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BORONIZING EFFECTS ON IMPACT TOUGHNESS OF LOW ALLOY TOOL STEEL

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This report is proposed to fulfilled some of the requirements to be honor with Bachelor of Mechanical Engineering (Structure and Material)

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"I verify that this report is my own work except for the citation and quotation that the source has been clarify for each one of them"

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Author:………………………....

Date:……………………………

To my beloved family for their encouragement and support especially, and for their understanding in the way I am.

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ABSTRACT

The purpose of this work is to study and discuss the effects of boronizing on impact toughness of boronized low alloy tool steel through statistical analysis. The types of steel that was choose in this study is Low Alloy Ateel (A2). The specimens need to apply the surface hardened by using boronizing techniques in which boron atoms diffused into the metal substrate form the metallic boride layer. The unboronized and boronized of specimens at different value of temperatures and times will be analyzed in term of their toughness and other abilities through Charpy impact testing apparatus. Different in impact toughness values for each specimen that was boronized at various conditions will be further analyzed using Statistical Analysis to verify the effects of boronizing time and temperature on impact toughness. All of the causes were discussed. Conclusion have been made that boronizing process made the low alloy tool steel more ductile due to more energy absorb during fracturing.

ABSTRAK

Kajian ini adalah bertujuan untuk menbincangkan kesan-kesan penyusukboronan ke atas ketegaran impak alat keluli beraloi rendah mengunakan kaedah analisis statistik. Jenis logam yang digunakan dalam kajian ini ialah keluli beraloi rendah sebagai spesimen. Spesimen-spesimen ini akan diaplikasikan rawatan pengerasan permukaan dengan mengunakan teknik penyusukboronan di mana, atom-atom boron akan menyerap masuk ke dalam spesimen dan menbentuk satu lapisan berkilat. Spesimen-spesimen yang tidak diaplikasikan proses penyusukboronan dan juga spesimen yang diaplikasikan proses tersebut pada tahap suhu dan masa yang berbeza seperti yang ditetapkan akan dianalisis sifat ketegaran mereka dengan menggunakan alatan pengujian impak. Perbezaan nilai ketegaran impak yang disusukboronan pada variasi berbeza dianalisis lebih lanjut menggunakan kaedah analisis statistik untuk mengesahkan kesan masa dan suhu yang berbeza semasa proses penyusukboronan terhadap ketegaran impak. Semua sebab-sebab berkenaan perkara tersebut dinyatakan dan kesimpulan telah dibuat bahawa proses penyusukarbonan menyebabkan alat keluli beraloi rendah bersifat lembut dan berikutan keupayaannya menyerap lebih banyak tenaga semasa mengalami kepatahan.

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LIST OF SYMBOL

μ	=	mean
σ	=	variance
wt%	=	percent of weight

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CHAPTER 1

INTRODUCTION

1.1 Background.

Boronizing or boriding is a well known thermo chemical surface hardening treatment process that can be applied to a wide variety of ferrous, non ferrous and cermets materials. The process involves heating well-cleaning material in the range of 700 to 1000 Celsius, preferably for 1 to 12 hour, in which boron atoms diffused into the metal substrate form the metallic boride layer on metal surface, providing high hardness, corrosion resistance, and 3-10 times increasing services life (Suwattananont,2004). Boronizing can complement the technology gap between conventional heat treatment and chemical/physical vapor deposition, therefore it used to replace many applications in carburizing, nitriding, and carbonitriding However, only the pack and paste boronizing techniques are able to process in many applications while other techniques, such as the liquid and gas boronizing techniques, that are incapable of the application because of toxicity problems (Sinha,2003).

Alloy steel may be defined as those steels which owe their improved properties to the presence of one or more special elements or to the presence of larger proportion of elements such as Mn and Si than are ordinarily present in carbon steels (*internet source, 12/9/07*). The alloying elements that contain in alloy steel can improve the mechanical and fabrication properties as well as hardenability. Broadly, alloy steel can be divided by two: (a) low alloy steels containing 2 to 8 wt% total non carbon alloy addiction and (b) alloy steels with more than 8 wt% total non- carbon alloy addition (Sinha,2003).By applying the surface hardening process which includes a wide variety of techniques to improve the wear resistance without affecting the softer, tough interior of the alloy steel parts.

