EVALUATION OF MICRO PATTERNING EFFECT ON ADHESION STRENGTH OF COMPOSITE-METAL INTERFACES

Jung-Ju Lee* and Won-Seock Kim
Corresponding Author* : leejungju@kaist.ac.kr

Department of Mechanical Engineering, KAIST, Science Town, Daejeon, 305-701, South Korea

Introduction

The use of adhesively bonded joints in structural applications has been steadily increasing in recent years. Adhesive-bonding offers considerable advantages compared with traditional forms of joining, such as bolting, riveting, and welding [1, 2]. Especially for joining of fiber-reinforced polymer (FRP) composites to other structural materials such as metal, adhesive bonding enables light weight and cost effective design. One of the predominant concerns for engineers in using adhesive bonding is to optimize the adhesion strength. Thus, it is essential to understand adhesion mechanisms and investigate the influence of each mechanism on adhesion strength since it can fundamentally allow us to reach the formation of strong and reliable adhesive joints. Among a number of mechanisms that account for the adhesion phenomenon, it has been well-known that adsorption and mechanical interlock are the dominant mechanisms that contribute to the adhesion strength of metal-polymer interfaces [1,2]. The purpose of the present work is to systematically investigate the influence of adhesion mechanisms on the adhesion strength of a composite-metal bond by incorporating periodic surface patterns on the metal substrate. In order to link microscopic adhesion phenomenon to macroscopic adhesion strength of a bonded joint, fracture mechanics concept has been utilized measuring adhesion strength as the required energy for fracture.

Experimental Methods

Materials and sample preparation

In order to investigate the fracture energetics of the metal-polymer interface, steel/composite bonded joints were fabricated. The steel plates were fabricated into 35 × 5 × 1 mm^3, and were finely polished using a rotating disk-type polisher with diamond suspensions. Afterwards, the polished steel surfaces were coated with a commercial photoresist (SU-8 from MicroChem, USA), and exposed to UV through a transparency-printed mask. The UV-exposed photoresist film was developed to have a series of line posts, whose width varied from 10 to 90 μm using different masks. After the conventional photolithography, the steel surfaces not covered by the photoresist films were chemically etched in an etchant called Nital to fabricate micro line-patterns on the steel surface (Fig. 1). After the surface patterning process, CFRP prepregs (USN-150 from SK Chemical, Korea) were laminated on the steel plate ([0_9/steel]) and bonded through the standard curing process of the CFRP prepreg. In other words, composite/metal joint specimens were fabricated using a co-cure bonding method.

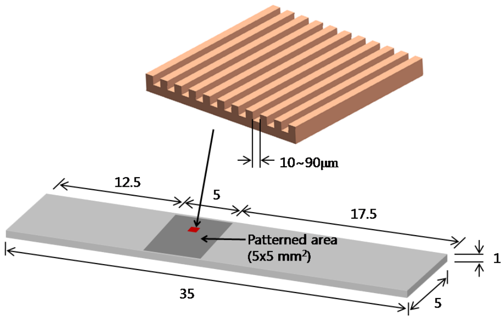

Fig. 1 Schematics of the line-patterned steel specimen.

Fracture tests

A bi-material end notched flexure test (ENF), which provides a pure mode-II loading condition [3] and a bi-material single leg bending (SLB) test, which provides various mixed-mode loading conditions [4], were employed. Figures 2(a) and (b) show schematic diagrams of the tests.

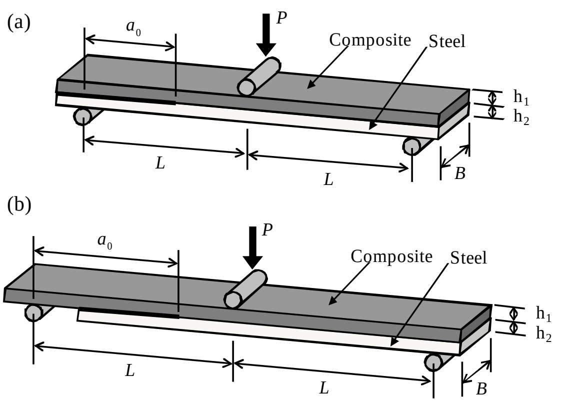

Fig. 2 schematics of the ENF (a) and SLB (b) tests.

Results and Discussion

Optical microscope cross-sectional images, presented in Fig. 3, show the steel/composite bonded interface. The cross-section of the periodic grooves became semicircular due to the wet-etching process applied to steel, an isotropic material. The epoxy resin, which was extracted from the CFRP prepreg during its curing process, has completely filled up the micro-grooves on the steel surface. Therefore, mechanical keying, or interlocking, of the polymer into the steel surface cavities has completely attained at the micro line-patterned steel/CFRP interface.

