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STUDY ON BORONIZING AND THE KINETICS IN LOW ALLOY TOOL STEEL

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"I verify that this report is my own word except summary and extract that every one of it I have clarify the resource"

Signature : ……………………………

Writer's Name: Mohammad Khabib bin Khalib

Date : …………………………..

For my beloved mother

Puan Che Long binti Hj Idris

My sisters and brothers

Khairani binti Khalib & family

Khairiza binti Khalib & family

Shakiroh binti Khalib & family

Mohamad Khairul Hafizhi bin Khalib

For all of their support and blessing

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ABSTRAK

Penyusukboronan adalah salah satu daripada kaedah rawatan permukaan bahan. Ia adalah proses dimana boron aktif akan diresapkan ke dalam permukaan keluli atau aloi dalam langkah untuk menghasilkan lapisan boron. Proses ini akan meningkatkan kebolehupayaan mikrostruktur dan kekerasan permukaan spesimen. Dalam kajian ini, bahan specimen yang digunakan adalah keluli beraloi rendah A2 dan agen penyusukboronan adalah Ekabor 1 yang biasa digunakan dalam industri pembuatan. Kajian ini merangkumi proses penyusukboronan iaitu prosedur proses, kaedah yang akan digunakan dalam proses ini dan juga keputusan yang diperolehi. Eksperimen akan dilakukan dengan masa dan suhu yang berlainan iaitu 3, 6, dan 9 jam serta 800°C, 850°C 900°C untuk suhu yang berlainan supaya keputusan yang diperolehi dapat dibandingkan dan keputusan yang terbaik akan diperolehi. Keputusan kajian ini akan diambil kira dari segi bentuk mikrostruktur, kekerasan spesimen dan juga kinetik dalam lapisan boron menggunakan persamaan Arrhenius. Selain penyusukboronan, penyahboronan juga diambil kira dalam kajian ini dimana proses ini melemahkan kekerasan permukaan specimen itu.

ABSTRACT

Boronizing is one of the methods of surface treatment. It is a process by which active boron atoms diffuse into the surface of substrate metal or alloy in order to produce a layer of borides. The process will improve the microstructure and surface hardness of the specimen. In this study, material used is A2 low alloy steel and the boronizing agent used is Ekabor 1 which is normally used in manufacturing industry. This research will cover about boronizing process which is the procedures of the process, method used in this research and the result of the research. The experiment will be done with different times which are 3, 6, and 9 hours and temperature variables 800°C, 850°C and 900°C so that the result can be compared and the best result can be determined. The result of the study will be verified in aspect of microstructure shape, hardness of the specimen and the kinetic of boride layer using Arrhenius equation. Instead of boronizing, deboronizing also considered in this research which is weaken the surface hardness of the specimen.

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INTRODUCTION

1.1 General

Boronizing is a thermochemical surface treatment that involves diffusion of boron into a base metal at a high temperature. The resulting metallic boride provides high hardness and resistance to acid corrosion, and lengthens service life by a factor of three to ten. Boronizing fills a gap between conventional surface treatments and the more exotic chemical and physical vapor deposition. In a number of applications, boronizing has replaced such processes as carburizing, nitriding, and nitrocarburizing. It has even replaced hard chrome plating in some cases, while achieving similar service life improvements. Boron can be uniformly applied to irregular surfaces, and can be applied to specific areas of a surface. It is also suitable for high-volume production applications, as first demonstrated in the European automotive industry (Stewart, 1997).

Boronizing is a thermo-chemical surface hardening process that boron atoms diffuse into a base metal (steel) and form the hard metallic boride layer on the surface. The process can be applied to both ferrous and non-ferrous materials by heating well-cleaned materials in the temperature range of 700 - 1000°C (1300 - 1830°F) for several hours. The process provides the metallic boride layer about 20-300μm thick. The resulting metallic boride layer yields the outstanding properties of high hardness, good wear and corrosion resistance, and moderate oxidation resistance at high temperature.

Although many metals and alloys can be boronized, aluminium and magnesium alloys can't be boronized due to their low melting points. In addition, cooper alloy is unable to form the stable boride phase. (Dearnly, 1985).

In this study, the problem statement of the research is to determine which condition of time and temperature are very suitable to be done in terms to get the best material properties. Low alloy steel will be used as the specimen in this research. Low alloy steel is steel alloyed with other elements, usually molybdenum, manganese, chromium, vanadium, silicon, boron or nickel, in amounts of up to 10% by weight to improve the hardenability of thick sections. Steel with higher alloy contents are generally called stainless steel, tool steel, or simply high alloy steel depending on the alloying elements (William, 2004).

