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Maximizing MRR During Drilling Novel PLA+CF Biocomposite with Step Drill and Comparing the Results with Drilling the PLA Polymer Using Statistical Approach

V. Sivaprasath[1], N. Senthilkumar[2]

[1]Research Scholar, Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India. Pincode: 602105.

[2]Project Guide, Corresponding Author, Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India. Pincode: 602105.

ABSTRACT

Aim: The objective of this work is to enhance the amount of material removed (MRR) in drilling 15% carbon fiber (CF) reinforced polylactic acid (PLA) polymer matrix composite using step drill bit of diameter 10mm. **Materials and Methods:** PLA is a biodegradable biopolymer used in medical implants, which is reinforced with synthetic chopped CF using injection molding technique. MRR during machining is important as it improves productivity. For this purpose drilling of PLA+15%CF in CNC vertical machining centre using step drill and twist drill was performed. In this study, two groups were considered: experimental group (PLA+15%CF) and control group (PLA); for each group 27 samples were considered based on G power 80% with alpha value of 0.05. **Result:** The machining is carried out and the MRR obtained for the two groups are determined and analysed for constant rate of feed and speed. The integration of CF in PLA matrix lowers the quantity of material lost when the interface and CF are greater. The mean MRR is 339,856 g/min for the experimental group (step drill) and 256,137 g/min for the control group (twist drill). There exists a substantial variation of the meaning value of 0.031 between the two groups ($p<0.05$). **Conclusion:** The addition of CFs in the PLA matrix enhances the composite's strength and stiffness within the limitations of this investigation, thereby reducing the removal of material during the processing; the step drill tool works better than the twist drill bit.

Keywords: Biocomposite, Novel polymer composite, Polylactic acid, Carbon fiber, Drilling, Step drill.

INTRODUCTION

This study addresses the processing behaviour of new biocomposites for carbon fibre (CF) reinforced polylactic acid (PLA). Polymer matrix combinants (PMCs), because of their low weight to strength characteristics, replace the high-weight metal structures (Hemnath, Anbuchezhiyan, and NanthaKumar 2021; Muthukumar et al. 2014; Dinakarraj, Sivasankar, and Senthilkumar 2020; Muniappan, Srinivasan, and Sandeep 2020; Vasanthkumar et al. 2019). In order to increase the strength and strength of the soft PLA biopolymer, reinforcements such as synthetic, natural fibres and metal powders may be added. This new biocomposite based on PLA is widely

utilised in biomedical, culinary and automobile applications (Zhang et al. 2021). Drilling is widely utilised in engineering manufacturing as a metal removal method. Drilling is used to produce various sizes of mounting and fitting holes. The machine productivity and quality may be extensively assessed by evaluating the material extraction rate (MRR), wear, surface ruggedness, cutting forces and temperatures (Palanikumar, Prakash, and Shanmugam 2008). Delamination of fibre happens during hole production with the addition of synthetic and natural fibres in PMC and thus is difficult to get higher quality and MRR. Different geometrical parameters of drill bit such as spade drill, step drill, twist drill and multifaceted drill are used to reduce the effect of the delamination (Rajamurugan, Shanmugam, and Palanikumar 2013). Apart from this drill bit geometries like diameter, point angle, helix angle and number of flutes can also be altered for improving the material removal process (Verma et al. 2021). Lower MRR in drilling PLA based composite is the problem identified; PLA+CF is mostly used in aerospace research, sports vehicles and sports equipment because it gives high power and reduces the weight of the vehicle and increases the mileage and vehicle performance (helmet, bumper, windshield etc.) due to their light weight-to-strength ratio (Yusoff et al. 2021).

