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Application of Digital Image Correlation in Uniaxial Tensile Test

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Abstract

Application fields of non-contact measurement techniques have been recently increasing by means of optics and technological development in measurement applications. Digital image correlation (DIC) is the one and powerful non-contact measurement method that can be used to obtain elongation and strain as well. It is versatile and flexible measurement method can be adopted to many traditional test experiments such as tensile, compression, and bending in order to calculate mechanical properties of materials. In this study, DP600, DP800 and DP980 steel materials were performed to uniaxial tensile test and DIC technique was used to determine local strains in terms of comparison in different regions at the fracture area. While performing experiments, commercial DSLR camera was installed to capture videos under the white led lighting which is needed to decrease visual blurring and keep contrast as constant. Recorded videos were analyzed with VIC-2D software in an effort to calculate strain data. As a result, it was showed that the strains at the fracture area that were measured with DIC were higher than those measured which out of the fractured area and concluded that DIC method was appropriate and efficient technique to measure local strains in traditional uniaxial tensile test.

Key words

Digital Image Correlation, Optical Measurement, Sheet Metal, Strain Measurement, Tensile Test.

1. INTRODUCTION

Rapid development of technology and improvements of optic instruments has caused widely usage of non-contact measurement techniques both in industry and private applications. Image based measurement methods has recently been popular not only traditional methods can not satisfy customer requirements but also specific instruments are very expensive and adapted hardly. To give an easy, low cost, and flexible solution for those problems, digital image correlation (DIC) method is developed and has been used in many fields such as automotive industry, material testing, and medical applications.

DIC technique is mainly based on the photogrammetry field which is a science of making measurements from photographs, especially for recovering the exact positions of surface points. Roots of image based measurements techniques dates back to Leonardo da Vinci writings about the perspective and imagery in 1480 and 1492 as pointed out by Doyle [1] and Gruner [2]. Photogrammetry and its mathematical improvements has been enhanced by means of development of optic tools and imaging technology, especially digital photogrammetry in 1985 up to present [3]. Hobrough [4] used digital image correlation so as to get position information. He purposed a tool that can be used to correlate high-resolution reconnaissance photography with high precision survey photography for calculating ground conditions. Yamaguchi [5] used laser speckles that are scanned by a linear image sensor in the diffraction field and made cross correlation function of the signal.

Ultrasonic approach was the prior studies in two dimensional measurement with digital image correlation. Peters [6] and Ranson [6] developed an approach. In their study, the ultrasonic waves were sent to the reference and deformed images and compared digital images of small areas as known subsets before and after process in order to calculate deformation measurements in material systems. They suggested to use continuum mechanics concept for measuring small areas in matching process to determine locating positions of all subsets. Sutton et all [7] improved some numerical algorithms based on earlier study and applied to experiments to record images with optical instruments and this is known today as 2D DIC. In the last decade, digital image correlation has been applied material testing experiments such as tensile, compression, bending and forming limit curves on the purpose of calculating mechanical properties of the sheet materials. One of the crack propagation study was accomplished by McCormick [8] and Lord [8]. They demonstrated the calculation of crack opening measurement using concrete specimens under compression and they suggested that output of DIC gives local deformation map which shows the cracks not visible to the human eye.

DIC measurement technique generally is adopted to material test experiments such as tensile, compression, and forming limit curves. Zhu et al [9] suggested the two cameras DIC system to measure true stress-strain curves of low carbon steel under uniaxial tension. They used dog bone specimen with 10mm circular cross section area. They calculated the true strain stress curves on the specimen using different local points along the length of the specimen and indicated that while region that enters the plastic zone provides axial plastic deformation because of decreasing cross sectional area, region that entered the plastic zone or not entered yet keeps constant deformed state. Dong et all [10] focused on an application of DIC under high temperature using micro scale pattern. They examined variety speckle patterns and sizes to get good correlation under the high temperature experiments and suggested that using a macro scale speckle patterns that is produced by ceramic based paint to micro scale caused the high number of errors of correlation when the subset size is too small. In addition, they found that fine-sprayed paint and abrasion of polished surface caused micro scale pattern stable under 1400 °C and errors were below 0.04 pixel.