1.2 Objectives

The objectives of the study are:-
To study the effects of time and temperature on hardness and microstructure of boronized layer in low alloy tool steel as well as to determine kinetics of boron atom diffusion in low alloy tool steel using Arrhenius equation.

1.3 Scope of Research

The scopes of the research are:-

i. To develop a suitable method for powder pack boronizing in laboratory's furnace chamber.
ii. To carry out boronizing treatment on low alloy tool steel A2.

iii. To carry out hardness and microstructure study on the boronized low alloy tool steel, as well as calculate the kinetics of boron atom diffusion in the material using Arrhenius equation.

1.4 Outline of Research

The research outlines are divided as follows:

1. Literature review

   The basic concept and the theories of the material used, boronizing process, and Arrhenius equation were reviewed in this chapter. The sources of the information were collected from various sources such as journals, text books, internet, previous dissertation reports and my supervisor for PSM.

2. Experimental works

   These phase of the project need me to do the experimental works of the experiment such as the preparation of the specimen before the boronizing process can be done. The steps of the process were clearly described in chapter 3.

3. Characterization

   After the experiment was done, the microstructure and the hardness of the surface before and after the boronizing process were measured. The method of measuring the microstructure and the hardness of the surface were explained in chapter 3.

4. Data collection and data analysis

   Raw data from the characterization process were collected according to the research phase. Chapter 4 includes the analysis of the data and the comparison with the unboronized data. The kinetic of boronizing process also determined in this chapter.

5. Discussion

All of the results obtained in this research work were compiled and discussed in chapter 4. Chapter 5 and 6 will represent the conclusion and the recommendation of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Boronizing

2.1.1 Historical Background

Boronizing is a thermochemical heat treatment that produces a hard, wear-resistant boride layer on steel. The process can actually be traced back to an article published in 1895, in which Henry Moissan described a method of hardening iron at red heat in a vapor of volatile boron halides *(internet source 21/9/2007).*

The application of boronizing to industry followed about 60 years later. From Russian publications it is known that the service life of salt-bath bonded parts in pumps for oil exploration was four times longer than parts that were casehardened or induction-hardened. As long ago as the turn of the century, it was realized that very hard and wear-resistant iron borides can be obtained by diffusing boron into the surface of steel parts.

Since then, there have been various attempts to develop an industrial method of boronizing steels. As the medium for boron emitting can take solid, liquid or gaseous form, development work has been carried out in all three fields. Gas, especially, offers a number of distinct technical advantages as a diffusion medium, and is used successfully, for example, for nitriding, case hardening and chromizing *(internet source 21/9/2007)*.

However, owing to unsolved problems and serious deficiencies that, to this day, remain unrectified, gas- and liquid-phase boronizing have not become state-of-the-art. Technological variants of boronizing are therefore based solely on solid boronizing agents. New, fundamental research work in the field of plasma boronizing has resulted in a patent application, and promises a technological leap forward in boronizing for the future.

During the process of boronizing, which as a rule takes place at temperatures between 850°C and 950°C, boron atoms diffuse into the metal surface and form metal borides. The structure and properties of these borides are influenced significantly by the type of substrate. With ferrous materials, the boride layers attain a Vickers hardness of between 1600 and 2000; with nickel-based alloys, by contrast, a Vickers hardness of up to 2800 is obtained. Depending on the application and the base material, layer thickness range between 20 µm and 300 µm. These layers adhere excellently to the substrate, since they are formed by a diffusion process which results in an intimate connection between boride and substrate (Stewart 1997).

2.1.2 Characteristic of Boronizing

Thermochemical treatment techniques have been well investigated and used widely in the industry. This is a method by which nonmetals or metals are penetrated by thermodiffusion followed by chemical reaction into the surface. By thermochemical treatment, the surface layer changes its composition, structure, and properties (Erdemir, 1995).

Carburizing, nitriding, carbonitriding, chromizing, and aluminizing are the most popular methods for industrial applications. Among these coating techniques, boronizing, being a thermochemical process, is used to produce hard and wear-resistant surfaces (Pengxun, 1992). Thermal diffusion treatments of boron compounds used to form iron borides typically require process temperatures of 700-1000°C in gaseous, solid, or salt media (Hu, 1990).

Boronizing is a process by which active boron atoms diffuse into the surface of substrate metal or alloy in order to produce a layer of borides (Hunger, 1994). This treatment can be applied to ferrous materials, certain nonferrous materials such as titanium, tantalum, niobium, zirconium, molybdenum, nickel-based alloys, and cermets (Wierzchon, 1998). Borides formed on steel surfaces increase their hardness to about 2000 HV, wear resistance, and corrosion resistance (Venkataraman, 1995). Diffusion boronizing forms boride layers on metal and steel with good surface performance (Pertek 1994).

