Frequency Analysis in Orthogonal Cutting of Glass Fiber Reinforced Composites

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1. Introduction

This paper discusses frequency analysis based on frequency spectrum in orthogonal cutting of fiber-matrix composite materials. A glass reinforced polyester (GFRP) was used as workpiece. Analysis method employs a force sensor and the signals from the sensor are processed using a fast Fourier transform (FFT) technique. The experimental correlation between the different chip formation mechanisms and model coefficients are then established.

Depending on the fiber orientation, cutting mechanisms can be categorized into the following 4 types in Figure 1:

(1) Type I (0° fiber orientation): Cutting mechanism is characterized by Mode I loading and fracture along the fiber-matrix interface, Mode II loading through tool advancement, and fracture perpendicular to the fiber direction under bending load.
(2) Type II (15°-75° fiber orientation): In this positive fiber orientation, cutting mechanism is composed of fracture from compression induced shear across the fiber axis and interfacial shearing along the fiber direction which eventually causes fiber-matrix debonding.
(3) Type III (75°-90° fiber orientation): Cutting mechanism is characterized by compression induced fracture perpendicular to the fibers and inter-laminar shear fracture along the fiber/matrix interface.
(4) Type IV (beyond 90° fiber orientation): Cutting mechanism in this type is basically similar to Type III. However, intermittent fracture across the fiber axis is visible.

2. Frequency Analysis

It is widely accepted that certain frequency components of the power spectral density of force signals are sensitive to cutting mechanisms in machining [1]. These frequency components can then be used as features for characterizing cutting mechanism. For efficient mapping of input patterns in the time domain into the frequency domain, the FFT technique was used. The resulting spectrum was smoothed by taking band averages to attain statistical stability and these averages were used for further analysis.

3. Experiment

A series of orthogonal cutting experiments were conducted for GFRP composite materials. Constituents of GFRP and experimental conditions are given in Table 1 and Table 2, respectively. The workpieces were mounted on a Rockfort Shaper-Planer. Multi-purpose C2 grade carbide inserts were used in dry cutting of GFRP. Schematic diagram of data acquisition and experimental setup is given in Figure 2. Schematic of the workpieces and relative angles between the cutting direction and fiber orientation is also shown in Figure 2. The force signals were obtained using a three-dimensional circular-type strain gage dynamometer that was attached to the tool post. Detailed description of the experimental procedures for obtaining sample data is given elsewhere [2,3,4].

4. Results and Summary

Figure 3 shows the normalized power spectrum for 90° fiber orientation angle. Glass fibers in 90° orientation are most densely spaced so that the fundamental frequency in this case has the highest value. The fundamental frequency was identified with an arrow in the figure. Figure 4 shows the effect of fiber orientation on the normalized frequency spectra where the fundamental frequencies for 45° and 135° fiber orientations are also marked with the arrows. The reference fiber orientation angle is 90°. In the figure, the relative variation of normalized power with the fiber orientation angle is represented by signal to noise ratio (ratio of the power at frequency ω to the power at frequency ω_r with 90° reference fiber orientation) in dB scale.

The cutting stresses for fiber orientation angle greater than 0° tends to increase only when the tool is in the vicinity of fiber regardless of the fiber orientation. The lower frequency components of the force signal are, in general, dominated by the components originating from the discontinuous nature of the fiber cutting and do not exhibit high sensitivity to chip formation mechanisms. It is also interesting to note that there is appreciable amount of energy above the fundamental frequency with 135° fiber orientation. This may be attributed to the intermittent inter-laminar fracture that causes burst type cutting force signal. Severe fiber pull-out also contribute to the high frequency contents of the force signal.

Tool geometry was found to have significant effect on the frequency characteristics of measured force signal. Figure 5 shows the effect of tool rake angle on the frequency characteristics of force signal. As the tool rake angle decreases from positive to negative value, less energy contents in the region below the fundamental frequency is clearly seen. The acute cutting edge (higher tool rake angle) induces Mode I loading and reduces the degree of Mode II component, provided that tool clearance angle is positive. This will certainly contribute to the low frequency contents of the measured force signal by intermittent delamination.

In summary, frequency characteristics in Type II cutting exhibit energy contents below the fundamental frequency region. This low frequency energy band is due to Mode I and Mode II loading which causes occasional delamination (fiber-matrix debonding) of fibers. Type III and Type IV cutting mechanisms are associated with more energy in the high frequency region originating from micro buckling, fracture along and across the fibers, and fiber pull-out.

5. References

1. G.C. Andrews and J. Tlusty, “A Critical Review of Sensors for Unmanned Machining”, Annals of CIRP, Vol.32, No.2, pp.563-572, 1983
2. C.W. Wern, “Fiber and Fiber-Matrix Interface Effects on the orthogonal Cutting of Fiber Reinforced Plastics”, PhD Dissertation, Department of Mechanical Engineering, University of Washington, 1996
3. C.W. Wern and M. Ramulu, “Influence of Fiber on the Cutting Stress State in Machining Idealized Glass Fiber Composite”, J. Starin Analysis, Vol. 32, No.1, pp.19-27, 1997
4. C.W. Wern, M. Ramulu and A. Shukla, "Preliminary Investigation of Stresses in the Orthogonal Cutting of Fiber Reinforced Plastics", Experimental Mechanics , Vol. 36, No.1, 1996, pp.33-41.

