A nondestructive validation of reverse impact experiment based on shape measurement using high speed photographs

D. Kohdadad¹, T. Sjöberg²

¹ Experimental Mechanics, Luleå University of Technology, SE-971 87, Luleå, Sweden

² Division of Mechanics of Solid Materials, Luleå University of Technology, SE-97187 Luleå, Sweden

Abstract: High speed photography of a reverse impact scenario was taken in order to make shape measurement. The results from the shape measurements were then compared with results from numerical simulations in order to evaluate the possibility to use noncontact shape measurement as a validation tool in future simulations.

Keywords: reverse impact experiment, nondestructive validation, shape measurement, strain.

I. Introduction

In order to improve the ability to validate results from numerical simulation with the use of experiments new reliable parameters to compare are always sought for. Usually the validating parameters need to be measured by a physical device included in the experimental set-up. The downside of this is that the measuring devices themselves are invasive and influence the controlled part meaning that they can introduce new unknown effects into the experiment. Therefore noncontact measurement is always desirable. Several different optical noninvasive technologies are already used to measure and characterize surface shape and deformation [1, 2, 3, 4]. In this work we track surface (edge) deformation and displacements in a sequence of images while keeping the method as simple as possible. It means the only thing needed is photos of the experiment as well as numerical software such as MATLAB.

In order to test the feasibility of using shape measurements as a way to find new validating parameters high speed photography were used to capture the impact of a reverse impact test.

II. Method

A. Reverse impact experiment

The experiment consisted of an instrumented slender steel rod, with a diameter of 10 mm, onto which a half spherical tip of tungsten-carbide was attached, an air-gun used to accelerate discs of sheet material towards the rod at speeds up to 70 m/s, and a cylindrical container made of PTFE to guide the specimens and make sure they hit the tip as straight as possible. The discs were made of Nickel alloy 718, had a diameter of 46 mm and a thickness of 1.6 mm. A schematic of the experiment can be seen in Fig. 1.

Fig. 1. Schematic of the reverse impact experiment.

The rod is instrumented with two sets of strain gauges mounted in Wheatstone half-bridges as to compensate for bending in the two principal directions perpendicular to the rod length. The strain gauges are used to capture the elastic wave formed at the impact. From this elastic wave the force of the impact can be calculated. This force is used to evaluate the plastic properties of the plates throughout the impact event. For more details on the reverse impact set-up refer to [5].

B. High speed photography

In order to capture the high velocity impact a Phantom v1610 high speed camera from Vision Research was used. This camera was able to record images of the size 80 by 512 pixels at speeds up to 280 000 images/second. This made it possible to capture around 50 images of the impact that takes around 200 μ s. In order to get enough light at these short exposure times the set-up included two flashes rigged to bounce on a white screen put behind the impact position, thereby creating good contrast between the background and the discs. The flashes had a burn time of around 2 ms meaning the entire impact event could be captured.

C. Shape measurements

Initial measurement step requires the segmentation of certain structures in the captured images. We need a set of structure that can be robustly tracked in all image sequences. A surface structure can be considered simple to segment if its associated intensities are fairly homogeneous. For this we used contrast

enhancement with adaptive histogram algorithm. Therefore, the best candidates for segmentation that are easily visible in all images are the contours and edges because they exhibit higher contrast and are easier to track the changes. An adaptive local thresholding algorithm based on the minimum and maximum intensity of each image combined with Canny operator used to extract the surface and edges. Fig. 2 shows the specimen and extracted edges. To measure the strain of the specimen the edges of specimen surface are repeatedly tracked in different sequences and their respective one-dimensional displacement vectors determined. A moving average filter is used to remove random noise and mutations while retaining a sharp step response, Cumulative surface edge displacement Δ_{surf} can be determined from the incremental displacements δ_{surf} between consecutive images using Eq. (1)

$$\Delta_{surf} = \sum \delta_{surf} \quad (1)$$

By calculating the difference of displacements $\Delta l = \Delta_{surf II} - \Delta_{surf I}$ and dividing it by a selectable but constant base length l_0 , any strain value can be determined as:

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{\Delta_{surf II} - \Delta_{surf I}}{l_0} \quad (2)$$

Fig. 2. An arbitrary image of specimen from the sequence of the images and corresponded extracted edge information are shown in left image and right one respectively. Tracking the edge displacement and using Eq.(2) lead to strain measurement.

D. Numerical analysis

A numerical analysis based on the reverse impact was performed using the commercial FE-code LS-Dyna. The numerical analysis modeled the plate as free-flying since the effect of the cylindrical guide could be neglected. The rod was modeled as purely elastic material since no plastic deformation in the rod could be observed after the experiments. The plates of Alloy 718 were modeled using the Johnson-Cook plasticity model [6]. The evaluation and validation of the parameters used for the Johnson-Cook model are described in [7].

III. Results

The results obtained from the shape measurements could then be compared with results from the numerical simulations. In Fig. 3 the average velocity for displacement of points on the specimen (dashed line for simulation and solid line for results from shape measurement) are plotted throughout the entire impact event. The trend of change in velocity of displacements can then be used to give initial feeling of how force is spreading through the specimen which can be one of the parameters of validation.

Fig. 3. Average velocity of displacement for the plate at the first 200 μs . The solid line is the results from the shape measurements while the dashed line shows results from the simulation.

Three arbitrary points on a plate are chosen to compare the results of shape measurement with FE-model. The strain evolution evaluated using shape measurement is plotted in Fig. 4 together with strain calculations from the FE-model. General increment of strain in both methods is seen along the time axis with closely same trend.

IV. Discussion

The results in Fig 3 and 4 show agreement with the simulations which verifies that shape measurement method can be a nondestructive validation tool for the results from numerical simulation with the use of experiments. In this work both the spatial as well as the temporal resolution of the high speed camera is quite low. The low spatial resolution makes edge detection difficult and the low temporal resolution means that the small quick changes in the impact become hard to resolve. Also in some images of sequence the specimen has been rotated

or moved which can cause some errors in displacement calculation and later on in image based strain measurement. Then image registration methods [8, 9] can be used in order to obtain a transformation between the images of sequence to monitor and compensate the movement or rotations between the images from different time. To make the validation more accurate and robust, recording images with pulsed digital holographic methods can be an alternative. In this case images with higher resolution including phase information are easily in access to use for shape measurement. Then the ability of tracking very small changes and displacements in holographic images will increase the accuracy of validation.

Fig. 4. The evaluated strain plotted for three points on the plate. The solid lines show results from the shape measurements and dashed lines from the simulations. The color grouping shows results taken from the same position on the plate radial axis.

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