ROLE OF LOCALIZATION LIMITERS AND LENGTHSCALES IN MESH OBJECTIVE DYNAMIC FRACTURE MODELING

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Abstract

The objective of this work is to critically assess two commonly used localization limiters, viz. the crack band model (CBM) and rate dependent damage (RDD) for continuum scale dynamic fracture predictions. For this purpose, dynamic mode I fracture for an isotropic brittle material is considered under various loading rates and mesh sizes. A scalar damage model is employed, in conjunction with both localization limiters. The analyses reveal that neither of the localization limiters can successfully regularize the solution across all loading rates. Thus, with local damage models, mesh objective prediction of dynamic fracture can be completely ensured only if the mesh size is kept fixed.

1. Introduction

It is well established that local continuum damage modeling of quasistatic fracture, implying softening damage and localized cracks, requires the use of localization limiters for mesh objectivity. However, the applicability and appropriate use of these for dynamic fracture problems, which often implies diffused (non-localized) and branched cracks, is not well understood. This knowledge gap is addressed here by assessing the mesh objectivity resulting from two of the most widely used localization limiters, viz. the crack band model (CBM) and rate dependent damage (RDD), for dynamic fracture problems.

A scalar continuum damage model is implemented in conjunction with both CBM and RD. The material properties used correspond to PMMA, an archetypical isotropic brittle material. Linear softening is assumed for damage evolution. For CBM, the mesh objectivity is achieved by modifying the slope of the post-peak branch, i.e. the softening modulus, for changing mesh size. For CBM based analyses, the damage evolution is rate independent. For RDD, the damage initiation and evolution is made dependent on the effective strain rate, such that the strength and fracture energy increase for higher rates, but keeping the softening modulus unchanged. Both CBM and RDD are evaluated at various loading rates, so as to achieve fracture predictions with varying degrees of crack branching, ranging from localized to fully diffused/branched. For each loading rate, results are compared for three different mesh sizes, and include the leading crack velocity, the fracture geometry, energy dissipation, and load displacement curves.

2. Results

The analyses employing CBM (i.e., rescaling of the softening modulus with changing mesh size) reveal that CBM yields mesh independent results only at lower strain rates for localized and slightly branched dynamic cracks. In fact, it a must for these cases. This is shown in Fig. 1a-c, where the variation in various predictions is found to be within 10%. When the degree of branching increases with increased loading rates, the results become increasingly mesh size dependent, as shown in Fig. 1d-f. It is found that for localized cracks, the energy dissipation scales linearly with the mesh size, which is an essential ingredient for the CBM regularization to work. On the other hand, for branched and diffused fractures, the energy dissipation scales with the square of the mesh size, which makes CBM inapplicable. Interestingly, for these cases, a "do-nothing" strategy (i.e. not scaling the softening modulus) yields mesh size independent results.

For the analyses employing RDD, the opposite was found to be true. Results were highly mesh dependent for lower loading rates involving localized cracks (fracture pattern is the same but not the crack velocity or energy dissipation). But for higher loading rates involving increasingly branched cracks, the results become perfectly mesh independent. A distinguishing feature of RDD is the development of thick damage bands, whose width is greater than the mesh size. This damage band width is found to be mesh size independent when other results are mesh independent. The RDD works at higher rates because of its implicit introduction of a lengthscale to the model, which is defined as *2mc/E*, where *m* is a material constant related to the rate sensitivity, c is the elastic wave speed, and E is the modulus. This lengthscale is different from that employed by CBM, which essentially equals the mesh size. It can be seen that the RDD works when the damage band width is greater than the intrinsic lengthscale, and is because it helps retain a real wave speed, which does not occur at lower rates.