2. EXPERIMENTAL

2.1. Materials

In this study, commercial automotive steels, DP600, DP800, and DP980 that consist of a ferrite matrix and a hard second phase, usually islands of martensite was used in order to calculate local strains using DIC method in uniaxial tensile test. The thicknesses of materials are 1.3mm and the tensile specimens were machined according to ASTM E8. Chemical compositions of these materials are given in Table 1.

Table 1. Chemical compositions of DP600, DP800, and DP980

DP800 [11]						
C % max	**Si % max**	**Mn % max**	**P % max**	**S % max**	**Cr % max**	**Al_{tot} % max**
0,160	0,250	1,90	0,020	0,004	0,500	0,015
DP980 [12]						
C % max	**Si % max**	**Mn % max**	**Mo % max**	**B % max**	**Cr % max**	**Al_{tot} % max**
0,135	0,05	2,1	0,35	0,007	0,15	0,45
DP600 [11]						
C % max	**Si % max**	**Mn % max**	**P % max**	**S % max**	**Cr % max**	**Al_{tot} % max**
0,120	0,300	1,660	0,020	0,004	0,500	0,020

2.2. Methods

All the mechanical tests were performed with 100 kN Instron 8801 uniaxial tensile machine. DIC is mainly used to calculate the displacement and strain over specified field in whole process. One of the crucial instruments in DIC measurement is the camera. The professional high resolution and high frame per second (fps) camera can increase the accuracy and precision of measure. In this study, Canon T3i DSLR with a 58mm diameter and 18-55mm (f/3.5-5.6) lens that has 1920x1080 resolution and 30fps was used, see Figure 1.

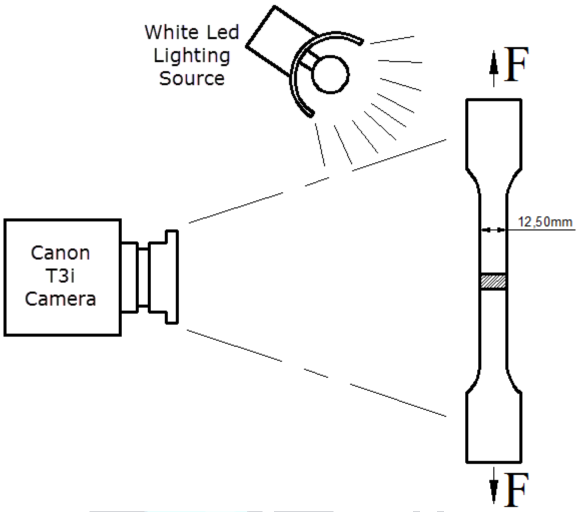


Figure 1. Schematic view of DIC setup

Creating random speckle pattern on the specimen surface is one of the important issues that can directly affect accuracy and precise of the correlation results. In order to obtain high and accurate correlation, the pattern size must be small. Experiments performed at room temperature, most of the water based paints can give proper correlation results to create speckle pattern. In this study, VHT FlameProof, a silicone ceramic based paint was used to create black speckles onto white background because of rapid drying time and high color contrast. As an example, DP600 painted specimen that consists of the calibration meter and dashed area of interest is shown in Figure 2. On the purpose of calculating local strains, five points were selected on horizontal alignment in the fracture area as seen in Figure 2(b). Point 1 is the nearest left edge of specimen and Point 3 is the middle of the fractured edge, and Point 5 is closed to the right edge of specimen out of fracture area. Lighting conditions is another important factor that is crucial for the correlation results. In this study, regular white led lighting source which was subjected to the specimen surface directly gives good correlation results.

