A PRELIMINARY STUDY OF TURNING OF COMPOSITES

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A Preliminary Study of Turning of Composites

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DECLARATION

The work contained in this dissertation is my own and has not been submitted for any other

qualification

SUMMARY

Most of the engineering parts are made from metal based materials. Composites have recently become an economic alternative to traditional materials like metals due to their considerable advantages especially in high specific strength and specific stiffness. But, turning of composites is different from turning conventional metals because of the inhomogeneity and anisotropic characteristics of composites. It also depends on the diversity of fiber and matrix properties, fiber orientation, and the relative volume of matrix and fibers. During a turning operation, vibration and noise are generated as a result of the interaction between the rotating work piece and moving cutting force. Therefore, there is a need to understand the dynamic behaviour of composites during machining particularly turning. In this project, the influence factors contributing to surface finish, vibration and noise during turning operation have been established. A mathematical model for the dynamic behaviour of the turning operation is constructed via Rayleigh beam theory and coded into MATLAB tool for simulation. A parametric study is also performed which involves several operational conditions and work piece characteristics to discover their effect on vibration of a work piece (hence the surface finish) through simulation. Results from the numerical simulation generated are found to be consistent with many experimental findings done by the previous researcher.

ACKNOWLEDGEMENT

TABLE OF CONTENTS

NOTATION

R_a	Roughness	-
f	Feed rate	Millimetre (mm)/min
FRP	Fiber reinforced plastic	-
GFRP	Glass fiber reinforced plastic	-
MMC	Material matrix composite	-
GFR	Glass fiber reinforced	-
F_f	Feed cutting force	N/m^2
n	Revolution per minute	Revolution per minute
K_f	Feed direction	-
a_c	Width of cut	Meter (mm)
h (t)	Dynamic chip load	-
h_c	Intended cut	Meter (mm)
ρ	Mass density	kg/m^3
I	Moment area	m^4
Ω	Rotational speed	m/s
E	Young's Modulus	GPa
P_x	Axial force	Newton
ω	Frequency of vibration	Rad/s
Δt	Time step	Second
r	Radius of gyration	Metre (m)
ω_i	Frequency of beam	Rad/s
C	Cutting constant	N/m^2
A	Cross section area	m^2

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Engineering is the most creative application of scientific principles to design or develop structures and it is also strongly involved during creation of new products or components. These products and components require satisfaction of several quality aspects including correct dimensions, correct finish and surface smoothness before being delivered to customers.

Manufactured products or components should have good surface finish for better quality, reliability, excellent performance and last but not least meet customer requirements. In most cases, excessive roughness is considered to be detrimental to performance and often a good predictor of poor quality of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

There are many different ways in which a product or component can be manufactured. Manufacturing itself can be described as a process of converting raw material to finished product or parts. The conventional technique encompasses processes like metal forming, machining, injection molding, die casting, stamping and others. Machining is the most important of the manufacturing processes. It is the traditional method for material removal and it is being used as one of the methods to change other manufacturing processes like casting or forgings from unfinished work piece into required shape with size, dimension and surface finish to accomplish product design requirement.

There are three principal processes in machining which are turning, milling and drilling. Turning process is one of the oldest and most versatile conventional ways to produce parts in cylindrical shape using a single point cutting tool. Turning is performed on a machine called a lathe in which the tool is stationary and the part is rotated. The tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the work piece, or along a specified path to produce complex rotational shapes.

Generally work pieces used in turning are made of metals due to their popular physical and mechanical properties in most engineering applications. In automotive industry for example, most of the parts are made from metals. Due to its homogeneity and isotropic

properties, metals had been undergone numerous of researches particularly to optimize its machinability.

Lately, many studies have been conducted to replace metals due to its shortcomings especially as sometimes they are heavy and most metals suffered from bad corrosion if not painted or coated. Plastic materials especially composites has become the preferred choice and prominent to replace conventional materials particularly metals to avoid these drawbacks and it has been seen implemented in wide variety of applications such as aeronautical, aerospace, automotive, biomechanical and mechanical engineering, as well as in other industries.

