

Full Field Strain Measurement of Punch-stretch Tests Using Digital Image Correlation

Xu Chen, Xin Xie, Jianfei Sun and Lianxiang Yang
Oakland Univ

ABSTRACT

Punch-stretch tests were conducted on Advanced High Strength Steel (AHSS) specimens. A special stretching mechanism with two embedded high resolution digital cameras had been designed and used in punch-stretch tests. The deforming processes were recorded by the cameras and the full-field strain distribution for each specimen was evaluated using Digital Image Correlation (DIC) technique, a full-field, non-contact, high accuracy optical and computational technique for contour, displacement and strain measurement. Data of Strain path, necking and other strain behavior were extracted using DIC. Different data analysis methods were tried to achieve useful information for predicting the failure. The data set could be used for researches on the effect of the strain path on the forming limit.

KEY WORDS: Digital Image Correlation (DIC), Punch-stretch test, Strain, Strain Path, Necking, Forming Limit Diagram

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1. INTRODUCTION

Research on the formability of sheet metals is of great importance because it's related to the safety of the products as well as economy. The formability indicates the ability of the sheets to undergo desired deformation without failure. Several techniques have been developed to measure the formability and predict the failure during the forming process. Forming Limit Diagrams (FLDs) had been built to present the formability of a certain material and punch-stretch tests were conducted to help researchers to achieve the FLDs and other material properties. In these tests, the sheet is fixed by a draw bead that prevents the sheet from being drawn into the die. Then the sheet will be stretched over a punch. Sheets with different widths will be tested and the strain distribution right before necking occurs will be evaluated. Current researches show that the strain path has effects on the forming limit, and the researchers would like to collect more data for the punch-stretching strain behavior.

The deforming processes of punch-stretch tests usually happen inside the die, thus the full-field strain distribution is hard to measure. People usually use the grid technique to evaluate the strain distribution in this case, but the measuring accuracy of the grid technique is low. Moreover, only two state of the sheet, before and after deformation, could be measured. The other problem for the measurement is that the tests are supposed stop right when necking starts. However, it

is not easy to control the stopping time and people developed the Limiting Dome Height Test to test the capability of the material to stretch before failure. In this method, the maximum travel distance of the punch before failure occurs will be evaluated before the tests.

In this paper, a specially designed punch-stretch mechanism with an open space in the upper die was used. Two cameras were fixed to the upper die and the whole stretch process was recorded. Strain distributions were then evaluated from the captured images using the DIC technique. The DIC technique is a non-contact, full field contour/displacement/strain measurement method with high accuracy. For the punch-stretch tests, a 3D measurement capability is required so two cameras were used in our tests. DIC technique also has very high measuring range, higher than 100% strain could be measured with this technique with proper parameters. This feature makes DIC very suitable for performing punch-stretch measurements. With DIC technique, we do not need to apply any grids or circles as we do in the grid technique, either. Usually, a punch-stretch test should stop right at the moment that necking starts, but with DIC's continuous recording feature, we do not need to control the stopping time anymore thus making the tests easier. Strain data were extracted and processed to show that DIC is a very convenient measurement method and the strain data from DIC could help in material property research.

