Acoustic Emission analysis of Diamond Turning Process of CNT Composite

E.J.T.Chicuta[1], Ph. Demont[2] , Pascal Puech[2], A.J.V. Porto[1], R.G. Jasinevicius[1]
1.Depto Eng. Mecânica, EESC, USP, C.P. 359, CEP 13566-590, São Carlos, São Paulo, Brazil.
2. Laboratoire de Physique des Polymères, Université Paul Sabatier Toulouse III Bâtiment 3 R1- B2118 route de Narbonne - 31 062 Toulouse Cedex 09 - France
*Corresponding author:*renatogj@sc.usp.br

Abstract In this paper face-turning using monocrystalline diamond tools of an epoxy nanocomposite containing multiwalled carbon nanotubes is investigated and compared with its base polymer (RTM6) and an aluminum alloy. Acoustic emission signals, machined surface integrity and chip morphology are the factors used to compare the machinability of the three materials. The acoustic emission results are compared to the response of an Al alloy cut under similar machining conditions.

1 Introduction

Machining of epoxy resin reinforced with carbon nanotubes composite materials is an area still full of open questions, pertaining to the assessment of machining and energy involved compared to metal cutting. CNT composite presents a very low weight and similar resistance with low carbon steels. This material has been studied mainly for aeronautic and aerospace field's applications. The machining of this material has been considered a challenge since its response to the cutting process is not well understood and brittle damage is easily introduced to the surface despite of been considered a soft material.

In this paper face-turning trials were performed on epoxy resin reinforced by CNT composites using monocrystalline diamond tools. The machinability of a epoxy nanocomposite containing multiwalled carbon nanotubes is investigated and compared with its base polymer (RTM6) and an aluminum alloy.

2. Experimental Method

Carbon nanotube–epoxy resin nanocomposite samples (15mm x 30mm, and 1.5mm thick) with different concentrations of CNT (see Table 1) were face turned.

Table 1 Composition of investigated materials.

Sample	CNT content (wt %)	Observation
1	0	Al7075-T6
2	0	RTM 6 - Epoxy Resin
3	0,7%	RTM 6; 0,024% wt in HDA* - **CNT6**

* *HDA: amphiphilic molecule $C_{16}H_{33}NH_2$ used as dispersant agent.*

Single-point diamond turning tests were carried out on a commercially available ultraprecision diamond turning machine, Rank Pneumo ASG 2500. The diamond tool had a nose radius of 0.76mm, a 0^o rake angle, and a 12^o clearance angle. No cutting fluid was used, as the material is very soft and there is no need for cooling or lubrication. Table 2 presents the cutting conditions. The AE signal was obtained using an AE piezoelectric sensor mounted on the toolholder and a microcomputer with a PCI-6111E 5MS/s National Instruments™ – DAQ board. The AE raw signal was acquired at a 1000 kHz sample rate. The AE signal was filtered through a high-pass filter with a 50 kHz cutoff frequency to minimize any ambient acoustic noise from the system. The signal was subsequently amplified by 40 dB. The AE signal was then passed through a Root-Mean-Square (RMS) filter with a time constant of 1 millisecond. The spectral characteristics of the raw AE signal and the surface finish was examined using optical profiler and correlated with the cutting mode. Filters were not used in order that the raw signal could be obtained for a later frequency spectral analysis. LabView was used for data acquisition and processing of the signal.

Table 2 Cutting conditions used in the face turning operation

Cutting condition	Al 7075-T6	RTM-6	CNT6
Feed rate (μm/rev)	5, 10 15, 20 and 25		
Depth of cut (μm)	10	10	10

3 Results and Discussion

In Figure 1 the AE RMS value for the CNT composite is very close to the values for the Al-alloy; for the lower value of feed rate (i.e, 5 and 10 μm/rev), the AE value is even lower for the composite, while for f = 20 μm/rev the value becomes higher than for the Al Alloy. Analyzing the AE RMS one can observe that values for the epoxy resin RTM-6 is higher than the other materials for almost all feed rates (5-

20μm/rev). In the case of the epoxy resin RTM6 brittle damage (microcracks) was detected for all cutting conditions which also were reflected in the surface roughness. Figure 2 shows the roughness Ra values for the three materials tested. The roughness of the epoxy resin was always higher than the other materials. Figure 3 show 3-D images of the epoxy resin sample (RTM-6) and the composite (0.7%CNT). Fig. 3 (a) shows that the epoxy resin presents more sign of brittle damage than the composite (Fig. 3(b)). Comparing these results with the RMS values, the higher the levels of AE signal may be attributed to the larger the number and concentration of cracks. One can conclude that frequencies are distributed in a manner that high frequencies and high level of signal are related with the presence of massive number of cracks (RTM-6), while lower frequencies and lower signal levels indicate ductile material removal (Al-alloy). The results showed that all cutting conditions yielded ductile material removal for the aluminum alloy.

