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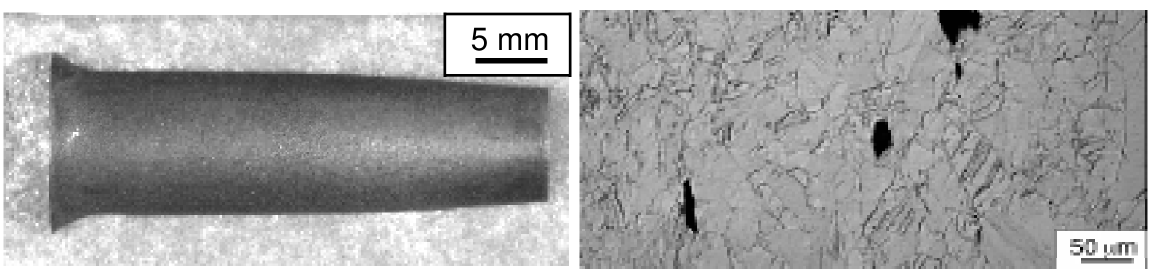
ABSTRACT - The use of Taylor cylinder impact tests to probe damage evolution processes is presented. Depending on the material, by overdriving Taylor impacts to velocities > 200 m/sec damage evolution processes can be examined as a function of the large stress, strain, and strain-rate gradient formed in a Taylor sample. The combined utility of using Taylor cylinder impact testing as a technique to validate both the constitutive and dynamic fracture response of a material is discussed.

INTRODUCTION: The Taylor cylinder impact test, named after G.I. Taylor who developed the test to screen materials for use in ballistic applications during WW II (Taylor [1948]), entails firing a solid cylinder rod of a material of interest, typically 7.5 to 12.5 mm in diameter by 25 to 40-mm in length, at high velocity against a massive and plastically rigid target. Taylor cylinder impact testing has previously been utilized to probe both the deformation responses of metals and alloys in the presence of large gradients of stress, strain, and strain-rate and as a means to validate constitutive models (Maudlin, et al. [1999]). This axi-symmetric integrated test provides a readily conducted experimental method by which to examine the large-strain high-strain-rate mechanical behavior of materials while simultaneously evaluating the accuracy and correct “physics” incorporation in constitutive models. As a matter of course, the final length, cylinder axial profile, and bottom footprint of the Taylor sample in addition to post-mortem microstructural analysis is compared with code simulations to validate the material constitutive model implemented in the application code. In the current study the utility of Taylor cylinders is expanded to examine damage evolution processes in Taylor samples overdriven to high shock pressures and plastic strains.

PROCEDURES, RESULTS AND DISCUSSION: Taylor tests were conducted at Los Alamos National Laboratory (LANL) where cylinders were launched using a caliber 30 He gas-driven gun. The Taylor cylinder facility at LANL utilizes a 30-caliber 0.300 inch [7.62 mm] smooth-bore launch tube and was designed to utilized high-pressure helium-gas propulsion of the cylinders rather than propellant drive. The HE-gas breech and valve design has been shown capable of reproducibly launching a 25 gram steel cylinder to 400 m/sec using 4500 psi He. The Taylor facility fires the cylinders into an evacuated thick-walled 304 stainless steel impact tank against a pneumatically-positioned AF1410 high-strength steel anvil (ground to a mirror surface finish). All testing is conducted under vacuum conditions (typically 10 torr). The velocity of the Taylor cylinders is measured using three laser beam timing circuits positioned between the muzzle of the barrel and the impact anvil so that the beams intersect the path of the Taylor cylinder in flight.

The damage evolution in copper was probed via the use of overdriven Cu Taylor cylinder testing. In the first case an annealed OFHC-purity copper cylinder was tested at 175 m/sec as shown in Figure 1a. Post-mortem sectioning and metallographic preparation of this cylinder following impact reveals the presence of ductile void damage within the central region of the Taylor cylinder approximately 3 mm from the impact interface (Figure 1b). Coupled constitutive and damage evolution modeling of these overdriven Taylor tests can be utilized to validate robust 3-D damage models of damage evolution in polycrystalline metals and alloys (Addessio, et al. [1993]). Increasing the velocity of impact can be utilized to examine non-homogeneous strain localization and damage evolution processes leading to strain / shear localization as shown in Figures 2a and 2b. These processes are also being probed using physically-based damage evolution models such as TEPLA (Addessio, et al. [1993]) coupled with the Mechanical Threshold Strength Model (Chen and Gray III [1996]).



