PLASMA ARC SURFACE MODIFICATION OF ASSAB 705 STEEL

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ABSTRACT

Modification of steel surface by hardening process is traditionally done either by oxy-fuel, induction, laser or electron beam hardening. The technique using plasma arc which needed low initial cost is a new alternative for surface hardening. In this work, single and multiple pass of plasma arc was used to improve the hardness of ASSAB 705 steel surface. The variable parameters investigated were scanning velocity, operating current, gas pressure and stand off distance. After single pass scanning treatment, four types of surfaces were observed. They were fully-melted, partially-melted, non-melted and inconstant-affected where each type of surface indicated different type of roughness. This work has showed that scanning speed and operating current was significantly influence the type of surface and roughness values. Analysis on non-melted surface after treatment gives maximum depth of hardened layer of about 186.7 μm as well as hardness values of about 1100 HV_{50}. It was also observed that the depth of harden layer and hardness value was significantly decreases with increase in scanning speed or with decreasing operating current. Microstructure analysis on hardened layer also revealed the formation of martensite structure. Single pass scanning treatment produced approximately 2 mm width of hardened surface. Larger area of hardened surface could be produced by multiple pass scanning treatment. However the treatment produced uneven hardness due to reheating effect on prior hardened layer. The results from this work indicate that plasma arc is viable tool for surface hardening.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

μm	Micrometer
Ra	Roughness average
A	Ampere
DC	Direct current
AC	Alternate current
W	Watt
cm	Centimeter
mm	Millimeter
K	Kelvin
RF	Radio frequency
F	Fahrenheit
L_M	Specified distance over which the surface deviation are measured
Y	The vertical deviation from nominal surface
n	the number of deviation included in L_M
HV	Hardness Vickers
HV_{50}	Hardness Vickers where the indentation load is set at 50 gram

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Steel are widely used in many applications especially in machine tool components and automotive parts due to its low manufacturing cost and machinability. Steel also provides a wide range of desirable mechanical properties such as toughness and hardness. Steel parts need to undergo several processes in order to achieve the desirable mechanical properties. The process is done by either treating the whole part or modification on the particular surfaces. In normal practice, the toughness is attributed to the composition of the steel and the type of pre-treatment. Surface modifications are used to enhance surface properties such as hardness, wear resistance and fatigue resistance.

1.1 Background Problem

Currently, there are many processes of surface modification by transformation hardening that are applied in industries. These processes can be categorized into two types, traditional and nontraditional. The traditional process includes flame hardening and induction hardening which are already well known and commonly applied to treat products in mass production. However both of these processes have their own disadvantages such as limitation in shape, size, difficult to control the surface intended for treatment, possibility of part distortion, limited range of suitable workpieces and can be costly. Consequently, over the years there are many researches conducted using direct high energy beam such as laser beam and electron beam as an alternative of thermal source. This process is categorized as non-traditional process.

The capability of high energy beam such as laser beam and electron beam being used for surface hardening are already intensively investigated by many researchers such as Zhang [1, 2], Ganeev [3], Choo [4] Hwang [5] and Song [6]. The investigations on the use of these energy sources have yielded promising results. However, there were some limitations to these methods, particularly with regard to constraints of movements and working area. This is especially so when working with complex and large workpieces which required three dimensional tool movements. Moreover, these methods usually incur high initial investment, maintenance and operating costs.

1.2 Problem statement

Plasma arc is another direct high energy beam source. It is commonly used in industry for variety of purpose such as welding and cutting of steel. The plasma arc for welding and cutting purpose has a temperature and particle charge density approximately ranges from 11000-30000 ^{0}C and $10^{17} cm^{-3}$ respectively [7]. With these properties the plasma arc can be used to heat the steel to its austenite temperature rapidly.

The plasma arc also has high efficient thermal transfer of about 50%-70% which contribute to its low operating cost [8]. Furthermore, the initial investment, maintenance and operating cost of plasma arc machine are less compared with laser and electron beam. In addition, the power input into the plasma arc can be controlled directly and independently by adjusting its parameters such as the arc current and gas pressure. This leads to simplified and improved process control. Moreover, the plasma torch that generates the arc has flexible movement and can be attached to robot so that part with complex shape and large in size can be reached. With all those advantages, the plasma arc is much better then laser beam and electron beam.

Presently, researchers such as Yan [9, 10], Bourithis [11], Yang [12] and Pan [13] have tried to use plasma arc as an alternative thermal source for transformation hardening of steel surface. The treatment resulted is a mixture of melting and non-melting surfaces. Although the results were favorable in terms of hardness and wear resistance, nevertheless from a commercial point of view, the surface melting process produced undesirable surface roughness conditions. For certain application, fine surface roughness is required and this can only be achieved by non-melted treatment. However non-melted treatment using the high energy beam of plasma arc is still rarely reported.

With the advantages of plasma arc described previously, this project will further explore the capabilities of plasma arc. This project investigates the effect of surface hardening of ASSAB 705 steel using plasma arc scanning process without melting the surface. In this study, commercial industrial equipments were used to reflect its relevance for application in industry. The objective and the scope of this project will be discussed as follows.

