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A Review of the Machining Process Parameters for Natural-Fiber-Reinforced Composites †

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Abstract: The important properties of natural composites include but are not limited to their strength-to-weight ratio, durability and biodegradability. Natural composites are inhomogeneous by nature; drilling operations are difficult because the drill bit must alternately pierce through the layers of the matrix and fibers. This may cause delamination, fibers are pulled out and the matrix breaks, etc. In numerous types of research, it is seen that the spindle speed, drill diameter and drill geometry greatly influence the delamination factor and feed rate, affecting the surface roughness. In this review, the impact of the drilling and milling parameters on various natural-fiber-reinforced composites are taken into account and assessed.

Keywords: natural fiber; NFRC; milling operation; drilling operation; machining parameters

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1. Introduction

Composites are heterogeneous mixtures of two different materials combined at a macroscopic level. Natural composites have a variety of important characteristics, such as less thermal expansion, corrosion resistance, a light weight, a better strength-to-weight ratio, fatigue resistance, wear resistance and ease of machining using conventional machining methods. The development of such eco-friendly materials can replace synthetic materials. The machinability of natural-fiber-reinforced composites (NFRCs) is significantly influenced by factors such as: (i) the type of fibers used in the composite, (ii) the mechanical characteristics of the fibers and (iii) the thermal characteristics of the fibers. The intended quality of the NFRC parts processed during operations is ensured by properly selecting the machining parameters. This study reviews articles that have studied the drilling and milling operations on natural-fiber-based composites. In composites, these operations are challenging since they lead to composite delamination. Hence, studies on the drilling and milling operations on composites are important.

2. Drilling Operations on NFRCs

In composite materials, there have been several techniques for drilling holes; however, conventional drilling is the most widely utilized technique. Composite drilling is considered to be a major process to study in machining natural fibers because of its proneness to delamination under forces such as shearing forces, traction forces and pushing forces. Some other issues that affect the surface finish include fiber/resin elongation and poor hole wall surface roughness. Because NFRCs have a low heat damage sensitivity and are very fragile in the direction of thickness, composites are difficult to drill. If the surface comprises unidirectional material, composites are particularly prone to surface splintering and delamination. Splintering and subsurface defects, as well as internal hole surface quality, are directly related to the delamination factor [1]. Damage measurements on NFRCs can be made either directly or indirectly. The variables that can be measured directly include the delamination factor and surface roughness. Examples of indirect measures include estimates of the damage enacted by the force and power produced during various operations.

2.1. Direct Assessment

2.1.1. Delamination

According to Durao et al., reducing delamination can be accomplished by carefully choosing the tool material, shape and certain machining parameters, which include the cutting speed and feed rate [2]. The drill's edge will make contact with the laminate as it begins to pierce the surface. This causes the flutes of the drill to tilt, creating an axial peeling force that pulls the plates apart and leaves a peeling zone on the laminate's top surface. The sharpening angle and cutting speed of the drill have the greatest effects on the amount of delamination. The feed rate and drill diameter play a significant part in the aforementioned mechanism, which occurs before the completion of the drilling of the laminate [3].

2.1.2. Surface Roughness

The functional performance of the machined components and the manufacturing costs are both significantly impacted by the resulting surface roughness. To achieve the appropriate surface roughness, many studies have been carried out to improve the process variables [4]. Ramesh et al. drilled on hybrid composites that contained sisal, jute, glass and bagasse fibers, utilizing a variety of drill geometries [5]. They claimed that compared to the other two drills, the brad spur drill outperformed them in terms of there being less thrust force and less damage around the edges of hole. In contrast, the composite laminate sustained more damage from high-speed steel twist drills. Bajpai, Singh and Debnath et al. discovered that the hole surface created when drilling using a trepanning instrument was free of any uncut or loose fibers [6,7].

