APPROACH ON THE PROBLEM OF CRACK PATH STABILITY OF DCDC TEST SPECIMEN

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ABSTRACT. *The existing theories for the prediction of the crack path are based on the perturbation method combining the analytical and finite elements methods. They require knowledge of the toughness equations. A different approach is used in the present work. The finite element technique is used to calculate the strain energy density contours. The predicted trajectory of the crack during unstable propagation, under small scale yielding, is assumed to coincide with the curve that passes the points with the maximum gradient of strain energy density (SED). The degree of crack path stability depends on the sharpness of the SED oscillations. This simple method offers a reliable prediction of the crack path stability for two as well as three-dimensional problems with complex geometry structures and arbitrary loadings. This method was applied in the DCDC specimen with hole set off from its centre line.*

1. INTRODUCTION

The search of methods for the prediction of the crack path and its type finally became an issue of particular interest due to the increasing use of advanced materials like composites or coated materials for improvement of their thermo mechanical attributes. With the increasing use of structural adhesives in construction and the aerospace and automotive industries, the need for an estimate of the locus of failure and the crack path propagation is essential to improve the durability of the bonded joints. In addition, the prediction of the crack path can be beneficial in the design of safe structures and gives answers on the possible initial conditions of loading in the case of a destructive fracture. To clarify the concepts of 'stable' and 'unstable' crack path in the fracture of a solid or a structure we define:

A part of the path of the propagated crack can be characterized as 'stable' if and only if this part resulting from repeated experiments onto bodies with the same geometry and under the same loading conditions appears with identical geometrical characteristics. Specifically, when a stable crack path situation prevails at the spread

of a fracture in specimen and leads to the catholic destruction of the specimen, the corresponding broken pieces have the same shape.

The verification of a theory or a method for the approach of a problem is usually based on the experimental process. However, if the results are exceptionally sensitive to the initial and general conditions that exist during the experiment, then a scattering of the results is very likely. The evaluation of this scattering in phenomena of "instability" can lead to erroneous conclusions. In other words, in each experimental process we should compare the scattering of the results owed to endogenous factors of instability of the problem with the magnitude of the divergence of the conditions of the experiment, like the constrained displacements, or the geometry of the specimens. Observations on experimental results show that the propagation trajectory of an extended crack depends on the material properties, the geometry of the specimen, the rate of loading, the dynamic loading and the temperature. Furthermore, the control of the load's or the displacement's increase on the specimen by the loading machine also plays an important role. On the interface, the propagation trajectory also depends on the tensile strength and fracture toughness of the bonded materials. Generally, the phenomenon of the crack path in/stability is influenced from the global stress situation, which prevails onto the specimen.

The sign of the second order asymptotic stresses at the crack tip, the *T*–stress, has been widely used for deciding whether directional stability prevails for straight cracks subjected to mode I loading under small scale yielding. However, there is little evidence for the reliability of such a criterion. On the contrary, it is shown that a local criterion is not applicable and that directional stability generally depends on body and load geometry as well as on material parameters, whereas the sign of the *T*-stress is irrelevant in most cases. In particular, the critical role of the sign of the *T*-stress applies only to the situation of a single crack growing in a large plate, and cannot be transferred to other situations directly [1].

Several papers that studied the problem of crack path stability, do not give a distinct discrimination between the concepts that characterize the crack path: '**curved**' and '**unstable**'. Interesting cases of crack path stability emerge in symmetrical specimens, under symmetrically imposed loading, where the mode I (K_{II}=0) is dominant on the pre-existing crack but propagation is not always straight. Under these conditions, most researchers consider the line of the crack's axis as a stable trajectory of the crack extension and any deviation is taken as a sign of instability.

In the present work, the problem of crack path stability is approached from a different viewpoint. Using a computer finite element program and carrying on with a plotting program, we take the contours of strain energy density before the unstable crack propagated on the idealization of a solid plane. The graphical application of the extension of the minimum strain energy density criterion on the contours maps, results to the predicted trajectory of the crack growth. Furthermore, the manipulation of the contours of the strain energy density in combination with the estimation criterion results in the degree of stability of the crack path for the propagation of an unstable fracture. Therefore, this simple method offers a good reliability in the prediction of the crack path stability for problems with complex geometry structures and arbitrary loadings under small scale yielding. Analytical presentation of this method has been given in [2,3]. In this work we try the predictability this method for DCDC specimen [4-7].

