EFFECT OF MACHINING PARAMETERS ON THE SURFACE FINISH QUALITY OF NATURAL FIBER COMPOSITES

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature fro any degree.

Signed_____________

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Date: 29th May 2019

STATEMENT 1

This thesis is the result of my own investigation, except where otherwise stated. Other sources areacknowledged by giving explicit references. References/bibliography are appended.

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STATEMENT 2

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

NFRC	Natural fiber reinforced composite
KFRP	Kenaf fiber reinforced polyester composite
SFRC	Synthetic fiber reinforced composite
FRC	Fiber reinforced composite
R_a	Arithmetic average height
R_q	Root mean square roughness
R_{max}	Maximum height of the profile
R_p	Maximum height of peaks
R_v	Maximum depth of valleys
R_{sk}	Skewness
R_{ku}	Kurtosis

ABSTRAK

Kebelakangan ini, komposite bertetulang gentian semulajadi (*natural fiber reinforced composite*, *NFRC*) semakin mendapat kegemaran di bidang pembuatan kerana kelebihannya yang mesra alam, kos rendah dan pelbagai pilihan sumber yang boleh diperbaharui. Komposit bertetulang gentian semulajadi adalah dibuat daripada matriks yang tertanam dengan serat semulajadi seperti pisang, kenaf, sisal dan sebagainya, manakala komposit bertetulang gentian (*fiber reinforced composite, FRC*) adalah dibuat daripada gentian buatan manusia atau sintetik and plastik matriks. Dalan kajian ini, jenis komposit bertetulang gentian semulajadi yang digunakan adalah komposit poliester bertetulang kenaf. Poliester adalah sejenis termoplastik yang tidak berubah bentuk pada suhu tinggi kerana struktur silang yang sangat tinggi di antara setiap molekul. Oleh itu, ia memberikan sifat yang baik kepada bahan tersebut, seperti kekuatan yang baik. Semua spesimen yang digunakan dalam eksperimen ini adalah disediakan oleh Pusat Pengajian Kejuruteraan Bahan and Sumber Mineral. Proses pemotongan spesimen komposit yang dilakukan dalam keadaan tanpa cecair '*coolant*'. Pemotongan dijalankan 2 kali dengan *cutting speed* dan *feed rate* yang berlainan. Kualiti permukaan spesimen komposit selepas pemotongan akan diukur dengan menggunakan cara *machine vision* dengan memproses gambar-gambar spesimen komposit pada sudut putaran, 0°, 90°, 180° and 270°. Dengan semua analisis yang dibuat pada semua keputusan tentang kualiti permukaan spesimen komposit, *cutting speed* yang serderhana dan *feed rate* yang sederhana boleh memberi kualiti permukaan yang lebih baik. Walau bagaimanapun, sifat non-homogen komposit memberi kesusahan untuk meramalkan kualiti permukaan dalam pemotongan seterusnya.

ABSTRACT

In recent years, natural fiber reinforced composites are getting greater attentions among manufacturers due to its advantages of environmentally friendly, low cost and wide range of available renewable resources in nature. Natural fiber reinforced composite (NFRC) is a composite material that consists of a matrix embedded with natural fibers such as banana, kenaf, sisal and so on, while the fiber reinforced composite (FRC) is consists of manmade or synthetic fibers and a matrix. In this research, the type of natural fiber reinforced composites used is kenaf fiber reinforced polyester composites (KFRP) to study the effect of machining parameters on its surface finish quality. Polyester is a kind of thermoplastics which will not deformed thermally under high temperature as highly cross-linked structure in between each molecule, thus it gives good properties to the material, for example, good strength. Turning operation without cutting fluids were carried out with different cutting speed and feed rate settings on KFRP specimens for two times with depth of cut of 0.5 mm. After that, the surface finish quality of the composite specimen were measured using machine vision method by processing the images of composite specimens with angle of rotations, 0 °, 90 °, 180 ° and 270 °. With the analysis of all the results of the surface roughness of all composite specimens, it can conclude that medium cutting speed and medium feed rate lead to the better surface finish quality. However, the non-homogenous properties of composite makes difficult to predict the surface finish quality in the subsequent turning.

