Multiscale simulation of fracture pattern of tempered glass

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ABSTRACT

Inducing a compressive stress in surface of brittle soda-lime silicate glass enhances its toughness and enables us to apply glasses to wide range of applications, such as automotive window shield, cover glasses for mobile phone and tablet devices. There are two major processes to achieve the residual stress profile [1]. One of the methods is namely thermal tempering which cools the glass surface more quickly than its interior. Another one is chemical strengthening by ion exchange process, in which larger ions replace smaller ions in the surface. Because of the difference of the processes, stress profile induced in the depth direction is not identical. Thermally tempered glass has deeper compressive layer than chemically tempered glass. On the other hand, higher compressive stress can be evoked in chemically tempered glass than in thermally tempered glass. It is therefore each method has different advantages and disadvantages for practical applications, and further development has been required to accomplish higher fracture toughness for wider applications. For example, Green et al., have developed engineered stress profile (ESP) glass, in which stress field is controlled by two step ion-exchange [2, 3]. ESP glass has more steep stress gradient beneath the surface and shows maximum compression at deeper position in thickness. Owing to the designed stress profile, crack pattern in ESP is well controlled and multiple surface crack is generated.

In this study, we apply Multiscale Cohesive Zone Model (MCZM) [4] to understand relations between stress profile and crack pattern in brittle glass. MCZM employs interatomic potential into constitutive relation of finite element method to express cohesive law in fracture process zone (Fig. 1). We extend the method to solve three-dimensional dynamic fracture problems with considering inhomogeneous deformation inside the cohesive zone [5]. In addition, in order to apply the method to amorphous materials, Molecular dynamics simulation is implemented to evaluate stress-strain relation with an unit cell composed of multiple atoms. Further, we will compare the fragmentation pattern with Peridynamics simulation [6].

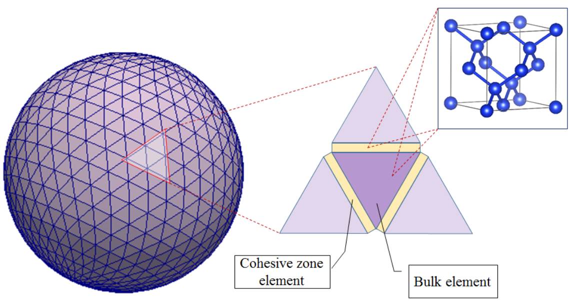

Figure 1. Illustration of multiscale cohesive zone model in 3D

Keywords: Fracture, Glass, Multiscale simulation, Cohesive zone model, Peridynamics

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