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Recent developments in dynamic testing of materials

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Abstract. New techniques for dynamic characterization of materials that have been developed in the last three years (since the last DYMAT conference in 2012), and results from recent dynamic testing of Inconel 718 are presented. The first development is a dynamic punch test in which three dimensional Digital Image Correlation (DIC) is used to measure the deformation of the rear surface of a specimen as it being penetrated. The second experimental technique that is under development is a dynamic tension experiment in which full-field strain measurement with DIC and full-field temperature measurement are done simultaneously during the test.

1. Introduction

Numerical simulation of the response of materials to loads has reached a level of maturity at which it can be used with confidence for design. Numerical codes like LS-DYNA and Abaqus include many material models for plastic deformation and failure (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. Accurate experimental results from tests under well-controlled conditions are needed for the determinations of the parameters in the material models as well as for the validation.

The current paper presents two new testing configurations that have been developed recently for the purpose of providing fundamental data for determining the parameters in material models for dynamic plastic deformation and failure. In addition, results from testing Inconel 718 over a wide range of strain rates and temperatures are presented.

2. Dynamic punch experiment

A dynamic punch test in which three-dimensional Digital Image Correlation (DIC) is used to measure the deformation of the rear surface of a specimen as it being penetrated is carried out by using a large diameter (50 mm) compression Split Hopkinson Bar (SHB) apparatus, Fig. 1. Flat, round Ti-6Al-4V disk specimens are attached to the transmitter bar of a compression SHB apparatus and a tungsten carbide punch is attached to the incident bar and positioned such that it is in contact with the disk, Fig. 2. During a test, a compression wave is introduced into the incident bar which causes the punch to penetrate into the specimen. The specimen is mounted on a die fixture that is slotted on both sides such that the rear surface of the disk specimen is visible to two high speed cameras. This provides a stereographic view of the specimen that is used to measure full-field displacement directly on the specimen using three-dimensional DIC. The contact force between the punch and the disk is determined from the wave in the transmitter bar.

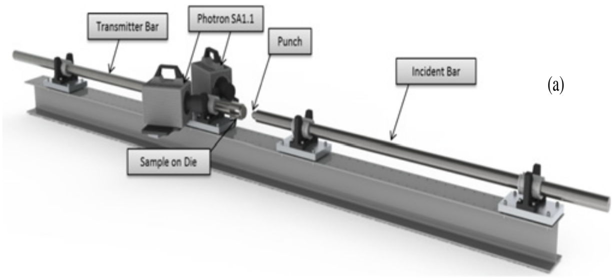

Figure 1. Dynamic punch test in a compression SHB apparatus.

Two Photron SA1.1 cameras running at 100,000 frames per second (10 μs interval) at 192 pixel by 192 pixel resolution record the rear surface deformation of the disk specimen. The images are processed by commercial Digital Image Correlation (DIC) software (VIC-3D).

Typical wave profiles recorded in a test are shown in Fig. 3. The amplitude of the incident wave in this experiment is 400 kN. Figure 4 shows the history of the strains at two points (the centre point and the point that failure first occurs) at the back surface of the specimen. The last DIC image recorded before failure is shown in Fig. 5.

Results from tests with punches of various geometries show that the punch geometry greatly influences the punching force and the failure mode. The data is used to construct and validate deformation and failure models.

3. Dynamic response of Inconel

Inconel 718 has been tested in compression, tension and shear at various strain rates ranging from 0.0001 s^{-1} up

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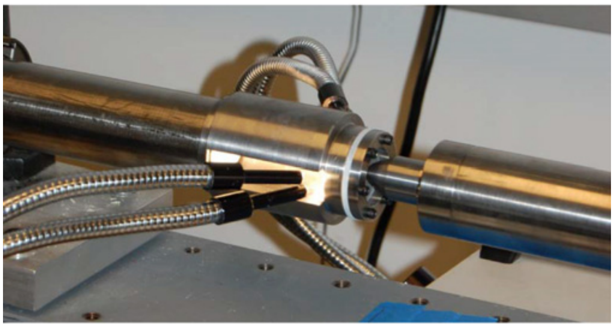

Figure 2. Close-up of the dynamic punch experiment.

