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Influence of specimen preparation by machining on the failure of polymer matrix off-axis tensile coupons

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Abstract

Milling is a usual operation to obtain composite coupons for mechanical tests. However, the machining of composite materials using cutting tools leads to high temperatures and machined surface damage that will tend to reduce their mechanical performances. This study presents an investigation of the influence of cutting parameters on the damage level and mechanical response of off-axis glass/epoxy unidirectional coupons machined by side milling. The analysis of cut surface roughness and micrographic observations reveals the primary importance of the relative orientation of the fibres with respect to the cutting direction. An analysis based on design of experiments underlines the influence of the cutting parameters and cutting edge geometry on the ultimate tensile stresses of the off-axis coupons. The results show the importance of the cutting configuration and fibre orientation on the mechanical performances. Two parameters have been defined to quantify the cut surface damages and relate it to the decrease of failure stress. A thorough statistical analysis is also included to separate significant from non-significant results in this study.

Keywords: A. Glass fibres; A. Layered structures; B. Matrix cracking; B. Mechanical properties

1. Introduction

Machining is a very common procedure to prepare polymer matrix composite test coupons. Indeed, it is recommended by most of the standard test procedures, as is documented below. However, cutting the surfaces of the coupons results in local damage caused by the action of the cutting edges. As a consequence, this damage may influence the response of the test specimen and therefore lead to underestimated design allowables. This is a very well identified problem but, surprisingly, not very well documented in the literature.

Most of the studies on polymer matrix composites machining deal with the application of the machinability evaluation procedures developed for metals to define suitable machining parameters [1–4]. Macroscopic criteria are used and the optimisation of the tool performance is often the objective. One of the main results is that the recommended tool materials are poly-crystalline diamond (PCD) or at least cemented tungsten carbide (CW).

Some other contributions take a closer look at the damage created on the cut surfaces [5–8]. By using criteria such as surface roughness and cutting forces, machining conditions can be optimized to a certain extent. However, it is now recognized by a majority of contributors to this subject that usual surface roughness parameters (such as Ra) measured using mechanical probing cannot be used for refined machining damage evaluation [2,8,9].

One-step further is to try to investigate the chip formation mechanisms as a function of the microstructure [8,10,11]. At this scale of observation, the heterogeneity of the composite cannot be ignored. According these authors, the fibre orientation is the principal factor of influence on the formation of the chip. Their conclusions make it possible to differentiate several chip formation modes which

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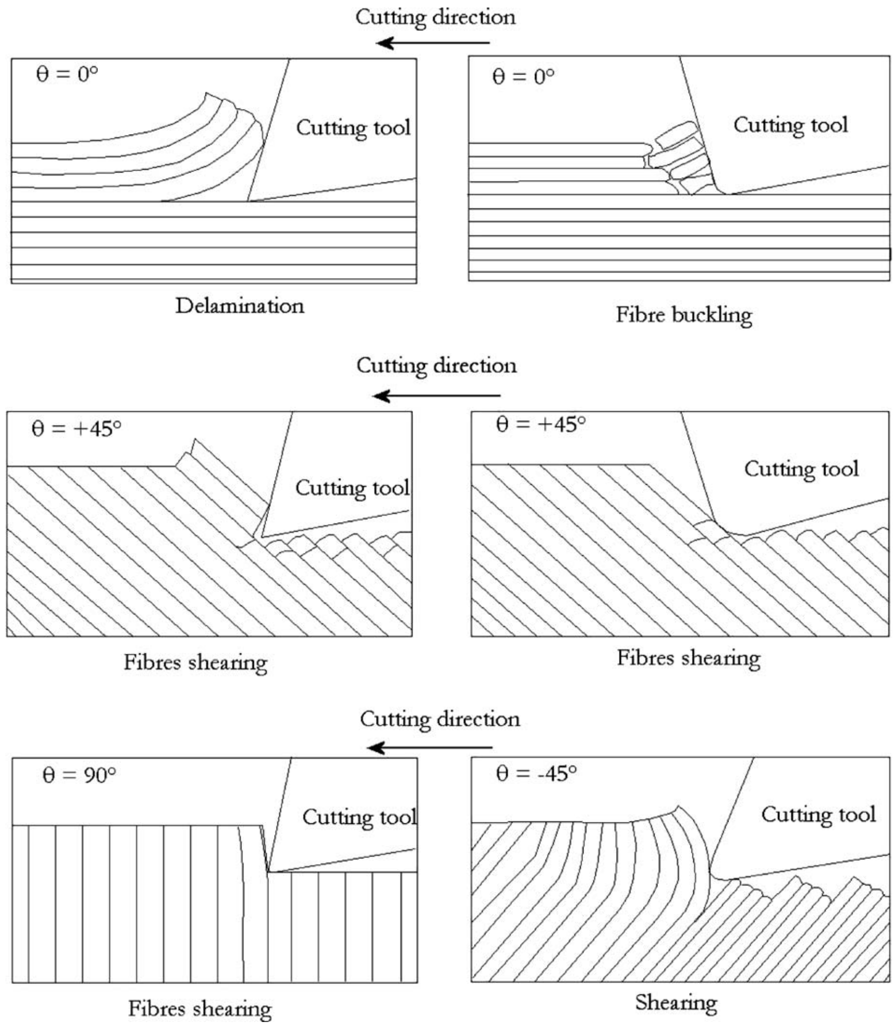

Fig. 1. Mechanisms of chip formation in UD composites [8].

are schematized in Fig. 1, with primary (initiation) and secondary (chip separation) chip formation mechanisms:

- for 0° fibre orientation and positive cutting angles, primary chip formation is a mode I opening with failure along the fibre/matrix interface. The separation of the chip (secondary process) occurs after bending failure of the fibres;
- for positive fibre orientations up to +75°, the mechanism of chip formation consists of a shearing of the fibres by the cutting edge (primary). The chip is then formed by shearing of the fibre/matrix interface (secondary);
- for 90° fibre orientation as well as for the negative orientations, the chip formation is initiated by an opening in mode I which penetrates in the composite workpiece (below the cut surface) along the fibre/matrix interface, followed by fibre shearing and eventually chip separation by fibre/matrix interface failure.

If this is now a well-understood process, numerical simulation of composites cutting is still at the very beginning. A couple of studies based on finite element analyses of the cutting process have been published [12–14]. If these predict the cutting forces reasonably successfully, they all rely on homogeneous equivalent material approaches that struggle to predict the chip formation mechanisms, even though anisotropic failure criteria are used. It is clear that more efforts should be put in this area of research to help understand and quantify the cutting damage.

The studies investigating the impact of machining-induced damage on the mechanical performances of test coupons are very seldom and most of them concern drilling since this operation is the most widely used on composite components. A detailed analysis of the literature on this particular point is available in [9], based on the following references [2,6,15–19]. The main conclusion of this state of the art review is that there is a close interaction between the type and location of cutting damage and the mechanical test performed. For a given mechanical test, one type of damage will influence the response of the specimen but another will not. Moreover, most of these studies try to establish this effect by an empirical approach but very little has been done to try to quantify the damage and predict its effect on mechanical performance. This is certainly because