Table 1 Constituents of GFRP used in this study

	GFRP
Resin	Unsaturated polyester polymal 6304, 6320F at a ratio of 1:1
Reinforcement	ECG-75-1 1/2 3.3 S NA glass yarn of 0.4mm diameter
Reinforcement Volume Fraction (%)	0.85%
Post Curing	120C for 2 hours

Table 2 Experimental conditions for machining GFRP. Depth of cut is 0.051 mm.

Class	Fiber Orientation Angle (FOA) (degrees)	Cutting Mechanism (Type)	Cutting Parameters		
			Cutting Speed (m/min)	Rake Angle (degrees)	θ_e (Degrees)
1	45	II	3	20	115
2	45	II	6	20	115
3	90	III	3	20	160
4	90	III	6	20	160
5	135	IV	3	20	205
6	135	IV	6	20	205
7	45	II	3, 6	0	135
8	45	III	3, 6	-20	155
9	90	IV	3, 6	0	180
10	90	IV	3, 6	-20	200
11	135	IV	3, 6	0	225
12	135	IV	3, 6	-20	245

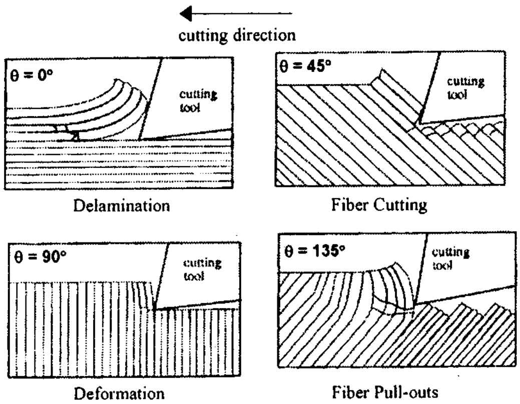

Figure 1 Schematic of cutting mechanisms in orthogonal cutting of GFRP

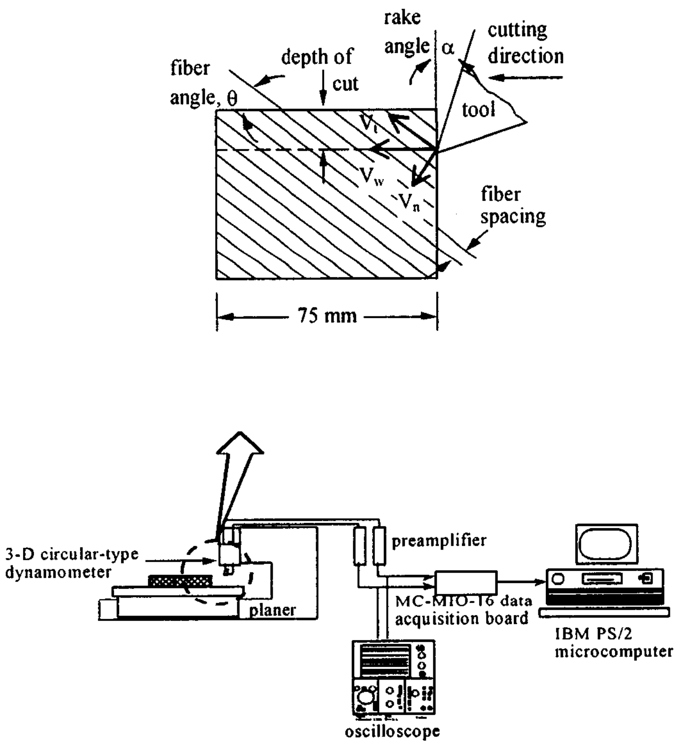

Figure 2 Designation of angles and schematic diagram of experimental setup

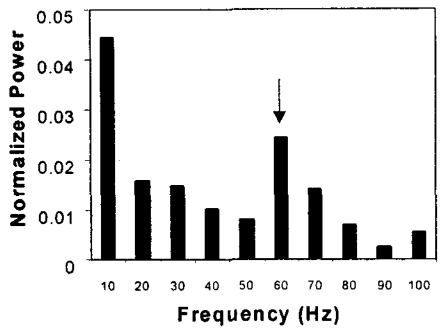

Figure 3 Normalized power spectrum for 90° fiber orientation angle.

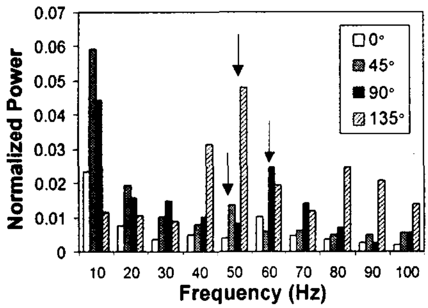

Figure 4 Effect of fiber orientation on the normalized frequency spectrum in cutting GFRP. The reference fiber orientation angle is 90°.

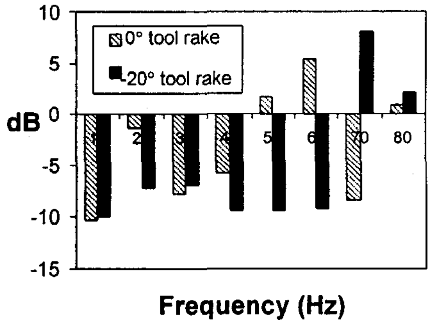

Figure 5 Effect of tool rake angle on the normalized frequency spectrum. Reference fiber orientation angle is 90°.