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Dynamic Fracture of Ductile Materials

Use of damage-based mesh adaptivity to predict ductile failure in blast-loaded aluminium plates

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Abstract

This study uses experimental data to evaluate the capabilities of a numerical model in EUROPLEXUS (EPX) to predict ductile failure in thin aluminium plates subjected to blast loading. The loading was generated using a shock tube facility designed to expose structures to extreme loading conditions. The plates had an exposed area of 0.3 m × 0.3 m and experienced large deformations including failure at the supports at the largest blast intensities. Pressure measurements were synchronized with two high-speed cameras in a stereoscopic setup to capture the dynamic response using three-dimensional digital image correlation. The experimental results were used as basis for comparison to finite element (FE) simulations in EPX. Failure was introduced in the FE simulations using element erosion. Adaptive mesh refinement was applied in an attempt to describe the crack propagation observed in the experiments. The mesh refinement was driven by the damage parameter in the material model and occurred at user-defined levels. The numerical results were in good agreement with the experimental data, and were able to predict both the global deformation and the crack growth in the plates with good accuracy. The numerical model was also used to investigate the influence of FSI effects on the dynamic response of the plates. It was found that FSI may significantly mitigate the blast load acting on the plate, resulting in reduced deformations.

Peer-review under responsibility of the scientific committee of the International Conference on Dynamic Fracture of Ductile Materials

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1. Introduction

Advanced numerical techniques are often required for sufficient insight when designing protective structures in blast environments. However, before such methods can be used it is essential to evaluate their performance in terms of robustness, reliability and effectiveness in predicting both the loading and the dynamic response. Experimental validation is often preferred as it represents the actual physics in the problem, and controlled small-scale experiments could be used to evaluate current computational methods [1][2]. When considering ductile materials, these loading conditions may involve large inelastic strains, high strain rates, temperature softening and failure.

Plated structures are frequently used in blast-resistant design and these structures are typically made with geometries that closely resemble shell structures, where one of the dimensions (typically the thickness) is significantly smaller than the others. Such structures often require a fine mesh size to represent localization of damage and crack growth. This is due to the discrete nature of the finite element (FE) method which makes the failure mesh-sensitive since element erosion cannot occur in less than one element size. The mesh size will therefore influence both the localization of damage and the crack propagation, and it is necessary to use a sufficiently refined mesh in the vicinity of the crack. A refined mesh will also allow for element erosion without too much loss of mass in the plate. However, since the increase in CPU cost may be significant when uniformly refining the mesh, it is desirable to evaluate the capabilities of adaptive mesh refinement (AMR) in predicting ductile failure in blast-loaded plates. Recent advancements in the FE code EUROPLEXUS (EPX) [3] allow for AMR based on a user-defined threshold criterion, which make it convenient to relate the AMR to the damage evolution in the plate. AMR may also be of importance in other practical applications and in fluid-structure interaction (FSI) simulations, because a finer mesh is often needed in the fluid compared to that in the structure to obtain an accurate pressure field at the fluid-structure interface.

This motivated studies on the performance of damage-based AMR to predict failure of coarsely meshed shell structures exposed to blast loading. A series of shock tube experiments were therefore performed to establish a basis of comparison to the numerical simulations. The shock tube technique is favourable compared to airblast tests using high-explosives since it produces a controlled and repeatable blast loading in laboratory environments [4], and avoids the complexity of ground reflections, light flashes, fireballs and other potential challenges related to HE detonations. Piezoelectric pressure sensors were employed for pressure recordings, and these measurements were synchronized with two high-speed cameras in a stereoscopic setup to capture the dynamic response using three-dimensional digital image correlation (3D-DIC). Synchronization of the pressure measurements with the dynamic response enabled a thorough assessment of the dynamic failure process and of potential FSI effects.

The numerical simulations of the blast-loaded plates were performed in the explicit FE code EPX [3]. The objective of this study was (1) to look into the capabilities of damage-based AMR to predict ductile failure in blast-loaded plates and (2) to investigate the influence of FSI effects on the response of thin aluminium plates in blast environments. Material tests were also performed to determine the material behaviour at large plastic strains and to identify the parameter in an energy-based failure criterion.

2. Experimental work

2.1. Material tests

The 0.8-mm thick aluminium plates were manufactured from low-strength, strain-hardened and cold-rolled sheets of the alloy EN AW 1050-H14 produced by Hindalco Industries Ltd. This is 99.5 % pure aluminium subjected to annealing before being work hardened by rolling. The nominal yield stress and ultimate tensile strengths were given by the manufacturer to be 110 MPa and 116 MPa, respectively.

Tensile tests on dog-bone specimens from the base material were performed to determine the quasi-static behaviour of the material, while the dynamic material properties were taken from the literature [1][2]. The tests were performed in a Zwick/Roell Z030 testing machine at a constant deformation rate of 2.1 mm/min. This corresponds