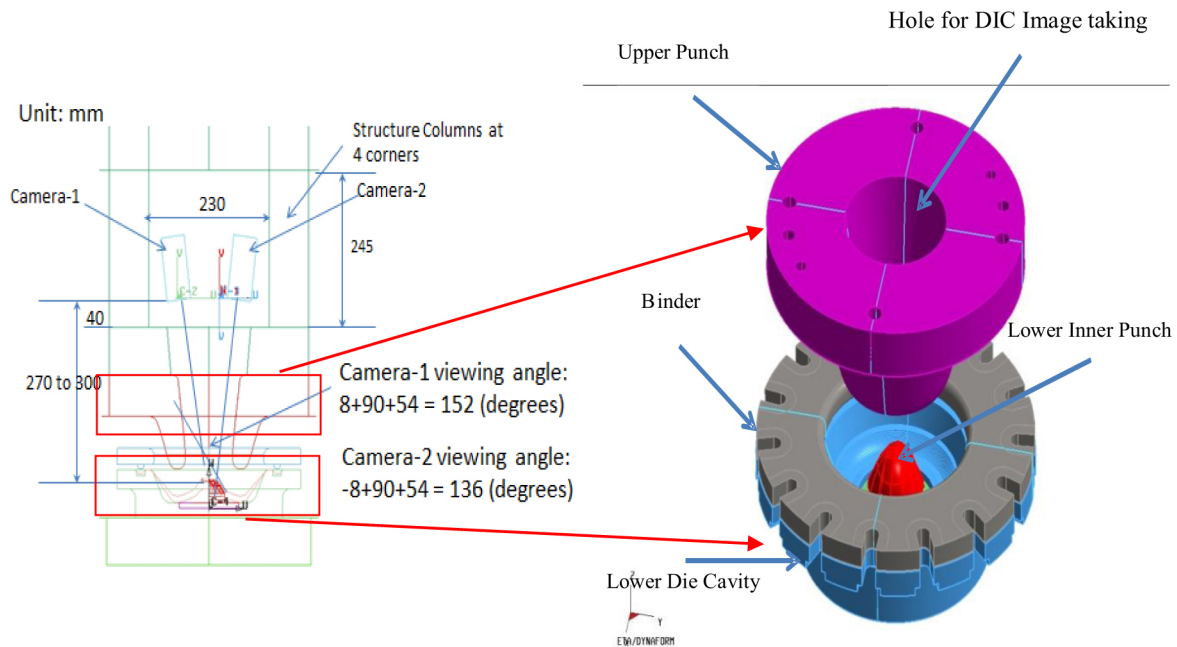


Fig. 1. Design of the Punch-stretch Mechanism (Designed by Dr. Changqing Du from Chrysler)

2. BASIC THEORY

The basic theory of Digital Image Correlation (DIC) is tracking an arbitrary point on a specimen's surface to calculate the motion vector and eventually get the displacement and strain distribution. These data can be used in engineering applications.

The DIC system overcomes the disadvantages of grid technique. They could track any point on the specimen surface without an accurate pre-made grid pattern. System error has also been greatly reduced by calibration. 3D DIC systems use at least two cameras, and these systems are also called stereo DIC systems. In a stereo DIC system, two cameras work in a similar way as human eyes. The depth between spatial points could be recovered by doing correlation on images from different cameras.

3. EXPERIMENTAL METHOD

Two different grades of AHSSs, EDDQS and TRIP780, were tested. Specimens with rolling direction and transverse direction were prepared. For a certain direction, specimens with different width were prepared. Full size (Round sheet) specimens that are expected to have an equal biaxial strain distribution and medium size (The width is half the round sheet's diameter) specimens that are expected to have a uniaxial strain distribution were tested.

3.1. EXPERIMENTAL SETUP

To enable DIC measurements during the deforming process, a specially designed punch-stretch mechanism was used in our tests. In Fig. 1, the image on the left shows the side view of the design. The upper die was designed to have an empty space for the cameras. A hydraulic tensile machine

with 100KN loading capacity was used to provide necessary pressure. The lower die was fixed to the lower arm of the tensile machine while the upper die with cameras was fixed to the upper arm. The image on the right shows a zoomed view of the die, the binder and the lower punch was fixed using multiple screws to provide enough clamping force. Two high resolution CCD cameras were used in our tests. A Light-Emitting Diode (LED) array with proper size and a diffuser was installed between the two cameras and was used for illumination. Detailed description for adjusting the setup will be provided in the following section.

Shock Absorption

To achieve a successful DIC measurement, the cameras are supposed to be rigidly fixed because even a very small angle change may involve negative effect to DIC results. In our setup, since the cameras were fixed together with the upper arm of the tensile machine, vibration from the cooling system and the machine itself may affect the stability of the cameras. To reduce or eliminate the effect of vibration, shock absorption mechanism was investigated and used. A vibration data collector was used to evaluate the vibration frequency and the amplitude. After the investigation, we found that the magnitude and the frequency were actually very small. The magnitude was less than 0.2mm and the frequency was less than 5 Hz. So, two small vibration damping platforms were used to improve the performance.