2.0   BACKGROUND AND SIGNIFICANCE OF RESEARCH

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure (Hull and Clyne, 1996). Composites also have been considered as an advanced material in which they are characterized by a combination of light weight, very high specific strength, high modulus and a high stiffness. The principal advantage of these materials is the very high strength to weight ratio, which makes them attractive in aircrafts, spacecraft, cars, boats, and sport equipment.

Composites have been seen as early as 1940s where glass-reinforced resin matrix composites were first introduced (Komanduri, 1997). Since then, the use of composites is growing steadily in various industries including aerospace, aircraft, automobile, sporting goods, marine, off-shore drilling platforms, appliances, etc. Composite materials have gained popularity in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions such as aerospace components (tails, wings, fuselages, propellers), boat and scull hulls, bicycle frames and racing car bodies. Other uses include fishing rods and storage tanks. Carbon composites are a key material in today's launch vehicles and spacecrafts. They are widely used in solar panel substrates, antenna reflectors and yokes of spacecrafts. They are also used in payload adapters, inter-stage structures and heat shields of launch vehicles.

With regard to the increasing use of composites in the aeronautical, aerospace, nuclear, biomedical, and automotive industries, the need to machine the materials, adequately, increases. The final operation on their fabrication is a machining process in which the dimension precision and the surface finishing are determined.

Machining of composites predominantly using turning process has becomes an exciting subject in recent years since the use of composites has increased tremendously in various areas of science and technology due to their special mechanical and physical properties such as good corrosive resistance and high specific strength and stiffness. Machining of composites differs significantly in many aspects from machining of conventional metals and their alloys. In the machining of composites, the material behaviour is not only inhomogeneous, but it also depends on diverse fiber and matrix properties, fiber orientation,

and the relative volume of matrix and fibers. The tool encounters continuously alternate matrix and fiber materials, whose response to machining can be entirely different.

The physical properties of composite materials are generally not isotropic in nature, but rather are typically orthotropic. For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. For instance, the fiber reinforcement and matrix used, the method of panel build, thermoset versus thermoplastic, type of weave, and orientation of fiber axis to the primary force. In contrast, isotropic materials such as aluminium or steel typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments.

Due to this inhomogeneity and anisotropic characteristics, turning of composite is different from turning conventional metal. Furthermore, according to Ramkumar et.al (2004), there is a significant difference between machining of metal and composite materials since composites are anisotropic, inhomogeneous, and mostly it is prepared in laminate form before going through the machining process. Besides, machinability of composites is influenced by fiber and matrix properties, fiber orientation and the type of weave.

Several attempts have been made to eliminate machining operation via fabrication techniques like near net shape forming and modified casting, but the scope of these techniques is limited and therefore machining is still an integral part of the composites component manufacture (Basavarajappa, Chandramohan et.al, 2006). Even though composite parts may be produced by moulding process, they require further machining to facilitate dimensional control for easy assembly and control of surface quality of functional aspects.

Apart from the utilization of composites in most engineering application and its difficulties to machine, the knowledge on machining of composites is still insufficient and more investigations are needed to be done to optimize the machinability of composites. As a result, there is an essential need to stud y and understand questions associated with the machinability of these unique materials. Additionally, very little has been found in the literature concerning machining of composites.

3.0 PROJECT OBJECTIVES

Several objectives have been planned to achieve the aim of this research. The objectives of this research are as listed below:

(1) To establish the factors that influence the surface roughness in turned composite.

The surface finish of turned composites is believed to be far from good as that of metals parts and this is mainly due to good homogeneity and isotropy of metals in comparison with composite. Hence, identifying the critical aspects affecting the surface roughness of composites is necessary to produce a high quality component.

(2) To identify the reasons that will lead to vibration and noise in turning.

Since composites are non-homogeneous and anisotropic, their chance of vibration leading to chatter during turning process is high and it is higher than turning of metals. Thus, by identifying the factors that influence vibration and noise in turning of composites, it would help to improve the surface finish of turned composites and the working environment as well.

