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Experimental Measurement of Elastic-Plastic Fracture Parameters Using Digital Image Correlation Method

Ivan Jandejsek[a]*, Ľubomír Gajdoš[b], Martin Šperl[c], Daniel Vavřík[d]

[1]Institute of Theoretical and Applied Mechanics AS CR, v.v.i,
Prosecká 76, Prague 9, 19000, Czech Republic

[a]jandejs@itam.cas.cz, [b]gajdos@itam.cas.cz, [c]sperl@itam.cas.cz, [d]vavrik@itam.cas.cz

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Abstract: This paper presents possibilities of an experimental measurement of elastic-plastic fracture parameters such as *J*-integral, CTOD and *J*-resistance curve of ductile materials with single specimen test employing the Digital Image Correlation method. Main advantage of this approach is that it allows evaluation of the parameters directly from its definitions in contrast to current standardized measurements defined mostly by ASTM where parameters are evaluated indirectly. Successful experimental results of the fracture parameters evaluation and determination of its critical values in the case of Aluminum alloy and low strength steel are presented.

Introduction

The Elastic-plastic fracture mechanics (EPFM) or nonlinear fracture mechanics deals with the situation when the vicinity of a crack tip undergoes large-scale yielding before the crack growth. In other words, the assumption of small-scale yielding used in the linear elastic fracture mechanics theory (LEFM) is not valid. It is well-known fact that this situation occurs in the case of high ductile materials (such as aluminum alloys or low/medium strength steels), plane stress loading conditions and thin-sheet specimens. Two fundamental concepts in the EPFM theory for materials under monotonic loading are the *J*-integral [1] and the crack tip opening displacement (CTOD) [2]. Both parameters describe a stress tip condition in an elastic-plastic body and can serve as a fracture toughness criterion. In EPFM the fracture toughness can be expressed as a single critical value of the *J*-integral or CTOD, or as a resistance curve, where the parameter values are plotted against a crack extension. Current standards defined mostly by the American Society for Testing and Materials (ASTM) include testing procedure for J_C, *J*-resistance curve and $CTOD_C$ [3]. The common feature of all standard procedures is that the toughness parameters are evaluated indirectly using simplified relations and load-displacement curve of the loading test. In terms of engineering practice, it is understandable and sufficient in many cases because such measurements are not demanding and time-consuming. However, this can be risky in the special cases such as high ductile materials or thin-sheet nonconventional specimens.

In this work precise experimental measurement of strain and stress fields in the vicinity of a crack allows an evaluation of the *J*-integral directly from its definition. The optical nature of the method allows simultaneous measurement of CTOD and crack length during loading which made possible to build the *J*-resistance curve. The method was employed in the case of fracture toughness determination of aluminum alloy and low strength steel.

Experimental

The first fracture experiment was carried out with a flat thin-sheet specimen made of aluminum alloy (ČSN 424415.21) with a symmetric central notch so-called middle tension (MT) specimen. Acquired optical data of the crack vicinity served for full-field strain and stress evaluation in this region. On the basis of these fields the *J*-integral was evaluated in each recorded loading step. The crack length extension during stable growth was obtained directly from the acquired images. The assembled resulting *J*-resistance curve is shown in Fig. 1. Fracture toughness of the material in the terms of critical value of the *J*-integral was extracted from the curve. The second experiment was carried out with low strength steel (ČSN 411373) used in pipeline industry. In this case, a comparison measurement of the CTOD evaluated by the DIC method and the δ_5 measured using standard displacement gauge was carried out.

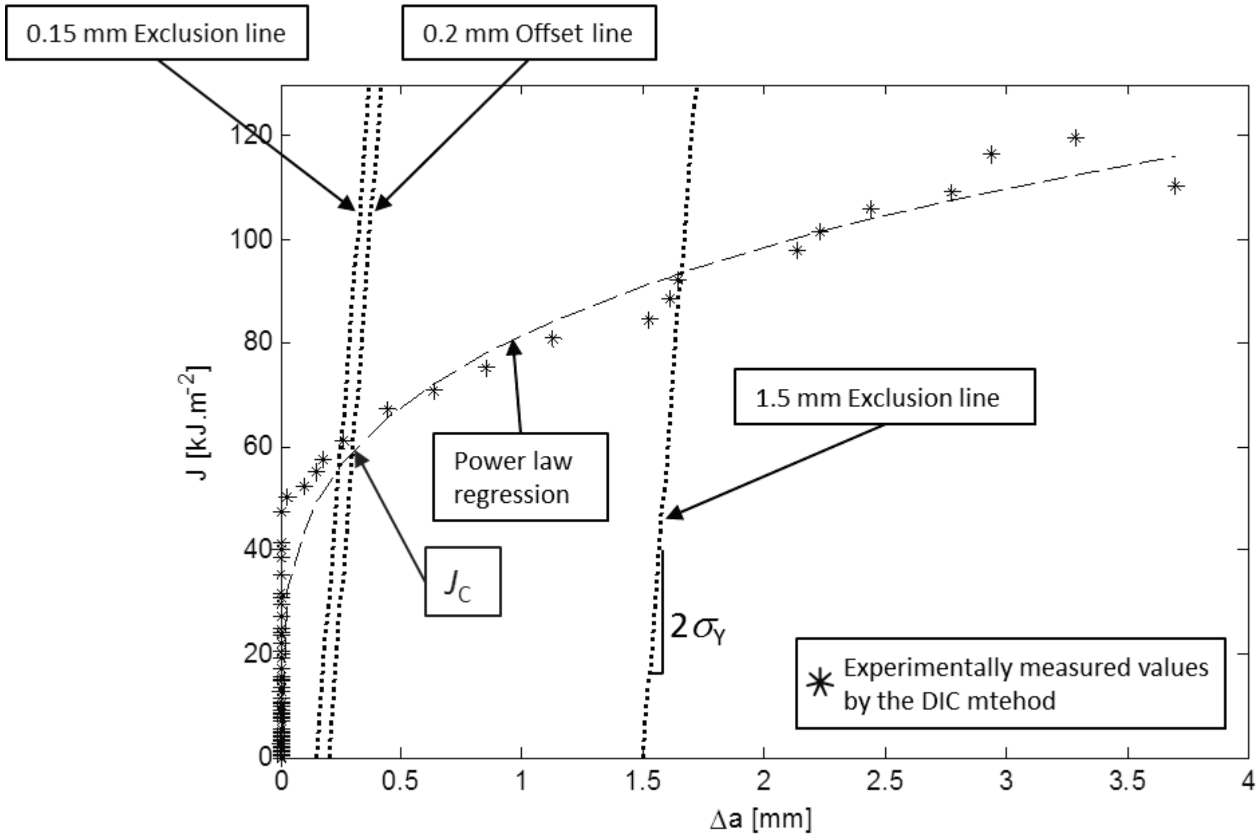

Fig. 1: Experimentally measured J-resistance curve of aluminum alloy using the DIC method.

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