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The methods of mini-samples fracture testing with subsized samples and Digital Image Correlation (DIC) measurements

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ABSTRACT:
In many cases of engineering practice there is limited amount of material available for mechanical properties determination and standardized tests are not possible. In such cases miniaturized samples have to be used. However, mini-samples utilization is related with additional phenomena presence related especially with scaling effect and obtained results often cannot be straightforwardly translated to results of standardized test. This problem is especially important when fracture tests are considered where smaller samples in general exhibit better performance in comparison to larger ones. The paper presents experimental work aimed to perform fracture tests of materials taken from 5.5” P110 casing pipe utilized in gas mining industry. Fracture toughness and crack growth rate tests results made with standard and mini-samples are reported. Later have been made with optical non-contact strain measurements by means of Digital Image Correlation (DIC) and inverse method for accurate stress intensity factor and crack length determination.

KEYWORDS: mini-sample, fatigue crack growth rate, inverse method, digital image correlation (DIC)

1. Introduction

Mini-samples technique might be applied in mechanical testing of materials in the cases of limited amount of material or geometry constrains. The example for later situation is 5.5” diameter, 10 mm thick pipe made of P110 carbon steel utilized in gas mining. Normalized arc type A(T) samples for fracture toughness for this geometry require manufacturing impractical grips with 2.25 mm pins diameter (see Fig. 1) while dimensions of compact D(T) or C(T) samples possible to be cut out of pipe wall preclude conventional clip-on-gage extensometer use due to not enough space for its mounting.

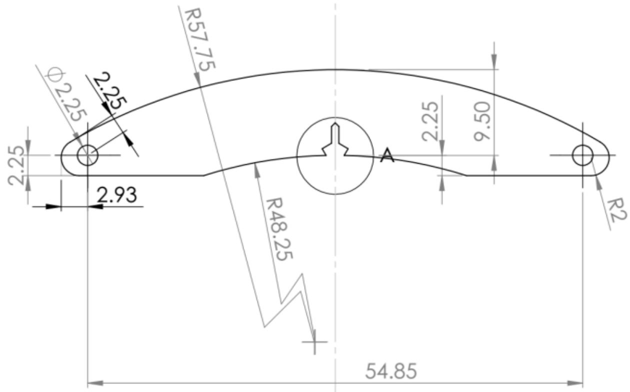

Fig. 1. Standardized A(T) sample for fracture-toughness testing possible to cut from 5.5” pipe

Having in mind over mentioned limitations miniaturized samples of SE(B) type have been proposed with the mechanical notch oriented analogically to A(T) sample (most pernicious crack orientation form the point of view of service conditions) – see Fig. 2.

Additionally, standardized SE(B) of largest possible width has been prepared and analogous miniaturized counterparts for comparative purposes. Fracture toughness tests has been done for larger samples while fatigue crack growth rate tests for both types of samples with the methodology described in next chapter.

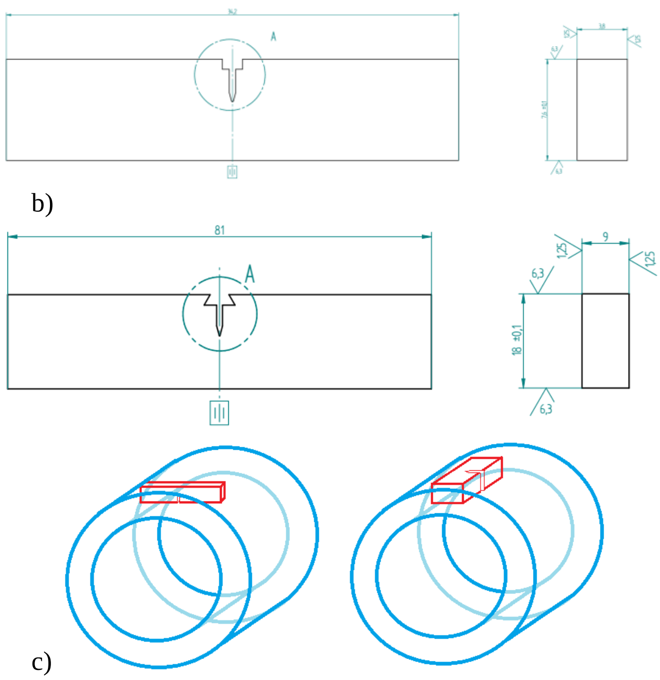

Fig. 2. Standardized (a) and miniaturized (b) SE(B) samples geometry used in fracture toughness and fatigue crack growth rate tests and positioning of mini-samples in the pipe (c)

2. Methodology and results

Fracture toughness and fatigue crack growth rate test on standardized samples were done according to ASTM E1820 and ASTM E647 standards on SE(B) samples.

Special procedures have been designed for mini-samples based tests allowing digital images registration for digital image correlation (DIC) measurements.

