Composite Structures 160 (2017) 118–127

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Prediction of delamination of steel-polymer composites using cohesive zone model and peeling tests

Jinhyeok Jang [1], Minchang Sung [1], Sungjin Han, Woong-Ryeol Yu *

Department of Materials Science and Engineering (MSE) and Research Institute of Advanced Materials (RIAM), Seoul National University, 599 Gwanangno, Gwanak-gu, Seoul 151-742, Republic of Korea

ARTICLE INFO

Article history:
Received 9 June 2016
Revised 20 September 2016
Accepted 10 October 2016
Available online 14 October 2016

Keywords:
Sandwich structures
Delamination
Cohesive zone modeling
Peeling test

ABSTRACT

This study reports on the prediction of the delamination of steel-polymer composites. To characterize the adhesive properties from peeling tests, a simple model was derived based on peeling mechanics, in particular considering plastically dissipated energy of polymer film due to bending. Peeling tests were performed at two angles so that the adhesive properties were determined in both normal and tangential directions. Then, peel strength at arbitrary angle was predicted and compared with experiments, showing that the peel strength at only two angles and peeling mechanics considering the bending of polymer film can accurately describe the adhesive properties of steel-polymer interface. Finally, finite element simulations based on the cohesive zone model were performed to predict the delamination between steel-polymer sandwich composites, demonstrating the validity of cohesive zone model equipped with necessary properties determined using peeling tests and the developed model in this study.

1. Introduction

Steel is a core material in almost every manufacturing field due to its excellent mechanical properties. In the automotive field, steel is very widely used and much related research has been carried out. On the other hand, steel has a low damping ratio, resulting in poor noise and vibration shielding. One of the solutions to this problem is to combine steel with a polymer with a high damping property. The development of steel-polymer sandwich structures with enhanced damping properties has been the subject of much research [1,2]. The interface between the steel and the polymer has to be guaranteed for the composite to have the desired effect [3]. Generally, adhesion between the metal and the polymer is not strong, so in industrial applications, the reliability of the materials remains problematic. Accordingly, much research has focused on enhancing the interfacial properties [4,5], but the reliability of the composites, which we would like to use as structural materials, is still not guaranteed.

As the interfacial properties are important, several studies have been conducted on the characterization of delamination failures in steel-polymer sandwich composites. One method used in these studies is the virtual crack closure technique (VCCT) [6–10]. The VCCT is based on linear elastic fracture mechanics (LEFM) and the assumption that the energy release rate when an interface separates is the same as the energy required to close the crack. However, the drawback of this method is that it can only be used when there is an initial inter laminar crack in the interface. Also, it is difficult to simulate the mixed mode and progressive delamination [11–13]. Another method is cohesive zone modeling, which is based on damage mechanics. This model was first suggested by Dugdale [14], who introduced the concept, while Barenblatt [15] introduced cohesive forces on a molecular scale. Subsequently, many researchers have worked on this model for solving the delamination problem [13,16–24]. The advantage of this method is that it allows prediction of the delamination of complex structures [25,26]. Moreover, this method is simple [12] and can be easily implemented using finite element methods [17,27–29]. Therefore, cohesive zone modeling is widely used for analyzing the delamination failure in composites.

Precise methods to evaluate the interfacial properties are required for exact analysis of the delamination. These properties include the adhesion strength in both the normal and tangential directions. The most widely used method is a lap shear test [30], which measures the interfacial shear strength between the adhesive and the material in the tangential direction. Tensile adhesive

* Corresponding author.
E-mail address: woongryu@snu.ac.kr (W.-R. Yu).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.compstruct.2016.10.025
0263-8223/

Table 1
Types of surface treatments and major components on the steel surface.

Types of surface treatments	Abbreviations	Major components on surface (%)
Electro-galvanized steel	EG	Zn (87.2), C (7.67), Fe (3.1), O (1.6)
Phosphate treated steel	PL	Zn (49.8), O (23.3), C (16.5), P (5.5), Fe (1.8)
Hot dip-galvanized steel	GI	Zn (94.2), C (3.4), Fe (1.2), O (0.8)
Alloy-plated steel	GA	Zn (74.0), C (11.4), Fe (9.6), O (3.4), Al (0.8)
Mg alloy-coated steel	POSMAC	Zn (83.2), C (5.1), Al (4.3), Mg (3.1), O (2.9)

tests can be used to determine the strength in the normal direction [31]. To measure the adhesive properties when external loads are applied from various directions, corresponding test must proceed individually. In this study, we used a peeling test to measure the adhesive properties between steel and polymers, as the test is easily carried out at different angles in the same machine. Using the peel mechanics and the hypothesized plastic deformation, a simple model was derived to define the interfacial properties based on adhesive properties between the steel and polymers, which were measured from the peeling test. Finally, numerical simulations using the cohesive zone model were performed to validate our analysis.