2. METHOD PREDICTION OF THE CRACK PATH AND STABILITY

For any two-dimensional problem with an arbitrary geometry for the body and arbitrary constrains the displacement and loading can produce the stress and strain fields, by the use of a computer finite elements program. Using those data, we can produce the contours map of strain energy density by the use of a computer graphical program. This map has common features with a geographic map: The point where the failure will begin according to the basic hypotheses will be the hilltops of the topographic map respectively. It will be surrounded from closed contours that may have U shape. The higher contours are always enclosed from lower ones.

In the present work, we will show how with the elaboration of this map we can estimate the stable or unstable crack path. When the critical locus on the plane body is the point O, which can be a crack tip, according to the SED theory, the beginning, the initial direction of crack growth as well as the crack path of propagation will occur.

According to an extension of the strain energy density criterion, the fracture initiates from O along the direction OL, by setting (OL)=r_c, when the $\left[(dW/dV)_{min}^{max}\right]_L$ reaches the critical value $(dW/dV)_c$. The predicted crack path during the unstable propagation is the curve that starts from the point L passes the points with the maximum gradient of (dW/dV) and ends up at point G, where the global minimum value of (dW/dV) develops.

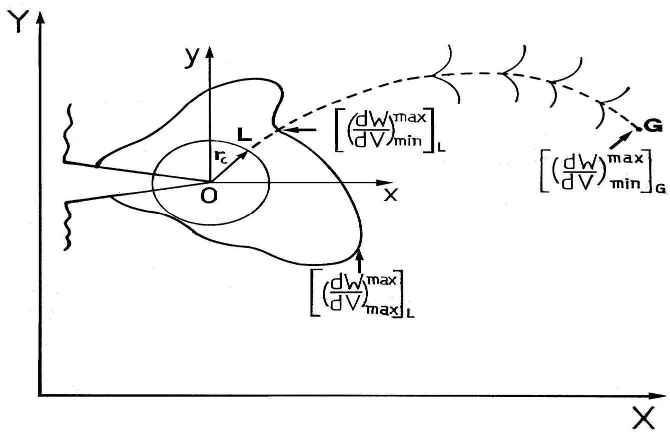


Figure 1. The predicted crack path, OLG curve with maximum gradient of strain energy density (dW/dV).

On the map, the crack path is indicated by V shaped contours of the strain energy density. If the apices of the V_s points are joined by a line, then the resulted plotting curve, starts from the peak O and arrives in vicinity of the point G. This curve is the trajectory of the propagated crack, and shown in Fig. 1. In the geographic map the curve OLG, represents a gorge or a riverbed, which starts from the hilltop O. The drawing of this gorge can give additional information for the estimation of the stability the crack path according to following hypothesis :

The stability of the crack path can be deduced from the degree of the sharpness with which the curve of the "gorge" is drawn.

3. THE FINITE ELEMENT MODEL OF DCDC SPECIMEN WITH AN OFFSET CIRCULAR HOLE

The DCDC specimen with a circular hole and cracks set off from centreline of the specimen, with the geometry and loading p shown in Fig. 2, is simulated by a 2D-plane strain model with eight-noded isoparametric elements, using the ABAQUS code. The dimensions of the specimen which remain constant are the length 2H=400 mm, the height 2W=40 mm, and the thickness B=10 mm. The other geometrical parameters are considered varying. More specific, were varied the radius R of hole to 5.0, 6.67 and 10 mm, the crack length α to 2R, 4R, 6R and 8R and the distance b from the centre of hole to the centreline of the specimen to the values 0.0, 2.5, 5.0 and 7.5 mm. The values of the material properties are assumed to be, for the Young's modulus E=3.0 Gpa, the Poisson ratio ν=0.33 and fracture toughness K_{Ic} =41.19 $Nm^{-3/2}$.