(3) To establish a mathematical model for turning and code it in MATLAB software

A mathematical model is going to be developed to model the behaviour of turning of composites before it could be coded into simulation packages. Simulation is then needed to imitate the dynamic behaviour of the turning process of composites prior to actual machining. One has to predict and visualize the effect of several cutting and machine parameters to the turned composite parts so that a good finished component can be achieved. It will involve a great deal of effort since the dynamic model for turning is very complicated in mathematics.

(4) To perform parametric studies

It is known that many parameters affect the surface roughness of a turned work piece. By means of the dynamic model established above, these operational conditions and work piece characteristics will be simulated to find out how they affect surface finish and vibration of a work piece and (partly) validate the dynamic model.

One of the original objectives included turning experiments of composites on a lathe. As the project proceeded, it was realized soon after submitting the Interim Report that that was not possible. The main reasons are as follows. First, as the construction of the New Department Building got delayed, there was no space available to site the lathe. The technical support required in operating te lathe for the special use of turning composites was not readily available. It also turned out that the mathematics of the established dynamic model was very difficult and complicated and hence learning it took time. Finally, coding in MATLAB proved to be a daunting task as the knowledge of MATLAB was very little at the beginning of this project.

So in the end, experiments were abandoned. However, there has not been a reduced quality of the project. The focus of the project has rightly changed to the mathematical aspect of coding and numerical simulation, after consultation with the supervisor.

4.0 INFLUENCE FACTORS CONTRIBUTING TO THE SURFACE FINISH OF THE TURNED PARTS

Quality of the surface finish and tolerances are among the most critical quality measures in many products and parts. As competition grows fiercer, customers now make higher demands on quality, making surface finish become one of the most competitive aspects in today's manufacturing industry. It reflects aesthetical value of the product besides its functionality.

In addition, the majority of engineering failures are caused by fatigue failure. Fatigue failure is defined as tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses. Surface roughness of a machined part is vital fatigue endurance and corrosion resistance. Nishitani and Imai (1983) found that the fatigue strength is more strongly influenced by greater surface roughness. To that extent, it is important to do further research on what are the factors that influence surface roughness in turning of composite and afterwards compare it with turned metal.

Figure 4.1 shows the surface profile which can be divided into roughness, weaviness and form error. Waviness refers to variations in the surface profile with relatively long wavelength while roughness had wavelengths shorter than those characteristic of waviness. Theoretically, the ideal value of certain arithmetical mean roughness, (R_a) for a given feed rate (f) and tool nose radius (r) can be calculated by this formula,

$$R_a = \frac{f^2}{8r}$$
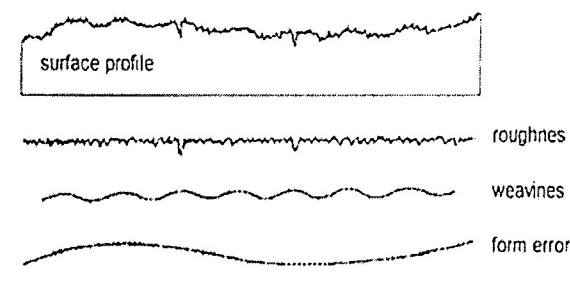
Figure 4.1 : Surface profile schematic by Dagnall (1986)

A considerable number of studies had been investigated the general effect of the cutting speed, feed rate, depth of cut, nose radius and other major factors on the surface roughness of turned metal. A representative summary of this study is shown below in Table 4.1.

