The Fourth Sandia Fracture Challenge – Predicting Puncture in a Metal Structure

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Abstract

The fourth Sandia Fracture Challenge (SFC4) investigated the puncture of aluminum structures through comparing various computational predictions to physical experiments. Five teams, internal to Sandia National Laboratories, submitted predictions with mixed success. Qualitatively, many teams were able to predict the deformation and failure modes at the critical velocity for puncture, but the extent of damage was underpredicted by all. Quantitatively, predictions for critical velocity varied widely, though were in the correct order of magnitude. The SFC4 highlighted difficulties in modeling damage and fracture in shear-dominated loading cases.

1. Introduction

Benchmark problems in mechanics enable comparison of simulations that utilize different computational approaches against experimental observations of single type of event. The Sandia Fracture Challenge [1-3] has been a series of international benchmark problems investigating ductile fracture. Most recently, the fourth Sandia Fracture Challenge was hosted for analysis teams internal to Sandia National Laboratories in the area of intermediate-rate puncture of aluminum structures. Unlike prior challenges open to an international community, SFC4 was internal to one organization, allowing for some interaction between the analysts and experimentalists during development; the analysis teams were first presented the overall Challenge problem and negotiated calibration experiments based on time and budget constraints.

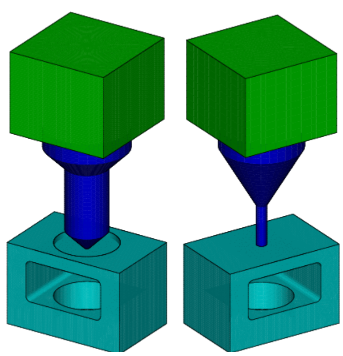

Fig. 1 – Schematic of the Al structures and the conical and cylindrical punches.

SFC4 considered three scenarios of aluminum structures being punctured by either a conical punch or a cylindrical punch, driven by a drop-table. In the blind phase of SFC4, analysts predicted the puncture of Al 2024-T351 structures with each punch as shown in Figure 1. A reinvestigation phase, after the initial comparison of experiments and predictions of the Al 2024 punctures, included improved predictions of the initial scenarios and predictions of puncture of an Al 6061-T6 structure with the conical punch; one purpose of the reinvestigation was to compare the predictions of puncture for the same geometry but different materials. Five teams, using different modeling approaches, submitted at least partial predictions to the first blind round, and three teams attempted the reinvestigation with two final submissions.

2. Results

The initial calibration data covered strain rates spanning 0.0001/s to 2000/s tensile-dominated test configurations. However, the nature of fractures in the challenge problems were shear-dominated plugging and petaling. Hence, some teams augmented with data from the literature. During reinvestigation, shear-dominated, and Charpy impact calibration tests were added; however, the teams did not fully utilize all available data due to the nontrivial nature of incorporating them. The submission from the five teams had mixed success. Qualitative comparisons can be made in terms

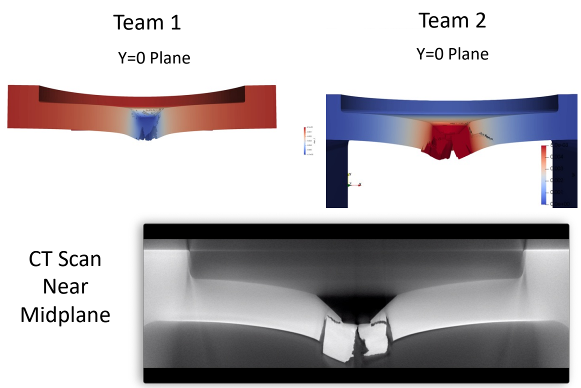

Fig. 2 – Comparison of mid-plane outputs from simulations from two teams to a post-test computed tomography (CT) scan

of deformation and failure modes: one team successfully predicted plug formation for the cylindrical punch case in Al 2024-T351; two teams successfully predicted local petaling and plugging for the conical punch case in Al 2024-T351 as shown in Figure 2; and one team successfully predicted local petaling and plugging for the conical punch case in Al 6061-T6. For many of these teams, the deformation and failure modes at the critical puncture velocity (i.e. the velocity to induce a through-thickness crack) were correct, but the extent of damage was underpredicted. Velocity and local displacement from Digital Image Correlation were captured from the experiments are quantities of interest, but critical puncture velocity was the primary of them, as displacements scale with critical puncture velocity. The critical puncture velocity predictions varied widely across all teams, both above and below the measured experiment values. All predictions were in the correct order of magnitude, and the best predictions achieved approximately 20-30% error on the initial prediction though one team improved their prediction with the reinvestigation to 3% error. While the teams straddled the experimental measurement for the cylindrical punch case (2024-T351), all submissions under-predicted the critical puncture velocity for conical punch case (2024-T351 and 6061-T6). The relatively high level of error in the initial submissions, especially compared to the best-performing predictions to previous SFCs, demonstrates that the fracture models used were less mature for shear-dominant applications than for positive-triaxiality cases.

3. Conclusions

The objective of the SFC4 was to exercise failure modeling capabilities and workflows on realistic puncture problems, specifically here a shear-dominated loading with two geometries and two grades of aluminum, 2024-T351 and 6061-T6, to rigorously assess predictive simulation capabilities. Relative to experiments, the SFC4 highlighted need for efficient testing of shear-dominant geometries that can be widely utilized in material model workflows. Relative to simulations, the SFC4 highlighted the need for investment in improved damage and failure models that can capture anisotropic failure physics and shear-dominant loadings.

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