

Fracture Behavior of Typical Structural Adhesive Joints Under Quasi-Static and Cyclic Loadings

2010-01-0969

Published
04/12/2010

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ABSTRACT

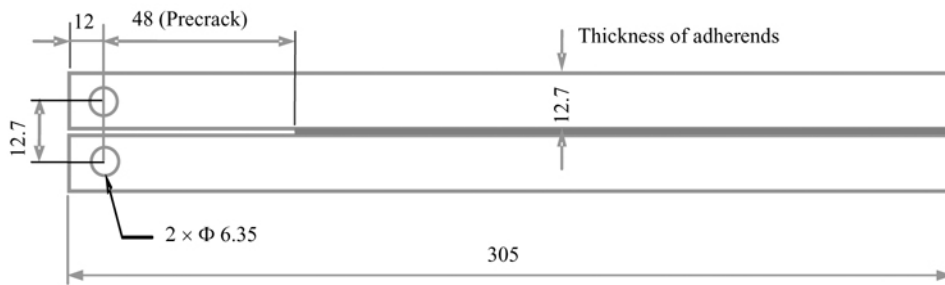
Structural adhesive joints are expected to retain integrity in their entire service-life that normally involves cyclic loading concurrent with environmental exposure. Under such a severe working condition, effective determination of fatigue life at different temperatures is crucial for reliable joint design. The main goal of this work was thus defined as evaluation of fatigue performance of adhesive joints at their extreme working temperatures in order to be compared with their fracture properties under static loading. A series of standard double-cantilever-beam (DCB) specimens have been bonded by three structural 3M epoxy adhesives selected from different applications. The specimens were tested under monotonic and cyclic opening loads (mode-I) in order to evaluate the quasi-static and fatigue performances of selected adhesives at room temperature, 80°C and -40°C. The test results revealed that the fatigue damage occurred at relatively low load levels when compared to quasi-static fracture forces. At room temperature, the maximum cyclic fatigue forces varied between 25% and 40% of corresponding quasi-static fracture loads of selected adhesives. More significant reductions in adhesive mechanical performances were observed at 80°C. At cryogenic temperature, the adhesives had their own characterizations; mainly increasing the fatigue resistance but very sensitive to testing parameters such as loading rate or crosshead speed. In conclusion, the experimental observations showed a significant influence of fatigue loading on adhesive joints mechanical performances that should be considered in joint design, particularly at non-ambient temperatures.

INTRODUCTION

Structural adhesives are now progressively used in different applications where the high strength bonds are required. Aircraft fuselages, ground transportation frames, renewable-energy like wind generators and adhesively bonded panels in construction applications are some good examples for structural adhesive joint applications. In many cases, it is often required to transfer cyclic loads concurrent with environmental exposure. Although this type of service condition is possibly the most destructive form of mechanical loading, yet the majority of durability tests and consequently the adhesive joint designs are based on the quasi-static test results. At such destructive loading condition, the knowledge of fatigue behavior becomes strategic for designers to rely on adhesive joining for structural applications particularly in automotive industries. Design of reliable structural adhesive joints requires the effective determination of fatigue life at corresponding environmental conditions. Therefore, this research work was planned to aim the evaluation of fatigue performances of typical adhesive joints in a comparison with their static fracture properties. The specific goal of this work was then a comparison between fatigue behaviors of three selected 3M adhesives and their static fracture properties at their extreme working temperatures.

SPECIMENS AND EXPERIMENTS

A fracture-based approach is used in this work to evaluate the temperature-dependency in monotonic and fatigue behaviors of three structural adhesives of 3M selected from different applications. Adhesive-A was a one-part epoxy adhesive with



Adhesive	Young modulus (MPa)	Poisson's ratio
A	671.74	0.38
B	2135.03	0.41
C	2263.45	0.41

Fig. 1. Geometry of DCB specimens and adhesives elastic properties (All dimensions are in millimeter).

