MILLING OF JUTE FIBRE REINFORCED POLYMER COMPOSITE USING UNCOATED CARBIDE CUTTING TOOL

BY

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ABSTRACT

Jute fibre reinforced polymer (JFRP) composite has become a great significance in a scope of applications. JFRP is being used in automotive, aircrafts, aerospace and domestic upholstery in industrial sectors as a result of its desirable properties, such as light weight, improved stiffness and rigidity, low thermal expansion and high chemical resistance. In this study, JFRP has been fabricated in different composition 60/40 and 70/30, by using Bangla Tossa grade one jute fabric and matrix material via hands lay-up technique. Here, jute fabric was used as reinforcement and epoxy used as matrix material, this hands lay-up processed composite plates were tested for mechanical test like tensile test, flexural test, impact test according to the ASTM standards. The machining process is like milling, drilling, turning, slotting which is necessary during the component assembling stage. Actually, various complexities arise during machining of Jute Fibre Reinforced Polymer (JFRP) such as poor surface finish, delamination, and tool wear. Thus, the objectives of this research are to determine the significant cutting parameters on JFRP milling that influence on the tool wear, tool life, surface roughness and delamination factor. Solid uncoated carbide cutting tool with diameter of 8.0 mm has been used in the CNC milling machine. A Central Composite Design (CCD) of the Response Surface Methodology (RSM) has been used to design the experimental run and to develop the mathematical model based on the collected data. The designed ranges of cutting parameters are spindle speed (671.573-6328.43 rev/min), feed rate (108.58-391.42 mm/min) and depth of cut (0.79-2.21 mm). Analysis of tool wear and surface roughness are conducted using Nikon Measuring Microscope and Veeco Wyko Optical Profiling System Microscope, respectively. In this study, it has been observed that the longest tool life of 41.6 minutes was achieved at lowest feed rate 108.58 mm/min, a cutting speed 3500 rev/min and depth of cut 1.50 mm. The polished and shiny surfaces of the tool wear area which was caused by the abrasive nature of the jute/epoxy composite. Less tool wear was observed at the lowest spindle speed 671.57 rev/min, a feed rate 250 mm/min and depth of cut 1.50 mm. Tool wear increased with the increase of spindle speed, feed rate and depth of cut. Better tool life was obtained at low spindle speed, depth of cut and feed rate. For the measurement of surface roughness, it was observed that the good surface roughness (smoother) achieved at higher spindle speed but became worse with an increasing of feed rate and depth of cut. Higher spindle speed generates the heat between the cutting tool and work piece and burned the pull out fibre which causes less delamination. It was found that higher spindle speed gives lower delamination. Delamination became higher at higher feed rate 391.42 mm/min and depth of cut 2.21 mm. Based on the developed mathematical model, feed rate was identified as the most significant factors for tool life and delamination factor. Depth of cut has an effect on surface roughness but on tool life and delamination have minor effect. The optimized cutting parameter is at spindle speed, feed rate and depth of cut of 4293.788 rev/min, feed rate 150 mm/min, and depth of cut 1.0 mm. These conditions yield optimum value of tool life, surface roughness, and delamination factor of 28.525 min, 1.188 µm, and 1.09, respectively.

