
Indentation of brittle materials – what micro-photoelasticity tells us about the stress field

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Abstract

Since the end of the 60s, our knowledge of the advanced mechanical properties such as plasticity, damage and cracking in brittle or quasi-brittle materials has made great progress thanks to the development of indentation (1,2). The choice of the applied load and the indenter geometry can selectively activate one or the other of these mechanisms, at least in part. As a result, indentation offers unparalleled insight into the non-linear and rupture properties of many brittle materials such as single crystal oxides and nitrides, semi-conductors, ceramics and glasses, and the effect of composition and processing.

Indentation studies in brittle materials are successful because the usually unstable fracture development is contained by the surrounding half space. However, this asset becomes a drawback when it comes to quantitative analysis because the deformation is very inhomogeneous and the indentation stress field is complicated. For more insight, several analytical or semi analytical models have been developed to take into account the presence of a plastically deformed zone below the indenter and its impact on the elastic field in the confining half space. Among these models, Yoffe's (3) has been used extensively because of its simple form (4). However, several questions are still open. For example, there has been some controversy over the suitability of indentation to measure fracture toughness (5), or the analysis of the experimentally observed cracking threshold in silicate glasses (6). In addition, it was recently found that Yoffe's model deviates considerably from the FEM predictions based on recently developed constitutive relations, to a point which raises doubts about the analysis of observed crack patterns (7). To clarify these and other questions, it would be expedient to accurately measure the stress field under indentation in brittle materials. However, this requires a mapping of stress or strain at a scale of the order of microns, to resolve the limited size achievable in a brittle material before fully developed fractures appear, and this is not an easy task.

To tackle this problem, we have used a highly-sensitive imaging system to record the low birefringence signal around shallow indents in silicate glasses, with optical path differences in the range of tens of nanometers. We analyze the data through the forward calculation

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of the birefringence pattern from FEA stress fields using accurately calibrated constitutive relations for the plasticity of silicate glasses. Comparison of predictions and experiments strongly support the validity of the method while suggesting refinements for the constitutive relations. In contrast, the photoelastic response predicted from Yoffe's analytical stress field is shown to differ significantly from the data, except in the far field. The perspectives opened by the method will also be discussed.

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