Faculty of Engineering

LOW POWER LASER CUTTING OF COTTON FIBRE LAMINATE FOR ELECTRICAL INSULATION AT LOW VOLTAGES

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LOW POWER LASER CUTTING OF COTTON FIBRE LAMINATE FOR ELECTRICAL INSULATION AT LOW VOLTAGES

BARRY LAWRENCE ANAK MENGGA

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
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Dedicated to my beloved parents

Mengga Anak Laga

Magdeline Ritta Anak Gruna

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ABSTRACT

In this research, low power laser cutting of Cotton Fibre Laminate for electrical insulation at low voltages was investigated. A 1.6 W diode of FABOOL Laser Mini was used to cut the samples with 0.4 mm and 0.8 mm thicknesses. The input parameters in this study were laser power, cutting speed, stand-off distance and number of beam passes. Meanwhile, the output parameters in this study were kerf width, heat affected zone and dimensional accuracy. Microstructure characterisation was conducted using scanning electron microscope in order to observe the cut quality of samples. Digital microscope was used to observe and measure the output parameters. Taguchi Experimental Design was used as an optimisation method in this study. Analysis of Variance (ANOVA) was conducted to analyse the experimental results using Minitab 18 in order to determine the optimum levels of all input parameters. It was found out that the optimum levels of input parameter are different for various types of output parameters. It was also found out that most experiments are largely affected by the cutting speed and least affected by the stand-off distance. Validation of experiments was conducted to verify the optimum levels of all input parameters.

ABSTRAK

Dalam kajian ini, pemotongan laser berkuasa rendah terhadap “Cotton Fibre Laminate” untuk penebat elektrik pada voltan rendah telah diselidiki. Diod 1.6 W “FABOOL Laser Mini” telah digunakan untuk memotong sampel-sampel yang berketebalan 0.4 mm dan 0.8 mm. Parameter masukan dalam kajian ini ialah kuasa laser, kelajuan pemotongan, jarak pendirian dan bilangan pancaran limpasan. Sementara itu, parameter keluaran dalam kajian ini ialah lebar kerf, zon terjejas haba dan ketepatan dimensi. Pencirian mikrostruktur telah dilakukan dengan menggunakan mikroskop elektron imbasan untuk melihat kualiti potongan sampel-sampel. Mikroskop digital dan mikroskop binokular juga telah digunakan untuk memerhati dan mengukur parameter-parameter keluaran. “Taguchi Experimental Design” telah digunakan sebagai kaedah pengoptimuman dalam kajian ini. Analisis Varians telah dilakukan untuk menganalisis keputusan-keputusan experimen dengan menggunakan “Minitab 18” untuk mendapatkan tahap-tahap optimum daripada kesemua parameter masukan. Analisis mendapati tahap-tahap optimum untuk parameter masukan ialah berbeza untuk pelbagai jenis parameter keluaran. Analisis juga mendapati bahawa kebanyakan eksperimen paling dipengaruhi oleh kelajuan pemotongan dan paling kurang dipengaruhi oleh jarak pendirian. Pengesahan eksperimen telah dilaksanakan demi mengesahkan tahap-tahap optimum untuk kesemua parameter masukan.

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LIST OF SYMBOLS

^{o}	–	Degree
^{o}C	–	Degree Celsius
μm	–	Micronmetre
%	–	Percent
∑	–	Sum of
dB	–	Decibel
fps	–	Frame per second
GPa	–	Giga Pascal
kJ/kgK	–	Kilojoule per kilogram Kelvin
kJ/m^2	–	Kilojoule per square metre
kV	–	Kilo Volt
kW	–	Kilowatt
L/min	–	Litre per min
m/min	–	Metre per minute
mg	–	Milligram
mm	–	Millimetre
mm/min	–	Millimetre per minute
mm/s	–	Millimetre per second
mW	–	Milliwatt
MHz	–	Mega Hertz
MPa	–	Mega Pascal
MPS	–	Mega Pixels
MV/m	–	Mega Volt per metre
nm	–	Nanometre
V	–	Volt
W	–	Watt
W/mK	–	Watt per metre Kelvin

LIST OF ABBREVIATIONS

a.c.l.	–	Actual cutting length
ANN	–	Artificial Neural Network
ANOVA	–	Analysis of Variance
CFRP	–	Carbon Fibre Reinforced Polymer
CFL	–	Cotton Fibre Laminate
CMOS	–	Complementary metal-oxide-semiconductor
CO	–	Carbone Monoxide
CO_2	–	Carbon Dioxide
CW	–	Continuous Wave
d.c.l.	–	Desired cutting length
Er:YAG	–	Erbium-doped Yttrium Aluminium Garnet
ERS	–	Electronic Rolling Shutter
f.p.p.	–	Focal Plane Position
FEM	–	Finite Element Method
GFRP	–	Glass Fibre Reinforced Polymer
GRA	–	Grey Relational Analysis
HAZ	–	Heat Affected Zone
LAD	–	Laser-assisted Drilling
LAM	–	Laser-assisted Milling
Nd:glass	–	Neodymium glass
Nd:YAG	–	Neodymium-doped Yttrium Aluminium Garnet
Nd:YVO_4	–	Neodymium-doped Yttrium Orthovanadate
NPM	–	Noise Performance Measure
PC	–	Polycarbonate
PMMA	–	Polymethyl Methacrylate
PP	–	Polypropylene
RSM	–	Response Surface Methodology