Table 4.1 : Factors affecting surface roughness and major investigators

Investigators	Major factors	Materials studied
Karmakar (1970)	Speed, feed, depth of cut	Steel C-45
Bhattacharya et al.(1970)	Speed, feed, nose radius, work-piece hardness	Plain carbon steel
Rasch and Rolstadas (1971)	Speed, feed	Carbon steel
Selvam and Radhakrishnan (1973)	Speed, built-up edge, work-piece strain hardening	Steel
Lambert and Taraman (1974)	Speed, feed, Depth of cut	Steel SAE 1018
Petropoulos (1974)	Tool wear, surface roughness distribution	Steel
Boothroyd and Knight (1989)	Speed, feed	Mild steel
Selvam (1975)	Vibrations, chatter speed	Steel
Sundaram and Lambert (1981)	Speed, feed, nose radius, depth of cut	Steel 4140
Miller et al. (1983)	Speed, feed, tool condition, cutting fluid	Alloy, cast iron
Lambert (1983)	Speed, feed, nose radius	Steel D6AC

(Source : Feng and Wang 2002)

From the table shown, it is obviously concluded that the most factors contributing to give significant impact on surface roughness was cutting parameter in this case cutting speed and feed rate. Figure 4.2 show the schematic diagram of cutting parameters mentioned.

Turning and the adjustable parameters

Figure 4.2 : Schematic diagram of cutting parameters
(Source : www.mfg.edu/.../trad/turning/turn.html)

Interest in turning of composites material is only a recent development in manufacturing. Understandably, there have been much 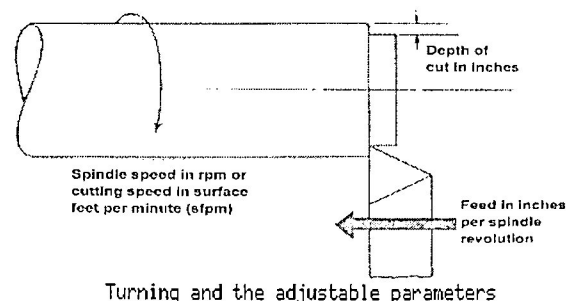fewer investigations into turning of composites than turning of metals. A literature survey has been conducted for several months well before the official start date of the MSc project until now and yields the following finding summarized in Table 4.2.

Table 4.2 : Factors affecting surface roughness and major investigators

Investigators	Major factors	Materials studied
1. Bhatnagar et al. (1995) 2. Jahanmir (1998) 3. Sakuma and Seto (1983) 4. Wang and Zhang (2003)	**A) Inhomogeneous and anisotropic material** 1. Fiber orientation angle	FRP Composite FRP Composite GFRP Composite FRP Composite
1. Palanikumar and Karthikeyan (2006) 2. Sonbaty et al.(2004)	2. Fiber volume raction, V_f	Al/SiC-MMC Composite GFR/epoxy Composite
1. Davim and Mata (2005) 2. Palanikumar et al. (2008)	3. Manufacturing technique (i) Hand Lay up	FRP Composite FRP Composite
1. Davim and Mata (2005) 2. Palanikumar et al. (2008)	(ii) Filament Winding	FRP Composite FRP Composite
1. Jahanmir (1998)	4. Type of fiber	FRP Composite
1. Birhan (2007) 2. Palanikumar and Karthikeyan (2006) 3. Palanikumar et al. (2008) 4. Ramulu et al.(1994) 5. Sonbaty et al.(2004) 6. Takeyame and Lijima (1988)	**(B) Cutting parameter** 1. Cutting speed	GFRP Composite Al/SiC-MMC Composite FRP Composite FRP Composite GFR/epoxy Composite GFRP Composite

Investigators	Major factors	Materials studied
1. Birhan (2007) 2. Hocheng et al.(1997) 3. Palanikumar and Karthikeyan (2006) 4. Palanikumar et al. (2008) 5. Sonbaty et al.(2004) 6. Spur and Wunsch (1988)	2. Feed rate	GFRP Composite Graphite/Aluminium Composite Al/SiC-MMC Composite FRP Composite GFR/epoxy Composite GFRP Composite
Less significant	3. Depth of cut	
1. Birhan (2007) 2. Bhatnagar et al. (1995) 3. Sakuma and Seto (1983)	**C) Tool** 1. Tool wear	GFRP Composite FRP Composite GFRP Composite
1. Birhan (2007)	2. Tool radius	GFRP Composite
1. Palanikumar and Karthikeyan (2006)	3. Built up edge	Al/SiC-MMC Composite

