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High Speed Cutting of carbon fibre reinforced plastics

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Abstract

The effects of high speed cutting (HSC) on metallic workpiece materials have been widely studied and the benefits are commonly employed in the machining industry. However, in the machining of composite materials, these effects have not yet been a focus of significant research work and core questions such as what impact HSC cutting parameters have on tool wear, process forces and workpiece quality remain open. As such, the work described in this paper shall focus on the use of HSC cutting parameters with spindle speeds up to 60000 rpm for the machining of carbon fibre reinforced composites. Workpiece quality and tool wear are quantified in dependence of cutting speed and feed rate and the known phenomena of reduced cutting forces at high cutting speeds are examined in the case of CFRP machining.

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Keywords: High Speed Cutting; CFRP; Milling; Chip formation; Tungsten Carbide; CVD-Diamond Coating

1. Introduction

Sustainable manufacturing from an environmental, economical and social point of view is key for the continued growth of the automotive and aeronautical industries. Cars and airplanes of the future must be quieter, lighter and more efficient. One way of achieving this is the use of innovative composite materials such as carbon or glas fibre reinforced composites (CFRP, GFRP), which are significantly lighter whilst exhibiting comparable or higher strength and wear resistance. CFRPs have been used in the manufacturing of airplanes for a number of decades, however their further development in recent years, for example in relation to the strength of the carbon fibres, plays

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a significant role for their increased use [1]. As such, large proportions of airplane structural components are now made of composite materials, for example the Airbus model A400M (Figure 1). In the automotive industry the use of CFRPs and GFRPs is relatively recent in series production, and is expected to increase dramatically in the coming years.

With few exceptions, CFRP/GFRP components are not produced as near-net shape, meaning machining is almost always required. Commonly this is done using milling, drilling and water jet cutting. Due to the continuous development of cutting tools, machining centres, robot-based machining and control systems, a significant productivity increase is expected, and also required in order to allow series production of CFRP components. In particular, the processing times and part qualities must be improved upon to achieve an economically viable production process of these parts.

Fig. 1. Airbus A400M - The wings (over 20 m long and 4 m wide) consist mainly of CFRP

In recent years research work has focused on the mechanisms of material removal in the machining of CFRPs using conventional machining parameters, with few studies on the use of high cutting speeds and feed rates [1, 2, 3, 4, 5]. Of course, the machinability of fibre reinforced composites depend on the selected materials of the matrix and the reinforcement, the cohesion between the two, the orientation of the fibres in the matrix, the volume fraction of fibres and matrix and the ratio of fibre length to fibre diameter [6]. A number of authors [1, 5, 7, 8, 9, 10] show that when milling fibre reinforced plastics, the type and orientation of the fibre, cutting parameters, and tool geometry have an essential influence on the machinability. When speaking about fibre orientation, it must be differentiated between the fibre orientation and the fibre orientation with respect to the cutting direction $\theta = 0°, 45°, 90°, 135°$ [7, 10, 11]. Everstine and Rogers [12] presented the first theoretical work on the machining of FRPs in 1971, since then the research carried out in this area has been based on experimental investigations. Hashin and Rotem [13], Koplev et al. [14] and Kaneeda [15] established that the principal cutting mechanisms are strongly related to fibre arrangement and tool geometry. Colligan and Ramulu [16, 17] carried out studies on machining of polymeric composites and concluded that an increasing of the cutting speed leads to a better surface finish.

Depending on the fibre orientation with respect to the cutting direction, different fundamental failure modes commonly occur in composite machining: fiber-tensile failure, fiber-compression failure, matrix-tensile failure and matrix-compression failure [7, 11, 13, 18, 19, 20, 21].

These fundamental failure modes usually occur in combination with one another and determine the chip formation modes in CFRP machining, with fibre buckling, fibre cutting, fibre delamination, fibre deformation, shearing and macrofacture being the main modes of chip formation [7, 10, 20]. Figure 2 shows the fundamental correlations between rake angle and chip formation modes with fibre orientations $\theta = 0°$ and $90°$. The different chip formation mechanisms strongly influence the tool loading situation, thus defining the tool wear and lifetime as well as the machined part quality.

Teti et al. [10] showed that at fibre orientations between $\theta = 0°$ and $30°$ it is possible to achieve high part qualities, as the cutting forces are low. With rising fibre orientations, for example between $\theta = 90°$ and $135°$,