DEVELOPMENT OF PACK BORONIZING FOR AUTOMOTIVE APPLICATION

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials)"

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DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged."

Signature: ....

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Date: 29 JUNE 2015

For all my beloved family and
supervisor for all their support and blessing

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ABSTRACT

Boronizing is a thermo-chemical surface hardening treatment in which boron atoms diffused into the metal substrate to form metallic boride layer, providing high hardness, corrosion resistance, and 3-10 times increasing service life. This type of surface treatment is widely used in many applications. The purpose of this work is to study and to investigation the hardness of the part before and after the boronizing treatment. The types of steel that was choose in this study is Stainless Steel AISI 316 (austenitic type). The boronizing powder pack that are used is Ekabor 1. The pack boronizing process involves the embedding of the metal into boronizing powder mixture. The unboronized and boronized of specimens at different value of powder condition will be analyzed in term of their hardness and other abilities using Rockwell Hardness testing apparatus. Different in hardness values for each specimen that was boronized at various conditions will be further analyzed to verify the effects of boronizing powder condition on hardness. The microstructure of boronized and unboronized specimens observed in this study. All of the causes were discussed.

ABSTRAK

Penyusukboronon adalah rawatan kimia dan suhu untuk tujuan mengeraskan permukaan logam dimana atom boron bercampur dengan logam asas, memberi tahap kekerasan yang tinggi, ketahanan terhadap kakisan dan meningkatkan jangka hayat kepada 3 - 10 kali lebih dari logam asal. Banyak aplikasi yang menggunanankan rawatan permukaan ini secara meluas. Kajian ini adalah bertujuan untuk menbincangkan kesan-kesan penyusukboronan ke atas kekerasan logam sebelum dan selepas penyusukboronan. Jenis logam yang digunakan dalam kajian ini ialah Stainless steel AISI 316 sebagai spesimen. Serbuk penyusukboron yang digunakan adalah Ekabor 1. Pek proses boronizing melibatkan pembenaman logam ke dalam boronizing campuran serbuk. Spesimen-spesimen yang tidak diaplikasikan proses penyusukboronan dan juga spesimen yang diaplikasikan proses tersebut pada keadaan serbuk yang berbeza seperti yang ditetapkan akan dianalisis sifat kekerasan mereka dengan menggunakan alatan pengujian kekerasan. Perbezaan nilai kekerasan yang disusukboronan pada variasi berbeza dianalisis lebih lanjut untuk menilai kesan serbuk penyusukboronan terhadap kekerasan. Microstruktur permukaan bahan sebelum dan selepas proses penyusukboronan dikaji. Semua kajian dibincangkan didalam kajian.

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1. x = Thickness

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U.T.e.M : Universiti Teknikal Malaysia Melaka

Hv : Vickers Hardness

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Boronizing is a thermochemical process in which boron atoms are diffused into the surface of a workpiece to form complex borides with the base metal. It is a diffusion-controlled process. In addition to nickel, titanium, cobalt alloys and cemented carbides, nearly any ferrous material can be boronized. It should be noted that the diffusion rate slows down in higher-alloyed steels. (R.Davis ,2002)

Boronized steels are extremely resistant to abrasion because of their high hardness and the service life can be significantly increased (R.Davis ,2002). The process uses boronized agents such as powder, granulates of various grain sizes and pastes, which are commercially available. Depending on the requirements of the parts, the diffusion layer thickness is in range of 20-200 µm depth. Layers are much thinner in the case of austenitic stainless steel. Boronized steel part can be vacuum hardened afterward to achieve the desired mechanical properties of the base material due to the similar thermal expansion coefficient. The process temperature for boronizing depends on the materials grade and lies between 700 ºC to 1000 ºC. A stress-relieving treatment can be carried out after machining and prior to boronizing to minimize distortion. Other heat treatment before boronizing, such as quench-hardening, should not be perform, since the boronizing process removes the results of a preheat treatment. Where dimensional accuracy is paramount, the boride layer will add 20-30% of its thickness to the size of the part and the workpiece must be undersized during manufacturing. (R.Davis ,2002)

Boronizing is used successfully for general wear resistance of carbon steel components, combined with the broad range of compatible substrates and the cost-effective nature of the process due to wear/performance benefits provided by the boronized layer. Boronizing is also a good choice for certain tooling applications due to its temperature and wear resistance (R.Davis ,2002). Table 1.1 shows the typical part for boronizing and benefit of boronizing.

