Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 46 (2016) 71 – 82
www.elsevier.com/locate/procedia
7th HPC 2016 – CIRP Conference on High Performance Cutting

High Performance Cutting of Fibre Reinforced Plastic Composite Materials

V. Lopresto[a], A. Caggiano[b,c], R. Teti[a,c*]

[a]Dept. of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, P.le Tecchio 80, 80125 Naples Italy
[b]Dept. of Industrial Engineering, University of Naples Federico II, P.le Tecchio 80, 80125 Naples Italy
[c]Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology (Fh-J_LEAPT), Naples, Italy

* Corresponding author. Tel.: +39-081-7682371; fax: +39-081-7682362. *E-mail address:* roberto.teti@unina.it

Abstract

Composite materials are difficult to machine because of the anisotropy and inhomogeneity of their microstructure and the abrasiveness of their reinforcement components. This low machinability can determine surface integrity damage in the machined parts and very rapid wear development in the cutting tool. To date, conventional machining processes, such as turning, drilling or milling, are increasingly required for composite materials parts manufacturing, and can be successfully applied if proper tool design is achieved and adequate machining conditions are selected. This paper presents an outline of the main issues pertaining the machining of fibre reinforced plastic composite materials.

Keywords: Composite materials; Machining; Chip formation; Surface integrity; Tool conditions

1. Introduction

Composite materials are made of two or more diverse materials providing properties that could not be obtained from any one material component alone. One of the materials performs as the matrix and at least one other material as the reinforcement in the composite. The matrix material has the role to protect the reinforcement; distribute the stress to the reinforcement; determine the final shape to the composite part. The reinforcement material(s) have the role to provide high mechanical properties and reinforce the matrix material also in preferential directions.

The properties of a composite material depend on the nature of the reinforcement and the matrix, the form of the reinforcement (particles, short fibres, long fibres) and the relative content of reinforcement and matrix.

Composite materials can be classified on the basis of their matrix material: polymer matrix composites; metal matrix composites; ceramic matrix composites.

This paper focuses on advanced polymer matrix composites reinforced with very resistant, though brittle, fibres impregnated in a soft and ductile polymeric matrix and referred to as fibre reinforced plastic (FRP) composites.

The first input to research on these new materials started in the aeronautical field. Today, FRP composite materials are utilized in a wide range of applications related to the aerospace, naval, sport, construction and medical industry due to well known advantages they can offer. They provide a higher strength to weight ratio and modulus to weight ratio when compared to metals and alloys and offer extraordinary opportunities for design.

With the increasing numbers and types of applications, the availability of production technologies that are economically sustainable becomes a vital issue to achieve fully automated large scale manufacturing cycles. However, one of the main problems concerning FRP composite materials parts manufacturing is their low machinability with conventional tools, a drawback which is not yet overcome.

The very fact that FRP composite materials are by definition inhomogeneous and anisotropic makes their machining processes difficult to realize and leads to extensive material damage generation, impairing product quality and dimensional accuracy and resulting in high scrap rate.

doi:10.1016/j.procir.2016.05.079

2. Basic studies on FRP composite materials machining

The phenomena underlining material removal mechanisms for composite materials are totally different from those characteristic of the machining of metals and alloys and the literature on composite materials machining is rather limited in comparison with what is available on metals machining.

Although non-traditional machining processes are available and can solve some of the problems related to composite materials machining, conventional machining processes are largely preferred for reasons of cost and time. However, deep studies on machining process optimisation are still required in order to achieve adequate cutting quality results.

In [1], it is stated that the first step to achieve this goal is the study of cutting forces under simple operating conditions. In [2] and [3] the cutting forces and the mechanism of chip formation in trimming Carbon Fibre Reinforced Plastics (CFRP) composites are shown to be fundamentally different from the machining of metals and highly dependent on reinforcing fibre orientation. The latter parameter is worth particular attention since it is mainly on it that the mechanisms responsible for composite materials removal depend.

