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Study of Shear Dominant Delamination in Thin Brittle-High Ductile Interface

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Abstract

Thin laminates of Aluminum (Al) foil and Low Density Polyethylene (LDPE) film are essential constituents of food packages where these two substrates are bonded together with a thin layer of LDPE acting as adhesive. Noticeably, Al is a low ductile/quasi brittle material, whereas LDPE is highly ductile. The mechanism of delamination and strength of bond between the interfaces dictates the continuum and damage behavior of this composite. However, measuring the shear delamination properties is challenging as conventional test methods have limitations when the substrates are very thin and flexible. This study explains a tentative method that uses uniaxial tensile testing on the pre-cracked specimen of this composite to find energy dissipation due to shear delamination and successfully uses it in Finite Element Simulation in Abaqus. The delamination was observed in a narrow strip-like region close to fracture surfaces and measured with special visualization aid. A similar response was found in FEM simulation. Scanning Electron Microscopic (SEM) study of delaminated interface confirms the delamination to be shear in nature. In a cohesive zone modeling in Abaqus, the measured shear delamination energy was used as input parameter along with an arbitrary bi-linear cohesive law for validation of the experimental measurement.

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Keywords: Interlaminar shear delamination; thin flexible substrate; composite; cohesive zone modeling; work of fracture; tensile testing

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1. Introduction

The adhesion level in composite effects the overall behavior of laminates significantly. Measurement of adhesion property in bi-material interface has been studied by many authors including Chen et al. (2003). For experimental determination of adhesive properties, methods like Double Cantilever Beam (DCB) or End Notch Flexure (ENF) are used. ENF is a popular testing method for Energy Release Rate (ERR) determination with respect to adhesive shear deformation at crack tip of composites with relatively thin adhesive layer and stiff substrates and was adopted by many authors for instance Alfredsson (2004). These methods prove to be inconvenient when the substrates are thin flexible films. Because of the simplicity of concept and geometry, peel testing (Fig. 3 (b)) is adopted instead for this purpose as mentioned by Thouless et al. (2008). However, some researchers, O'Brien (1998) among them, argued that the apparent shear energy release rate measured by conventional methods is inconsistent with the original definition of shear fracture. This claim was based on the observation that there is tensile failure of the adhesive fiber during shearing, which is not practically sliding of two planes relative to each other.

Tensile testing of thin flexible laminates with pre-defined center crack of varying length is common practice for determination of relation between mechanical property of the laminate and adhesion level and similar study was done by Kao-Walter et al. (2004). Close observation of the propagation path of the pre-crack showed noticeable delamination around this area which should result in additional energy dissipation during the test. The key idea in this study was to claim that this additional dissipation due to delamination can be separated as the difference of work of fracture in a pre-cracked laminate and single layer substrates. Further study of the delaminated surface with the help of Scanning Electron Microscope (SEM) showed the delamination to be of shear in nature. This article addressed this observation to find an alternative method for separating the delamination energy using work of fracture. Several attributes and assumptions of such a method were described here and finite element simulation was used as validation tool.

2. Test method

Materials used for this investigation were thin and flexible Aluminum (Al) foil and Low Density Polyethylene (LDPE) film provided by a packaging industry. Al foil was manufactured by rolling till 9 µm (microns) of thickness. LDPE was extruded on to Polyethylene Terephthalate (PET) film in very high speed that induced material orthotropy due to polymer chain orientation. When LDPE film was separated from PET, film thickness was 27 µm. At a later stage, Al and LDPE were laminated with a 5 µm thin layer of additional LDPE. The specimens cut from the laminate were 230 mm in length, 95 mm wide and total thickness was 41 µm. Sharp blade was used to cut the

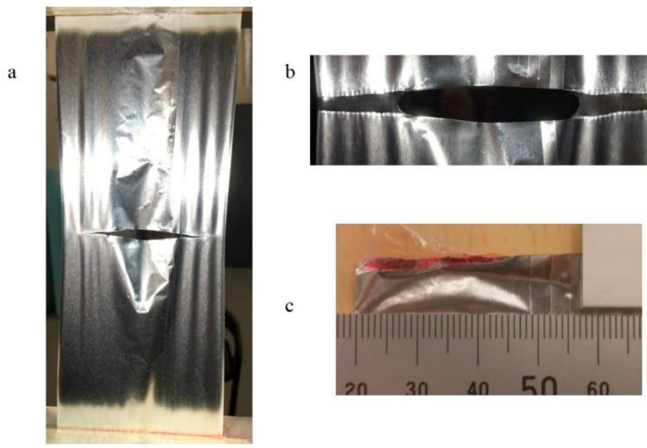

Fig. 1. Laminate test, (a) Tensile test of LDPE-Al laminate when Al pre-crack started to propagate; (b) Stretching and delamination of LDPE near crack tip; (c) Highlighted delamination area of one strip (out of four).