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Bi-axial fatigue analysis by stereo-correlation measurement

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Abstract. This paper deals with the development of an experimental method to make measurements by the digital image correlation technique during a dynamic test on a bi-axial tensile system. The aim of this method is to be able to cover a complete cycle of a dynamic test, regardless of its form and to follow a position during a long time test. Results are presented for different measurement fields.

1 Introduction

The digital images correlation technique (DIC) allows to having results in a large panel of test [1, 2, 3, 4]. Some works have been made on elastomer properties identification by Mistou et al. [4, 5] where DIC performances are used for large deformation measurements. This technique was also implemented to improve the density of results in dynamic test, like vibration of thin wall during high speed machining [6] or for velocity measurement [7]. Secondly, the quality of the DIC technique is investigated in comparison with other optical methods regarding dynamic measurements [8]. These results exploit a high density of information given by the measurement system. Regarding the multi-axial tests, the optical methods are also interesting in their results on simultaneous multiple axis in damages or the identification of mechanical properties for cruciform specimens. [10, 11, 12]. If the DIC technique present many advantage, it is very important to determine the reliability of the testing procedure, especially the speckle pattern quality. In this optic, some studies have been made to improve the speckle pattern characterization [3, 13, 14].

2 Experimental setup

The proposed method to make measurements during a fatigue test is only based on the experimental way. So here is a presentation of all experimental equipments used to provide results which are given in this paper.

2.1 Bi-axial tensile system

A biaxial tensile system is used to create the mechanical solicitation during the fatigue test. This machine is an Instron® 8800 bi-axial. The capacity of this system is 100 kN to each actuators and a frequency until 200 Hz with very small amplitudes. The configuration of the machine is a made for cruciform specimens, and there is no restriction for specimen material. The advantage with the Instron® 8800 is the choice of working with two opposed actuators working together (Modal mode) or not. In the modal mode, the software is set up to program a displacement on the deformation (no displacement of the center point) or the translation or the both for each axis of the test machine. Thus, there is a very large panel of possible cycle. The Figure 1 presents this bi-axial testing machine. For advanced applications, outputs are available to trigger external equipment on the system signals, like load, displacement, number of cycles. This functionality was very useful to work on the synchronization between various systems in this study.

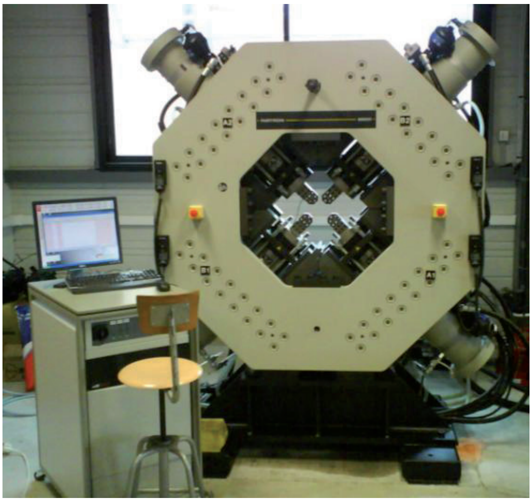

Fig. 1. Instron 8800 bi-axial fatigue tensile machine

2.2 Lightening system

Measurements during dynamic tests require specific equipment for the lightening. Indeed, it is necessary to provide sufficient light at the right moment to fix a position at a deformed state. For this study, the illumination is made by a stroboscope which can generate a flash until a 10 kHz frequency. The stroboscope is trigged to the bi-axial test machine for the synchronization, which is managed by the Instron software. At a specific voltage level receive by the tensile machine, the stroboscope triggers a flash. This level is fixed arbitrary at 2.5V.

2.3 Digital image correlation

The digital image correlation equipment used is the GOM® ARAMIS [15] package included the ATOS® mobile system constitute of two digital cameras capable of shooting eight images per second, associated to the ARAMIS® software, which make the correlation of numerical images and the computation of results. It consists in recording with two cameras some digital images of a specimen undergoing a deformation state (steps of a load cycle) and computing the image correlation by appropriate software. Before the test, a speckle is made on the specimen surface to allow the discretization of this surface in many correlation windows. For each step, the displacement of each correlation windows is calculated in relation with the previous step. This technique allows to determine the cartography of the displacement and the deformation during a test with a good accuracy.

3 Applications

The following application is the support of this study. It is a fatigue test with a sinusoidal signal. There are several objectives to be achieved during this experiment. The major is to be able to determine the displacement at all positions on the sinus signal. Especially, it is interesting to follow the maximum displacement of the test at different times in the fatigue test.