*1-*4 sequence of most importance factor influence surface roughness

According to Sonbaty et al (2004), increasing the volume fiber fraction, V_f of GFREC can improve surface roughness but in the same time cutting speed and feed have a vice versa effect. Wang and Zhang (2003) investigated unidirectional FRP composite and the result shown surface roughness is greatly influenced by the fiber orientation. In the mean time, Takeyama and Lijima (1988) had examined the surface roughness on machining of GFRP composites and found out that the higher the cutting speed, the rougher and the more damaged the machined surface is. Ramulu et al (1994) also achieved better surface roughness at high velocity whereas Birhan (2007) discovered that surface roughness will decrease of increase of cutting speed and increased with increase of feed rate. He also discovered that the surface roughness decreased with the increase of tool nose radius. In addition, Spur and Wunsch (1988) realized that during turning of GFRP composites, surface roughness increased with the increase of feed rate but it is not depends on cutting velocity.

A good surface finish is required for improving the physical properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. It is vital to find out the factors that will influence surface roughness. From the literature survey that has been carried out, the major factors influencing surface roughness during turning of composites are feed rate, fiber orientation, hand layup technique and tool wear. The feed rate is the cutting parameter that has the highest influence on surface roughness. An increase in feed rate will increase the heat generation and hence, tool wears which results in higher surface roughness. Tool wear will decrease the cutting tool life and subsequently increase the cost of machining of the turned parts. In the mean time surface roughness will fluctuate for different angle of fiber orientation. The higher the orientation angle, the rougher the surface finish will be generated whereas for the manufacturing technique, hand layup process is proven to be producing better surface roughness than the filament winding process in machining of composites.

5.0 INFLUENCE FACTORS CONTRIBUTING TO THE VIBRATION AND NOISE

Vibration and chatter is one of the most important problems which arise in machining operations and is almost impossible to be avoided during machining operations. The presence of vibration can increase surface roughness of finished parts or components increase the cutting tool wear and produce unacceptable noise.

Referring to Khraisheh (1995), vibration in machining can be classified in two types which are forced vibration and self excited vibration. Force vibration is caused by cyclic variation in the cutting force while self excited vibration is caused by relative movement of the tool with work pieces. Vibration in turning process is self-generated and it is produced from the friction caused by the spindle rotation with work piece as well as from tool work piece relative motion. The usual cause of vibration during machining is the dynamic interaction between the cutting process and the machine tool structure which the source come from the variation of cutting force generated between the tool and work piece. This force strains the structure elastically and causes a deflection of the tool and work piece, which alters the tool-work engagement. A disturbance in the cutting process, such as a hard spot in the work material, causes a typical deflection which then alters the cutting force. This may then cause the initial vibration to be self-sustaining and to build up with the machine oscillating in one of its natural modes of vibration. Therefore, it is essential in the early stage of this research to investigate what factor influences the vibration and noise in turning of composites.

Sandvick Coromont (2005) suggest ones to choose a smaller nose radius less than the depth of cut and increase the feed to avoid the vibration from happening. The schematic diagram in Figure 5.1 represents the tool nose radius and depths of cut.

Rn: Nose Radius
Dc: Depth of Cut
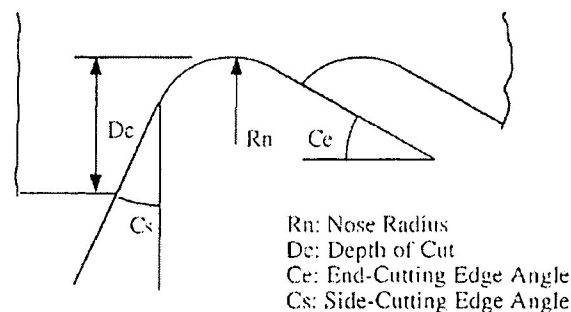Ce: End-Cutting Edge Angle
Cs: Side-Cutting Edge Angle

Figure 5.1 : Schematic diagram of tool nose radius by Lin and Chang, (1998)