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A study on the drilling process of hemp/epoxy composites by using different tools

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Abstract

As result of the increasing environmental awareness, the interest of bio-composite materials is growing rapidly in the last years in order to use them in various engineering application fields.
For some of these applications, drilling is often required to facility the assembly of the parts and to make final products. However, drilling can induce a number of problems such as delamination, pull-out and strength reduction depending on the used cutting tools and cutting process parameters that can negatively affect the final product properties.
Therefore, in order to reduce these problems on hemp/epoxy composites the aim of this study is to evaluate the effect of both the drilling parameters and tools on the drilling forces and delamination factors.

Keywords: Hemp; Biocomposites; Drilling; Delamination factor

1. Introduction

Due to the increasing environmental awareness, depletion of petroleum resources, disposal problems after use, and introduction of new rules and regulations by legislative authorities to satisfy the demands of the society, the new products must minimize the environmental impact.

This aspect is especially relevant in the composite manufacturing field, where petroleum polymers and synthetic fibres are still widely used [1,2].

This concept is directly connected with an efficient use of the material and energy resources, waste management and with the use of products and technologies with less impact on the environment.

In this context the interest for the use of natural materials is increasing more and more in the last years with the aim to replace synthetic or petroleum materials.

In particular, natural fibers are becoming an interesting alternative reinforcing filler in various areas of polymer composites due to the increased emphasis on sustainability and on their advantages over synthetic fibers: low density, high specific strength and stiffness, lower manufacturing cost than synthetic fibres, less tool damage during processing, low emission of toxic fumes when subjected to heat and during incineration at end of life and their availability as a renewable resource [3–5]. Therefore, it is clear that there is still need to investigate and to increase their engineering application fields.

Among various kinds of natural fibres, the hemp is one of the most attractive due to its interesting properties, high cellulose content and low costs. In addition, the hemp plant is characterized by the ability of extracting heavy metals from the soil makes [6] and the environmental conditions required from its cultivation allow the easy growth of this plant around the world.

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The hemp fibre had a considerable history in terms of providing high tensile strength, especially in the use for roping, and in being part of a large productive system [7].

After a few decades of oblivion, due to drug production-related issues, the availability of varieties with low tetrahydro-cannabinoids (THCs) content allowed to the hemp production to resume. Therefore, it is now necessary to raise up the profile of this fibre use towards more engineered components, which can be interesting in several fields, including automotive, building and leisure sectors[8].

Regarding the matrix, both thermoplastic and thermoset polymers have been widely used as matrices of natural fiber composites (NFCs): thermoset resins (e.g., epoxy, polyester, phenolic, and polyurethane) are used for NFCs in applications where higher performance is required[2].

Although composite parts are made to near net shape, a large number of holes are often required for assembling different parts [9]. Therefore, drilling is one of the most ordinary machining operations and then the control of the hole quality is a relevant question, particularly considering that differently from traditional materials, the presence of fibers produces cracks and delamination problems into the laminate that can severely affect the mechanical properties of the structural parts [10,11].

Therefore, many research works focused the attention on the reduction of the hole damages of composite laminates after drilling; the most frequent forms of investigated damaged are: delaminations, peel-up and push-down mechanisms, micro-cracks and matrix burning [12,13]. Among all the above said defects caused by drilling, the delamination is one of the most critical, because it results in poor assembly tolerance and reduces the structure integrity of the material [14,15]. Indeed, this defect is responsible for the rejection of around 60% of the components produced in the aircraft industry [14,16].

A lot of techniques are utilized to measure the delamination after drilling composites, such as optical micrograph, C-Scan and photography. Even if the C-Scan method is very accurate and allow to observe the internal damages, due to the simplicity and fastness respect to the C-Scan method, the optical micrograph is very often preferred to the C-Scan, so the most utilized parameter to evaluate the degree of damage on the composite at the entrance and the exit of a hole is the delamination factor, F_d.

Therefore, the determination of the delamination factor obtained by observing only the top and bottom surfaces of the laminate via micrographics or photographs is a simple way to have a qualitative evaluation of the hole quality, and then to study how it is in relation with process parameters is very interesting. For this reason, several researchers studied the machining of composite materials and evaluated the damage considering the delamination factor [15–17].

In summary, from the literature review, it emerged that the study of the drilling process of NFCs needs of further investigation.

To this aim, this work is focused on the study of the drilling process of hemp/epoxy biocomposites to produce holes 6 mm in diameter under different cutting conditions that mainly differ in the cutting speed, feed rate and tool type.Both the cutting forces and the delamination factor were considered and correlated with the process parameters.

2. Materials and methods

2.1. Work Piece Material

Hemp fibers in form of woven fabrics with areal weight of 160 g/m^2, were impregnated with an epoxy resin SX10 (supplied by Mates Italiana srl).