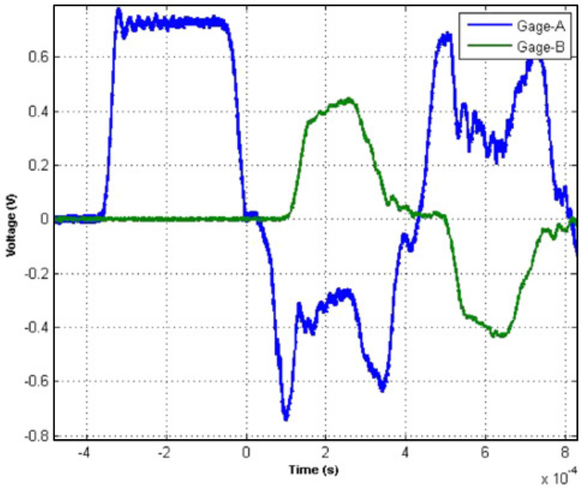

Figure 3. Waves recorded in a dynamic punch experiment.

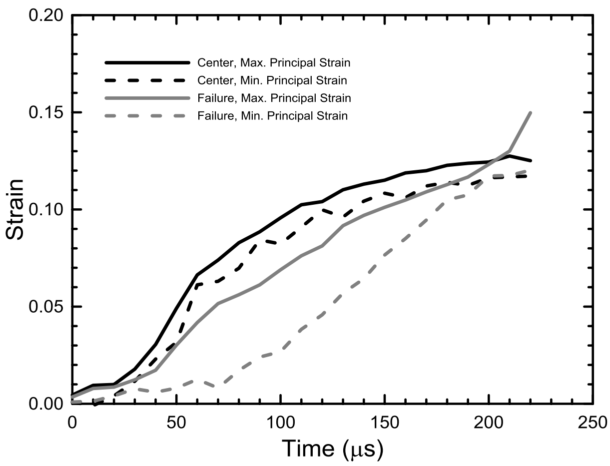

Figure 4. Strains measured with DIC.

to 5.200 s^{-1}. A hydraulic frame is used for the quasi-static tests and the SHB technique (with DIC used to measure strains directly on the specimen) is used for the dynamics tests. Results from tensile and compression tests with specimens initially at room temperature are shown in Figs. 6 and 7, respectively.

The results show a significant effect of the strain rate on the stress. There is also a noticeable difference in

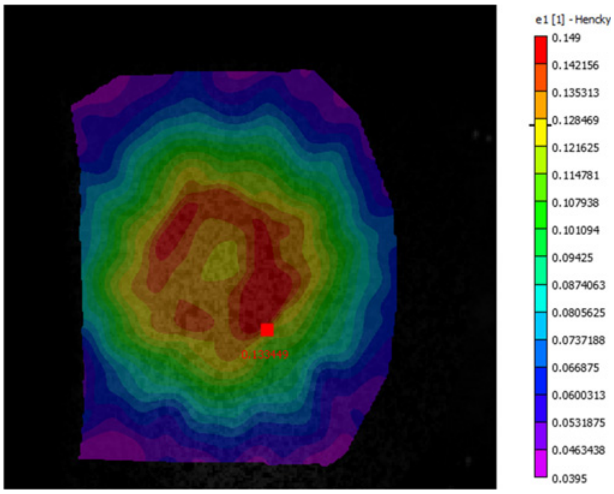

Figure 5. Last DIC image prior to failure (red dot is the failure point).

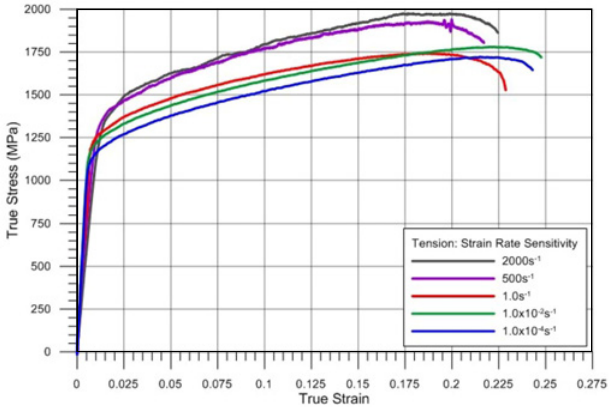

Figure 6. Tensile stress strain curves for Inconel 718 at various strain rates.