In previous years, there were 18900 research items in Google scholar on drilling of PLA-based and CF-based PMCs and 1070 in Sciencedirect. Flax/poly(lactic acid) bio-composites were machinable and found to lower thrust strength and delamining size, but increased feed-and-boil diameters resulted in a substantial increase in thrust strength and delamination (Lotfi, Li, and Dao 2018). High-speed machining of CFRP composite and consideration of delamination factors, delamination susceptibility decreases with rise in cutting speed and recommended lower feed rate and point angle combined effect for damage reduction (Gaitonde et al. 2008). Damage factor and thrust forces comparison for two alternative drill configurations on Flax/PLA biocomposites was performed and identified that the increase specimen thickness lowers the exit and entrance damage due to drilling (Díaz-Álvarez, Díaz-Álvarez, and N. Feito 2021). To develop a connection among cutting velocity and feed rate with output parameters power, delamination in carbon fibre reinforced plastics and specific cutting pressure were optimised. It was discovered that delamination in composite is greater for increased cutting speed and greater feed rate (Paulo Davim and Reis 2003). The best study on novel polymer composite performed previously was the influence of drilling parameters on delamination behaviour (Lotfi, Li, and Dao 2018). Moreover, our workforce has extensive expertise working on a variety of research initiatives across several fields (Samuel et al. 2019; Johnson et al. 2020; Venu, Subramani, and Raju 2019; Keerthana and Thenmozhi 2016; Thejeswar and Thenmozhi 2015; Krishna and Babu 2016; Subashri and Thenmozhi 2016; Sriram, Thenmozhi, and Yuvaraj 2015; Jain, Kumar, and Manjula 2014; Menon and Thenmozhi 2016)

The goal of this research is to optimise the sustainable processing by employing step drills to compare the quantity of MRR generated for the novel CF-reinforced PLA biocomposite and the outcomes are compared with the plain PLA. The impact of adding CFs in PLA on machining characteristics are studied in this work.

MATERIALS AND METHODS

Novel Polymer composite fabrication, characterization and machining studies were done at Central workshop, Saveetha School of Engineering (SSE), Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai. The ethical approach of working on human samples is not applicable in this research. Two groups are considered here; control and experimental group. PLA is reinforced with 15% CF and drilled with step drill in the experimental group, whereas in control group PLA+15%CF is drilled with twist drill. Experiments were conducted using Taguch's approach (Thirumalvalavan and Senthilkumar 2019; Tamizharasan et al. 2019; Senthilkumar and Tamizharasan 2012), for each group 27 samples were considered and total sample size is 54. The G-power 80% calculator is used for identifying the sample size with 0.05 alpha value, the mean values of MRR for PLA+15%CF machined with step drill bit 339.85 g/min and with HSS drill bit is 250 g/min with standard deviation of 3.5 and 2.1 (Palanikumar et al. 2012).

Polylactic acid (PLA), or polylactide is a thermoplastic polyester obtained by condensation of lactic acid with loss of water. PLA is a biodegradable polymer, which is used in food handling and in medical implants (DeStefano, Khan, and Tabada 2020) that biodegrade over a time within the body as it is different from most thermoplastic polymers in that it is derived from renewable resources like cornstarch or sugar cane. Carbon fibers (CFs) are synthetic fibers that are lightweight and strong compared to steel and have high stiffness, chemical resistance, tensile strength, fatigue resistance, temperature tolerance and creep resistance with lower

thermal expansion (Gajalakshmi et al. 2020). Due to high strength-to-weight ratio and stiffness of CFs, reinforced composites are widely used in superstructures of ships, aerospace, civil engineering, automotive, sports equipment, and higher trends in technical and consumer applications (Manocha 2001).

CFs are weighed as per the 15% weight fraction to be added with PLA, then mixed in a twin screw extruder and finally specimens are made in injection molding machines, which are subjected to drilling studies. Two drill bits; step drill (experimental group) and HSS drill (control group) were used for drilling the novel polymer composite.

Pellets of PLA are made to melt in the twin screw extruder and mixed with required quantity of CFs and the same is injected into the die in the injection molding machine to prepare specimens as per required dimensions for testing and analysis. A CNC based vertical machining center (VMC) is used for drilling with carbide tools (twist drill and step drill). MRR is calculated by using the formulae given in Equation (1) (Senthilkumar and Selvakumar 2016).

$$\boldsymbol{MRR = (weight\ before\ machining - weight\ after\ machining) / machining\ time} \ldots\ldots (\mathbf{1})$$

Statistical Analysis

The analysis is done in statistical software SPSS considering independent factors as type of drill bit (step and twist drill) and dependent variables as MRR For each group, 27 samples are considered for analysis to satisfy the confidence interval of 95% so that probability of failures will be below 5% ($p<0.05$). Analysis of experimental and control groups were done by adopting Independent sample T-test.

