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Low frequency oscillated milling of carbon fiber-reinforced plastics

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Abstract

Components made of carbon fiber-reinforced plastics (CFRP) are usually manufactured by near net shape processes. Nevertheless, post processing is necessary and milling is a common technology. In this study, the feasibility of an oscillated milling with a maximum frequency of less than 30 Hz for chipping unidirectional CFRP with a thickness of 1.5 mm was investigated. The influence of the tool and the fiber orientation on delamination, chip formation and surface quality were studied. It was found that the tool and the fiber orientation angle have a significant influence on delamination. The additional movement could be advantageously for reducing delamination.

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Keywords: oscillated milling; CFRP; lightweight design; fiber-reinforced plastics; chipping, tool oscillation

1. Introduction and State of the Art

The use and the development of constructive and material lightweight principles are essential in order to achieve the ambitious targets for the reduction of resource consumption in various industries. The current development, especially by the increasing demands in transport applications, shows the importance of fiber-reinforced plastics. Components made of carbon fiber-reinforced plastics are usually manufactured by near net shape processes. Nevertheless, post processing is necessary for functionalization, and milling is considered as a common technology [1][15].

The machining of fiber-reinforced plastics, especially endless carbon fiber-reinforced plastics, is particularly a challenge for machining technology due to the tendency for defects. These defects occur at each of the outer layers, the so-called delamination. In many applications, the prevention of such defects is essential for the functionality of the entire assembly. Primarily, the mechanical properties of the composite and the resistance of the fibers are irreversibly weakened [1][2].

Therefore, the primary aim is to develop a defect-free machining process of fiber-reinforced plastics. Especially, for processing of brittle-hard materials, vibration-assisted strategies are proved to be advantageous in past. The main advantages compared to conventional machining are extended endurance [3][4], improved surface finishes [5] and the machining of hard-to-cut materials [3][6][8]. In general, vibration-assisted machining is subdivided into ultrasonic-assisted machining and low-frequency oscillated machining. By using the ultrasonic machining for drilling CFRP or CFRP-joints, several investigations show that both force and torque can be reduced. In addition, the rate of material removal can be increased. At the same time chip removal from the hole and the borehole accuracy can be improved, as well as the tool wear and the delamination can be reduced [8][9][10][11][12].

Pecat and Brinksmeier [13] studied the low frequency vibration-assisted drilling of CFRP-Titanium joints. The tool wear and process temperature could be reduced, whereas the feed forces increased. In addition, a chip remove motion was not necessary, due to the oscillating tool movement [13]. Zemann et al. examined the low-frequency superimposed

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processing of CFRP plates, both during drilling and milling. It was found that tool oscillation reduces the delamination of the workpieces compared to conventional machining [14].

In particular, the tool geometry shows a significant influence on workpiece quality by CFRP processing. An approach to design a new drilling tool is given in [16]. The authors equipped a tool from a combination of a "dagger" and multi-faceted geometry with an additional saw-tooth geometry. This saw-tooth geometry allows to cut the remaining material at the bore outlet, in opposite direction to the feed motion. Their presented result was a nearly delamination-free drilling. [16]. This saw-tooth geometry is also used for current special CFRP-milling tools.

Due to the near net shape processing, unstable workpieces are machined. In [15] the influence of workpiece clamping systems were investigated. For this purpose two different clamping devices were developed which enable a stable and an unstable fixture. As the distance between the clamping jaws increases, the process force in the tool axis direction increases as well. However, forces in the feeding plane remain unchanged and are not influenced by the clamping system. If a critical length between the clamping jaws is exceeded, the milling process becomes unstable and the workpiece may fail. Until failure, workpiece damage due to increased forces in the tool axis direction could not be determined [15].

Based on these researches, it can be assumed that the oscillated milling can be an effective method for improving the workpiece quality. This paper investigates the low-frequency tool movement on unidirectional CFRP plates as a function of the fiber orientation and different tools. Further, the influence of the surface quality and phenomenological effects will be evaluated.