DIC [1] is non-contact optical method of displacement/strain measurements based on comparing a few pixel size rectangular subset of area of interest in digital images registered during object deformation. Observed surface in the case of 2D method (with one camera) should be flat and speckle contrast usually obtained by white and black paint sparing is required.

In the case of fatigue crack growth rate investigation tests consisted of two consecutive blocks executed cyclically to the sample damage. First block was related with crack nucleation and propagation performed with 20 Hz frequency, Fmax=800 N and R=0.1. Every 2000th cycle it has been switched to 0.5 Hz frequency block (with conserved other parameters) aimed for high quality images registration utilized further for DIC evaluation. Camera triggering was synchronized with samples loading, therefore determination of actual sample compliance was easy achievable by using data from load sensor and DIC. In these test DIC measurements has been made in "optical extensometer" mode allowing precise crack opening measurements in the particular extensometer placing. Additionally, selected images registered in maximal loading moments were used in the inverse method based procedure of crack position and stress intensity factor determination sin a similar way as described in [2]. The inverse method calculation algorithm utilized near the crack tip displacement field measurements as the input data to the iterative procedure of the parameters optimization of appropriate equations describing these fields.

Here, only inverse method based results are presented.

Due to large plastic deformation in the area near the crack tip only few points on J-Δa plots were valid in terms of standards requirements and J_{IC} or K_{IC} were not possible to determine. Therefore, K_{fc} from fatigue crack growth rate testing was planned to be use as the parameter describing fracture toughness of investigated material.

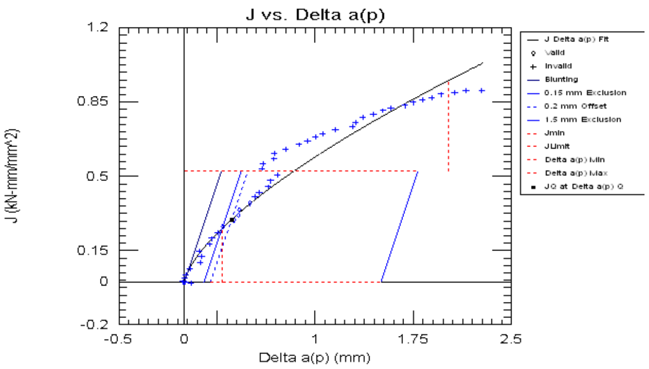

Fig. 3. Exemplary results of fracture toughness test on standardized sample

Exemplary results of parameters optimization procedure are shown in Fig. 4 for the last successfully performed calculations (calculations were break when specified error function has not been achieved after 50 iterations). Obtained displacement fields maps from DIC and model are in good agreement evidencing reliability of calculations algorithm. Comparison of crack growth kinetics plots shows noticeably lower crack growth rate in the case of mini-sample, however K_{fc} values seems to be at similar level (calculations for mini-samples did not succeed in the case of a few images from the end of the test).

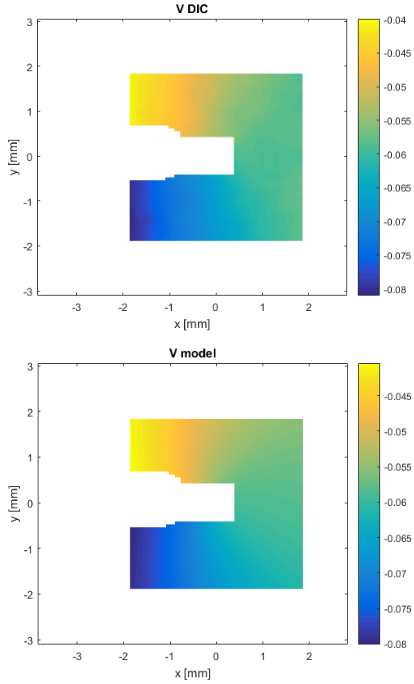

Fig. 3. Exemplary results of vertical displacement fields measurements (a) and analytical models after parameters optimization (b) (KI=64.6 MPa*m^0.5, a=1.13 mm)

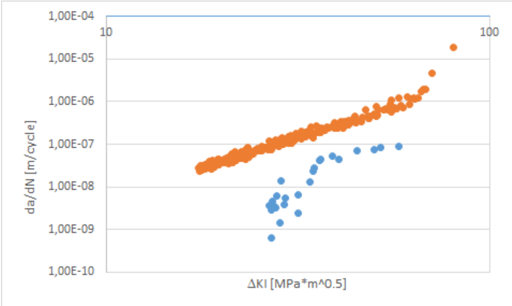

Fig. 4. Exemplary results of standardized (orange) and DIC based (blue) fatigue crack growth rate tests

3. Summary

Fatigue crack growth rate testing procedure of SE(B) miniaturized samples accompanied with optical displacements measurements has been developed and preliminary tests done. Mini-samples tests showed lower crack growth rates in comparison to standardized ones. Further tests on larger number of mini-samples and different methods of crack length and stress intensity factor determination (DIC and inverse method or DIC and compliance method) are planned to investigate scale effect influence on the results.

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References

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