خلاصة البحث

لقد أصبحت المركبات البوليمرية المقواه بألياف الجوت (JFRP) لها أهمية كبيرة في نطاق التطبيقات الهندسية. حيث تم أستخدامه (JFRP) في صناعة بعض قطع السيارات، الطائرات، المركبات الفضائية، وفي قطاع صناعة المفروشات المنزلية لما له من خصائص ملائمة لهذه الأستخدامات. مثل خفت الوزن ، الصلابة الجيدة، التمدد الحراري البسيط وله مقاومة كيميائية عالية. في هذه الدراسة ، تم تصنيع (JFRP) بتركيبة مختلفة 40/60 و 30/70 ، وذلك باستخدام نسيج الجوت من الدرجة الأولى البنقلاديشي المنشأ Bangla Tossa ومواد مساعدة عبر تقنية الخلط بالأيدي. هنا ، تم استخدام قماش الجوت كألياف مقوية ومادة الإيبوكسي أستخدمت كمواد مساعدة. تم اختبار هذه الألواح المركبة المصنوعة بالأيدي للاختبارات الميكانيكية مثل اختبار الشد ، واختبار الثني ، واختبار الصدم وفقًا لمعايير ASTM. عمليات التصنيع مثل الجلخ ، الثقب، الخراطة، والقطع أمر ضروري خلال مرحلة تجميع المكونات. في الواقع ، هناك العديد من التعقيدات التي تنشأ أثناء تصنيع البوليمر المقوى بالألياف الجوتية (JFRP) مثل خشونة السطح ، والترقق ، وتأكل معدات القطع. وبالتالي ، فإن أهداف هذا البحث هي تحديد معلمات القطع الهامة في تجليخ (JFRP) التي تؤثر على تآكل الأدوات ، وعمر الأداة ، وخشونة السطح ومعامل إزالة الترقيق. تم استخدام أداة القطع الكربيدي بقطر 8.0 ملم في آلة الجلخ (CNC). كما تم استخدام برنامج التصميم الأحصائي (CCD) بطريقة (RSM) لتصميم التشغيل التجريبي وتطوير النموذج الرياضي استنادًا إلى البيانات المجمعة. النطاقات المصممة لمعلمات القطع هي سرعة المحور (671.573-6328.43 لفة / دقيقة) ، ومعدل التغذية (108.58-391.42 ملم / دقيقة) وعمق القطع (0.79-2.21 ملم). يتم إجراء تحليل خشونة السطح وتأكل أدوات القطع باستخدام مجهر نيكون للقياس ومُجهر نظام التنميط البصري فيكو ويكو ، على التوالي. في هذه الدراسة ، لوحظ أن أطول عمر لأداة القطع 41.6 دقيقة قد تم تحقيقه في أدنى معدل تغذية 108.58 ملم / دقيقة ، وسرعة القطع 3500 لفة / دقيقة وعمق قطع 1.50 ملم. الأسطح اللامعة والمصقولة على حواف أداة القطع كانت واضحة تحت المجهر اللأكتروني (SEM) التي سببتها طبيعة الألياف الكاشطة لمركب الجوت / الايبوكسي. لوحظ انخفاض تأكل أداة القطع في أدنى سرعة للمحور 671.57 لفة / دقيقة ، ومعدل تغذية 250 ملم / دقيقة وعمق قطع 1.50 ملم. ازداد تآكل الأدوات مع زيادة سرعة المحور ومعدل التغذية وعمق القطع. تم الحصول على أفضل عمر تشغيلي لأداة القطع بسرعة دوران وعمق قطع ومعدل تغذية منخفض. ومن خلال قياس خشونة السطح ، لوحظ أن خشونة السطح الجيدة (أكثر نعومة) قد تحققت عند سرعة

محور أعلى ولكنها أصبحت أسوأ مع زيادة معدل التغذية وعمق القطع. سرعة دوران العالية تولد الحرارة بين أداة القطع وقطعة العمل وتحرقها وتخرج الألياف من مكانها والتي تتسبب في عملية تنسل أطرافها. وقد أتضح أن سرعة المحور العالية تعطي أقل تنسل للألياف. ويصبح التنسيل أعلى مع معدل تغذية أعلى 391.42 ملم / دقيقة وعمق قطع 2.21 ملم. وبناء على النموذج الرياضي المتحصل علية من البرنامج الأحصائي أتضح أن معدل تغذية هو العامل الأكثر أهمية لأداة عمر أداة القطع وعامل التفريغ. عمق القطع له تأثير على خشونة السطح ، ولكن على عمر أداة القطع والتفريغ له تأثير طفيف. إن معلمة القطع المثلى هي في سرعة المحور ، معدل التغذية وعمق القطع من 4293.788 لفة / دقيقة ، معدل التغذية 150 ملم / دقيقة ، وعمق القطع 1.0 ملم. هذه الظروف تعطي القيمة المثلى لعمر أداة القطع، وخشونة السطح ، وعامل التفريغ من 28.525 دقيقة ، 1.188 ميكرومتر ، و 1.09 ، على التوالي.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Manufacturing Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Mir Akmam Noor Rashid

Signature.. Date..