2.2. Indirect Assessment

2.2.1. Cutting Forces

The force generated during various machining operations are significantly influenced by the specific machining characteristics as follows: (i) cutting speed, (ii) cutting feed, (iii) tool geometry and (iv) the stiffness of the cutting tool. According to Jayabal and Natarajan, for coir fiber-reinforced composites, using a smaller-diameter drill and operating it at a slower feed rate and higher spindle speed resulted in the lowest drilling force [8,9]. When penetrating NFRCs composed of pure banana and all-purpose polyester fibers, Patel et al. discovered that the feed rate and nose angle both increased the tensile force [1]. When drilling composite laminates, the peel-up and push-down mechanisms involve thrust forces as their primary cause of delamination. The generated thrust forces and torque are mostly impacted by changes in the drill's geometry since the drilling mechanism differs depending on the drill's geometry [10]. Jayabal et al. created hybrid composites with short coir/glass fibers and polyester as the reinforcement [11]. They investigated using a high-speed steel twist drill to drill this composite. According to the machining data, the speed of the spindle and diameter of the drill have less impact on the reaction forces than the feed rate.

2.2.2. Tool Wear Mechanisms

Drilling coir polyester composites required the best cutting settings, according to Jayabal and Natarajan [8]. They discovered that to drill holes without delamination, the minimal wear to the tool was 0.1198 mm for a 6 mm diameter, a 600 rpm cutting velocity and a 0.3 mm/rev feed rate. According to Jayabal et al., the type and orientation of the fibers affect how deeply a drill may penetrate a composite material [11,12]. In addition, the key characteristics determining the tool wear in the model for tool wear were the drill diameter and feed rate, whereas speed had little effect and had little interaction with the other parameters. The reduced cutting forces and torque caused by a quicker spindle speed reduce the delamination at the entrance and exit of a drilled hole.

3. Milling Operations on NFRCs

As composite parts are often mesh-based, milling is not the most widely utilized machining technique for producing fiber-reinforced plastic parts [13,14]. Using the hand layup process, Vinayagamoorthy and Rajeswari designed a new composite plate using natural jute as the fiber and isophthalic polyester as the matrix [15]. Babou et al. looked at how fibers affected the cutting parameters (cutting speed and feed rate), as well as the delamination factor and surface roughness, in end milling [16]. The feed rate and cutting speed were shown to have the biggest effects on the delamination factor and surface roughness. Chegdani et al. focused on how the natural fiber type affected the tribological traits during profile milling [17]. A wood–plastic composite had a content of wood particles higher than 70%, and the remaining polyethylene matrix underwent mechanical processing by Zajak et al. [18]. The rotational speed and feed were two factors that were altered throughout processing. For a superior surface quality, a wider tool nose radius is advised [19].

4. Challenges in the Machining of NFRCs

According to Debnath et al., and Balaji et al. [20,21] and other researchers' findings, drilled NFRCs display less delamination than glass-fiber-based composites. The condition of the surface of the component to be machined and drill tool wear are significant factors during drilling (in the machining process). Induced delamination, fiber pull-out, uncut fibers and breakouts all impact the surface quality. For processing delamination evaluation, taking clear photos are crucial. While refined stratification is more precise, the normal stratification coefficient is the most often utilized coefficient for stratification assessment. Nevertheless, it is important to categorize the degree of damage into three phases to achieve a refined peel coefficient [22]. Hence, choosing a suitable exfoliation factor is a challenging process in and of itself. Processing and analyzing clear photographs is now considerably simpler and more precise. The feed rate was discovered to be the process parameter that influenced delamination more than any other.

5. Conclusions

NFRCs are easily employed in non-critical structural applications in the building, transportation and consumer goods sectors. Natural fibers' economic benefits should also be taken into account. Numerous manufacturing procedures might be employed to create a variety of NFRCs, based on the kind of matrix substance. NFRCs are typically net-shaped products; thus, mostly only auxiliary production processes like drilling are necessary before they may be approved for a particular use. As drilling has an impact on NFRCs' structural integrity, the right process parameters, including the tool's material and shape, should be selected with the utmost care.

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