The main disadvantage of boronizing is the brittleness of boronized layers, especially of FeB boride (Xu, 1997). To lessen this brittleness, the production of multi component and composite boride layers is applied (Wierzchon, 1995). The simultaneous boronizing and aluminizing produced under the gas-phase reactions from paste mixtures have been successfully studied. The complex diffusion layers could be separated into three groups: the needle-shaped layer with aluminum dissolved into iron boride, the layer showing conglomerates of boride and aluminum phases, and the layer with rich aluminum phases on the external surface (Sinha, 1991).

The boronized layer has a number of characteristic features with special advantages over conventional case-hardened layers. One basic advantage is extremely high hardness values (between 1450 and 2100 HV). This clearly illustrates that the hardness of boronized layers produced on carbon steel is much greater than any other conventional surface treatment; it exceeds that of the hardened tool steel and hard chrome electroplate, and is equivalent to that of the tungsten carbide. The combination of high hardness and a low surface coefficient of friction of the boronized coating also make a significant contribution in combating the main wear mechanisms: adhesion, abrasion, and surface fatigue (Fichtl, 1983).

By boronizing, very hard layers are produced, allowing a better wear strength and abrasion than other thermochemical processes such as carburizing and nitriding (Hunger, 1994).

Boronized steel consistently outperforms nitrided and carburized steels, 9, 16, 31 essentially because the iron boride formed exhibits substantially higher hardness (HV = 1600-2000) as compared to carburized or nitrided steels (HV = 650-900). In particular, boronized steel exhibits excellent resistance to a variety of tribological wear mechanisms (Sundararajan, 1998). In addition, the resistance of boronized steel to attack by nonoxidizing dilute acids, alkalis, and molten metals is also outstanding (Chatterjee-Fisher, 1989).

2.1.3 Mechanism of Boronizing

The boronizing process consists of two reactions. The initial stage taken place between boron medium and component surface. The nuclei are formed as the function of boronizing temperature and time are followed by the growth of the boride layer (Borgess et al, 1998). The second stage is a diffusion-controlled process, which the thickness of boride layer is formed under parabolic time law:

$$X^2 = kt$$

Where,

X = the thickness of the boride layer

k = constant depending on the temperature

t = the boronizing time

(Borgess et al, 1998).

In case of ferrous materials, according to *Buijnster et al.* (2002) boron atoms prefer to diffuse in the crystallographic direction and for the body-centered tetragonal lattice of ironboride (Fe_2B) to achieve the maximum atomic density along this direction. The growth of ironboride (Fe_2B) is columnar aggregates of crystals, which exhibits the saw-tooth morphology (Waterhouse, 1975). For the double phase, the columnar growth of ironboride (Fe_2B) prefers to grow in the crystallographic direction and the saw-tooth structure of FeB is lower than ironboride (Fe_2B).

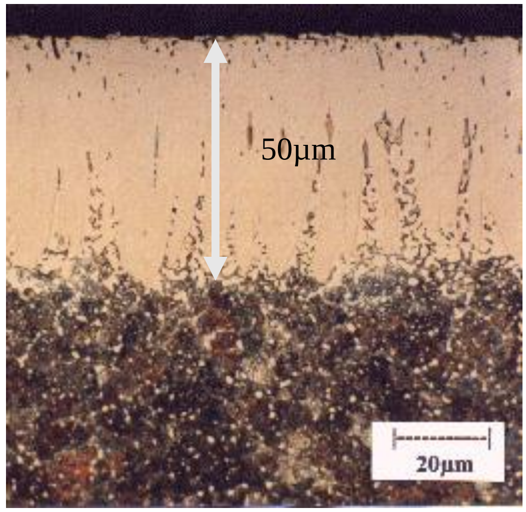

Figure 2.1**:** Boride layer on steel of type 100Cr6 / Thickness of the boride layer: 50µm*(internet source 21/9/2007)*.

