THE OPTIMIZATION OF LASER MACHINING PARAMETERS FOR HOLE CUTTING OF STAINLESS STEEL USING RSM APPROACHES

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DECLARATION

I hereby, declared this report entitled "The optimization of laser hole machining parameters for hole cutting of stainless steel using RSM approaches" is the result of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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(PROF. MADYA. DR. MD NIZAM BIN ABD RAHMAN**)**

ABSTRACT

Broad applications of laser hole cutting in manufacturing industries with the capability of precise cutting are of great importance. In laser hole cutting, the ability to machine a wide range of material types and dimensions are some of the significant advantages compared to other advance machining processing. There are numerous laser micro-hole cutting optimization studies published. Based on those studies, the qualities of laser hole cutting are affected by various process parameters such as laser power, pulse frequency and gas pressure. However, laser hole cutting of hole diameter larger than 5 mm on stainless steel is less studied. Hence, the optimization of the laser hole cutting parameters of 10 mm diameter on stainless steel was studied. The quality characteristics that were taken into considerations in this study are hole taper, surface roughness and heat affected zone, (HAZ) thickness. Visual observation through stereomicroscopes was used to measure HAZ thickness. The average surface roughness, Ra and hole taper were measured by using surface roughness tester and digital caliper respectively. The adopted approach of the experiment was the response surface method (RSM) and the analysis was carried out using Design Expert (trial version) software. The analysis done were ANOVA to identify the significant parameters influencing the process, the main effect, the interaction analysis, and 3D surface analysis. Based on the regression analysis, a polynomial model was developed to predict the output responses based on input parameters. The validations of the polynomial mathematical model were done by comparing the predicted and the experimental output responses. Based on the result of the experiment, the evaluated input parameters, within the range of evaluation settings, do not significantly influence the hole taper. The laser power significantly affecting the surface roughness and HAZ thickness; higher laser power led to wider HAZ thickness and higher surface roughness. The developed linear polynomial model predicting the influence of process parameters to the surface Ra and HAZ thickness were successfully validated with average percentage of error of less than 10%.

DEDICATION

DEDICATED

TO MY DEAREST PARENTS

Mr Lim Chin Tiam and Ms. Yaw Hoon Fang

TO MY HONOURED SUPERVISOR

Prof. Madya Dr Md Nizam bin Abd Rahman

For his advices, support, motivation and guidance during accomplishment of this project

TO ALL LECTURERS & TECHNICIANS

For their support and advices during completion of this project

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LIST OF ABBREVIATION

LHC - Laser Hole Cutting

LBM - Laser Beam Machining

LBC - Laser Beam Cutting

LD - Laser Drilling

UMP - Unconventional Machining Process

AMP - Advanced Machining Process

HAZ - Heat Affected Zone

N_2 - Nitrogen

CO_2 - Carbon Dioxide

O_2 - Oxygen

Ar - Argon

LSA - Laser Supported Absorption

Ra - Arithmetical Mean Roughness

Ry - Maximum Height

Rz - Ten-Point Mean Roughness

LASER - Light Amplification by Stimulated Emission of Radiation

Nd:YAG - Neodymium doped Yttrium-Aluminium-Garnet

He - Helium

Ne - Neon

MRR - Material Removal Rate

GRSM - Grey based response surface

RSM - Response surface method

GRA - Grey relational analysis

ANN - artificial neural network

GA - Generic algorithm

DOE - Design of experiment

ANOVA - Analysis of variance

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Laser Beam Machining (LBM) is one of the most widely used unconventional machining processes in the present day to achieve precise cutting of almost all material. Laser hole cutting (LHC) is a method of hole making that can cut a variety of engineering materials, particularly materials with high strength, including materials with high shock resistance such as stainless steel and high-speed steel. Among all unconventional machining techniques, the laser is superior than other machining techniques on the basis of applicability due to lower tooling cost and ability to machine almost all materials either conductive or non-conductive. It is high precision and mostly does not require additional finishing process. LBM can be the alternative to wire electro-discharge drilling, punching, broaching, or other popular destructive hole drilling methods.