CHAPTER 1

INTRODUCTION

1.1 Research Background

In most of the research studies related to machining on natural fiber reinforced composites (NFRC), the relationship between machining parameters such as cutting or spindle speed, feed rate, types of cutting tool used and surface finish quality of the cut surface was been investigated. This area of study is helpful for obtaining the good surface finish of NFRC after net shape finishing even though the mechanical anisotropy and inhomogeneity and the abrasive nature of the fiber reinforcement make the composite material difficult for doing machining on it (Nassar et al, 2017). However, natural fiber reinforced composite has superior advantages compared to synthetic fiber reinforced composite in terms of low cost, low weight, less abrasive to processing equipment and good relative mechanical properties (Pickering et al, 2016). With studying the machining process of NFRC, it can help for encouraging the use of NFRC in various industries such as construction, automotive and so on.

The manufacturing method of producing NFRC is hand lay-up, pultrusion, filament winding, vacuum bag molding and resin transfer molding. (Babu et al, 2013). These manufacturing process only produce near-to-net shape product. Commonly, some other machining processes such as milling, drilling or turning is required to fabricate into the final product. However, there is difficult for doing machining on NFRC as it possibly results in damages such as fiber pull-out, delamination and more at the end of machining process. Studying the effect of machining parameters on surface finish quality of NFRC is possible to minimize the damages after machining.

In the past, a number of studies related to the drilling of NFRC have been published. Commonly, the NFRC products are produced into almost net shape and only some finishing process has been carried out if it is required. Therefore, only very few researches on milling and turning process of NFRC has been conducted detailedly. Suggesting for using higher cutting speed, low feed rate and higher tool noise radius for machining can produce the better surface quality of NFRC (Zajac et.al, 2014). Additionally, the parameter used for measuring surface roughness of composite specimen is arithmetic average height (R_a). R_a is not an appropriate parameter to be used for measurement of surface roughness as it does not distinguish between peaks and valleys along with the surface profile of the specimen. Hence, it is unable to characterize the amount of fibers on the machined composite surface.

Contact measurement is the most common way for measuring the surface roughness of the final NFRC products. The stylus tip traces and detects electrically the motion of the stylus tip along with the measured surface profile. However, the presence of uncut fibers on the surface profile of NFRC after machining can disturb the movement of the stylus tip and lead to the inaccuracy of results. As a result, machine vision method for non-contact measurement of surface roughness of NFRC was used to measure the surface roughness of the composite specimens after turning operation. Therefore, the uncut fibers on the machined surfaces of composite specimens can be clearly displayed in an image and the accuracy of surface roughness measurement can be highly improved by using machine vision method.

1.2 Research Statement

Most of the current researches done related to NFRC are on the drilling process. Even though, NFRC is usually manufactured into the net shape of the product but it might need some turning operations to fabricate the part into the final shape of the product. In addition, the researches related to the machining of NFRC hve measured the surface roughness of machined surface with R_a as the parameter.

However, R_a does not differentiate between peaks and valleys along with the surface profile. Furthermore, it does not sufficient enough to show the surface profile of composite specimens after machining. Therefore, in this research, R_{max}, R_p and R_{ku} are measured for each composite specimen after dry turning process to provide more information about the surface profiles of machined composite surfaces.

1.3 Objectives

- To study the effect of cutting speed and feed rate on the surface finish quality of NFRC.
- To determine the best machining parameter setting for turning of NFRC with least amount of uncut fibers.
- To describe the surface profile of NFRC after machining with different surface roughness parameters.

