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Mixed-mode fracture behavior of glass fiber reinforced polymer concrete

A. Avci[a], A. Akdemir[a], H. Arikan[b,*]

[a]Department of Mechanical Engineering, Selcuk University, Konya, Turkey
[b]Cihanbeyli Technical College, Selcuk University, Cihanbeyli, 42850 Konya, Turkey

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Abstract

Fracture toughness of chopped strand glass fiber reinforced particle-filled polymer composite beams was investigated in Mode I and Mode III loading conditions using three-point bend tests. Effects of crack angles on fracture behavior were also studied. The specimens, which have inclined crack at an angle θ to the axis of the specimens, were used to carry out the tests. The specimens were tested with inclination angles 30°, 45°, 60° and 75°. The results are compared with the values of K_{IC} obtained using conventional (θ=90°) specimens. In addition, J integrals were also determined. J_{IC} increases continuously with increasing in crack angle from θ=30° to θ=90°. In contrast, J_{IIIC} decreases with the crack inclination angle θ from 30° to 90°.

Keywords: Mixed mode; Fracture toughness; Polymers; Composite

1. Introduction

Polymer concrete, a mix of polymers and mineral aggregates, is becoming attractive due to its good properties, such as rapid setting, high strength, corrosion and water resistance for various applications. Because of these, the polymer concrete is being used in various constructions, rehabilitation, repair of pipelines, bridges and roads [1–7].

In order to obtain good properties of the polymer concrete, it is necessary to know the types and sizes of fillers and percentages of components, which play an important role in the composition [1]. The enormous potential of high-performance fibers that is so successfully exploited in the conventional polymer composites has not been widely used in the polymer concretes. Nevertheless, the fiber reinforcement of the polymer concrete is not a new concept, the chopped strand glass fiber has been applied to the polymer composites for improving the strength and controlling the cracking [8,9]. To characterize the failure behavior of the polymer composites in terms of the constituents, some attempts have been made for efficient use [10,11].

Mode I fracture type according to loading condition is taken into consideration in most of the study performed in the fracture mechanics. However, there occur random cracks in general loading conditions.

This type of cracks must be explained with Mode I, Mode II and Mode III. There is a very limited number of studies where Mode I and Mode II type fracture are together. In addition to Mode I loading, there is no tendency in the explanation of the effect of Mode III. Kamat et al. [12] show that addition of Mode III has little effect on Mode I for aluminium alloy metal–matrix composites. Manoharan and Lewandowski [13] investigated experimentally fracture toughness in Mode I and Mode III loading conditions, together in particulate metal–matrix composites and they demonstrated that Mode I loading condition is very effective. Moreover, addition of Mode III to the system does not affect the critic fracture criterion.

Under shear forces, cracks tend to propagate in Mode I, Mode II and Mode III configuration. Attempts to

* Corresponding author. Tel.: +90 332 673 40 91; fax: +90 332 673 40 90.
E-mail address: harikan@selcuk.edu.tr (H. Arikan).

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apply fracture mechanics concepts to study mixed-mode failure and crack propagation of concrete have been made [14–18].

In this study, Mode I and Mode III fracture behaviors of the chopped strand glass fiber reinforced polymer concrete were investigated using single edge notched beams loaded three-point bending. The effects of the crack angles on the fracture behaviors of the polymer concrete system were analysed. The fracture toughness values of the combined Modes K_{IC} and K_{IIIC} and J_C integrals (J_{IC} and J_{IIIC}) were determined for the same materials.

2. Experimental

2.1. Specimen preparation

In this study, chopped strand glass fiber in combination with an isophtalic polyester resin Neoxile 266 (Cam Elyaf) and sand fillers were used. Chemical and sieve analysis of the sand fillers and production details were given in Ref. [8]. E-glass fibers 10–12 mm in length were produced by cutting from continuous fibers. Initially, the composite system was formulated by using only polyester resin and sand. The composition of the composite material used was a weight of 16.50% of the polyester and 84.50% of the sand. The second type of the polymer concrete system was fabricated with a weight of 16.50% of the polyester resin, 1.50% of the glass fiber and 83.00% of the sand.

The glass fibers, sand fillers and polyester resin as indicated ratio were poured into a disposable container and mixed together until the mixture becomes homogeneous. The polymer composite mixture was cast in aluminium trays, 250×50×25 mm, with polyvinyl alcohol film coated to facilitate demoulding. The polymer composite in the trays was compressed and cured at room temperature for 2 days. Postcuring was done at 80 °C for 24 h. The specimens were cut by using a 2-mm-thick diamond saw to create notches 20 mm deep with the inclination angle θ to the beam axis as shown in Fig. 1. The notch tips of the specimen were sharpened with a surgery blade. Because the polymer composite specimens were brittle, there was no need to open a starter fatigue crack.

2.2. Fracture mechanics tests

Mode I fracture toughness tests of the polymer composite system were conducted on three-point bend specimens with the applicable ASTM standard E-399 for evaluation of the K_{IC} [8]. All mixed-mode fracture toughness tests were carried out using a modified three-point bend specimen [13,19]. The modification of the specimen is the slanted starting notch as shown in Fig. 1. The crack inclination angle θ from specimen axis is measured. The conventional three-point bend specimen is obtained at the inclined crack angle 90°. When the crack reduces from the 90° and bending loads are applied, Mode I and Mode III crack surface displacements are present. Therefore, Mode I and Mode III fracture behavior can be investigated. In the mixed-mode situations, crack growth direction can be deviated from the original crack plane.

In order to obtain K_{IC} and K_{IIIC}, the linear elastic fracture mechanics tests on inclined cracks on the modified three-point bend specimens for θ=30°, 45°,60°,75° and 90° according to ASTM E 399 and the ratio a/W=0.40 were carried out. The cross-head speed of the test machine was 0.05 mm/min. All beams were tested to maintain a constant rate of increase of the crack mouth opening displacement (CMOD) measured by a clip

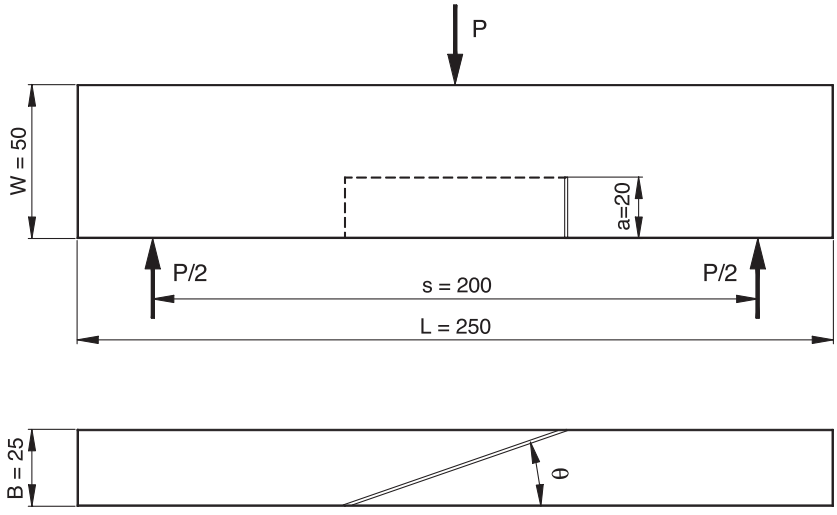

Fig. 1. Sketch of three-point bending specimen.