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Drilling delamination and thermal damage of carbon nanotube/carbon fiber reinforced epoxy composites processed by microwave curing

Nanya Li, Yingguang Li*, Jing Zhou, Yongxi He, Xiaozhong Hao

College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

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ABSTRACT

The drilling-induced delamination and thermal damage of carbon fiber reinforced epoxy composite materials are serious problems especially for high value components of the aviation industry. To suppress the delamination and drilling ablation, an innovative approach was employed in this study. The multi-walled carbon nanotubes (MWCNTs) were introduced to the matrix resin to improve the interlaminar strength and thermal conductivity. The as-prepared composite was processed by microwave curing to enhance the interface strength between carbon fiber and the carbon nanotubes modified matrix. During the drilling processes, optical fiber Bragg grating sensors were utilized to precisely measure the drilling temperature. Experimental results indicated that the interlaminar fracture toughness was increased by more than 66% compared to that of the traditional thermal cured samples without MWCNTs. And the delamination factor was decreased by 16% according to the computerized tomography scanning results. The maximum drilling temperature of the MWCNTs reinforced composite was below the glass transition temperature of the matrix resin and declined by 23 °C compared to traditional composites. With this novel method of carbon nanotube modification and microwave curing, we provide the capability of reducing the drilling delamination and thermal damage of carbon fiber composites simultaneously, and explored the possibility of manufacturing and machining integration.

1. Introduction

Carbon fiber reinforced polymer composites are increasingly used in the aerospace industry. Drilling is an obligatory operation for composites to assemble with other parts in aircraft structures, but the delamination and thermal damage in drilling processes give rise to high risk of components damage during the whole service life cycle [1].

For the sake of reducing the delamination and thermal ablation of carbon fiber reinforced polymer composites, many research teams have proposed efficient approaches to solve these problems. Different drill bits have been studied to reduce the thrust force during drilling processes [2,3], as the large thrust force usually leads to delamination when the drilling tool approaches the exit plane. Through optimizing the cutting parameters (such as feed rate and spindle speed) [4–6] and using back-up plate [7], the delamination of composites can be suppressed to a certain extent. Tsao and Hocheng [8] presented a drilling-induced delamination detective method by using computerized tomography which was a feasible and an effective tool compared with ultrasonic scan. Davim et al. [9] measured the adjusted delamination factor using digital analysis. On account of the fiber reinforced polymer composites tend to absorb moisture, dry drilling is frequently applied in aerospace fields. When the drilling temperature exceeds the glass transition temperature of composite materials, a potential security liability are expected, such as reduction of the strength and appearance of serious defects [10]. By means of non-traditional drilling strategies [11] and optimization of drilling parameters [12], the cutting temperature can be decreased. The thermocouple [13,14] and thermal infrared imager [15,16] were mostly employed to measure the temperature variation during drilling.

The extremely low manufacturing efficiency and high energy consumption of traditional composite processing technologies drive the aerospace industry to search new curing technologies to replace the traditional thermal processing. Microwave curing technologies could solve the above problems and provide better interfacial strength than the traditional heating process [17]. Therefore, the drilling induced delamination was expected to reduce by applying microwave curing. In recent years, carbon nanotube/carbon fiber hybrid composites draw many attentions as the next-generation aircraft composite [18]. As the carbon nanotubes can offer better interlaminar strength and higher thermal conductivity by modifying the matrix resin.

The aim of this work is to present an innovative approach to

* Corresponding author. Fax: +86 25 84895906.
E-mail address: liyingguang@nuaa.edu.cn (Y. Li).

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suppress delamination and drilling ablation in composite materials, via carbon nanotubes and microwave curing process to enhance the interlaminar strength and thermal conductivity simultaneously. The drilling-induced delamination was measured by computed tomography, and a special technique using optical fiber Bragg grating sensor to directly measure the drilling temperature was adopted in the experiments.

2. Experimental

2.1. Sample preparation and devices applied

The unidirectional fiber cloth made of carbon fiber and small amount of glass fiber was applied. For the matrix resin, the bisphenol-A epoxy resin and polyether amine curing agent were used in this experiment. The Multiwall Carbon Nanotubes (MWCNTs) with 20–50 nm diameter and 50 μm length are modified by carboxyl. The drilling tool is made of cemented carbide, with 6 mm diameter, 140° point angle, 30° helix angle and 0.3 mm chisel edge (AHNO cutting tool technology Co., Ltd.). Other materials used in the experiment were purchased from supplier Airtech, including vacuum bag DPT1000, release film WL5200B, perforated release film RP3, breather Ultraweave 1332 and sealing tape AT200Y.