1.4 Scope of Research

In this study, the natural fiber reinforced composite used is kenaf fiber polyester composite (KFPC). The machining is limited to dry turning operation using carbide cutting insert. For capturing images of edge surface profiles of composite specimens, a close up +8 lens with the size of 55 mm was attached to SONY DSLR-A230 alpha camera in order to reduce the minimum focus distance and capture more detail information of surface profile of the composite specimen. Additionally, backlighting was installed to take images of composite specimen surface profiles with an angle of rotation about 0°, 90°, 180° and 270°. In order to obtain a good quality image, the background lighting setup was required for some modifications. For instances, blocking some light from the background was done in order to reduce the radiant light which blurs the edge surface profile of composite specimens. Different gamma values were tested and compared with measured values on stainless steel rod by camera calibration method to ensure that the results from tester and software are almost matched to each other. The best gamma value was selected and used in MATLAB coding for processing images of composite specimens to obtain the values of surface roughness. Lastly, the results of surface finish quality of each composite specimen were analysed and determined the best cutting parameters setting for dry turning operation.

1.5 Research Approach

Firstly, the information regarding about machining process, the effect of machining parameters on surface finish quality of natural fiber reinforced composites and machine vision method for measuring surface roughness were gathered from the journal papers. Next, the kenaf fiber polyester composites with a diameter size of 12 mm were prepared by School of Materials and Mineral Engineering. The materials were cut into 70 mm long and nine specimens using bandsaw machine. Subsequently, the coding for detecting the subpixel edge of composite specimen was prepared. The camera setup with backlighting and camera calibration were done for choosing the best gamma value with the minimum measured error of surface roughness between using Mitutoyo Surftest 210-J and MATLAB coding. Experiments were started by observing the area of materials which is cut through for each time of turning with the depth of cut about 0.5 mm by taking the top cross-sectional view pictures for each composite specimen using ring light and close up +8 lens at a fixed object-to-lense distance. Then, nine sets of combinations with different cutting speed and feed rate setting plus the fixed depth of cut of 0.5 mm were prepared for nine composite specimens. The turning process was carried out using OKUMA lathe machine. After completing each turning with the depth of cut about 0.5 mm, the edge pictures of the machined surface of composite specimens were taken with an angle of rotation about 0°, 90°, 180° and 270°. These pictures were processed using subpixel edge detection coding to obtain surface roughness values. Besides, the pictures of top cross-sectional view of composite specimens after turning were also taken with same camera setup as previous. Finally, based on the values of surface roughness which were obtained from MATLAB coding, a discussion regarding these results were presented. Figure 1.1 illustrates the flow chart of the research approach for this study.

