

Effect of Temperature Variation on Wear Behaviour of Austenitic Stainless Steel

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Abstract. The effects of boronizing temperatures on the wear and hardness properties of austenitic stainless steel were investigated in this study. The samples were prepared in accordance to standard samples preparation for wear and hardness test. Pack boronizing were conducted using EKabor®1 powder medium at two different temperatures which are 850°C and 950°C. The wear resistance properties were evaluated through pin on disk test and the surface characterization was analyzed through scanning electron microscopy (SEM), observation. Vickers microhardness tester was performed to obtain the hardness of the samples. The results indicated that there are presences of FeB and Fe₂B phases on both samples, but thicker FeB phase was produced at Po-950 samples. This resulted in reduction of abrasion wear properties but major improvement of the hardness properties of boronized stainless steel.

1. Introduction

The enhancement of wear and surface hardness of boronized steels and alloys depend on the thickness of boride layer. Boride layer consisting of two separated phases which are FeB and Fe₂B with thickness of more than 100 µm [1-3]. The selection of boronizing temperature is one of the key elements in producing deeper boride layer thickness. Previously, boronizing treatment in low alloy steels was conducted at temperatures within 700°C to 900°C as these temperatures provide significant improvement of more than five times the microhardness and two times the wear resistance of boronized steel and alloys [4-5]. However, the implementation of pack boronizing on stainless steel required higher boronizing temperature and longer boronizing times (6- 8). The higher chromium (10-20 wt. %) and nickel (8-10. wt %) content in stainless steel restricted the formation of boride layer thickness, thus higher boronizing temperature may be implemented. Chromium reduced the diffusivity of boron atom by concentrating at the boron diffusion layer, which restricted the formation of boride layer. Therefore, it is vital to find the most suitable temperature that provides optimal diffusion to the surface of stainless steels. The diffusivity of boron atom onto the surface of boronized steels during boronizing is highly influenced by the applied temperature [5]. Higher boronizing temperature resulted in higher activation energy that facilitated the formation of deeper boride layer thickness. Thus this study emphasized on the effect of temperature variations on wear resistance and hardness properties of grade 304 stainless steel.

2. Methodology

Grade 304 stainless steel with chemical compositions obtained through Spectro Maxx Spectrometer machine as shown in Table 1 was used for this study and was identified as Po-850 and Po-950 respectively.



Table 1. Chemical compositions of 304 stainless steel samples

Wt (%)	C	Mn	Si	P	S	Cr	Mo	Ni	Fe
304	0.065	1.8	0.75	0.04	0.03	18.5	0.0	8.5	Balance

Pack boronizing was conducted at two different temperatures which were 850°C and 950°C using the commercial EKabor®1 powder inside the induction furnace for 8 hours holding times. All samples were prepared according to the standard sample preparation methods comprising of cutting, grinding and polishing in according to ASTM E3 standard. The sliding wear resistance of boronized samples were evaluated through pin on disk test according to ASTM G99 and the surface characterization was analyzed through scanning electron microscopy (SEM) observation and conformation of FeB and Fe₂B phases was conducted using XRD test. Vickers microhardness test was accomplished in accordance to ASTM E384 in order to attain the hardness of the samples.

3. Research Findings

Microstructure observation

Figure 1 shows the SEM micrograph of powder boronized stainless steel at two different temperatures which are 850°C and 950°C at 1000 times magnification. Boride layer thickness with FeB and Fe₂B formation was developed. The validation of FeB and Fe₂B phase was conducted using XRD analyzer at 2 Theta angles of 37° [1 1 9], 62° [6 0 6] and 80° [5 4 4] for FeB phase and 35° [0 2 0], 42° [4 2 4] and 80° [4 3 4] for Fe₂B phase, shown in Figure 2. The FeB phase is located to upper surface of the samples and was known as hard and brittle layer consisting 16.23 wt% boron atom and Fe₂B phase located below the FeB phase with 8.8 wt% boron atoms. Boride layer with thickness of 15 µm was developed in Po-B850 sample and the thickness of boride layer increased 22.4 µm in Po-B950 sample.

This was because higher temperature caused higher activation energy that promoted further boron atom migration via interstitial diffusion. As the increment of temperature increased the boron concentration which was caused by higher amount of boron atom were diffused into the diffusion zone, thicker layer of FeB phase was produced [9]. However, there are presences of crack on the surface of FeB phase which was due to sensitization of chromium during boronizing at higher temperature. The thickness of FeB and Fe₂B formed on Po-B850 samples are 8 µm and 7 µm respectively. While after boronizing at 950°C, the formation of FeB increased two times as compare to Fe₂B with value of 15 µm and 7.4 µm.