a lower elastic modulus that was developed to efficiently work at a wide range of working temperatures. Adhesive-B was a general-purpose non-sag two-part epoxy adhesive and the third adhesive was a film-based one part epoxy adhesive (Adhesive-C). The elastic properties of selected 3M adhesives are tabulated in Fig. 1. Three double-cantilever-beam specimens (DCB) were fabricated by 3M for each combination of selected adhesive and working temperature totally 27 adhesive specimens. The specimens were cut from the bonded aluminum plates (2024-T351, 1/2"×12"×12") that were treated as a standard sulfuric acid / sodium dichromate etch (FPL etch) and phosphoric acid anodization process prior to bonding, Ref. [4]. A thin-layer primer was also applied and fully cured before applying the adhesive. In order to control the adhesive bondline thickness, the 150 mm brass shims (635 mm for Adhesive-C) were placed along three sides of aluminum plates and on the fourth side a Teflon tape was applied as a precrack. The DCB specimens were cut from bonded aluminum plates in accordance to ASTM standard D3433-05 with a final geometry schematically shown in Fig.1. Prior to testing, the average bondline thickness of each specimen was determined from five microscopic measurements along specimen length in order to determine and discard the out-of-range specimens. This was the case for the first series of DCB specimens bonded by Adhesive-C those were lately replaced by a new series of specimens with the thicker nominal bondline thickness (635 mm rather than 150 mm).

<figure 1 here>

The specimens were tested under opening monotonic and cyclic loads (mode-I) by employing a novel fracture test technique in which some crack detection sensors were installed on one face of DCB specimen for controlling the testing machines by their signals. The machines alternatively changed the loading case from monotonic forces to variable-amplitude cyclic loads as crack broke a sensor. Two closed-loop servo hydraulic systems (810 MTS) together with the optical crack length measuring systems were used in this work. A dual-actuator (2 × 15kN) hydraulic machine equipped with two unidirectional hydraulic actuators was used for the tests at room temperature and 80°C. This

machine was especially designed for adhesive joint strength evaluation under complex loading modes which was equipped with a custom-made temperature chamber for the tests at higher temperatures. For the tests at -40°C, a standard 50kN hydraulic system equipped with liquid nitrogen (LN2) injected chamber was employed. Due to limited space in this chamber, a loading fixture was fabricated to convert vertical actuator load into horizontal loads and allow longer DCB specimens to be mounted vertically in the chamber. Fig. 2 shows both testing setups with the typical adhesive joints installed. It should be mentioned that the conformity of the test results obtained from different loading setups was verified through a series of validation tests with 50 kN load frame at room temperature and 80°C.

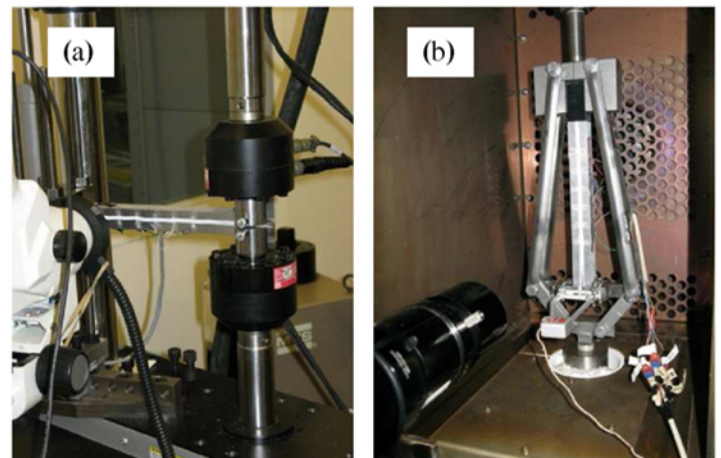


Fig. 2. Testing setup on (a) dual-actuator unit, (b) 50kN unit that was only used in cryogenic tests.

Each fracture test was started by a series of monotonic loading stages at room temperature in order to determine the quasi-static resistance of tested specimen. Five or six variable-amplitude cyclic tests were then performed under force control at a load ratio of 0.1 and a frequency of 8Hz. Prior to each cyclic loading, at least five more monotonic loadings were again applied to sharpen the crack tip and also to determine the local quasi-static resistance at testing temperature. Fig. 3 schematically shows the loading stages during a typical fracture test of this study. In quasi-static test