ELSEVIER

Journal of Materials Processing Technology 185 (2007) 184–190

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Online monitoring of acoustic emission for quality control in drilling of polymeric composites

S. Arul [a], L. Vijayaraghavan [a,*], S.K. Malhotra [b]

[a] Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India
[b] Composites Technology Centre, Indian Institute of Technology Madras, Chennai 600 036, India

Abstract

Automation and optimization of the manufacturing processes play an important role in enhancing productivity. For this, monitoring and diagnostic systems are becoming increasingly necessary to asses the response of materials in manufacturing. In this paper, acoustic emission (AE) sensing was employed for on-line detection of workpiece status and to improve the process stability and workpiece quality by minimising associated defects. Drilling trials were conducted on woven glass fabric/epoxy with high speed steel (HSS) drills to determine the relationship between AE rms and cutting parameters. The variation of AE rms and power are in close correlation to the flank wear and hole shrinkage. The experimental results show that AE is very sensitive to the response of the drilling environment.

Keywords: Acoustic emission; Thrust force; Flank wear; Hole shrinkage

1. Introduction

The use of composite materials has grown rapidly in recent years, especially in the aerospace and automotive industries due to their useful properties such as, high specific strength, high specific stiffness, good corrosion resistance and good fatigue performance. These properties can be tailored to suit many engineering applications. Even though near-net manufacturing of composite materials is possible, drilling will remain an unavoidable operation, particularly in assembly practices. There is a considerable difference between the machining of metals, their alloys and that of composite materials due to their anisotropy and inhomogeneity. Fiber reinforced polymer composites pose considerable problems in drilling such as delamination, fiber pull-out, hole shrinkage, spalling, fuzzing and thermal degradation [1–3]. Many researchers proposed that the quality of drilled surfaces is strongly dependent on drilling parameters.

Among the defects caused by drilling, delamination is the most critical. Delamination can result in a lowering of bearing strength and can be detrimental to the material durability by reducing the structural integrity of the material, resulting in long-term performance deterioration. Drilling induced delamination occurs both at the entrance and the exit planes of the workpiece. Investigators have studied analytically and experimentally cases in which delamination in drilling have been correlated to the thrust force during exit of the drill and there is a ‘critical thrust force’ below which no damage occurs [2–4]. A rapid increase in feed rate at the end of drilling will cause the cracking around the exit edge of the hole. It was also stated that the larger the feeding load, the more serious is the cracking [5].

The ultimate goal of on-line monitoring of composite drilling is to produce defects-toleranced high quality holes. Numerous types of sensors are available for monitoring the drilling environment. Inasaki et al. [6] mentioned that among those, acoustic emission (AE) sensor is considered to be one of the practical and potential candidates.

AE can be used as an active, intelligent indicator for monitoring process status. AE generated during drilling of composite laminates mostly emanate from sources like matrix deformation, fiber cutting, friction mechanisms, delamination and tool wear. Everson and Cheraghi [7] identified the characteristics of these individual sources in terms of AE signal.

Jiaa and Dornfled [8] examined the use of acoustic emission for detecting delamination of composite laminates during drilling. Their results showed a linear energy level increase in AE based on the size of entry and exit hole in the composite. Lee et al. [9] investigated the application of AE for process monitoring of dull or broken twist drills. Mizutani et al. [10] used AE during drilling of composites. AE generated during drilling of composite laminates carries valuable information on the state of material being cut.

* Corresponding author. Tel.: +91 44 2257 8533; fax: +91 44 2257 8578.
E-mail address: lvijay@iitm.ac.in (L. Vijayaraghavan).

0924-0136/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2006.03.114

Ravishankar and Murthy [11] stated that the AE signature is highly dependent on the type, nature and surface characteristics of the tool and the laminate. Sreejith and Krishnamurthy [12] used AE to study the performance of carbon/phenolic composite machining with PCD and PCBN tools. They explained the tool behavior while machining at different cutting speeds.

In this work, an experimental study on the drilling of GFRP has been carried out to study the influence of drilling parameters (cutting speed and feed rate) on thrust force and flank wear which influences the hole shrinkage and also to monitor the material response through AE to assess the relationship between monitored parameters.

2. Workpiece material

Woven glass fabric reinforced plastic (GFRP) composites of 4 mm thickness were used for conducting the drilling studies. The reinforcing material used was 10 mil woven glass fabric. The matrix used was epoxy resin LY-556 and the hardener is HT-972, both manufactured by Ciba–Giegy. Due to low cure shrinkage, GFRP laminates are stable and free from internal stress. The laminate was made by compression molding. Care was taken to ensure complete wetting of the fibres and removal of entrapped air and excess resin. The nominal fibre volume fraction was 0.4.