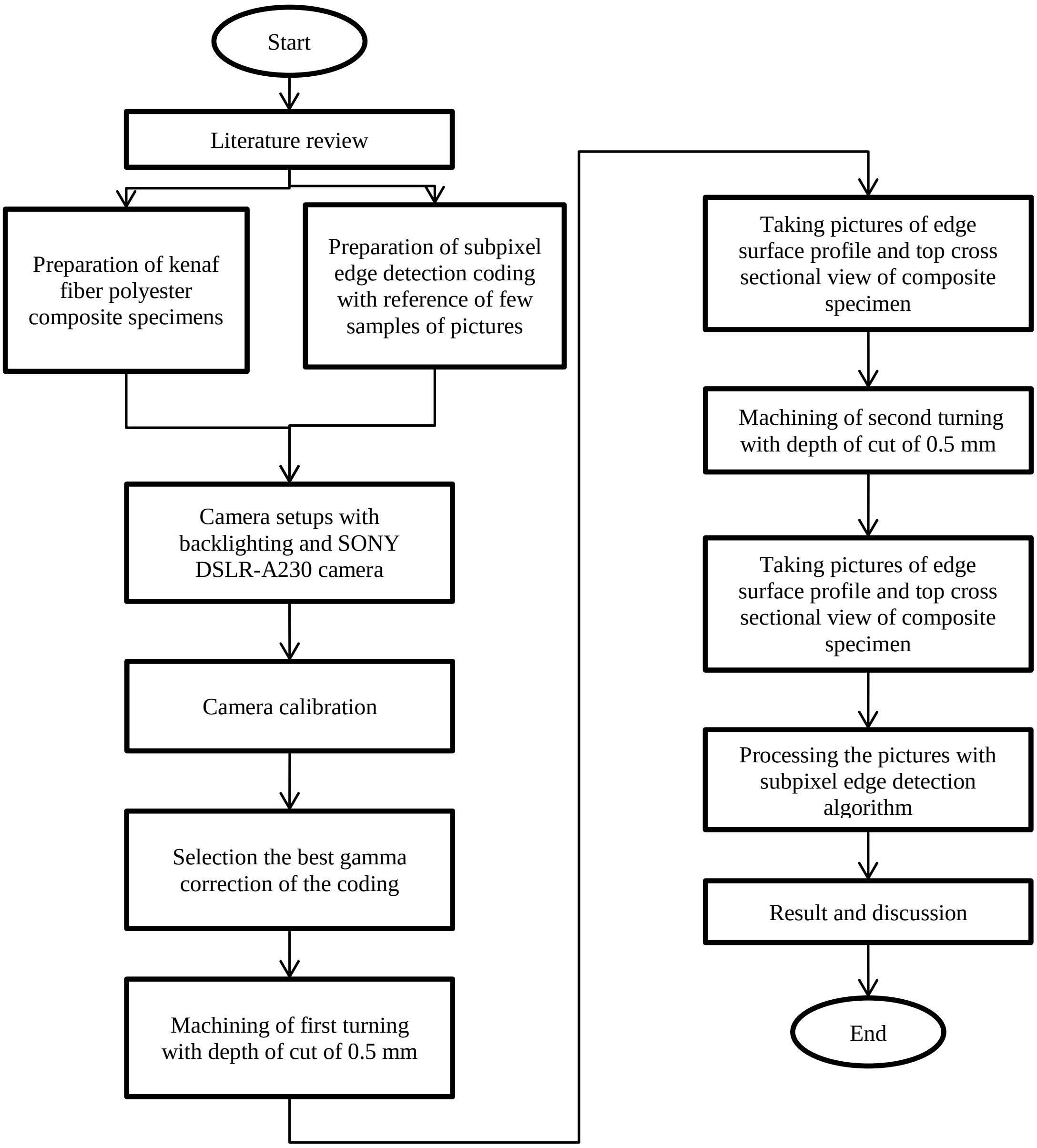

Figure 1.1 Flow chart of research approach

1.6 Thesis Organization

The thesis is organized into five chapters and the description of each chapter is as follows:

Chapter 1 introduces about the importance of natural fiber reinforced composites to the environment and its uses and properties. Besides, the limitations of using R_a as surface roughness parameter for determining the surface finish quality of composite specimens after machining is briefly explained in this chapter too. In addition, problem statement, objectives and scope of research are also elaborated in this chapter.

Chapter 2 reviews about the journals and works that had been done in the past researches. The importance of replacing synthetic fiber reinforced composites with natural fiber reinforced composites (NFRC) was explained briefly. The details of machining operation such as drilling, milling, trimming and turning on NFRC were studied for ensuring the research title had not been published before. At the end of this chapter, non-contact method on measuring surface roughness of a part was studied and revised too.

Chapter 3 describes the camera setup, coding, camera calibration, selection of gamma correction and experiment setup. The adjustment on the lighting had been done to improve the quality of images. In order to read the results in standard unit, calibration using pin gauges had been done to convert pixel to micrometer(μm). Different gamma correction values were used and compared to identify the best gamma value of processing the images of composite specimens. Finally, the sub-pixel edge coding was created and explained.