Toughness is a measure of the amount of energy a material before fracturing. Basically, one of the methods of measuring toughness is to use an impact toughness apparatus. The methods of using this apparatus are to place a Charpy V- Notch specimen across parallel jaws in the machine. In the impact test a heavy pendulum released from a known height strikes the sample on its downwards swing, fracturing it. By knowing the mass of the pendulum and difference between its initial and final heights, the energy absorbs by the fracture can be measured and analyze. For any combination of alloy steel and heat treatment, three factors tend to decrease toughness; low service temperature, high loading rates, and stress concentrations or residual stress. The general effects of these three conditions are qualitatively similar, so low-temperature impact tests (to -50°F) are useful for many applications as toughness indicators under various service conditions and temperatures (*internet source, 12/9/07*).

1.2 Objective.

The purpose of this work is to study and discuss the effects of boronizing on impact toughness of boronized low allow steel using statistical analysis where the toughness of low alloy steel can be measured. It becomes of engineering importance when the ability of a material to withstand an impact load without fracturing is considered.

1.3. Scope.

The scopes of this study are:

i. To develop suitable method for powder pack boronizing in laboratory's furnace chamber.
ii. To carry out boronizing treatment on Low Alloy Steel A2.
iii. To carry out impact toughness on material and discuss the data using statistical analysis.

1.4. Problem Statement.

In many industrial applications, surface hardening treatment is necessary to develop a high surface hardness on a steel part so that it can resist wear and abrasion. This can achieve by increasing the hardness of a high carbon steel but high hardness then accompanied by low ductility and toughness (Totten,2007). The majority of ferrous alloy are low carbon steel and low alloy steel. In many applications, the poor ductility and toughness cannot be tolerated throughout the entire part, and another solution to the problem must be found.

1.5. Outline of Research.

The research outlines are as follows:

1.5.1. Literature review.

The principle and theories of boronizing as a thermo chemical surface hardening treatment, including methods to apply, impact toughness testing and the properties of alloy steel were reviews from various sources such as journals, books, previews reports and the world wide website. Summary of the literatures was presented in Chapter 2.

1.5.2. Experimental works.

Experimental works were divided into two phase which are the boronizing process and impact toughness test. Before the experiment start, standard Charpy specimens 10x10x55mm with a 2mm V-notch were prepared from low alloy tool steel A2. Effect of process variables changes on the impact toughness of low alloy steel was investigated. Pack boronizing is carried out at several times and temperatures. The experimental procedures and the methodology of this task were described in Chapter 3.

1.5.3. Data collection and analysis.

The data collected from the experimental were presented by using statistical analysis. The data were also analyzed to obtain the effect of time and temperature variation on impact toughness of boronized low alloy steel using statistical analysis. Data comparisons for each specimen were done and the results were discussed in chapter 4.

1.5.4. Discussion.

All results that obtained in the research were compiled and discussed in chapter 5. Finally, the conclusion and recommendation for future research were presented in Chapter 6 and Chapter 7.

CHAPTER 2

LITERATURE REVIEWS

2.1 Boronizing.

Boronizing, or boriding, is a thermochemical treatment that diffuses boron through the surface of metallic substrates. As boron is an element of relatively small size it diffuses into a variety of metals; including ferrous, nickel and cobalt alloys, metal-bonded carbides and most refractory alloys (Glukhov,1990). The process involves heating pre-cleaned material in the temperature range of 700 to 1000 C (1300-1832 F) for 1 to 12 hour, in contact with boronaceaus solid (boronizing compound), paste, liquid, or gaseous medium (Sinha,2003). The process provides the metallic boride layer that the resulting metallic boride layer yields the outstanding properties of high hardness, good wear and corrosion resistance (Suwattananont,2004).Other development of thermochemical boronizing include plasma boronizing, pulsed plasma boronizing, and fluidized-bed boronizing. Currently, multicomponent boronizing also are used. During boronizing, the diffusion and subsequent absorption of boron atoms into metallic lattice of the component surface form the interstitial boron compounds. The resulting layer may form which either a single-phase boride or a poly-phase boride layer (Sinha,2003). Several characteristic features of borides layers, including morphology, growth, and phase composition can be influence the alloying elements in the base material are show in Table 2.1.

Table 2.1: Microhardness of Different Boride Phases Formed after Boriding of Different Substrate Materials (Sinha,2003).

