in making alloys. The addition of niobium to steel greatly increases its strength. For example, Niobium used in the construction of nuclear reactors because its ability to keep its strength at the maximum high temperatures [2]. Vanadium is a potent hardenability element which plays a useful role in the vanadium nitride and vanadium carbide formation. The formation of vanadium carbide is an important for wear. Due to the stable form of nitrides and carbides, it increases strength while retaining ductility and increases the toughness at high temperatures. It also promotes fine grain structure. About 80 % of the Vanadium produced is used as a steel additive [3-5].

Wear is one of the most commonly encountered problems in industry which requires frequently replacement of components [2][3]. Boronized steels and cast irons are characterized by their increased surface hardness and increased wear resistance. When ferrous materials are boronized at temperatures in the range of 800-1000 ºC for periods varying between 1 and 8 h, (Fe_2B + FeB) or Fe_2B iron-boride phases are formed at the material and a boride layer having hardness up to 2000 HV hardness and thickness in the range of 40-270 µm is produced [4]. Boronized steels and cast irons can resist wear and oxidation without losing their tribological properties starting from surface temperatures up to 1000 ºC [5]. Boronizing enhances the corrosion resistance and oxidation resistance at temperatures up to 850 ºC [6] [7]. Although, many researchers had proven the improvement of surface hardenability of steels and pure ductile iron through boronizing process, they are a least number of studies investigated the boronizing process of alloyed ductile iron. Thus, this paper aim to investigate the effect on microstructure, hardness and wear (slurry erosion) of alloyed ductile iron

(DI) with addition of 0.019 % of Niobium and 0.145 % of Vanadium after boronized at 850 °C and 900 °C for 8 hours holding time.

Experimental Procedure

Sample preparation

Steel scrap, pig iron, niobium, carburizer and alloying elements were arranged and melted in a 60 kg induction furnace until it reached the melting temperature of 1450 ºC. Y blocks samples of ductile iron (DI) and 0.019 % of Niobium and 0.145 % of Vanadium alloyed ductile iron were produced through a conventional CO_2 sand casting process. The chemical compositions of all types of samples (as shown in **Table 1**) were obtained through Arc Spark Optical Emission Spectrometer. The specimens were coated completely with boronizing paste in estimation about 3-5 mm thickness before heated in the Carbolite furnace. The boronizing process was carried out at 850 ºC and 900 ºC for 8 hours of holding time before being self-cooled to room temperature.

Table 1: Chemical composition of alloyed ductile iron sample (wt%)

Element	C	Si	Mn	P	S	Nb	V	Mg	Fe
Alloyed DI	3.6	1.86	0.41	0.45	0.01	0.019	0.145	<0.001	bal

Microstructure and Scanning Electron Microscopy (SEM) observation

After the boronizing process completed, microstructures of the specimens were prepared using hot mounting process, grinded and polished using 3 μm and 6 μm diamond liquid suspension. The formation and the thickness of borides layer and were observed using Olympus B X 41M optical microscope after being etched with Nital 2 %. Wear surface condition after slurry erosion wear test and roughness test were observed by using IMAPS 4.0 edition software Scanning Electron Microscopy.

Microhardness Test

The Microhardness of the samples were measured using the Hardness Vickers (HV) tester machine. 10 readings of microhardness were taken at different position at each sample’s surface.

Slurry Erosion Wear and Roughness Test

The specimens (as shown in **Figure 1(a)**) with dimension of 76 mm (length) x 25 mm (width) x 6 mm (height) were first ground on a belt emery to ensure the surface was flat on either side. To mount the samples in the equipment, a 6 mm hole was drilled in each sample. This test was run by using the slurry erosion test machine as shown in Figure 1(b). The slurry mixture consisted of silica sand of nominal size 1.18 mm and water. The sand and water concentration was maintained in the ratio of 30:70. The pH level of water was maintained at 7.5 by adding sodium chloride. All the samples were dipped in slurry water and silica sand and stirred at the speed of 180 RPM. The tests were conducted at ambient temperature and the testing time was fixed for 20 hours (4 hours for each interval) which is equivalent to 4000 km of travel distance. After each trial the test samples were thoroughly cleaned in acetone and weighed. The weight loss was converted to volume loss for each sample. Surface Roughness Test was done by using Alicona tester machine to observe the surface structure of the samples before and after slurry erosion test.

