Recent Developments in Mechanical Characterization (Deformation and Failure) of Materials

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Abstract

Several new testing methods that have been recently developed for mechanical characterization (deformation and failure) of materials are presented. The data from these tests is used for the development and calibration of material models (constitutive relations) in LS-DYNA®. The first method involves the use of Digital Image Correlation (DIC) in tests that are used for generating data needed for using the MAT224 model. In these test specimens with different geometries are loaded and DIC is used for measuring full field strains and relative displacements. The second testing configuration is a shear test for sheet metals. The experiment is done by using a flat notched specimen in a tensile apparatus. The shear strain is measured by using DIC within and on the boundary of the notch. The third development is a high strain rate tensile testing technique for Kevlar cloth and Kevlar yarn in a tensile Split Hopkinson Bar (SHB) apparatus. The Kevlar cloth/yarn is attached to the bars by specially designed adaptors that keep the impedance constant. In addition to the traditional method of determining the specimen's stress and strain from the recorded waves in the bars the strain is also measured with DIC. The fourth development is an apparatus for testing at intermediate strain rates in compression. In this apparatus the specimen can be deformed at strain rates ranging from 20 s^{-1} to 200 s^{-1}. The apparatus is a combination of hydraulic actuator and a compression SHB. The stress in the specimen is determined from the stress wave in a very long (40 m) transmitter bar and the strain and strain rate is determined by using DIC. The results show very clean (no ringing) stress strain curves.

Background

Numerical simulation of the response of materials under loads has reached a level of maturity at which it can be used with confidence for design purposes. Numerical codes like LS-DYNA include many material models (constitutive relations) that can be selected for specific applications. The various models require input parameters that are specific to the material that is being simulated. The accuracy of the simulations depends on the values of the input parameters which are determined from experimental data.

The focus of the present paper is on several new testing configurations and techniques that have been developed recently for the purpose of providing fundamental data for determining the parameters in material models for deformation and failure.

Testing for MAT224 Input

MAT224 is a relatively new deformation and failure model in LS-DYNA. The input requires stress strain curves and values of equivalent failure strain at various state of stress (various combinations of stress triaxiality and Lode parameter). This data is obtained from tension tests of smooth specimens, tension tests of notched flat and notched round specimens with different notch sizes. Plane strain tension experiments with smooth and notched specimens with different notch sizes. Biaxial tension-torsion and compression-torsion tests and punch tests. Digital Image

Correlation is used in all the tests for a direct measurement of the strain (full field) on the surface of the specimens. The DIC data together with numerical simulation of the experiments is used for determining the state of stress (triaxiality and Lode parameter) in the specimens at the fracture point. Figure 1 shows DIC results from tensile test of notched round specimen.

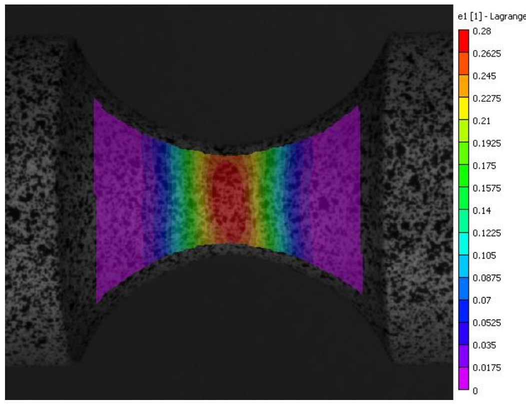

Fig. 1 DIC strains in tensile test of notched round specimen.

Shear Test for Sheet Metal

Simulation of many applications, especially in the automotive industry, requires knowledge of the shear properties of sheet metals. Shear properties are ideally obtained from a torsion test of a thin-walled tube where the gage section is under a state of simple shear. Since tubes cannot be machined from sheet metal other methods need to be used. A new configuration in which a state of nearly pure shear is created in a notched gage section of a specimen that is loaded in tension is presented, Fig. 2. The end tabs are loaded in tension while the gage section, which is the notch in the center, is under a stress state of nearly pure shear. The average shear stress in the gage section is determined by dividing the force by the area in the gage section that is being sheared. The shear strain is determined by measuring the deformation with DIC directly in the gage section. Figure 3 shows processed data from one DIC frame. The figure shows a state of almost pure shear within the notch. Figure 4 shows a shear stress strain curve from a test with specimen made of 2024-T351 aluminum. The tests can also be conducted at high strain rate by using a tensile split Hopkinson bar apparatus.