Substrate	Constituent phases in the boride layer	Microhardness of layer, HV or kg/mm^2
Fe	FeB	1900-2100
	Fe_2B	1800-2000
Co	CoB	1850
	Co_2B	1500-1600
Co-27.5 Cr	CoB	2200 (100 g)
	Co_2B	~1550 (100 g)
Ni	Ni_4B_3	1600
	Ni_2B	1500
	Ni_3B	900
Inco 100	. . .	1700 (200 g)
Mo	Mo_2B	1660
	Mo_2B_5	2400-2700
W	W_2B	
	WB	~2700 (overall hardness)
	W_2B_5	
Ti	TiB	2500
	TiB_2	3370
Ti-6Al-4V	TiB	
	TiB_2	3000 (100 g) (overall hardness)
Nb	Nb_2B_2	
	NbB_4	2600-3000 (overall hardness)
Ta	Ta_2B	3200-3500
	TaB_2	2500
Zr	ZrB_2	
	Zr_2B	2300-2600 (overall hardness)
Re	ReB	2700-2900

Boride layers possess a number of characteristic features with special advantages over conventional case hardened layers. Boride layers have extremely high hardness values (between 1450 and 2000 HV) with high melting points of the constituent phases (Sinha,2003).The typical surface hardness values of boride steels compared others treatments and other hard materials are listed in Table 2.2. This clearly illustrates that the hardness of boride layers produced on carbon steels is much greater than that are produced by any others conventional surface hardening treatments.

Table 2.2**:** Typical Surface Hardness of Boronized Steels Compare with Others Treatment and Hard Materials (Sinha, 2003).

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.

Unlike the carburizing treatment on ferrous materials, where there is a gradual decrease in composition from carbon-rich surface to the substrate, the boronizing of ferrous material results in formation of either a single-phase or double-phase layer of borides with definite compositions (Sinha,2003). The single phase boride layer consists the Fe_2 B, while the double-phase layer consist of an outer boron rich, dark etching phase of FeB and an inner boron-deficient light-etching phase of Fe_2 B. The formation of either a single or double phase depends on the availability of boron. Fe_2 B is obtained for a single-phase layer, while the double-phase layer consists of an exterior phase of FeB and interior phase of Fe_2 B, where the morphology of the boride layer is a saw-tooth structure. The saw-tooth structures helps improving the mechanical adherence at the Fe_2 B/substrate interfaces (Suwattananont,2004).

State that FeB phase is more brittle than Fe_2 B phase, the formation of Fe_2 B phase is expectedly preferred than that of FeB phase. In addition, it is observed that Fe_2 B forms a surface under the high compressive stress, while FeB forms a surface under the high tensile stress. However, the boronizing process avoids having the coincidence of Fe_2B and FeB phases, which cause to the crack formation at the FeB or Fe_2 B interface of double phase layer. The crack formation leads to the spilling and even the separation of double-phase layer under the applied mechanical strain or the thermal mechanical shock. Fortunately, the annealing process can be decrease the occurrence of FeB phase after boronizing treatment (Sinha,2003).

Generally, the formation of a monophase Fe_2B with saw-tooth morphology is more desirable than a double-phase layer with FeB and Fe2B for industrial applications. The boron rich FeB phase containing approximately 16.23 wt % of B is not desirable because FeB (orthorhombic) is more brittle than the iron sub-boride, Fe_2B (tetragonal) phase which contains about 8.8 wt % B. Furthermore, FeB and Fe_2B phases exhibit substantially different coefficients of thermal expansion. They also have inherent differences in stress levels. Hence crack formation is frequently observed at the FeB/ Fe_2B interface of a double phase layer. These cracks often lead to flaking when mechanical load is applied. Through the control of boriding process parameters, i.e., boriding powder composition, temperature, and time, and laser heat treatment after boriding, Fe_2B phase can be consistently achieved during pack boriding. A single Fe_2B layer produces superior wear resistance and mechanical properties compared to double phase (FeB–Fe_2B) layer (Sundararajan,1995).

Typical properties of the FeB phase are (Sinha, 2003);

a) Microhardness of about 19-20 GPa.
b) Modulus of elasticity of 590 GPa.
c) Density of 6.75 g/cm^3
d) Thermal expansion coefficient of 23 x 10^{-6} /C between 200-600 ^{o}C
e) Composition with 16 to 16.2 wt% boron.
f) Lattice parameters: a= 4.053A, b=5.495A, and c=2.946A.

The typical properties of Fe_2 B phase are (Sinha, 2003);

a) Microhardness of about 18-20 GPa.
b) Modulus of elasticity of 285 to 295GPa.
c) Density of 7.43 g/cm^3
d) Thermal expansion coefficient of 7.65 x 10^{-6} / ^{o}C between 200-600 ^{o}C
e) Composition with 8.8 wt% boron.
f) Lattice parameters: a= 5.078A, and c=4.249A

2.1.2 Boronizing Reactions.

The boronizing process consists of two types of reaction. The first reaction takes place between the boron-yielding substances and the component surface. The nucleation rate of the particles at the surfaces is a function of the boronizing time and temperature. This produces a thin, compact boride layer. The subsequent second reaction is diffusion-controlled, and the total thickness of the boride layer growth at a particular temperature can be calculated by the simple formula: