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High Speed Trimming of Carbon Fibre Reinforced Plastics using Router Tool and Online Tool Life Monitoring

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Abstract

Carbon fibre reinforced plastics (CFRP) have been used extensively by the aerospace industries for their high strength properties. Due to CFRP's inhomogeneous nature they encounter numerous problems during machining. Router tools are preferred in order to get delamination free surfaces during high speed trimming. Experiments were carried out for measuring cutting force using Box Behnken design by varying spindle speed, feed and width of cut. From the study it is concluded that feed and width are the two major parameters influencing the cutting force. Measurement and prediction of tool life of router tools are a challenging task. In this work the router tool life was monitored by using acoustic emission signals online, during machining and compared with the offline measurement of tool wear.

Keywords: Circularity Error, Sphericity Error, Coordinate Measurement data.

1. INTRODUCTION

Though polymer composite components are often made to near-net shape, few machining operations like drilling and trimming are often unavoidable. Resin flashing may also result after moulding and curing of fiber-resin performs. After demoulding of CFRP parts from the moulds, the parts are needed to be trimmed at its edges. Such process is called edge trimming. During edge trimming, delamination of composites and poor surface roughness are related to proper selection of machining parameters [1-3]. During machining of composites tools are subjected to rapid because of abrasive fibres present in the polymer composites. Measurements of wear on cutting tools involve flank wear and crater wear measurements. But all the wear measurement methods are sensitive to cutting distances and to the machining parameters.

New tools are developed for machining of polymer matrix composite, in which routers are the preferred cutting tools for machining of composites. The new router tools are shaped by multiple left-hand and right-hand helical edges, which form small pyramidal cutting edges along the length [4]. The results during milling of composites show that delamination is mainly dependent on the fiber orientation and the tool sharpness [5]. During online tool condition monitoring, wavelet packet transform can be used as a tool, to characterize the acoustic emission signals. The selected monitoring indices from the wavelet packet coefficients are found capable of detecting the tool condition effectively [6]. Machining damage due to excessive cutting force may result in rejecting the components at the last stage of production cycle. Therefore, the ability to predict the cutting forces is essential for selecting process parameter that would result in minimum machining damage [7]. The present work focuses on edge trimming of CFRP using router tools and study the quality of the machined surface and online monitoring of tool life using acoustic emission.

2. EXPERIMENTATION

The CFRP used in this investigation has a volume fraction of 60% with a layup sequence of [90/-45/0/45/90/-45/0/45]s. The laminate is made up of 16 plies and having a total thickness of 4.2 mm. Φ6 mm solid carbide router tool used for the experimental study is presented in Fig.1. Experiments were conducted using CNC Makino high speed machining centre and the forces were measured using Kistler three component dynamometer.

Fig.1 Router Tool

Table 1 presents the factors and levels used for conducting the experiments. Fig 2 presents the experimental setup used for measuring the cutting forces in CNC milling machine. The resultant forces for various machining parameters were calculated using the components of all the three forces measured. Once the force values are measured for all the experimental conditions the results are analyzed.

Table.1

Box Behnken design of experiments

Levels	Factors		
	Spindle Speed (rpm)	Feed (mm/rev)	Width of cut (mm)
-1	12000	0.10	0.5
0	15000	0.15	0.75
1	18000	0.20	1.0

A separate set of experiments were conducted for tool life study by clamping acoustic emission sensor to the workpiece. Fig 3 shows Kistler acoustic emission sensor used for signal monitoring during tool life study. Tool wear is also measured after machining a length of 1m.

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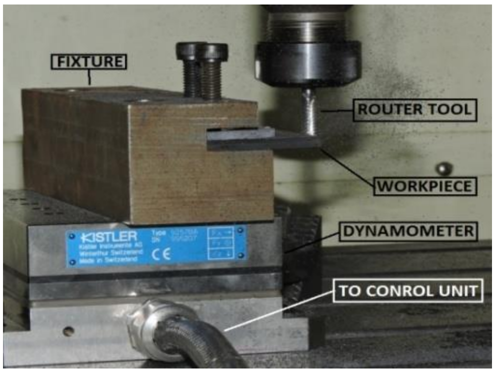


Fig.2 Force measurement setup

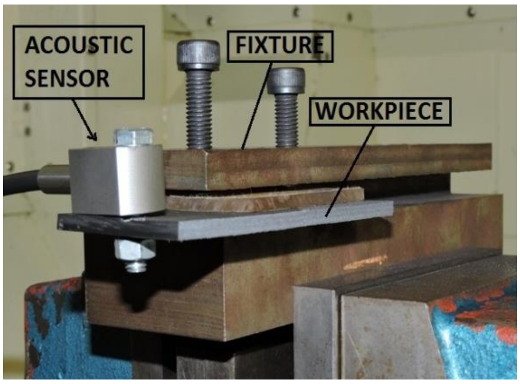


Fig.3 Acoustic emission sensor setup

3. RESULTS AND DISCUSSION

From the contour plot (Fig 4), it can be inferred that low feed exhibits lesser forces to machine and the effect of spindle speed on forces seems to be marginal.

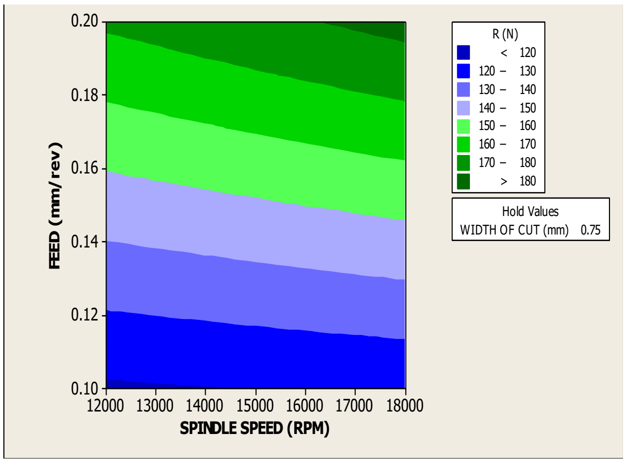


Fig.4 Resultant forces for spindle speed vs feed

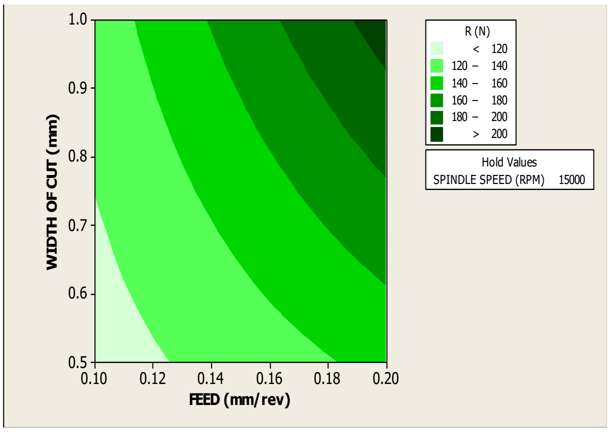


Fig.5 Resultant forces width of cut vs feed

From Fig 5 & 6, it can be inferred that lower feed and lesser width of cut at high spindle present lower forces to machine the CFRP. High spindle speed and lower width of cut presents lower forces (Fig.6), this may be because at high spindle speed the cutting temperature could lower the cutting forces.

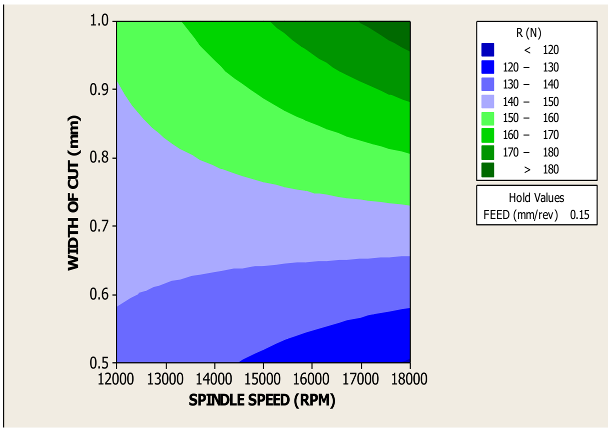
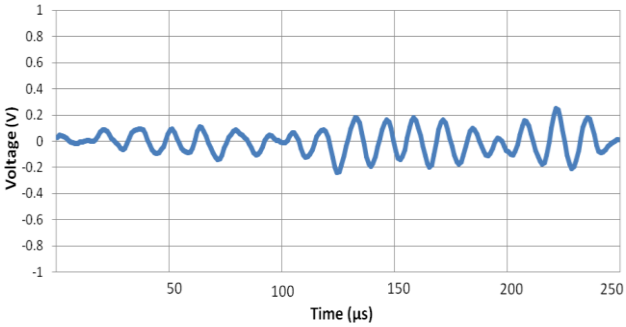
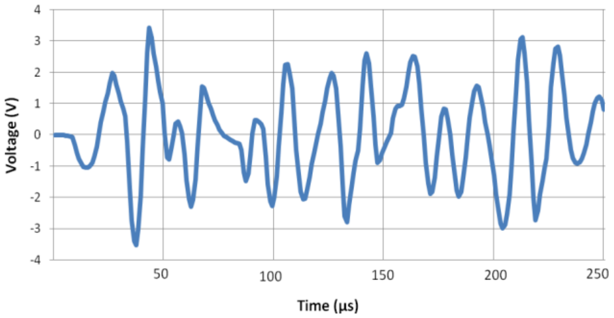


Fig.6 Resultant forces width of cut vs feed

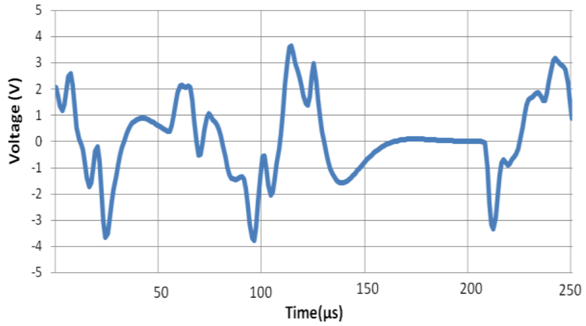
AE generated during trimming of CFRP mostly emanate from sources like matrix deformation, delamination and tool wear. Hence, acoustic emission can be considered as one of the practical and potential application for online tool life monitoring. The signals from the sensor were fed into coupler in order to process high frequency sound emission signals. The data acquisition system was used to acquire signals from the coupler. The DAQ was then connected to a computer with DEWEsoft data acquisition software. AE filter value was taken as the monitoring index for online tool life monitoring. Since the acoustic signal outputs are correlated to tool wear, acoustic signal measurement was essential. In this study, a crest factor (C) obtained from the software was used as a monitoring index to study the condition of the router tool in edge trimming of CFRP. The crest factors are recorded for 130 passes (each pass of 100 mm) approximately equal to the length of machining of 13 meter at the cutting condition of high speed (15000 rpm), feed (0.2 mm/rev) and width of cut (0.5 mm).



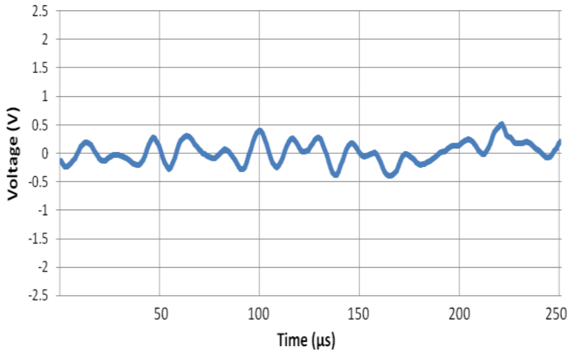
(a) During the 1st pass (0.1 meter)



(b) During the 50th pass (5 m)



(c) During the 100th pass (10 m)



(d) During the 130th pass (13 m)

Fig.7 The AE output recorded for different cutting distances for a duration of 250 microseconds

From Fig.7 (a-d), it is seen that the magnitude of the AE output signals in volts are sensitive to change of tool status. Initially, the tool is fresh and the trimming is smooth. From Fig 7 (a-c), as the machining progresses, the AE signals are increasing indicating deterioration in tool condition. It is noted that when the machining progresses after 9 m, the signal amplitude started decreasing. This is because; the signals are damped, portraying the damage and the tool wear resulting in poor quality (Fig 7 d). The monitoring index (crest factor) can be calculated theoretically using the Equation 1 [6].

