



Investigation of Bolt Clamping Force Effect on T-stress in Mixed Mode Fracture

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ABSTRACT: In order to investigate effect of bolt clamping force, resulting from torque tightening, on fracture behavior and T-stress of a rectangular center cracked specimen under mixed mode I/II loading condition, experimental and numerical studies have been carried out. Fracture experiments were conducted on four types of polymethyl methacrylate (PMMA) specimens. Complete range of mode mixities from pure mode I to pure mode II was created by placing the specimens in a modified Arcan fixture and their fracture strength under different loading directions were obtained using a tensile machine. To give explanations for the obtained results from fracture tests by using mixed mode fracture theories, finite element simulations of the experimental tests were performed to compute mode I and mode II stress intensity factors and also T-stress. The results revealed that bolt clamping force has positive effect on fracture strength of the specimens in all loading directions. Also it was shown that bolt clamping force has a considerable effect on increasing T-stress values.

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1- Introduction

Mechanical joints are important parts of any structure. Bolted joints are the major types of the joints which are widely used in the industries. In these types of joints tightening torque, which is applied to the bolt for fastening the joint, creates a tensile pre-load in the bolt shank. This pre-load produces compressive stresses around the hole and activates the frictional force between the contacting surfaces of the joining elements by compressing them together. In the case of crack presence or crack initiation at the edge of the bolt hole, the clamping force, in conjunction with the activated friction force results in complicated stress and strain distribution around the hole which influences the stress intensity factors and T-stress around the crack tip. T-stress is a constant stress parallel to the crack line, which is only due to a symmetric component of loading and vanishes for pure mode II. There are various studies about the brittle fracture of engineering materials under mixed mode loading conditions and the effect of bolt clamping force on fracture strength of cracked parts. For instance, the effect of bolt clamping force on fracture strength and stress intensity factors of simple edge cracked specimens, made from polymethyl methacrylate (PMMA), was investigated and it was shown that bolt clamping force has a major effect on reduction of both modes I and II stress intensity factors under mixed mode loading conditions [1].

In the present study, to investigate the effect of bolt clamping force on T-stress under mixed mode loading condition, four types of rectangular center cracked specimens made from PMMA were tested using a modified Arcan fixture. Also, to simulate the tests and to obtain required parameters, i.e. stress intensity factors and T-stress value, ANSYS finite element

(FE) package was utilized.

2- Experimental Tests

A modified Arcan fixture was used to create different mode mixities. Specimens were cut from a 5 mm thick PMMA sheet using a high precision laser cutting machine. Four batches of specimens were tested including simple center cracked specimens, holed center cracked specimens and bolted center cracked specimens with bolt tightened of 3.5 and 7.0 N.m torques. The geometry and dimensions of fixture and specimens are illustrated in Figure 1.

After placing the specimens in the fixture, based on demanded mixed mode angle, they were loaded through loading pins at a constant rate of 0.1 kN/s by means of a Zwick/Roell static tensile testing machine. In Figure 2 the loading set up is shown under pure mode I and pure mode II loading conditions.

3- FE Analysis

For numerical analysis a 3D FE model of fixture and specimens was prepared and the stress intensity factors and T-stress of tested specimens were calculated from the simulation (Figure 3). Mechanical properties of the materials, which are needed for FE model, were all determined through standard tests.

4- Results and Discussion

Results of fracture tests at various loading directions are shown in Figure 4. This figure indicates the average value of fracture forces obtained from three repeated tests. It can be seen that the presence of bolt clamping force increases the fracture strength of the specimens under all loading directions and this effect is considerable for mode I dominant loading angles.