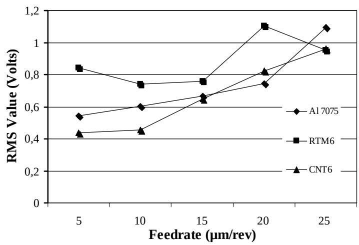


Figure 1. Acoustic emission RMS value for different feedrate.

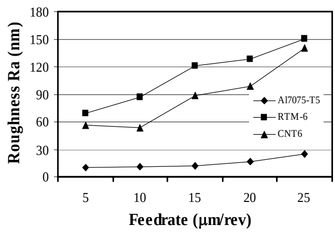


Figure 2. Surface roughness values versus feedrate.

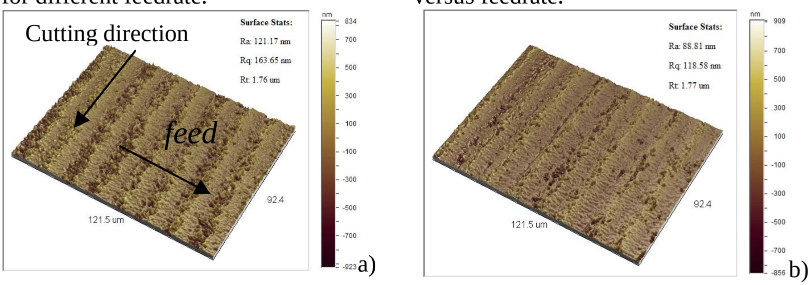
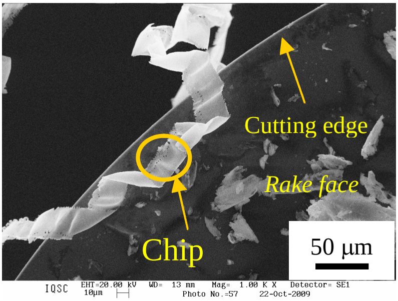
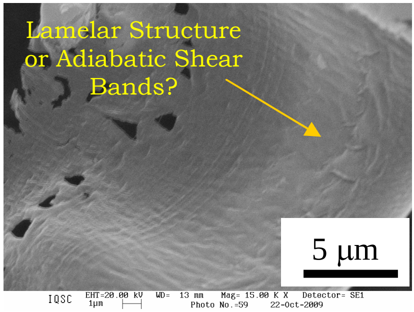


Figure 3. 3-D image of the machined surfaces, a) RTM6; b) CNT6 -0,7% wt . (f= 15 μm/rev and ap= 10 μm).

Figure 4 (a) show some chips left on the cutting edge of the diamond tool used. Fig. 4 (b) shows a detail view of the chip shown in Fig. 4(a). The “microstructure” shown on the free surface of the chip is not clear if there is a lamellar structure or adiabatic shear bands which is characteristic of materials having low thermal conductivity [4]. In high CNT concentration (10%) in Polycarbonate matrix the shear bands do not appear [5]. Just reminding that in our composite the concentration was 0.7% wt.



a)



b)

Figure 4. SEM image of the cutting edge used in the machining tests.

In summary, in this paper acoustic emission technique was used to monitor micromachining of epoxy resin CNT composite. The RMS signal amplitude of the acoustic emission response increased with the increase in feed rate. The increase in feedrate seems to have a direct relation to the brittle response of the epoxy resin during machining. RMS signal amplitude is increased when the brittle mode is achieved during machining of the composite and stable when monitoring the aluminum alloy. Chips were observed by means of SEM and it is not clear if shear bands or lamellar structure were the mechanism responsible for chip formation from the base epoxy. For the composite sample some “traces” of very small (~300 nm) shear bands were observed on the free surface of the chips. No sign of cutting edge wear was observed.

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