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ON THE DIFFICULTY OF IMPLEMENTING THE COUPLED CRITERION TO PREDICT GLASS FRACTURE

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Abstract

Glass is an extremely brittle material that behaves almost perfectly linear elastic until it fractures. The linear-elastic fracture mechanics (LEFM) approach described by Griffith's energy criterion is typically used to explain failure from a pre-existing crack like defect. However, LEFM reaches its limits in explaining failure processes at general stress concentration points and implementing the Coupled Criterion (CC) to take over is a tricky task. This mainly because it requires the knowledge of the tensile strength of the material which is a parameter not easy to characterize in glass. It is in general defined through a statistical law and relies strongly with surface flaws. The general aim of this work is to give an overview of the current understanding of glass tensile strength.

1. Introduction

In recent decades glass panels are increasingly used as structural components in architecture. However, glass remains a brittle material, failure must be accounted for security reasons and a correct prediction is crucial. Griffith's energy criterion is typically used to explain phenomena related to glass failure from a pre-existing crack like defect. However, LEFM reaches its limits in explaining failure processes at general stress concentration points and another approach must take over. A promising one is the Coupled Criterion (CC) that has already been proved to work well for predicting the fracture of other brittle materials such as ceramics or laminates. It requires the knowledge of the tensile strength of the material together with its toughness. However, defining the tensile strength of glass is challenging [1] and the presence of residual stresses in tempered glass further complicates the problem. Indeed, measuring the tensile strength by a standard bending test (e.g., 4-point bending or ring-to-ring bending tests) in glass specimens is more a measurement of the presence of surface flaws than the determination of a constant material property, explaining that it leads to a large scattering. While an intrinsic strength of glass has been suggested in a range of several GPa [2], the observable strength in bending tests is in a range of a few MPa (typically somewhere between 5 – 200 MPa) [2]. Indeed, it is admitted that it has not a deterministic value but is defined through a probabilistic distribution, the Weibull law. Such a situation makes it difficult to use the Coupled Criterion (CC) which specifically requires the knowledge of the tensile strength of the material to implement the stress condition. This condition complements the energy condition deriving from the energy balance to form a twofold criterion [3].

However, in some cases, ceramic materials for instance, this difficulty can be partially overcome. In bending tests, polishing the specimens leads to an increasing load at failure, but the curves reach a plateau, the intrinsic strength, when the surface defects become smaller than a threshold. In ceramic materials, this plateau is strongly related to the grain size, i.e., a microstructural length scale. It has been shown in [4] that this plateau is the value to be used by the CC to predict, for instance, crack nucleation at a sharp V-notch. A sharp V-notch is a major defect, stresses are singular and any statistical rule fails. Unfortunately, such a plateau does not exist in glass, due to its amorphous microstructure.

2. Results

Unlike Griffith's criterion, the CC does not assume the existence of a pre-existing crack. In an annealed glass specimen under bending, the peak stress, where a crack is supposed to initiate, is located at the surface under tension and coincide with the location of the surface flaw. Then, no difference is observed between

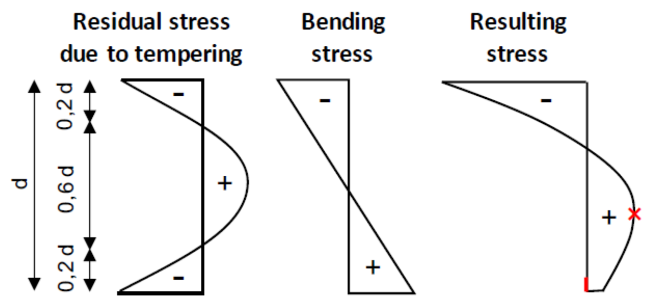

Fig. 1 – Location of the peak stress in a thermally tempered glass specimen

Griffith's criterion taking into account a pre-defect and the CC using a smooth surface and the tensile strength σ_c measured in the flexural test, typically around 50 MPa.

On the contrary, in a thermally tempered specimen, the peak stress is transferred to the interior (Figure 1) and assuming for the CC either an initiation from the surface (i.e. not at the peak stress but at the same location as Griffith's) or an initiation at the peak stress (but not at the location of the flaw responsible for the value of σ_c) leads to a difference that is all the greater as the stress peak is far from the surface.

Based on additional simulations, it seems obvious that the supposed location of the initiation point compared to that of the peak stress is determinant in the reliability of the CC. Moreover, clearly, the measured σ_c in such a material is far from being a material constant valid at any point.

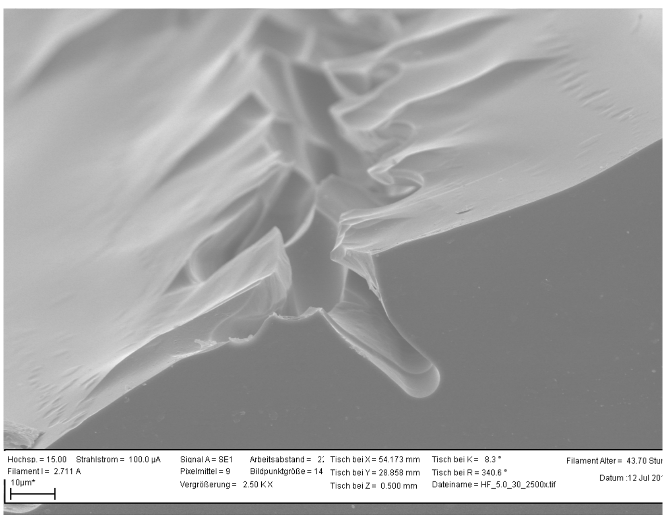

Figure 2. – A typical surface flaw after etching (according to [5])

3. Upcoming results and conclusion

In the absence of a reliable parameter defining the tensile strength, the use of the CC without special caution seems hazardous in a material like glass. However, the etching process, which is known to reduce surface defects in glass, seems a promising way to determine an intrinsic tensile strength. The acid exposure duration allows controling the flaw depth and root radius (Figure 2). Then, an inverse approach permits the CC to identify a value of the intrinsic tensile strength in the range 1000–1500 MPa. According to [2], it corresponds to the measured tensile strength of glass fibers, far below the theoretical limit of molecular resistance but above the values measured on standard glass panels.

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