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COMPLEXITIES OF FRACTURE DEVELOPMENT IN BRITTLE ROCK-LIKE SOLID MATERIALS

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ABSTRACT

In this contribution, our recent experimental observations of the collective behavior of a group of cracks in brittle solids will be summarized. The complexities of fracture development in rock-like materials and their implications in earthquake source dynamics will be briefly mentioned.

1. INTRODUCTION

An earthquake, occurring in the solid earth either slowly (related to the so-called slow slip event) or rapidly (an ordinary dynamic seismic event recorded by seismographs), is normally considered to be generated by mechanical destabilization of fracture in brittle rock-like solid materials that are subjected to tectonic or other loads. As can be noticed from the existence of both slow and fast seismic events, fracture associated with an earthquake may develop spatiotemporally in complex ways, but generally, fracture areas (cracks) are first nucleated in solids, and then they expand stably and sometimes induce catastrophic failure of the solids later. During this physical process, multiple cracks may expand simultaneously and interact mechanically with each other, stably (quasi-statically) or unstably (dynamically with radiation of waves). The collective (global or overall) mechanical behavior of these multiple cracks in brittle solid materials may play a key part in comprehending the mechanics of earthquake generation, but previous study has usually treated the development of a single crack only or at most, the extension and interaction of few cracks, and the collective behavior of a group of cracks has been rarely handled, not only experimentally but also theoretically.

Latest analytical investigation into the nonlinear deformation of an originally linear elastic solid with sets of cracks[1], however, has shed new light on such unexplored field of mechanics of complex fracture process involving multiple cracks. The study has indicated that the prescribed, timewise constant strain rate that is externally applied to the solid governs the global stress-strain relation of that solid. A higher strain rate renders usual stress-strain relationship with smooth increase of stress with strain, followed by smooth decrease. On the other hand, a lower rate gives a sudden stress drop in the stress-strain relation as can be often found in the literature of seismology and mechanical instabilities of solid materials. Also, it has been depicted that the overall tensile strength of that solid increases with the external strain rate imparted.

2. EXPERIMENTAL OBSERVATIONS

The above theoretical prediction of the dependence of the collective behavior of multiple cracks in a solid on external strain rates exerted, looking contrary to our intuition, has not been confirmed by experiments yet. Therefore, for the validation of the prediction, photoelastic experiments have been conducted in our laboratory by using initially elastic polycarbonate plates that contain sets of cracks parallel to each other. The transparent and birefringent specimens with the cracks have been prepared by a digitally controlled laser cutter[2]. For the preliminary observations, material behavior in tension has been investigated first, and a tensile testing machine, together with a high-speed digital video camera, has been utilized to globally as well as locally record the stress development in the specimens elongated at several different levels of timewise constant strain rates (displacement rates). The experiments have shown clearly sudden stress drops with relatively smaller displacement rates and at the same time the increase of the overall tensile strength with the displacement rate. The newly discovered rate dependence in the stress-strain relation for solids with multiple cracks may deepen our understanding of the similarity and difference between, e.g. quasi-static diastrophism and dynamic faulting in geotechnical science, but further scrutiny of the former analytical results, in particular that of the total amount of energy released, as well as more systematically organized experiments employing specimens with optimally distributed cracks and applying much higher displacement rates may be required to give more decisive remarks[3].

Fig.1 A typical snapshot depicting the time-dependent distribution of the maximum in-plane shear stress in a photoelastic specimen with a set of parallel cracks.

3. CONCLUSIONS

If there exist a group of cracks, not only a single one, in solid materials, each individual crack may expand simultaneously and interact with each other mechanically in complex manners. As stated above, the global behavior of such sets of cracks has not been extensively investigated, and therefore, this article has provided a concise summary of our experimental findings regarding the nonlinear deformation of a solid that is originally linear elastic but having multiple cracks. As theoretically predicted, it has been experimentally illustrated that the prescribed, timewise constant strain rate controls the collective stress-strain relation and as a result also the overall tensile strength of the solid. Mechanical destabilization of fracture in brittle solids may induce not only earthquakes but also failures of structures that are subjected to some loading conditions. Therefore, the findings described here may be of importance in enhancing the safety and security of structures made of solid materials.

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