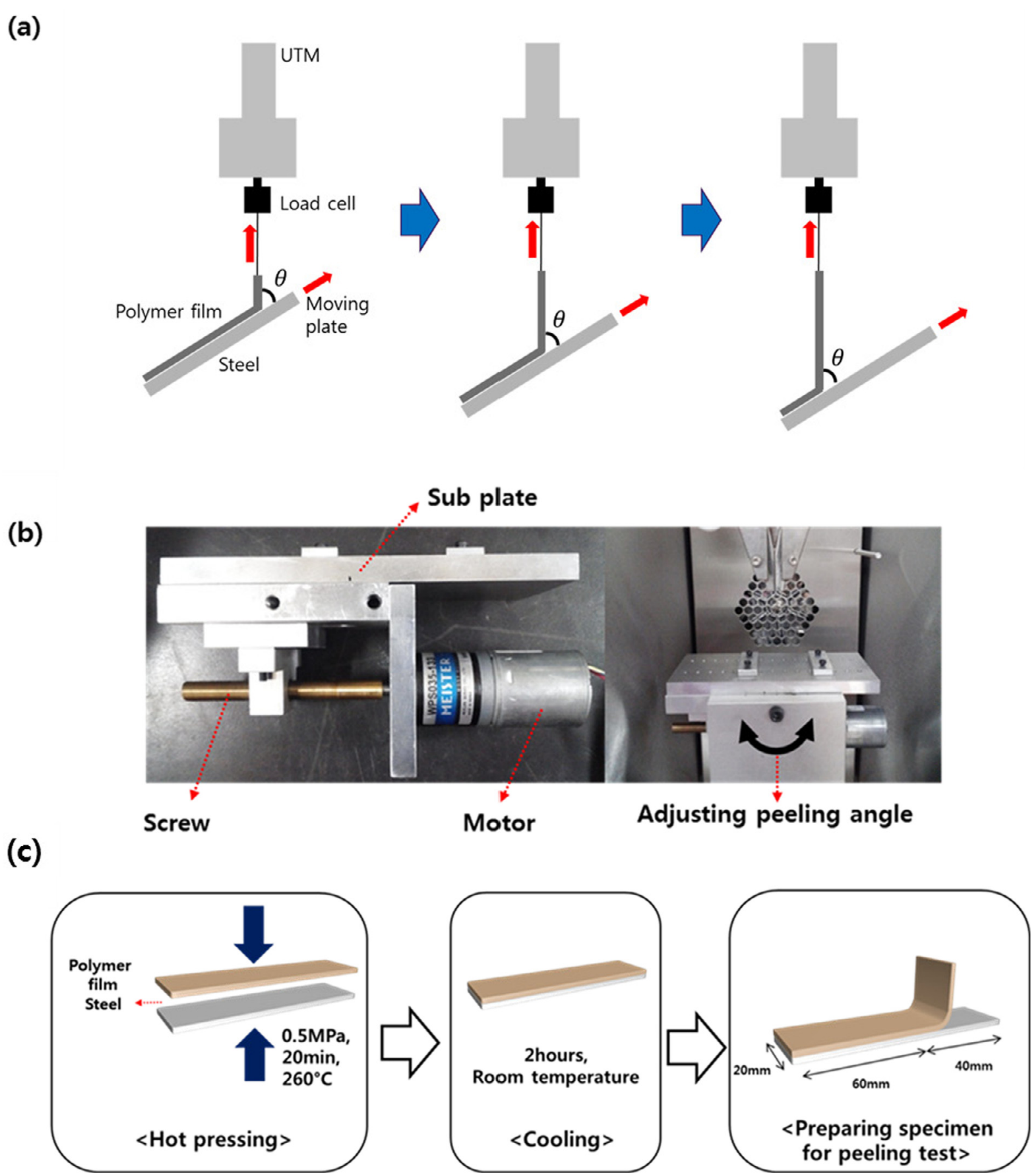

Fig. 1. (a) A schematic diagram of the apparatus used in the peeling tests, (b) the peeling apparatus built in laboratory, and (c) the method for preparing the specimens used in the peeling tests.