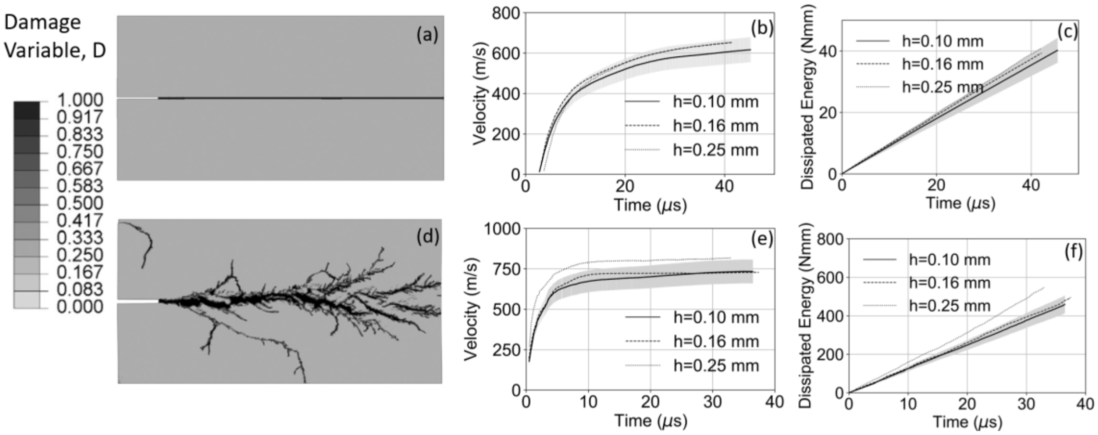

Fig 1- Crack geometry, leading crack velocity, and dissipated energy prediction by the crack band model at lower (a, b, c) and higher strain rate (d, e, f)

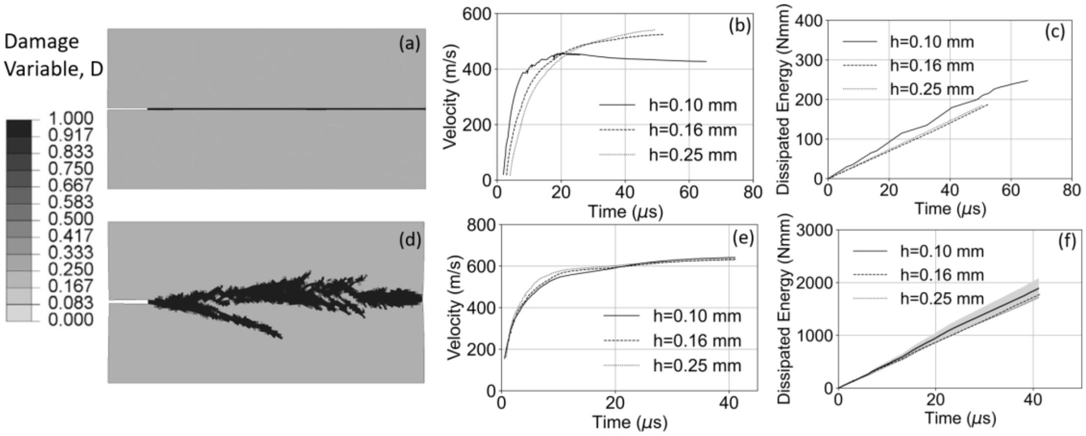

Fig 2- Crack geometry, leading crack velocity, and dissipated energy prediction by the rate dependent damage model at lower (a, b, c) and higher strain rate (d, e, f)

3. Conclusions

Thus, we show here that neither the CBM nor RDD are mesh objective for all loadcases in dynamic fracture problems. CBM remains applicable (and is a must) below a certain strain rate where a localized or a slightly branched crack is expected. However, above that strain rate, if diffused or highly branched cracking is expected, the CBM approach should in fact be bypassed, and replaced with the do nothing approach. This can be done if the damage model is rate independent. On the other hand the RDD should be employed only for high strain rates. These issues can be circumvented by using a fixed mesh size and avoided by using a gradient-based damage model, or adapting nonlocality of strain or damage.

Acknowledgements

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