LHC is categorized as thermal energy based unconventional machining process which is superior over other known unconventional machining process due to its high production rate, high flexibility, better dimensional accuracy, high precision, good surface quality, low tools wear and better material removal rate. According to Amit and Vinod (2017), laser hole cutting (LHC) is a process that able to make holes in high hardness and brittle material. However, other issues in LHC need to be addressed, such as micro-crack, surface roughness, taper angle, heat affected zone, kerf width, etc.

Laser hole cutting is a complex process. Maojun Li et al., (2018) explained that laser hole cutting depends on many process parameters such as laser power, cutting speed, pulse frequency, pulse width, assist gas type, assist gas pressure, etc. These process parameters play an important role to achieve the desired hole cutting. The study on the optimization of process parameters towards the hole quality is important for the future development of manufacturing technology in LHC. This research investigates the effect of process parameters including laser power, pulse frequency and gas pressure towards the hole cutting quality of stainless steel in LHC.

1.2 Problem Statement

Optimization studies and researches on laser hole cutting have been carried out extensively and it is widely used in industrial applications. Although most of these researches focus on parameter optimization of LHC in high-speed steel or high strength metal alloys, the study of parameters optimization in stainless steel is still limited. Though LHC has the capability in cutting high strength material, its parameter's effects on cutting material with high temperature resistance such as stainless steel are less studied. There are several quality problems occur when cutting stainless as mentioned by Jae Sung et al., (2019). This statement leads to a kick start for exploration and investigation on the effects of process parameters on stainless steel with high strength and high temperature resistance that are essential in LHC. There are numerous laser micro-hole cutting optimization studies published however laser hole cutting of hole diameter larger than 5 mm is less studied. Hence, the optimization of the LHC parametric variables on stainless steel for hole diameter larger than 5 mm is pursued.

1.3 Objectives

The major aims and objective of this study are:

1. To optimize laser hole cutting process parameters on stainless steel workpiece.
2. To develop polynomial equation to relate hole taper, surface roughness and heat affected zone to the input process parameters.
3. To validate the optimum condition.

1.4 Scope

The scope of this study includes process parameters of LHC and the output quality that need to be investigated. Experiments of LHC need to be carried out to find the effect of process parameters on output quality. Stainless steel is chosen as experimental material in this study to investigate its output quality under LHC. This material is widely used in various industries application due to its excellent mechanical properties such as high hardness and high temperature resistance. Three process parameters to be evaluated in this study are laser power, gas pressure, and pulse frequency. Hole taper, surface roughness and heat affected zone are selected as output quality measurements. The response surface methodology (RSM) is used as the approach for this investigation.

1.5 Significant of the study

This study is believed to help industries and other manufacturers to enhance hole cutting quality in terms of hole taper, surface roughness and heat affected zone by knowing the optimum parameters. In other words, this study is expected to provide more efficiency and effective knowledge towards an understanding of LHC. Nowadays the maximum production rate and good product quality with minimum production cost is the main objective for all industries in the manufacturing field. Good hole cutting quality of products is important to improve the performance of products and marketability for the manufacturing industry. Thus, reworks and scraps can be reduced which results in less operation time to manufacture the products. At the same time, the productivity of the entire production line can be increased, indirectly will increase profitability when it becomes cheaper to manufacture products since the time plays an important role. An increase in productivity enables production to meet the high consumer demand by optimizing resources. Good hole cutting quality products also improve the level of competition in the market since the production rate is faster than competitors, it may lead to opportunities if the business is growing.

CHAPTER 2

LITERATURE REVIEW

2.1 Unconventional Machining Process (UMP) or Advanced Machining Processes (AMP)

Invention and creation of unconventional machining process (UMP) or advanced machining processes (AMP) is due to the incapability of conventional machining to machine advanced engineering material in precision condition, Parandoush and Hossain (2014). Unlike conventional machining, there is no direct contact of tools and workpiece material in UMP or AMP. These UMP or AMP use a form of energy to remove or eliminate unwanted workpiece material. The unconventional machining process (UMP) or advanced machining processes (AMP) can be categorized into several types based on the type of energy used in machining such as mechanical, thermal, electrical, chemical and electrochemical. According to Prasad et al., (2018), a chemical-based unconventional machining process uses chemical active reagent to dissolve the workpiece material by immerse workpiece material in the chemical active reagent. In addition, there are some examples of mechanical energy based unconventional machining processes had been studied such as water jet machining, abrasive jet machining and magnetic-abrasive machining.