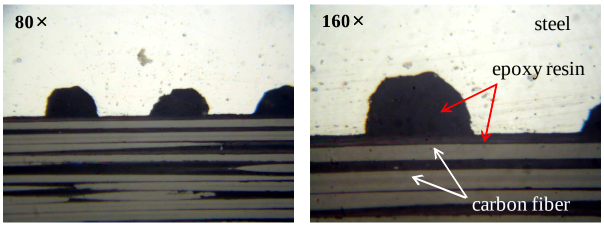

Fig. 3 Cross-section of a steel/composite interface.

The determined values of interfacial fracture toughness, *R* are plotted against the pattern depth, *R* in Fig. 4. The width and depth of patterns were varied in a congruent manner by maintaining the width ratio as constant to investigate the roughness effect only. The lack of correlation in Fig. 4 suggests that the surface roughness, *R* does not control adhesion strength. As seen in Fig. 5, the excavated region on steel surfaces shows pure cohesive failure and the preserved region on steel surfaces shows pure interfacial failure regardless of the variation of pattern dimensions. As long as the width ratio is maintained as constant, the total area of cohesive and adhesive failure regions are the same. This observation reveals that the total area fraction of cohesive and adhesive failure region is directly related to adhesion strength while the surface roughness, *R* is an indirect parameter, which contributes to failure mode transition from adhesive to cohesive or vice versa.

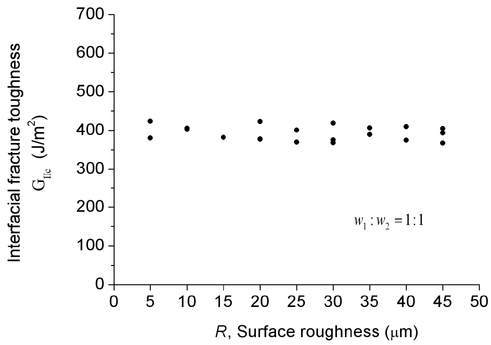

Fig. 4 Interfacial toughness according to pattern depth.

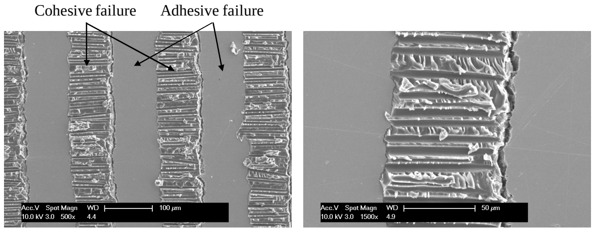

Fig. 5 Fracture surfaces on the patterned steel side.

In order to increase adhesion strength by increasing the area fraction of cohesive failure, the width ratio of line patterns were varied as $w_1 : w_2 = 1:1;\ 2:1;\ 4:1;\ 6:1;\ 8:1$. Typical load-displacement curves obtained from ENF tests with different pattern width ratios are presented in Fig. 6. The failure load of adhesive joints increases according to the increment of the ratio of the excavated width, w_1 to the preserved width, w_2 of line-patterns. The excavated region on steel surfaces always shows pure cohesive failure and the preserved region on steel surfaces always shows pure interfacial failure regardless of the variation of the pattern width ratio. The cause of high interfacial toughness of specimens having a large pattern width ratio can be explained by the increase of the area fraction of cohesive failure. Therefore, mechanical interlock provides the main source of adhesion strength of metal-polymer interfaces by provoking energy dissipation processes in the polymer resin during joint failure.

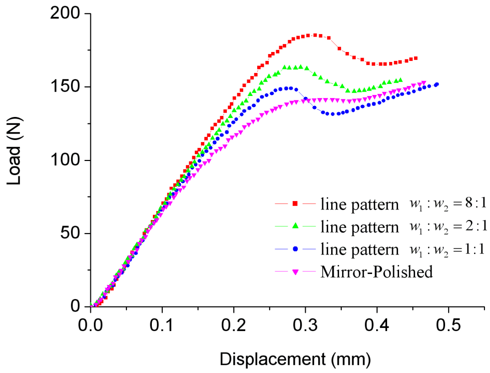

Fig.6 Load-displacement curves of bi-material ENF specimens with different pattern width ratios.

References

1. A. J. Kinloch, Adhesion and Adhesives: Science and Technology, Chapman and Hall, NY. 1987.
2. D.E. Packham, Handbook of Adhesion, Longman, UK, 1992.
3. W.S. Kim and J.J. Lee, *Engng. Fract. Mech.* doi:10.1016/j.engfracmech.2009.03.014.
4. B.D. Davidson and V. Sundararaman, *Int. J. Fract.* Vol. 78, pp. 193 (1996).