3. Experimental work

Drilling trials were performed on precision Deckel CNC machine where in the thrust force during machining was measured with Kistler two component dynamometer (model 9271A). The resulting charge signals were converted into output voltages proportional to the forces sustained and then these voltage signals were amplified by two charge amplifiers (model 5015) and managed via a data acquisition system. AE was measured with a Kistler wide band piezoelectric AE sensor (model 8152A2) and the signal amplified and conditioned. AE parameters like peak power and root mean square (rms) values were obtained by processing the raw AE signal using AET 5500 system. The sensor was positioned on the work piece near the tool, using light lubricant oil as acoustic couplant. The tool wear on flank face was evaluated using toolmakers microscope. The hole shrinkage was measured by non-contact co-ordinate measuring machine. The schematic layout of the experimental set up is shown in Fig. 1. Table 1 shows the experimental conditions for GFRP drilling.

Table 1
Experimental conditions

Machine used	Deckel CNC milling machine
Tool (material)	High speed steel
Diameter	6 mm
Workpiece	Woven glass fabric/epoxy
Cutting speed	9.43–30.16 m/min in steps
Feed rate	0.02–0.08 mm/rev in steps
Tool dynamometer	Kistler two component dynamometer (model 9271A)
AE system	Kistler wide band piezoelectric AE sensor (model 8152A2)
Tool makers microscope	Leitz Wetzlar
Non-contact co-ordinate measuring machine	Vidicom Qualifier 866

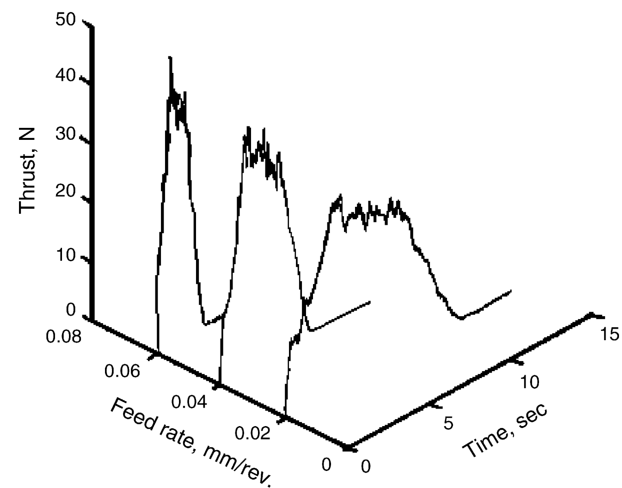

Fig. 2. Variation of thrust force over drilling cycle for 18.85 m/min cutting speed.

4. Results and discussion

4.1. Parametric influence of cutting parameters on thrust force

Thrust force, a direct indicator of the status of the cutting wedge, can be used as a process indicator. Any change in the cutting force can be attributed to change in the status of cutting wedge either by deformation, chipping and other modes of wear of tool material over the cutting edges or possible reactions between the tool and work materials. Fig. 2 illustrates a sample chart of thrust force, for three feed rates examined (0.02, 0.04 and 0.06 mm/rev) and 18.85 m/min cutting speed. At the beginning of the cycle, the thrust force rises quickly. During full engagement of the drill, there is a gradual drop in the thrust force, perhaps due to the softening of the matrix by the heat generated during the drilling process. The forces decrease as the drill emerges out of the laminate. However, only the thrust force goes to zero when both the chisel edge and the cutting lips have emerged out of the laminate. The trend of variation in thrust force is not steady during drilling. It can be attributed to the high value of the rake angle at the periphery for which an axial component

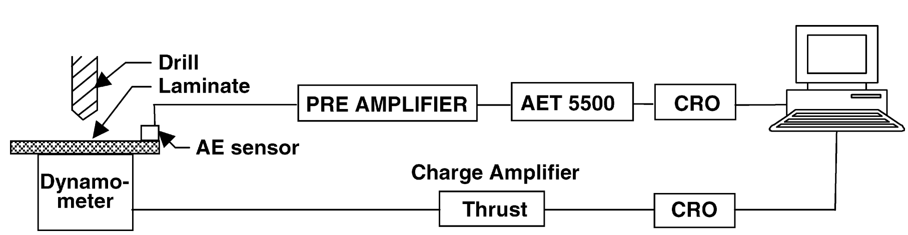

Fig. 1. Experimental setup for drilling tests.