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ORIGINAL ARTICLE

Investigation of the machining behavior of unidirectional Alfa (*Stipa tenacissima* L.)/epoxy composite material

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Abstract

Nowadays, with regard to many environmental problems, the development of environmentally friendly materials such as natural fiber composites is a real alternative to synthetic fibers. They have many interesting advantages such as their availability, their low cost, their low density, their biodegradable character, their specific resistance properties and their low impact on the environment. The present paper is aimed at fabricating and machining of an epoxy composite material reinforced with Alfa (*Stipa tenacissima* L.) fibers. The full factorial analysis was used to assess the effect of cutting parameters such as cutting velocity and feed rate on the arithmetic roughness R_a of machined surfaces obtained by down milling and up milling operations. For this purpose, a two flutes high-speed steel (HSS) cutting tool was used. The results showed that the up milling mode provides better surface roughness than down milling mode for almost all machined specimens. The feed rate is the main factor affecting the surface roughness, with a contribution of about 90%. The worst values of arithmetic roughness were observed, at low feed rate (0.05 mm/rev) regardless of the cutting velocity. The results also showed that machining parallel to fibers direction (0°) offers better surface roughness than machining perpendicular to fibers direction (90°). Microscopic and SEM images show some defects such as matrix cracking, cavity, fibers breakage, loss of matrix, fluffing, and thermal damage.

Keywords Natural fiber composite · Alfa (*Stipa tenacissima* L.) fiber · Trimming · Roughness · Surface damage

1 Introduction

The progress of composite materials was first related to the development of the aeronautical, aerospace, defense, and automotive industries; then more recently the field of application has widened to many areas such as construction, marine, sport, wind turbine, bicycle, storage of pressurized fluids, braking systems, electrical, and household appliances [1]. Natural fiber composites are considered an important achievement in the field of materials science in the last decades. Considered an environmentally friendly material, it offers a real alternative to more common synthetic fibers such as glass and carbon fibers. Their use have experienced strong development in recent years in various industrial sectors such as automotive [2, 3] and marine [4, 5]. Furthermore, the growing demand for greener and biodegradable materials has led to advances in materials science and biodegradability. Natural fibers are one of the most important and interesting reinforcement in polymer composite sectors for transformation into greener-based materials [6, 7]. They have been exploited for various purposes as materials for aerospace and construction. The natural fibers most commonly used in composites are bark fibers, such as hemp, jute, sisal, and kenaf [8–11]. These natural fibers have advantages that cannot be compared to synthetic fibers in terms of relatively renewable resources, biodegradation, low cost and less damage for process equipment, low weight, high flexibility during machining, and relatively good mechanical properties, as well as minimal health risks [12].

Obtaining a composite material part requires two fundamental steps. The first is the manufacture of the composite components. This step makes it possible to obtain the near net shape of the part with more or less accurate dimensions. The second step called completion regards the finishing of the part. This allows trimming the part to comply with its

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final dimensions and tolerances but also to create additional functional features necessary for the use of the part (through holes, spacers, cutouts, etc.).

However, the implementation of these materials comes up against the difficulty of machining, caused by the anisotropy and the non-homogeneity of their structure, as well as by the high abrasiveness of the reinforcements [13]. The cutting tools usually used to machine-metallic materials are now reaching their limits when utilized to cut composite materials reinforced with synthetic fibers such as fiberglass, carbon fiber, and Kevlar due to their abrasive nature. For example, carbide tools provide good quality but their lifespan is very short due to the abrasive nature of composite materials [14–16].

Trimming is a machining operation that is characterized by the removal of material with the aim of delimiting the free edges of metal or composite structures. Several parameters resulting from the tool/material interaction influencing the machining quality can be identified. Regarding the cutting tool, it was found that the number of teeth, the diameter, the useful length, the helix angle, the radius of the edges (sharpness), the relief angle, the angle of attack, and the tool material are the most important parameters influencing machining accuracy. Regarding the material to be machined, some parameters include the nature of the fibers (carbon, glass, aramid, etc.), the nature of the resin, the orientation of the fibers and/or the stacking sequence of the plies, the thickness to be machined, and the additives present in the resin can also influence the quality of the machined parts. Furthermore, the different mechanisms developing during the interaction between the cutting tool and the material to be machined are strongly influenced by the cutting parameters, which are the cutting velocity, the feed rate, and the machining distance traveled by the cutting tool [17].

The machining of natural fiber composites differs significantly from the machining of metals. Therefore, the theory and machining models associated with metals cannot be applied to composites. On the one hand, the behavior of the composites depends on the distribution and the dispersion of the reinforcements in the matrix and on the other hand, this distribution is random and inhomogeneous. A thorough investigation is therefore necessary to determine the optimal cutting conditions such as, the geometry of the cutting tool and the orientation of the fibers.

Recently, in many applications, high quality machined surfaces are required, as well as dimensional accuracy and optimal surface integrity. For this reason, various researches have been carried out with the aim of optimizing the cutting parameters, in order to obtain a specified roughness [18, 19]. The quality of the finished product can be characterized by two criteria, namely the integrity of the surface (roughness and delamination) and the machinability of the finished part (the cutting forces and the wear of the cutting tool) [20]. There are several types of surface defects recounted during machining composite materials such as, fiber tearing, uncut fibers, interlaminar separation (delamination) or thermal damage of the matrix (degradation and spreading). It is therefore important to measure, quantify, and control these defects. The measurement of roughness and delamination is the most aspect applied in machined composite parts. As for the roughness, several studies agree that the latter is a function of the cutting parameters and the orientation of the fibers. Ramulu et al. [21, 22] conducted orthogonal cut characterization studies of fiberglass reinforced composite materials and analyzed the effects of fiber orientation, cutting parameters, and tool geometry on surface quality. Similar studies used statistical analysis of variance (ANOVA) to observe the influence of cutting parameters and tool diameter on the delamination of hemp [23], coconut [24], banana fiber composites, sisal and roselle [25], vetiver [26], sisal [27], jute [28], hybrid glass-sisal [29], and glass sisal-jute [30] composites. All these authors show that small tool diameter, low feed and high cutting speed are the best operating parameters. Furthermore, high cutting speed, low feed, and low depth of cut are the parameters offering the lowest cutting forces [31]. Babu [32] goes further and investigates the influence of cutting parameters (spindle speed and feed per revolution) on the delamination factor and surface roughness for different composites, such as hemp, jute, banana, and glass fibers. For all composites studied, the delamination factor and surface roughness increase with feed and decrease with spindle speed increase. The hemp fiber composite provides the best results in terms of roughness and the lowest delamination factor [32]. Zain et al. [33] predicted the surface roughness in milling. Palanikumar et al. [34] investigated the influence of cutting conditions on surface roughness parameters when turning composite materials. They found that surface roughness increases with an increase in feed rate and almost decreases with an increase in cutting speed. They also developed empirical models to correlate machining parameters with surface roughness.