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

FRP	Fiber-reinforced polymer
JFRP	Jute fiber reinforced polymer
PCD	Polycrystalline diamond
ASTM	American society for testing and materials
TGA	Thermo gravimetric analysis
DSC	Differential scanning calorimeter
DMA	Dynamic mechanical analysis
SEM	Scanning electron microscopy
FESM	Field emission scanning electron microscopy
CBN	Cubic boron nitride
V_B	Flank wear
CFRP	Carbon fiber reinforced polymer
NFRP	Natural fiber reinforced polymer
BFRP	Banana fiber reinforced polymer
KFRP	Kenaf fiber reinforced polymer
HFRP	Hemp fiber reinforced polymer

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The improvement of humanity is characterized as far as advance uses in materials that are the Iron Age, the Stone Age, and the Bronze Age. The present time of material has been chosen for the composite materials owing to its higher strength, lighter weight, corrosion resistance, and durability. The composites are known to the humanity; it has a past filled with over 3000 years. In old Egypt, individuals used to manufacture dividers from the blocks made of mud with straw as reinforcement part (Azwa et al., 2013). The word “composites” has come from the Latin word “compositus” which means “put together” indicating something made by assembling diverse parts or materials (Das & Pourdeyhimi, 2014). Generally, composite materials are consisting two or more mechanically and physically different components, presenting in two or more stages (Ahmad et al., 2015). Usually, composites are two phases that is continuous and discontinuous. The discontinuous phase is typically stronger and rigid than the continuous phase which is known as reinforcement, and continuous phase is called as the matrix. Composites can be categorized in two ways, which are the reinforcement used for particle reinforced or fiber reinforced and the matrix used for polymer matrix, metal matrix and ceramic matrix (G. A. Khan et al., 2016).

Since long time ago, composites are being used to resolve the technological problems, but only in 1960s with the primary introduction of polymer based composites, it starts getting the attention of industries. From then, it has turned into a common industrial material (Sanjay et al., 2015). The growing demand in its application also came out because of greater consciousness in terms of product performance and amplified competition in the world market for lightweight components (Kabir et al., 2012). Last few decades, the fiber reinforced polymer (FRP) composites attained an important space in the field of composite materials. In the reinforced polymer, the reinforcing agent may be either natural or synthetic. There is an extensive variety of different natural fibers which can be used as reinforcement or fillers. Various types of natural fibers are cotton, silk, wool, linen, hemp, ramie, kenaf, sisal, flax, coconut, jute, pineapple, kapok, angora, wood fiber, banana, bamboo etc. Among all the natural fibers, jute is more promising as it is comparatively inexpensive and commercially available in various forms (Gon et al., 2012). Jute fiber has wide range of inherent advantages like high tensile strength, luster, low extensibility, high flexural strength, moderate heat and flame resistance and long staple length (Al-Oqla & Sapuan, 2014).

Jute fibers are used to reinforce both thermoplastic and thermosetting matrices (Gassan & Bledzki, 1999). Thermosetting resins such as epoxy, polyurethane, polyester and phenolic, are usually used today in natural fiber composites, in which composites demanding higher performance applications. Jute fiber reinforcement polymer (JFRP) composite provide sufficient mechanical properties, in particular strength and stiffness, at acceptably cost effective (Bongarde & Shinde, 2014). Natural fiber composite is used in aerospace (cabin, chair), automotive, sport goods and domestic upholstery (Gowda et al., 1999).

The increasing demand of fibre reinforced polymer (FRP) in various industries made researchers to look for new cost effective natural fibres as an alternative for synthetic fibres. Many types of natural fibres have been utilized by researchers along with several polymeric resins in the form of composite and the mechanical, chemical and physical properties of the developed composites are studied (D. Liu et al., 2012).

(Holbery & Houston, 2006) concluded that natural fibres are superior to synthetic fibres in terms of low price and better quality. Jute fibre reinforced polymer composite is now being applied to a surprise range in aircraft, automotive, sport goods and domestic upholstery because of its dimensional constancy over wide range of temperature, high strength and high stiffness weight ratio with low specific gravity (Babu et al., 2013c).

The research activities on jute fibre reinforced polymer (JFRP) composite are currently going through a transition phase. Moreover, material properties and theoretical mechanics have been the dominant research areas in the field of composite materials (Sathishkumar et al., 2012). With increasing demands, applications, inexpensive techniques of production are very important to achieve fully automated large scale manufacturing cycles. An important aspect of production technology is machining such as milling, drilling and slotting process (A. Azmi et al., 2013). Figure 1.1 shows that the door panel, trim panel, seat panel and various damping and insulation parts are being made by JFRP composite.