2. Experimental Setup

The experimental investigations were carried out with a 5-axis simultaneous milling machine (Spinner U-620P), but the working configuration was in 3-axis. The oscillation was generated in main spindle direction by using the z-axis movement. There are no special tools for oscillated milling available. Therefore four types of milling tools were selected. Three different diamond coated solid carbide tools and one PCD tool, each with a diameter of 6 mm were applied. These tools are also used for conventional and oscillated supported machining. The four tools (Table 1) were selected from three of each group in preliminary tests in terms of the achievable surface quality. A CERATIZIT WD451-L end mill and a WD828-L router from the same manufacturer were selected. Two MAPAL slot drills were chosen. One was a special CFRP-slot drill (SCM450) and the other one was a PCD-tool (SHM51).

Table 1. Used milling tools

	Milling tools	Number of tool cutting edges	Helix angle
1	End mill	4	+ 35° / + 38°
2	Router	(8)	25° compacting cut
3	CFRP-slot drill	8	0°
4	PCD-slot drill	2	0°

All tools are suggested for channel milling and trimming, whereby a cut through channel milling was used. The cutting speed and the feed rate per tooth were selected in the range of the manufacturers' guidelines and were validated by preliminary tests to the surface quality. For the main test, they were kept constant with v_c = 190 m/min and f_z = 0.04 mm, in order to be able to compare the cutting conditions and to understand the phenomena at the tool-component interface.

The used base material in these investigations was a unidirectional carbon fiber-reinforced plastic based on an epoxy matrix. The material was cut out into 0°, 45°, 90°, 135° workpieces with a length of 150.0 mm, a width of 50.0 mm and a thickness of 1.5 mm. The fiber volume content was 62 % ± 3 %. Three samples were tested for each configuration.

Due to the interpolation of the CNC-controller a decoupling of the feed rate and the oscillating movement was necessary in order to achieve an unaffected result. Figure 1a shows the schema of the independent tool movement. The oscillating motion was generated by the spindle axis. In order to facilitate the feed rate a linear actuator was installed. The actuator allows to change and fix several clamping systems. Before the investigations were carried out, preliminary tests were made to evaluate the linear actuator as against a conventional vice clamping.

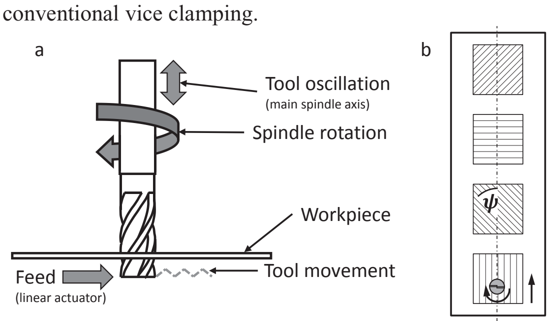

Fig. 1. (a) Schema of tool movement; (b) fiber orientation angle - ψ.

Figure 2 shows the used clamping systems. These allowed a “stable” (a) and “unstable” (b) fixture. Based on [15], the influence of the milling process as a function of the clamping was investigated. In addition, the unstable clamping system resulted in an uncovered milling area which allowed process monitoring by using a high-speed video camera.

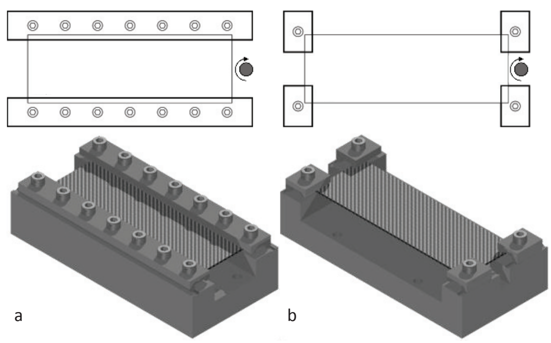

Fig. 2. (a) Stable clamping system; (b) Unstable clamping system.