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Conventional Orthogonal Cutting Machining On Unidirectional Fibre Reinforced Plastics

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Abstract

The results of orthogonal cutting tests on unidirectional carbon and glass fibre reinforced plastics are presented. The specimens were under shape of rectangular plates, circular disks and cylinders with different fibre architectures and a milling machine, a lathe machine and a five-axis high-speed vertical machining centre, were used for the experimental tests. The cutting speed was varied. During the tests, performed at low cutting speed, avoiding thermal effects, and high speed, to investigate about the effect of the cutting velocity on the cut quality, the fibre orientation respect to the cutting direction, the tool rake angle and the depth of cut were varied to investigate their influence on the phenomenon. A high speed steel tool in different geometries, was used.

The mechanisms of chip formation and the cutting quality were investigated. A tentative to correlate the mechanisms of chip formation and cutting forces signals was done. Since the anisotropy, the mechanisms of chip formation consists of different failure modes occurring simultaneously and their identification, on the basis of the cutting force evolution, is very complex. Only in particular conditions, the features of cutting forces allow a precise identification of the chip development and detachment.

The results indicated that the fibre orientation respect to the cutting direction determines the mechanisms of chip formation and influences the cutting quality. It was noted that for fibre orientation higher than 60°, the quality of the surface was revealed unacceptable. These conclusions were obtained independently of the particular shape of specimen tested and of the speed adopted.

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Keywords: Orthogonal cutting; machining; composite laminates; cutting speed; fibre orientation.

1. Introduction

Composite materials present a higher strength to weight and modulus to weight ratio when compared to metals and offer new opportunities for design. They are utilized in a lot of applications in fields like aerospace, naval, sport, civil and medical since their good mechanical properties. The homogeneity and anisotropy make the machinability with conventional tools difficult to realize and lead to extensive damages, impairing quality and dimensional tolerances, or resulting in part rejection. The mechanisms of cutting processes are completely different from metal machining.

Traditional processes are preferred respect to the non-traditional ones, for reasons of cost and time, but deep studies to the optimization of the machining must be designed to improve the cut quality.

What already done on the topic [1-13], highlighted the importance of the forces and the mechanism of chip formation in trimming Carbon Fibre Reinforced Plastics (CFRP) highly dependent on the fibre orientation: all the mechanisms of material removal were found to be primarily dependent on the fibre orientation whereas the tool geometry and the operating conditions have only a secondary effect.

The difficulty to achieve a satisfying cut quality has been evidenced [1]: some researchers [2-5] have analyzed the mechanisms of chip formation in orthogonal cutting of composites laminates showing that a lot of parameters, like tools material and tool rake and relief angle, depth of cut and fibre orientation, play an important rule in the machining. To

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obtain a better quality, it is important to analyze various operating conditions to select the most adequate ones to the process optimization.

For this reason, a large experimental campaign was carried out at the aim to generate data for the understanding the phenomenon and to investigate the influence of cutting parameters on the cutting mechanism and on the cut quality of composites unidirectional laminates.

During the tests performed on a milling machine at low cutting speed, avoiding thermal effects, the fibre orientation respect to the cutting direction, the tool rake angle and the depth of cut were varied. A number of tests were carried out at higher cutting speed. The cutting forces were considered related to the mechanism of chip formation as well as to the interaction between material and tool.

The mechanisms of chip formation and the cutting quality were investigated. When it was possible, a correlation between the mechanisms of chip formation and cutting forces signals was evidenced. The cutting forces trend was analyzed too.

The results showed that the fibre orientation with respect to the cutting direction, rather than the tool rake angle, determines the mechanisms of chip formation and influences the cutting quality: for fibre orientation higher than 60° the quality of the surface was unacceptable.

High orthogonal cutting speed tests were carried out on unidirectional GFRP cylinders and disks in order to evaluate the influence of the velocity. The low cutting speed, in fact, is not a good solution since adversely affects productivity. The circular shape of the disks allows changing continuously the fibre orientation with respect to the cutting direction during a single test, so that its influence on the development of cutting forces is observed. The latter tests confirmed what obtained at low velocity denoting an independency of the machining by the speed.

