Measurement and comparison study of deformation using extensometer and 2D DIC technology

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Abstract. The article deals with a short study of deformation measurement two different approaches. First is measurement by extensometer which is the contact technology and second is 2D DIC, which is the optical and contactless method of measurement. The paper starts with introduction to the 2D DIC measure method and continue with results of measurements of both methods. In the conclusion there is comparing results of two presented experimental methods.

1. Introduction

Actual engineering practice, which is in the period of automated high-productivity production, is characterized by an increase in quality requirements. Because many factors affect the production process, it is not possible to produce material with ideal properties. The manufactured components exhibit minor or greater deviations from the ideal mechanical properties. Therefore, the function of product reliability and durability is affected not only by the keeping accuracy of the dimensions, the accuracy of the geometric shape and mutual position of the elements of parts, but also keeping the mechanical properties of the material [1–5].

Nowadays is produced a lot of new material and is necessary to measure their properties. During testing materials different parameters can be measure by different ways. One of them is measurement of deformation by using extensometer or DIC technology [6–9].

Experimental techniques in solid mechanics rely heavily on surface displacement field measurements. Several optical methods, such as moiré interferometry, holographic interferometry or speckle pattern interferometry have long been used in experimental solid mechanics to study mechanical deformation of solids and the mechanics of fracture. Among them, digital image correlation technique, which can obtain the deformation of a surface by comparison of digital images of the undeformed and deformed configurations, is becoming popular and widely used. Since this method does not need a complicated optical system, the measurement can be performed easily. In addition, unlike other methods which utilize the interference of light waves, phase analysis of the fringe pattern and subsequent phase unwrapping process are not required [10, 11].

2. Two-dimensional Digital Image Correlation

In Two-dimensional Digital Image Correlation (2D DIC), displacements are directly detected from digital images of the surface of an object (specimen). Figure 1 shows the schematic illustration of a typical experimental setup using an optical imaging device for the two-dimensional digital image correlation. The plane surface of an object is observed usually by a CCD camera with an imaging lens. Then, the images on the surface of the object, one before and another after deformation, are recorded, digitized and stored in a computer as digital images. These images are compared to detect displacements
by searching a matched point from one image to another. Here, because it is almost impossible to find the matched point using a single pixel, an area with multiple pixel points (such as 20 × 20 pixels) is used to perform the matching process. This area, usually called subset, has a unique light intensity (gray level) distribution inside the subset itself. It is assumed that this light intensity distribution does not change during deformation. Figure 2 shows the part of the digital images before and after deformation. The displacement of the subset on the image before deformation is found in the image after deformation by searching the area of same light intensity distribution with the subset. Once the location of this subset in the deformed image is found, the displacement of this subset can be determined. In order to perform this process, the surface of the object must have a feature that allows matching the subset. If no feature is observed on the surface of the object, an artificial random pattern must be applied. Figure 3 shows a typical example of the random pattern on the surface of an object produced by spraying paint. The above concept is common among other techniques in digital image correlation [10–12].

**Figure 1.** Setup for displacement measurement using digital image correlation [10].

**Figure 2.** Illustration of a reference subset before deformation and target (deformed) subset after deformation [10].
Figure 3. Example of random pattern on specimen surface.

Based on the above basic concept, several functions exist to match the subset from one image to another. One is the magnitude of intensity value difference as:

$$R(x, y, x^*, y^*) = \sum |F(x, y) - G(x^*, y^*)|$$  \hspace{1cm} (1)

and another is the normalized cross-correlation as:

$$C(x, y, x^*, y^*) = \frac{\sum F(x, y)G(x^*, y^*)}{\sqrt{\sum F(x, y)^2 \sum G(x^*, y^*)^2}}$$  \hspace{1cm} (2)

where $F(x, y)$ and $G(x^*, y^*)$ represent the gray levels within the subset of the undeformed and deformed images, and $(x, y)$ and $(x^*, y^*)$ are the coordinates of a point on the subset before and after deformation, respectively. The symbol of the summation represents the sum of the values within the subset. The coordinate $(x^*, y^*)$ after deformation relates to the coordinate $(x, y)$ before deformation. Therefore, displacement components are obtained by searching the best set of the coordinates after deformation $(x^*, y^*)$ which minimize $R(x, y, x^*, y^*)$ or maximize $C(x, y, x^*, y^*)$. Functions except for Eq. (1) or (2) can be used, however, the normalized cross-correlation (Eq. (1)) is widely used for matching the subset in digital image correlation [11, 13].

