Preface to the special volume on the second Sandia Fracture Challenge

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Ductile failure of structural metals is a pervasive issue for applications such as automotive manufacturing, transportation infrastructures, munitions and armor, and energy generation. Experimental investigation of all relevant failure scenarios is intractable, requiring reliance on computational models. Our confidence in model predictions rests on unbiased assessments of the entire predictive capability, including the mathematical formulation, numerical implementation, calibration, and execution. The Sandia Fracture Challenge (SFC) is one such effort to evaluate blind predictive capabilities of ductile failure of an unfamiliar geometry, under practical engineering constraints including limited experimental evidence and computational time. This Special Volume describes the second installment of the SFC, considering ductile failure of a rate-sensitive titanium alloy under quasi-static and moderate-rate dynamic loading.

This second SFC was preceded by several internal assessments at Sandia National Laboratories, documented in a 2011 report [Report number SAND2011-6801], and by the first SFC issued to the external mechanics community in 2012, reported in a previous Special Volume of the International Journal of Fracture [Vol. 186, Nos. 1–2, March/April 2014]. The first

SFC asked for blind computational predictions of ductile failure in a mechanically complex but geometrically simple compact-tension-like specimen with holes of various sizes around a blunt notch. An unexpected result from the experimental testing was the appearance of two different crack paths, observed in three independent testing labs and ultimately attributed to geometric variations. Some of the key findings from the first SFC were the following: (1) most teams could predict elasticity, yield, and hardening; (2) the teams had no consensus on failure model or numerical implementation; (3) the provided standard calibration data (tensile and fracture toughness tests) were insufficient to predict the conditions of crack initiation, particularly for shear-dominated failure; and, (4) no team accounted for geometric tolerance uncertainties.

For the second SFC, we wanted to explore a new area of mechanics, material rate sensitivity and thermomechanical coupling, while trying to improve upon lessons we learned from the first SFC. Volunteer teams were asked to predict the crack path and quantities of interest associated with the load-displacement curve for two different loading rates of a new unfamiliar geometry in a rate-sensitive titanium alloy, Ti-6Al-4V. The teams were given extensive geometric measurements of the Challenge geometry specimens so they could explore geometric variability and both tensile and shear-dominated loading data of the base material at the loading rates of interest. The Challenge was issued to the international mechanics community through iMechanica.org and through direct e-mail to known groups

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with potential interest. The volunteer teams were given five months to return their predictions.

This Special Volume begins with a lead article that provides a comprehensive record of the outcome of the second SFC. The lead article details the Challenge, the experimental calibration data provided, the blind predictions along with a brief description of their salient methodologies, a comparison to the experimental results obtained for the challenge tests, and a discussion of sources of discrepancy and areas for improvement. Supplementary information, including videos of the ductile failure for the quasi-static and moderate dynamic loading rates, is available from the journal's website. Perhaps the most important parts of this lead article are the comparison of the state-of-the-art computational methods and the assessment of the predictive capabilities. This lead article was made possible by the contributions from its 54 co-authors from 17 institutions that compose the computationalists and experimentalists that participated in this SFC. The writing of the lead article was facilitated by an NSF-sponsored workshop on the SFC, held at University of Texas at Austin on March 2–3, 2015, where participants gathered to discuss the experimental observations and compare the modeling efforts. Several months of e-mail correspondence to organize the writing of each section and to discuss details of the SFC led to the lead article that represents a unified assessment of the SFC. In addition to the lead article, this Special Volume includes individual articles from eight of the fourteen participating prediction teams; all teams were offered the opportunity to submit an article for this Special Issue. All articles included in this Special Volume were subject to the customary peer review process of the Journal.

The SFC is a unique endeavor that could not have been possible without numerous people who supported it. The 50+ Challenge participants from 17 institutions who offered predictions did so at their own expense, without remuneration, coming together to test and compare their methods. These volunteers represent an international sampling of reputable developers and practitioners in computational mechanics. These participants were asked to solve a very difficult problem with limited data and time, many working on their own time to meet the prediction deadline and afterwards for the post-blind assessment and compilation of the work in this Special Volume. Their commitment to learning and to leading the mechanics community in self-evaluation

is both humbling and inspiring. For that, we offer our sincere gratitude.

Several researchers made the experimental observations for the SFC. In Sandia's Structural Mechanics Lab, Mrs. Jhana Gearhart, Dr. Mathew Ingraham, Mr. Thomas Bosiljevec, Dr. Edmundo Corona, Mr. John Laing, Mr. Darren Pendley, Mr. Artis Jackson, and Dr. Charlotte Kramer performed all the base material tensile and shear testing, measured geometries of all specimens, and performed the bulk of the Challenge geometry testing. In Sandia's Material Mechanics Lab, Mr. Thomas Crenshaw, Mr. Bradley Salzbrenner, and Dr. Brad Boyce led the specimen fabrication and performed corroboration tests of the Challenge geometry. Prof. K. Ravi-Chandar and Dr. Andrew Gross at the University of Texas at Austin performed post-blind experimental testing of the Challenge geometry with Digital Image Correlation.

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The SFC represents a snapshot of the state-of-practice for ductile failure modeling. However, in isolation the SFC cannot delineate between methods that are in differing states of maturity. Emerging methods, such as multiscale models, that incorporate a more physical representation of the deformation and fracture process may lack the maturity in implementation to fare well in any one challenge. Only with a progression of SFC challenges (this being the second installment) can we

begin to see trends in successful methodologies and emerging capabilities. In that regard, it is our intention for the SFC to be an enduring effort: researchers coming together as a mechanics community to evaluate the state-of-the-art, identifying and documenting our strengths and weaknesses so that we can ultimately improve how we predict ductile failure. Each iteration of the SFC is designed to explore new aspects of ductile fracture, while building upon prior lessons-learned. Clearly, the SFC has already demonstrated a need for improvement in many aspects of our predictive capability, from the fundamental, such as what material calibration tests and measurements need to be made and how do we model boundary conditions, to the far-reaching, such as how to capture triaxiality

dependence of the material failure and how to quantify the uncertainty of our constitutive model forms. In the spirit of continuing our work, we would like to announce the third SFC, tentatively scheduled to be issued on iMechanica.org in Fall 2016. If you would like to receive an e-mail notification, please contact us: slkrame@sandia.gov and blboyce@sandia.gov.

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