2. Materials and experimental methods

Orthogonal cutting tests were carried out on rectangular specimens, 100 mm in length, 3.15 mm in width and 40 mm in depth, cut from pultruded bars made of unidirectional carbon fibre reinforced plastics (CFRP) in an Atlac 580/05 vynilester resin, charged with 17% by weight CaCO3 particles. The final fibre volume fraction of $V_f = 30\%$ was obtained.

During the tests, the workpiece and the tool (made of High Speed Steel (HSS) 10 mm in width) were fixed to the table and the stationary overarm of a milling machine, respectively. The relative tool-material motion was accomplished by the table feed. A particularly low cutting speed (10 mm/min) was first adopted, to avoid thermal effects and allow an easy examination of the tool-material interaction mechanisms. At the aim to verify the effect of the velocity, a number of tests were carried out on the same flat rectangular specimens and in the same conditions at higher speed, v = 460 mm/min and v = 2200 mm/min.

In addition, glass composite cylinders were then fabricated by overlapping 0°/90° pre-preg layers Mxb-7701, 0.25 mm in thickness and 350 g/m^2, by vacuum bag technique. The layers were differently oriented to obtain four different fibre orientations: 0°/90°, 30°/120°, 45°/135° e 60/150°. The final thickness was 5 mm and the fibre volume fraction, V_f, 47%. The tests at high cutting speed were carried out on a lathe machine. HSS tools with five different geometries were adopted in order to verify their effect on the cutting forces. The cutting velocities of about 18 m/min, 35 m/min and 44 m/min, were tested. During the tests, the workpiece and the tool were fixed to the spindle and to the stationary overarm kistler of the machine, respectively. The relative tool-material motion was accomplished by the spindle (Fig. 1).

Fig. 1: Cutting apparatus

Moreover, panels of UD-GFRP, 410 x 410 x 3.8 mm^3, were produced by infusion process by overlapping 20 layers of unidirectional glass fibre, 300 g/m^2, in epoxy resin. The average fibre volume fraction is about 60%. From these panels, circular specimens, 200 mm in diameter, were cut. On both the side surfaces of some specimens, two plates in polycarbonate (1 mm thick) are glued by a 0.5 mm thick layer of Araldite 2021 structural adhesive in order to avoid the formation of a damage explained hereafter and called burrs.

The cutting tests were carried out on a five-axis high-speed vertical machining centre using tools made of High Speed Steel and the circular shape allowed to investigate all the fibre orientations in the range 0°-360° in a single machining.

Fig. 2 shows a cutting test (a) and a schematization (b), in which the cutting angles (clearance angle α and rake angle γ), the cutting speed (v_c), the fibre orientation angle, θ, and the principal cutting and thrust forces (F_p and F_t) are videnced.

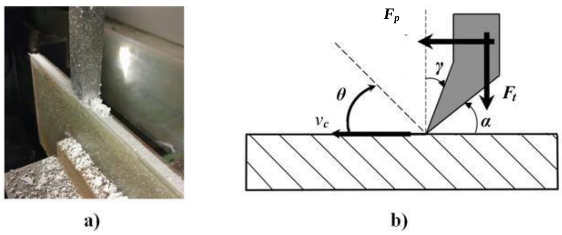

Fig. 2: a) Orthogonal Cutting apparatus; b) Scheme of the machining.

On the disks, a single radial notch is realized to detect the fibre orientation, θ, during the machining: the notch causes a sudden decrease in the forces value, evidencing a reference point to identify θ in the force signals.

An high speed camera, Olympus i-SPEED 3 with a maximum resolution 1280x1024 and an acquisition velocity of 150.000 fps, was used to record the machining and to investigate the mechanisms of the chip formation as well as to correlate them to the cutting force trend.