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NON-STANDARD SPECIMENS FOR FRACTURE TOUGHNESS TESTING OF WELDS

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1. INTRODUCTION

In many experiments on engineering components, specimens play an important role in achieving the correct results. They can be provided in various dimensions and shapes. Their sizes are strongly related to geometry and features of structural elements which depend on the cut places location, as well as on the material volume (Szymczak and Kowalewski, 2013). Therefore, in many cases the miniaturized specimens are often taken for testing. Specimen miniaturization means manufacturing of the smaller specimens than the standard ones. In principle, they should be obtained using almost the same manufacturing methods. Many mini-specimens are produced from tubes, spheres (Sakaguchi 2012), or plates even with welds (Dzugan et al, 2018; Sokolov, 2018). Some typical examples are shown in Fig. 1. Thanks to the miniaturization a hard to reach places of the element can be examined, and as a consequence, a strong and weak areas can be indicated.

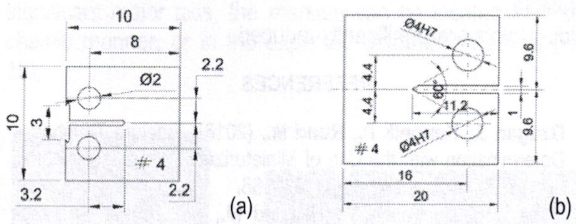

Fig. 1. Miniaturized CT specimens: micro (a) (Dzugan, 2018) and mini (b) sizes (authors' own project)

In application of the CT compact mini-specimens for fracture toughness investigations a mounting method is a key point. In the case of small specimens an effect of force misalignment appears much often, and it is more important than for the standard ones. As a consequence of the force misalignment, the bending moment is generated leading to the creation of complex stress state conditions, and in the final result, receiving of the false data. Therefore, a special gripping system is required. It should eliminate additional loading (Fig. 2a, b). Another issue for this kind of specimens is COD extensometer which should have a very small gauge length (Fig. 2b).

The aim of this paper is to check suitability of the CT compact mini-specimens for determination of the fracture toughness of welding joints.

2. DETAILS OF THE EXPERIMENTAL PROCEDURE

The non-standard CT compact specimens were designed taking into account the sizes of welded objects. Their dimensions were not larger than 30×30×6 [mm]. Engineering drawing of the suitable specimen is shown in Figure 1b. In the case of experiment for determination of fracture toughness of welds and Heat Affected Zones (HAZ) the specimens' notches were parallel to major axes of the regions in question. All tests were carried out by means of the 8802 Instron servo-hydraulic testing machine using special gripping system and COD extensometer (Fig. 2).

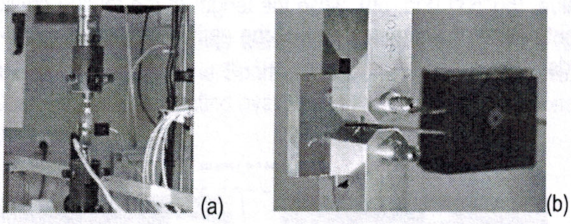

Fig. 2. CT compact mini-specimen in the testing machine: (a) general view, (b) in the gripping system with the COD extensometer

Fatigue pre-cracking was produced under force control for the stress asymmetry coefficient R = 0.1 and based on variations of specimen stiffness. The process was carried out until the crack length no less than 1.3 mm was achieved. Fatigue zones were investigated using optical measuring instruments and Scanning Electron Microscopy (SEM). The front crack length was measured in selected places in order to check whether the differences between subsequent measurements were within requirements of the ASTM E399-90. The non-standard CT specimens were produced from spherical and tubular objects containing welds. After each fracture toughness test an examination of the fracture zones features was conducted taking into account crack propagation and defects appearance. The crack propagation was executed on the basis of American (ASTM E399), British (BS 7448) and European (PN-EN ISO 12737) standards.

3. RESULTS

The CT compact mini-specimens were used to determine the fracture toughness of welds located in a steel pipe used in the power industry (Fig. 3) and in a fragment of the titanium alloy spherical tank (Figs. 5, 6) used in the army. In the case of a weld in the pipe, contradicted results were observed from the point of view of the applicable standards. Analysis of the fracture location showed that crack propagation direction with respect to its initial orientation (Fig. 3a) complied with the requirements of ASTM Standards 7448 and E399 BS, i.e. ± 10^0, that was a reliable result in the assessment of fracture toughness. In turn, the observation of the fatigue zone revealed significant differences in the length of the crack front, Fig. 3b, that from the point of view of the mentioned standards, excluded the possibility of determining the fracture mechanics parameter for the tested weld. In addition, the low quality of the welded joint was confirmed by the presence of voids in the cracking zone, Fig. 3b.

Fig. 3. CT mini-specimen produced from steel tube used in the power plant: crack view (a); (b) specimen after fracture. Specimen thickness was equal to 5.5 mm

The CT compact mini-specimens were also used to assess the fracture toughness of the parent material of the pipe. In contrast to the result for weld in the material examined the crack propagated at an angle exceeding the standard limit value, (50°53') (Fig. 5b), while the length of the fatigue crack front fulfilled the requirements of the earlier mentioned standards.

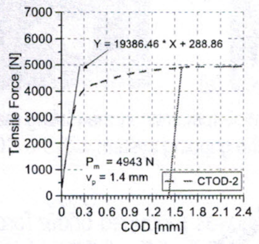

Fig. 4. Force versus COD, test conducted on the CT compact mini-specimen shown in Fig. 3 (CTOD = 0.37 mm)

Reliable results of the fracture toughness tests using the CT compact mini-specimens were obtained for the spherical tank built of Ti-6Al-4V (TC4). In this case, both the development of the fatigue crack in the parent material, weld, as well as heat affected zone (Fig. 6) met the requirements of ASTM and E399 BS 7448 standards. On the basis of the graph representing the tensile force as a function of the critical notch opening a critical tip of the opening displacement (CTOD) was determined. In the case of a weld, it was equal to 0.071 mm, which is in line with the value presented in the literature. The value of this parameter for the parent material was equal to 0.10 mm, while for the heat affected zone 0.11 mm.

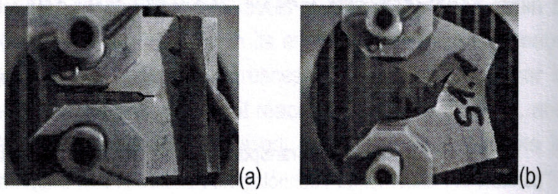

Fig. 5. CT compact mini-specimen produced from steel tube used in the power plant: tested at temperature T = -10°C: initial (a) and final (b) stage of the fracture (CTOD = 0.37 mm)

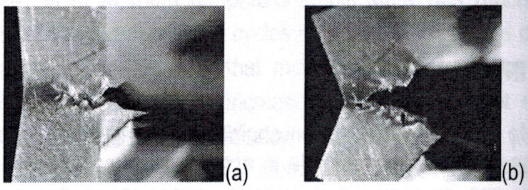

Fig. 6. CT compact mini-specimen containing HAZ in the notch direction, it was cut from the spherical object made of the Ti-6Al-4V titanium alloy (TC4). Specimen thickness was equal to 4 mm

4. SUMMARY

Non-standard CT specimens are especially suitable for the fracture toughness tests of components characterized by complicated shapes and small sizes. Thanks to them some important features of fatigue pre-cracking process (crack propagation, type of fracture, etc.) can be captured.

Testing technique for fracture toughness analysis on mini specimens can be particularly useful for applications related to welding technology, where some dimensions of highly responsible
welding joints are significantly reduced.

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