The originality of this paper lies in its investigation of the machining behavior of unidirectional Alfa/epoxy composite material, which has not been extensively studied before. While previous research has focused on the feasibility of using Alfa fibers as reinforcement for polymer composites [35–41], this study addresses a critical gap in the literature by examining the trimming of these fibers. By evaluating the suitability of cutting tools typically used for metallic materials, specifically for cutting Alfa fibers, our research presents new insights into the unique mechanical properties of these natural fibers and their potential implications for the development of more efficient cutting tools. The paper's innovative focus on a specific natural fiber and its machining behavior not only contributes to the advancement of knowledge in the field of natural fiber cutting but also has the

Fig. 1 Vacuum casting for producing composite plates

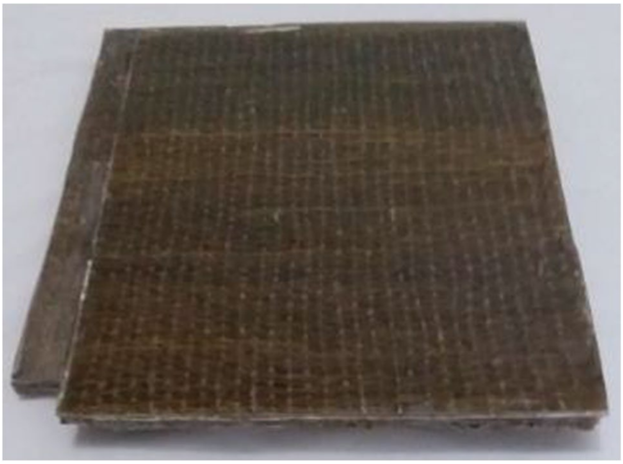


Fig. 2 Produced Alfa/epoxy plates

potential to impact the use of Alfa fibers as an alternative to synthetic fibers in polymer composites. Therefore, this paper's originality lies in its exploration of new frontiers in natural fiber cutting research and its potential to open up exciting new avenues for future investigation.

2 Materials and methods

The development of the composite material used in this research is based on the vacuum-assisted resin transfer-molding technology (Fig. 1).

The manufacture of test specimens is represented in the following steps. The preparation of the stack of unidirectional (0°) plies is the first step in the process, followed by the injection process, and then a final cure in an oven at 80 °C for 6 h is performed. Finally, a plate of four plies with dimension of 200 mm × 200 mm × 10 mm and with a fiber volume fraction of 45% was obtained (Fig. 2).

The epoxy resin used in the elaboration of the composite was provided by the company Granitex of Oued Smar, Algeria. The Alfa fibers were collected from the region of Boussaâda, M'sila, Algeria. These fibers have a basis areal density of 600 (g/cm^2) and a volume density between 0.89 and 2.10 (g/cm^3).

Tables 1 and 2 summarize the main characteristics relating to the reinforcement layers and the epoxy resin.

Table 1 Characteristics of Alfa fibers

Surface density (g/cm^2)	600
Volume density (g/cm^3)	0.89–2.10
Kind	Dry fiber
Orientation	Unidirectional (UD° 0°)

Table 2 Characteristics of the epoxy matrix, according to the data sheet

Viscosity (NF T76-102)	11,000 MPa.s at 25 °C
Density (ISO 758)	1.1 ± 0.05

To withstand the cutting force and then eliminate any source of vibration, the composite plate must be firmly held on the machining fixture. Accordingly, several holes were drilled in the composite plate (Fig. 3). To accomplish the task, a machining fixture (jig) was developed to properly fix the specimens during the trimming tests.

The drilling and trimming operations were conducted using a PEARL RIVER NC F-VMC 510L machining center (Fig. 4). It is a three-axis numerically controlled machine tool (MOCN) equipped with a SIEMENS 840D controllers.

The subset plate and machining fixture is firmly fixed on the machine table (Fig. 5).

The jig is pre-grooved to allow the evacuation of the tool and then avoid collisions between the end of the tool and the jig during trimming. Furthermore, the grooves in the jig are slightly larger (10.5 mm) than the diameter of the tool (10 mm) to allow the routing tool to pass without friction (Fig. 6).

The correct selection of the tool and the cutting parameters (cutting speed, feed rate, and depth of cut) are very important in the machining process [42–44]. The effect of cutting tool geometry on cutting parameters has been evaluated by Wang et al. [45, 46].

In this work, the choice of the cutting tool was mainly made on the basis of experimental results of trimming flax/epoxy bio-composites found in the

