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Additional Comments as related to the fracture resistance criteria

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With the guidelines of linear fracture mechanics methodology the fracture driving force and the resistance criteria are frequently formulated by fracture toughness parameters. As such, a design criteria is expressed either by the critical stress intensity factor (K) or by the critical values of the elastic strain energy release rate (G). As known, the aforementioned parameters are equivalent for elastic solids. Nevertheless attention is required regarding to the totality meaning of such concepts and the exact implications it might bear on engineering design criteria. Examples concerning such issues and others are the main concern of the current study. Considering a scale factor namely down to a small volume application criteria arguments become more involved or even ambiguous and the appropriate reasoning is accentuated by various trade off aspects.

1. INTRODUCTION

Further input is always desired in the engagement of the design criteria dilemma. There are ample of circumstances in which this critical question raises the requirement for refinements and explorations. Various aspects associated with these issues on different levels are the objectives of the current investigation. In this context three different arguments are developed and described. First, the case in which a given discontinuity in an open mode loading activates a non uniform K along its periphery [1]. Second, on a completely different scale of a layer the segment stability (debonding) is evaluated by continuous micro scratch testing methodology. The main point here remains in the notion that in contrast to K which involves two parameters G is founded on additional parameter to be essential. The third, fatigue case which stimulates discussion on the distinction between crack initiation and propagation and the role of the scale on the design criteria.

2. EXPERIMENTAL PROCEDURES

2.1. 3D-embedded elliptical planner crack.

Open mode tests were performed by utilizing single edge notched (SEN) and cylindrical cracked specimens at ambient temperatures. Polyester resin was selected and segments were produced by molding technique. Cracks have been introduced by fine Teflon foils of 75 μm in thickness. Prior uniaxial tensile test indicated typical linear elastic behavior for cross head speed of 1 mm minute^{-1}. The SEN specimens provided fracture toughness parameters that suited for comparative studies that included elliptical geometries and penny shaped cracks. Particularly for the elliptical cracks the loading cycle was tracked by polarized light with quarter wave plates. These procedures enabled the observation of local events in terms of crack extension which occurred at the crack periphery. The cylindrical specimens were 25.4 mm in diameter and the elliptical crack geometry was in the range of a/c ratio from 0.3 to 0.75 (where a and c are the minor and the major axes for the elliptical planner crack respectively). Direct crack observations were conducted by light microscopy and crack extension and the in formation was supplemented by scanning electron fractography.

2.2. W/X Ps composite layer

The W/X Ps composite layer was constructed according to the following specification. On a glass substrate polystyrene (PS) thin layer was produced by spin casting. In addition, W over layer was selected and deposited. While the over layer consisted of a constant thickness of 200 nm the PS under layer varied in thickness in the range from 110 to 790 nm. Test up to debonding allowed the evaluation of fracture mechanic parameters. This was achieved by nanoindentation and continuous micro scratch tests at ambient temperature.

2.3. Fatigue crack initiation in pure copper

Pure polycrystalline copper was tested at ambient temperatures under cyclic loading in strain controlled test. With the assistance of replication techniques and visualizations by Atomic Force Microscopy (AFM) the initiation stage in a sub micron crack order was established. The comprehensive testing program enabled to gather information regarding stress response and saturation, dislocation structures and crack initiation. This was summarized by a damage rule concerning the fatigue life for crack initiation in a typical elastic-plastic FCC crystal structure solid.

3. EXPERIMENTAL RESULTS, DISCUSSION AND CONCLUSIONS

In the case of the planner 3D elliptical flaw, crack extension initiated at the minor axes front. Following a local burst, similar to a "pop-in" event crack extension approached gradually a stable penny shaped geometry. The emphasis here is to illustrate that the exact crack extension behavior eventually dominates the G value. As addressed by Key [2,3] different cases of a/c=constant, fixed major axes mode namely c=constant or a local criteria based on extension at the minor axis result in different criteria. In terms of normalized values σ_1 / σ_2 vs. a/c ratio where σ_1 and σ_2 are the critical stresses for the penny and the elliptical planner crack respectively, Table 1 has been organized. As demonstrated, the mode of the crack extension behavior results in discrepancies of the critical stress values ratio.

Table 1
σ_1/σ_2 as a function of a/c

a/c	Constant shape	Constant c	Local
0.3	0.85	0.75	0.70
0.5	0.87	0.80	0.74
0.8	0.89	0.86	0.82
1	1	1	1

The experimental finding regarding the crack extension pattern is given in Figure 1.

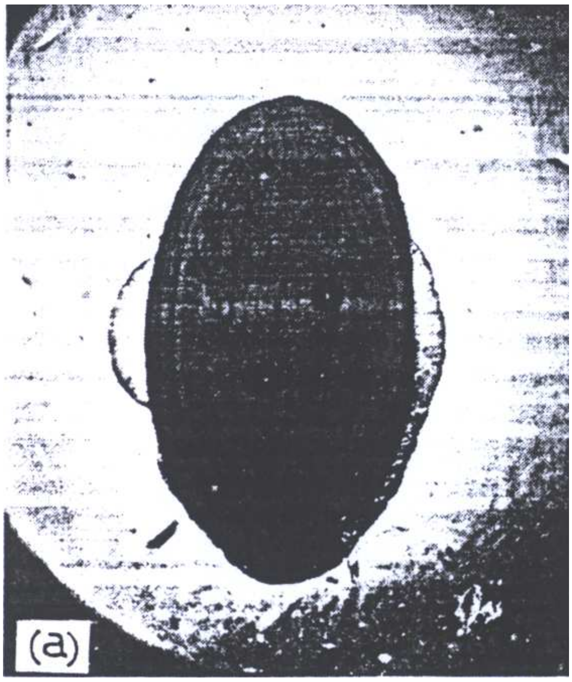

Figure 1. Crack extension at the minor axis front consistent with the maximum stress intensity factor site.[4]

For the thin layer W/XPs the variations of the composite modulus E_c were significant. For example E_c for 110 nm to 790 nm thickness of PS varied by almost the factor of 8. Thus, G_I in terms of K_I that introduce the essential value of the modulus becomes critical. This might result also in a trade off considerations regarding the production procedures concerning the layer optimization. For the copper fatigue case other insights regarding the understanding of a damage rule for fatigue crack initiation is emphasized. Beside the elaboration on fatigue crack initiation stage it becomes apparent that the dependency of the strain amplitude range is more severe for the crack initiation life [5]. Consequently in a small volume application like thin films, connectors or multilayer in which geometrical constraint are dominant the crack initiation event becomes a direct design criteria. At the same time damage evolution rule for initiation might differ from a total fatigue life formulation and in fact highly depends on the application scale. A brief summary of the aforementioned experimentally based examples indicate that defect geometry, scale factor and situations in which fatigue stress initiation controlled processes become functional and might have implications on technological criteria. Consequently the following is concluded:

- even in a linear fracture mechanics methodology, fracture toughness parameters in terms of design criteria require a case by case critical assessment.
- material constitutive properties might need additional input of the scale factor.
- small volume technological applications as in electronic devices almost define the boundary of initiation controlled processes in fatigue to be an essential structural integrity element.

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