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Effect of temperature and cyclic hygrothermal aging on the interlaminar shear strength of carbon fiber/bismaleimide (BMI) composite

Pei Sun, Yan Zhao *, Yunfeng Luo, Lili Sun

School of Materials Science and Engineering, Beihang University, Beijing 100191, China

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ABSTRACT

In this research, hygrothermal aging behaviors of carbon fiber/bismaleimide (BMI) composite materials were investigated. Water diffusivity was measured through 3 wet–dry cycles for BMI resin reinforced with unidirectional carbon fiber CCF300/QY9511 composite. The changes of the diffusion coefficient and saturation level of water absorption during the 3 cycles were determined. Electron microscopy revealed that micro-cracks near the weak interface together with the de-bonding provided routes for water uptake. The interlaminar property of composite was characterized by interlaminar shear strength (ILSS). ILSS reduction of CCF300/QY9511 from hygrothermal aging could come to a plateau during the first 14 days. The different damage morphologies between dry specimens and wet specimens were characterized by electron microscopy. ILSS under different test temperatures was also studied with an Arrhenius method, and the result of the Arrhenius method confirmed that routes, such as micro-cracks and de-bonding, for water uptake were also instrumental in speeding up the drying.

1. Introduction

Carbon fiber reinforced plastic (CFRP) have been increasingly used in aerospace industry during the past decades due to their attractive properties, such as light weight, corrosion resistance, and easy to design. Thermoset bismaleimide (BMI) resins have played an important role as matrix materials in high-temperature aerospace structural applications due to their superior thermal stability and fatigue resistance at high humidity [1]. In such applications, the composites are exposed to harsh and changing environments featuring a wide range of temperatures and "hot-wet" exposures, which accelerate decline in their mechanical and other properties [2,3]. And a variety of correlative experimental and theoretical researches have been done to discuss the impact of aging on the material performance [4–8].

Some work focused on moisture absorption mechanism in BMI resin and its composites. A two-stage diffusion model [9] has been established: the initial fast diffusion can be predicted by Fick's law, but no equilibrium uptake was observed after nearly a year, while the second stage considered the structural relaxation induced by absorbed moisture. The similar result came from the analysis of Li [1], and his FTIR results showed that the non-Fick diffusion behavior was due to the hydrogen bonding between water and the matrix. Bao's research demonstrated that the slope for the second stage absorption was lower in the BMI composites [10].

During the moisture absorption of composites, physical changes such as micro-cracks propagation and swelling, as well as chemical changes such as hydrolysis and chemical scission increase, which can degrade properties of the materials. Also, the fiber/matrix interface can be influenced by moisture absorption [11–13] because resin is extremely easy to absorb water which leads to volume expansion, while carbon fiber is almost non-absorbent, so that the resin's swelling generates stress and can cause interface debonding [14,15]. Roughly annular micro-channels which are wider in low quality composite interfaces are prime conduits of moisture diffusion, and widen further as water penetrates the material [13]. In addition, water could interrupt the chemical bonding of the matrix or the interface, and could change the network structure of the matrix, hereby influencing material performance [1,16,17]. The hygrothermal diffusion behavior of the matrix can be affected by both hydrogen bonding and the nature of the network architecture [1]. The increased polarity of composite due to water uptake could lead to more chemical degradation [16].

When the composites absorbs water and then are dried, water uptake and loss can cause stresses and micro-cracks, which leads to even greater water absorption [18], so some researchers focused on the influence of the wet–dry cycling on composites and matrix [9,19,20]. Newman's study demonstrated the importance of testing the water resistance of plant-fiber composites over multiple cycles instead of a single cycle [20]. Through wet–dry cycling experiment,

* Corresponding author. Tel./fax: +86 10 82317127.
E-mail address: jennyzhaoyan@buaa.edu.cn (Y. Zhao).

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