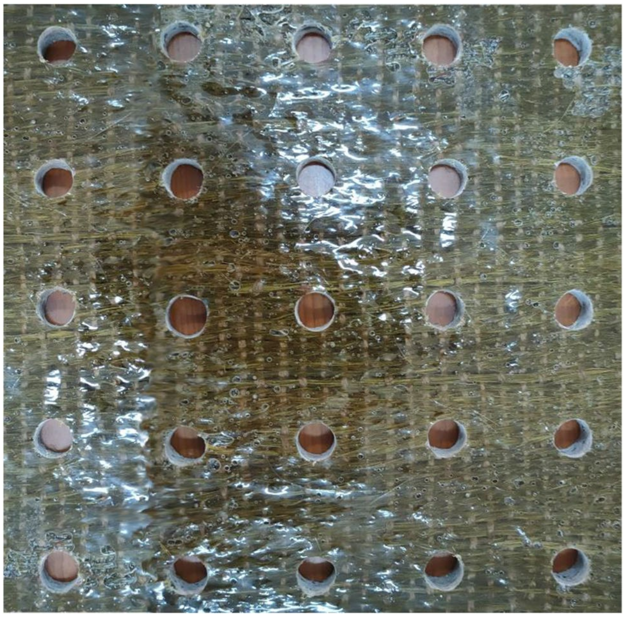


Fig. 3 Drilled composite plate

Fig. 4 PEARL RIVER NC F-VMC 510L machining center

Fig. 5 Composite plate fixed in the machining fixture

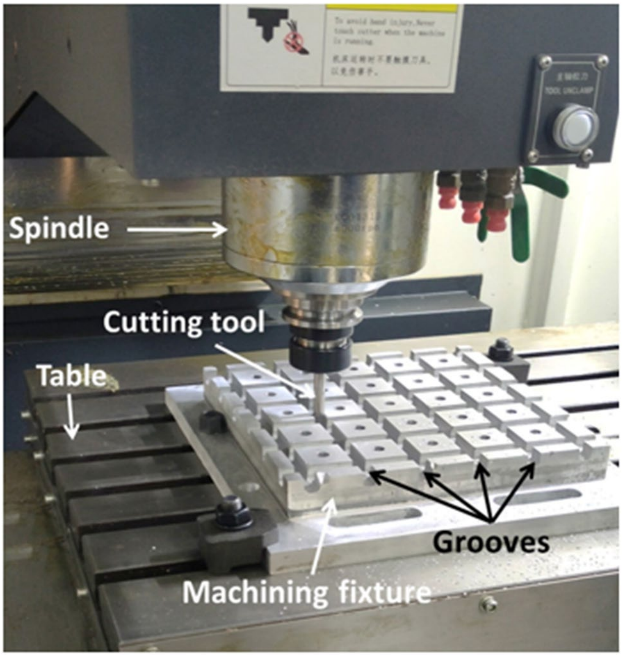


Fig. 6 Machining fixture

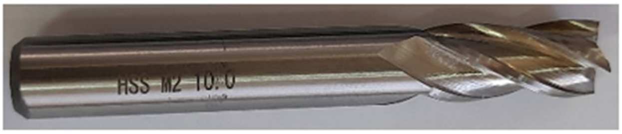


Fig. 7 High speed steel (HSS)

literature. Delahaigue [47] used a 4-tooth HSS abrasive cutter to study the effects of cutting parameters and fiber orientation on cutting forces and surface finish. Inoue and Hagino [48] used six tools, two of them are made of HSS high speed steel and studied the influences of cutting distance, cutting force, cutting temperature, and tool wear on the surface characteristics of carbon fiber-reinforced polymer (CFRP) materials. The results of their experiments reveal that the cutting force and the cutting temperature increase when cutting randomly oriented materials, regardless of the type of cutting tool used. They have concluded that an HSS cutter used at low feed rate and high spindle speed causes minimal delamination and allows for longer cutter life. Accordingly, an HSS cutting tool with 10-mm diameter is selected in this work to trim Alfa composite material (Fig. 7).

The characteristics of this cutter are shown in Table 3.

To obtain meaningful conclusions about machining Alfa fiber composite, a full factorial experimental design with two factors, each having five levels is used. A total of 25 tests were

Table 3 Tool characteristics

Material	High speed steel (HSS)
Diameter	10 mm
Number of teeth	4
Helix angle	30°
Total length	70 mm
Usable length	28 mm

Table 4 Complete factorial experimental design

N°	V_c(m/min)	f (mm/rev)
1	50	0.05
2	50	0.15
3	50	0.25
4	50	0.40
5	50	0.50
6	100	0.05
7	100	0.15
8	100	0.25
9	100	0.40
10	100	0.50
11	150	0.05
12	150	0.15
13	150	0.25
14	150	0.40
15	150	0.50
16	200	0.05
17	200	0.15
18	200	0.25
19	200	0.40
20	200	0.50
21	225	0.05
22	225	0.15
23	225	0.25
24	225	0.40
25	225	0.50

carried out (Table 4). The factors are the cutting velocity (v_c) expressed in (m/min) and the feed (f) in (mm /rev).

The composite plate is cut along two directions parallel to the direction of the fibers and perpendicular to the direction of the fibers (Fig. 8a).

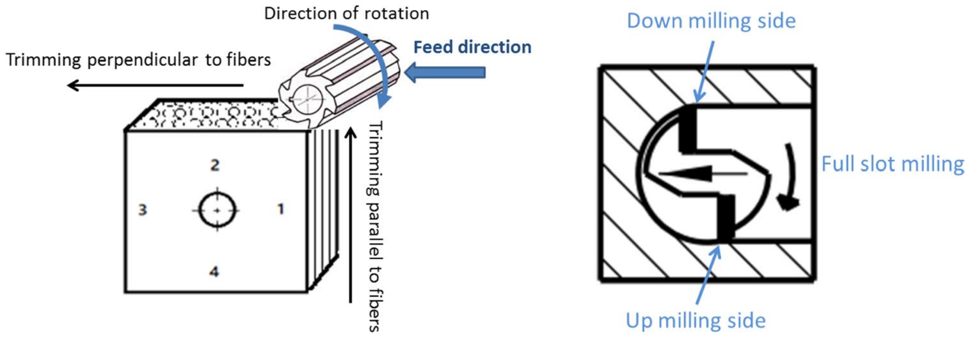
As shown in Fig. 8a, each coupon represents a maximum of 4 distinct experimental combinations (one combination per side) including two combinations of down milling and two combinations of up milling (Fig. 8b).

After machining, all samples are carefully cleaned to remove all impurities and dust using blown compressed air. Then, the surface roughness (roughness average (R_a)) of each side of each coupon (each cutting condition) was measured using a Mitutoyo Surftest-4 tester (Fig. 9) equipped with a probe having a 2-μm diameter and an orientation of 60° with respect to the surfaces. All measurements were repeated three times.

3 Results and discussion

To study the effect of the cutting conditions on the surface roughness during trimming Alfa fibers reinforced composite, a series of slot were machined parallel (Fig. 10) and perpendicularly to the fibers under dry condition (Fig. 11). This leads to a total of 25 machined square coupons (Fig. 11). Each coupon has four machined faces, two faces machined by up-milling and the two other faces machined by down milling.

