IN-SITU HEALING OF STATIC AND FATIGUE CRACK IN THERMOSET FIBER-REINFORCED COMPOSITES

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Abstract

In this study, static fracture experiments under mode-I and mixed mode loading, and fatigue testing under mode-I loading were carried out on double cantilever beam (DCB) specimens, and subsequent healing of the delamination was investigated. Thermoplastic healants dispersed in a thermoset CFRP composite were used to perform the healing, triggered through brief heating in an oven. It was observed from the test results that delaminations can be healed efficiently and the healing was found to be repeatable. As a result of healing, significant crack closure was observed and fatigue crack growth rate was considerably reduced. These findings can be helpful in extending the service life of laminated composites.

1. Introduction

Composite structures often experience different types of loads during their service life and hence exhibit different damage modes which leads to structural failure. Interlaminar damage (delamination) is one of the leading damage modes observed in laminated composites and it is essential to investigate the damage behavior and explore ways that can help maintain structural integrity. To this end, double cantilever beam (DCB) specimens were manufactured from carbon fiber laminates consisting of thermoplastic healants which helps effectively in healing the crack upon application of heat. There are different healing techniques that have been employed since the inception of healing in composites and are broadly classified into autonomous and non-autonomous healing. Autonomous healing does not require external intervention to trigger the healing process such as in structures with microcapsules containing thermoset healants where the macrocapsules are ruptured due to crack growth causing release of healants leading to in-situ polymerization. As a result of the polymerization, rebonding of the fracture surface takes place thereby healing the crack. The primary drawback of this technique is in its lack of repeatability. On the other hand, the non-autonomous healing requires external intervention (e.g. heat, UV) to trigger the healing process. In this study, non-autonomous healing is attempted where mendable thermoplastic additives are added to the matrix during the manufacturing stage. After the damage detection, healing is realized by thermoplastic melting and bonding of the fractured surfaces by melted healants upon heat application. This method is advantageous to other methods owing to its simplicity, repeatability, and capability of the application to a wide range of thermoset-thermoplastic combinations as long as polymers are compatible with each other.

2. Results

The DCB specimens were used to perform experimental testing involving following failure modes:

a. Static mode-I delamination with healing
b. Static mixed mode delamination with healing
c. Mode-I fatigue delamination with healing

In the interest of space, only results from mode-I fatigue delamination testing with healing are presented here. Mode-I fatigue experiments were performed on unidirectional carbon/epoxy laminates by following the ASTM D6115-97 standard under displacement control mode for displacement ratio of 0.1 and a frequency of 5 Hz. A initial pre-crack of 38.1 mm was created with the help of PTFE film in the fabrication stage. Initial Mode-I fatigue delamination tests (i.e., the virgin case) were carried out until the delamination crack extended 25 mm from the pre-crack end. The delamination crack length was recorded at regular intervals of loading cycles with the help of a digital camera. The specimen was tested for the virgin case and then kept in an oven at 80°C for 30 min to activate healing. It was then allowed to cool at room temperature for 24 hours to allow thermoplastic healants to congeal, and the same fatigue test procedure

was followed to test the healed specimen for five additional healing cycles. Once the fatigue tests are performed, the fatigue crack growth rate (da/dN) was plotted against the maximum mode-I strain energy release rate (G_{max}) on a log-log scale, and linear regression was used to extract the Paris Law parameters m and A.

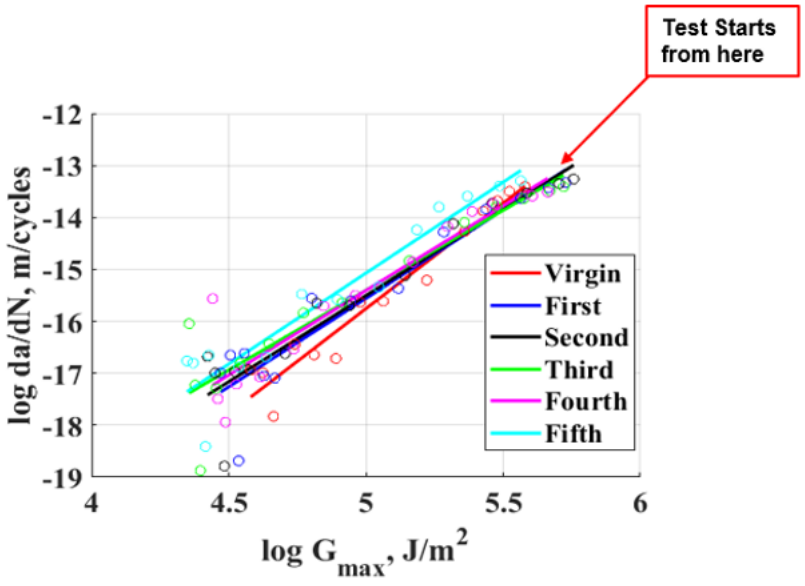

Fig.1 – Variation of da/dN with G_{max} for virgin and healed DCB specimen under mode-I fatigue loading

To further examine the repeatable healing capability of the proposed healing system for mode-I fatigue damage, the fatigue damage and healings were carried out for five successive cycles. The variation of crack growth rate (da/dN) vs. maximum strain energy release rate (G_{max}) for virgin and healed DCB specimen under mode-I fatigue loading is plotted on log-log scale in fig.1. The Paris Law parameters m and A were obtained from the linear fit shows that the slope parameter (m) for virgin case was 4.06, and that of first heal, second heal, third heal fourth heal, and fifth heal were 3.40, 3.31, 3.07, 3.25, and 3.49 respectively. It is clear from fig.1 that due to healing of the crack, the crack growth rate reduced significantly with respect to the virgin specimen. Similar results were observed for number of DCB specimens obtained from different laminates. After healing, healant fibrils were observed bridging the crack which are responsible for rebonding the delminated surfaces. The data also highights the repeatability of this healing process.

3. Conclusions

The mode-I fracture, mixed mode fracture, and mode-I fatigue delaminarion was carried out on DCB specimens obtained from thermoset composite laminates with thermoplastic healants, and the heat activated healing was performed on delaminated specimens. The results obtained indicates that the intelaminar fracture and fatigue cracks can be repeatably healed by means of thermoplastic healants. In addition, work is currently underway to activate the healing by means of macro fiber composite (MFC) actuators instead of oven heating, the details of which will be presented in the final manuscript.

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