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Effect of Fillers on Machinability of Polymer Matrix Composites: A Review

Kiran M D[1*], Lokesh Yadhav B R[2], Keerthi Shetty[3]
[1]Department of Mechanical Engineering BMS Institute of Technology and Management, Bengaluru 560064, India
[2]Department of Mechanical Engineering R.L.Jalappa Institute of Technology, Doddaballapur 561203, India
[3]NMAM Institute of Technology (NMAMIT), Nitte (Deemed to be University), Nitte - 574110, India
*kiranmdg@gmail.com

Abstract

Polymer matrix composites have become emerged materials for innovative structures in a variety of industries, such as the automotive, aerospace, and marine industries due to their unique mechanical and physical characteristics. The machinability of these composites has a considerable impact on performance of materials. The machinability of polymer composites largely depends on reinforcements/fillers composites. The present review paper gives the precise review on influence of reinforcement and functional fillers on machining of polymer matrix composites in terms of its mechanism and machining responses. This includes the effect of fiber orientation and fiber/filler loading on machining response of polymer composites. in addition, the different machining process and performance competences polymer composites have been reviewed. The comprehensive review shown the mechanical properties and machinability of the polymer composite are significantly influenced by the fiber orientation. Additionally, the physical properties of the fibers and fillers, size, length, diameter and dispersion of fibers/fillers were found to affect the machinability of the polymer composites formed. At the conclusion, a thorough assessment of the results and projections for the future are provided, which may help this machining technique advance further in the future.

1. Introduction

Composite materials are consisting two or more dissimilar materials and have properties that cannot be attained by a single material. In the composite materials one material performs as the matrix and another one material acts as reinforcement. The matrix of composites protects the reinforcement and distribute the stress among the reinforcement to achieve the required strength of the composite part. The reinforcement achieves the strength of the composite in particular directions and confirms the excellent mechanical properties composite parts. Polymer matrix composites have substituted several conventional materials in different applications including marine, automotive, and aerospace applications [1]. Polymer matrix composites consist of thermoset/thermoplastic as matrix materials and fibers/particulates are reinforcements. The properties of polymer composites are determined by the type of matrix and reinforcements, the geometry of reinforcements (short/long fibres or fabric, particles), the amount of reinforcement and matrix used in composites. Polymer matrix composites reinforced with fibers and fillers exhibits improved strength-to-weight ratio [2, 3]. Addition of fillers in the polymer matrix composites plays key role in improvement of the mechanical properties of composites. The strong interface between constituents causes the effective load transfer [4]. Along with mechanical properties thermal and electrical properties are inherent with the filler for biomedical application, structural application, aerospace application, etc [5-8].

Machining of polymer matrix composites is a difficult process due to their nonhomogeneous and anisotropic nature than the conventional materials. These characteristics of polymer composites certainly makes them tough to machining and it leads to significant damage of material, poor surface finish and dimensional inaccuracy [9,10]. The various machining parameters such as tool geometry/material, depth of cut and fiber orientation of the composites plays the important role in machining of composite materials [11].

In present review article gives the precise review on effect of reinforcement and fillers on conventional machining such as drilling, turning, and milling. And reviewed effect of filler properties, size, shape, and filler loading on machinability of polymer composites.

2. Machining processes of polymer matrix composites

The conventional machining processes, such as turning, milling, and drilling are used to achieve the required shape and size of polymer composite parts. Many researchers carried out study on machining of polymer matrix composites to reduce the defects occurs during machining process [12]. The machining process of polymer matrix composites is mainly depending on material constituents, cutting tool geometry and machining parameters such as feed, depth of cut, speed etc. [13].

2.1 Effect of fillers on turning of polymer matrix composites

Turning process is used to obtain the cylindrical shape as per dimensions with essential tolerances. Turning process used in composite manufacturing industries especially for finishing of the cylindrical shape products [14, 15]. During turning of polymer composites the surface finish of the product is largely depending on feed rate. The surface finish decreases as the feed rate increases, however the surface finish improved with increase in cutting speed. The higher cutting speed and low feed rate exhibits better surface finish of component. The depth of cut during of polymer composite will not affect the surface finish of product [16,17]. The cutting force during turning and cross-sectional area of chip are related to each other and directly effects the surface finish of the workpiece [18]. Many researchers carried out study on turning of polymer composites. The main problems with turning of polymer composites are surface integrity, hasty tool wear, and significant damages such as delamination or fiber pull-out. To reduce these problems, different filler materials such as graphene, CNT, SiC, fly ash etc. are used as functional fillers in polymer matrix composites. Addition of nano fillers in polymer matrix composites significantly enhances the strength and properties of composites [19]. The feed rate and cutting speeds are the most significant parameters effect on tool wear in uncoated carbides. The surface finish of the CFRP products enhanced at lower cutting force and it achieved by inserting coated and uncoated carbides [20].

2.2 Effect of fillers on drilling of polymer matrix composites

There are many studies carried out on drilling of polymer matrix composites. Fiber pull-out/ delamination surface roughness and rapid tool wear due to thrust force are the major challenges during drilling of polymer matrix composites. Various filler materials are added to matrix to minimise or eliminate these challenges. The mechanical properties of polymer composites will be enhanced with the addition of nano fillers such as graphene, CNTs, clay, fly ash, silicon carbide, boron nitride, etc. In present study, effect of fillers on drilling operations on polymer composites were carried out.

