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Experimental and Numerical Determination of Fracture Toughness in Gas Pipeline Steel of Grade API X65

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ABSTRACT

Plain strain fracture toughness is extremely important for failure assessment in high strength steels used in gas transmission pipelines. In the current research an experimental method based on three point bend test specimens was used to calculate fracture toughness of steel pipes of grade API X65 (with outer diameter of 1219 mm and wall thickness of 14.3 mm). A value of 308 MPa√m was found for fracture toughness of test material. Then a finite element solution for the test specimens was conducted using modified Gurson's damage theory. In this model, the critical crack tip opening displacement was calculated from damaged elements in the early stage of crack growth. This model resulted in 297 MPa√m of fracture toughness. A comparison between the experimental and numerical results illustrated the fitness of common methods for determining fracture toughness of tested steel in ambient temperature. Due to the lack of experimental data for this steel, the obtained results can be used for safe performance of domestic gas pipelines made from API X65 steel.

KEYWORDS

Fracture Toughness, Gas Pipeline, Ductile Crack Growth, Gurson Model, Three Point Bend, API X65.

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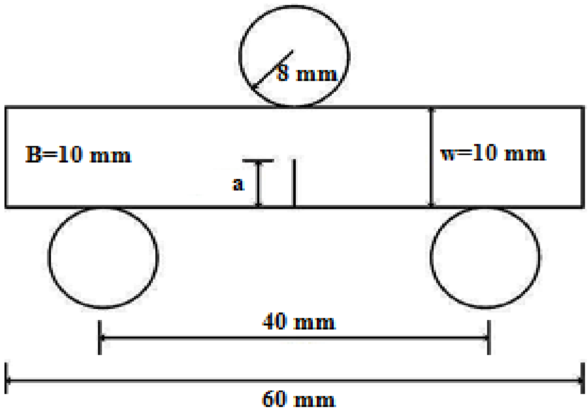
1- INTRODUCTION

Accurate measurement of plain strain fracture toughness is extremely important for failure assessment in high strength steels. These steels are often used in long-distance gas transmission pipelines. Such structures are subjected to high internal pressures from conveying medium (gas or fluid), and any flaw could result in catastrophic consequences. Several research studies have been carried out so far for characterizing material properties (e.g. fracture toughness) of API X65 steel [1-4]. In the current research, an experimental method based on three point bend test specimens was used to calculate fracture toughness in steel pipes of grade API X65 (with outer diameter of 1219 mm and wall thickness of 14.3 mm). New data (in terms of plane strain fracture toughness) were obtained for the tested API X65 steel, which can be used for the safe design of domestic gas pipelines. The obtained results were verified by a 2D finite element analysis based on the modified Gurson damage theory. The comparison of experimental data and numerical simulation from this research showed good agreement with those from the available literature, which is promising. Due to the lack of experimental data for this steel, the obtained results are of great importance for pipeline engineers and designers for domestic applications.

2- METHODOLOGY



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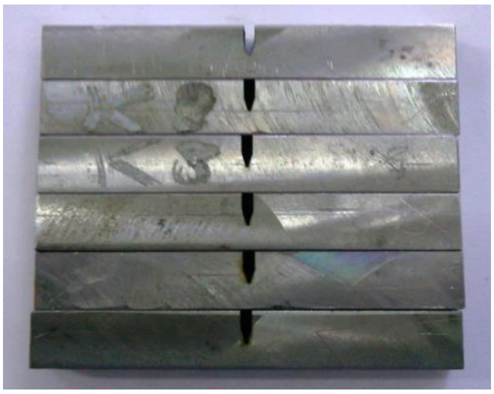
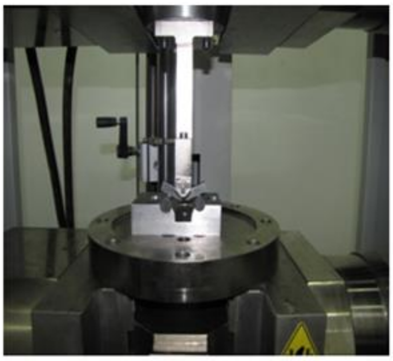


(b)

Fig.1. Fracture mechanics specimens used in this research, (a) geometry and design dimensions of 3PB samples, (b) photograph of test samples before fracture tests.