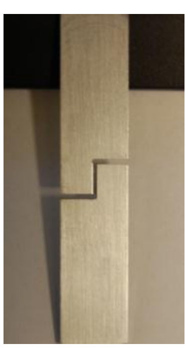

Fig. 2 Shear sheet metal specimen.

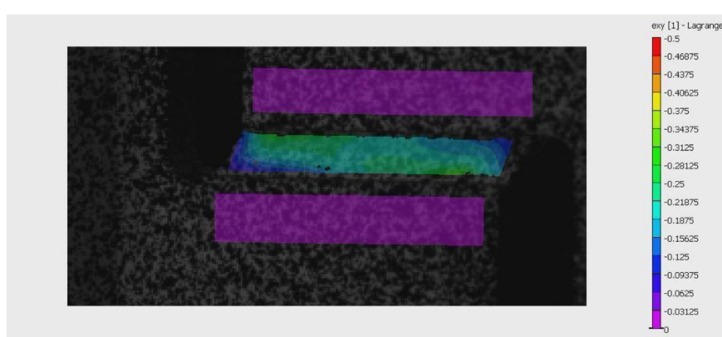

Fig. 3 DIC shear strains in sheet metal specimen.

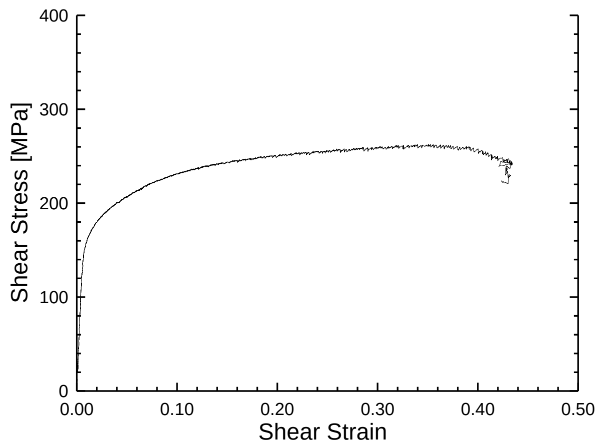

Fig. 4 Shear stress strain curve for 2024-T351 aluminum.

Tensile Testing of Kevlar at High Rate

Testing Kevlar cloth and yarn requires special attention to the mounting, or gripping, of the specimen. At low (quasi-static) strain rates there are no limits on the specimen and mounting fixtures geometries. Testing these materials with the tensile SHB apparatus requires special attention since the specimen has to be small, has to be attached between the bars while keeping the impedance constant, and the connection has to be strong enough such that the specimen will fracture in the gage section between the bars. Figures 5 and 6 show fractured Kevlar 49 cloth specimen and fractured single yarn specimen following a test.

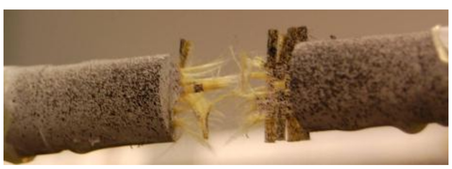

Fig. 5 Kevlar cloth following a tensile SHB test.

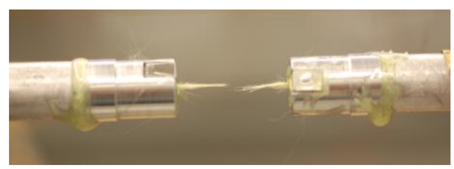

Fig. 6 Kevlar yarn following a tensile SHB test.

The stress and strain in the specimen are determined from the wave in the bar using the standard method. In addition, the strain is determined with DIC directly on the specimen and from measuring the displacements of the adaptors. Figure 7 shows DIC data (displacements) from one frame during the test, and Fig. 8 shows stress strain curves from a test with Kevlar 49 cloth.

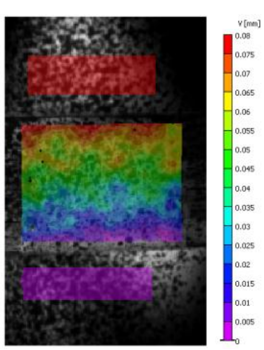

Fig. 7 DIC data from a tensile SHB test on Kevlar cloth.

