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Preface

Recently, the application of composite materials has increased in various areas of science and technology due to their special properties, namely for their use in aircraft, automotive, defense and aerospace industries as well as other advanced industries. Machining composite materials is a rather complex task owing to their heterogenity, and the fact that reinforcements are extremely abrasive. In modern engineering, high demands are being placed on components made of composites in relation to their dimensional precision as well as to their surface quality. As a result of potential applications, there is a great need to understand the questions associated with the machining of composite materials.

This book aims to provide the fundamentals and the recent advances in the machining of composite materials (polymers, metals and ceramics) for modern manufacturing engineering.

Chapter 1 provides the mechanisms and modeling of machining polymer matrix composites reinforced by long fibers. Chapter 2 contains machinability aspects of polymer matrix composites. Chapter 3 covers drilling technology. Chapter 4 contains information on abrasive water jet machining of composites. Chapter 5 then focuses on the machining of metal matrix composites. Finally, Chapter 6 is dedicated to the machining of ceramic matrix composites.

This book can be used as a textbook for students in their final year of an undergraduate engineering course or those studying the subject of the machining of composite materials at the postgraduate level. This book can also serve as a useful reference for academics, manufacturing and materials researchers, manufacturing and mechanical engineers, as well as professionals in composite manufacturing and related industries. The scientific interest in this book is evident for many important centers of research, laboratories and universities in the world. Therefore, it is hoped that this book will encourage and enthuse others researching in this field of science and technology.

I would like to thank to ISTE-Wiley for this opportunity and for their professional support. Finally, I would like to thank all the authors of the chapters for their availability to work on this book.

J. Paulo Davim
University of Aveiro, Portugal
October 2009

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Chapter 1

Mechanics and Modeling of Machining Polymer Matrix Composites Reinforced by Long Fibers

1.1. Introduction

Polymer matrix composites reinforced by long fibers (PMCRLF) are an important class of materials in advanced structural applications due to their lightweight, highly modulus and highly specific strength. However, because of their anisotropic and heterogenous nature, these materials are difficult to machine. Machined composite surfaces often contain damage such as delamination, cracks and fiber dislodgements [DAV 03, RAM 97, WAN 03].

To improve the surface integrity of machined surfaces, while maximizing the machinability of PMCRLF, significant investigations have been carried out to understand the mechanics of cutting, the effect of fiber orientation and PMCRLF fabrication conditions on the quality of machined surfaces using various machining processes such as orthogonal cutting [WAN 03], drilling [ZHA 01*a*] and grinding [HU 03, HU 04].

Chapter written by Liangchi ZHANG.

In terms of the study methodology, the investigations can generally be divided into three categories, experimental study focusing on the macro/microscopic behavior of PMCRLF [WAN 03], mechanics modeling [ZHA 01*b*] and numerical simulation that treats the PMCRLF as macroscopically anisotropic materials or focuses on the fiber-matrix interactions microscopically [MAH 01*a*, MAH 01*b*].

This chapter will discuss some advances in the investigations on the machining of PMCRLF in relation to orthogonal cutting and drilling.

1.2. Orthogonal cutting

Two commercial resin systems, the F593 and MTM56 prepregs, were used in the experiment. To investigate the effect of cutting conditions on machinability, the F593 prepregs were used to make unidirectional 4 mm-thick carbon/epoxy panels, cured under the pressure of 0.6 MPa at a temperature of 177°C for 2 hours. These panels, with the dimensions of 300 mm × 500 mm, were then cut into specimens with dimensions of 15 mm × 45 mm with desired fiber orientations for the cutting experiment.

The fiber orientation θ is defined clockwise with respect to the cutting direction, as shown in Figure 1.1. The cutting tools used were made from tungsten carbide with a clearance angle of 7° and rake angles from –20° to 40°. The cutting forces were measured by a three-dimensional (3D) dynamometer, Kistler 9257B. The cutting speed was fixed at 1m/min.

Table 1.1 lists the cutting conditions. To examine the effect of the ratio of depths of cut to the fiber diameter, the machinability at small depths of cut was also investigated.

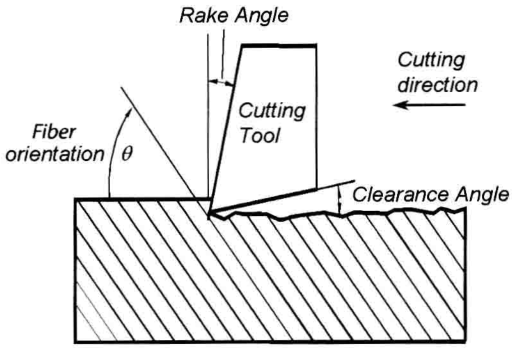


Figure 1.1. *A schematic of the orthogonal cutting of a PMCRLF specimen with unidirectional fibers orientated between 0° and 90°*

Fiber orientation (°)	0, 30, 60, 90, 120, 150
Rake angle (°)	–20, 0, 20, 40
Depth of cut (mm)	0.001, 0.050, 0.100

Table 1.1. *Cutting conditions for the F593 specimens*

Cure procedure	Temperature (°C)	Holding time (minute)
T1 (Under cure)	110	0
T2 (Standard cure)	120	10
T3 (Over cure)	120	20

Table 1.2. *Curing conditions for making the MTM56 specimens*

Fiber orientation (°)	0, 30, 60, 90, 120, 150
Rake angle (°)	0
Depth of cut (mm)	0.025, 0.050, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.250
Cure procedure	T1, T2, T3

Table 1.3. *Cutting conditions for the MTM56 specimens*

In studying the influence of curing conditions, only the MTM56 prepregs were used because the F593 prepregs were not available on the market at that experiment stage. Table 1.2 lists the cure procedures under the pressure of 0.62 MPa. The temperature in each cure procedure was increased at 3°C/minute to the specified value, held at this value for the duration listed in Table 1.2 and then cooled down to room temperature.