$$C_j^i = \frac{T_j^i}{E_j^i} \qquad (1)$$

Where, $T_j^i = max\left\{P_j^i(t)\right\}^2 - max\left\{P_j^i(t)\right\}^2$

Where N_j = no. of data points in feature packets

$$\bar{E}_j^i = \frac{1}{N}\sum_{i=1}^{N_j} P_j^i(t)$$

P^i_j = wavelet coefficients in feature packets

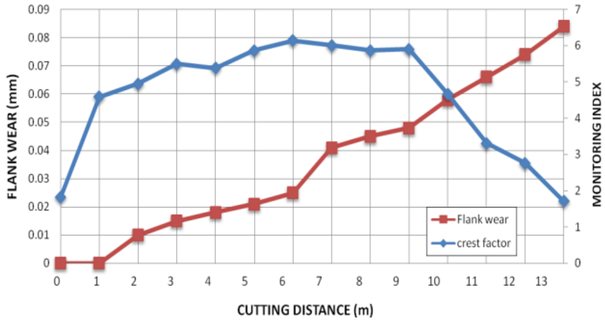


Fig. 8 Comparison between monitoring index and flank wear

Fig.8 presents the monitoring index versus flank wear of the tool. Flank wear was measured at regular intervals using tool maker's microscope. It is seen from Fig.8 that the value of the monitoring index increases rapidly up to 2 m, showing the running-in wear of the tool. From 2 m to 9 m, it raises progressively indicating the normal wear of the tool. After 9 m, it starts decreasing, possibly due to the rubbing of worn tool against the work piece leads to less energy release [6]. The flank wear also progresses rapidly after machining 9 m. Hence, 9 m can be considered as the threshold value.

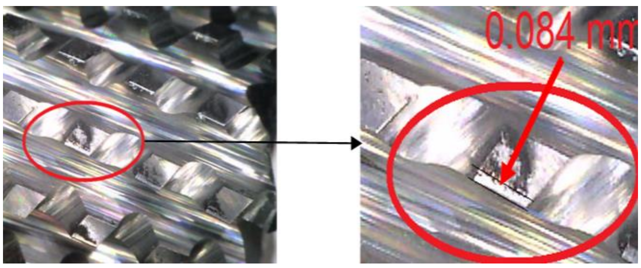


Fig.9 Tool Wear after machining

Measuring tool wear in router tool is a challenge and cutting edge rounding in router tool reduces the performance of machining. Sharp cutting edges are required for machining of CFRP in order to get a delmination free surface of composites. Fig 9 shows the cutting edge of router tool after the machining experiments. Though amount of flank wear is not high, cutting edge rounding is a major factor during routing of CFRP, which is evident in Fig 10.

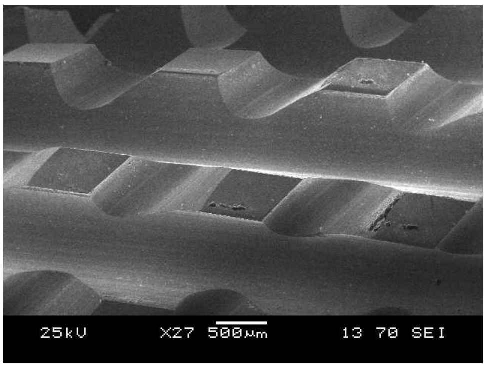


Fig.10 SEM of worn out tool

4. CONCLUSION

Feed and width of cut are the parameters having the higher influence on the resultant force (N). It is found from the experiments that spindle speed of 15-18 K can be used at low feed (0.1 mm/rev) and width of cut (0.5mm) for machining CFRP. From the series of trials conducted using acoustic emission, it is concluded that the magnitude of the AE output signals are sensitive to change in tool status. It is seen that during the progression of machining, the AE signals are higher indicating deterioration in tool condition. After a threshold value, signals are damped portraying the damage and the tool wear. Hence, after the threshold value is reached, the tool may be discarded. From the tool wear study using SEM, it may be concluded that cutting edge radius is the major factor in determining the life of the tool.

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