SEM	–	Scanning Electron Microscopy
SN	–	Signal-to-noise
TPM	–	Target Performance Measure
UV	–	Ultra-violet
Yb:YAG	–	Ytterbium-doped Yttrium Aluminium Garnet

CHAPTER 1

INTRODUCTION

1.1 Overview

Weakness of parent polymers is that they can easily undergo a plastic deformation under certain conditions. For this reason, composites are introduced in order to improve the properties in terms of strength and stiffness. For instance, glass fibre reinforced polymer (GFRP) is used for engine cowlings, luggage racks and medical applications. Meanwhile, carbon fibre reinforced polymer (CFRP) is used for aircraft, automotive and guide rail. Lasers have been used to cut those materials (Choudhury & Chuan, 2013; Fatimah et. al, 2012; Patel et. al., 2016; Li et. al., 2010; Riveiro et al., 2012; Leone et. al., 2014).

Types of laser that are commonly used in material processing are carbon dioxide (CO_2), carbon monoxide (CO), excimer, neodymium-doped yttrium aluminium garnet (Nd:YAG), ytterbium-doped YAG (Yb:YAG), erbium-doped YAG (Er:YAG), neodymium glass (Nd:glass), and diode lasers. These types of laser are commonly used in material processing due to the fact that they are reasonably powerful.

Laser has been essential in material removal. According to Ready (1997), material removal by using laser composes typical applications such as hole drilling, cutting, scribing, marking, balancing, paint stripping and laser deposition of thin films. The properties of the workpiece are significant in material removal applications especially the latent heat of vaporization, the thermal diffusivity and the surface reflectivity.

Laser cutting of composites and non-composites have been crucial to the modern industries. The common composites that use laser for cutting purposes are carbon fibre composites and glass fibre composites. Meanwhile, the common non-composites that use laser for cutting are plastics, wood and glass. Laser has been employed for cutting of die board, cloth, furniture, Kevlar, aerospace materials, and electronic appliances.

In some respect, laser is more effective in cutting than other conventional methods due to its precise cutting, able to produce complex geometrical cut, non-contact and capable of cutting a variety of material thickness. A quality cut is desirable especially in manufacturing industries for reasons of operational cost reduction and aesthetic values. Laser cutting quality can be determined by observing the response parameters such as surface roughness, Heat Affected Zone (HAZ), dimensional accuracy, kerf width and depth of cut.

1.2 Problem Statement

Cotton Fibre Laminate (CFL) is very useful for electrical insulation applications at low voltages. CFL is usually used in gears, spacers and coil supports in turbine generator. Turbine generator consists of many components by which they carry voltages. In order to avoid low voltage leakages between components, the turbine generator needs insulating material. In low voltage applications insulation, CFL is the potential candidate. For the purpose of insulation, shapes may come in many geometrical forms.

One of the conventional methods of cutting this type of composite is using shear cutter. For cutting applications, shear cutter is not a reliable method because of its limitations which are introduce unwanted pressure due to contact processing method, cannot produce complex geometrical features, slow processing time, and thicker material is hard to cut.

Therefore, laser can be used as a substitute for cutting the aforementioned composite in order to overcome the limitations of the conventional method. Most materials are being cut by using a high power laser that consumes high electrical energy and it is costly. However, there is no study on low power laser cutting of CFL has been made. Hence, the study on the feasibility of low power laser cutting of CFL is conducted. This study is believed to be useful in the future as to promote use of complex CFL shapes for electrical insulation applications.

In manufacturing industries, the main priorities of cutting are to have a clean cut, high speed cutting and aesthetically pleasing. Waste of materials would occur if a lot of experiments are being conducted to achieve those priorities and thus, resulting an increase of operational cost. For this reason, an optimisation method is needed to identify the optimum laser cutting processing parameters.

1.3 Research Objectives

a) To study on the feasibility of low power laser cutting of CFL for the application in electrical insulation at low voltages.
b) To characterise laser cut quality of CFL.
c) To perform an optimisation method to determine the optimum laser cutting parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to Steen & Mazumder (2010), the term “laser” is an abbreviation for light amplification by stimulated emission of radiation. There are four types of laser which are solid-state laser, gas laser, dye laser and free-electron laser. The idea of using light for cutting has attracted attention to the mankind since the first time they discovered the method of burning paper on a sunny day with the aid of a magnifying glass. Laser cutting has been widely used in process industries in many countries. This is because laser cutting has better advantages in term of surface finishing, cut quality and fast cutting when compared to other competing processes.

In this chapter, a brief overview of the existing non-composites and composites that use laser for cutting will be provided which can be found in the previous studies that were investigated by the researchers. Moreover, the discussion will mention about the benefits and limitations of the proposed optimization methods and a little bit of explanation as a path for future researches. Table 2.1 shows brief knowledge on conventional methods and their limitations on several non-composites and composites.