Modeling Fracture of Tempered Glass Using an Eigenfracture Approach

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The failure mechanism of glass structures varies depending on several factors, which include the processing techniques used during the manufacture of glass-based elements (i.e. glass panels). To increase safety upon the fracture of glass structures, thermal or chemical treatment can be employed to produce toughened or tempered glass. Thermal tempering of glass is a process, where a glass pane is heated at high temperatures and is then cooled down rapidly, which induces residual compressive stresses at the outer surfaces and tensile stresses within the inner layer. This process influences the fracture pattern of glass panes significantly, where upon the initiation of fracture due to impact loading a thermally toughened pane breaks into relatively small fragments.

From a physical point of view, the dynamic process of glass fragmentation can be regarded as a result of multiple initiation of cracks, progressive crack branching and interlocking. The numerical modeling of this dynamic process has proven challenging due to various aspects. The emulation of the crack initiation and propagation criteria can be regarded as a demanding task, where different factors and comparatively complex scenarios (i.e. extremely small crack sizes) must be taken into account. Furthermore, the computational effort needed to model the process of fragmentation is generally considered as beyond the borders of practicality. Several approaches have been proposed in the literature to model the fragmentation process of brittle materials using numerical methods, such as the finite element method. These approaches include the introduction of a cohesive zone at the interface between finite elements, where a certain fracture criterion is met [1]. New surfaces are adaptively created as required based on a cohesive law, where certain nodes are duplicated along initially intact finite-element boundaries [1].

An eigenfracture approach is an approximation method proposed by [2] to simulate brittle fracture. The idea of eigenfracture has been implemented in the form of element erosion, which is an approach denoted by eigenerosion [3]. In order to predict the realistic crack kinematics, the representative crack element (RCE) method has been employed within an eigenerosion framewrok [4]. The RCE approach has advantages compared to other formulations, which are used to predict the crack-driving force (i.e. volumetric-deviatoric split) [4].

This contribution aims towards the finite-element simulation of fracture exhibited by annealed and tempered glass, under high loading rates. The eigenfracture method based on RCE approach [4] is adopted and further extended by taking into regard the emulation of brittle-fracture's evolution in the existence of residual stresses. In this work, the eigenfracture method is used to simulate crack branching in glass panes under tensile loading. Moreover, it is aimed to present the results of initial attempts to simulate the process of fragmentation, ranging from relatively big sizes of fragments (i.e. due to low residual stresses) to small sizes of fragments (i.e. caused by high levels of residual stresses). Finally, argumentations to improve the prediction capability of the developed approach and its efficiency are discussed.

References

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