It has been found in previous research works [49, 50] that smoke can appear when machining CFRPs using worn tool. This in turn leads to matrix burning due to the high tool wear and high cutting force [51]. Although machining natural fiber composites preserve the quality of the cutting tool and do not cause tool wear due to the non-abrasive nature of natural fibers, it was observed during the present tests that smoke appeared when slotting Alfa fibers composites (Fig. 12) under low feed rate and high cutting velocity. This can be explained by the fact that the heat generated during



a) Trimming parallel and perpendicular to fibers

b) Up-milling vs. down milling

Fig. 8 Cutting modes on each face

Fig. 9 Mitutoyo Suftest-4 roughness tester

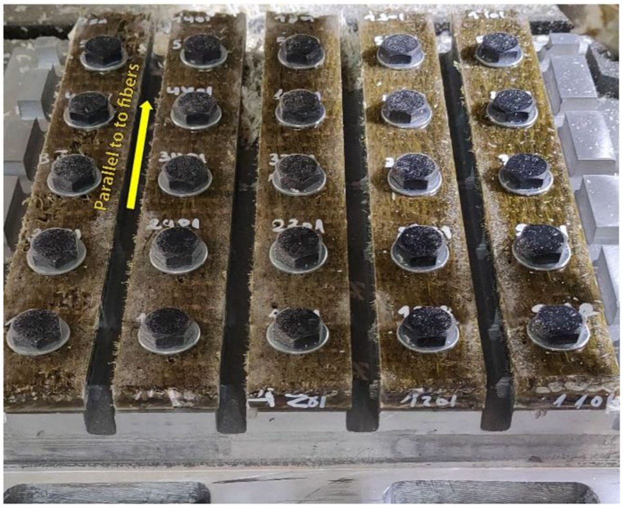


Fig. 10 Slotting parallels to fibers orientation

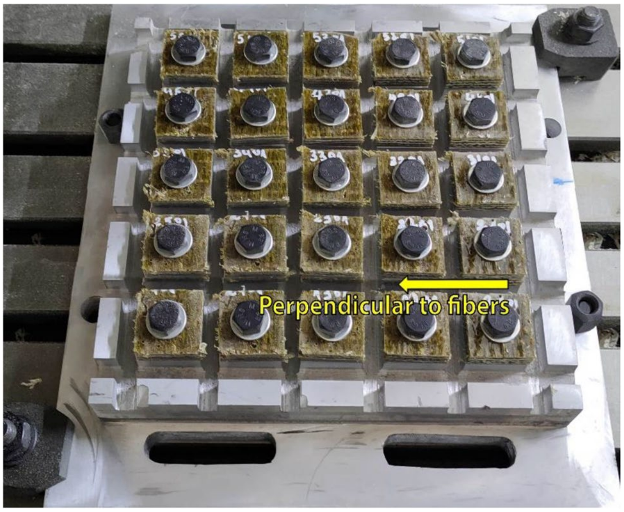


Fig. 11 Square coupons obtained by the trimming tests

Fig. 12 Smoke emitted during slotting Alfa fibers composite

cutting remains retained in the cutting zone due to the low thermal conductivity of the epoxy resin matrix. Accordingly, the friction and the low feed rate lead to an increasing temperature at the cutting zone. Consequently, the high flammability of natural fibers compared to synthetic fibers [52] and the high temperature at the cutting zone causes the combustion of the Alfa fibers, burning of the matrix and hence the emission of smoke. This could also lead to the softening and the degradation of the matrix [53].

3.1 Surface roughness

The machined surfaces obtained by cutting perpendicular (90° ply orientation) and parallel (0° ply orientation) to the fibers were exanimated in this section. In order to evaluate the surface roughness of the Alfa/epoxy composite, measurements of the arithmetic average roughness were taken using the Suftest-4 roughness tester mentioned in the previous section. Generally, the quality of machined surfaces is represented by roughness. Surface roughness influences not only the visual appearance of a part but also many other characteristics, such as the level of wear expected and the quality of assembly. It also has a great influence on the physical and mechanical properties of the parts. Therefore, the evaluation of the roughness of the surface is necessary.

Figure 13 shows a histogram of the surface roughness as a function of the machining mode (up milling vs. down milling) whatever the cutting velocity and feed rate. It can be seen from the results presented in Fig. 13 that the up milling mode provides better surface roughness than down milling mode. Furthermore, cutting parallel to fiber orientation (0°) delivers more accurate results in terms of surface roughness than cutting perpendicular to fiber orientation (90°). Similar results were obtained by Slamani et al. [54, 55] and

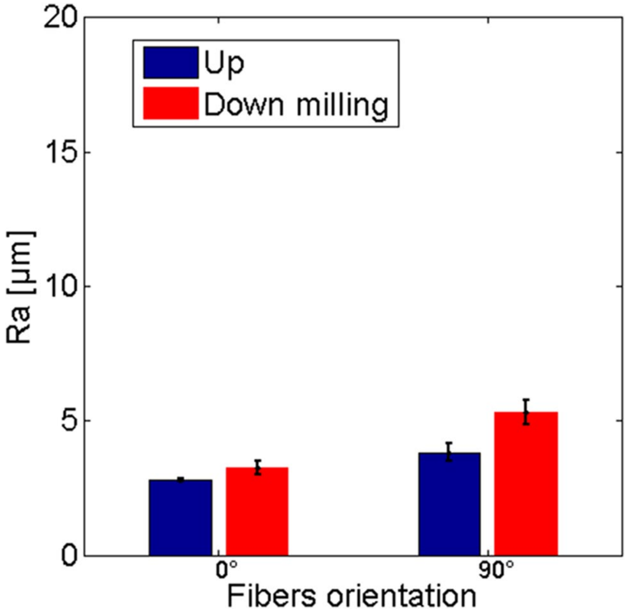


Fig. 13 Surface roughness R_a as a function of fibers orientation in up milling and down milling modes

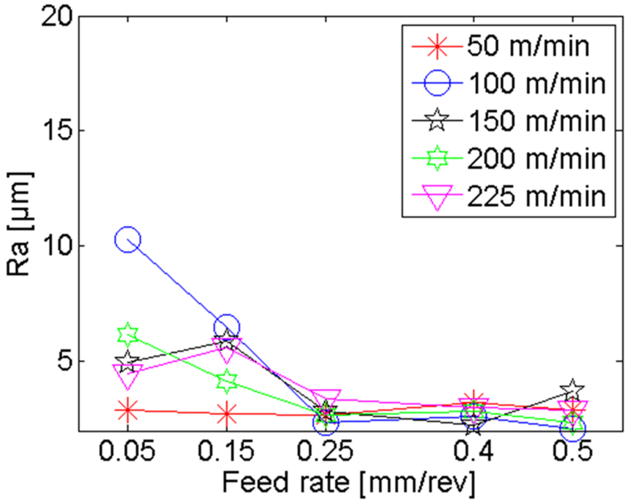


Fig. 14 R_a as a function of the feed rate in up milling mode for 90°

Chegdani et al. [56] when machining flax fibers reinforced composites.