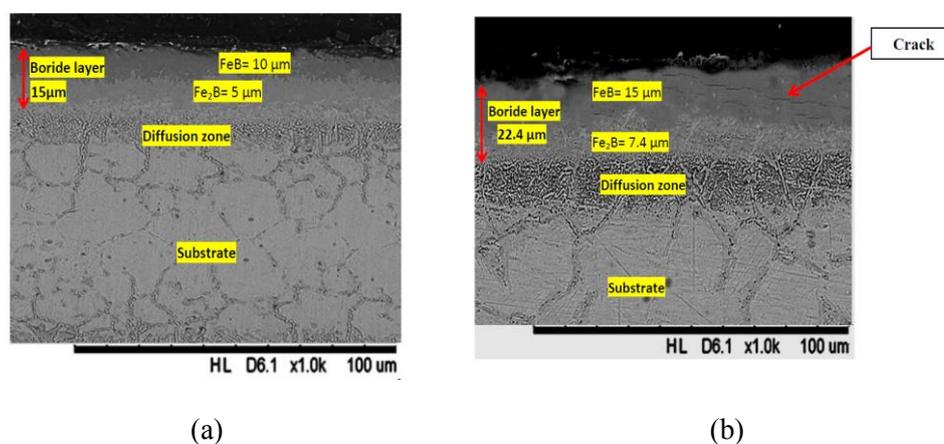


Figure 1. SEM micrograph of (a) Po-B850 and (b) Po-B950 sample at 1000 times magnifications.

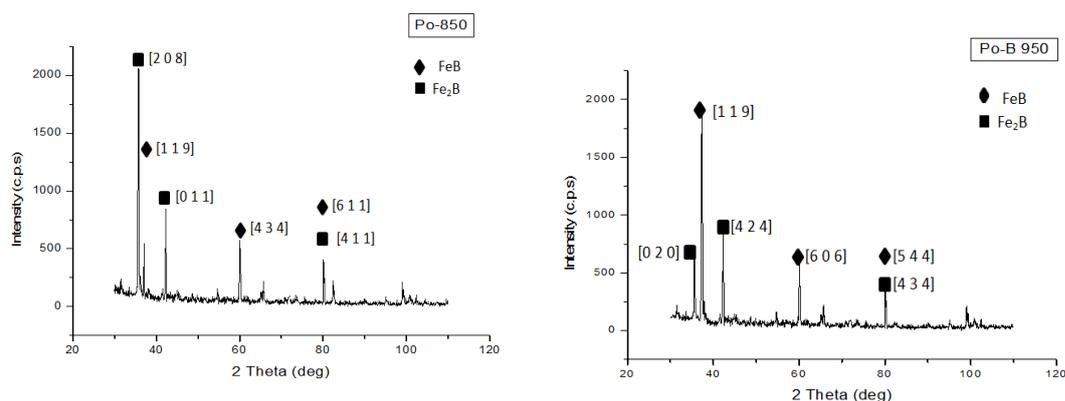


Figure 2. XRD spectra for (a) Po-B850 and (b) Po-B950 samples.

The coefficient of friction (COF) curve of Po-B850 and Po-B950 sample is shown in Figure 3. The COF curve of Po-B950 sample was slightly higher with the value of 0.688 as compared to 0.611 in Po-B850 samples. Higher coefficient of friction indicated lower resistance to wear. Although deeper boride layer was produced at higher temperature, the formation of FeB that possessed thickness of more than two times of Fe₂B phase contributed to the reason to this finding. The result was also associated with the presence of crack in FeB phases. On the other hand, it was specified that formation of single Fe₂B phase is most favourable as it offers superior wear and toughness properties compared to intermetallic of FeB and Fe₂B phases [3, 10]. Conversely, formation of thicker FeB phase had unfavourably exaggerated the wear resistance as it is more brittle than Fe₂B. This denoted that increment of boronizing temperature does not necessary beneficial to the wear resistance properties as it is mainly influenced by the thickness of FeB and Fe₂B.

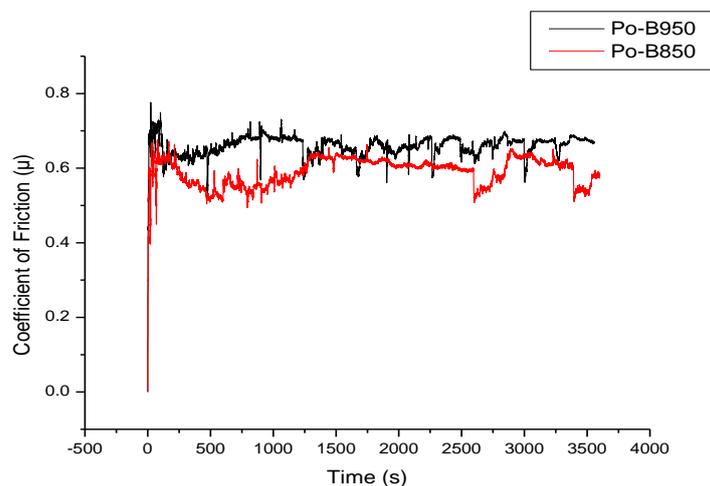


Figure 3. Coefficient of friction (COF) curve of Po-B850 and (Po-B950) samples generated through pin-on-disk testing