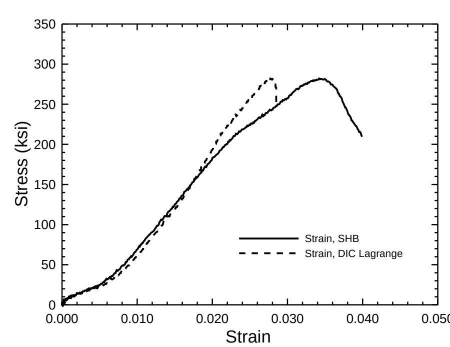

Fig. 8 Tensile stress strain curve for Kevlar cloth.

Intermediate Strain Rate Test

A new technique for testing in compression at intermediate strain rates ranging from about 20 s^{-1} to 200 s^{-1} is presented. The technique is a hybrid of a compression SHB and a hydraulic machine. A specimen (short, small diameter cylinder) that is placed on the face of the cross-section of a long bar is loaded by a hydraulic actuator, Fig. 9. As the specimen is loaded, a compression wave propagates to the end of the bar and reflects back. The force in the specimen is measured by strain gages that are placed on the bar and the strain in measured directly on the specimen with DIC. The actual setup is shown in Figs. 10 and 11.

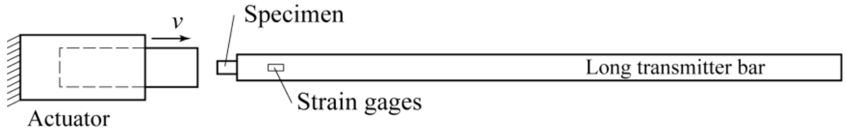

Fig. 9 Schematic of the intermediate strain rate apparatus.

Fig. 10 Intermediate strain rate apparatus.

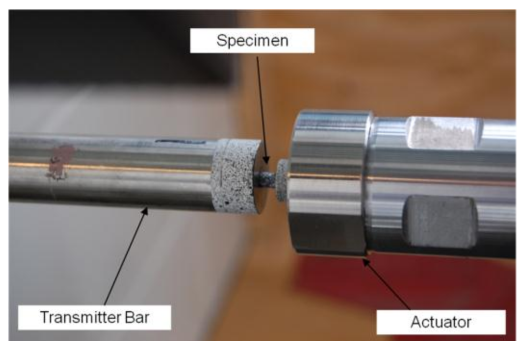

Fig. 11 Intermediate strain rate apparatus.

The bar is more than 40 m long which allows a test duration (until the reflected wave arrives at the strain gages that measure the force) of more than 0.016 s. At a strain rate of 20 s^{-1} it provides enough time for the specimen to deform to a strain of 0.3. Results from a test on a 6061-T6 aluminium specimen are shown in Figs. 12 and 13. Figure 12 shows one DIC frame during the test, and the stress strain curve from the test is shown in Fig.13. The strain rate during this test is approximately 70 s^{-1}.

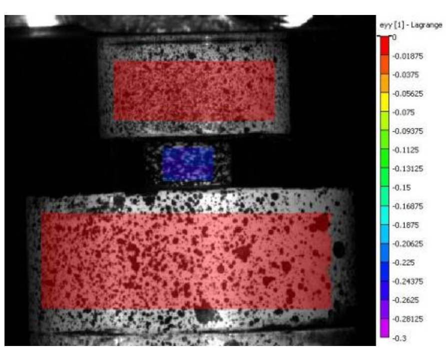

Fig. 12 Axial strain measured with DIC in a compression test.

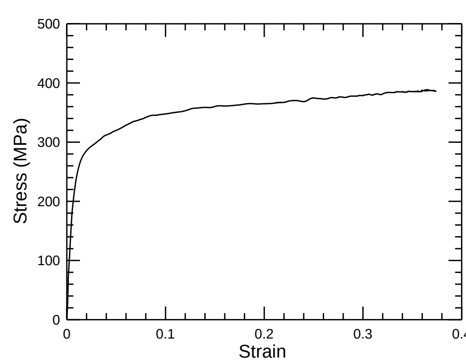

Fig. 13 Stress strain curve for 6061-T6 aluminum.

Aknowledgements

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