Before impregnation, the hemp fabrics were soaked in 2% NaOH solution at room temperature for 30 min. After treatment, fibres were copiously washed with water to remove any traces of alkali on the fibres surface and subsequently neutralized with 1% acetic acid solution and then dried in an oven at 60°C for 12 h, according to other researches methodologies [18–21].

The impregnation of the reinforcement, constituted by 10 fabric layers, was obtained through the infusion technique. The produced laminates had a thickness of 3.8 mm and a volume fibre content equal to 35%.

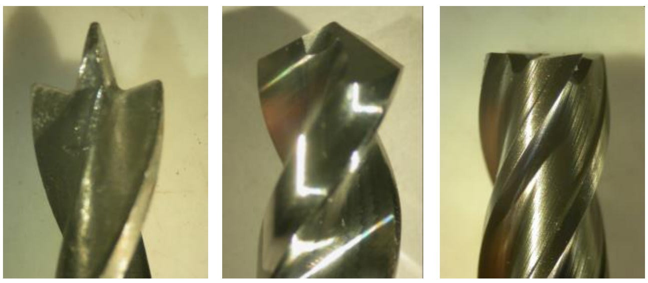
2.2. Experimental procedure

The experimental campaign was carried out by using a five-axis computer numerical control machine CNC (C.B. FERRARI) and different drilling tools 6 mm in diameters showed in Fig. 1. The composite laminate was placed on a MDF plate in order to reduce push-down effects.

For each tool type, the experimental campaign was carried out according to the design of experiment (DOE) showed in Table 1.

Table 1. Process parameters adopted for the experimental campaign.

Feed rate, *f* [mm/rev]	Spindle speed, *n* [rpm]
0.05	500
0.10	1000
0.20	2000
0.40	4000



a) b) c)

Fig. 1. Wood drilling (a), twist (b) and milling (c) tool.

In order to study the trend of the force during the drilling process, the thrust forces, F_z, was recorded by using a KISTLER 9257 load cell. Because of in the drilling process the push-down defect effect is more severe than the peel-up one, according to other works [14,22] the exit hole surface of each hole were observed for the estimation of delamination factor, F_d. This is defined as the ratio between the maximum delaminated diameter (D_{max}) and the nominal one (D_0), as indicated in equation (1).

$$F_d = D_{max} / D_0 \quad (1)$$

3. Results and discussion

Fig. 2 shows the typical trend of the forces acquired during the manufacturing of a hole by using the different tools. The small oscillation in the recorded signals is explained by the cutting mechanism of the composite laminates, indeed the angle between the instantaneous velocity vector of the cutting lips and the fiber orientation, i.e. the cutting angle, changes instantaneously. Therefore, the magnitude of the force varies with these changes.

In order to evaluate the influence of the process parameters on the reached forces and correlate these ones with the degree of damage induced during the drilling process, a representative value of the axial force has to be taken into account. To do this, the maximum value of the thrust force reached during the drilling of the biocomposite laminate were considered and hereafter indicated with F_z .

In Fig. 3 the mean of F_z values, for each drilling tool, as function of the feed rate are plotted.

It is possible to note that for each drilling tool, the mean value of the maximum thrust force decreases as the spindle speed (then the cutting speed) increases passing from 500 to 1000 rpm. This is a conventional and expected trend because the increasing of the cutting speed involves in the decreasing of the undeformed chip thickness and then of the thrust force.

However, when the spindle speed further increases (i.e. from 1000 to 4000 rpm) the values of force increases too; this trend is instead unexpected.

In this spindle speed range the thickness of the undeformed chip decreases so much that the cutting edges do not work efficiently. The fibers are then bended and pulled instead of cut. Similar considerations can be done to explain the effect of the feed rate on the thrust force.

Considering the drilling process of composite materials reinforced by other and more brittle fibers like carbon and glass, an increase of the thrust force with the feed rate is usually observed. Conversely, when natural fibers are considered, due to their ductile behavior, in the range of investigate parameters, as the feed rate increases the efficient of the cutting edge decreases and the fibers tend to be bended or pulled instead of cut.