Table 1.1 : Typical part for boronizing and the benefit of boronizing (R.Davis ,2002).

Typical parts for boronizing	Benefits of Boronizing
Moulds for glass bottle production	Increased tool and mold life
Steam turbine blades, tri-pin blades and nozzle rings	Good resistance to abrasive, sliding and adhesive wear
Oil & gas field tubing (OCTG)	Reduced use of lubrication
Plungers and rollers	Can be polished to a high finish
Gears and shafts	Reduced tendency to cold weld
Burner nozzles	Low coefficient of friction
Pump and valve components	

1.2 OBJECTIVE

The objective of this study are :

1. To propose automotive parts which are suitable to be treated by pack boronizing.
2. To design and fabricate a suitable container for powder pack boronizing procedure.
3. To develop pack boronizing process and investigate the hardness of the part using FKM, UTeM facilities.
4. To determine factors that influence boronizing process on stainless steel materials.

1.3 SCOPE

The scope of this study includes the followings :

1. Experimental works of a proposed boronizing procedure on several automotive parts.
2. Analysis of hardness for the boronized part.
3. Analysis on the influence of the boronizing powder concentration to the hardness of materials.

1.4 PROBLEM STATEMENT

In numerous automotive applications, surface solidifying treatment is important to create a high surface hardness on a steel part with the goal that it can oppose wear and scraped area. In this project, the boronizing applicability to some automotive parts is studied and the effects of boronizing on the hardness of the parts are analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 BORONIZING

Boronizing, or boriding, is a thermochemical treatment that diffuses boron through the surface of metallic substrates. As boron is a component of generally tiny size, it diffuses into a mixture of metals; including ferrous, nickel and cobalt combinations, metal-reinforced carbides and most refractory alloys (Glukhov,1990). The procedure gives the metallic boride layer that the ensuing metallic boride layer yields the extraordinary properties of high hardness, great wear and consumption safety (Suwattananont,2004). The procedure includes warming pre-cleaned material in the temperature range of 700 to 1000 ºC (1300-1832 F) for 1 to 12 hour, in contact with boronaceaus solid (boronizing compound), glue, fluid, or gaseous medium (Sinha,1991).

Other advancement of thermochemical boronizing incorporate plasma boronizing, beat plasma boronizing, and fluidized-couch boronizing. Boron atoms diffuse and subsequently absorb into the metallic lattice of the component surface during boronizing. As a result, an interstitial boron compound is formed with either a single-phase boride or a poly-phase boride layer(Sinha,1991). Most ferrous materials, with the exception of aluminium and silicon bearing steels, e.g. structural steels, case hardened, tempered, tool and stainless steels, cast steels, ductile and sintered steels and also air hardened steels can be carried out by boronizing. In addition, materials such as nickel-based alloys, cobalt-based alloys and molybdenum can be boronized. A boronized Nickel alloy produce an extreme hard surface wear resistance. Nitrided steels, leaded and resulfurised steels are not suitable for boronizing (Sinha,1991).