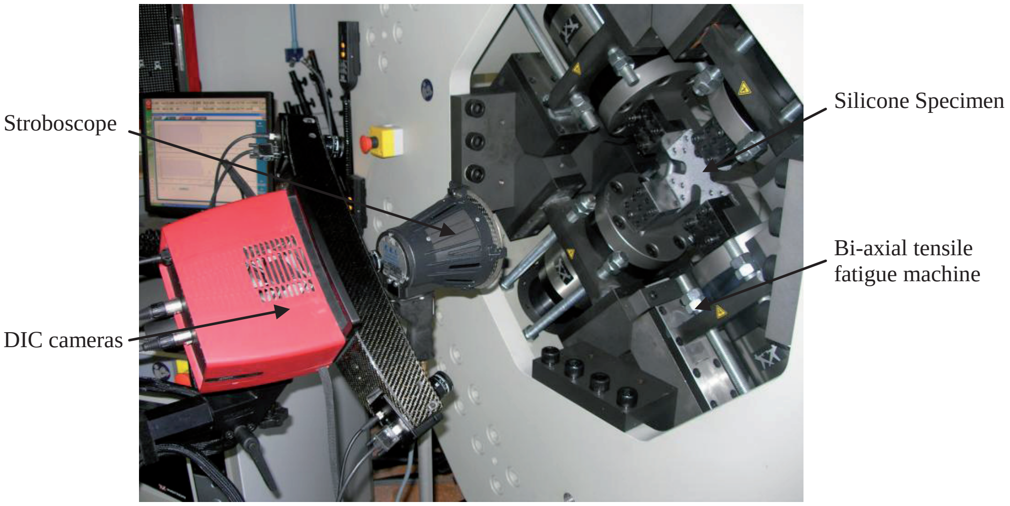

Fig. 2. Photo of experimental setup

3.1 Specimens

In order to exploit capacities of the DIC technique, we choose to work with a silicone specimen. It allows to easily having results in large deformation. The material is a RTV silicone with a 33 Shore A hardness. The design of this specimen is corresponding with the bi-axial cruciform tensile machine.

Fig. 3. Cruciform silicone specimen

3.2 Speckle pattern characterization

In order to anticipate the quality of correlation results, a works in relation with the speckle pattern characterization is made. Criteria are the grey value distribution and the average size of speckle. The tool used to study the quality of this speckle is a software developed by Fazzini [3] in the LGP laboratory called Autocorr. The Figure 4 and 5 respectively plot the grey value distribution and speckle size repartition. The major result of this work is the determination of the correlation window size, corresponding to 16.3 pixels. This value is based on the average radius of speckle, corresponding to the half height of the autocorrelation function.

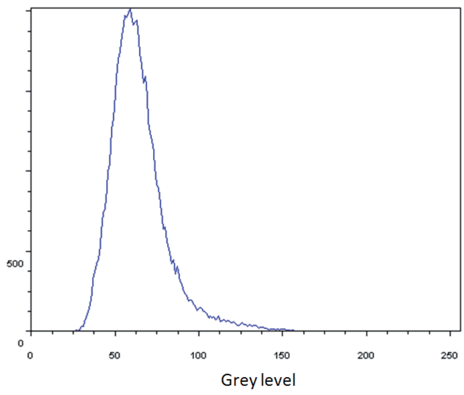

Fig. 4. Grey value distribution

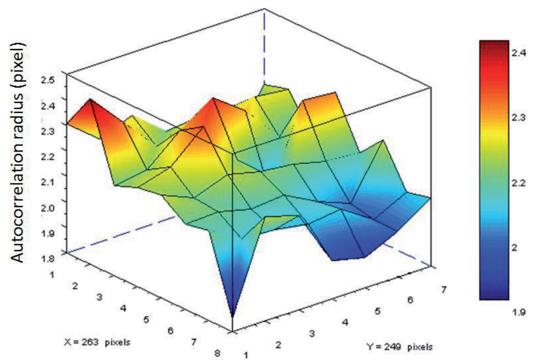

Fig. 5. Speckle radius repartition

Figure 4 show that images are mostly dark. The speckle pattern is manually made with black and grey paint sprays on initial white colour. Other, the speckle size is quite regular over the specimen surface, it is shown by the Figure 5.

3.2 Sinus cycle

The signal used to make correlation test in fatigue is a sinusoidal form with 6 mm amplitude and 5 Hz frequency. This signal is an arbitrary choice and has no real physical signification, except the tensile solicitation of the silicone specimen. The graph of this sinus solicitation is shown on Figure 6.