RESULTS

Table 1 shows the MRR produced from PLA+15% novel polymer composite from the drilling investigations by two drill bits: step and twist drills. The finding reveals that the strengthened CFs in the PLA matrix tend to reduce the MRR, but MRR may be enhanced using specialised geometry drill bits. Compared to the twist drill, the step drill bit delivers greater MRR. The mean standard deviation and error values achieved through statistical analysis for both groups are presented in Table 2. Step drill bit yields a mean 390.8352 g/min MRR and a 256.137 g/min MRR for twist drill. The standard deviation and standard error value for step drilling is 3.3089 and 0.637 whereas it is 2.2145 and 0.4262 for twist drilling.

Table 3 describes the results of the independent sample T-test with a F value of 4.596 and t value of 175.789 with 0.037 significance value among the considered group that is less than the necessary p-value of 0.05, and thus the significance between the two groups is established. Figure 1 shows the bar graph with the error value achieved with the standard deviation of ±1, step drill effectiveness with lesser error is preferable.

DISCUSSION

In a recent work on the characterisation of 15% CF reinforced biocomposite PLA, it has been shown that the strength of the binding of CFs and PLA matrix is good and offers strength and rigidity to the composite (Gavali, Kubade, and Kulkarni 2020). Step drill is a conical surface drill with a flat surface (step point) producing a linear chisel and generates the least amount of heat of all the drill point patterns; featuring 150% less thrust and 70% less heat than a conventional drill (Paulo Davim 2009) because of this higher material removal is obtained. The twist drill with two flutes is used as the control group which contains 118° (Ismail 2021). The difficulty found during the drilling process of PMC is the inclusion of CFs that make removal harder (Srinivasan et al. 2017). Material removal done with traditional twist drill on CF reinforced PMC becomes tough and hence lesser MRR whereas with specialized step drill, easy removal of CF is achieved and hence higher MRR is observed (Kumar, Verma, and Mondal 2021).

In addition to the tool shape, machining factors such as spindle speed and feed speed and the kind of machining materials also affect the MRR. With greater spindle speed and feed rate, MRR tends to improve, but applies more heat and cutting forces (Soriano et al. 2013). The machining results will also be determined by the geometry of cutting equipment (point angle, helix angle, number of flutes, cutting edge angle etc.). The results

of this study mirror the results of other researchers' machining studies (Rezghi Maleki et al. 2019). No opposing findings were found related to this study.

The constraints of this study are that only MRR is examined, while the created and generated cutting forces must be monitored and adjusted for higher quality of drilled troughs and alternative geometries for superior machining conditions are taken into account.

CONCLUSION

Within the limits of this study, step drill produces higher MRR than the conventional twist drill and lowers the delamination of incorporated CFs in the PMC. Hence it is concluded that fiber reinforced PMC can be better machined with improved cutting tool geometries.

DECLARATION

Conflict of Interest

The authors declare that there is no conflict of interest.

Authors Contribution

The author VS was involved in data collection, analysis and drafting of the manuscript and author NSK was involved in conceptualization, data validation and critical review of manuscript.

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TABLES and FIGURES

Table 1. MRR obtained for experimental and control groups during drilling with different drill bits having different geometries at constant spindle speed and feed rate in dry machining condition.

