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Surface profile topography of trimmed and drilled carbon/epoxy composite

Xavier Rimpault[a]*, Jean-François Chatelain[b], Jolanta E. Klemberg-Sapieha[c], Marek Balazinski[a]

[a]*Department of Mechanical Engineering, Polytechnique Montréal, Montréal, QC H3T 1J4, Canada*
[b]*Department of Mechanical Engineering, École de Technologie Supérieure, Montréal, QC H3C 1K3, Canada*
[c]*Department of Engineering Physics, Polytechnique Montréal, Montréal, QC H3T 1J4, Canada*

* Corresponding author. Tel.: +1-514-627-8794; fax: +1-514-340-5170. *E-mail address:* xavier.rimpault@polymtl.ca

Abstract

The surface finish of Fiber Reinforced Plastic (FRP) laminate is challenging to characterize, due to the heterogeneous structure of the composite. Profile roughness parameters are highly impacted by the different layer properties, and their distributions are relatively spread out. In this paper, the surface topography of a 24-ply quasi-isotropic Carbon FRP (CFRP) is observed through primary profiles and the roughness parameter Ra in the transverse direction on trimmed and drilled CFRP surfaces. The surface characterization using the Ra parameter is found inadequate in providing useful information as to the machined surface quality.

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Keywords: Fiber reinforced plastic; Topography; Roughness

1. Introduction

Due to high strength-to-weight ratios of composite materials, they have been increasingly used in the aerospace industry. Composites are produced close to their final shape, but finishing operations are still required, e.g. trimming and drilling. The composite surface topography after such machining operations needs to be investigated for assembly purpose. The laminate composite mechanisms are different depending on the tool-fiber angle due to the different fiber orientations. In consequence, the surface topography is impacted as well [1, 2]. Profile roughness parameters obtained in the ply plane direction of trimmed laminated composite surfaces are highly different depending on e.g. the fiber angle and the tool wear. It was found a radical difference of surface profile behavior of trimmed, 0° and 45° vs the -45° ply orientations [3, 4].

In the transverse direction, the surface topography analysis is more complex. Due to its laminated structure, the composite stacking sequence leads to different stratified surface properties. Each layer surface should be examined separately to perform an accurate roughness profile analysis. But such solution would be time-consuming. Due to a relatively high thickness variation of each ply, an automation procedure of the profile analysis would be extremely complicated to implement. Thus, the surface profile analysis should be carried out using traditional techniques. However, Landon et al. found a very poor reproducibility rate for the roughness parameter Ra from measurements taken at different heights and different angular positions along the hole axis [5]. This is caused by the deep valleys, generated during the machining of -45° plies, in the roughness profile. Surface profile in the transverse direction should be investigated further to identify additional problems and propose a viable surface profile characterization solution. Besides, profiling contact measurement, which is preferred in hole inspection, leads to a slight surface alteration of the composite. Because of this and to reduce the characterizing time of composite surfaces in the industry, the smallest number of measurement repetitions should be reached to achieve a reliable surface characterization.

This study raises the problems of the surface profile characterization of holes in carbon fiber reinforced plastic (CFRP) material. To have a clearer understanding of the challenges involved, the profile characterization of CFRP trimmed surfaces was performed for different tool wear. For both machining processes (trimming and drilling), primary profiles as well as roughness parameters are presented and discussed to highlight the characterization difficulties.

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2. Materials and methodology

2.1. Material and machining setup

For drilling and trimming experiments, the laminated composite was a quasi-isotropic CFRP prepared using 24 pre-impregnated plies. The K2X10 Huron® high-speed machining center was used to perform the machining tests. A dust extraction system was mounted onto the machine for health and safety purposes. A 3/8” diameter end-mill router with six flutes was selected to conduct the trimming experiments and a twist drill for the drilling tests. The tool wear was estimated using images taken with VHC 600+500F Keyence® optical microscope. The maximum tool wear was evaluated based on images taken at the tool edge clearance faces, according to ISO standards recommendations [6]. The tool wear VB corresponds herein to the average of the six maximum tool wear values estimated for each of the tool cutting edges.

2.2. Measurement setup

The surface topography was extracted from profiles taken with Mitutoyo® SV-CS3200 profilometer. All measurements, on both hole and trimmed surfaces, were performed using the same cut-off lengths (0.25 mm) and the same 0.2 µm pitch. Two different stylus configurations (standard and deep-hole) with the same tip geometry (2 µm tip radius and 60° tip angle) were used.

