Crack growth resistance evaluation of ductile material using DCB specimen

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Abstract

An analytical method is derived to determine the tearing resistance of a material using the double-cantilever-beam specimen. The analysis makes use of a beam-on-elastic foundation model to determine the elastic deflection of the specimen and the Dugdale model to simulate the stress field at the crack tip. J resistance curve of 2024-T3 aluminium material is obtained based on the experimentally observed load and crack extension and is compared with those deduced using compliance method and finite element method.

1. Introduction

The critical value of the J-integral \( J_{lc} \) [1] has been widely accepted to be a satisfactory parameter for describing fracture initiation associated with moderate or large scale yielding in the same way as \( K_{lc} \) can be used to describe fracture in material obeying linear elastic fracture mechanics (LEFM). However, substantial stable crack growth preceeds fast or dynamic fracture in a ductile material unlike the case of a brittle material. The initial phase of crack growth is quasi-static in which dynamic effects are negligible and the flow of strain energy is associated with the material separation itself as well as with the growth of the yield zone around the crack tip. Therefore the process is essentially a local phenomenon. Subsequently, the growth assumes a state of fast fracture during which global energy flows rapidly to the process zone and the increase in plasticity at the crack tip is very little. The process of fast fracture in ductile material is quite similar to that in materials conforming to LEFM.

The present study is focussed on the quasi-static crack growth which is associated with a large increase in resistance to tearing due to the increase in plastic zone size. Hence for a ductile material the increase in tearing resistance with crack growth is the governing parameter for stability rather than the critical fracture toughness value itself. It is widely accepted that \( J_{lc} \) measures the intensity of the crack tip field associated with the crack initiation and in a similar manner the crack growth resistance curve measures the strength of the crack tip field of a growing crack before the commencement of unstable fracture. The crack growth resistance curve can be either J-based or COD-based and can be a material property depending on the condition of the crack tip whether it is plane stress or plane strain as the case may be and for limited crack growth in which \( J \) or COD uniquely characterizes the fracture process. The present investigation deals with the evaluation of tearing resistance of Aluminium 2024-T3 material under near plane stress conditions.

Double-cantilever-beam (DCB) specimen has been used extensively to study slow stable as well as fast fracture in both brittle and ductile materials [2,3]. The convenience in the application of the beam-on-elastic foundation (BEF) model to determine the load-deflection behaviour has greatly promoted the use of this specimen in fracture studies.
Moreover, the specimen possesses an inherent geometric stability so that tests can be carried out over a large extent of stable crack growth preceding fast fracture. However, the crack growth is normally arrested even after the commencement of dynamic fracture. A modified version known as the reinforced-double-cantilever-beam (RDCB) specimen has been developed [4–6] and it has the additional advantage of the crack tip plasticity being confined to a narrow groove enabling the application of LEFM theory even for testing relatively ductile material. The present authors have proposed a modification for the previously used BEF theory in the fracture analysis of RDCB specimen in order to account for the elastic-plastic effects and the results have been proved to be satisfactory [7].

A simpler DCB specimen is used in the present investigation to deduce the tearing resistance curve. The analysis makes use of the Dugdale “strip-yield” model to represent the stress field near the crack tip in addition to the use of the BEF model to idealize the load-deflection behaviour of the rest of the specimen configuration. The analysis is only valid for fracture under near plane stress conditions. The proposed method deduces the tearing resistance curve by making use of experimentally determined load and crack extension data. The method is relatively simple and the results are compared with those obtained using the compliance method given in Ref. [8] as well as with those of the finite element analysis for growing cracks [9–13].

2. Application of modified BEF model to crack growth analysis of DCB specimen

The BEF model can be conveniently used to represent the load-deflection characteristics of the DCB specimen shown in Fig. 1. One half of the specimen can be considered as a beam supported on the other half which acts as an elastic foundation along the length of the uncracked ligament. In the case of elastic-plastic materials, the crack tip yield zone is substantially large compared to the total length of the uncracked ligament and the present authors have dealt with the effect of crack tip plastic zone using the Dugdale “strip-yield” model [7]. However, this assumption restricts the applications of the modified BEF model only for the specimens made of non-work-hardening material cracking under near plane stress conditions. Figure 2 shows one half of the specimen sectioned along the centre line. The total length of the beam AD is denoted L, the initial length of the crack AB is a, the length of the resulting plastic zone BC due to the application of an opening load P at end A is w and the remaining ligament length BD is w + d. For the purpose of evaluation of the plastic yield zone it is assumed that the fracture behaviour of the DCB specimen is similar to that of an infinite plate of the same thickness having a semi-infinite crack opened by a concentrated wedge force P acting at a distance a from the crack tip. Approximating the crack tip stress field by the Dugdale model the plastic zone length w

![Figure 1. DCB test specimen.](image)