Deformation Criterion and Residual Life of Low Carbon Structural Steel Subjected to Blast Loading

W. Visser¹, Y. Sun², O. Gregory², H. Ghonem¹
¹Department of Mechanical Engineering, ²Department of Chemical Engineering, University of Rhode Island, Kingston, RI, 02881, USA

Abstract

Effects of impact loading on microstructure of low carbon steel have been studied. Shock loading tests have been carried out on specimens using a gas gun with projectile velocities up to 500 m/sec. A Johnson-Cook constitutive model was employed to simulate the material behavior and obtain the particle velocity at the impact surface. This was coupled with an analytical approach to determine the twin volume fraction as a function of impact load. Tensile tests of post-impact specimens revealed an increase in yield and UTS, and a decrease in the hardening and strain energy as a function of impact load. Serrated flow characteristics of stress-strain curves suggest microstructure instability and twinning interactions.

Relevance

An integrated multidisciplinary program to develop a fundamental understanding of the mechanisms of deformation response of structural steel subjected to blast loading. Such understanding will be used to (1) identify the force limit for blast mitigation designs suitable for resistance to single and multiple blasts; 2) provide the material dynamic deformation flow characteristics required for the microstructure development of a blast resistant reinforcing metal phase.

Accomplishments Through Current Year

1) A series of blast experiments was carried out to establish a blast deformation criterion for low carbon structural steel in terms of twin volume fraction (TVF) as a function of blast load.
2) A combined numerical/analytical model capable of determining TVF as a function of impact stress has been developed.
3) Post-blast residual life has been measured experimentally and correlated with TVF as a function of impact stress.

Future Work

Design and construct a new gas gun capable of extending the impact load experiments to a range beyond that of conventional TNT blast energy in order to examine deformation mechanisms and residual life corresponding to single and multiple severe blast loading of structural steel and cast iron materials as well as new structural alloys capable of absorbing high energy impact loads.

Technical Approach

•Objective: Establish a quantitative deformation criterion for blast loaded low carbon steel in terms of twin volume fraction and use the criterion to assess the residual life as a function of impact loading.

•Approach: A physically based deformation criterion developed by integrating three studies: i) Experimental program to determine twin volume fraction as a function of impact load, ii- A mechanistic based deformation criterion associated with high loading rates, and, iii-An experimental methodology to determine post blast residual life in terms of ductility reduction and available fracture energy.

•Post-Impact Residual Life

•Post-Impact Microstructure (Twin Formation)

•Johnson-Cook Numerical Model

•Experimental Plate Impacts

•Analytical Model

Conservation of Mass & Momentum Equations

Volume Fraction of Twins and Twin Growth Rate

\[
\alpha = \alpha_0 \left[ 1 + \int \left( \frac{\tau - \tau_{tw,0}}{\tau_{tw,1} - \tau_{tw,0}} \right) \right]
\]

\[
\rho_v dt v = \rho_{f,0} \left[ 1 + \int \left( \frac{\tau - \tau_{tw,0}}{\tau_{tw,1} - \tau_{tw,0}} \right) \right]
\]

\[
\rho_v \left( \mathbf{u} \cdot \nabla \right) \mathbf{u} = -\nabla \mathbf{p} + \frac{2}{3} \rho_{f,0} \mathbf{e} + \rho_{f,0} \mathbf{e} \nabla \tau + \frac{2}{3} \rho_{f,0} \mathbf{e} \nabla \tau
\]

\[
\rho_v \left( \mathbf{u} \cdot \nabla \right) \mathbf{u} = -\nabla \mathbf{p} + \frac{2}{3} \rho_{f,0} \mathbf{e} + \rho_{f,0} \mathbf{e} \nabla \tau + \frac{2}{3} \rho_{f,0} \mathbf{e} \nabla \tau
\]

Post-Impact yield & UTS increase with impact stress

Type-C Serrations in post-Impact tests: Instability due to twin-dissolution interactions

Post-impact energy available up to the onset of the UTS

Residual strain energy decreases with TVF

Future Work

W. Visser, Y. Sun, O. Gregory, and H. Ghonem, Deformation Criterion for Blast Loading in Low Carbon Steel, Int. J. Material Science and Eng., December 2010

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-D0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.