According to ISO standards, the typical profile sampling length (1.25 mm herein) was selected to calculate roughness parameters, based on five cut-off lengths (0.25 mm each) [7]. Primary profiles were obtained after linear correction of the measured raw profiles [8]. The parameter Ra was calculated using the roughness profiles which were obtained after the primary profile filtering, to remove the profile waviness. This parameter Ra was selected due to its extensive use and to highlight the characterization issues.

2.2.1. Profile topography in trimming

Fig. 1 depicts the measurement location on the trimmed coupons. Five measurements of 3.75 mm were performed for each machined side. Out of each measurement, five roughness parameters Ra were calculated from profile length (1.25 mm), giving a total of 25 Ra values per face. This allows to estimate the Ra parameter deviation influenced by the measurement position in the composite height thickness.

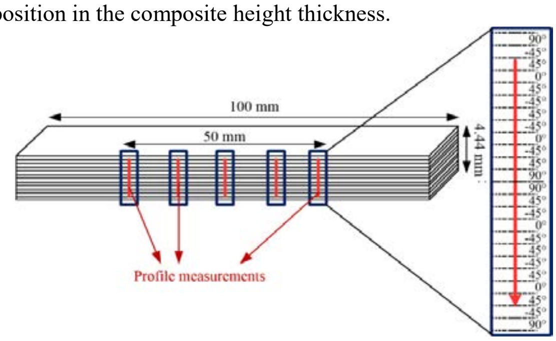

Fig. 1. Measurement positions on trimmed surfaces in the transverse direction

2.2.2. Profile topography in drilling

Fig. 2 shows the location and orientation of the hole topography profile measurements. Five profiles of 2.25 mm were measured for each of the 36 angular positions along the hole generating line, so every 10° increment. Three roughness parameters Ra were calculated from each measured profile, giving, in total, fifteen roughness parameter repetitions per angular position per hole.

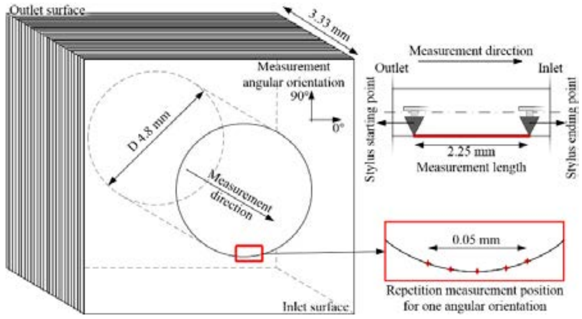

Fig. 2. Measurement positions diagram on hole surfaces

3. Results and discussion

3.1. Trimmed surface profiles

Samples of primary profiles for different tool wear are presented in Fig. 3. Plies with various fiber orientations can be relatively easily identified, in particular for low tool wear. In agreement with the literature, the deep cavities correspond to the -45 plies. The other ply orientations are difficult to distinguish from one to another. Up- and down-milling coupon sides also have different characteristics. Down-milling surfaces for different tool wear are similar. But down-milling surfaces are smoother at a low scale, as well as the total height of the primary profile rises, with the tool wear increase. Regarding up-milling surfaces, the -45° plies become more difficult to track with the tool wear increase. The profile roughness becomes higher with the tool wear increase.

Fig. 4 depicts the Ra results in up- and down-milling. Due to the different properties of the laminated composite surface, characterization parameters are strongly impacted by the measurement position. The value distribution of Ra is relatively large. The average variation of Ra remains relatively stable along the tool life for both up- and down-milling. However, based on surface analysis in the ply plane direction, such surface characterization is inadequate and misrepresentative of the composite topography [9]. Due to the Ra calculation characteristics, this parameter shrinks the surface characterization into a single number corresponding to the profile height deviation average. This cuts out any profile singularity impact on the parameter value. Though, averaging is preferred for the surface analysis of homogeneous materials allowing the reduction in the effect of outliers but should be investigated in composite surface case.

The mischaracterization can be the consequence of the composite lamination characteristics, such as the number of -45° plies, their thickness and the composite stacking sequence.

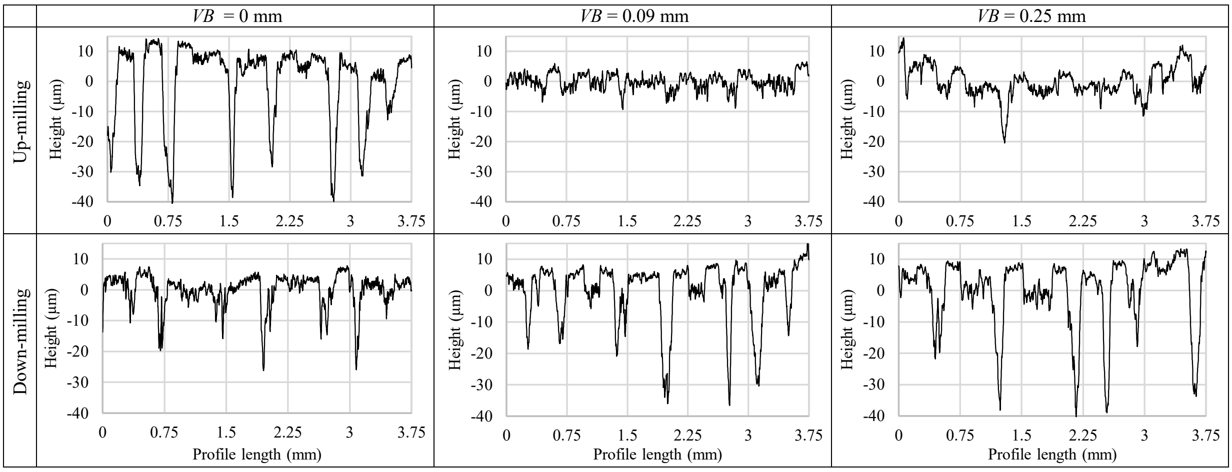

Fig. 3. Primary profiles of up- and down-milling trimmed surfaces for three different tool wear

In addition to the reduced information involved in the parametrization, the filtering, generating roughness profiles, can cause artifacts [5].

The profile misrepresentation of Ra, presented in Fig. 4, is instigated by the characterization process itself (filtering and parametrization). This explains why the same roughness parameter Ra value can be calculated from such different primary profile samples, shown in Fig. 3.

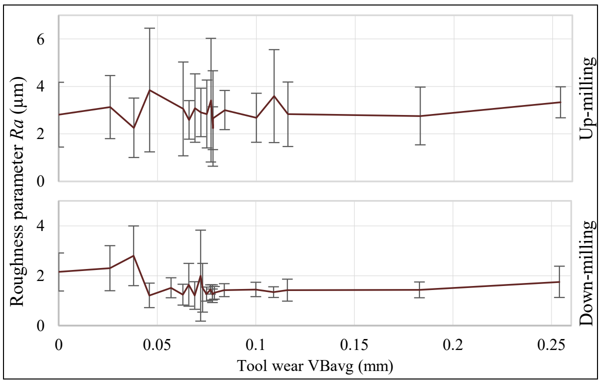

Fig. 4. Ra average results with ±2 standard deviations obtained on up- and down-milling faces

3.2. Drilled surface profiles

Fig. 5 depicts the results of the roughness parameter Ra vs the hole orientation for a new tool. Depending on the measurement position, the Ra deviation admits a relatively high difference ratio up to twelve (standard deviation values of 0.07 mm for 20° and 0.88 mm for 270° in Fig. 5).

Fig. 6 displays the averages and dispersions of the parameter Ra for medium and high tool wear. For medium tool wear (0.09 mm VB) compared to Fig. 5 results, the Ra average and deviation tends to be lower but the Ra deviation still varies widely. For high tool wear (0.25 mm VB), the deviation difference tends to be limited. But the parameter Ra increases so the roughness average is higher.

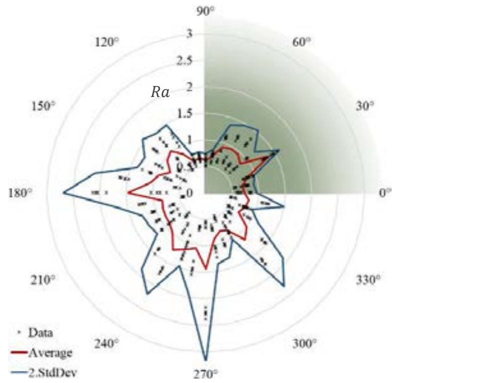

Fig. 5. Roughness parameters Ra along the hole orientation for a sharp tool

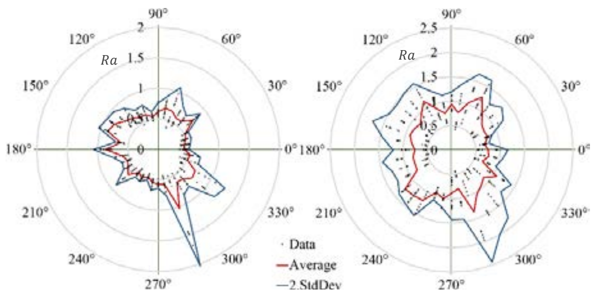

Fig. 6. Roughness parameters Ra for medium (left) and high (right) tool wear

Fig. 7 shows primary profile examples measured in a hole quarter for different tool wear. The tool wear estimation varies between the drilling and trimming operations because of the tooling difference, so the tool wear comparisons are fairly limited. However, similar trends are observed in the primary profiles measured for different tool wear. With a new tool, the machined surface is relatively rough and erratic. Above a tool wear limit, the surface generated is smoother and stable due to the cutting mechanism change. When the tool wear becomes even higher, the number of topographic defect raises highly which leads to a rougher surface.