Figures 14 and 15 show the evolution of the surface roughness (for 90° fibers orientation) as a function of the feed rate at different cutting velocity for up milling and down milling respectively. Results show that the surface roughness evolves similarly for both machining mode. It generally decreases as the feed rate increases and reaches its low values at high feed rate.

A similar behavior was observed when slotting parallel to fiber (Figs. 16 and 17). However, a closer look at these figures reveals that 0° fiber orientation provide more accurate results in terms of surface roughness. Furthermore, up milling mode remains better than down milling mode.

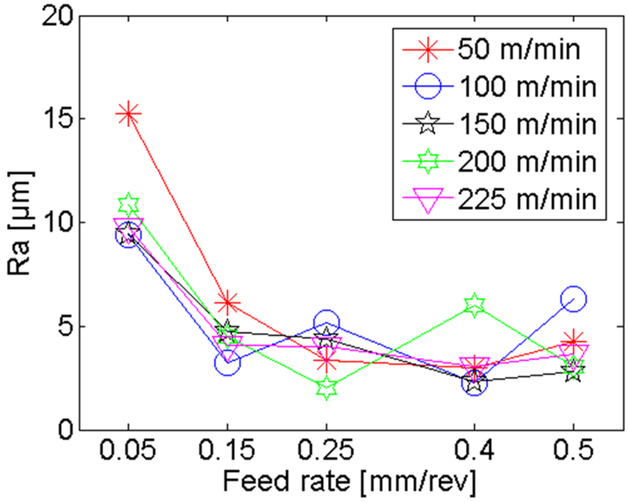


Fig. 15 R_a as a function of the feed rate in down milling mode for 90°

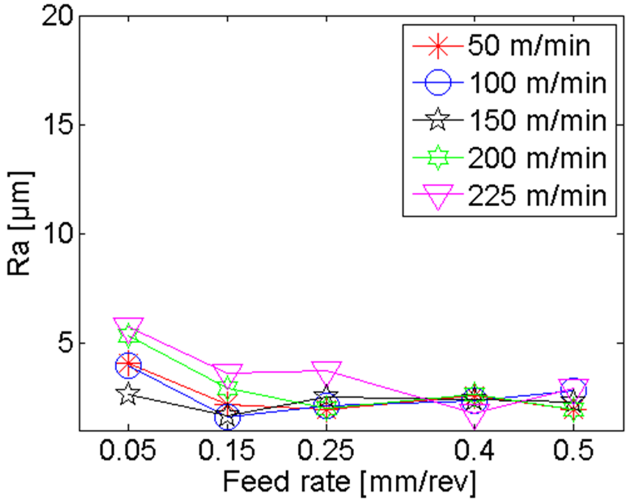


Fig. 16 R_a as a function of the feed rate in up milling mode for 0°

Figures 18, 19, 20, and 21 show the evolution of the surface roughness as a function of the cutting velocity in up milling and down milling modes for 90° and 0° fibers orientation respectively.

It can be clearly seen from these figures that the worst surface roughness is mostly obtained at low feed rate, whatever the cutting velocity.

On the other hand, it is not obvious to draw robust conclusions based on Figs. 18, 19, 20, and 21 about the contribution of the feed rate and the cutting velocity on surface roughness. Thus, further statistical analysis is required to overcome this problem and draw valid conclusions.