(a) (b)

Fig. 1: Copper Taylor Cylinder impacted at 175 m/sec: a) profile of Cu Taylor cylinder, and b) ductile voids formed in center of overdriven Taylor sample.

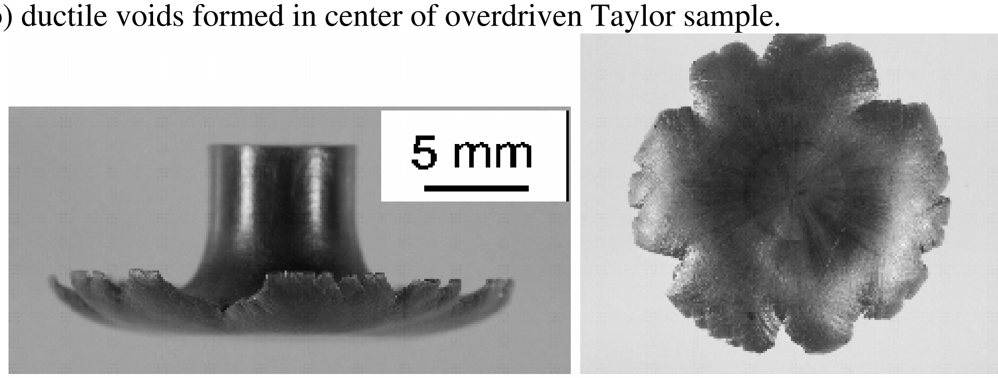
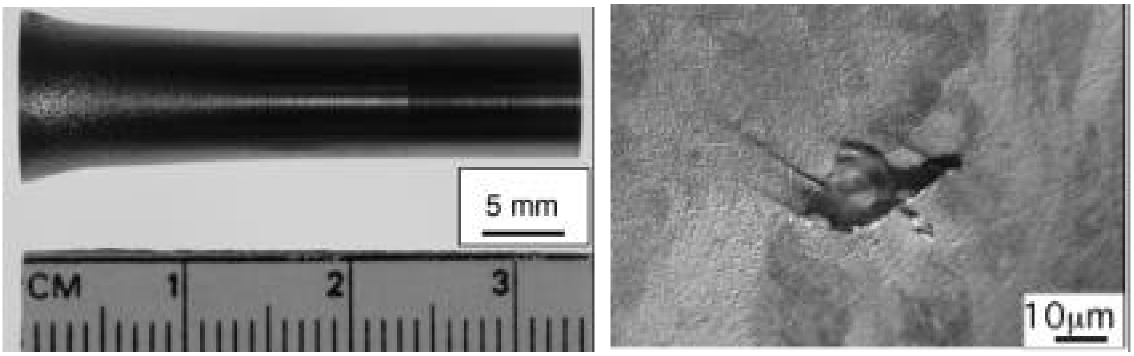


Fig. 2: Copper Taylor Cylinder impacted at 323 m/sec: a) side profile of Cu Taylor cylinder, and b) footprint of cylinder: note the large-strain plastic flow, strain localization, and tearing due to shear band formation.



(a) (b)

Fig. 3: Taylor cylinder of 1080 eutectoid steel impacted at 210 m/sec: a) cylinder profile, b) damage evolution in MnS stringers oriented orthogonally to the Taylor cylinder axis.

The damage evolution in a fully pearlitic 1080 euctectoid steel as a function of microstructural anisotropy, due to elongated MnS stringers, was also probed using Taylor cylinder tests. Decohesion of the MnS-matrix interface was found to result in anisotropic damage evolution in the central region of the Taylor impact cylinders(Gray III, et al. [2001]). Figure 3b shows cracks emanating from a MnS stringer, oriented transverse to the cylinder axis, in the central portion of the cylinder sample.

CONCLUSIONS: Damage evolution in metals can be probed using the gradient in stress, strain rate, and strain in Taylor cylinder tests conducted under carefully selected impact conditions. These post-test specimens can be compared with 3-D finite element simulations to validate the constitutive response in terms of elasto-plastic deformation and damage evolution.

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