Ultrasonic Machining of Carbon Fiber Reinforced Plastic Composites: A Literature Review

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***Abstract*- Carbon fiber reinforced plastic (CFRP) Composites have been widely employed in a variety of purposes, in a variety of industries because of its exceptional abilities. Drilling a number of holes is required in CFRP in the aircraft industry. As a result, developing inexpensive drilling method is critical. Rotary ultrasonic machining (RUM) was used to successfully drill CFRP. By categorizing the findings provided in two angles, this paper investigates literature review and gives a complete evaluation of the improvements in USM of CFRP composites. To begin, the review highlights the majority of the reported investigations from 2012 to 2022 on the basis of used USM process on CFRP material including equipment/ system utilized to conduct experiments, output results and process variables evaluated, and problems investigated. The purpose of this literature study is to emphasize USM's current research position in CFRP composite drilling and thereby provide direction and a foundation for future research.**

Keywords-CFRP composite, Drilling, Rotary ultrasonic machining

1. INTRODUCTION

Due to the rising use of composite materials in numerous industries for example, aerospace and automobiles, composite machining has become more essential recently. Composite materials are made by many synergistic micro-constituents that differ in physical shape and chemical makeup [2]. CFRP are employed in a variety of applications due its excellent properties such as: high ratio of strength to weight, tensile strength, fatigue strength and low thermal conductivity [3]. CFRP materials consist of Polymer as base matrix mateial with carbon fiber serving as the material's reinforcement element. CFRP composite constituents are frequently used in a great number of aerospace components because of their exceptional qualities, which include high stiffness and strength, low weight, and great fatigue resistance. Drilling, the most typical type of machining in aircraft manufacturing is the main application and this is the object of this paper this application may include both small and large components, like clips and doors, as well as wing-side flaps and main body of aircraft [4]. However, everyone knows that drilling a CFRP hole is tough because the material's unique qualities of CFRPs such as, low thermal conductivity abrasive nature and anisotropic structure [5].

RUM successfully accomplished Drilling operation on various Brittle and Ductile materials. These brittle mateials are silicon, alumina, glass, silicon carbide, graphite etc. and ductile materaials are aluminum, stainless steel alloys, tin, copper and composite mateials. The metal bonded diamond drill is used as tool for cutting in RUM. Under an ultrasonic vibration frequency, the cutting tool rotates, and feed rate will be axially toward the workpiece at a feed rate. Coolant is also pumped through the drill's core, cleaning away swarf while leaving workpiece intact at a comparatively less cutting temperature [6].

2. COMPOSITE MATERIALS

Composites are materials that are made by two or more chemically distinct elements are combined on a large scale. For the base material for composites, metal, polymer, or ceramic can be used. The composite is known as a polymer matrix composite (PMC) if the basis material is polymer. CFRP mateials were successfully used in various high perforformance applicaltions whereas traditional materials were also used. Both type materials were used in high performace application such as: aerospace. Body structure of a Aeroplane is manufacture through lightweighted CFRP aterials where as turbine blades with nickel-based alloys to bear high heat and stress at extremely high temperatures.

3 ULTRASONIC MACHINING OF COMPOSITES

RUM is an unconventional machining method. The RUM process with better cutting-tool of a metal-cored core drill with diamond abrasives illustrated in fig.1.1. more than 5 mm thick CFRP materials may be machined and have a fibre weihgt ratio of 50 to 60 percent in particular, frequently results in coating delamination and poor workpiece quality, and this is an issue that must be addressed by novel procedures [7]. Mechanical vibrations are created by converting high-frequency electrical energy in USM by combining a transducer or booster with an energy focused device called a horn/tool assembly. An abrasive gun provides abrasive slurry, which is typically a mixture of abrasive material and alumina and abrasive materials like silicon carbide, boron carbide and alumina with water in a correct ratio is continually poured over the space between tool and the job. It can be observed that the vibration of tool creates waste slurry with fine abrasive-particles to hit workpiece's surface, causing Micro-chipping events are used to remove materials. The tool vibrates at a higher frequency, usually exceeding 20 kHz, with amplitude of 12-50 µm of along its longitudinal axis [8]. However, no research has been published a thorough comparison between drilling CFRP utilising RUM and other published techniques. Comparative research on CFRP RUM is presented in this paper. It is observed that high MRR is achieved during Rotary USM as compared to conventional one.