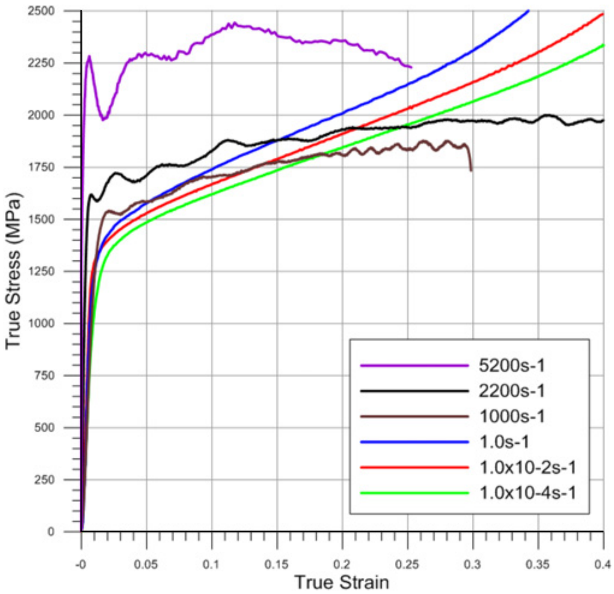

Figure 7. Compression stress strain curves for Inconel 718 at various strain rates.

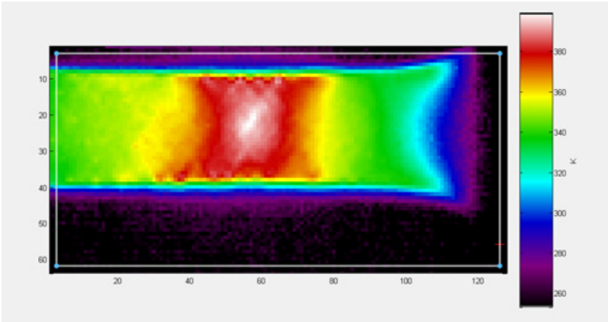

Figure 8. IR measurement in a dynamic tensile test.

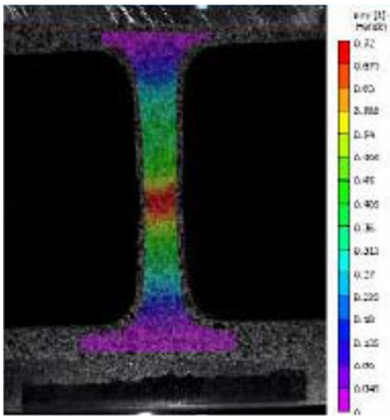

Figure 9. DIC strain measured in a dynamic tensile test.

the response between tension and compression. Higher strain rates are achieved in the compression tests which show an increase in strain rate sensitivity at strain rate of about 5.000 s^{-1}.

4. Full-field strain and temperature measurements during dynamic tensile test

Under development is a dynamic tensile experiment that features a full-field strain measurement, and a full-field temperature measurement at the same time (on opposite sides of the specimen). The strains are measured with DIC and the temperature is measured with a high speed IR camera. Pilot experiments have been conducted at strain rate of 150 s^{-1} and 500 s^{-1}. Figures 8 and 9 present results from tensile testing of specimen made of 304 stainless steel at strain rate of approximately 150 s^{-1}. Figure 8 shows the last frame before failure that was recorded with an IR camera (Telops Fast MWIR 1500, resolution 128 $\times$ 64, frame rate 10.000 fps). The maximum temperature observed is about 270 °C. The full-field strain measured with DIC at the same time is shown in Fig. 9 (Photron SA1.1, resolution 448 $\times$ 592, 20.000 fps). The maximum strain the is measured in the neck is about 0.8.

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