Material Selection for Boronizing :

- Non alloyed and low alloyed steels
- Stainless steels
- cast iron, casted steel
- Cold work,hot work, and HSS steel
- Powder metallurgical steel
- Cobalt based materials
- Cemented carbides
- Nickel-based alloys

A few trademark peculiarities of borides layers, including morphology, growth, and phase composition which can influence the alloying components in the base material demonstrate in Table 2.1

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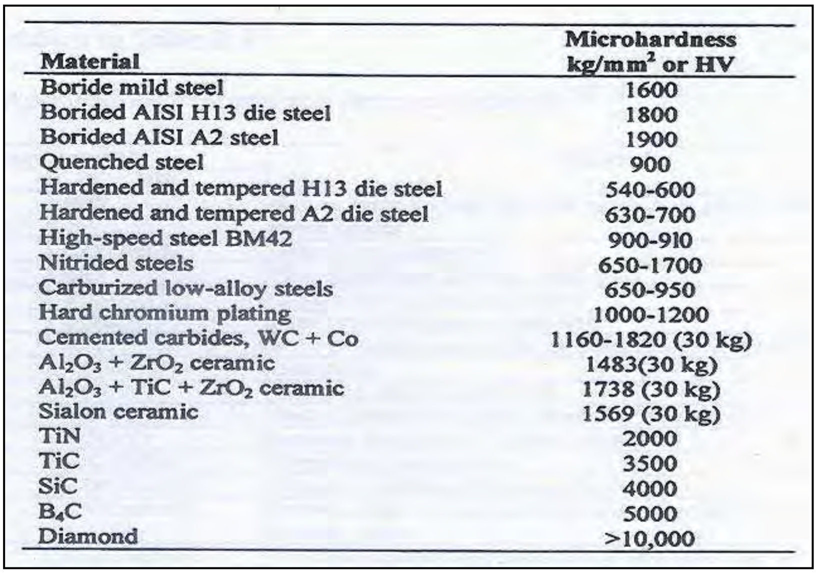
Table 2.1: Microhardness of Different Boride Phases Formed after Boriding of Different Substrate Materials (Sinha,1991).

Substrate	**Constituent phases in the boride layer**	**Microhardness of layer, HV or Kg/mm^2**
Fe	FeB Fe_2B	1900 - 2100 1800 - 2000
Co	CoB Co_2B	1850 1500 - 1600
Co-27.5 Cr	CoB Co_2B	2200 (100g) ~1550 (100g)
Ni	Ni_4B_3 Ni_2B Ni_3B	1600 1500 900
Inco 100	. . .	1700 (200g)
Mo	Mo_2B Mo_2B_5	1660 2400 - 2700
W	W_2B WB W_2B_5	~2700 (overall hardness)
	TiB	2500

Ti	TiB_2	3370
Ti-6A1-4V	TiB TiB_2	3000 (100g) (overall hardness)
Nb	Nb_2B_2 NbB_4	2600 - 3000 (overall hardness)
Ta	Ta_2B TaB_2	3200 - 3500 2500
Zr	ZrB_2 Zr_2B	2300 - 2600 (overall hardness)
Re	ReB	2700 - 2900

Boride layers have various trademark characteristics with unique points of interest over conventional case hardened layers. Boride layers have greatly high hardness values (somewhere around 1450 and 2000 HV) with high liquefying purposes of the constituent stages (Sinha,1991).The common surface hardness estimations of boride steels compared others medicines and other hard materials are recorded shown in Table 2.2. This obviously outlines that the hardness of boride layers produced on carbon steels is much greater than that are delivered by any others conventional surface solidifying treatment.

Table 2.2: Typical Surface Hardness of Boronized Steels Compare with Others Treatment and Hard Materials (Sinha,1991).