Figure 4 portrayed the Vickers microhardness value of powder boronized samples at two different temperatures which are 850°C and 950 °C. The microhardness of Po-B950 samples are higher than Po-B850 samples at the outer most layer of FeB with the average value of 1350 Hv and 1112 Hv respectively, with increment of approximately 21.4%. Both samples divulged

similar trend of decrement beginning from the outer boride layer towards the substrate. Achievement of thicker hard but brittle nature of FeB phases are related with the boron composition of two times the value of Fe₂B phases which is 16.23 wt%. Reduction of microhardness values were observed on the Fe₂B region of approximately 780 Hv and 670 Hv for Po-B950 and Po-B850 samples respectively. This was mainly because Fe₂B phase is more ductile than FeB phase. The value further reduced as the indentation moved toward the substrates with the average value of 280 Hv was perceived.

This was also supported by past studies indicating that FeB is much harder than more ductile Fe₂B phase in boronized steels. Boronizing of AISI M2 high speed steel at temperature of 850 to 1050°C resulted in formation of boride layer consisting of surface layer, primarily contained FeB and Fe₂B phases and also transition zone, which is boron rich area and the steel matrix or substrates. Similarly the hardness divulged a reduction from 1800 Hv to 280 Hv beginning from the outer layer towards the matrix due to change of the phases [7].

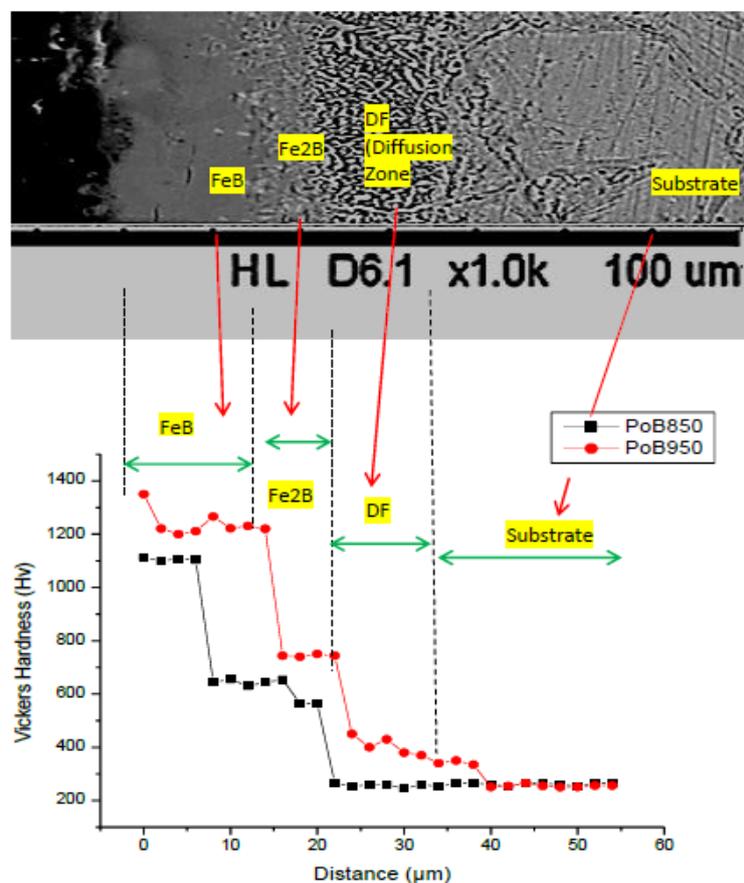


Figure 4. Microhardness profile comparison between powders boronized samples at temperature of 850°C and 950°C.

4. Conclusion

In conclusion, pack boronizing of grade 304 stainless steel at temperature of 850°C was found to have superior properties in term of abrasive wear resistances but lower microhardness values. This was mainly because this samples exhibited similar thickness of FeB and Fe₂B phases. Increasing the temperature to 950°C resulted in favorable effect on the microhardness properties as thicker FeB phase was produced. However, due to formation of this phase, the boride layer became brittle and thus reduced the wear resistances of the boronized stainless steel.

5. Acknowledgement

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6. References

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