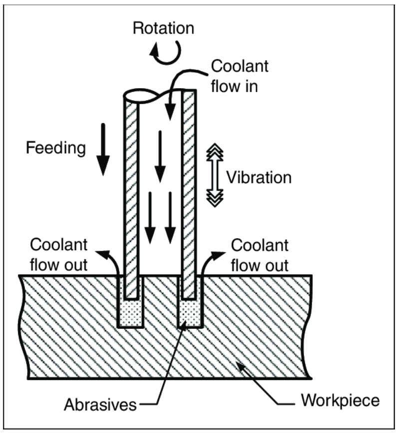

Fig. 1 Rotary Ultrasonic Machining [27]

USM is a material eliminating procedure that involves grit-loaded wet slurry travelling between a tool vibrating perpendicular to the workpiece at a frequency above human hearing, and the workpiece. It is different from other machining approach in that it produces approximate low heat. Because the tool never comes in contact with the workpiece, rarely is the machining pressure greater, making this process ideal for machining exceptionally hard and frangible materials like ruby, glass, diamond, sapphire, and ceramics [30,31]. A recent study on composites presented a state of art on ceramics and endorsed suitability of Rotary USM for difficult to machine materials for achieving high MRR and reducing defects such as out of roundness, cracks and edge chipping [32]. Furthermore, regardless of their electrical conductivity, it is a suitable manufacturing procedure for hard shaping materials and also breakable materials. It's a difficult process with a lot of variables, including the machine tool, the abrasive grain, the concentration of slurry, the workpiece stuff, and the operating settings.

4 LITERATURE REVIEW

The method that was taken in selecting the papers to be evaluated is outlined below. The first search string was "ultrasonic machining (USM)" followed by "CFRP" and "CFRP composites" within the search query. After then, articles are gathered from various databases (like Science Direct, Google Scholar etc.) The supporting articles aid in the development of the study's contexts by providing a theoretical backdrop.

Table 1: Comparison of investigations on composites using RUM

Year	Authors	Input parameters	Output examined	Process variants	Findings /result	Operation	Thickness of CFRP sheet
2022	Sharma et al.	Rotation speed of tool, ultrasonic power and the feed rate	Cutting force, MRR, chipping thickness	RUM	Based on state of art presented on machining of cermamics, found RUM is capable to machine materials with high strength, toughness, hardness, brittle, thermal stable, low fracture toughness. Exit chipping is minimised using RUM [32]	Milling	4.5mm, 8mm, 10mm
2021	Asmael and Safaei et. al	Rotation speed of tool, ultrasonic power and the feed rate	SR, magnitude of cutting- force, MRR, and tool wear rate.	RUM	They mention that limited research is available on USM of CFRP composites, but major experimental investigation is conduct on RUM and their hybrid method i.e. UAD, UAM, UEVR, etc. They also mention that limited reaearch is conduct on power intake of RUM. The operation process parameters such as: speed of rotation rate of feed, ultrasonic power was frequently used by researchers where as other parmeters abrasive material, shape, size, and ultrasonic vibration amplitude, etc. were less used by researchers [9].	Drilling	5.4mm, 8.1mm,12.4mm
2021	Geieret et al.	cutting streak, feed rate, tool-work system,	acoustic emission, cutting force, cutting temperature, vibrations, digital images.	_	They used special trochoid milling technology and traditional machining technology to cut CFRP composites and check sourface roughness quality and found that traditional methoed is better than special trochoid milling technology [10].	Drilling	_
2020	Geng et al.	feed speed, cutting speed	delamination formation	RUEM	In balancing to core drilling (CD), this study looked into the mechanisms of delamination production and squashing in rotary ultrasonic elliptical machining (RUEM) [11].	core drilling (CD)	10 mm.
2019	Sivakumar et al.	spindle force, ultrasonic power, cutting rate	Surface Roughness, Material Removal Rate	RUM	In order to examine the effects of a few sequential input elements, recent investigations conducted by diverse researchers have been critically examined in this study, on executions measures [12].	Surface grinding	5.2 mm
2019	Wang, et al.	rotational speed of tool, feed rate, depth of cut	cutting forces, SR	RUSM	In this study, differentiation of RUSM and CSG with horizontal ultrasonic vibration were made[13].	conventional surface grinding	18.5 mm
2019	Wanga et al.	ultrasonic power, depth of cut, federate, and rotational speed of tool	surface roughness, cutting forces	rotary ultrasonic surface machining (RUSM)	By managing the roughening tests, the mechanisms of material removal were surveyed, and characteristics induced by scratching and the scratching forces (feeding-directional forces and normal forces) were inspected and discussed [14].	scratching	18 mm
2019	James, and Panchal	frequency, amplitude, feed rate	depth of cavity, and cutting forces	Micro Ultrasonic Machining (µUSM)	The results of a Fixed Element (FEM Analysis) on micro-machining on blended composite materials utilising Ultrasonic Machining [15].	micro-drilling	30 µm
2019	Baraheni and Amini	velocity of cutting, feed rate, and vibrational amplitude.	Thrust force and delamination	Rotary ultrasonic drilling (RUD)	The rotary ultrasonic drilling technique on CFRP utilising a diamond core drill is studied in this research [16].	Drilling	3 mm, 6 mm
2018	Ozkana et al.	Cutting velocity, feed rate, and vibration amplitude.	Tool wear; delamination; surface roughness; cutting force	RUM	The milling operation of CFRP was the focus of this work since it is the second most widely utilized procedure, after drilling, for shaping the composite material[17].	edge-milling	11.37mm
2018	Karatas et al.	cutting speed, feed rate	surface roughness (SR)	Comparison between conventional and non conventional	Researchers have reported the comparative study of conventional machining processes (Drilling, cutting and milling) with non-traditional making methods [2].	Drilling, milling, cutting	16mm