Chapter 4 exhibits the results of R_{max}, R_p and R_{ku} for first and second turning operations. Each result was explained clearly at each level of cutting speed and feed rate setting. Then, the best cutting parameter settings were identified at the end of this chapter.

Chapter 5 concludes the work of this thesis and suggests recommendation for the future works about studying machining process of NFRC.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In recent years, natural fiber reinforced composites are getting greater attention among manufacturers due to its environmentally friendly, low cost and wide range of available renewable resources. In this chapter, the past researches about the machining process of natural fiber reinforced composites and the non-contact method of surface roughness measurement are reviewed. From the reviews, the importance of studying the effect of machining parameters on the surface finish quality of natural fiber reinforced composites after dry turning is emphasized. This chapter also reviews the limitations of the past researches by using R_a as surface roughness parameter on measuring the surface finish quality of composites.

2.2 Natural fiber reinforced polymer composites

Several researchers have put in effort on studying the material properties and machinability of several types of natural fiber reinforced polymer composites. It is found that there are several advantages of using natural fiber reinforced polymer composites instead of using synthetic fiber reinforced polymer composites (SFRC). Natural fiber reinforced polymer is a composite made of polymer matrix reinforced with natural fibers. There are many types of natural fibers and matrix can replace glass to be used in manufacturing composites for improving mechanical and strength properties of the materials. It was proven by Paul et al. (2003) who carried out tensile and impact tests on natural fibers reinforced polypropylene composites (sisal, hemp, coir, kenaf and jute fibers) and then the results showed that the natural fiber reinforced polymer composites has great potential to replace glass fiber reinforced composites in many applications. Besides, Joshi et al. (2004) showed that the natural fiber composites (NFRC) that are environmentally friendly superior compared to glass fiber reinforced composites (GFRC) as NFRC has lower environmental impact as it reduces the use of non-renewable resources and lowers the emissions during the manufacturing process. In addition, low cost and low density compared to glass reinforced composites are attractive in automotive applications. For instances, hemp fiber-epoxy, flax fiber-polypropylene (PP) and china reed fiber PP are popular types of natural fiber reinforced composites used in automotive industries.

2.3 Machining of natural fiber reinforced composites

Most of the studies done related to natural fiber reinforced composites on the effect of machining parameter are mainly on drilling and milling operations. Very few researchers studied about the topic on dry turning process.

2.3.1 Drilling

Several researchers have put effort on investigating the effect of the cutting condition of fiber reinforced composites (FRC) either natural or synthetic fibers. Due to the need for assembling operation, drilling holes on FRC is unavoidable action. It is not easier for drilling holes on FRC due to its abrasive, heterogeneous and anisotropy properties. Ismail et al. (2016) used hemp fiber reinforced polymer (HFRP) and carbon fiber reinforced polymer (CFRP) samples to study on the machinability of natural and synthetic fiber reinforced polymer composites using Taguchi method for designing experiment. Two sizes of hole diameter which were studied are 5.0 mm and 10.0 mm to analyze the damages of these two sizes of holes at different cutting conditions. The drilling was carried out in dry condition without liquid coolant due to the possibility of absorption of liquid coolant by FRC which can affect the accuracy of final results. Besides, the effects of the material removal rate of HSS (high speed steel) twist drills with the amount of delamination defects caused at the end of the machined samples was also investigated in this research. The delamination damage was quantified by delamination factor, F_d. The maximum delamination and drill bit diameter are shown in Figure 2.1 below.

$$F_d = \frac{D_{max}}{D_o}$$

$F_d = delamination\ factor$

$D_{max} = maximum\ delamination\ (mm)$

$D_o = drill\ bit\ diameter$

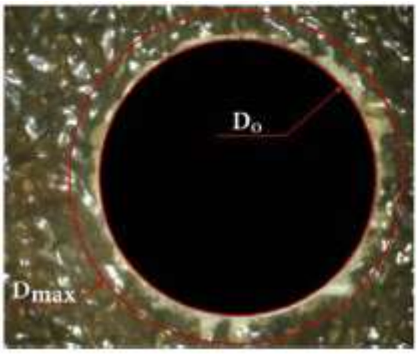

Figure 2.1 Delamination quantification with D_{max} dividing by D_o (Ismail et al, 2016)

