Development of Dynamic Punch test with DIC for Verification of Simulations with MAT224

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Abstract

A new dynamic punch test, that can be used to calibrate and validate LS-DYNA® simulations in which plasticity and failure models (like MAT224) are used, is introduced. In this test, a round disk specimen is attached to the transmitter bar of a compression Split Hopkinson Bar (SHB) apparatus, and a punch is attached to the incident bar of the SHB apparatus. During a test, a compression wave is introduced into the incident bar which causes the punch to penetrate into the specimen. The full-field deformation of the back surface of the specimen is measured during the test by using the Digital Image Correlation (DIC) technique. The specimen is supported with a slotted tubular adaptor that provides a stereographic view of the deforming back surface. The force measured in the transmitter bar of the SHB apparatus corresponds to the contact force between the punch and the specimen. Various states of stresses and different penetration modes (petaling, bending, plugging) can be obtained by changing the specimen thickness and punch geometry. Results from tests on specimens made of Ti-6Al-4V with various punch geometries show that the punch geometry greatly influences the punching force and the failure mode. The 3D DIC and the force measurements provide data that can be used to construct and validate deformation and failure models.

Background

The accuracy of numerical structural simulations depends on the quality of the constitutive relations that are used for modeling the materials. This is especially true when plastic deformation and failure are involved. The material parameters in the models are typically determined from the results of testing coupon material specimens at simple and well-defined loadings such as tension, compression and shear. Verification of the models and the computational techniques requires data from well-controlled and measured experiments in which components are loaded differently than in the tests that were used to determine the model parameters. The punch test is an example of such an experiment. In this experiment a punch is driven into a flat plate specimen. Different states of stress and consequently different failure modes can be obtained by using different combinations of punch geometry and specimen thickness. For example, mostly shear stresses will develop when a flat, large diameter punch penetrates a relatively thick specimen, or equal biaxial tension stresses exist in the middle of a thin specimen punched by a large diameter spherical punch. In a typical quasi-static test done in a hydraulic machine the force of the punch is measured by the load cell of the testing machine and the deformation is determined from the motion of the actuator. In the last few years Digital Image Correlation (DIC) has been incorporated into the the punch test to measure the deformation on the back surface of the deforming specimen. To validate or calibrate the material models, the experiment is simulated and the measured deformations and corresponding punch force are compared with the simulations. Until recently, however, the use of DIC in the punch test was limited to quasi-static experiments.

Many numerical simulations of practical applications involve high strain rate deformations. Examples are the simulation of containment during blade-off and disk failure in jet engines, crash of automobiles, and high speed forging and stamping. The simulation of these (and other applications) requires material models that are sensitive to the strain rate and valid over a wide range of strain rates including high rates. As at low strain rates, there is a need for a well-controlled experiment that can be used for the validation and calibration of the plasticity and failure models that are used in the simulation of applications at high strain rates. The current paper describes a new dynamic punch experiment that has been developed for this purpose. The development of the experiment was supported by the FAA in order to provide means for validating the new material model MAT224 that was recently introduced into LS-DYNA.

Experimental Setup

The experimental setup for the dynamic punch test is shown in Fig. 1(a), (b), and (c). A round disk specimen is attached to the transmitter bar of a compression Split Hopkinson Bar (SHB) apparatus, and a punch is attached to the incident bar of the SHB apparatus. The compression SHB apparatus consists of two, 50.8mm diameter, 1930.4mm long Ti-6Al-4V bars; and a 774.7mm long, 50.8mm diameter Ti-6Al-4V striker projectile. During a test, a compression wave with duration of 320 μs is introduced into the incident bar by shooting the incident bar at the incident bar. The compression wave causes the punch to penetrate into the specimen. The specimen is attached to the transmitter bar via slotted adapter that allows for stereographic view of the rear surface of the specimen. A synchronized pair of Photron SA1.1 cameras running at 100,000 frames per second record the rear surface deformation of the disk specimen. The full-field deformation of the back surface of the specimen is determined from the recorded images using the Digital Image Correlation (DIC) technique. The contact force between the punch and the specimen is determined from the wave recorded by the transmitter bar. Before a test, the punch is positioned such that it is in contact with the surface of the punch specimen and the contact surface is lubricated with grease. Different states of stresses and different types of failure can be obtained by using different combinations of specimen thickness and punch geometry. Three tungsten carbide punches, shown in Fig. 2, were used to punch 5 mm thick specimens made of Ti-6Al-4V. The flat punch shears the specimen and penetrates the specimen by plugging, while the hemispherical and the pointed punches penetrate by combinations of bending and petaling.