Figure 1(a): Specimen of Slurry Erosion Test

Figure 1(b): DUCOM Slurry Erosion Test Machine

Results and Discussion

Microstructure Observation

The boron atoms were reacted with the material and a number borides were formed [6][8]. As the result in terms of metallographic investigation of boronized materials, it has been shown that the layer of the boride contains a tooth-shaped structure. The diffusion of boron into the iron crystalline lattice leads to the production of two different kinds of iron borides which are FeB and Fe_2B [9]. Analysis showed that the thickness of the boride layer increases with increasing the boronizing temperature. The approximate depths of borided layers varied between 83.11 µm and 118.29 µm depending on boronizing temperature. Figure 2(a-c) presents the variation of boride layer thickness depending on boronizing temperature at the same process time. The results proved that the higher the treatment temperature, the thicker the boride layer became. The boride layer thickness increased by 43 % when the boronizing temperature increased from 850 ^oC to 900 ^oC. The original graphite shape of ductile iron did not changed with the boronizing temperature [10]. Depending on the type of material, the graphite preserved its morphology in the boronized layer as well as in the base material [11].

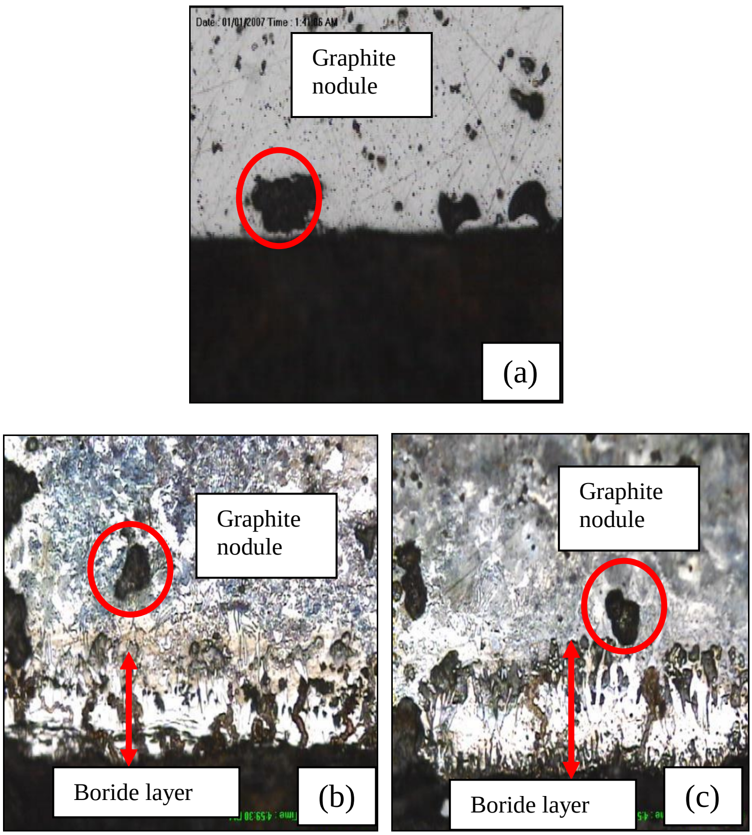

Figure 2: Microstructure of 0.019 % of Niobium and 0.145 % of Vanadium alloyed ductile iron
(a) untreated (b) boronized at 850 ^oC for 8 hours
(c) boronized at 900 ^oC at 8 hours

indicated in Figure 3). It is considered as a high hardness value and be classified as in FeB phase since hardness value of FeB is in the range for more than 1000 HV. The greatest difference of hardness value in a short distance gap between the previous points that can be seen at the hardness value of 1318 HV and 641.4 HV with the smallest difference about 1.62 μm. This difference value shows that there are two different phases exist in this range as 1318 HV is a form of FeB phase while 641.4 HV is a form of Fe_2B phase. Therefore, the FeB thickness of 900 °C is measured to be thicker than the 850 °C according to its hardness value plotting graph pattern. Meanwhile for the FeB of 850 °C specimen is expected to be slightly more than 16.24 μm since the value of hardness at 16.24 μm is 1101 HV. In between these two lines, it can be concluded that the sample that has undergone 900 °C has greater hardness value compared to 850 °C sample, and both pattern line shows a decreasing trend of hardness value when the distance from the Point 1 was getting further.

