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Editorial

Manufacturing of Fibrous Composites for Engineering Applications

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Fibrous composites are advanced engineering materials featuring the impregnation of fiber phase with a polymer matrix base to yield enhanced properties. They can be categorized in terms of the fiber type, such as aramid-fiber-reinforced polymer (AFRP), carbon-fiber-reinforced polymer (CFRP), glass-fiber-reinforced polymer (GFRP), Kevlar-fiber-reinforced polymer (KFRP), etc. They can also be classified into continuous and discontinuous fiber composites. In general, discontinuous fiber composites show better isotropic behavior than continuous fiber composites, as short fibers can enhance the matrix in every direction [1]. The fibrous composites are often fabricated with a polymer matrix, which can be either thermoset polymers or thermoplastic polymers. The thermoset polymers have the property of becoming permanently hard and rigid when heated or cured. The thermoplastic polymers entail the linear chain of the molecular structures; thus, they can be recycled and reused when heated [2–4].

Since fibrous composites show higher specific mechanical and physical properties than conventional alloys and steels [1,5], they are very attractive in modern aerospace industries [6–9]. For instance, CFRP composites are often employed in the aircraft wing boxes, horizontal and vertical stabilizers, and wing panels [10]. GFRP composites are mainly used in the fairings, storage room doors, landing gear doors, and passenger compartments [10,11]. Reports indicate that most international aircraft manufacturers, including Airbus and Boeing, are seeking the use of fibrous composites to fabricate large load-carrying structures favoring the energy saving of new-generation airplanes. Despite the net shapes of molded fibrous composites, secondary manufacturing operations are still required to create the target shapes and desired quality [8,9,12,13]. However, fibrous composites are extremely difficult to machine, as they possess rather poor machinability compared to conventional alloys and steels. The term "machinability" signifies the degree of difficulty of cutting a workpiece material with qualified quality. The poor machinability of fibrous composites may arise from the inherent anisotropic behaviors of the fiber/matrix system and the heterogeneous architecture of the composites. The most-used machining operations for shaping fibrous composites mainly include trimming, turning, milling, and drilling. Since the reinforcing fibers and the matrix base show completely different properties, machining of these composites has posed huge challenges to the current manufacturing community. The specific issues associated with the cutting of fibrous composites are difficult chip removal, poor surface quality, and rapid tool wear.

Chip separation mode is a critical procedure determining the eventual cutting responses of workpiece materials. However, the cutting mechanisms of fibrous composites are much complicated than those of conventional metallic alloys, as the composite separation modes are fiber-orientation dependent. Many studies have attributed the fiber-orientation-dependent chip removal to the effects of the fiber layup on the properties of chips under specific cutting loads. Consequently, producing consistent surface finish of cut composites is very challenging. The fundamental chip removal modes encountered in composite machining mainly include shear-induced fracture, bending-induced fracture, and fiber/matrix interfacial debonding, depending significantly on the varying fiber cutting

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angle [14–16]. Additionally, cutting forces and machining temperatures are also firmly related to the variation of the fiber cutting angle during the machining of fibrous composites. Normally, lower magnitudes of cutting forces/temperatures can be produced under the along fiber cutting relation, in which the fiber cutting angle is acute. In contrast, chip separation occurring under the against fiber cutting relation is often considered unfavorable for producing desired surface quality for fibrous composites. Therefore, selecting a proper fiber-cutting angle plays a crucial role in the high-quality machining of fibrous composites.

Poor surface quality is another critical issue associated with fibrous composite machining. Since the removal mechanisms of fibers and matrix are different and change continuously with the fiber layup, even under the action of the identical cutting edges, serious defects involving delamination, burrs, tearing, surface cavities, and glass transition failure easily occur, which can greatly deteriorate the quality of machined composite parts [17]. Additionally, the aforementioned damage not only reduces the surface finish and assembly tolerance, but also affects the fatigue strength of cut holes, accounting for a large proportion of part rejections [18–21]. Moreover, delamination and tearing are often noted as the most critical failures of fibrous composites, and should be carefully suppressed during the machining operations as they cannot be repaired once they occur. Functionally designed special tools are feasible for minimizing the generation of various cutting-induced damages for fibrous composites. The use of optimized cutting parameters can also benefit the improvement of the surface quality of cut fibrous composites. To deal with cutting-induced damages, future endeavours must optimize the process parameters, develop functional cutting tools and use advanced machining techniques for fibrous composites.

Rapid tool wear is a crucial issue when cutting fibrous composites, as hard fibers induce severe abrasions/modifications onto the tool surfaces and lead to the blunting of tool edges. The primary wear mode frequently encountered in the machining of fibrous composites is abrasion wear in the form of cutting-edge rounding (CER) [22–25]. Additionally, CER has become a significant indicator for the assessment of tool wear, particularly for drilling fibrous composites, which provides a more accurate quantification than the conventionally used wear-width indicator [1]. As the composite chips are often separated within a small tool–chip interface, crater wear shows no ability to take place. Progressive abrasion wear often results in undesired consequences when machining fibrous composites, such as increased cutting forces, excessive machining temperatures, deteriorated surface quality, and reduced tool life. Moreover, the dominant tool failure in machining fibrous composites is edge chipping or coating peeling during the chip removal process. Developing superior tool coating materials and optimizing tool geometries would be a feasible solution to the tool wear issues for fibrous composites.

In the end, with the rapid development of manufacturing technologies, various types of advanced machining methods have been developed in recent years, providing new prospects for achieving damage-free machining of fibrous composites. For instance, helical milling, variable feed drilling, and ultrasonic vibration-assisted machining have emerged and have been extensively used in the machining of fibrous composites, which yield outstanding performances in suppressing cutting-induced damages. Moreover, intelligent manufacturing technology, which has become a hot research focus in both academia and industry, can be applied to composites machining to realize the in-situ detection and high-precision control of online machining status. Then, high-efficiency and high-quality machining of fibrous composites can be accomplished.

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