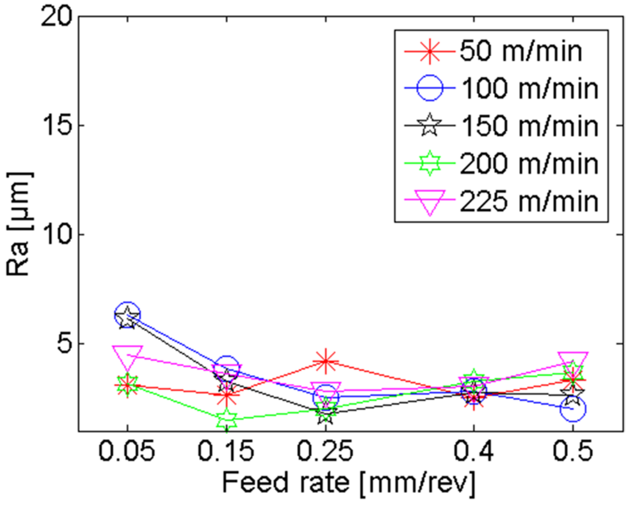


Fig. 17 R_a as a function of the feed rate in down milling mode for 0°

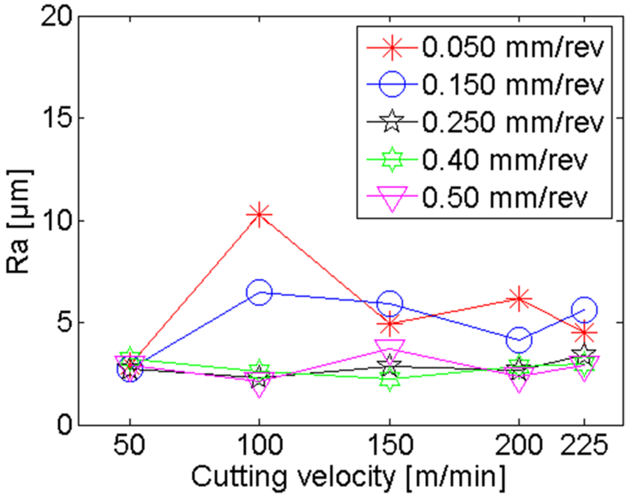


Fig. 18 R_a as a function of the cutting velocity in up milling mode for 90°

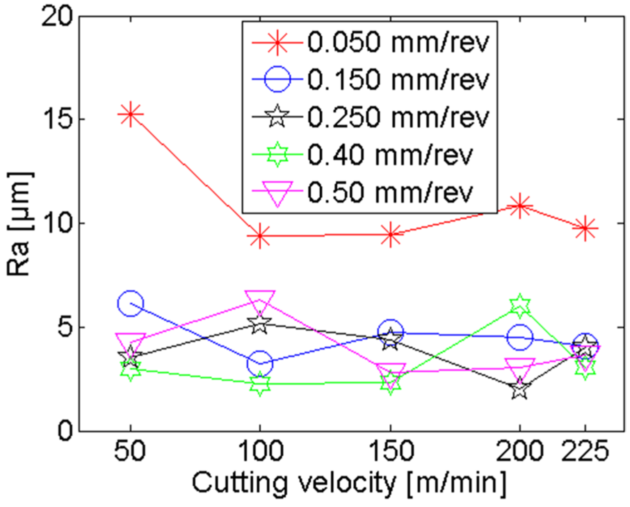


Fig. 19 R_a as a function of the cutting velocity in down milling mode for 90°

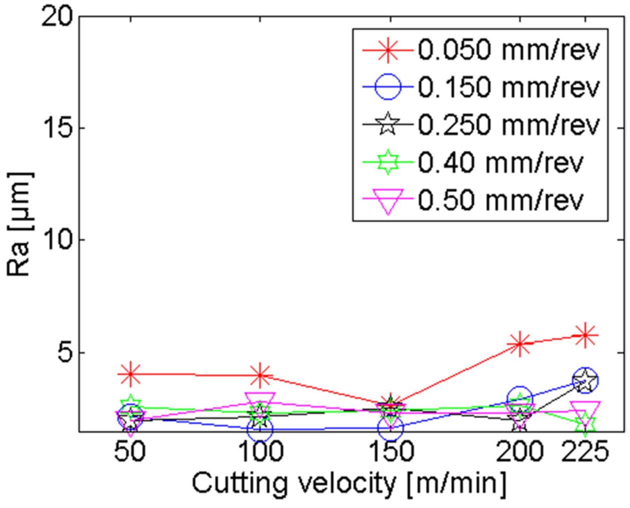


Fig. 20 R_a as a function of the cutting velocity in up milling mode for 0° fibers orientation

In combination with the design of experiment (DOE), the Analysis of Variance (ANOVA) approach is a well-recognized technique and important research tool that is used by scientist to measure the percentage contribution of each parameter on the output response.

Figures 22a and b illustratively convey the results of the ANOVA test in terms of the percentage contribution on a histogram graphs for the up milling and down milling mode respectively for fibers orientation of 90°. It can be seen from these figures that the feed rate is the main determinant, with a contribution of about 90.12% and 76.35% for up milling and down milling mode, respectively, followed by the cutting velocity with values of about 7.8% and 16.42%, respectively, and finally the interaction effect of the feed rate and the cutting velocity with a contribution of about 2.08% and 7.23%, respectively.

For the 0° fibers orientation, it is observed that the feed rate remains have the highest contribution in the down milling mode (Fig. 23b) with a contribution value of 62.72%, followed by the interaction effect of the feed rate and the cutting velocity with a contribution value of 21.31% and then the cutting velocity with a contribution of 15.97%.

However, it is surprising to observe that the effect of the feed rate is negligible (0.45%) when trimming parallel to fibers (0° fibers orientation) in up-milling mode (Fig. 23a).

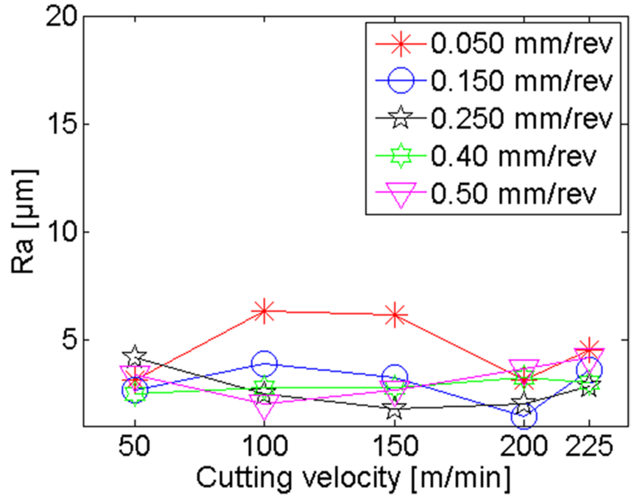


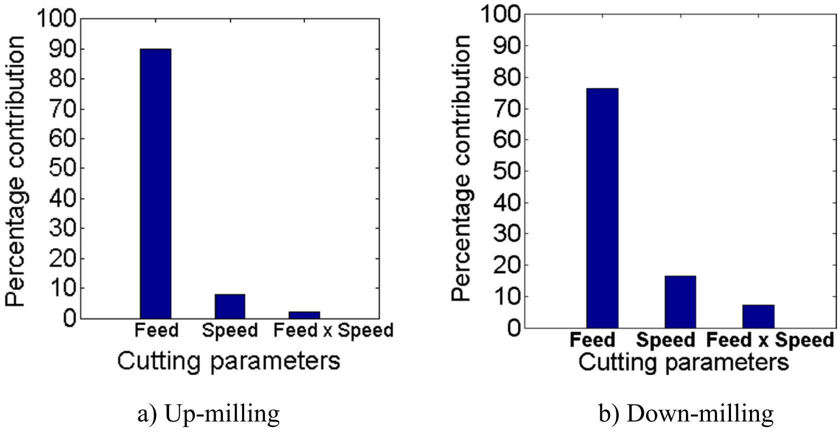
Fig. 21 R_a as a function of the cutting velocity in down milling mode for 0° fibers orientation

Hence, the cutting velocity becomes the most imperative parameter with a contribution of about 67.01% followed by the interaction effect of the cutting velocity and the feed rate at 32.54%.