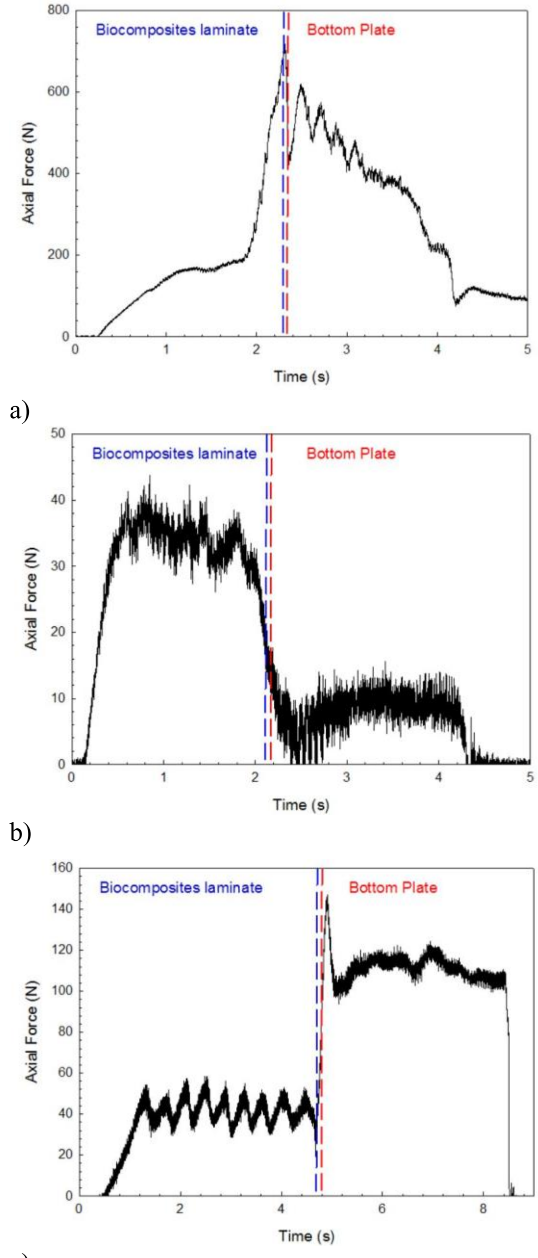
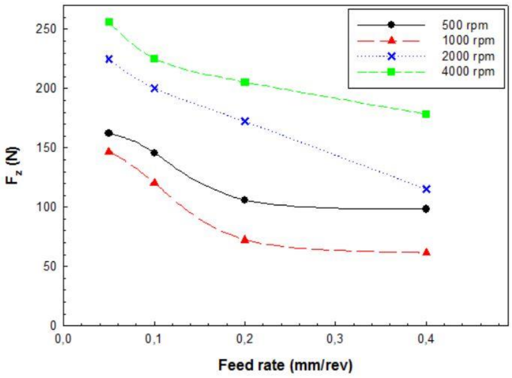


Fig. 2. Typical trend of the thrust force recorded during the process by using the wood drilling (a), twist (b) and milling (c) tool.

This phenomenon is especially relevant considering the wood tool (Fig.1a). Fig. 4 show the exit hole side of holes obtained by using the twist tool at the minimum values of feed rate and cutting speed, f = 0.05 mm/rev - n = 500 rpm, (Fig. 4a) and with their maximum values, f = 0.40 mm/rev - n = 400 rpm (Fig. 4b). In the latter it is evident the presence of delamination, pull out and broken fibers. Regarding the wood drilling tool (Fig. 1a), the exit hole surface generally showed a poor quality, independently from the process parameters. With this tool, additionally to delamination and broken fibers present for each process conditions, the presence of burned fibers at the maximum spindle speed were also highlighted, as shown in Fig. 5. This aspect cannot be neglect when vegetable fibers are considered as reinforcement; as known these fibers due to their cellulosic content are very sensitive to high temperature.



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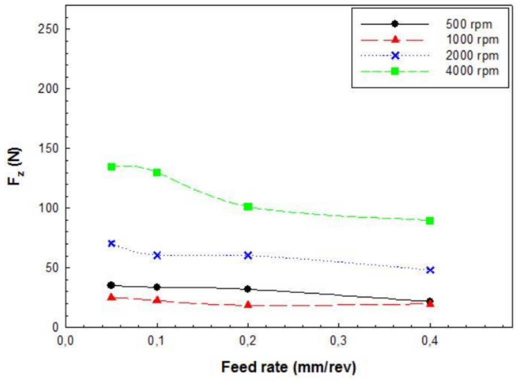

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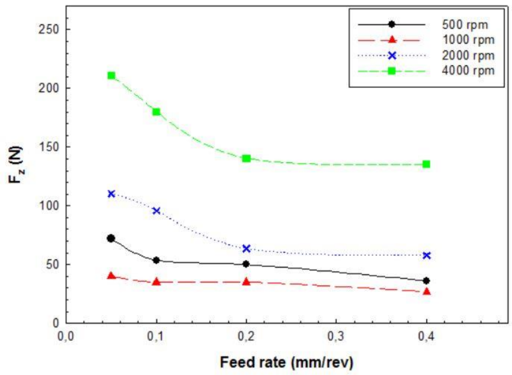
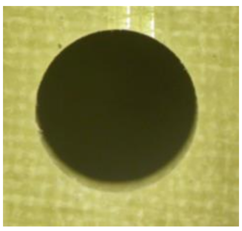


c)

Fig. 3. Trend of the thrust force versus the feed rate for each tool: wood drilling (a), twist (b) and milling (c) tool.



