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DUCTILE DAMAGE EVOLUTION AND EXPERIMENTAL SIMULATION UNDER HIGH RATES OF STRAIN IN 10100 COPPER

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ABSTRACT-The high strain-rate damage evolution and fracture behavior of half-hard 10100 Cu was investigated by experiments and computer simulations. Testing of uniaxial stress and axisymmetric notched bars of the Hancock-Mackenzie geometries were performed using a momentum trapped tensile split Hopkinson pressure bar. Specimens were tested to fracture and to several stages of incipient failure prior to fracture. Recovered specimens were sectioned and metallographically examined using image analysis and optical profilometry to quantify the resulting damage. The quantified damage is described by spatially resolved porosity distributions, spatially resolved volumetric number densities, and spatially resolved void size distributions. Concurrent to mechanical testing, explicit finite element simulations of the tensile split Hopkinson pressure bar experiments were performed to quantify the local stress-state and strain-state within the material and to determine the evolution of damage within the notch region. The compressive plasticity behavior of the material was fit to the mechanical threshold stress constitutive model, and was used in the simulations. The quantified damage was compared with damage model (TEPLA) predictions and used to refine model parameters and damage nucleation criteria. The simulation results also show that the maximum stress triaxiality in the specimens quickly enlarges after the onset of plastic flow or tensile instability to almost twice that of the Bridgman predicted levels.

INTRODUCTION:-High purity copper is a quintessential model material for studying the process of ductile fracture, which is characterized by the nucleation, growth and coalescence of voids. A common modeling formulation for describing the process of ductile fracture is the Gurson flow surface (Gurson [1977]). Axisymmetric round uniaxial stress and notch bars of the Hancock-Mackenzie geometries (Hancock and Mackenzie [1976]) are convenient experimental and computational geometries for studying and modeling ductile fracture. Needleman and Tvergaard have previously performed numerical simulations of ductile fracture using these geometries and the Gurson flow surface enhanced with normal distribution effective strain and hydrostatic stress based nucleation criteria and a porosity threshold rapid, with respect to strain, linear coalescence criteria (Needleman and Tvergaard [1984]). Becker *et al.*, also using these geometries and the Gurson flow surface, have performed a comparison between experimental tests and model predictions using initially porous iron, thereby significantly reducing the complicating effects of void nucleation (Becker et al. [1988]). They concluded that the shape of the predicted void distribution along the centerline of the notched specimens was not very dependent upon the two Gurson flow surface fitting parameters.

The purpose of this work is to compare and contrast Gurson flow surface damage model predictions of dynamic incipient failure experiments in high purity copper with experimental measurements of stress, strain, strain rate, and final two dimensional porosity, void size and volumetric number density distributions to better elucidate a procedure for obtaining unique damage model parameters.

PROCEDURES, RESULTS AND DISCUSSION: Half-hard Hitachi 10100 Cu was tested to full and incipient failure in uniaxial stress and the five Hancock-Mackenzie notch geometries. Full failure tests were performed under both quasi-static rates in an Instron and at dynamic strain rates in a momentum trapped tensile split Hopkinson pressure bar (TSHPB). The incipient tests were performed on the TSHPB. The plasticity constitutive behavior of the material was characterized using static and dynamic compression tests and fitted to the mechanical threshold stress (MTS) model. The tensile elasticity plasticity Los Alamos (TEPLA) damage model was used (Addessio and Johnson [August 1, 1993]). The starting TEPLA parameters used were the Johnson-Cook strain to failure parameters for 10100 Cu,

$$\varepsilon_p^f = D_1 + D_2 e^{D_3 \frac{-P}{\tau}}, \tag{1.1}$$

where $D_1 = 0.54$, $D_2 = 4.89$, and $D_3 = -3.03$. P is the mean stress and τ is the flow stress. The simulations were performed using the EPIC hydrocode.

Preliminary results are shown herein. Fig. 1 shows the dynamic stress strain response of three dynamic e-notch specimens tests. Load displacement data was converted to conventional engineering stress-strain data by assuming that the gage length is equivalent to notch radius and the gage diameter is equivalent to the specimen waist diameter. Fig. 2 is an optical micrograph of damage from test Cu7 in Fig. 1.