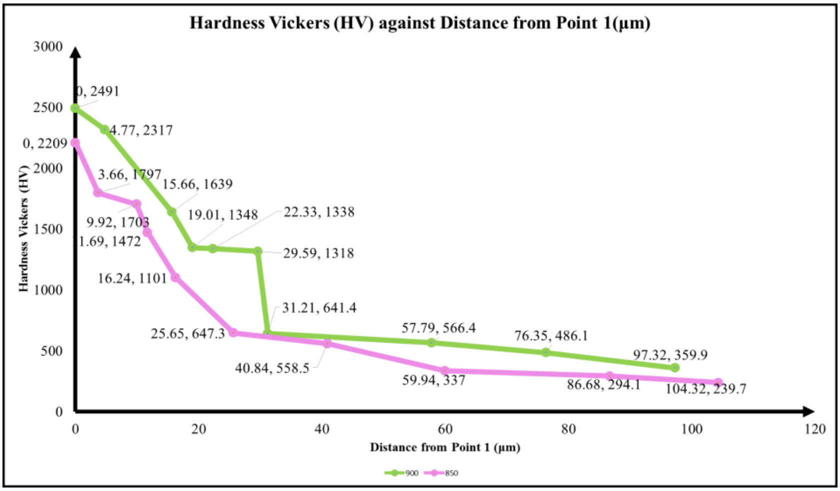

Figure 3: Hardness value on two difference temperature of boronized alloyed ductile iron

Slurry Erosion Test

Figure 4 shows three different types of sample consists of as-cast and the other two set of samples were boronized at 850 °C and 900 °C. It shows wear behaviour of boronized alloyed ductile iron at two different temperatures which are 850 °C and 900 °C. The weight losses for boronized specimens are lower compared to unboronized specimen (as-cast). The value of weight loss for both samples of 850 °C and 900 °C at first interval (first 4 hours) was increased. This phenomenon was due to attachment of boron paste residues on the outer surface of the samples. So, the process at first interval was removing the residual pastes as shown in Figure 5. Second interval, show the weight loss value of sample 900 °C is less than sample 850 °C which is 0.0203 g less than 0.00269 g. At this interval, sample 900 °C are still removing the residues of boron paste and also the few sand that attached at the sample's surface. For the third interval until fifth interval show the weight loss value for sample of 900 °C is less than the sample of 850 °C. The surface hardness of sample 900 °C is harder than sample of 850 °C. It can be conclude that the higher the hardness, the higher the wear resistance of the sample [12]. The highest wear resistance is obtained if the layer is made up only Fe_2B phase, i.e. not containing FeB. FeB is not preferred also because it has higher internal stress [13]. Increasing the boronizing temperature also resulted in raising the hardness and wear resistance of NbV alloyed ductile iron. 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 occurring [14]. These layers will protect the samples from suffering a greater weight loss that resulted from the low wear resistance [10].

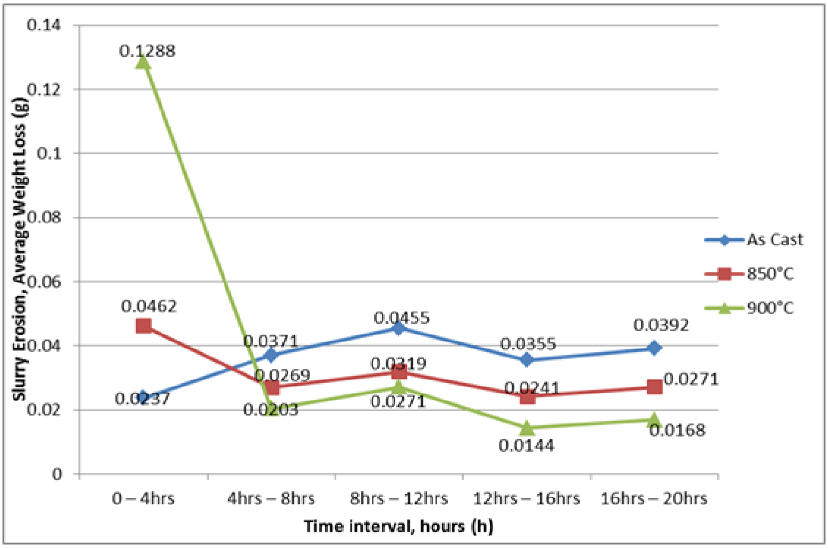

Figure 4: Weight loss value due to the time travel on two difference temperature and as-cast