				machining processes			
2017	Fuda et al.	Rotation speed of Tool, vib. amplitude of ultra sonic power, abrasive size, rate of feed, with the depth-cut	Cutting force	RUM	Author developed a model for feed and cutting force direction for grinding of surface of CFRP [18].	Surface grinding	18 mm
2017	Abhishek Sonate et al.	Grain size of Abrasive with its material along with material of tool, Amplitude	MRR	micro ultrasonic machining	They perform micro machinning on CFRP/Ti stacks [19].	Micromachining	7mm
2017	Ninga et al.	Depth-cut, amplitude along with the frequencyof ultrasonic	surface roughness, torque, and cutting forces	Rotary ultrasonic surface machining (RUSM)	A relative investigation on CFRP composites using RUSM and CSG Technique conduct. They observed the effect of operating paramters on torque, axial cutting forces, and SR [20].	Conventional surface grinding (CSG)	18 mm
2016	Ning et al.	Feedrate, inner dia. and outer dia. of the tool.	MRR	RUM	This research established a new modeling method for ultrasonic vibration amplitude assessment in hard materials using cutting force in RUM [6].	Cutting	16 mm
2016	Li et al.	Initial hole diameter, Countersunk hole depth, Rotary speed, Feedrate, Vibration frequency, Vibration amplitude.	Surface integrity accuracy torque cutting temperature	RUEM	This paper reports a practical study on the RUEM for countersinking of CFRPs for prior [21].	conventional countersinking (CC)	10 mm
2016	Wang et al.	Rotational speed of tool, Feedrate, Ultrasonic power, Operating frequency, Tool amplitude, abrasive concentration, abrasive size, tool geometry, and number of slots	SR, torque, and Cutting force.	RUM	In this paper, the effects of RUM variables of tool on the response variables have been explored in process of grinding processes when MRR was kept as it was at starting [22].	Surface grinding	6 mm
2015b	Geng et al.	Cutting speed, feed rate, cut length and cut depth	Cutting force, surface integrity, tool wear	Rotary ultrasonic elliptical machining (RUEM)	In this paper, the side milling of composite CFRP using RUEM were investigated and diamond-grinding tool were utilised to shape the slots using the CG & RUEM methods in a control environment [23].	Side milling	10 mm.
2015a	Geng , et al.	Cutting speed, vibration amplitude, vibration frequency	Grain wear, Surface integrity, Cutting force and diameter of tool wear analysis	RUEM	This study examined how the RUEM technique's speed ratio affected the routing of CFRP's edges[24].	Surface grinding	10 mm.
2014	Geng et al.	Input voltage amplitude with frequency, Input voltages phase shift, Elliptical vib. amplitude, Rotary speed, Rate of Feed, Depth-cut	Drilling force	Rotary ultrasonic elliptical machining (RUEM)	A number of drilling experiments were conducted both with and without the help of the mechanism and elliptical ultrasonic vibration on composite. [25].	Drilling	10 mm
2014	Sasaharaa et al.	Feed rate, Depth of cut, Flow rate of grinding fluid, Radial depth of cut	Surface quality, Tool wear	conventional cutting	Cutting and grinding of CFRP Composites materials with standard coolent supplied internally through the grinding wheel and both were tested and compared. [26].	Face grinding	7.6 mm