Simulations were performed of the entire TSHPB. The impact of the striker with the flange was also simulated. The threads at the sample-bar interface were not modeled; the sample was assumed to be rigidly fixed to the ends of the bars. Fig. 3 shows a calculation of final porosity for a simulation of the test Cu-8. Note that the specimen failed, but the simulation predicts a final porosity almost two orders of magnitude lower than the incipient test Cu-7. The simulation achieved the correct magnitude for the incident wave, but the fine structure of the predicted wave differed greatly from the experiment. The simulation, however, over predicted the

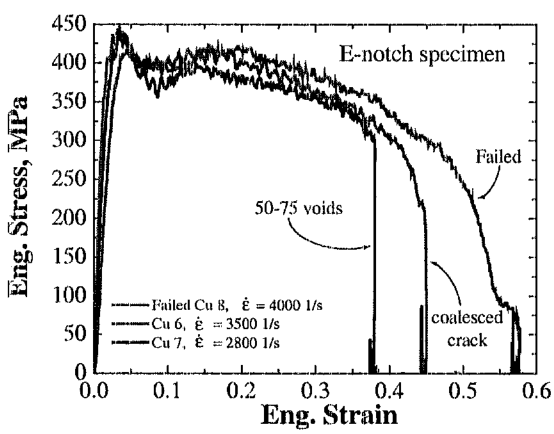

Figure 1: Eng. stress-strain for the e-notch tests.

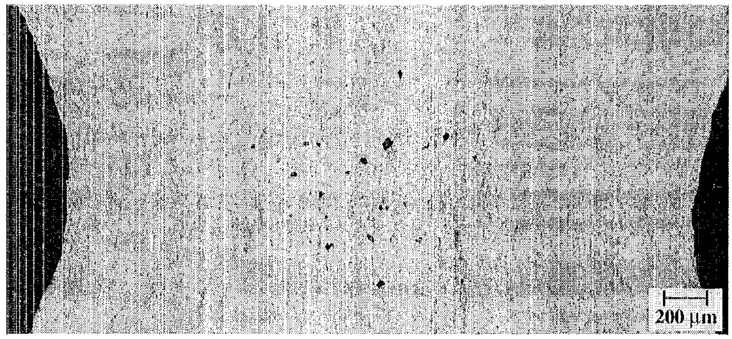

Figure 2: Optical microscopy of e-notch test Cu-7, showing the porosity maximum is around 5 %.

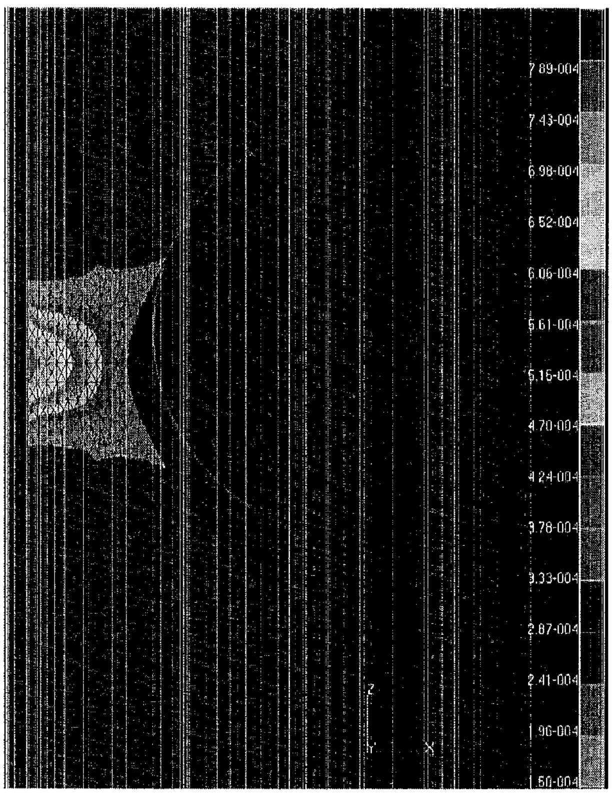

Figure 3: Model porosity predictions for a simulation of experiment Cu8.

transmitted wave by about a factor of two compared to the experiment, and did not get the shape of the transmitted stress pulse close to that of the experiment, consistent with the small amount of porosity shown in Fig. 3.

CONCLUSIONS:

Simulating TSHPB experiments of incipient and full failure provides a valuable tool for evaluating the integration of constitutive plasticity and damage models into hydrocodes. The suitability of modeling the striker impact is dubious because the incident wave is well characterized and fully elastic.

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