DIC Parameters

To increase the accuracy and obtain more details from the images, high resolution CCD cameras were used in our tests. The full resolution of the cameras was 2500 * 2000 pixels. To capture more details of the deforming process, the frame rate

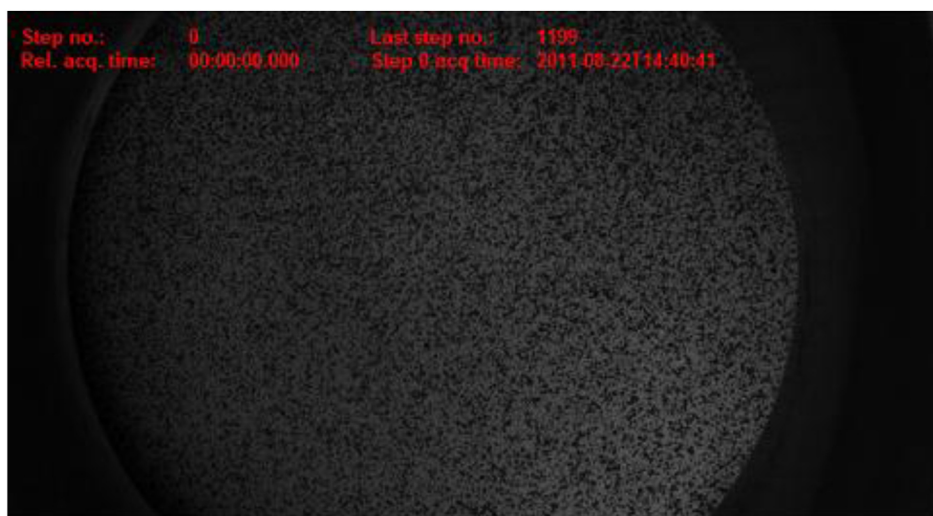


Fig. 2. Prepared Specimen (Clamped, image captured from 1 camera)

was set to 10 FPS and the punch travelling speed was set to 0.5 mm per second. Bottle necking occurs while saving images to the hard drive because the resolution of each image is very high while the capability of writing image, mainly the access speed of the hard drive, is low. To solve this problem, a 64 bit compatible image capturing software was used. And the images were first saved to the RAM (16GB) via 1394B cable and then saved back to the hard drive after the test is done.

Illumination

The requirement for illumination of our test is higher than normal DIC tests. Because, 1st, the measurements were taken place inside the die with a reflective metallic surface; 2nd, since the specimens were subject to very large out-of-plane, the shadow generated from such deformation should be eliminated. In our test, non-reflective paint was applied to the inner surface of the die. To avoid involving unexpected clamping force, the paint was carefully applied and there was no contact between the paint and the draw bead. To cover all interested areas, a LED array consists of sixteen monochromatic LEDs (wavelength: 550nm) was used for illumination. To make the illumination evenly distributed, a diffuser was applied before the LED array.

Sample Preparation

As shown in Fig. 2, random speckles were applied to the specimens' surface. A mask was used when applying the speckles to guarantee that there's no paint in the contact area of the draw bead and the specimen. Because a slightly change of the sample thickness will result in large unexpected clamping force.

3.2. CALIBRATION

To transform the pixel information in the images to the real dimension of the object, the calibration process is needed. Physical parameters of the cameras, such as the focal

length and distortion, and the spatial parameters, such as rotation and the angle between cameras, will be calculated during calibration.

In our tests, one important factor that has to be taken into consideration is defocusing. For an arbitrary point on a 3D object, when the distance between this point and the focal plane become larger, the points will appear to be "vague" on the images. This kind of "vague" could be used for DIC to calculate the spatial position of the point because the focal length has already been calibrated. However, there is a range, also called Depth of Field (DoF) that defocusing doesn't affect the DIC results. An investigation had been conducted and we found that with a pair of 25mm CCTV lenses, the DoF is ± 50 mm of the focal plane. The range could be increased with the decrement of the aperture. To make best use of the DoF, calibration is usually done at the position of the focal plane.

The estimate max out-of-plane deformation in our tests is about 55mm, so the calibration was taken at the plane that is 28mm higher than the non-deformed specimen surface. Fig. 3 shows the calibration position and the estimated maximum deformation. The blue area shows the shape of a deformed specimen with an estimated height of 55mm, the red lines on the top and the bottom show the DoF is actually ± 28 mm, slightly larger than 55mm. The effect of defocusing is thus reduced.

3.3. DATA PROCESSING

There are several purposes of the data processing in our research: 1st, full field strain histories are expected to show a clear strain behavior during deforming. 2nd, the points that start necking first are expected to be found because these points show the weakest points of the specimen and are valuable for material property analysis. 3rd, strain paths of these points are expected to be used for strain behavior analysis.