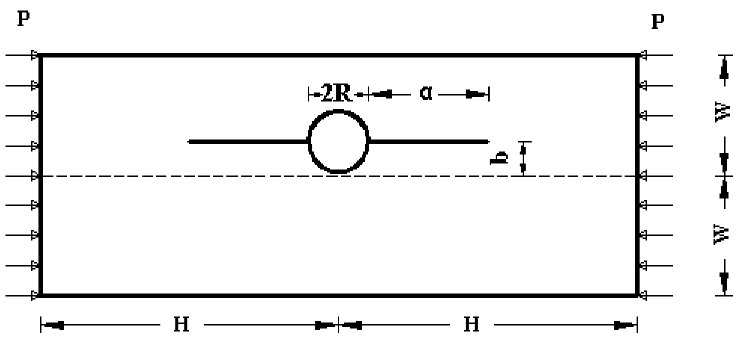


Figure 2. The DCDC specimen with an offset circular hole.

For all cases, only half of the specimen was covered with elements, because of the symmetry on geometry and loading. High concentration of finite elements was used around the region of the crack tip. A fine focused mesh with quarter-point elements served to model the singularity at the crack tip. The computer finite elements program supplies the values of the mechanical quantities and plots the contours map of the strain energy density on the idealized geometry of the specimen.

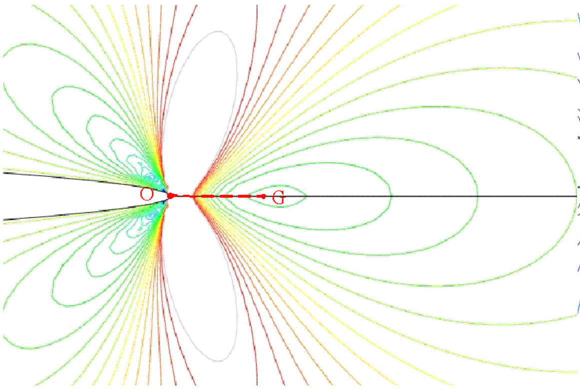
4. RESULTS AND DISCUSSION

From the elastic nodal values of the stresses and displacements we can determine the stress intensity factors K_I, K_{II}, which influence first the singular terms of the crack tip asymptotic stresses field and has been used for years as the single controlling parameters for the initiation and propagation of a crack in brittle materials. Furthermore, we evaluated the second term "*T*-stress" in the near-tip stress field of the cracked body, which is regular normal stresses acting in the direction parallel to the crack plane. The resulting *T*-stresses for different ratios of geometrical characteristics for the DCDC specimen are shown in Table 1.

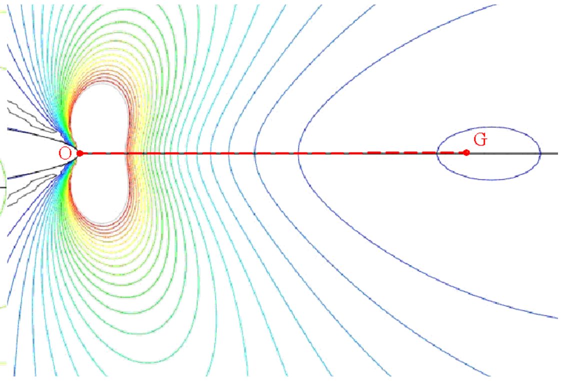
Table 1. *T*-stress of DCDC

T/[p]						
α/R	**b=0 mm**			**B=2.5 mm**		
	R/W=0.25	R/W=0.33	R/W=0.5	R/W=0.25	R/W=0.33	R/W=0.5
2	-0.747	-0.614	-0.343	-0.68	-0.599	-0.292
4	-0.807	-0.701	-0.419	-0.799	-0.689	-0.390
6	-0.837	-0.747	-0.487	-0.834	-0.738	-0.469
8	-0.910	-0.784	-0.549	-0.857	-0.773	-0.529
	b=5 mm			**B=7.5 mm**		
	R/W=0.25	R/W=0.33	R/W=0.5	R/W=0.25	R/W=0.33	R/W=0.5
2	-0.659	-0.564	-0.262	-0.634	-0.507	-0.243
4	-0.781	-0.666	-0.351	-0.757	-0.621	-0.324
6	-0.818	-0.715	-0.421	-0.799	-0.637	-0.371
8	-0.842	-0.753	-0.475	-0.825	-0.709	-0.414