These UMP or AMP superior to other known conventional machining due to better dimensional accuracy, high precision, good surface quality, low tools wear and better material removal rate. Other than that, UMP able to manufacture more complex shape geometries that cannot be done in conventional machining and normally used in a situation where there is no direct contact between workpiece material and tools to avoid surface damage due to stresses created by conventional machining. Some engineering materials are ineffective to be machined using conventional machining due to their unique properties such as hard and brittle material like ceramic, metal alloy, tungsten carbide, diamond, etc. If such materials are machined by conventional machining, the tool will wear rapidly and is impossible to achieve very tight dimensional tolerances. Engineering ceramics (alumina) is reviewed in the next section.

Many UMPs are implemented in the industry to take over the conventional machining such as electrical discharge machining, electrochemical grinding, electron beam machining, plasma arc machining, photochemical machining, laser beam machining, etc, but these processes have their pros and cons. Prasad and Chakraborty (2015) mentioned that UMP or AMP is widely developed in manufacturing industries since it solved a lot of engineering problems through years and it becomes more important to study the various type of UMP to utilize it to full potential.

2.2 Introduction to Stainless Steel

Stainless Steel is an iron-based metal alloy usually containing a minimum ten percent of chromium. Stainless Steel is widely used in various industrial applications due to its physical properties, corrosion resistance, mechanical strength and chemical stability when compared with other materials. It is commonly used in making architectural paneling, springs, screws, nuts, bolts, sinks, splash backs, tubing and cookware. Stainless steel can be supplied in various forms such as sheet, strip, bar, plate, pipe, tube, coil and fittings. Considering the wide use of stainless steel, it was selected as the major experimental sample in this program. However, high hardness and high heat resistance have become a challenge to process stainless steel. The laser hole cutting had been introduced to machine stainless steel for better dimensional accuracy and lower production cost as compared to conventional hole cutting methods.

According to Marlin Steel (2019), there are thousand series of stainless steel based on its alloy components. Basically, they can be divided into three main categories. Austenitic stainless steels are one of the most common types in stainless steel families. They have a high content of chromium compared to other steel alloys, resulting in greater corrosion resistance. Another common feature of austenitic stainless steel alloys is that they tend to be non-magnetic, however they may become magnetic after cold working. The second most common type of stainless steel is ferritic stainless steel. Unlike austenitic stainless steels, ferritic stainless steels are magnetic. This alloy is cheaper due to their lesser nickel content. Martensitic stainless steels tend to has lower corrosion resistance compared to austenitic stainless steels and ferritic stainless steel. Martensitic stainless steel alloys are widely used in extremely high tensile strength and impact resistance applications due to its high hardness properties.

Stainless steel SAE 304 is the most widely used stainless steel and it is categorized as austenitic stainless steel. It is widely used in home and commercial applications due to its good materials properties. The material properties of 304 stainless steel showed in table 2.1. The 304 Stainless Steel usually contain between 8 to 11 percent of nickel and 17.5 to 20 percent of chromium by weight and its composition showed in table 2.2.

Table 2. 1: Material properties of 304 stainless steel (CES Edu pack, 2010 level 3)

Material Properties	Value	Units of measure
Young modulus	$190 \times 10^9 - 203 \times 10^9$	Pa
Shear modulus	$74 \times 10^9 - 81 \times 10^9$	Pa
Bulk modulus	$134 \times 10^9 - 151 \times 10^9$	Pa
Hardness- Vickers	$1.6671 \times 10^9 - 2.0594 \times 10^9$	Pa
Compressive strength	$205 \times 10^6 - 310 \times 10^6$	Pa
Tensile strength	$510 \times 10^6 - 620 \times 10^6$	Pa
Yield strength (elastic limit)	$205 \times 10^6 - 310 \times 10^6$	Pa
Melting point	$1.67315 \times 10^3 – 1.72315 \times 10^3$	K
Thermal conductivity	14 - 17	W/m ·℃
Specific heat capacity	490 - 530	J/kg ·℃
Thermal expansion coefficient	$16 \times 10^{-6} - 18 \times 10^{-6}$	strain/ ℃