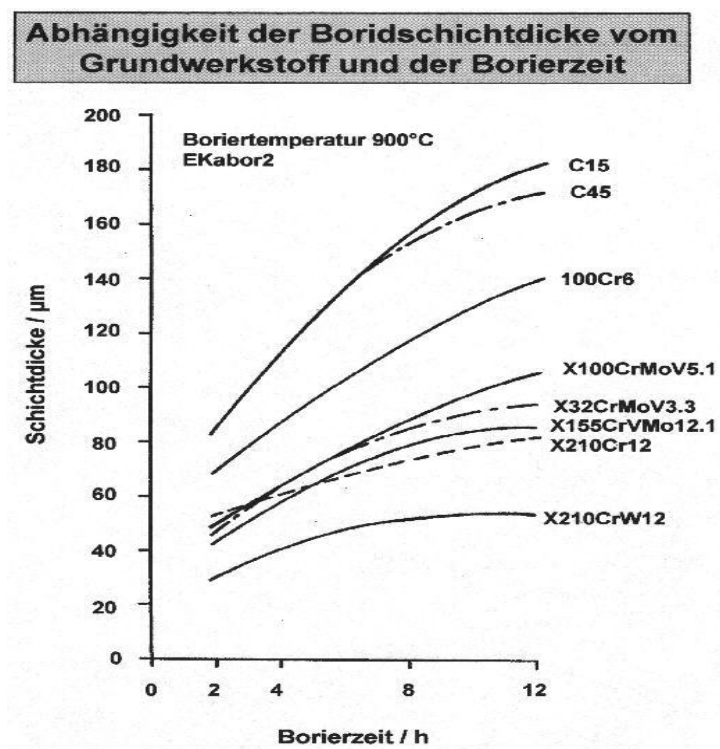

Figure 2.2: Boride layer thickness as a function of time for various steels under the same boronizing conditions, layer thickness decreases as the proportion of alloying elements increases *(internet source 21/9/2007).*

2.1.4 Applications of Boronizing

Abrasion and adhesion are the principal forms of wear and is a feature of almost all types of mechanical stress. Boronized steels are extremely resistant to abrasion on account of their extremely hard surface. Depending on the application, boride layer thickness varies from 20 to 300μm and result in a several-fold increase in service life. Applications for a reduction in abrasive wear include pneumatic transport systems, plasticizing units in plastic processing, parts for mills, pumps and valves (valve balls), plungers for the glass industry and parts for textile machinery. In addition to high abrasion resistance, the boride layers exhibit the important property of having little tendency to cold-weld.

Other applications of boronizing such a wear-resistant body may be used to manufacture cutting tools, drawing dies, inserts for an earth-boring bit, face seals, bearing surfaces, nozzles, and etc *(internet source, 20/9/2007).*

Other developments in boronizing include gas boronizing techniques such as fluidized bed boronizing and plasma boronizing. Physical vapor deposition and CVD, plasma spraying, and ion implantation are alternative non-thermochemical surface coating processes for the deposition of boron or co-deposition of boron and metallic elements onto a suitable metallic on nonmetallic substrate material *(internet source, 20/9/2007)*.

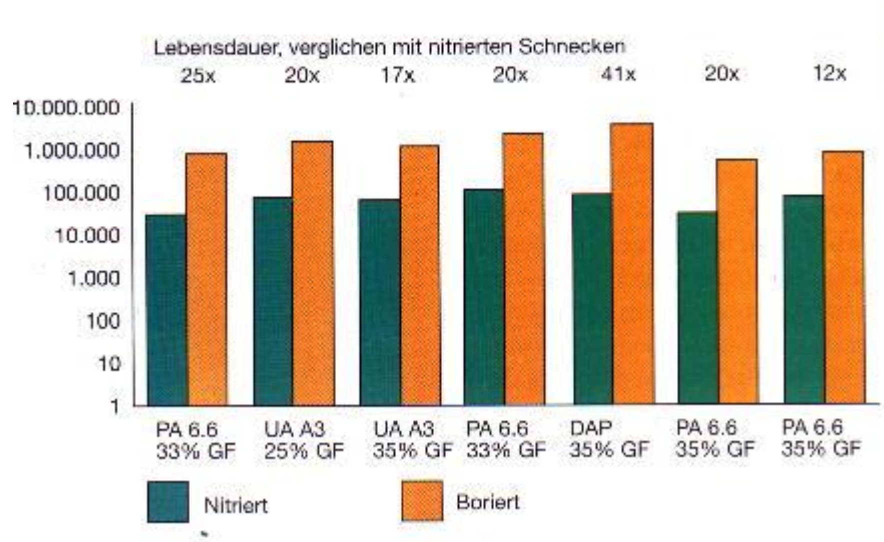

Figure 2.3: Comparison of the service lives of boronized and nitrided *(internet source, 20/9/2007)*.

Where,

PA = polyamide;

UA = unsaturated acrylonitrile;

DAP = diallyl phthalate;

GF = glass-fibre content

Figure 2.4: Boronized valve balls*(internet source, 20/9/2007)*.