Proceedings of Asia International Conference on Tribology 2018, pp. 424-426, September 2018

Diffusion kinetics of boronized compacted graphite iron

Khalissah Muhammad Yusof*, Bulan Abdullah, Nor Hayati Saad

Faculty of Mechanical Engineering, Universiti Teknologi Mara, 40450 Shah Alam, Selangor Malaysia.

*Corresponding e-mail: ykhalissah@yahoo.com.my

Keywords: Boronizing; diffusion kinetics; alloyed ductile iron

ABSTRACT – In this study, the case properties and diffusion kinetics of Boronized Compacted Graphite Iron were investigated. The experiments conducted at temperatures of 750 ºC, 800 ºC and 850 ºC for 3, 5 and 7 hours. The boride layer was characterized by optical microscopy, X-ray diffraction technique (XRD) and Vickers hardness tester. XRD analysis of boride layers on the surface of the iron revealed the existence of FeB, Fe2B compounds. The thickness of boride layer increases by increasing boronizing time and temperature. The hardness of the boride compounds formed on the surface ranged from 900 to 1450 $HV_{0.10}$. The activation energies (Q) of Boronized Compacted Graphite Iron was 90.58 kJ/mol. The growth kinetics of the boride layers forming on the Compacted Graphite iron (CGI) and thickness of boride layers were also investigated.

1. INTRODUCTION

The compacted graphite iron form lies between grey iron, where graphite is in flake form, and ductile iron where graphite is in nodular form [1]. Boronizing is a thermochemical diffusion which boron atoms are diffused into the surface of work piece to form hard borides [2]. The use of boronizing surface treatment on engineering materials can improve their corrosion resistance and increase their wear strength while it can decrease the friction coefficient [3]. The main objective of this study is to investigate the diffusion kinetics (growth acceleration and growing rate) and the effect of process parameters, such as temperature and time on the boride layers formed on CGI through paste boronizing process.

2. EXPERIMENTAL PROCEDURE

2.1 Boronizing and characterization

Table 1 gives the composition of untreated CGI. The boronizing heat treatment was carried out in the paste boronizing medium placed in Carbolite furnace operated at temperatures of 700 ºC, 750 ºC and 800 ºC. The holding times were 3, 5 and 7 hours and allowed to self-cooled in the furnace until reached the room temperature. The specimens were observed under Olympus BX-60 optical microscope. The presence of borides formed in the coating layer was confirmed by means of X-ray diffraction equipment (Ultima IV XRD) using Cu Ka radiation. The thicknesses of borides were measured using optical microscope (Olympus BX-60). The hardness measurements of the boride layer on each substrate were made on the cross-sections using a Vickers indenter with a 100 g load.

Table 1 The chemical composition (wt.%).

C	Si	Mn	P	S	Cu	Fe
2.8	1.77	0.468	0.03	0.075	0.484	92.9

2.2 Kinetics

On the condition that boron diffuses and grows parabolically, the alteration of boride layer thickness with time can be described by the following equation:

$x^2 = D.t$ (1)

Where x is the depth of boride layer (mm), t is the boronizing time (s), D is the growth rate constant with respect to boronizing temperature. The relationship between growth rate constant, D, activation energy, Q, and the temperature in Kelvin, T, can be expressed by:

$D = D_0.exp\ (-Q = R/T)$ Arrhenius eq (2)

Where Do is a pre-exponential constant, Q is the activation energy (J/mol), T is the absolute temperature in Kelvin and R is the gas constant (J/mol K) [2].

3. RESULTS AND DISCUSSION

3.1 Characterization of boride coatings

The cross-section of optical micrographs of the boronized CGI at temperatures of 700 ºC,750 ºC, 800 ºC and 850 ºC for 8h is shown in Figures 1 (a-d). Referring to Figure 1, the boride layer formed on the CGI has a saw tooth morphology. The coating thickness was influenced by alloying elements in the metal substrate can modify the active boron diffusivity by entering the iron boride lattice [4].

3.2 X-ray diffraction analysis

XRD results showed that boride layers formed on CGI contained Fe2B, FeB phases (shown in Figure 2). With increasing time and temperature, Fe2B phase content decreases and FeB phase content increases.

3.2 Boride layer thickness and hardness

Micro-hardness measurements were done from the surface to interior along a line to see variation of hardness of boride layer, transition zone and matrix, respectively (shown in Figure 3). As a result of the boronizing process, boride layer thickness increases with increasing boronizing temperature and time. Boride layers' thickness on the surface of CGI were increased in a range from 37.63 to 60.86 µm. The boride layer thickness changes depending on the boronizing time and temperature. Microhardness measurements were carried out on the cross-sections from surface to interior along a line. The hardness of boride layer formed on CGI varied between 900 to 1450 $HV_{0.10.}$

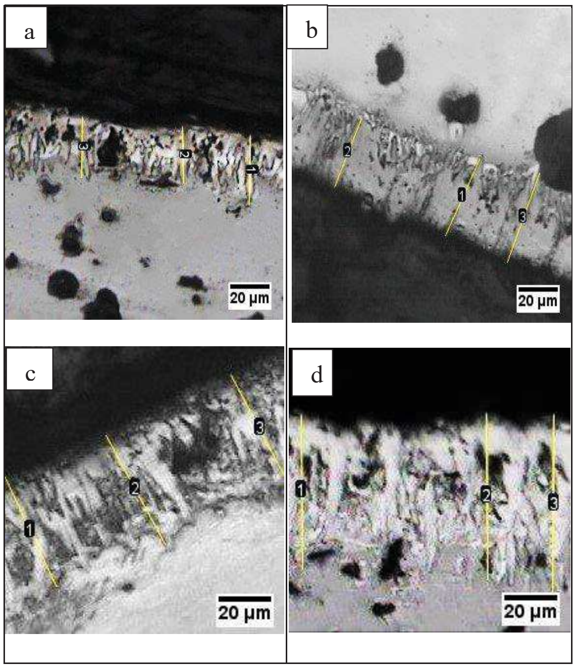
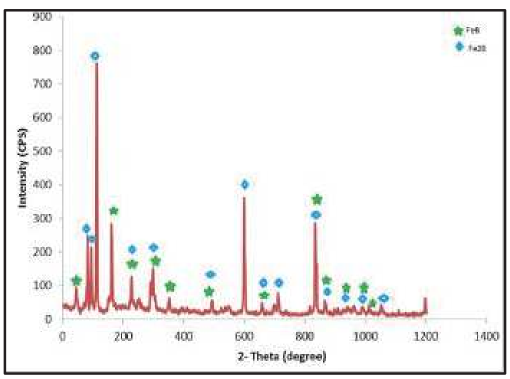
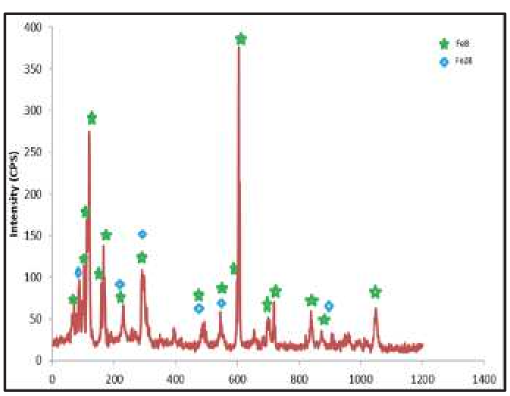


Figure 1 Microstructures of Boronizing Heat Treatment for 8 hours at (a) 700ºC (b) 750 ºC (c) 800ºC (d)850 ºC.



(a)



(b)

Figure 2 XRD Pattern of boronized alloyed ductile iron at 8 hours for (a) 750 (b) 800ºC.