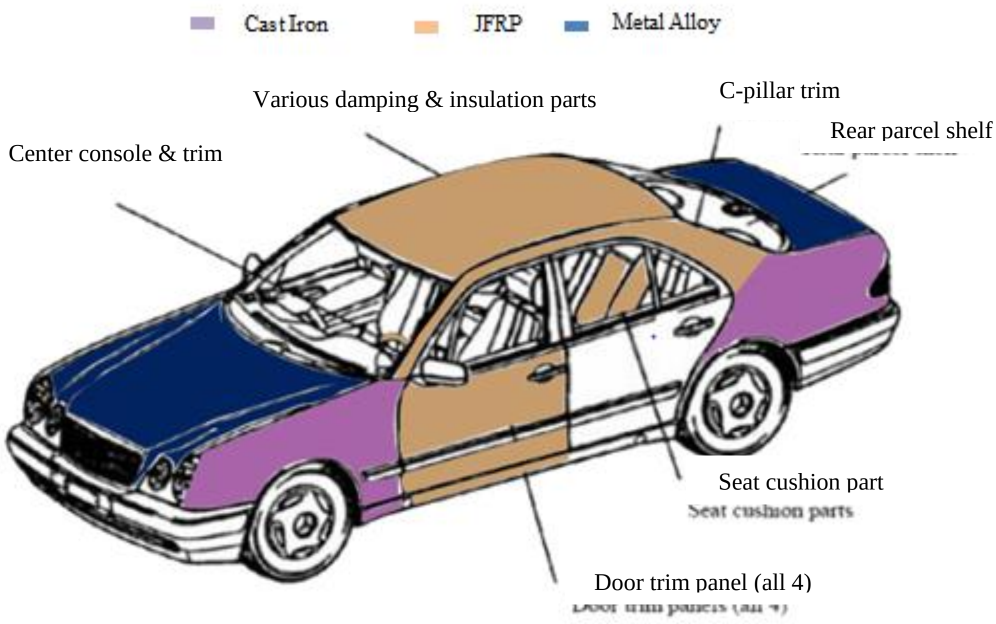

Figure 1.1 Material used for automotive car components (Fakultat, 2009)

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Fiber reinforced polymer (FRP) composites are using in several structural applications in which some machining operations like drilling, trimming, milling, slotting, grinding and surface finishing may involve. Due to different characteristic of the reinforcing constituents, above operation play important role in the time of machining. During machining, FRP composite create interaction during between the reinforcement and the matrix material (Calzada et al., 2012). Machining tends to interrupt the structure of the reinforcement through deterioration and permanent damage of the material. Problem arises due to machining are such as matrix cracking fracture of fiber, inter laminar delamination, high tool wear, surface damage and poor cut surface quality (Holbery & Houston, 2006).

The success of machining depends on the properties and application of the composite. These characteristics and properties are summarized in terms of its machinability, which denotes the relative ease of machining using appropriate tool and cutting parameters (Hensher, 2016). A material that has good machinability requires less power or force, which will produce a good surface finish and longer tool life. There are several aspects that need to be considered by the machinist during machining such as the type of fibers and their composition, cutting tool (carbide tool, ceramic and diamond), tool geometry, cutting parameters (feed rate, cutting speed and depth of cut) and cutting methods (dry machining or machining with a coolant) in fact, these are some factors that affect the end products. Moreover, facilities such as the clamping method and the rigidity of the machine, can also impact the machinability (Yashiro et al., 2013).

Machining of FRP arises some difficulties because of abrasive nature of the fibres and some physical and mechanical characteristics of the fibre-matrix systems (Babu et al., 2013a). Regarding the quality of machining of FRP composite, the principal drawbacks are severe tool wear, surface delamination, and poor surface roughness. During machining surface roughness drawing attention for many years because it can affect the product performance, dimensional precision and production cost (Iovinella et al., 2013). In conventional machining methods, has proved that FRP composite material faces difficulties in achieving acceptable surface quality (Palanikumar, 2008). Fibre delamination occurs generally in drilling and milling and affects product quality. During machining, the heterogeneous FRP composite causes delamination and this reduces the bearing strength, structural integrity, durability, and tool wear. Therefore, researchers and manufacturers face greater pressure as they need to establish a better understanding of FRP cutting processes, in respect to accuracy and efficiency (Yashiro et al., 2013).