3.2 Analysis of surface damage

Composite materials are usually characterized by the appearance of uncut fibers, the tearing of material particles, and the thermal degradation of the resin. The defects observed during the machining of natural fibers composites are different and this is due to the specific property of the material. Delamination and surface damage are common defects in the machining of composite materials. Generally, the machining defect is quantified by measuring the roughness. On the other hand, this criterion does not really represent the damage caused during machining. Depending on the damage suffered by the machined surface, the criterion usually used (the roughness R_a) does not always correlate with the extent of the damage observed visually, in particular damage in the subsurface (fiber loosening, cracks, tearing). Thus, the location and distribution of the damage on the machined surface are generally not represented by the roughness, for this other qualification criteria for machining defects are required. According to Slamani et al. [51] microscopic analysis is required to confirm the absence of surface damage when the R_a parameter is used to indicate the level of surface roughness. The determination of this defect is of

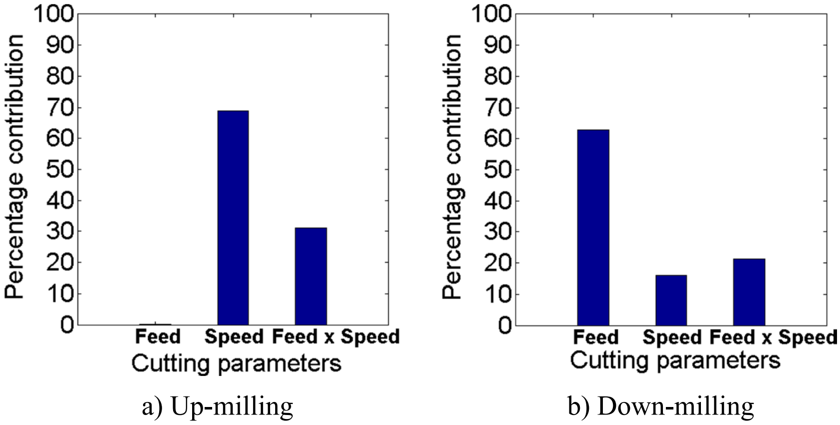
Fig. 22 Percentage contribution of cutting parameters on surface roughness for 90° fibers orientation



a) Up-milling

b) Down-milling

Fig. 23 Percentage contribution of cutting parameters on surface roughness for 0° fibers orientation



a) Up-milling

b) Down-milling

Fig. 24 Up milling mode vs. down milling mode when cutting perpendicular to fiber

a) Up milling mode perpendicular to fiber, f=0.05mm/rev and $v_c = 100m/min$

b) Down milling mode perpendicular to fiber, f=0.05mm/rev and $v_c = 100m/min$

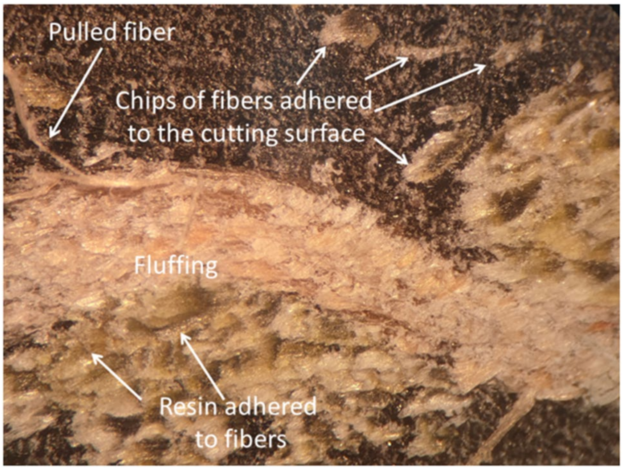


Fig. 25 Image of the machining defects encountered during trimming Alfa fibers composite

paramount importance in order to validate the use of this type of material as alternative to synthetic fibers.

Figure 24 present images of the specimens obtained by cutting perpendicular to the fibers in up milling and down milling modes for the same cutting conditions. These images show that compared to the down milling mode, the up milling cutting mode provides the best results with a cleaner surface. On the other hand, fluffing defects were appeared at the surface peripheries when cutting perpendicular to the fibers (Figs. 24 and 25). The fluffing defects are more severe on the specimens machined by down milling mode (Fig. 24b). Some Alfa fibers chips were observed adhered to the cutting surface (Fig. 25). Re-deposited and adhered resin was also observed (Fig. 25).

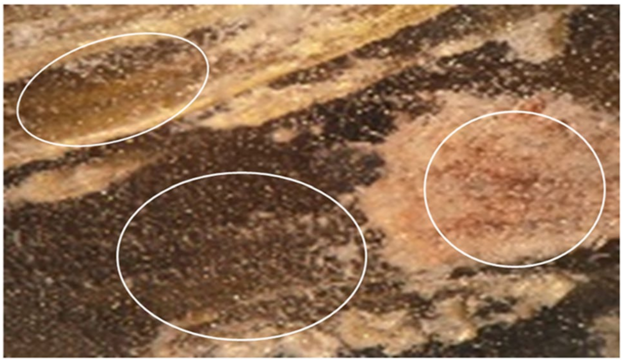


Fig. 26 Thermal damage of the matrix and fibers

In some trimmed specimens, the presence of thermal damage was clearly distinguished (Fig. 26). There is no distinction of the folds, which reflects a spreading of the degraded matrix. It is clear that the transition temperature has been reached on the surface, which generates a melting of the resin and a homogenization of the surface.

The presence of broken fiber debris, re-solidified and adhered resin, cavities, and loss of matrix were also observed on some of the trimmed surfaces (Fig. 27).

Figure 28 presents the experimental SEM observation of a trimmed surface of the Alfa/epoxy composite material. The SEM image reveals distinct features that provide valuable insights into the machining behavior [57–62].