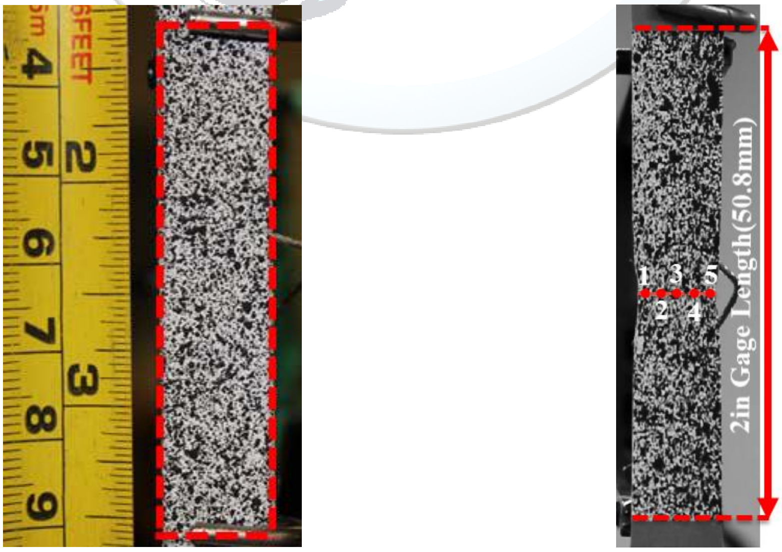


Figure 2. (a) Calibration meter and area of interest *(b) Virtual gage length and selected points*

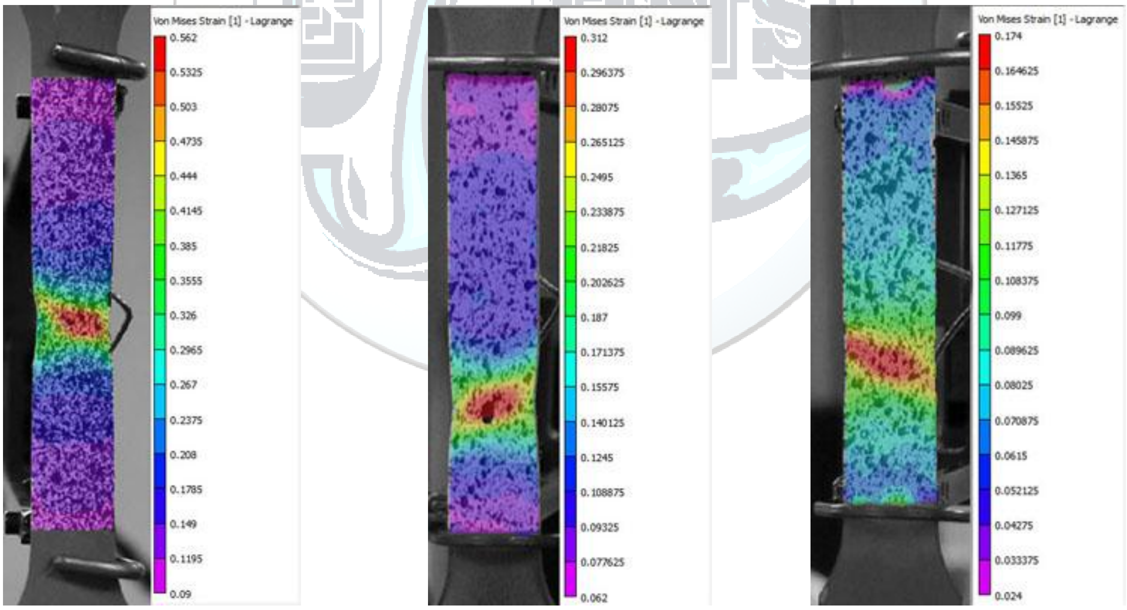
3. RESULTS AND DISCUSSION

In conventional tensile tests, regular extensometer which has 2in (50.8mm) gage length has been used in order to measure the elongation and calculate strain. On the other hand, regular extensometer is not able to install some special experiments as hot tensile tests or hot forming limit tests due to high temperature of test environment and require special equipment like ceramic grips. Therefore, these special tools increase the measurement setup’s cost. As an alternative method, DIC, can easily adopt to room and high temperature material mechanic tests. Elongation can be calculated by DIC as well as physical extensometer measurement.

Uniaxial tensile tests were performed with 0.1mm/s cross head speed for three materials. The frames were created from test movies after the whole recorded processes. In the case of non-contact measurement, the extension was obtained from the images using VIC-2D software. Two boundaries were defined that overlay with the two gage length edges, which were created by two Scott types that shielded the paint. After the paint was dried, the types were peeled out. Figure 2 shows the clear boundary of the tensile gage length.

Converting pixels to millimeter was established with common tape measure onto specimen surface at the beginning of the uniaxial tensile test. The camera was setup as 1920x1080 pixels resolution and 16:9 aspect ratio and 16 bit depth of color. The total test times were 35.457 seconds for DP600, 23.779 seconds for DP800, and 18.706 seconds for DP980. The recorded videos were edited with video editing software to obtain series of image sequences. The images were got as 30 frames per second. The images were converted into greyscale format as a TIF file type that has better quality rather than other image types after getting image sequences. Performing correlation the image sequences were imported into VIC-2D software.