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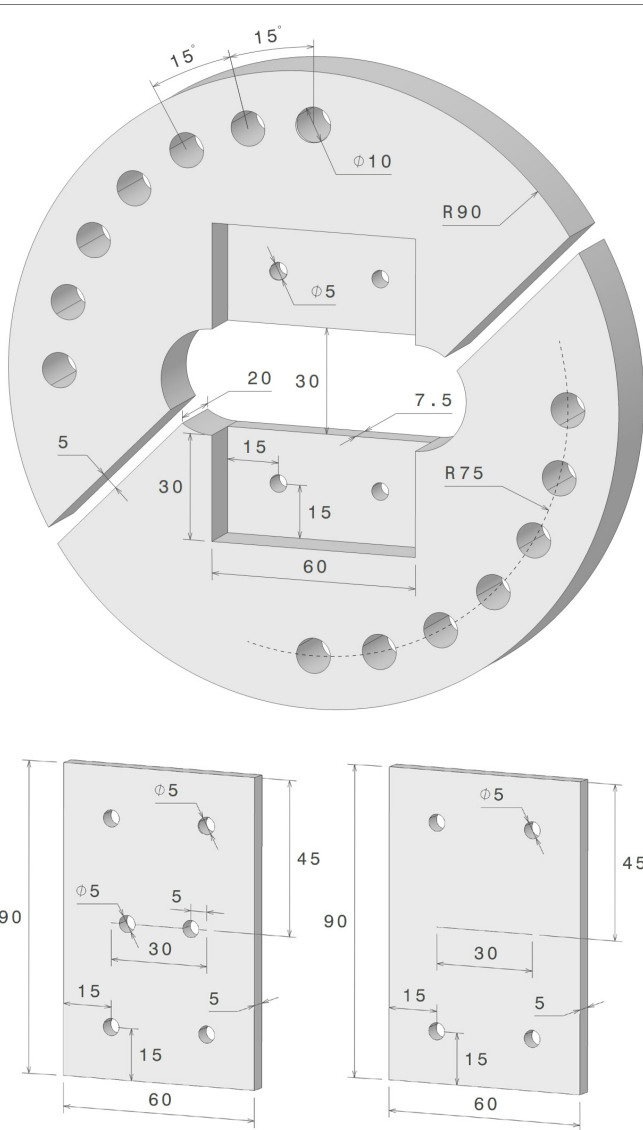


Figure 1. The geometry and dimensions of modified Arcan fixture and test specimens in millimeter

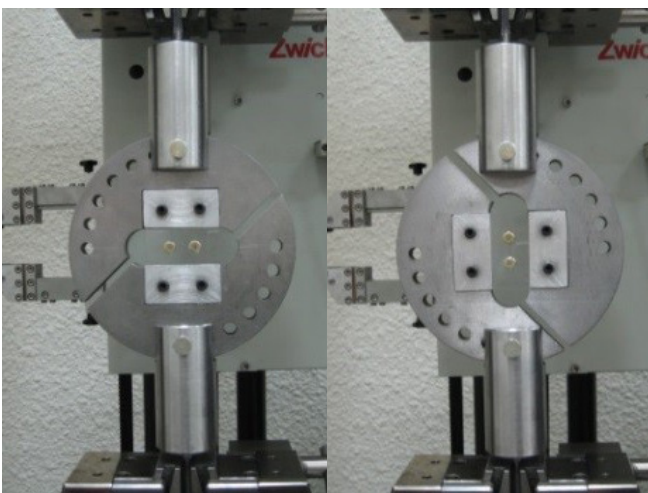


Figure 2. Loading set up under pure mode I and pure mode II conditions

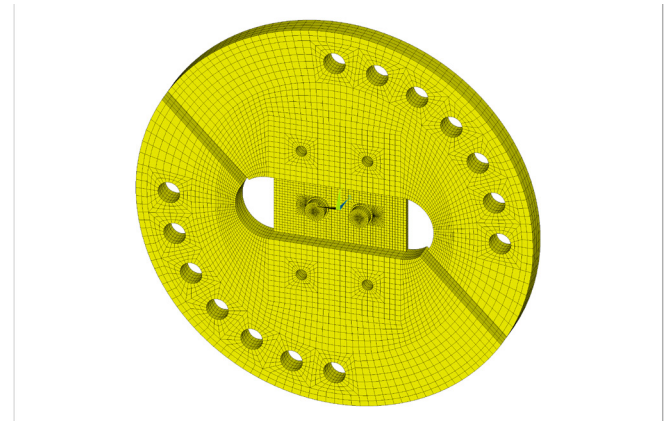


Figure 3. FE mesh of fixture, specimen and bolts

As introduced in Ayatollahi et al. study [2], T-stress can be determined in mixed mode problems using the stresses or displacements

along the two faces of the crack from the finite element simulation. Figure 5 depicts the variation of T-stress values at different loading angles. It is observed that bolt clamping force produces a negative T-stress in the specimens. It is worth noting that T-stress has a significant effect on mode II fracture toughness and for negative T-stress it is increased [3].