1.3 Objectives

The objectives outlined from the current work are as below:

i. To determine the treatment condition that produces non-melted surface of ASSAB 705 steel.
ii. To determine the treatment condition that produces maximum depth harden layer within the non-melted surface.
iii. To determine the effects of the selected parameter, namely scanning speed, arc current, stand off distance and gas pressure on the following surface properties; surface topography, surface roughness, depth of hardening and the pattern of hardness distribution on treated ASSAB 705 steel surface.
iv. To determine the hardness pattern when reheating prior hardened surface.

1.5 Scopes

The scopes outlined to achieve the objectives above are as follows:

i. Analyze the surface topography using high resolution digital camera, microphotograph and roughness test of melted and non-melted surface of single pass scanning treatment.
ii. Analyze the depth of harden layer and hardness distribution of non-melted surface of single pass scanning treatment.
iii. Analyze the hardness distribution of multiple scanning.

iv. Analyze the microstructure of non treated surface and the treated surface of single and multiple pass scanning treatment.

1.6 Summary

This thesis is divided into 6 chapters. Chapter 2 presents the fundamental of plasma arc and related literature review within the interest of the current work. The topics discussed in this chapter include high energy beam transformation hardening such as laser, electron beam and plasma arc. Chapter 3 presents research methodology. The various analytical and experimental techniques utilized in this project are described along with the equipment used and engineering standard referred. Chapter 4 shows the results obtained from the experiment and tests conducted on the specimen for single and multiple scanning. Initial part of the chapter presents the results from single pass scanning treatment such as surface topography, average roughness, hardness test and hardness distribution of each selected treatment condition. This is followed by the results of multiple pass scanning treatment. Chapter 5 discusses the results obtained from the single pass scanning and multiple pass scanning. The research work is finally concluded in Chapter 6. This chapter also present the recommendations made for the future work.

CHAPTER II

LITEREATURE REVIEW

This chapter discusses the fundamental of plasma as well as related previous works and theories. The first subtopic discusses the fundamental of plasma including the history, type of plasma, plasma arc generation and parameters governing the plasma arc thermal energy. The second subtopic presents a review of early literature with regards to plasma arc as thermal processing. The third subtopic discusses the steel surface modification which includes surface hardening of steel, phase transformation of martensite and selective surface hardening. The fourth subtopic discusses the recent literature of high energy beam hardening which include laser beam, electron beam and plasma arc surface hardening. The fifth subtopic discusses on the evaluation of steel surface properties.

2.1 Fundamentals of Plasma

The scientific study of plasma was made possible with the development of steady state direct current (DC) arc discharged by Sir Humphry Davy in 1808 and high voltage DC electrical discharged tube by Michael Faraday and others in the 1830's [14]. The term plasma was introduced by Irving Langmuir in 1928, by mean electrically neutral collection of ions and electrons which may or may not contain a back ground neutral gas, and which was capable of responding to electric and magnetic field.

In general, plasma is a gas of sufficient energy content consisted of electron, free electrical charge of positive and negative ion and atom [7]. Although there are free electrical charges in plasma, the negative and positive charges compensate each other. Therefore in overall plasma is electrically neutral. Gases at room temperature are excellent insulator. However, the free electrical charge in plasma gas made it a highly electrical conductor [7].

2.1.1 Types of Plasma

Plasma can be classified into two types, namely, thermal plasma or equilibrium plasma and cold plasma or non-equilibrium plasma [15]. The type of plasma is differentiated according to the charge particle density.

The charge particle density of the thermal plasma is above 10^3 cm^{-3}. Examples include DC electrical arc, AC electrical arc and radio frequency (RF) inductive plasma torches. Such plasmas are in or near thermal equilibrium and often used for thermal plasma processing. These plasmas are capable of melting or even vaporizing bulk materials and are used extensively in a broad range of application such as welding, cutting, plasma spraying, in arc furnace technology and other high temperature processing application. Nowadays, thermal plasma has been extensively used in a broad range of applications such as in surface treatment [9-13], material processing [16-18], cutting [19] and welding [20]. This trend may be attributed to the low initial cost, easy control of energy and less maintenance of plasma arc.

The second type of plasma called cold plasma produces active species that are more numerous, different in kind, and more energetic than those produced in chemical reactors. These active species make it possible to modify the surface of material. This is especially so when there is no other way or economically impracticable by other methods. Cold plasma is widely used in the processing of electronic materials such as plasma etching [21], plasma cleaning [22], plasma assisted chemical vapor deposition [23]. The cold plasma is frequently produced by corona or low discharged plasmas which the power densities ranging from 10^{-4} to 10 W/cm^2 [15].

2.1.2 Plasma Arc Terminology and Generation

Lucas [20] given the terms used to describe plasma arc torch geometry and adjustments as shown in **Figure 2.1**. Plasma gas refers to the gas that is directed into the torch to surround the electrode. It becomes ionized in the arc to form the plasma, and issues from the orifice in the torch nozzle as the plasma jet. The distance that the electrode is recessed within the torch is called the electrode set back. This is the dimension from the outer face of the torch nozzle to the arcing tip of the electrode. The dimension from the outer face of the torch nozzle to the work piece is known as stand-off. Plenum chamber is used to describe the cavity within the torch containing the arcing tip of the electrode. The plasma gas is directed into this chamber and thence through the orifice to the work.