Upon careful examination, it becomes evident that the machined surface displays several noteworthy characteristics. First, fibers protrusion is observed, indicating variations in fiber height across the surface. This phenomenon could be

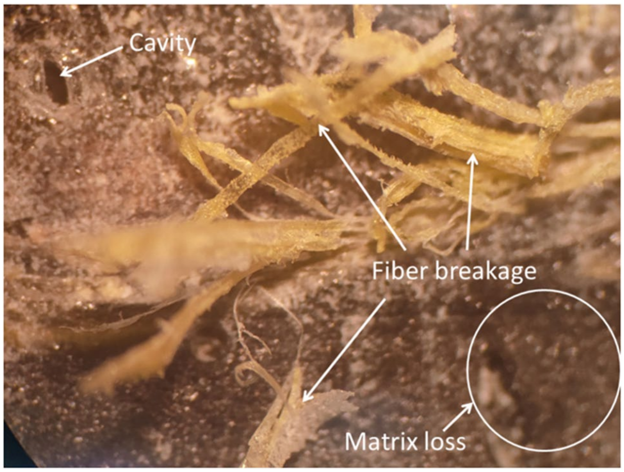


Fig. 27 Image shows the cavity, fibers breakage, and loss of matrix

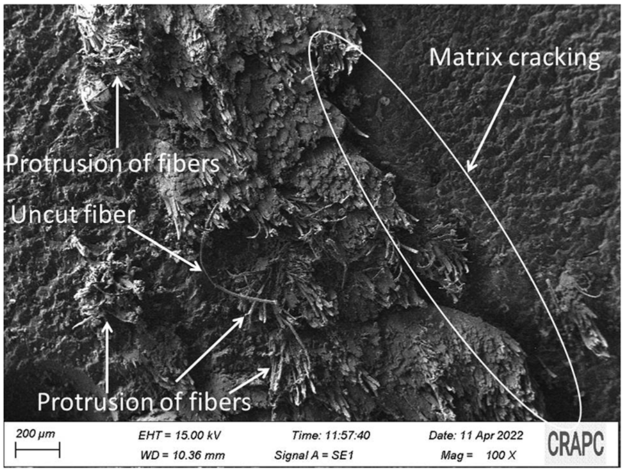


Fig. 28 Typical SEM image of the trimmed surface of Alfa/epoxy composite

attributed to irregular cutting forces acting on the composite during the machining process. Furthermore, the dynamic force initiates the initial damage in the laminate, resulting in fiber deflection instead of complete fiber detachment [63]. In other words, the fibers bend or deviate, resulting in them remaining uncut, and subsequently, they revert to their original position within the composite material. This results in protruding fibers on the machined surface [64].

Secondly, the presence of uncut fibers is noticeable, suggesting that the cutting tool may not have effectively severed some fibers, resulting in incomplete material removal. Possibly, the presence of uncut fibers can be attributed to the ductile nature of the fibers, while fiber pull-out may be a consequence of inadequate bonding between the fiber and the matrix [65]. This finding highlights the need for optimizing cutting parameters to achieve more precise and uniform machining results.

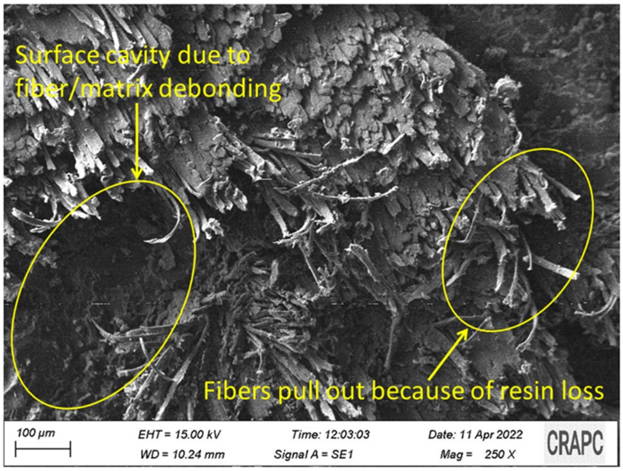


Fig. 29 High-resolution SEM image revealing specific defects in the Alfa/epoxy composite material

Lastly, matrix cracking is apparent in the SEM image, indicating the occurrence of material damage during the trimming process. Such cracks are likely the result of stresses induced by the cutting forces and can affect the overall mechanical properties of the composite [63].

Figure 29 shows a high-resolution SEM image that highlights specific defects observed in the Alfa/epoxy composite material. This image offers profound insights into the material's machining behavior, providing a comprehensive understanding of the observed defects.

Figure 29 displays the existence of surface cavities. Surface cavities are an indication of damages beneath the surface and can result from factors such as fiber pull-out, matrix loss, interlayer delamination, and subsurface fiber-matrix debonding, as mentioned in references [66, 67]. Furthermore, Wang et al. [68] stated that the primary cause of surface cavities was the initiation and propagation of fiber-matrix debonding, leading to subsequent bending-induced and shear-induced fiber fractures.

4 Conclusion

Thanks to their properties combining mechanical resistance and lightening, natural fibers make it possible to meet the new challenges imposed by sustainable development. Generally, the criterion used to define the quality of a composite part is often linked to its surface quality after machining.

The objective of this experimental study was to investigate the influence of the cutting parameters on the surface roughness and surface damage during trimming Alfa/

epoxy composite material using a two flutes HSS cutting tool.

From the present work, the following conclusions can be drawn:

- The down-milling cutting mode is not recommended during trimming Alfa/epoxy composite material. It provides the poorest results in terms of surface roughness and surface damage;
- The greatest damage was observed when machining perpendicular to fiber orientation (90°);
- Fiber orientation has a dominant influence on both surface roughness and subsurface damage;
- The surface roughness evolves similarly with feed rate for both trimming modes (up milling and down milling). The Ra value decreases with higher feed rates, indicating improved surface quality;
- The worst surface roughness is mostly obtained at low feed rate, whatever the cutting velocity;
- Smoke is observed when slotting Alfa fibers composites under low feed rate and high cutting velocity;
- The effect of the feed rate was found negligible when trimming parallel to fibers (0° fibers orientation) in up-milling mode;
- Fluffing is the major defect observed when trimming Alfa/epoxy composites;
- The SEM image shows that the machined surface was characterized by fibers protrusion, uncut fibers and matrix cracking.

Author contribution The paper was authored by a team of individuals, each contributing in their own way. Madani Grine conducted the literature study, experiments, analyzed the data, and wrote the paper. Mohamed Slamani served as the supervisor of the project, providing the research idea, technical scheme, and necessary support throughout. He also participated in data analysis and was responsible for completing the article. Mustapha Arslane was responsible for conducting the experiment, while Mansour Rokbi worked on the elaboration of composite materials. Jean-François Chatelain contributed to the discussion and played a significant role in the final draft of the article. All authors carefully reviewed and approved the final manuscript.

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Data availability All data presented in this paper are available.

Code availability Can be made available upon request.

Declarations

Ethics approval Not applicable.

Consent to participate All authors contribute and participate in the work carried out in this paper.

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Competing interests The authors declare no competing interests.

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