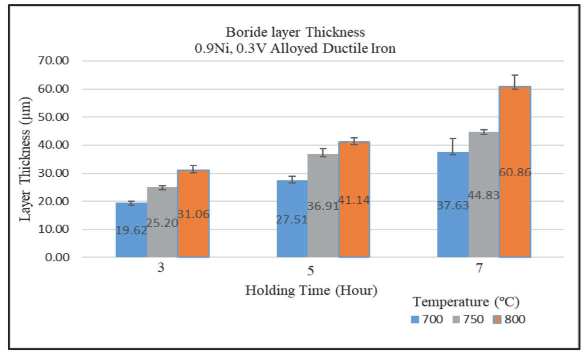


Figure 3 Boride layer thickness.

3.3 Kinetics

In this study, the effects of the processing temperature and boronizing time on the growth kinetics of the boronizing layer were also investigated (Figure 4). Kinetic parameters such as processing temperature and time must be known for the control of boronizing treatment and the growth rate constants were calculated using Eq. (1). The plot of LnD versus 1/T exhibits a linear relationship (Figure 5) and, activation energy of 90.58kJ/mol were obtained from the slope of the straight lines.

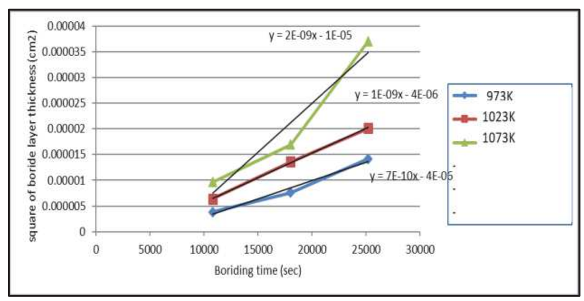


Figure 4 Square of the boride layer thickness vs. holding time.

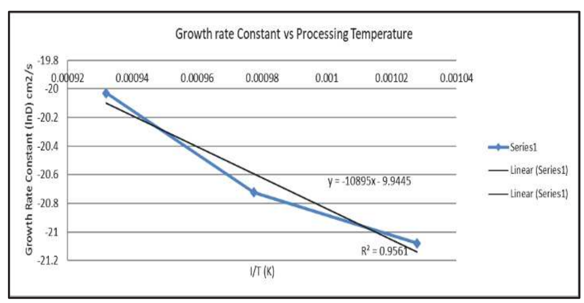


Figure 5 Growth rate constant vs. processing temperature.

4. CONCLUSION

Boride types formed on the surface of the boronized CGI have saw tooth morphology. The multiphase boride coatings that were thermo chemically grown were constituted by FeB, Fe2B phases. The kinetics of formation of the total boride layers followed a parabolic growth law. The total boride layer thickness increased with an increase in the boriding temperature. The boron activation energy was estimated as 90.58 kJ/mol for CGI.

It is interpreted as the required energy to stimulate the boron diffusion through the substrate. This value was then compared with the results found in the literature. It is seen that the determined values of boron activation energies are found to be dependent on the boriding method and on the chemical composition of the substrates as well as on the mechanism of boron diffusion into the substrate surface.

REFERENCES

[1] Lin, G., Zhang, Z., Qiu, Z., Luo, X., Wang, J., & Zhao, F. (2013). Boronizing mechanism of cemented carbides and their wear resistance. *International Journal of Refractory Metals and Hard Materials*, *41*, 351-355.

[2] Narayanaswamy, B., Hodgson, P., & Beladi, H. (2016). Comparisons of the two-body abrasive wear behaviour of four different ferrous microstructures with similar hardness levels. *Wear*, *350*, 155-165. Sen, S., Sen, U., & Bindal, C. (2005). The growth kinetics of borides formed on boronized AISI 4140 steel. *Vacuum*, *77*(2), 195-202.

[3] Campos-Silva, I., Ortiz-Domínguez, M., Tapia-Quintero, C., Rodríguez-Castro, G., Jiménez-Reyes, M. Y., & Chávez-Gutiérrez, E. (2012). Kinetics and boron diffusion in the FeB/Fe 2 B layers formed at the surface of borided high-alloy steel. *Journal of materials engineering and performance*, *21*(8), 1714-1723.