The surface roughness of surface walls of the drilled holes was determined using Mitutoyo profilometer with R_a as the measurement parameter. Besides, the composite samples were sectioned into two halves in order to allow the probe stylus of profilometer measuring the drilled walls uninterruptedly along the direction of drilling. The limitation of this research is using R_a as the measurement parameter of surface roughness because it does not differentiate between peaks and valleys along with the measured surface profile of the composite specimen. As a result, the information about the spatial structure of the composite specimen surfaces is unable to be identified. Furthermore, the contact method of measuring surface roughness of drilled hole walls using the stylus is not suitable to be used due to the movement of the stylus can be disturbed by the fiber pull-out on the drilled hole walls. Therefore, this might cause some inaccuracies to the results of the surface finish quality of drilled holes. Besides, the model of Mitutoyo machine which is used for surface roughness measurement was not specified in the research paper. Lastly, the tool wear after machining and the detail information about the cutting tool used such as nose radius, edge angle and so on was not clearly explained in this research.

2.3.2 Milling

Slotting is one of the important machining processes in assembly operations. The milling of natural reinforced composites is an essential step in assembling. There are several researchers using different types of natural fiber plastic composites to study the machinability effect on surface roughness. Azmi et al. (2016) used kenaf reinforced epoxy composite which was fabricated using a vacuum assisted resin transfer molding (VARTM) method to study on machinability effect of surface roughness in milling using response surface methodology (RSM). It is an approach for determining the modelling equation which is more reliable in obtaining the optimized cutting conditions for better surface quality. The experiments were designed using full factorial method to investigate the importance of parameters (spindle speed, feed rate and depth of cut) on the defects of composites surface. In this study, the high-speed steel (HSS) was chosen instead of carbide insert due to the greater strength on withstanding cutting forces and lower cost. For measurement of surface roughness of milled kenaf composites, Mitutoyo CS 3000 525-780E-1 was used to measure three points on the slotted kenaf composites as shown in Figure 2.2 below. The surface roughness parameter of R_a was used to measure the surface finish of milled kenaf composites.

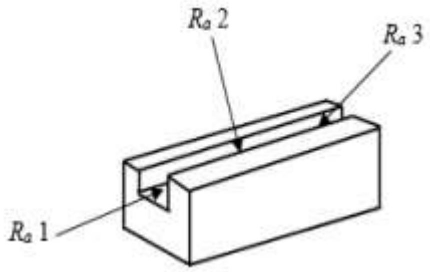

Figure 2.2 Three measured points for surface roughness of R_a (Azmi et al, 2016)

The results of surface roughness of the composite specimens were used to identify the significance of spindle speed, feed rate and depth of cut on the surface finish quality of the milled kenaf composites using Analysis of Variance (ANOVA) method. In addition, the modelling equation for predicting the optimum milling parameters was done using Design Expert software. The measurement of surface roughness of milled kenaf composites was limited at R_a parameter which is unable to characterize between peaks and valleys and only giving the average mean height of peaks and valleys along sampling length. Therefore, R_a is not a good parameter to determine the surface finish quality of milled kenaf composites. Besides, the damages of milled kenaf composites such as fiber pull-out, delamination and so on were not discussed and showed clearly in this result. As fibers might disturb the movement of probe stylus of Mitutoyo tester, it can leads to the error in measurement of surface roughness. Therefore, the contact type of measurement is not suitable to be used in measuring the surface roughness of natural fiber reinforced composites.