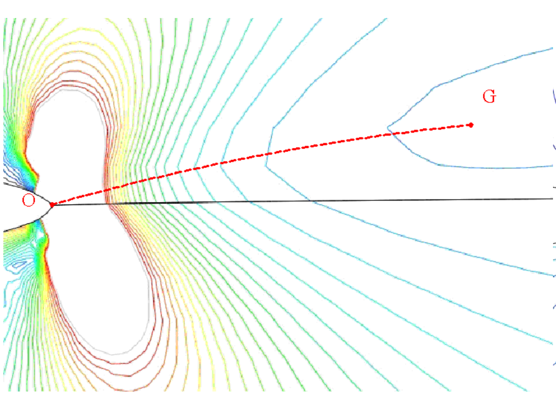
Figure 3 shows the contours map of the strain energy density on the front area of the crack tip, for the DCDC specimen with an offset of the circular hole and cracks for different characteristic ratios R/W and a/R. The predicted trajectory propagation of the crack is OG (dashed line). We see that the crack path for the symmetrical case (b=0.0), is drawn with distinctness and is straight and therefore stable.



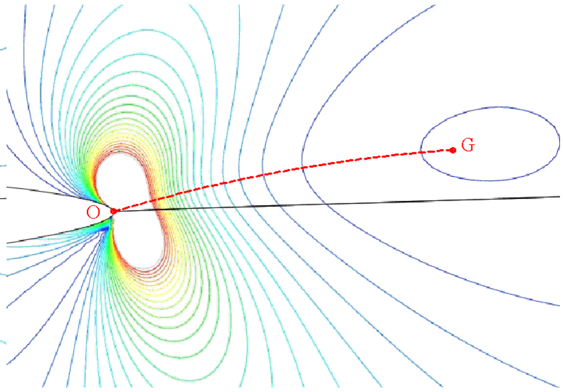
b=0.0mm, R/W=0.33, α/R=6



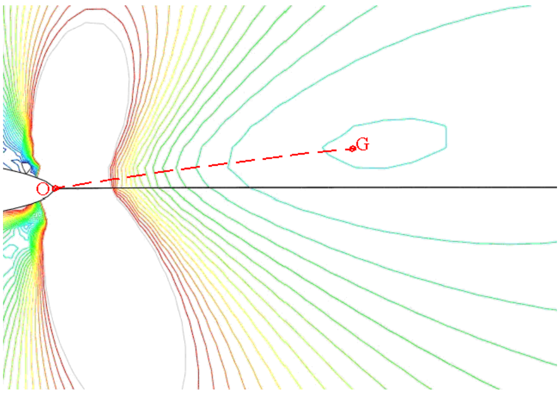
b=0.0mm, R/W=0.5, α/R=4



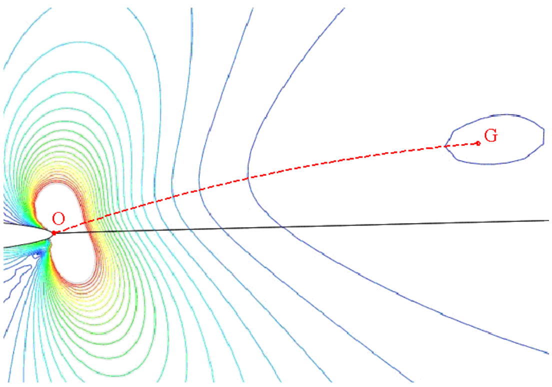
b=2.5, R/W=3.3, α/R=4



b=2.5, R/W=0.5, α/R=4



b=2.5mm, R/W=0.25, α/R=2



b=2.5mm, R/W=0.5, α/R=6

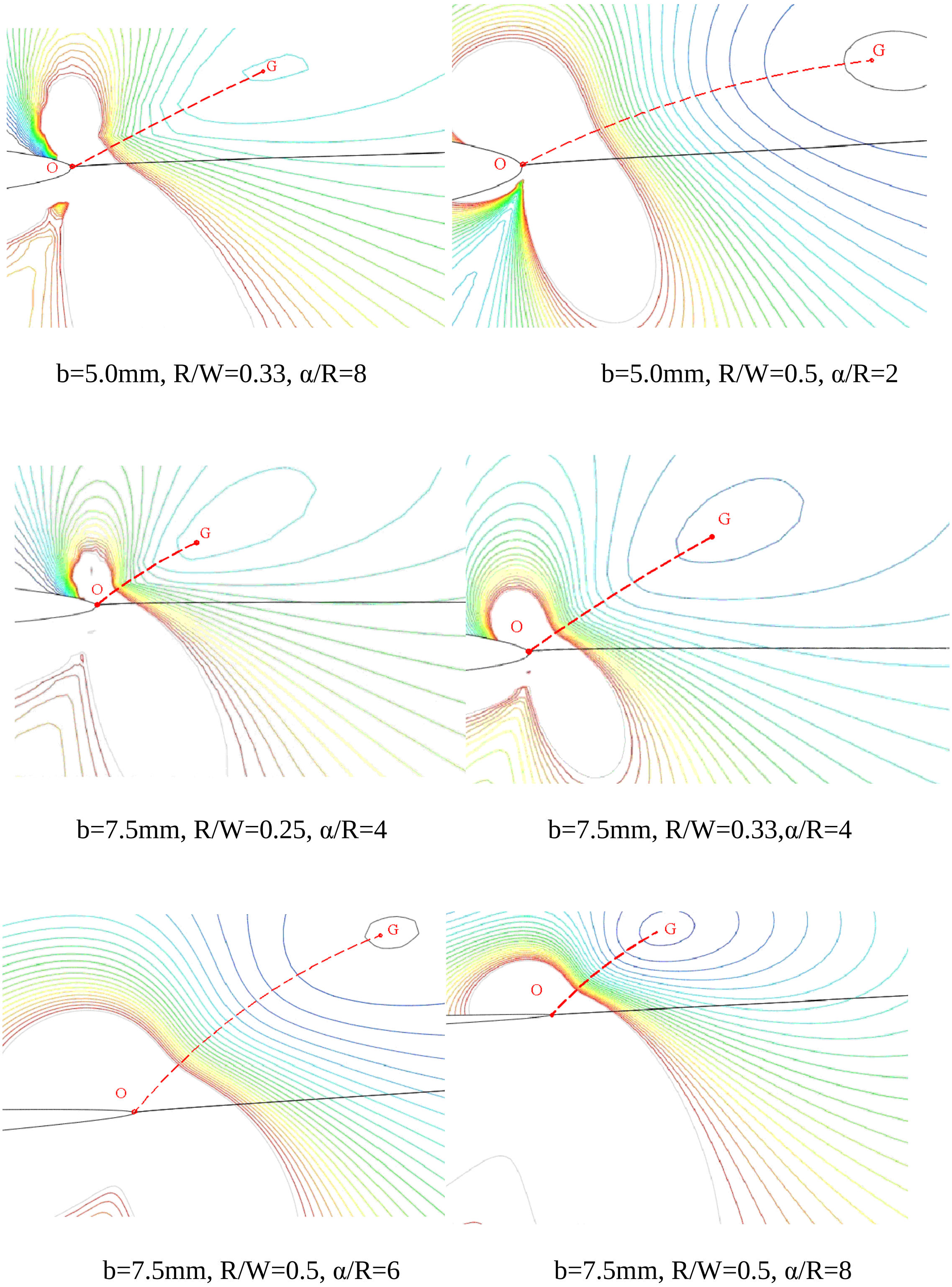


Figure 4. Contours maps of (dW/dV) in vicinity of crack tip of DCDC specimen

Furthemore we observe that on the contour map of the strain energy density for the cases with b=2.5, 5.0 and 7.5mm, the "gorge" OG is clearly traced out, implying that the crack path is a stable curve.

According to the above hypothesis, the initiation of the crack propagation is sudden and after the extension a provisional arrest in the vicinity of the G takes place, where the global minimum of the strain energy density appeared in the contour map. In order to study further crack growth after the point G, the mesh elements need to be rearranged along the formed curvilinear crack.

From the above the idea that an important role in the stability of the crack path is played by the more general stresses situation that have developed far from the neighbourhood of the crack tip is strengthened. Especially, when the crack is extended in a rapid and unstable way. An advantage of the present method is that it takes in account the global stresses situation as it occurs from the contours map of the strain energy density.

4. **CONCLUSIONS**

The *T*-stress term that was computed for the double cleavage drilled compression (DCDC) specimen is strongly negative. Consequently, this specimen exhibits a strong crack directional stability. The present theory provides information for estimation of crack path and its stability.

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