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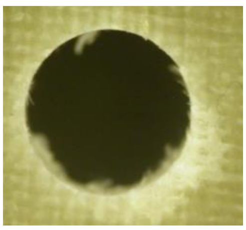
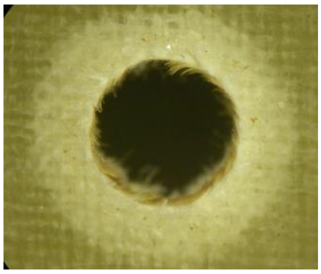
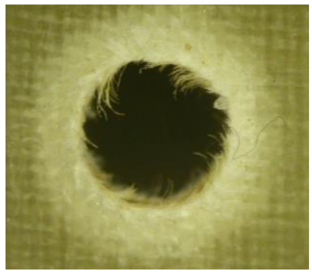


b)

Fig. 4. Typical hole obtained by using the twist tool at minimum (a) and maximum (b) feed rate and spindle speed

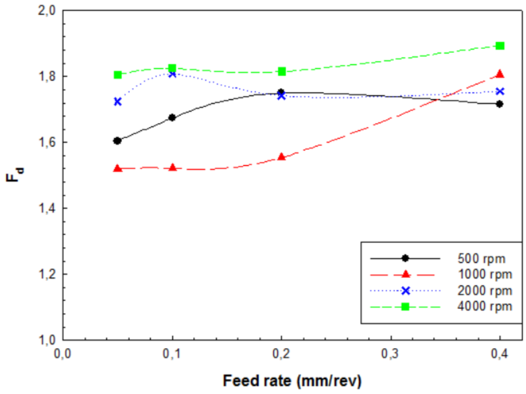


a)

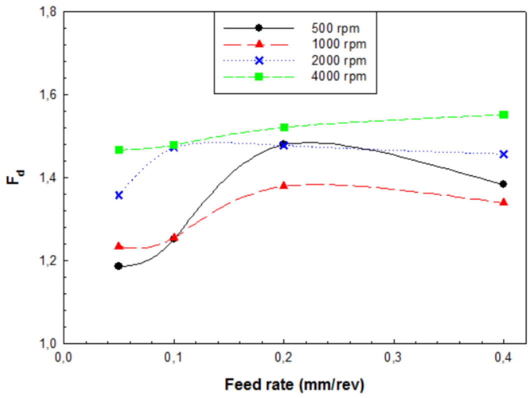


b)

Fig. 5. Typical hole obtained by using the wood drilling tool at maximum (a) and minimum (b) feed rate at 4000 rpm.



a)



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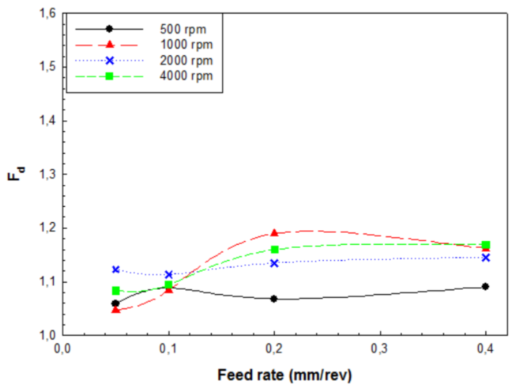

c)

Fig. 6. Trend of the delamination factor versus the feed rate for each tool: wood drilling (a), twist (b) and milling (c) tool.

It was not possible to correlate the value of the delamination factor with the values of the thrust forces, especially when the exit hole surface is characterized by a very low quality (i.e. when the wood drilling tool is considered).

However, a significant difference in the F_d values obtained with the different tools was evidenced.

In Fig. 6 the mean values of the F_d as function of the feed rate were reported. Considering that the type of defect investigated (delamination on the exit hole side) is emphasized by pointed tip, the milling tool showed the lower delamination factor (Fig. 6c) thanks to the flat tip that characterize the tool surface; contrary, the wood drilling tool showed the highest F_d value (Fig. 6a).

4. Conclusions

Holes 6 mm in diameter on hemp/epoxy composite laminates were produced by using wood drilling, twist and milling tool at different spindle speed and feed rate. The results showed that the thrust force was not correlated with the process parameters as for drilling of CFRPs or GFRPs composites except for a spindle speed comprising in the range 500-1000 rpm. At higher speed, i.e. 2000 and 4000 rpm, when natural fibers are considered, due to their ductile behavior, as the feed rate increases the efficient of the cutting edge decreases and the fibers tend to be bended or pulled instead of cut. For the same reason a clear relationship between process conditions and F_d values were not detected. Among the different tools under investigation, the use of the milling tool guaranteed the best hole quality proved by the lowest F_d value, the absence of broken and burned fibers and delaminations.

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