Kinetic study of boron diffusion in powder-pack boronizing

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ABSTRACT – In this study, boronized properties of AISI 304 ball bearing was investigated using powder-pack boronizing method. The experiment was carried out in temperature range from 850 to 950 ^{0}C with durations 2 – 4 hours. Microstructure of boride layer revealed a smooth surface using SEM micrograph analysis. The thickness of boride layer varied from 17-140 µm while the hardness varied between 470-900 HV. The growth of kinetic rates were plotted using Arrhenius equation and the activation energy measured from the graphical calculation is 126 kJ/mol. From this study, a new knowledge on diffusion of boron atoms on spherical surface is established.

1. INTRODUCTION

Boronizing is a thermochemical heat surface treatment that diffuses the boron atoms into a substrate [1]. It is a diffusion controlled surface hardening treatment in which boron atoms are diffused into the surface of a substrate and form borides with base metal, due to chemical reaction at high temperature [1]. Boronizing can be applied to variety of different materials including ferrous metals, non-ferrous metals and cermet [1]. Boronizing process can be performed in solid, liquid or gaseous medium but powder-pack boronizing (solid) is a process that being used frequently because of the simple method and low cost as well as easily implemented in the industry [1,2]. Besides, the simple powder-pack process can be also combined with other process such as superplastic boronizing [3]. The aim for this present study is to analyze the diffusion of boronizing powder on surface of ball bearing using metallurgraphic technique and to determine the kinetics of boronizing using the Arrhenius equation.

2. METHODOLOGY

2.1 Experimental Setup

The boronizing treatment is carried out in a solid medium using powder-pack boronizing method. 10 mm stainless-steel ball bearing is used as the samples. The sample is buried and packed with boronizing compound (Ekabor 1) in a stainless-steel container then sealed with a lid from the same material as the container. More explanations on the powder-pack boronizing was discussed in other paper [4]. The variables for this experiment are shown in the Table 1. These variables are accordance to the basic boronizing conditions as stated in Davis, 2002 [5]. Stainless-steel is used in this study since the material has shown the ability to perform as superplastic material [4]. However, this ability is not the main concern in this current study.

Table 1 Boronizing parameters.

Boronizing Time (hours)	Boronizing Temperature (^{0}C)
2	850
4	900
6	950

3. RESULTS AND DISCUSSION

3.1 Microstructure

In Figure 1, the SEM micrograph analysis showed the smooth surface of boride layer. This morphology observation is a characteristic property of the boride layer and it depends on the concentration of alloying elements as well as the treatment time and temperature from the boronizing process [2].
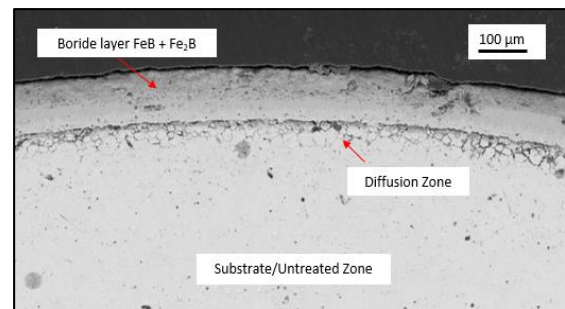

Figure 1 Boride layer morphology.

3.2 Boride layer thickness and hardness

In this present study, the hardness variation of boride layer are between 470 – 900 HV which is higher than untreated specimen (392 – 440 HV). The boride layer thickness varied from 17 to 140 µm. As the boronizing time and temperature increased, the boride layer hardness and thickness also increased as shown in Figure 2 and 3. These results are accordance to the nature of boronizing treatment because of more boron atoms diffused into the substrate with the increment in time and temperature [2].
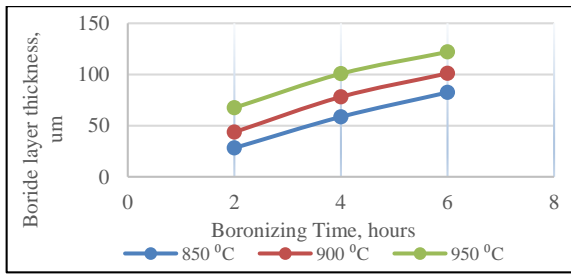
Figure 2 The variation of boride layer thickness as a function of process time.
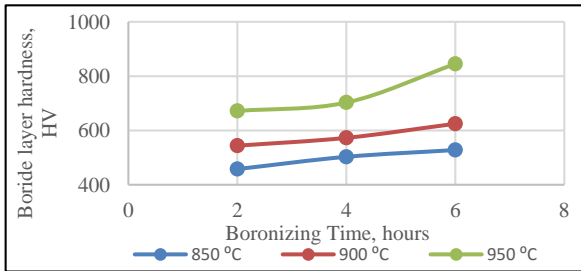

Figure 3 The variation of boride layer hardness as a function of process time.

3.3 Kinetics of atoms diffusion

The kinetics of the layer growth is controlled perpendicularly into the substrate layer [2,6] and it is describing as in Equation 1 and plotted as in Figure 4:
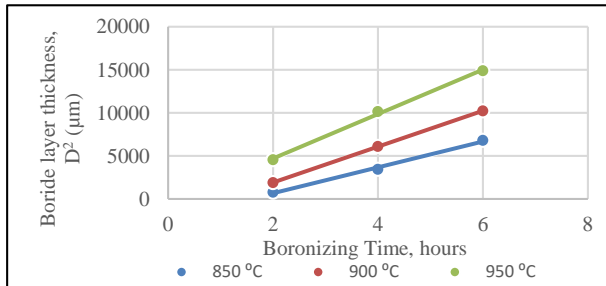
$$D^2 = Kt \qquad (1)$$

Figure 4 Square of boride layer thickness of borided stainless steel as a function process of time.

The plot of ln K versus 1/T in Figure 5 showed the linear relationship with the temperature and the value of activation energy measured from the slope is 126 kJ/mol using the Arrhenius equation as in Equation 2.
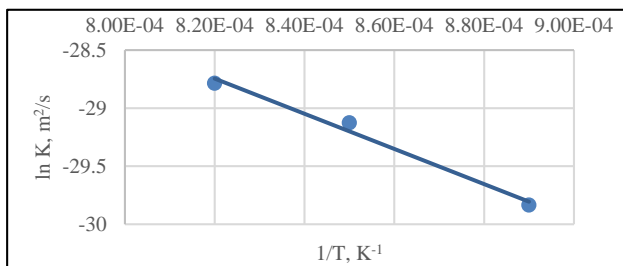

Figure 5 Natural logarithm of growth rate constant as a function of reciprocal boronizing temperature.

$$K = K_o \, e^{-Ea/RT} \qquad (2)$$

4. CONCLUSIONS

In conclusion, boronizing time treatment and boronizing temperature influenced the boride layer hardness and thickness. As the boronizing temperature and time increased, the boride layer hardness and thickness also increased. The minimum energy required to start the boronizing process (Activation Energy) is 126 kJ/mol. This study is a part of optimization study for boronizing of stainless-steel ball bearing, in which further explanation can be found in other paper [7]. From this study, a new knowledge on diffusion of boron atoms on spherical surface is established, thus can contribute to the practical engineering applications. This new improved material can be adapted in tribological field due to its high hardness that can reduce friction.

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