2014	Cong et al.	Ultrasonic power, rotation speed of tool	Torque, tool life, CFRP groove depth, cutting force, CFRP entrance delamination, surface roughness, and hole size variation	RUM	This paper describes a study that used RUM to drill CFRP/Ti stacks. It compares different machining parameters comparing studies employing RUM to those in the literature that use other methodologies [27].	Drilling	14 mm
2013	Cong et al.	ultrasonic vibration amplitude, feedrate, rotational speed of tool, abrasive concentration, and abrasive size	Cutting force	RUM	A mechanistic model has been created to estimate cutting force in CFRP RUM. The mechanism for removing CFRP material has been investigated [28].	Drilling	16mm
2012	Cong et al.	Ultrasonic power, federate, coolant type, tool rotation speed,	cutting force, SR, delamination, torque, and tool wear	RUM	This paper presents research on the amount of power used by the CFRP's RUM. Under various settings for feedrate, ultrasonic power of machine, rotation speed of tool, and Composite material, power intake of the total RUM system and each component was examined. [29].	Drilling, Grinding	7mm, 12mm, 16mm, 18mm

There are several gaps are identified on the basis of past studies as discussed in Table 1, are listed below:

- Over the last ten years there was no study on fabrication of composite material with some fibers like carbon fiber, jute fiber, banana fiber, pineapple fiber etc.
- No literature has found where testing (mechanical and thermal properties i.e., hardness, tensile strength, compressive strength etc.), of composite materials with above mentioned fibers has been conducted.
- Only a few studies have looked into the effect of process factors on the response parameters, which are temperature of cutting and burr removal rate.

Since a result, more investigation is required for fabrication of composites with fibres, like carbon, jute, banana, pineapple fibers into the matter of cutting temperature, as it can impact the qualities of the work-piece material's surface integrity, particularly when cutting composite materials that are both hard and fragile.

5 CONCLUSIONS & RECOMMENDATIONS

The literature review is summarized in this and confers a conclusion of the developments of USM for CFRP composites are classified based on the studies that have been published in different research papers. The document analysis the majority of the studies published between 2012 and 2022 based on the method used, platform type, in addition it was utilized to conduct experiments, as well as process parameters (frequency, amplitude, feed rate, cutting speed etc.) and output variables (Surface Roughness, MRR, cutting forces and challenges investigated and USM was used to fill gaps during the machining of CFRP composites.

Rotary USM is utmost important for machining most difficult to machine materials, attaining high MRR and minimising imperfections such as out of roundness, cracks and edge chipping.

Researchers found that raising the feed rate resulted in higher cutting pressures, while increasing the speed of cutting and reducing the rate of feed caused in lower surface roughness while milling CFRP composite materials with RUM.

Others alternatively achieved lowest factor of delamination by using a reduce level of cutting force along with low level of the feed-rate. The combination of high speed of cutting (2000-6000 rpm) and low level of rate of feed (0.2-1mm/min) was observed to decline the average surface-roughness in general [6, 18, 20].

Based on this study, instead of utilising USM or other machining methods, like rotary ultrasonic elliptical machining (RUEM), Micro Ultrasonic Machining (μUSM) etc it has been shown that employing RUM in context of cutting of various types of CFRP-hybrid composites enhances machining properties. As CFRP composites are used in various applications. The machining properties of the various CFRP (like very thin, thick yarn- woven and continuous) kinds need to be researched.

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