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Boronizing on grooved metal surface

R. Hasan[1,2,*], J.Z.L. Liew[1]

[1)] Fakulti Kejuruteran Mekanikal, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
[2)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[*]Corresponding e-mail: rafidahhasan@utem.edu.my

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ABSTRACT – Boronizing is a thermo-chemical surface hardening process in which boron atoms diffuse into metal surface. This research investigated on boronized layer thickness of different grooved surfaces. Four different groove shapes were engraved on specimens that were treated with boronizing process at several durations and temperatures. The surfaces were characterized to reveal the layer thickness of respective process duration and temperature. The results of boronized layer thicknesses were analyzed and activation energies for the boronizing processes were calculated. Different values of activation energy were determined for different grooved shapes, and this finding suggests that the surface contours affect the outcome of boronized metal surface.

1. INTRODUCTION

It is known that almost all metals can be treated with boronizing to harden the outer surfaces. However, the content of alloying elements as well as the grain size of materials can influence the diffusion rate of boronizing process [1]. Diffusion of boron atoms can produce layer thickness of around 10 µm to 200 µm, that increase surface hardness up to 1400 HV to 2000 HV [2, 3].

The boronizing process can be applied to any shapes of industrial parts and components [4], but the results of boronizing on these different applications have not been discussed qualitatively and quantitatively. Although a study reported that geometry has no effect on the formed boride layer thickness [5], the study agreed that there was geometrical effect at the high stress concentration areas, and boronizing at this particular parts has not yet been addressed in details.

As industrial parts include a lot of surface contours and shapes, boronizing at high stress concentration areas is unavoidable. Thus, is it important to quantify the effect of boronizing at the high stress concentration surfaces so that a strong knowledge on this matter can be acquired.

This current study investigates on the effect of boronizing on grooved metal surfaces. These surfaces represent high stress concentration areas that can be found in real boronizing parts. Thicknesses of boride layer formed at these grooved surfaces are analysed and activation energies are determined for all grooved surfaces. The results provide a quantified effect of boronizing on grooved surfaces which can benefit the surface engineering field.

2. METHODOLOGY

Nine cube specimens (20 mm x 20 mm x 20 mm) with four different groove surfaces were prepared from standard mild steel material, as shown schematically in Figure 1. The details of groove shapes in this study are listed in Table 1.

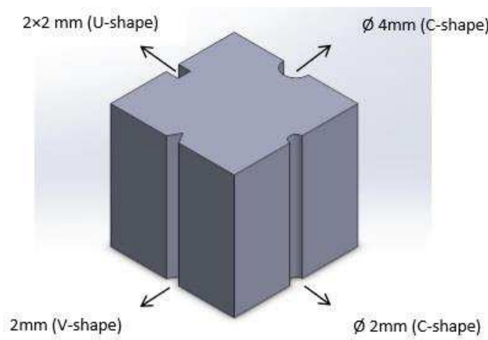

Figure 1 Schematic of grooved surfaces specimen.

Table 1 Details of groove shapes.

Groove shapes	Details of cross-section
U-shape	Square 2 mm x 2 mm
c-shape	Semi-circle diameter 2 mm
C-shape	Semi-circle diameter 4 mm
V-shape	Triangle height 2 mm

All specimens were boronized at temperatures between 1123 K and 1223 K for durations between 2 to 6 hours, respectively, by following the procedures as described in earlier study [6]. After boronizing, the specimens were undergone metallographic procedures for characterization under optical and scanning electron microscopes (SEM). Boride layer thicknesses for respective groove shapes were observed and measured. Average values were calculated from all the specimens. Activation energies for all groove shapes were determined by using Arrhenius equation as in Equation (1) and following procedures as described in previous study [7].

$$K = K_o e^{-Ea/RT} \quad (1)$$

Where K = growth rate constant; K_o = pre-exponential constant; Ea = activation energy; R = universal gas constant; T = absolute temperature.

3. RESULTS AND DISCUSSION

Figure 2 shows the example of boride layer thickness measurement for a groove shape. Meanwhile, Figure 3 shows tabulation of boride layer thickness for different grooved surfaces at 6 hours duration. The activation energies for all grooved surfaces were calculated using Equation (1) and listed in Table 2. The activation energy results showed all single values without deviations since they were derived from the mathematical equation.

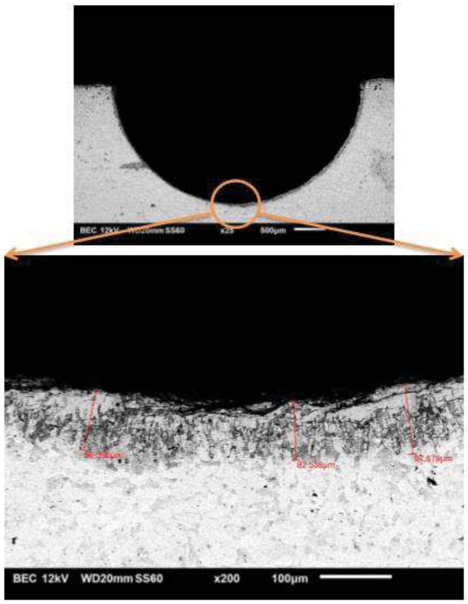

Figure 2 SEM cross-section image of C-shape groove at 1123 K for 6 hours.

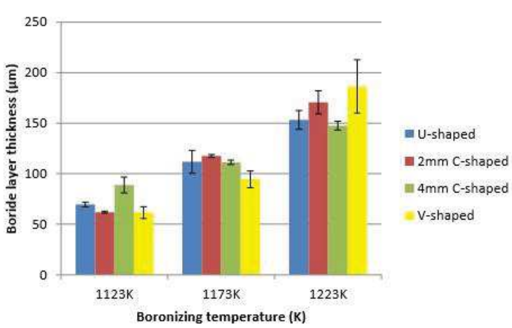

Figure 3 Boride layer thickness for different grooved surfaces at 6 hours duration.

Table 2 Activation energy of different grooved surfaces.

Groove shapes	Activation energy, *Ea*
U-shape	148.64 kJ/mol
c-shape	244.36 kJ/mol
C-shape	76.51 kJ/mol
V-shape	241.33 kJ/mol

Result in Table 2 shows that grooved surface of C-shape was having the lowest value of activation energy as compared to that of other grooved surfaces. This can be understood as being the lowest energy required by boron atoms to diffuse into the surface. The finding from this study is a new interesting phenomenon that requires further detail and in depth study, as this is found as contradict to that mentioned by Calik et al. [5]. It was shown in this study that geometries of high stress concentration areas affect the formation of boride layer thickness on metal.

4. SUMMARY

The values of activation energies were found as different for all grooved surfaces. The finding showed that geometries of high stress concentration areas such as grooved surfaces need to be well considered and cannot be ignored during boronizing process. As boronizing is widely applied in surface hardening industry, this study contributes to a new knowledge on the effect of geometries on boronized metal surfaces.

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