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Letter

The effect of fiber orientation on fracture response of metallic fiber-reinforced adhesive thin films

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HIGHLIGHTS

- The metal fibers were incorporated with different orientations in the adhesive layer of a bonded joint.
- Fracture tests were conducted on double cantilever beam (DCB) specimens to study the fracture behavior of metallic fiber-reinforced adhesives.
- The orientation of the fibers and the distance between the fibers were the key parameter in bond design.
- Longitudinally reinforced adhesives resulted in higher fracture energy improvements compared to the laterally reinforced adhesives.
- Reducing the distance between the fibers, considerably increased the fracture energy of epoxy adhesive.

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ABSTRACT

Incorporation of metallic fibers into the adhesive layer can significantly improve the mechanical behavior of the adhesive joint. This paper aims to assess the fracture behavior of an epoxy adhesive reinforced by longitudinal and lateral metallic fibers. Double cantilever beam (DCB) specimens were used to obtain the fracture energy of both non-reinforced and reinforced adhesives under mode I loading condition. In addition to the fiber orientation, the distance between the metal fibers was considered as the second key parameter in the experiments. It was concluded that although incorporation of metallic fibers in the adhesive layer improves the fracture behavior of neat adhesive, however, higher improvements were observed for the adhesive reinforced with longitudinal fibers. Furthermore, reducing the fiber distances resulted in higher values of fracture energy.

Adhesive bonding has been widely used in various industries such as aerospace, automotive, and marine. However, adhesive joints are usually considered as the weakest link in the structure. Hence, numerous researches have been conducted by scholars to improve the mechanical behavior of this category of thin films including modification of interface geometry [1-4] and modification of the adhesive material by incorporating nano, micro, and macro additives [5-12].

Application of metallic fibers for reinforcing the adhesive layer was considered as an efficient method for improving both fracture behavior and also the load bearing capacity of the adhesive joints. The reinforcing fibers can be incorporated both in the adhesive fillet and adhesive layer along the joints or in lateral direction [7, 10].

Khoramishad and Razavi [8] studied the effect of incorporating longitudinal metallic fibers in the adhesive layer of single lap joints. They performed both experimental and numerical analyses to assess the mechanical behavior and stress distribution of the metallic fiber reinforced adhesives. According to their research, incorporation of aluminum fibers improved the shear strength of an epoxy adhesive. Additionally, lower shear and

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peel stresses were reported for the reinforced adhesive joints resulting more uniform stress distribution. For the case of lateral orientation of the metallic fibers in the adhesive layer, Nemati et al. [10] reported lower shear strengths of the reinforced adhesive compared to the neat adhesive. They reported higher peak stress values for the transversal reinforced joints leading to lower load bearing capacity of the adhesive joint.

Khalili and Fathollahi [9] employed longitudinal NiTi shape memory metallic fibers to enhance the creep behavior of adhesively bonded joints. Several single-strap adhesive joints were fabricated by incorporating the NiTi shape memory fibers in the adhesive layer resulting a positive impact on the creep life of bonded joints. A maximum value of 55% improvement in the creep rupture time was observed for the reinforced adhesive joints.

For failure assessment of the adhesive joints using fracture mechanics or damage mechanics approaches, it is necessary to have the fracture energy of the adhesive. Hence, Razavi et al. [11] conducted extensive experiments on longitudinally reinforced pre-cracked samples under mixed mode I/II loading conditions. It was reported that the fracture behavior of the longitudinally reinforced adhesive joints can be 12 times higher than that of the non-reinforced adhesive.

Dealing with the pure mode I loading condition, the majority of the available researches in the literature used the DCB and the tapered double cantilever beam (TDCB) tests [11]. The main aim of the present study is to determine the impact of the orientation of the metal fiber incorporation in the adhesive on the mode I fracture behavior of an epoxy based adhesive through experimental investigations using the DCB specimens. Metallic fibers were incorporated into the adhesive layer along the width and length of the joints with different fiber distances and the results were compared to assess the effect of reinforcing fiber orientations.

