Constitutive Characterization of Metals for Dynamic Plastic Deformation with Shear-Compression Specimens

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ABSTRACT

Constitutive models strive to capture the fundamental relationship between how independent variables such as stress, strain rate, strain, stress-state and temperature independently affect the constitutive behavior of materials. Robust material models capturing the controlling physics of high-rate material response are required for large scale FE simulations of many complex engineering systems and processes. These include: (i) automotive crashworthiness, (ii) aerospace impacts, including foreign object damage such as during bird ingestion in jet engines, blade containment in engines, and meteorite impact on satellites, (iii) dynamic structural loadings such as that occurring during an earthquake, (iv) high-rate manufacturing processes including high-rate forging, machining, shot-peening, shock welding, and laser surface processing, (v) cavitation and particulate erosion in turbines and marine propulsion, and (vi) defense applications including projectile/armor and explosive or propellant/material interactions.

In this attempt to develop predictive constitutive models, the basic information comes from well-designed and instrumented high-strain-rate experiments. This talk will focus on the potential of so-called **S**hear-**C**ompression **S**pecimen (SCS) as a new experimental tool and the results of a validation study on 1018 cold rolled steel as a model material will be discussed. The SCS technique enables the seamless characterization of the constitutive behavior of materials over a large range of strain rates from $\dot{\varepsilon} = 10^{-3}$ to 5×10^{4} s^{-1} and allows investigating the dynamic large strain behavior of materials at strain rates an order of magnitude greater than that achievable by classical cylindrical specimens. The comparison of results with those obtained by cylindrical specimens shows an excellent correlation up to strain rates of 10^4 s^{-1}. The study also shows a marked strain rate sensitivity of the steel at rates exceeding 100 s^{-1}. With increasing strain rate, the apparent average strain hardening of the material decreases and becomes negative at rates exceeding 5,000 s^{-1}. This observation corroborates recent results obtained in torsion tests, while the strain softening was not clearly observed during dynamic compression of cylindrical specimens. The modifications to the Johnson-Cook constitutive model, which is commonly used in commercial FE codes, will also be discussed to represent the experimental data over a wide range of strain rates and by taking into account the role of adiabaticity in plastic deformation process.