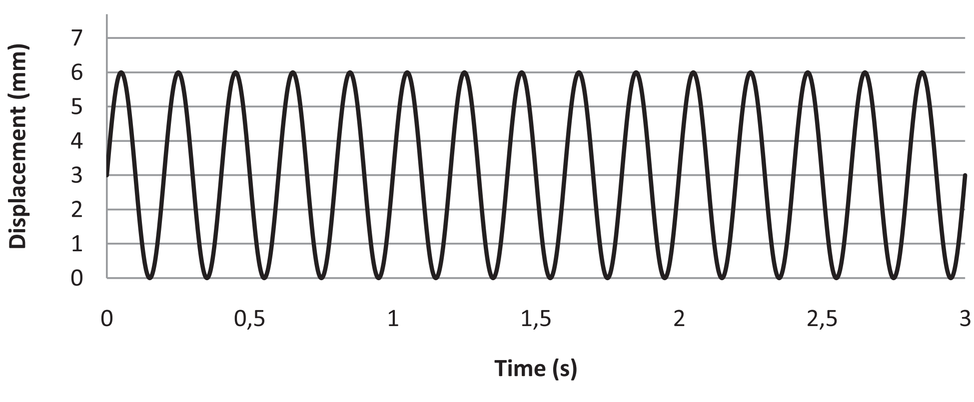

Fig. 6. Sinusoidal displacement cycle

3.3 Synchronization

The major problem to develop this method is to obtain the right synchronization between all equipments: DIC camera, stroboscope and bi-axial tensile machine. Where every system are connected and trigged, during the fatigue test, we observed a phase shift between the stroboscope flash and the maximum position on the sinus signal. The delay can be attributed to the transfer of data and their treatments. The Figure 7 describes the synchronization issue by the plot of different signals versus time.

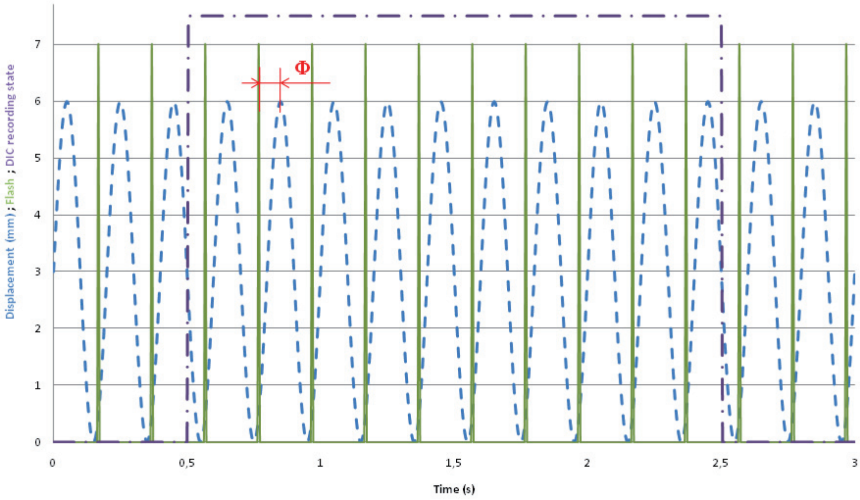

Fig. 7. Graph of synchronization issue

Both approaches have been discussed to have the right configuration. The first approach is the analogical way. Indeed, by the known of the stroboscope flash voltage level S_F, the full scale S of the tensile machine output signal (0V-10V) and the maximum displacement U_{max}, we are capable to determine the phase shift Φ between the flash time and the maximum position time, by the following equation.

$$U_{max} - \left(\frac{S \times S_F}{10}\right) = \sin[(\Phi + 270) + 1] \times \frac{U_{max}}{2} \tag{1}$$

This method provided approximate results very quickly. By the numerical application of the equation (1), the phase shift Φ between the flash and the maximum displacement was estimated at 156.4°.The second approach is an experimental evaluation of this phase shift. This method requires the integration of a numerical oscilloscope in the measurement loop, to receive two output signals: the tensile machine displacement and the stroboscope flash. Figure 8 presents a schema included all test equipments.