Cutting temperature is one of the main problems during machining. The temperature increases at higher cutting parameters which generate worst scenario tool life and surface roughness. The cutting parameters to be addressed are cutting speed (V), feed rate (F) and depth of cut (D). It is most important to discover the most significant factors that affect the machinability of the materials.

The machining of JFRP is an important aspect and interest due to the excessive tool wear and poor surface quality and also the delamination and fibre pull-out during machining. It is time consuming and expensive during machining because of required shape, design and various automotive applications. To achieve high productivity and cost effective, many approaches have been attempted. In this study, to overcome the problems carbide cutting tool is used to cut JFRP. Applying uncoated carbide cutting tool, suitable cutting parameters and methods to produce quality parts while, machining JFRP is expected to improve tool life, surface smoothness and delamination factors.

1.3 RESEARCH OBJECTIVES

The main purpose of this research is to study the machinability of jute fiber reinforced polymer composite for automotive application. The following are the objectives of the experiments.

a) To determine the most significant cutting parameters (cutting speed, feed rate and depth of cut) that influence the tool life, surface quality, delamination factors during milling of jute composite.

b) To investigate the effect of cutting speed, feed rate and depth of cut on tool life, surfaces roughness and delamination factor in JFRP composite machining.

c) To determine the optimum cutting parameters of milling on jute composite by using Response Surface Methodology (RSM).

1.4 RESEARCH METHODOLOGY

To achieve the stated goals, the research methodologies adopted are as follows:

1) At first, fabrication of jute fibre reinforcement polymer composite was carried out through hands lay-up technique. The JFRP panel were fabricated in different composition like 60/40 and 70/30 which means 40% epoxy resin and 60% woven jute fabric and 30% epoxy resin with 70% woven jute fabric. The panel was formed according to American Society for Testing and Materials (ASTM) formula to continue mechanical tests.
2) Secondly, different composition of JFRP composite has been machined based on preliminary cutting parameters to find out the best composite for actual machining. After machining, the results found that 60/40 panel is consisting less tool wear and delamination factor comparing to 70/30 panel. The panel 60/40 was selected for actual machining.
3) Thirdly, actual machining for 60/40 JFRP panel was carried out by using an solid uncoated carbide cutting tool. The cutting tool has a diameter of 8.0 mm. The machining experiment was conducted on Universal DECKEL MAHO-DMU 35M (CNC Milling)
4) Fourthly, to identify the data of tool life, surface roughness and delamination factor of the composite was carried out through Nikon Measuring Microscope MM-400 and VEECO Wyco Optical Profiling System Microscope respectively. The tool wear mechanism was analysed by using Scanning Electron Microscope machine.

5) Finally, experimental design was done on the basis of Response Surface Methodology. Three machining variables were investigated which is described as input and output (response) variables. Following variables are given below:

a) Input Variables

i. Spindle speed (671.47 – 6328.43 rev/min);

ii. Feed rate: millimetre per min (108.58 – 391.42 mm/min); and

iii. Depth of cut: millimetres (0.79 – 2.21 mm).

b) Response Variables

i. Tool life (min)

ii. Surface roughness: micrometres (µm); and

iii. Delamination factor

1.5 RESEARCH SCOPE

Jute fiber reinforced polymer composite was fabricated in different composition like 60/40 and 70/30 following the technique of hands lay-up. Machining of JFRP composite is performed on a flat panel with 5.0 mm thickness. The end milling was conducted on Universal DECKEL MAHO 35 MU Computer Numerical Control machining center which has a maximum spindle speed of 12000 rpm. A 2-flute 8.0 mm uncoated solid carbide cutting tool was used to mill the JFRP panel. The ranges of spindle speed, feed rate and depth of cut, used for this research are 671.57-6328.43 rev/min, 108.58-391.42 mm/min and 0.79-2.22 mm respectively. The tool wear was determined through analyzing the tool life and tool wear mechanism. The quality of JFRP panel is studied in terms of surface roughness and delamination factors. Finally, the cutting parameter was optimized through Response Surface Methodology (RSM).