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A synthesis of geometry effect on brittle fracture

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ABSTRACT

There are numerous analytical solutions in order to take into account the geometry effect on the fracture toughness and the fracture load of the cracked specimens. However, due to the complexities of the mentioned criteria it is practical to have an engineering method which can be used for fracture prediction in cracked samples of various shapes and loading conditions. In this paper, the fracture behaviors of five different testing samples made of various brittle and quasi-brittle materials have been studied using an energy based criterion namely the Average Strain Energy Density (ASED) criterion. According to the formulation of the ASED criterion, all the stress terms around the crack tip were taken into account and the brittle fracture of different samples with various geometry constraints were well predicted.

1. Introduction

Brittle fracture is the dominant failure mechanism in a wide range of brittle and quasi-brittle materials. Hence, failure load assessment is an important task for numerous practical applications of brittle materials such as rocks, concretes, ceramics and polymers. The majority of available researches in this field are related to the failure criteria based on singular terms of stress at the vicinity of the crack tip. Considering the pure mode I loading, cracks can be deviated from the original crack plane due to the presence of large values of higher order terms of stresses. In this case, several researchers have shown that the fracture toughness of the materials is considerably different from the results obtain from the standard testing samples such as Compact Tension (CT) and these differences are influenced by the shape of the tested specimen [1–12].

In this case the available fracture criteria which are based on only the singular terms of stress (i.e. stress intensity factor, SIF) fail to predict the onset of the fracture [1–4]. One possibility is to include the higher order terms (such as T-stress) contribution in the fracture criteria by reformulating the previous models based on SIFs. Various fracture criteria have been proposed based on the leading terms of series expansion governed by the SIFs combined with the T-stress. It has been reported that these two-parameter fracture criteria provide more reliable fracture assessments [13–16]. Among the various two-parameter fracture criteria, the generalized maximum tangential stress (GMTS) and the generalized strain energy density (GSED) criteria are mostly used for brittle fracture of cracked specimens [10,11]. The GMTS and GSED criteria are modified versions of the maximum tangential stress (MTS) [17] and the strain energy density (SED) [18,19] criteria by considering the

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Nomenclature

a	crack length
B	biaxiality ratio
E	elastic modulus
h_1	minor height of cracked specimen
h_2	major height of cracked specimen
K_I	mode-I stress intensity factor
K_{Ic}	mode-I fracture toughness
F	applied load in finite element analysis
F_c	fracture load
r_c	critical distance
T	T-stress
W	width of cracked specimen
σ_t	ultimate strength
ν	Poisson's ratio
ASED	average strain energy density criterion
ASTM	American Society of Testing Materials
CT	compact tension specimen
DCB	double cantilever beam specimen
TDCB	tapered double cantilever beam specimen
GMTS	generalized maximum tangential stress criterion
GSED	generalized minimum strain energy density criterion
LEFM	linear elastic fracture mechanics
MTS	maximum tangential stress criterion
PMMA	polymethylmethacrylate
SED	strain energy density criterion
SIF	stress intensity factor
$\overline{W}$	average strain energy density
W_c	critical strain energy density

effect of T-stress in the closed form formulations. Although these failure criteria provide better approximation of the fracture behavior, they have more complex formulations compared to the previous models based on SIF.

Lazzarin and Zambardi [20,21] presented the ASED criterion by improving the SED criterion and considering a control volume instead of a critical distance. According to the ASED criterion, brittle fracture occurs when the averaged strain energy density over a control volume is equal to a critical value which is a function of material properties of the material. By using a control volume around the crack tip and obtaining the strain energy densities, all terms of Williams's series can be considered in calculations leading to more accurate results. Although successful ability of the ASED criterion has been reported in several researches for various loading conditions in different engineering materials (such as rocks, graphite, polymers and metals [22–30]) and different practical applications (such as welded joints in constructional industries [31] and the rollers in metal forming industries [32]), the validity of this criterion has not yet been examined for different geometries of cracked specimens. Hence, the main aim of the present research is to investigate mode I brittle fracture in PMMA testing samples of five different geometries. For this aim, the experimental fracture results of PMMA specimens reported in a recently published article of the current authors (see Ref. [11]) are assessed using the ASED criterion. It has been shown that very good agreement exists between the experimental results and the theoretical findings. Additionally, the same methodology was used to analyze the geometry effect on the fracture behavior of three different rocks namely Harsin marble, Johnstone, South Korean Yeosan.

2. Experiments

Fig. 1 illustrates the geometry of five different specimens used for conducting the fracture tests, namely CT, two types of double cantilever beam (i.e. DCB^1, DCB^2) and two types of tapered double cantilever beam (i.e. $TDCB^1$, $TDCB^2$). Due to different geometric constraints in these specimens, they can provide a wide range of positive T-stress. Samples were cut from a PMMA sheet of 10 mm thick. The geometrical dimensions of the test samples are provided in Table 1. The initial notch in the samples was created using a 0.2 mm thick strip saw blade. Then, a razor blade was pressed on the notch tip to create a sharp pre-crack. The final crack length for all the cases was equal to a/W = 0.5.