A NEW SPECIMEN FOR MODE II FRACTURE TESTS

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ABSTRACT: A novel crack specimen has been designed to study brittle fracture in mode II loading. The test specimen is simulated using finite element analysis and the crack tip parameters K_{II} and T are calculated. Both tensile and compressive loading can be applied to the specimen. For tensile loading where the specimen is subjected to positive shear, the T-stress is positive. Whereas T is negative for compressive loading, that is when the specimen is subjected to negative shear. Fracture tests are carried out on several specimens made of PMMA. The Mode II fracture toughness is determined for both tensile loading (positive T specimens) and compressive loading (negative T specimens). Experimental results show that mode II fracture toughness for negative T specimens are significantly larger than those for positive T specimens.

INTRODUCTION

Mode I fracture toughness has been studied extensively for brittle materials using a large number of various crack specimens. However, much less information is available on fracture tests in mode II. There are a few specimens designed by researchers for mixed mode I/II fracture. Some of these specimens can provide pure mode II when subjected to specific loading configurations.

For example, Erdogan and Sih [1] and Maiti and Smith [2] conducted a set of fracture tests on centrally cracked specimens. To provide mode II deformation, they applied two skew-symmetric point loads applied at holes located near the crack edges. Royer [3] designed a Y shape mixed mode specimen containing two edge cracks. For appropriate angles of loading in two top branches of the specimen Royer could achieve pure mode II. Richard [4], Bank-Sills and Bortman [5] made use of a rather complicated configurations in which a compact tension-shear specimen was located inside a fixture. Davenport and Smith [6] replaced the compact tension-shear specimen by single edge cracked and single edge notched specimens. Most of experimental studies in mode II brittle fracture have been conducted on PMMA which is a cheap and easily machinable polymer known for its high brittleness.

Recent computational studies by Ayatollahi et al [7] revealed that there are circumstances where large amounts of positive or negative *T*-stress can be present in the shear loading of cracked specimens. Further theoretical investigations by Smith et al [8] showed that the *T*-stress may influence considerably fracture toughness in specimens failing by mode II brittle fracture.

In this paper, a new specimen is suggested for providing large amounts of *T*-stress in mode II loading. Fracture tests are conducted on this specimen to study experimentally the influence of *T*-stress on mode II fracture toughness.

THE NEW SPECIMEN

The dimensions of mode II specimen is shown in Figure 1a. The specimen was made of PMMA with material properties of: Young's modulus E=2800 MPa, Poisson's ratio ν=0.38 and Yield stress σ_0=45 MPa. To produce the crack in the specimens, a slit of almost 9 mm length was introduced using a fret saw of 0.35 mm thickness. By pushing a razor blade for another 1 mm inside the slit a sharp tip was produced to make the total crack length around 10 mm. In this case the remaining ligament was about 10 mm. A high ratio of cross section area to length L was considered in designing the specimen to prevent possible buckling when subjected to a compressive load. It is useful to be reminded that the specimen is subjected to positive shear for tensile loading and negative shear for compressive loading (see Figure 1b).

FINITE ELEMENT MODELING

The mode II specimen was simulated using the finite element code ABAQUS. The specimen was considered to be linear elastic with the Young's modulus and Poisson's ratio given in the previous Section. The mesh design, the boundary conditions and the loading point are shown in Figure 2. The crack tip zone consisted of 30 rings of elements where each ring had 36 eight-noded plane strain elements circumferentially. The specimen was subjected to compressive and tensile reference loads of the same magnitude 5 kN.

A comparison of the displacement components along the crack faces showed that the mode I stress intensity factor K_I is negligible relative to K_{II}. Therefore, the specimen can be considered as a mode II crack specimen. The *J*-integral obtained from ABAQUS was equal to 2027 N/m for both cases of tensile and compressive loading. The *T*-stress was determined by using the displacement method described in [7] for mixed mode loading. The values of *T*-stress for compressive loading was -28 MPa and for tensile loading was +28 MPa.

If the mode II stress intensity factor K_{II} is written as $K_{II}=Y.P$ where P is the load applied whether compressive or tensile and Y is a geometry factor then from the results of finite element analysis Y is determined as

$$Y = \frac{K_{II}}{P} = \frac{\sqrt{E'J}}{P} = 499.6\mathrm{m}^{-3/2} \quad (1)$$

With reference to the sign of the *T*-stress, in the present analysis the mode II specimen is called a +*T* shear specimen for tensile loading and a -*T* shear specimen for compressive loading.