The nano graphene filled polymer composites are commonly used in graphene nanosheets. Addition of graphene with epoxy jute composites improves the mechanical properties and exhibits maximum brittleness 3 wt% graphene. The composites shows improved machinability during drilling operation at entry and exit of tool due to addition of graphene causes the better bonding and lower shrinkage. The damage occurs around the hole at higher wt% of graphene (3 wt%) due to maximum brittleness of the resin [21]. Addition of 1 wt% graphene oxide exhibits better dispersion and it leads to excellent mechanical properties and machinability CFRP composites due to optimum thrust force [22]. Graphene oxide filled CFRP composites shows the improved properties than graphene filled CFRP composites. The graphene and graphene oxides are added to increase the cutting force and cutting torque during drilling operation [23].

Addition of CNT as filler/reinforcement in polymer composites exhibits the excellent mechanical properties [24]. CNT filled composites have greater tensile strength due to crack bridging effect and effective load transfer in composites. Microwave curing of CNT filled CFRP composites shows the lower delamination factor and tool temperature throughout the drilling operation [25]. Addition of MWCN in GFRP composites significantly effects on delamination force at beginning of drilling operation [26]. Feed rate significantly effect on delamination factor and thrust force during drilling operation of GFRP composites. Addition MWCNT enhances the flexural strength GFRP composites and reduces the delamination factor and thrust force during drilling operation [27]. MWCNT filled GFRP composites shows better fracture toughness with low delamination factor at entry side. Addition of MWCNTs in epoxy improves the thermal conductivity and it reduces the built-up edge on wall of drilled hole [28].

Polymer composites filled with nano clay have shown brittle nature and it leads to minimum contact at tool-chip interference and nano clay filled PA6 composites shows lower thrust force during drilling operation [29]. Addition of small wt.% of nano clay also reduces the delamination factor during drilling of polymer composites. The delamination factor increases at higher wt.% loading of nano clay due to weak bonding and higher stress concentration [30].

Addition of fly ash in CFRP composites increases the surface roughness of drilled hole surface. The low density of fly ash creates the weak region in composites and it forms the deep valley when drill bit passes through this region. The lubrication property of fly ash decreases the thrust force and it led to reduced friction between tool and work piece. Delamination factor also reduces with increase in loading of fly ash upto 10wt.% [31]. The force required to drill the composites increases with the addition of SiC, boron nitride filler due to better strength of the composites which increases the thrust force. Addition of ceramic fillers shows lower surface roughness and delamination factor due to strong interference bonding [32,33].

2.3 Effect of fillers on milling of polymer matrix composites

Machining parameters and proper tool selection is very essential during milling operation on polymer matrix composites to reduce the surface roughness, fiber pull-out and delamination [34]. Many investigations have been carried out to select the optimum parameters and fillers to reduce these defects. Addition of Graphene platelets reduces the mean chip thickness which led to easy formation of chips during milling. Graphen platelets loading under 0.2wt.% reduces the tool wear rate due to lubricant property of graphene and requires large cutting force due to better tensile strength and fracture toughness. The graphene presence in epoxy composites enhances the shape accuracy and alters the mode of fracture. Surface finish of milling operation improves with feed per teeth values due to brittleness of plain epoxy. The milling of plain epoxy produces broken chips, which causes the cavities on the milled surface. Epoxy composites filled with graphene exhibits greater surface finish at low feed per teeth due to toughening mechanism of graphene [35,36].

The MWCNT filled composites produces thick and continuous chips during milling operation. The CFRP composites shows lowest surface roughness and highest cutting force due to better thermal conductivity and strong interference between CNT and polymer [37]. The polymer phase in CNT filled composites decides the machining behaviour and shows improved thermal conductivity. Also, addition of MWCNT reduces the thermal softening effect in polymer phase and it leads to improved machining performance at higher cutting speed [38]. Addition of MWCNT filler with GFRP or polyamide 6 composites reduces the surface roughness and delamination factor due to lubricant characteristics of MWCNTs at tool-chip interface and it reduces the matrix debonding and fiber pull-out [39,40]. The many researchers carried out study on effect of other fillers on milling operation of polymer composites. The nano clay filled CFRP composites showed lower surface roughness and delamination factor than unfilled CFRP composites [41]. Cutting forces during milling of polyamide 6 composites significantly affected by $CaCO_3$ nano filler and it reduces the surface roughness due to lubricant property of $CaCO_3$ [42].

3 Conclusions

The present comprehensive review article presented conventional machining operation such
As turning, drilling, and milling of polymer matrix composites and influence of functional fillers on machining of polymer matrix composites. From the review of several studies have
showed that their machinability of polymer composites by conventional machining be contingent on the constituents of composites and machine parameter. This review study it was found that addition of fillers into polymer matrix enhances the mechanical properties due to fillers are stiffer than matrix and addition of fillers improves the interfacial strength between matrix and fibers. The enhancement of mechanical properties depends on type, size, and shape of the fillers and dispersion and loading of fillers. During machining of polymer composites, the matrix materials becomes soft due temperature developed by spindle speed and feed rate tool. Addition of fillers in polymer matrix composites avoids the damage due to crystallization property of filles and it produces the optimal response at tool-chip interference. Addition of filler in different wt.% in polymer matrix enhances the bonding between matrix and fiber which leads to improving machining quality and surface finish of composites.

Achievement of accurate size, shape and surface finish is very important task during machining of polymer composites. Development of polymer composites with better machining performance can achieved with addition of various fillers.

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