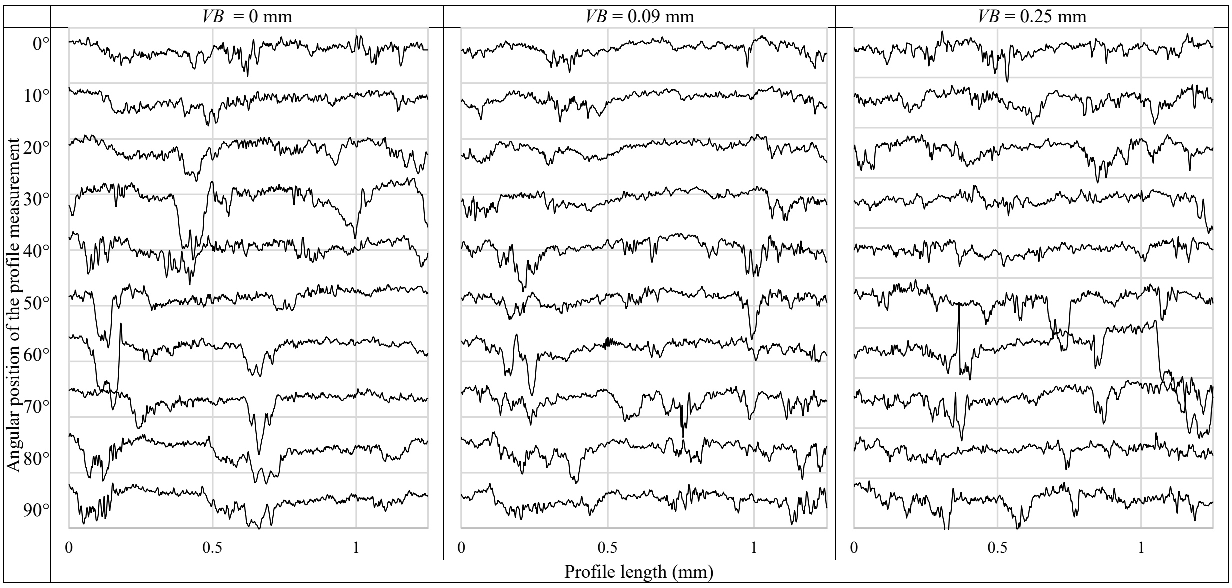

Fig. 7. Profile samples for different tool wear at several hole angular positions (colored section in Fig. 5)

The -45° plies seem relatively easy to be spotted but, in some locations, those plies are particularly difficult to observe. Moreover, with the tool wear increase, the -45° plies become highly difficult to be differentiated from the other. This issue is due to the topography of the machined -45° plies. In the ply plane, those plies admit large variations. So depending on the measurement position, the -45° ply can be measured at the high or at the bottom location of its surface in the transverse direction. In the case of the former location, the profile prevents exposing the -45° plies. The filtering and parametrization problems, identified in the surface profile analysis in trimming, remain present for the hole surface case. In addition to those problems, the measurement position and orientation accuracy is another problem source in the hole surface analysis.

4. Conclusion

In this study, the machined surface topography of CFRP drilled and trimmed surface was investigated. Trimmed and hole surfaces were measured in the transverse direction of the composite lamination. Due to the heterogeneous structure of laminated composite, the machined surface has different stratified surface topography properties. The -45° ply orientation admits higher surface roughness than the other ply orientations (0°, 45° and 90°). Based on the measurement results, the roughness parameter Ra is found inadequate to characterize such surfaces. Depending on the composite ply stacking sequence and the measurement position, the results deviation can be relatively high. The filtering and the parameterization can influence the deviation of the results. In hole surfaces, another problem may be highlighted. Set up position and orientation variations between the measurements are an additional source of the variations in the roughness parameters. Using the Ra parameter should be avoided for composites' surfaces and different approaches may be considered such as the introduction of new roughness parameters and alternative filtering techniques.

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