Exp. No	Step Drill	HSS Drill	Exp.No	Step Drill	HSS Drill
1	337.15	256.781	15	339.1876	254.57
2	340.8653	255.244	16	340.2345	257.636
3	338.4552	257.342	17	342.9231	252.702
4	336.6055	259.636	18	337.4285	257.768
5	337.3525	259.91	19	335.7887	254.834
6	338.5329	258.976	20	340.6598	255.957
7	339.2956	254.042	21	343.7369	256.966
8	338.8584	253.108	22	342.7369	258.032
9	343.6543	257.174	23	338.2991	253.098
10	346.9876	255.24	24	337.1526	256.164
11	345.1265	256.306	25	341.425	253.235
12	337.1567	253.372	26	338.2379	256.296
13	341.922	258.438	27	337.1564	253.362
14	339	259.504			

Table 2. Independent sample T-test group statistics obtained during MRR analysis for two drill bit geometries for which the mean values, standard deviation and standard error values obtained respectively are provided

Material	N	Mean	Standard deviation	Standard Error
Step Drill	27	390.8352	3.30888	0.63679
Twist Drill	27	256.13678	2.214512	0.42618

Table 3. Independent sample T-test performed among experimental and control groups. Significance level obtained is 0.037 showing that variances exist between the two groups when analyzing the obtained MRR.

Hypothesis	F	Significance	DoF	t	95% Confidence Interval	
					Lower	Upper
Equal variances assumed	4.596	.037	52	175.789	133.1608	136.236
Equal variances not assumed			45.399	175.789	133.155	136.241

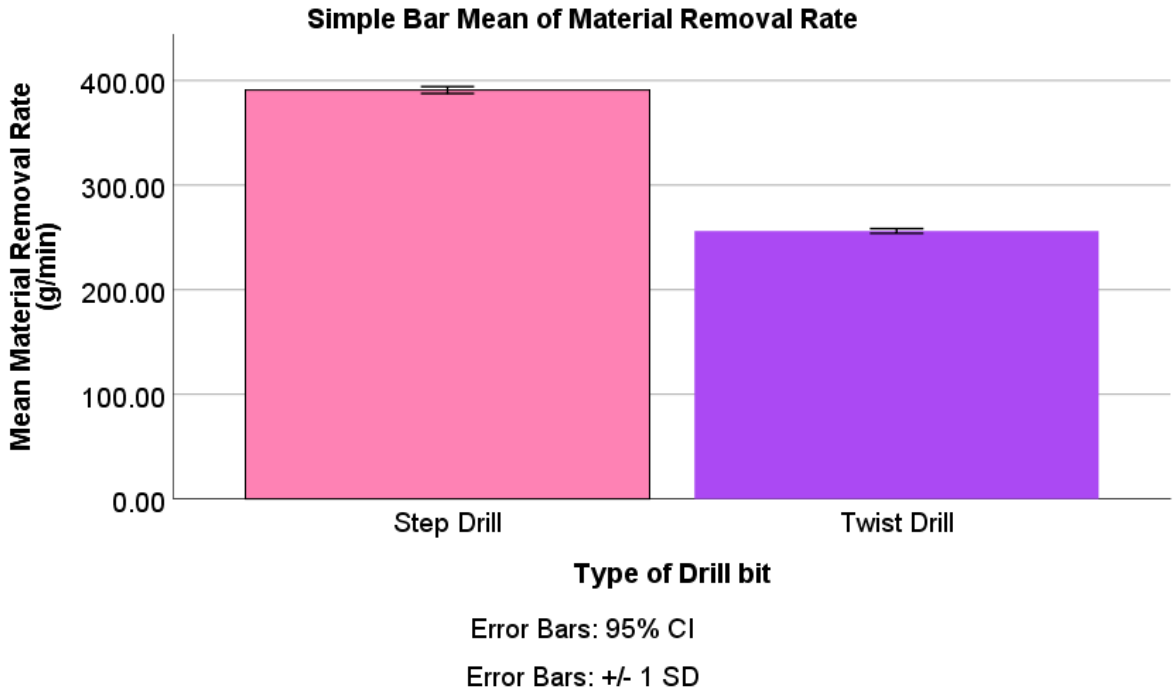

Fig. 1. Bar chart showing the mean values of the MRR for both drill bits along with the error bars drawn with a standard deviation of ±1. MRR obtained is higher for step drill and low for HSS drill