In [4-6], orthogonal cutting of unidirectional (UD) and multidirectional (MD) CFRP composites with PVD coated tools for different reinforcing fibre orientations is studied. The authors analysed cutting forces, chip formation and machined surface topography. All the mechanisms of material removal were found to be primarily dependent on the fibre orientation, whereas the tool geometry and the operating conditions had only secondary effects. A different shape of the chip was verified by changing the fibre orientation angle and the presence of diverse mechanisms in edge trimming of FRP was observed. However, a clear correlation among the different aspects of the cutting process was limited to fibre orientations up to 90° and the presence of a characteristic defect, named "burrs", that worsens the cut surface quality was noted starting from fibre orientation angle equal to 60°.

In [7] the cutting forces were correlated to the mechanisms of chip formation in orthogonal machining of UD CFRP composites. The analysis was limited to the cutting parallel to the fibres and the cutting speed was kept very low (v =10 mm/min). In [8], studies on orthogonal cutting at low cutting speed too are presented. The authors also found a strong influence of the fibre orientation.

In [9], a testing campaign of high speed orthogonal cutting of discs made of CFRP was carried out. The particular shape of the work material specimens allowed to record the cutting force data by continuously varying the fibre orientation angle in the range 0°-180°. However, the shortcoming of incomplete cutting of the specimens in the width direction for a fibre orientation angle up to 30° prevented a correct analysis of the forces for these studies that were limited to the influence of depth of cut and cutting speed. In addition, the work provided no significant information on chip formation mechanism and cut surface quality.

In [10], the effect of fibre orientation on cut quality and surface damage was evaluated. The surface roughness of UD and MD CFRP composite machined surfaces was measured and statistically analysed. The experimental tests were limited only to some selected values of fibre orientation below 90° and the correlation between the cutting mechanism and the values of the cutting forces during processing was neglected.

In [11], a model of chip formation in cutting operations on FRP composites normal to the fibre direction was performed, providing valuable information on cutting mechanisms only with reference to this orientation.

In [12], the chip formation mechanisms, the cutting forces, the subsurface damage, and the influence of process parameters variation were analysed. Also in this work, the cutting speed was very low and the chip was found to be typically discontinuous.

A study on milling of CFRP composites at very high cutting speed (up to 200 m/min) was carried out by [13] on rectangular specimens by considering only some fibre orientation angles.

The difficulty in achieving a satisfactory cut quality has been evidenced by many authors [13-15]. Some researchers have analyzed the mechanisms of chip formation in orthogonal cutting of composites laminates [5, 7, 11, 16] showing that a significant number of parameters, like tool material, tool geometry, depth of cut and fibre orientation, play a fundamental rule in composite materials machining.

To obtain a satisfactory cut surface quality, it is necessary to analyze diverse operating conditions in order to select the most adequate for machining process optimization. For this reason, an experimental campaign was carried out by [7, 9, 14-16] with the aim to generate detailed data for the understanding of the nature of the formed chip and the influence of some particular parameters, such as the interaction with the tool flank, on the cutting mechanism and the cut surface quality.

During the cutting tests performed on a milling machine at low cutting speed in order to avoid significant thermal effects, the fibre orientation with respect to the cutting direction, the tool rake angle and the depth of cut were varied. Moreover, a limited number of tests were carried out at higher cutting speed. The cutting forces were detected and considered in relation to the mechanism of chip formation as well as the interaction between work material and cutting tool.

The mechanisms of chip formation and the cut surface quality, in terms of induced material damage and average surface roughness, were investigated. Whenever possible, a correlation between the mechanisms of chip formation and the cutting force values was searched for and obtained, and the trend of the cutting forces was attentively analysed.

In general, the mechanisms of chip formation are based on different composite materials failure modes occurring simultaneously. This renders their identification difficult on the basis of the cutting force evolution. Only in special cases, the cutting force features allow for a precise identification of the chip formation and detachment.

The experimental results showed that the fibre orientation with respect to the cutting direction, rather than the tool rake angle, determines the mechanism of chip formation and strongly influences the cut surface quality. For fibre orientations higher than 60°, the quality of the cut surface was deemed fully unacceptable.