2.1. Advantages and disadvantages of 2D DIC

Compared with the interferometric optical techniques used for in-plane deformation measurement, the 2D DIC method has both advantages and disadvantages [10, 12–14].

Advantages:

1. Simple experimental setup and preparation of specimen: There is needed only one fixed CCD camera to record the digital images of the test specimen surface before and after deformation. If the natural texture of a specimen surface has a random gray intensity distribution, then specimen preparation is unnecessary or can simply be made by spraying paints onto the specimen surface.

2. Low requirements in measurement environment: 2D DIC does not require a laser source of light. A white light source or natural light can be used for illumination during loading. Therefore, it is suitable for both laboratory and field applications.

3. Wide range of measurement sensitivity and resolution: Since the 2D DIC method deals with digital images, thus the digital images recorded by various high-spatial-resolutions digital image acquisition devices can be directly processed by the 2D DIC method. For example, 2D DIC can be coupled with optical microscopy, laser scanning microscopy (LSCM), scanning electron microscopy (SEM), atomic force microscopy (AFM) and scanning tunneling microscope (STM) to realize microscale to nanoscale deformation measurement.
Disadvantages:
(1) The test planar object surface must have a random gray intensity distribution.
(2) The measurements depend heavily on the quality of imaging system.
(3) The strain measurement accuracy of the 2D DIC method is lower than that of interferometric techniques and is not recommended as an effective tool for non-homogenous small deformation measurement.

More information about system of digital image correlation is possible to find in appropriate literature like [10–23].

3. Experimental measurement of deformation by using extensometer and 2D DIC
Experimental measurement was performed on specimens created by additive manufacturing on 3D printer Mark Two. Specimens were created from Onyx. Onyx is a material based on extremely rigid nylon in combination with micro-carbon fibres. During loading of specimens were used both technologies of measurement deformation, mechanical extensometer and two-dimensional digital image correlation system. Figure 4 shows the experimental setup and its elements for 2D DIC system. Onyx has a black surface and therefore for DIC technology it was necessary painted monitored surface with a white colour and then create black points with spraying black colour to crate random pattern on specimen surface. By spraying white colour to create white points on black surface of material there was problem with light intensity (gray level). Figure 5 shows the prepared surface of specimen for two-dimensional digital image correlation measurement.

![Experimental setup and its elements for 2D DIC system.](image-url)
For comparation between displacement measured by extensometer and by 2D DIC technology were performed 2 types of tensile tests. In first case were specimens loaded up to break and with speed of loading 10 mm min$^{-1}$ and in second case specimens were not loaded up to 1500 N and with speed of loading 0.5 mm min$^{-1}$. In both cases the deformation was monitored by extensometer and 2D DIC. Figure 6 shows graph of strain-stress dependence for ultimate force for both technologies. Figure 7 shows graph of strain-stress dependence for 1500 N force for both technologies.

Figure 5. Prepared surface of specimen for DIC measurement

Figure 6. Stress-strain graph for ultimate loading.
Figure 7. Stress-strain graph for 1500N load force.

3.1. Results of measurements

Figure 6 shows a plot of ultimate stress vs. strain for both technology of measurement by ultimate loading and speed of loading $10 \text{ mm min}^{-1}$. From the figure, it can be seen that there is very small difference between strain measured by extensometer and by 2D DIC technology.

Figure 7 shows a plot of stress vs. strain for both technology of measurement by loading up to 1500 N and speed of loading $0.5 \text{ mm min}^{-1}$. Form the figure, it can be seen that there is very small difference between strain measured by extensometer and by 2D DIC technology.

4. Conclusion

Measurement properties of materials can be performed by different technologies. 2D DIC technology is becoming popular and widely used. Measurement can be performed easily, because this technology does not need the complicated system. According to series of tensile tests which were performed on specimens with different speed of loading, it can be arranged that the 2D DIC measurement is precise and change speed of loading has not significant impact on measurement by 2D DIC. Based on these results the 2D DIC can be used for determining the deformation field and characterizing the deformation mechanism of materials. Young’s modulus, Poisson ratio, stress intensity factors and others mechanical parameters can be further identified based on the computed displacement field or strain field. In any case it is need to know limits of use this technology, advantages and disadvantages of this technology for suitable use.

The authors also plan use DIC technology to determine Poisson ratio for different structures which is possible to create by additive manufacturing.

5. References

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