Results

Detailed results are shown from a dynamic punch test with a hemispherical punch. The impact velocity of the striker in this test is 17.6 m/s. Fig. 3 shows elastic waves recorded at the midpoint of the incident and transmitter bars. The incident wave amplitude is 400 kN, and the maximum contact force from the transmitter bar wave is 110 kN. Six images of the maximum principle strain from DIC measurements on the rear surface of the specimen are shown in Fig. 4. These images (a-f) correspond to the specimen immediately before loading, 40, 90, 130, 180, and 230 μs after load initiation, respectively. Fig. 4 (f) corresponds to the instant that fracture is observed. The DIC measurements can be used to generate a wide variety of data. Fig. 5, for example, shows the history of principal strains at the specimen center point as well as at the point where fracture is first observed. The principal strains at the center point are nearly the same, while those at the failure point are different. Such data and contact force history are valuable for calibration of fracture models and validation of simulations.

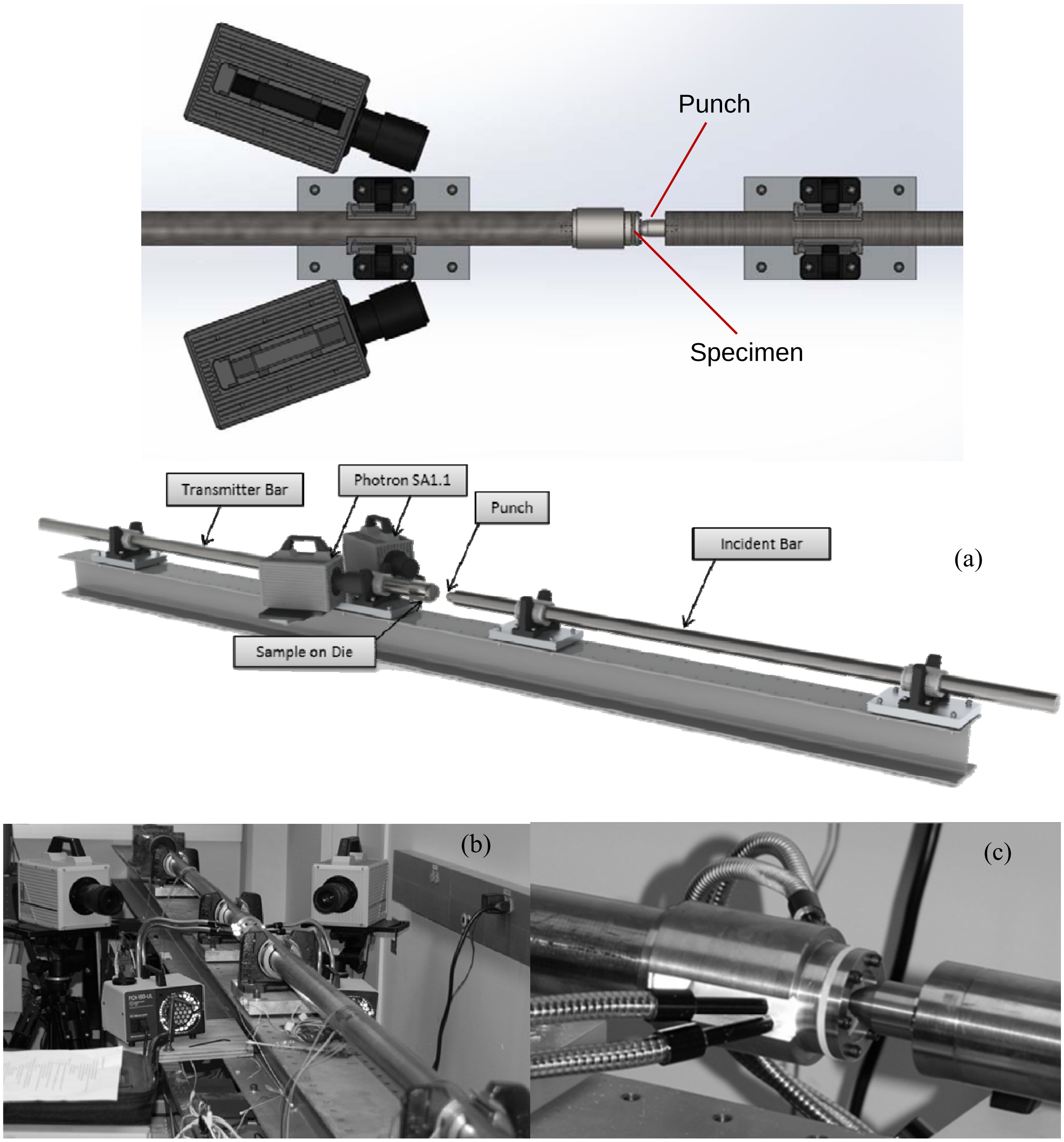

Figure 1: Experimental setup of the dynamic punch test.

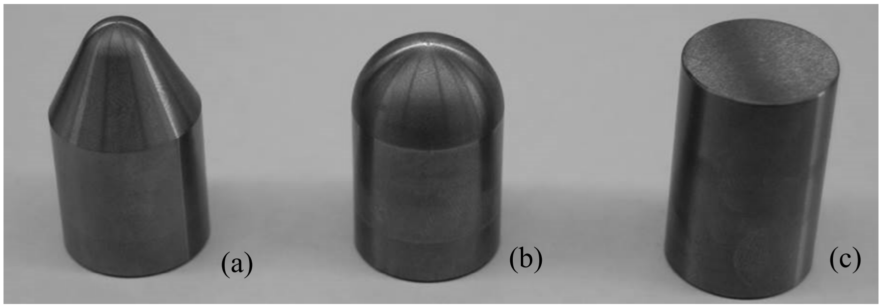

Figure 2: Punches

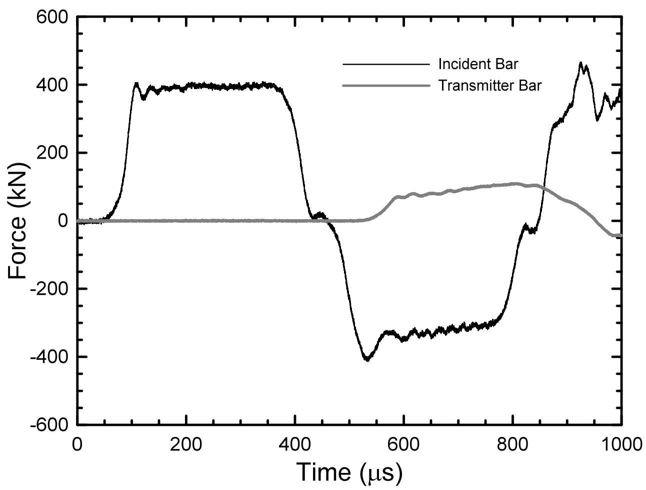

Figure 3: Waves recorded during a dynamic punch test with a hemisphirical punch.