The test specimens were machined in TL orientation (T is transverse loading direction and L is longitudinal crack growth direction) from an actual gas pipe with 1219 mm outer diameter and 14.3 mm wall thickness of grade API X65 steel as specified by BS EN ISO 7448 standard [5] as shown in Fig.2.



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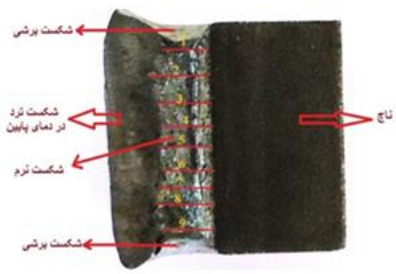

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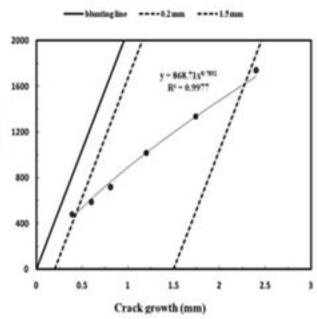

(c)

Fig.2. 3PB experiment on API X65 steel, (a) overview of experimental setup, (b) fracture surface of test specimen, (c) J-R curve for test material.

Due to thickness limitation of the test pipe (14.3 mm), full thickness KIC specimens in plane strain conditions (with around 400 mm thickness) could not be prepared. Therefore, the J test results were used to calculate the KIC indirectly. From the experimental work, a value of 308 MPa√m was found for fracture toughness of the test material. This KIC level is comparable with similar results from recent literature [1-4]

3- SIMULATION RESULTS

The 2D finite element analysis of the test specimen was conducted using modified Gurson's damage theory [6], as shown in Fig.3.

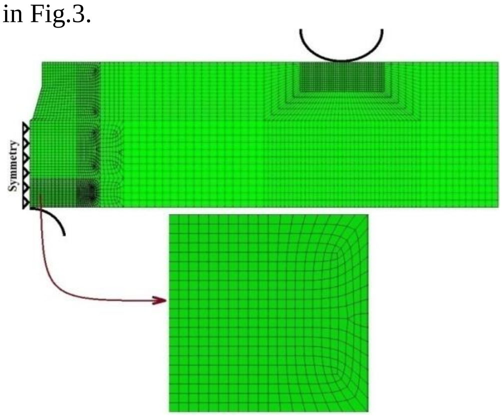

Fig.3. Finite element modeling of 3PB experiment.

The relative consistency between load-displacement from the test and FE model for a 3PB specimen is shown in Fig.4. As can be seen, the damage theory well predicted the softening behavior of the test specimen after the peak load.

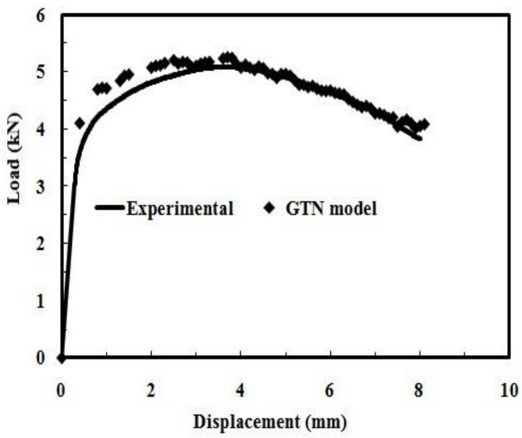

Fig.4. Variation of load versus displacement from test and FE model for 3PB specimen.

In the FE model, the critical crack tip opening displacement (CTOD) was calculated from the damaged elements in the early stage of crack growth. This gave 0.38mm for CTOD, which was then converted to plane strain fracture toughness for the

tested steel. The FEA resulted in 297 MPa√m for fracture toughness, which was consistent with 308 MPa√m from experimental work. The CTOD value of 0.38mm from the FE model and similar data for this steel are given in Table1

.Table 1. The FEA results and their comparison with the available KIC data.

CTOD (mm)	Reference
0.33	[1]
0.57	[2]
0.54	[3]
0.37	[4]
0.38	Current research

As can be seen in Table 1, CTOD values between 0.33mm (lower bound) and 0.57mm (upper bound) have been reported for similar steels of grade API X65. The obtained CTOD parameter of 0.38mm value in this research fits well in this range. Moreover, the comparison between the experimental (308 MPa√m) and numerical (297 MPa√m) results illustrates the fitness of common methods for determining fracture toughness of tested steel in ambient temperature with acceptable accuracy.

4- REFERENCES

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