Material	Microhardness kg/mm^2 or HV
Boride mild steel	1600
Borided AISI H13 die steel	1800
Borided AISI A2 steel	1900
Quenched steel	900
Hardened and tempered H13 die steel	540-600
Hardened and tempered A2 die steel	630-700
High-speed steel BM42	900-910
Nitrided steels	650-1700
Carburized low-alloy steels	650-950
Hard chromium plating	1000-1200
Cemented carbides, WC + Co	1160-1820 (30 kg)
$Al_2O_3 + ZrO_2$ ceramic	1483(30 kg)
$Al_2O_3 + TiC + ZrO_2$ ceramic	1738 (30 kg)
Sialon ceramic	1569 (30 kg)
TiN	2000
TiC	3500
SiC	4000
B_4C	5000
Diamond	>10,000

2.1.1 Boronizing of Ferrous Materials

Either a single phase or double-phase of boride layer shaped on iron and steel can be of corresponding to a definite composition from Fe-B, Fe_2B acquired for the single-stage layer, while the double-phase layer comprises of an outside period of FeB and inner part phase of Fe_2B with is a saw-tooth structure as the morphology of the boride layer The saw-tooth structure helps improving the mechanical adherence at the Fe_2B /substrate interfaces. (Suwattananont,2004).

The formation of Fe_2B stage is expectedly favored than that of FeB stage, express that FeB stage is more brittle than Fe_2B stage. Also, it is observed that FeB forms a surface under the high tensile stress while Fe_2B form a surface under the high compressive stress. The boronizing process cause to the break arrangement at the FeB which avoids from having the coincidence of Fe_2B and FeB stages. Fe_2B interface of double phase layer. The separation of double phase layer under the applied mechanical strain or the thermal/mechanical shock and the crack formation leads to the spalling. After boronizing treatment, annealing process can decrease the occurrence of FeB phase. (Sinha,1991).

Typical properties of the FeB phase are (Sinha,1991):

a) Microhardness of about 19-20 GPa.
b) Modulus of elasticity of 590 GPa.
c) Density of 6.75 g/cm3
d) Thermal expansion coefficient of 23 x 10-6 /C between 200-600 oC
e) Composition with 16 to 16.2 wt% boron.
   Lattice parameters: a= 4.053A, b=5.495A, and c=2.946A.

The typical properties of Fe2 B phase are (Sinha,1991) :

a) Microhardness of about 18-20 GPa.
b) Modulus of elasticity of 285 to 295GPa.
c) Density of 7.43 g/cm3
d) Thermal expansion coefficient of 7.65 x 10-6 / ºC between 200-600ºC
e) Composition with 8.8 wt% boron.
f) Lattice parameters: a= 5.078A, and c=4.249A

2.1.2 Boronizing Reactions

The boronizing procedure involves two reactions. The first reaction is the beginning stage happens between component boron medium and surface. Boronizing temperature and time and are followed by the growth of boride layer are structured as the function of the cores. Fe_2B cores are initially formed and grow as a thin boride layer at the defect point of the metal surface if there should be an occurrence of ferrous materials. The rich boron product stage on the off chance that the active boron medium is excess for example FeB will form and grow on the Fe_2B phase. (Chatterjee,1989)

The second stage is a diffusion-controlled process, which the thickness of bride layer is formed under an parabolic time law:

$$x^2 = kt \qquad \text{[Equation 2.1]}$$

where x as the thickness of the bride layer, t as the boronizing time and k as an constant relying upon the temperature, (Chatterjee,1989). Boron molecules diffuse in the crystallographic direction and form the body-focused tetragonal in the case of ferrous materials grid of Fe_2B to accomplish the greatest nuclear thickness along this direction. The growth of Fe_2b is columnar totals of crystals, which shows the saw-tooth structure. The columnar growth of FeB grow (Sinha,1991) in the crystallographic direction and the saw-tooth structure of FeB is lower than that of Fe_2B for the double phase, (Palombarini. and Carbucicchio, 1984)

2.1.3 Influence of Alloying Elements

The prominent saw-tooth structure of boride layer is decently seen in pure iron, unalloyed low-carbon steel, and low alloy steels. The thickness of the boride layer is decreased at the point when the alloying components and/or carbon substance in the substrate steel are expanded. An alternate impact of alloying components (aside from nickel, cobalt, and manganese), which retard the boron diffusion into the substrate, is to increase the proportion of FeB constitution (Dearnleyand Bell,1985).