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DEVELOPMENT OF AN AUTOMATED REMESHING SIMULATION FRAMEWORK FOR QUASI-STATIC DELAMINATION PROPAGATION USING THE VIRTUAL CRACK CLOSURE TECHNIQUE

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ABSTRACT

Delamination is a critical failure mechanism in composite laminates leading to stress redistribution, reducing stiffness and residual strength, and posing serious risks to the component's structural integrity [1,2]. The ability to predict its propagation under both quasi-static and cyclic loading is essential to ensure the safety and reliability of these materials in safety critical applications. Numerical techniques like the Cohesive Zone Model (CZM) [3] and the Virtual Crack Closure Technique (VCCT) [4] are widely used for delamination modeling, but present significant limitations. Between the two, the CZM is more robust, but it requires difficult-to-obtain traction-separation laws as input and can become computationally expensive. The VCCT is based on Linear Elastic Fracture Mechanics and the required input values can be obtained experimentally. This technique is highly sensitive to front-mesh alignment and prone to noise near discontinuities caused by non-conformal meshes. For large delaminations and curved fronts, often encountered in structural applications, this becomes a critical issue, leading to an over-estimation of propagation.

This work introduces an automated numerical framework for quasi-static delamination propagation, addressing the limitations of the VCCT through an automated remeshing algorithm. The framework is implemented using Abaqus CAE and Python scripting. Multiple simulations are sequentially launched and their results automatically extracted by the code, building onto the work by Martulli and Bernasconi [5]. Between simulations, the delamination front is advanced along the local normal direction by imposing that the Strain Energy Release Rate (SERR) equals the material's fracture toughness. Pointwise Taylor expansion series are solved for the advancement length. Equations 1 and 2 show the use of 1st order expansion, but both 1st and 2nd order were considered.

$$G_{C,0} = G_0 + \left.\frac{\delta G}{\delta a}\right|_0 da + \left.\frac{\delta G}{\delta P}\right|_0 dP \tag{1}$$

$$\Delta a = \left(G_{C,0} - G_0 - \left.\frac{\delta G}{\delta P}\right|_0 \Delta P\right)\left(\left.\frac{\delta G}{\delta a}\right|_0\right)^{-1} \tag{2}$$

The delamination front is subsequently smoothed using a triangular moving window to eliminate sharp corners and resampled with a modified Akima interpolating function to achieve a uniformly spaced mesh. Finally, the remeshing algorithm reintroduces the updated delamination front into the Finite Element (FE) model. The remeshing algorithm effectively reduced noise in the SERR calculations, ensuring a smooth and stable propagation throughout the simulations (Figure 1).

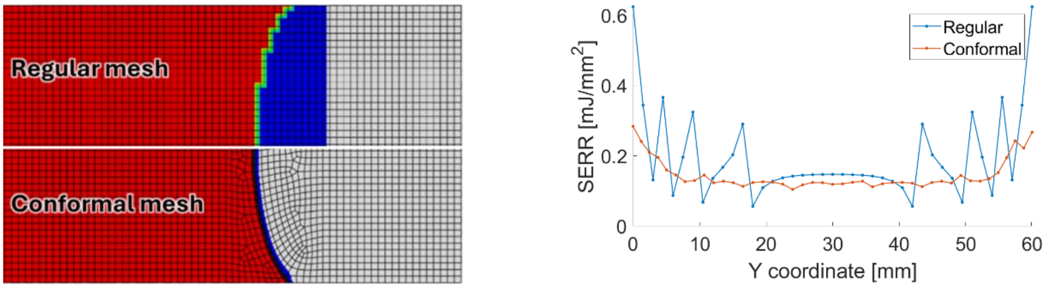

Figure 1: SERR calculated with regular and conformal meshes

This framework was assessed on 3D FE models of Double Cantilever Beam (DCB), End-Notched Flexure (ENF), and Mixed Mode Bending (MMB) tests to study the framework behaviour on various degrees of mode mixity. A thorough sensitivity analysis was carried out to evaluate the impact of variables such as mesh size, maximum propagation length, and front smoothing parameters on accuracy, stability, and computational efficiency of the simulations. The analysis revealed critical thresholds for mesh density and smoothing factor to achieve optimal results in the SERR calculations while maintaining computational cost within practical limits. The results obtained from these analyses demonstrate the framework's accuracy in simulating quasi-static delamination propagation.

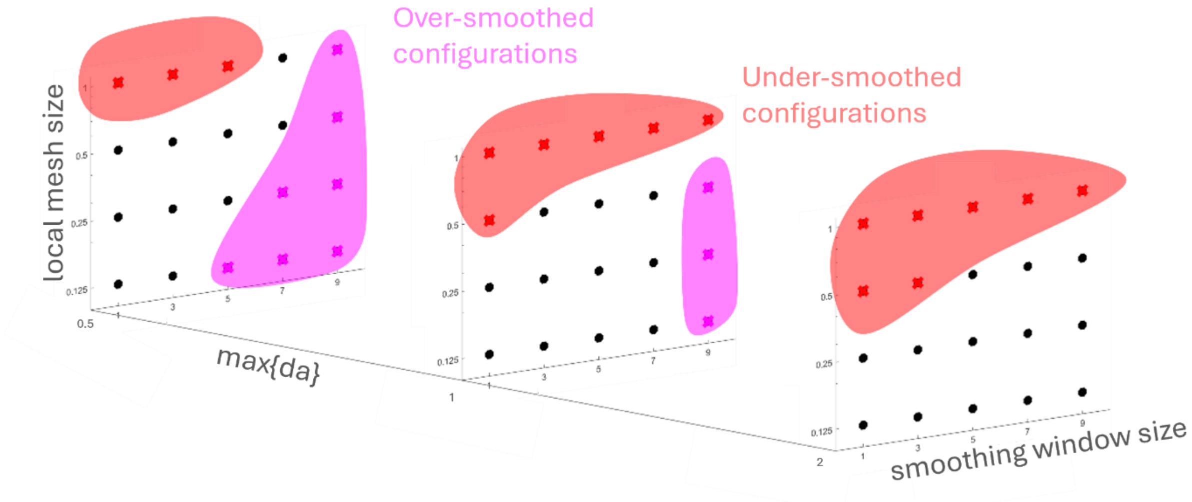

Figure 2: Sensitivity analysis: stability on DCB

Building on these results, the framework's capability may be further expanded to more complex geometries and loading conditions. Future work aims to incorporate fatigue propagation laws, such as Paris-like models, to enable simulations of delamination under cyclic loading. Additionally, expanding the procedural remeshing algorithm to handle non-planar and penny-shaped delamination fronts will further enhance the versatility of the framework.

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