EXPERIMENTAL RESULTS

A total of ten +*T* shear tests and ten -*T* shear tests were conducted. The load-displacement results were plotted using an *x*/*y* chart recorder. All the specimens exhibited a linear load-displacement diagram prior to fracture, confirming the linear elastic behaviour of the material. The measured fracture loads are shown in Table 1 for the +*T* shear specimens and in Table 2 for the -*T* shear specimens.

Fracture toughness values were calculated from $K_{IIf} = Y.P_{cr}$ and using Equation 1. Figure 3 shows the mode II fracture toughness data for the +*T* shear tests and the -*T* shear tests. Also shown in this figure are the mean values of the results for each case.

DISCUSSION

Earlier theoretical studies [8] for linear elastic materials propose that based on the maximum tangential stress criterion [1] the mode II fracture toughness increases for negative values of *T* and decreases for positive values of T. This is in agreement with the experimental results shown in Figure 3. The average values of K_{IIf} for positive T specimens is 1.27 MPa$\sqrt{m}$ and for negative T specimens is 2.43 MPa$\sqrt{m}$. Although the results of the finite element analysis show that for the same magnitude of load, the stress intensity factor for both $+T$ and $-T$ shear specimens are identical, the average of K_{IIf} for the negative T specimens is almost twice the average of K_{IIf} for the positive T specimens. This indicates that the maximum tangential stress criterion solely based on the singular terms of the crack tip stresses can introduce a considerable error in predicting mode II fracture toughness.

Mixed mode brittle fracture has been studied by many researchers for different materials. They have often attempted to design test specimens capable of producing symmetric loading for mode I and antisymmetric loading for mode II (*e.g.* [4] and [5]). However, antisymmetric loading is a specific type of shear loading where in addition to K_I, the T-stress also vanishes [7]. Furthermore, ideal antisymmetric loading rarely occurs for real engineering components and in practice a considerable value of T-stress can be present for mode II loading. This suggests most of the experimental results presented in the literature for mode II brittle fracture can be used only for a limited set of real applications where the crack tip is subjected to conditions very close to antisymmetric loading.

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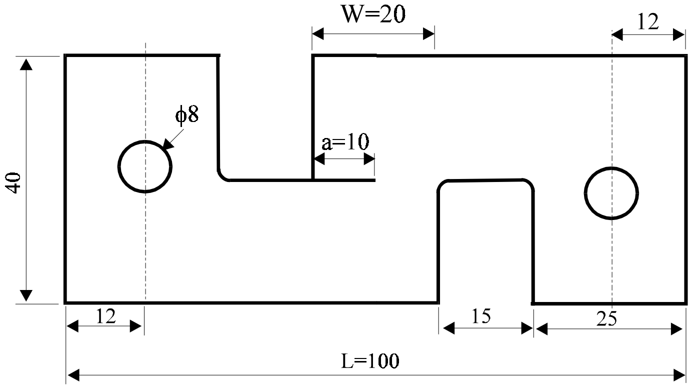
TABLE 1. Results for the +*T* shear test specimens.

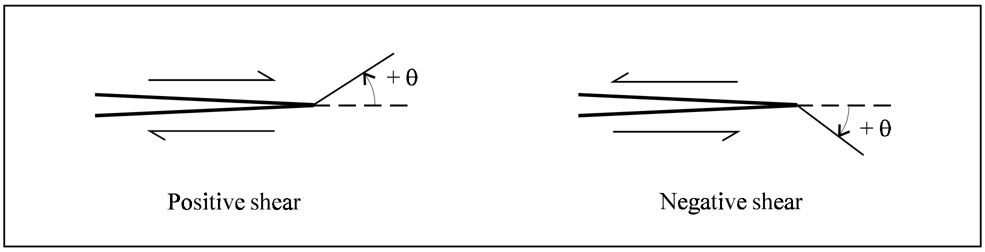
Specimen	Loading (T/C)	P_{cr}(N)	K_{IIf}(MPa $\sqrt{m}$)
M2t-2	Tensile	2410	1.16
M2T2	Tensile	2615	1.26
M2T3	Tensile	2595	1.25
M2T4	Tensile	2860	1.37
M2T5	Tensile	2835	1.36
M2T6	Tensile	2175	1.05
M2T7	Tensile	2535	1.22
M2T9	Tensile	2880	1.38
M2T11	Tensile	2990	1.43
M2T12	Tensile	2550	1.23
Average		**2647**	**1.27**

TABLE 2. Results for the -*T* shear test specimens.