According to the experimental results [19,20] and theoretical analysis [21], the 1.0% weight ratio of multiwall carbon nanotube was suitable for this experiment, thermal conductivity could improve over 40% and not too many to result in agglomeration and decrease the strength of matrix resin. To improve the reliability of the experimental results, three samples were tested for each drilling parameters. The composite laminate sample's was prepared by manual lay-up and gumming, stacking-sequence was $[0]_{36}$, that means 36 layers of the unidirectional fiber clothes were laid up in one direction. The dimensions of samples were 80 mm in length, 80 mm in width and 5.4 mm in thickness. As the MWCNTs hybrid resin have high viscosities than others, the breather and release film should applied more to increase the resin flow ability. Both of the thermal and microwave curing process of composite samples were set as heating to 90 °C and hold for 30 min and then dwell at 120 °C for 120 min. The heating rate was 1.5 °C/min and cooling rate was about 1.3 °C/min. Metal materials are known to reflect microwave energy, thus a high strength silicon tool was employed.

The schematic of sample preparation and experimental measurement were shown in Fig. 1. A rotation-revolution mixer (LY-250) was applied to disperse the carbon nanotubes into epoxy resin, and provided about 800*G* dispersion force. The composite samples were cured in a high performance octahedron microwave oven which was designed and manufactured by the authors' research team [22]. This kind of construction can guarantee a more even electromagnetic wave distribution than regular oven by

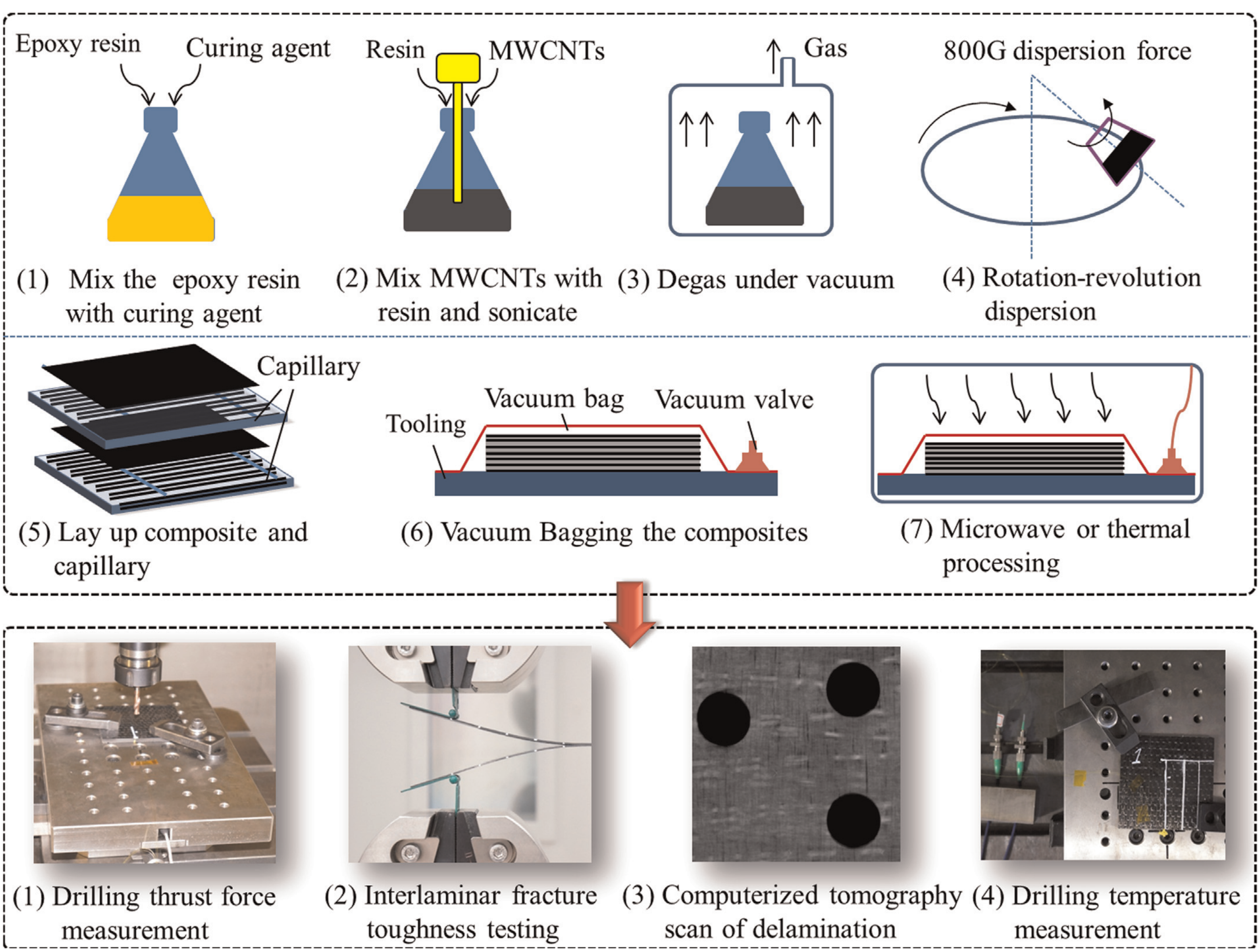

Fig. 1. The schematic of sample preparation and experimental measurement.