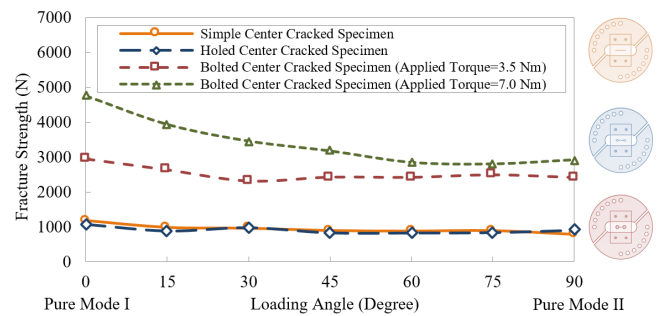


Figure 4. Variation of fracture strength with loading angle

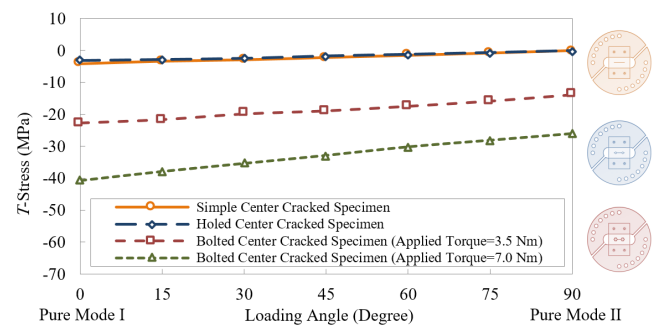


Figure 5. Variation of T-stress with loading angle

In Figure 6, mixed mode fracture loci for each group of specimen were drawn using generalized maximum tensile stress (GMTS) criterion [3] for critical radii of 0.1 and 0.5 mm which were proposed for PMMA [4]. Test data and maximum tensile stress (MTS) criterion [5] locus were also displayed for each group.

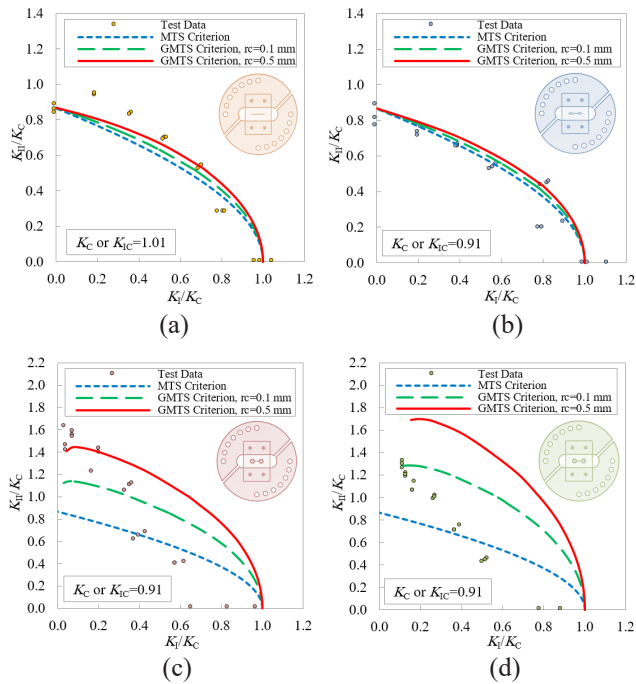


Figure 6. GMTS curve for complete mode mixtures
(a) Simple specimens (b) holed specimens
(c) bolted specimens (3.5 N.m) (d) bolted specimens (7.0 N.m)

5- Conclusions

In this study mixed mode fracture tests along with FE simulation were conducted using a modified Arcan fixture on specimens having bolt clamping forces on their crack tips. Some of the main results can be listed as below.

- Presence of bolt clamping force near the crack tips, increases the fracture strength of specimens under all

loading angles and this effect is remarkable for mode I dominant loading angles.

- Bolt clamping force increases the value of T-stress under all mixed mode fracture conditions.
- For without bolt specimens the value of T for pure mode II is almost zero which indicates fully anti-symmetric deformation field created by the Arcan fixture.
- GMTS criterion gives better estimation of fracture loci rather than MTS criterion with $T=0$.
- T-stress has a major effect on fracture behavior of specimens and considering it along with stress intensity factors is inevitable.

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