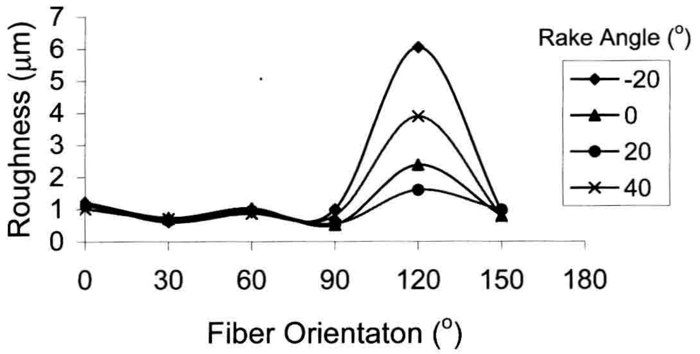
Procedure T2 is a standard cure cycle recommended by the manufacturer of the MTM56 prepregs. Procedure T1 led to under-cured components and Procedure T3 gave rise to over-cured products. Table 1.3 lists the cutting conditions used for the MTM56 specimens.

The surface roughness of a machined surface was measured using a profilometer (Mitutoyo, Surftest 402 Series 178, cut-off = 0.8 mm). The morphology of the machined surface was observed using an optical microscope (Leica LEITZ DMRXE) and a scanning electron microscope (SEM) Philips XL-30.

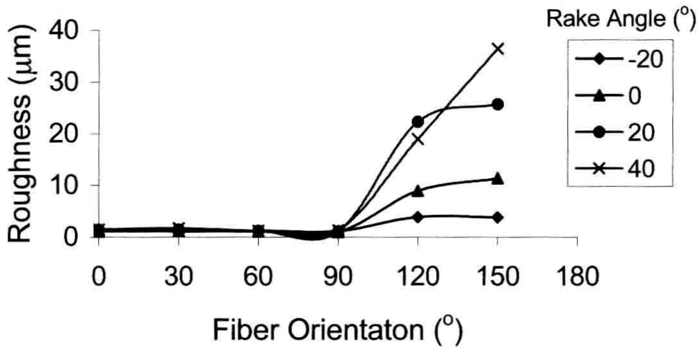
1.2.1. *Surface roughness*

The surface roughness of the machined specimens made from F593 panels is presented in Figure 1.2, which shows the significant effect of the fiber orientation of the composite θ. It is clear that there exists a threshold, $\theta = 90°$, beyond which the surface roughness varies remarkably. At a given depth of cut smaller than the fiber diameter (7 μm – 9 μm), 1 μm for example, the surface roughness increases sharply when $\theta > 90°$ but decreases again when θ reaches 120°.

Before reaching the threshold of 90°, the change of the surface roughness is small, ranging from 0.6 μm to 1.2 μm, and the effects of rake angle and fiber orientation are relatively minor. At the most unfavorable fiber orientation of 120°, the surface roughness shows little dependence on the rake angle γ_0 with the best surface finish at $\gamma_0 = 20°$ and the worst at $\gamma_0 = -20°$.



(a)



(b)

Figure 1.2. *Effect of fiber orientation on surface roughness (F593 specimens). The depths of cut were (a) 0.001 mm and (b) 0.050 mm*

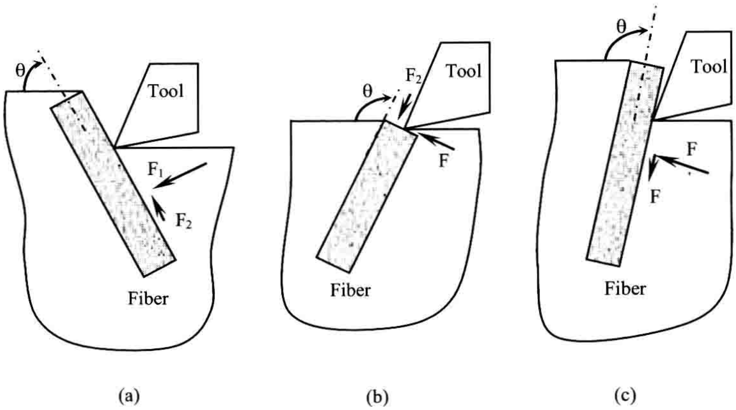


Figure 1.3. *Schematic cutting models*

When the depth of cut becomes larger than the fiber diameter, a different mechanism occurs. For instance, at the depth of cut of 50 μm the surface roughness does not decrease when θ is over 120°, as shown in Figure 1.2(b). The rake angle effect becomes greater and a sharper cutting tool (larger positive γ_0) produces a rougher surface. However, it is still true that θ = 90° is a critical angle, below which the effects of rake angle and fiber orientation are trivial. In this case, the surface roughness is in the range of 1 μm to 1.5 μm and is comparable to that when the depth of cut is smaller than the fiber diameter.

The above phenomenon may be explained by the variation of deformation mechanisms in the cutting zone when the depths of cut and fiber orientation change, as schematically illustrated in Figure 1.3 using a model with a single fiber. When θ is less than 90°, as shown in Figure 1.3(a), regardless of the depth of cut, the fiber is pushed by the tool (force F_1) in the direction perpendicular to the fiber axis and toward the workpiece subsurface. In this case, the fiber is better supported by the material behind and hence the bending of the fiber can be small. Meanwhile, the force component along the fiber axis (F_2) creates a tensile stress to make the fiber easier to break in the neighborhood of the cutting zone. This is because carbon fibers are