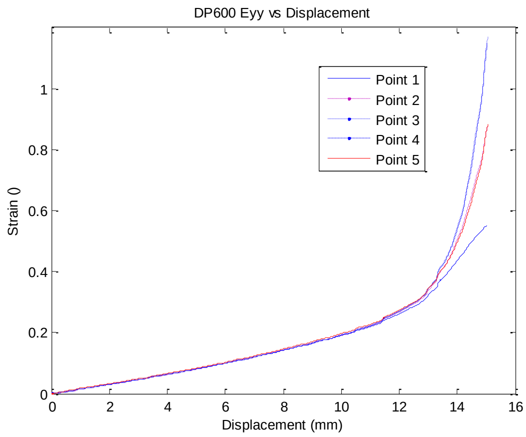
The DIC technique is based on tracking and matching process for each unique pattern regions among images or different times. The unique pattern of each location can be defined using subset size and step size to track and calculate displacements. The subset size for room temperature tensile tests is 24x24 pixels and step size 2x2 pixels. Figure 3 shows the Von Misses strains of the fractured areas for DP600, DP800, and DP980. On the scale bar, red color shows the maximum Von Misses strains in the fracture zone before the failure of specimens. Maximum Von Misses strains were found as 0.562, 0.296375, and 0.164625 for DP600, DP800, and DP980, respectively.



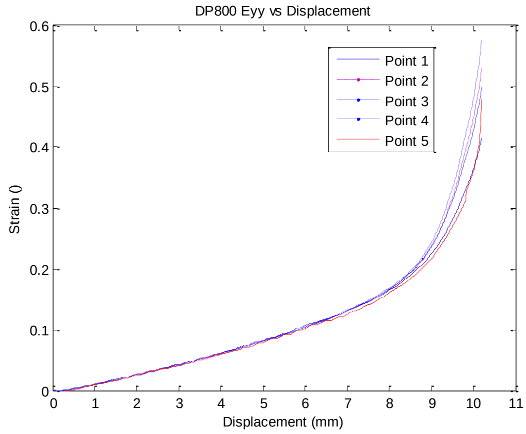
(a) *(b)* *(c)*

Figure 3. Von Misses strains before fracture. (a) DP600, (b) DP800, (c) DP980

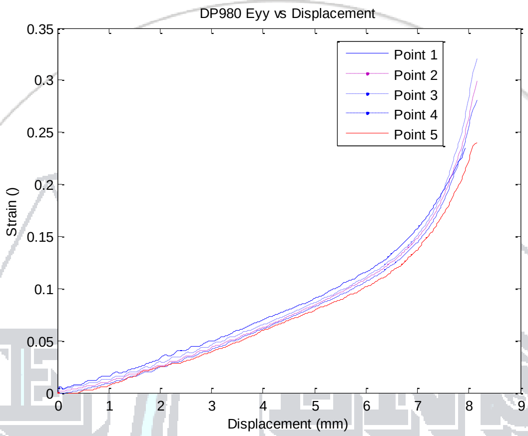
Figure 4 shows the plot of the strains in y direction of five points that are shown in Figure 2(b). In Figure 4, Point 3 which is a middle point of the fracture area is always higher points that are slightly out of the fractured area.



(a)



(b)



(c)

Figure 4. Strains in y direction of five points for (a) DP600, (b) DP800, and (c) DP980

4. CONCLUSIONS

In this study, DIC technique was performed to install uniaxial tensile test in order to get local strains. Three different material, DP600, DP800, and DP980, were used to calculate all points of strain curves versus displacement. Following conclusions can be made about the DIC method;

1) DIC can easily adapt to materials mechanical tests instead of traditional measurement methods.
2) A low cost, easy to setup and consumer camera system can be used for non-contact strain and displacement 2D measurements over flat specimens in uniaxial tensile test.
3) When the local strains take into account, the region (Point 3) which is the middle of the fracture area has always higher strains than the regions that are out of the fracture area for those materials.
4) The strains along the gage width are not homogenous. So, DIC method is an effective technique that can be used to determine local strain evolutions at the crack edge in notch specimens.

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