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Review Article

# Drilling on fiber reinforced polymer/nanopolymer composite laminates: a review

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ABSTRACT

Among various machining operations, drilling is the most commonly employed machining operation for polymer composite laminates owing to the need for joining structures. Work with commercial composites has identified numerous parameters during the drilling operation that can influence the drilling factors and the material damage. The present paper gives a precise review of drilling on current state of fiber reinforced polymer as well as nanopolymer composite laminates. Specifically, the influence of machining parameters, tool geometry, tool materials and tool types on the cutting force generation and delamination mechanisms. Based on the comprehensive literature survey from the past few years, it is noticed that limited research has been made and published concerning to nanopolymer composite drilling and has led to a partial understanding of the cutting mechanics activated in machining/drilling. Some key contributions such as experimental and numerical studies are urgently demanded to address accurately various projections in drilling of nano-particle reinforced FRP composite laminates.

## 1. Introduction

Composite materials are made-up of least two distinct intended materials which together improve product performance and lower manufacturing cost [1]. Many materials, continuously designated by other terms are also considered composites including clad, coated metal tools, etc. [2]. Nowadays, FRP composite laminates are the materials of option for many engineering applications; namely, automotive parts, sporting goods, aerospace components, consumer goods, marine and oil industries, due to their special physical and mechanical properties [3].

The basic initiative behind the learning of FRP composite laminates mainly comprise Glass Fiber Reinforced Polymer (GFRP) composite laminates, Carbon Fiber Reinforced Polymer (CFRP) composite laminates and nanopolymer composite laminates and their applications are based on the possibility of using materials with definite characteristics and ultimate properties that are not found in any of the raw materials [4].

The most recent commercial aircraft designs propose a reduction in weight about 50% by replacing the primary

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structural components with fabricated nanopolymer composites. Using light weight and elevated strength composites are essential in order to achieve the reduced fuel consumption and better passenger comfort goals of these future commercial aircraft design innovations [5]. In generally, all the composite materials will undergo some machining processes in their fabrication procedure or its specific engineering application. With the concern of the current industry, drilling is the most frequently used hole making operation for assembly of structures or components. Various industries; such as automotive, aerospace, marine and oil industries, have already started the utilization of nanocomposites in their structures.

The composite damage called delamination is an inter-ply failure phenomenon induced by drilling, which is a very serious problem and has been recognized as an unexpected major damage when drilling composite laminates [6]. Due to the non-homogeneity, multi-phase structure and anisotropic nature of the composites lead to an inter-ply failure during drilling [7]. With that reason, about 60% of the drilled holes on composites are rejected at the initial stage only [8].

In addition to delamination, sub-surface deformation is another important drilling induced damage while composite machining. Interfacial debonding, matrix deformation, fiber pullouts, matrix crazing, cracking, hole shrinkage and spalling are few examples of sub-surface deformations [9,10]. So, in order to improve the product performance and structural integrity of machined holes, the material defects such as sub-surface deformation and delamination has to be trim-down by proper selection of cutting parameters, tool geometries, tool types and cutting conditions [11,12]. Nevertheless, the structural integrity is also strongly depending on fiber matrix interfacial interactions, fiber orientations, cutting directions and tool wear.

Zhang et al. [13] have investigated the spalling, fuzzing exit sub-surface deformation defects during drilling of unidirectional as well as multi-directional CFRP laminates with HSS twist drill. Spalling and fuzzing are considered as the major exit damage mechanisms during drilling of FRP composite laminates and these damages increase with an increase in feed rate and decrease in spindle speed. Spalling at hole exit is usually a severe damage and it is bigger for UD-CFRP laminate as compared to multi-directional CFRP laminate under the same drilling conditions. Khashaba et al. [14] reported that catastrophic shear failure of the composite layers has been done due to the higher feed rates and cutting temperatures resulting poor surface integrity, lower bearing strength of machined holes while GFRP composite drilling. Heisel et al. [15] investigated the influence of point angle, cutting parameters on cutting forces and drill hole quality i.e. frying, burr formation and delamination have been investigated while drilling of CFRP laminates. The increase in point angle increases cutting temperature resulting frying of epoxy matrix with poor quality drilled hole and severe burr formation.

Brinksmeier et al. [16] tried three (Aluminum/CFRP/Titanium) different materials to investigate the surface quality of boreholes after orbital and conventional drilling processes. Compared to the conventional drilling process, orbital drilling gives the finest borehole surfaces with tiny matrix cracks and without fiber breakage under lower cutting temperatures and large cutting speeds. Arul et al. [17] have utilized acoustic emission technique to improve the quality and surface integrity of the machined hole during drilling on woven glass fabric/epoxy composite laminates. The effect of cutting parameters on axial force, flank wear and their influence on the hole shrinkage was monitored and correlated with AE parameters. Abhishek et al. [18] employed PCA-fuzzy integrated with Taguchi's philosophy technique to optimize the cutting parameters for trim down the delamination, sub-surface damage defects while drilling of CFRP composites. Eneyew and Ramulu [19] have studied the effect of cutting parameters, cutting direction and fiber orientation on the drilled hole surface quality in the UD-CFRP composite laminate. The lower value of thrust force was identified at a rotational angle of 135° and 315°, fiber pullouts are observed at two cutting regions where the cutting direction and fiber orientation interface angle is from 135° to 175° and 315° to 355°. The examined sub-surface damages i.e. delamination, surface roughness, fiber pull outs are captured through SEM.

Generally, when the drill tool is commerce with the FRP laminate, the drill chisel edge generates a nominal thrust force in the axial direction and subsequently initiates the surface deformation due to the frictional rubbing action of tool and work-piece [20,21]. This deformation can remain the same upto the last two piles of composite laminates and increases drastically for further drill extent due to the smaller uncut chip thickness, lower resistance to deformation and stiffness. At this instant, the exit side of the laminate undergoes severe damage of matrix and initiation of crack propagation resulting poor surface integrity [22,23]. Tool-work piece Tribological interactions are also reasons for sub-surface deformation of the composites and these thermo-mechanical mechanisms can be reported in the form of tool wear [24]. Abrasion is considered as chief tool wear mechanism during drilling on FRP as well as nano composite laminates and it can be occurred mainly on rake and flank face of the tool cutting edge causing severe abrasive wear on the flank face resulting poor structural integrity and long-term performance deterioration of the machined surface [25]. Inoue et al. [26] inspected the effect of tool wear on the sub-surface deformation in drilling of small diameter holes of GFRP composites. Based on experimental results, it was concluded that higher flank wear occurs at lower feed rates and larger cutting speeds.

So, in order to eradicate the defects induced during drilling on conventional composites such as GFRP and CFRP, these composites are modified with secondary reinforcements called nano-fillers; namely carbon nano-fibers (CNFs), carbon nanotubes (CNTs), polyamide 6, Polypropylene-Silicon for the property enhancement of composite laminates. A typical layout of classification of composite materials is shown in Fig. 1.

Abrao et al. [27] have made an extensive literature on drilling of FRP composites. Aspects such as tool geometry, machining parameters and their influence on thrust force, torque and delamination are examined in the review. Liu et al. [4] provided a review on mechanical drilling of composite materials such as FRP (CFRP, GFRP) as well as fiber metal composite (FML) laminates. This review paper also encloses with grinding drilling, Vibration-assisted twist drilling (VATD) and high speed drilling (HSD) operations of both FRP and FML composites.

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