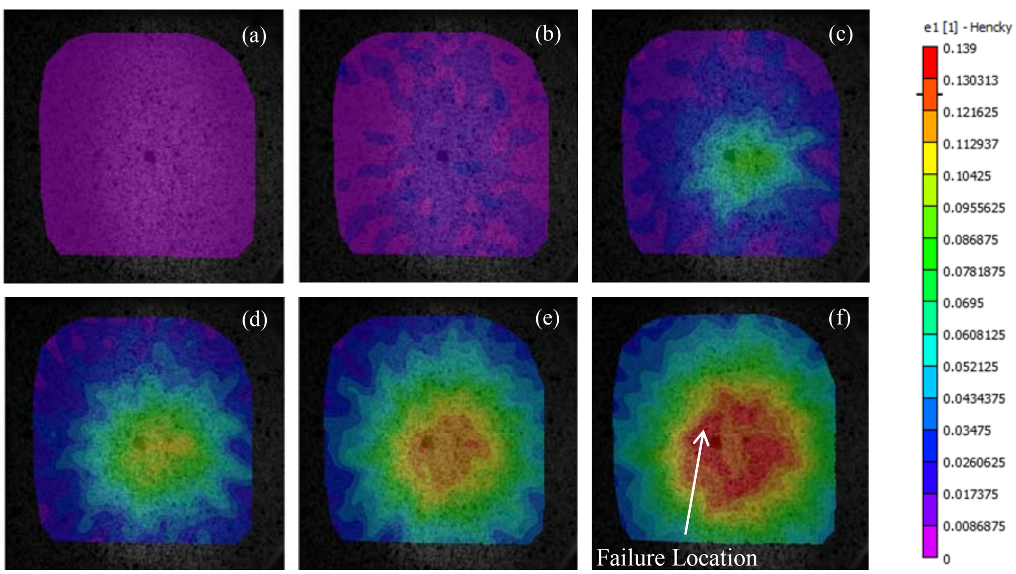

Figure 4: Maximum principal strain contours measured with 3D DIC:
(a) 0μs, (b) 40μs, (c) 90μs, (d) 120μs, (e) 180μs, (f) 230μs

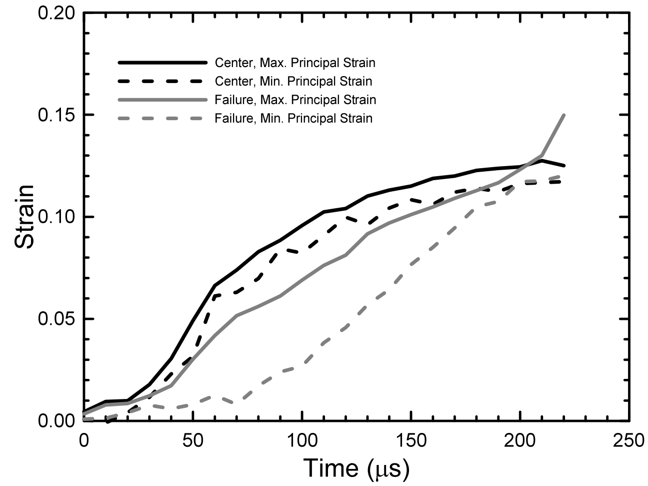

Figure 5: Maximum and minimum principle strains at the center and at the failure point.

Summary and Conclusions

A dynamic punch test in which the full-field deformation of the rear surface of the specimen is measured with DIC is introduced. A compression SHB apparatus is used with a round disc specimen mechanically mounted to the transmitter bar and a tungsten carbide punch attached to the incident bar. The punching action begins when a loading wave in the incident bar arrives at the punch. Two slots allow two high speed cameras to have a stereoscopic view of the rear surface of the specimen. Three-dimensional DIC uses images from these cameras for determine full field displacements and strains on the rear surface of the specimen. The results provide data that is useful in calibrating and validating constitutive models for plastic deformation and failure.

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