Specimen	Loading (T/C)	P_{cr}(N)	K_{IIf}(MPa $\sqrt{m}$)
M2c-1	Compressive	5340	2.57
M2c-2	Compressive	5000	2.4
M2C1	Compressive	5180	2.5
M2C2	Compressive	4555	2.19
M2C3	Compressive	4190	2.01
M2C4	Compressive	4635	2.23
M2C6	Compressive	4920	2.36
M2C8	Compressive	5710	2.74
M2C9	Compressive	5560	2.67
M2C10	Compressive	5500	2.64
Average		**5065**	**2.43**



a. Thickness=20mm



b. Definition for positive and negative shear in mode II loading.

Figure 1: The new mode II specimen.

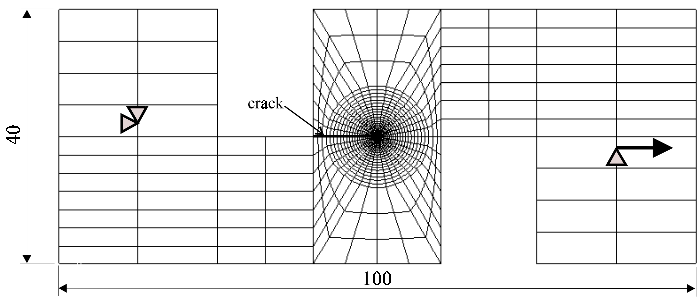


Figure 2: The mesh design for specimen.

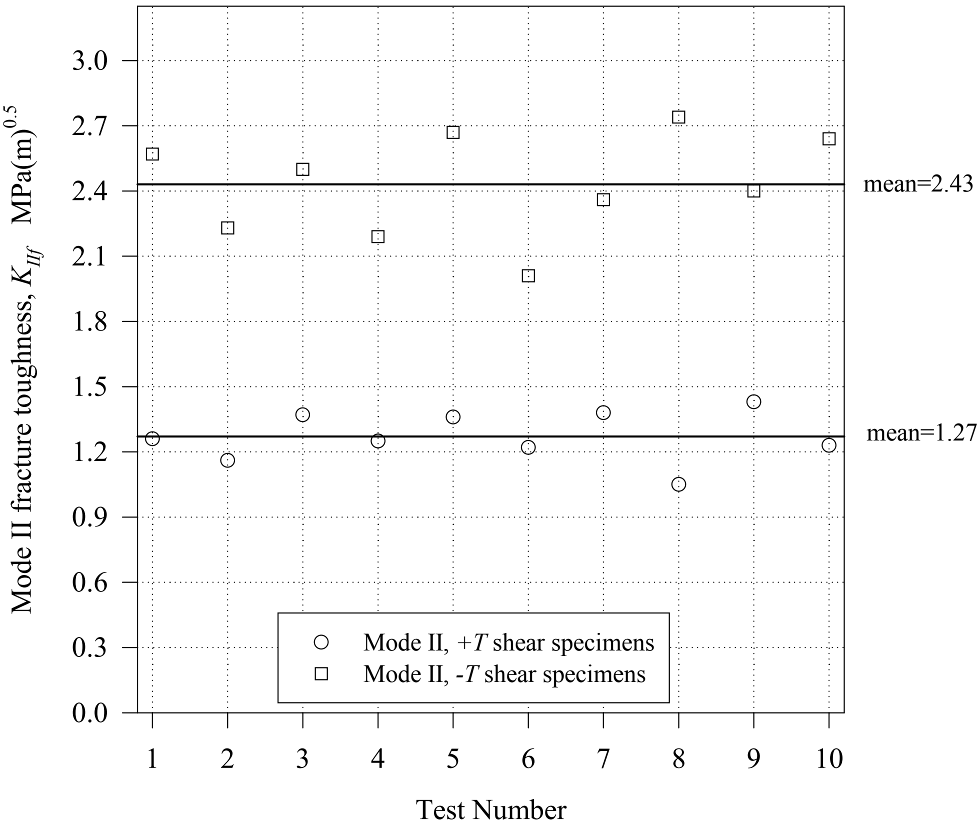


Figure 3: Experimental results for mode II fracture toughness.