Babu et al. (2012) used the Taguchi method to determine the optimum cutting parameters which give minimized appearance of delamination and best surface finish quality of milled unidirectional natural fiber reinforced composites. There are four types of natural fiber plastic composites used in this research which are hemp, jute, banana and glass fibers. In order to identify the delamination defects caused by milling as shown in Figure 2.3 below, Mitutoyo TM 500 toolmaker's microscope was used to examine the composite specimens. The value of delamination factor can be calculated based on the following formula:

$$F_d = \frac{W_{max}}{W}$$

$W_{max} = maximum\ width\ of\ the\ damage\ around\ the\ slot\ periphery$

$W = width\ of\ cut$

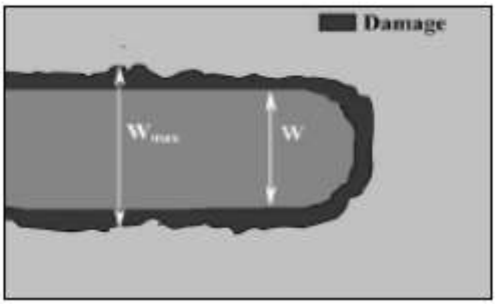

Figure 2.3 Schematic of the measurement of the maximum width (W_{max}) and width (W) on a milled slot (Babu et al, 2012)

For surface roughness measurements, R_a of each composite specimen was measured using Mitutoyo SJ-301. All the results of surface roughness of composite specimens were collected and used for further analysing using the ANOVA method to obtain the desired optimum cutting parameters. In this study, the fiber orientations of the materials were not explained clearly. It is important because of the orientation of fiber can affect the ease of the samples to be machined. For example, laminate types of composites are easier to be machined as it is less abrasive to the tool. Besides, probe stylus type of instrument is not suitable to be used in measuring the surface roughness of milled composite specimens as the surface of milled composite specimens are attached with uncut fibers or defects which might affect the accuracy of the measurement. Lastly, R_a is not a good surface roughness parameter to identify the surface quality of milled composite specimens.

2.3.3 Trimming

There is almost none of researcher studying about the effect of cutting parameters on natural fiber reinforced composites after trimming operation, except for the research conducted by Delahaigue and his team in 2017. Delahaigue et al. (2017) studied about the influence of cuttting parameters (cutting speed and feed rate) and fiber orientation in flax epoxy composite laminate on the cutting forces, surface integrity and the surface roughness during trimming prcoess. The trimming process was carried out by 3-axis CNC high speed machine (HURON K2X10) and the composite plates was predilled and then trimmed in column direction followed by row direction as shown in Figure 2.4 below.

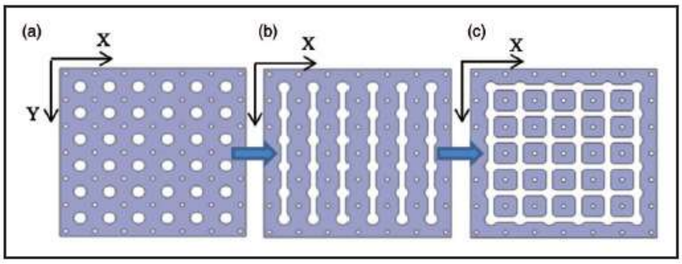

Figure 2.4 Trimming methodology, (a) before trimming, (b) trimming in column direction, (c) trimming in row direction (Delahaigue et al, 2017)

The finished surface of composites were analyzed using optical microscope KEYENCE VHX-500FE while Mitutoyo Suftest SJ-400 was used to measure the surface roughness of composites. The fiber orientation set in the experiment was 0°, 90° and $\pm 45^{\circ}$. Besides, the delamination damages and fiber pull-out on the composite specimens after trimming were captured using optical microscope. Based on the results of surface roughness and delamination defects of composite specimens with different cutting parameters were analyzed to understand the influence of cutting parameters on these results. This research study about the trimming of natural fiber reinforced composites are giving detail information about types of cutting insert used,