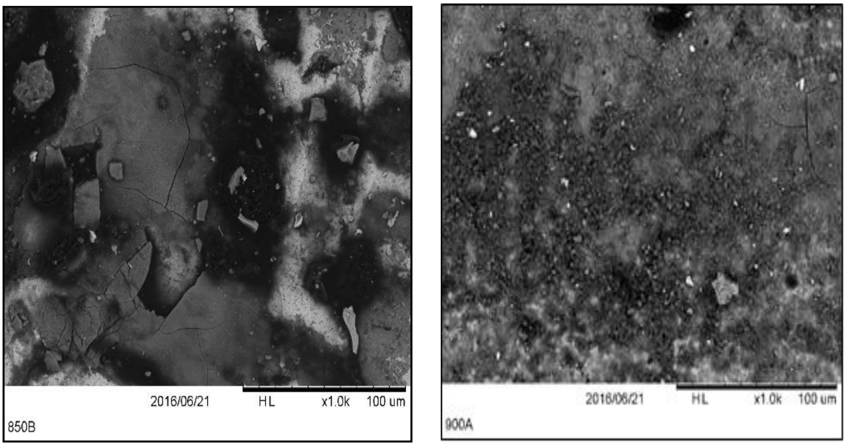

Figure 5: Microstructure of residual Paste (a) 850 °C (b) 850 °C

Surface Roughness

As the result of comparison between the values of Ra that were obtained from the Surface Roughness were tabulated as shown in Figure 6. The values of Ra before the slurry erosion test were mostly greater than the Ra values that were obtained after they have gone through the slurry erosion test. However, the Ra values of the as cast Sample shows slightly increased from 1.4059 µm to 1.4344 µm. Meanwhile the other samples show a slightly decreased of Ra values between before and after the Slurry Erosion test. This probably shows that after the samples undergone the process of Slurry Erosion, the surface roughness value decreased due to the rough surface. Theoretically, roughness is often closely related to the friction and wear properties of a surface. The hardness of surface for each sample is affected to this roughness test. A surface with a large Ra value will usually have high friction and low wear resistance [15] . Ra values for samples boronized at 850 ºC and 900 ºC were decreased because the surface was hard to wear. Thus, it can be concluded that the increasing of Ra value at 900°C resulted the lowest wear resistance compared to 850°C and as cast sample.

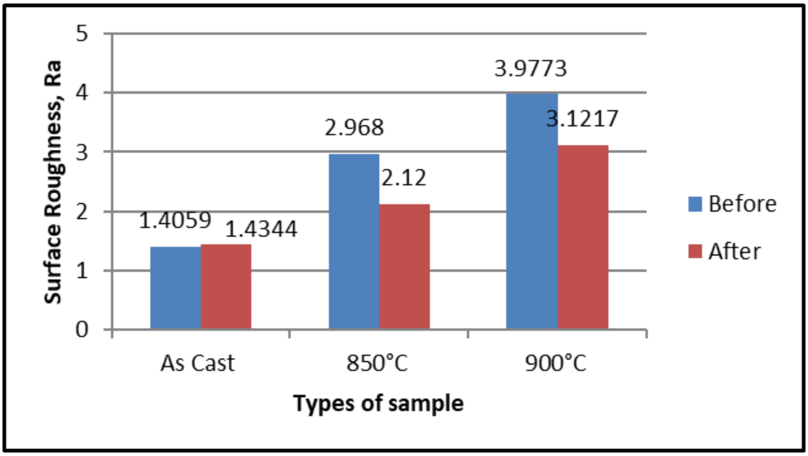

Figure 6: Surface Roughness (Ra) before and after Slurry Erosion Test

Conclusion

In conclusion, the thickest boride layer was observed at the sample boronized at 900 ºC for 8 hour holding time, which the layer thickness was 118.29 µm compared to the sample at temperature of 850ºC which was 83.11 µm. The highest hardness value in the boride layer at temperature of 900 ºC was measured as 2500 HV. Meanwhile, the hardness value in the boride layer that has been detected at temperature of 850 ºC measured as 2209 HV. Therefore, the hardness of surface at temperature 900 ºC is greater than the hardness of surface at temperature 850 ºC. The surface properties were observed from the weight loss of the samples. The samples boronized at 900 ºC has high wear resistance compared to the sample of boronized at 850 ºC and also unboronized (as cast) sample due to the values of weight loss and average roughness, Ra.

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