The DCB substrates were cut from 5 mm thick 7075-T651 aluminum sheet with a yield strength of 500 MPa. The length and the width of the substrates were 200 mm and 30 mm, respectively. AISI 304 stainless steel wires with a diameter of D = 0.6 mm were used as reinforcing fibers. The substrate surface was grinded using 200-grit sandpaper followed by acetone bath. Finally, the aluminum substrates and reinforcing fibers were acid etched according to the German Institute for Standardization (DIN) 53281 [13] to improve the adhesion between metallic parts and adhesive and also reduce the environmental effect on the efficiency of the bonding. Gaging sheets were used to keep the reinforcing fibers align and with constant distance through the fabrication process. The bonding thickness was controlled by 1 mm thick spacers at the ends of the joints. Two substrates were bonded using UHU® plus endfest 300 adhesive [14] and a 12 μm thick non-stick polyethylene film was inserted in the bonding line as a pre-crack in a way that the pre-crack length was equal to 57 mm for all the testing samples.

A schematic view of longitudinal and lateral metal fiber incorporation is illustrated in Fig. 1. For each case of fiber orientation, two different sets of DCB samples with fiber distances of d/t = 3 and 2 were prepared in which d is the horizontal distance between the fibers and t is the bond line thickness. It should be mentioned that the volume fractions of the reinforcing fibers for fiber distances of d/t = 3 and 2 are approximately 10% and 16%. Adhesive joints were cured for 5 min at 150°C and post cured for one week at 25°C. At least four DCB specimens were tested for each reinforcement configuration.

A constant displacement rate of 0.25 mm/min was applied to the DCB joints and the load-displacement curves were obtained. The crack propagation during the test was captured using a digital camera. In this paper, the simple beam theory was employed for fracture energy calculations using the values of applied load and crack length at each stage during the test. Accord-

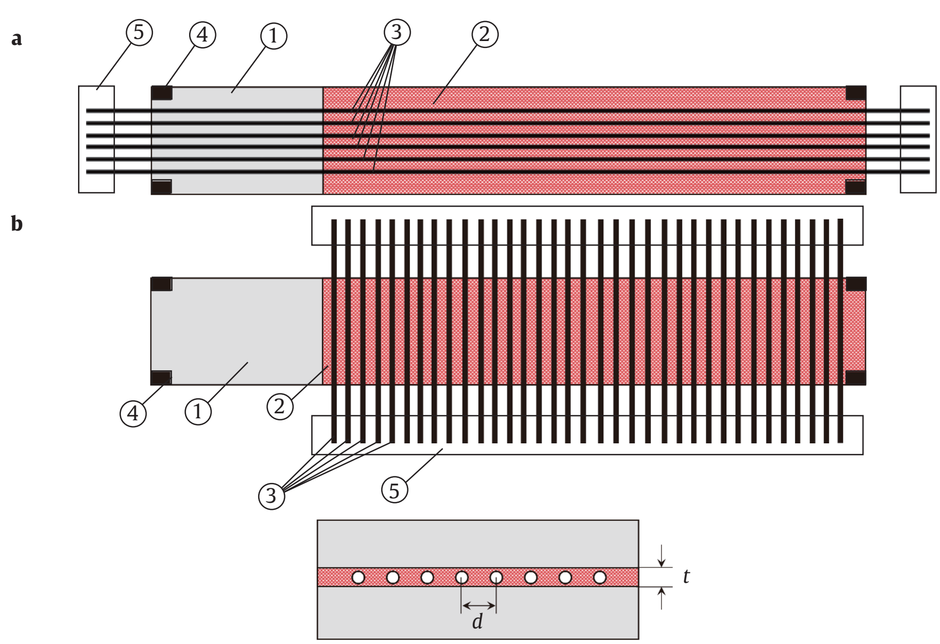

Fig. 1. Schematic view of the cross section of the metallic-fiber reinforced adhesive joint. (a) Longitudinally reinforced joint, (b) laterally reinforced joint. ① Aluminum substrate, ② adhesive layer, ③ metal fiber, ④ spacer, ⑤ gaging sheet.