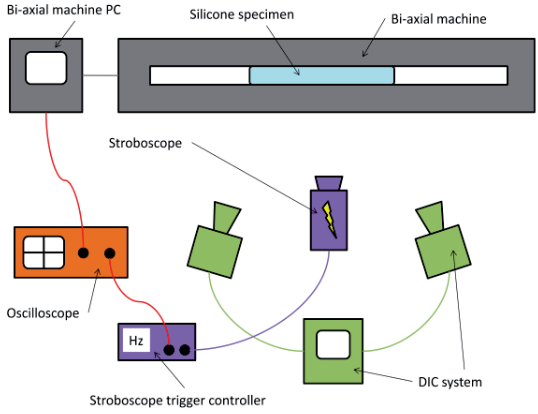

Fig. 8. Schema of experimental equipments for phase shift determination

By the fitting of the maximum stroboscope signal, corresponding to the flash, on the maximum displacement, we ensure the right phase shift setting. Φ is set by the stroboscope trigger controller, indeed it is possible to put a phase shift from 0° to 360°. The optimized value for the phase shift was determined at 116° Thus, we are able to follow the maximum displacement U_{max} position during a fatigue test. The Figure 9 illustrates this result and shows that the technique used allows well to follow sinusoidal displacement.

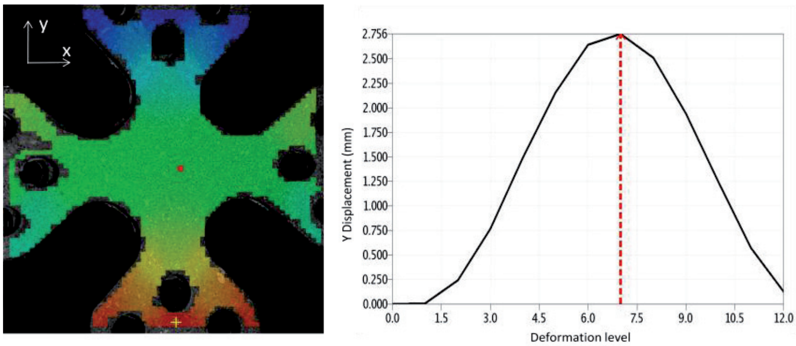

Fig. 9. Results of correlation with phase shift synchronization

3.4 Results

In order to validate the dynamic stereo-correlation method, here is a review of the different kind of results available after a fatigue test using a sinusoidal signal of 6 mm amplitude a 5 Hz frequency on a silicone cruciform specimen. Figure 10 show that the deformation value is completely available on all the specimen area. It is the same for displacement X, Y and Z, and Euclidean shown by Figure 11. The two last Figures 12 and 13 show the distribution of major deformation and Z displacement along a section of the specimen for each step of the testing cycle.

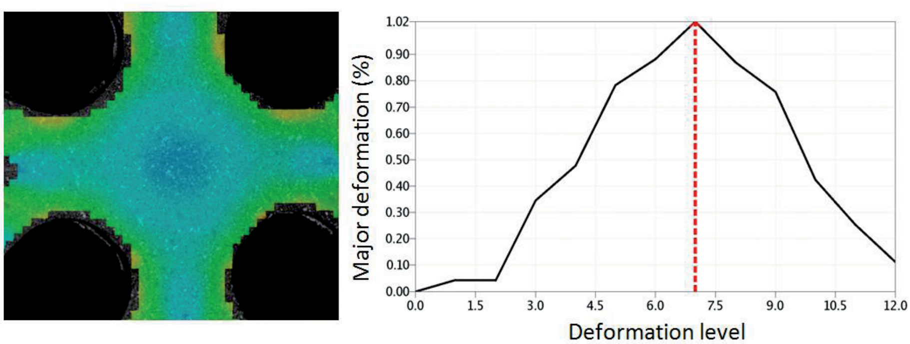

Fig. 10. Major deformation (%) at the maximum amplitude

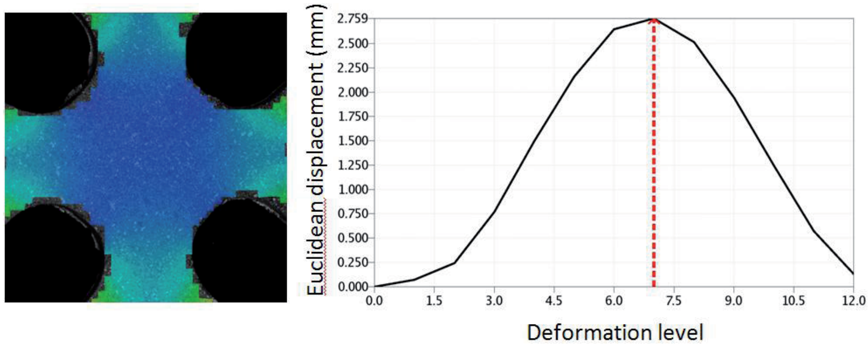

Fig. 11. Euclidean displacement (mm) at the maximum amplitude

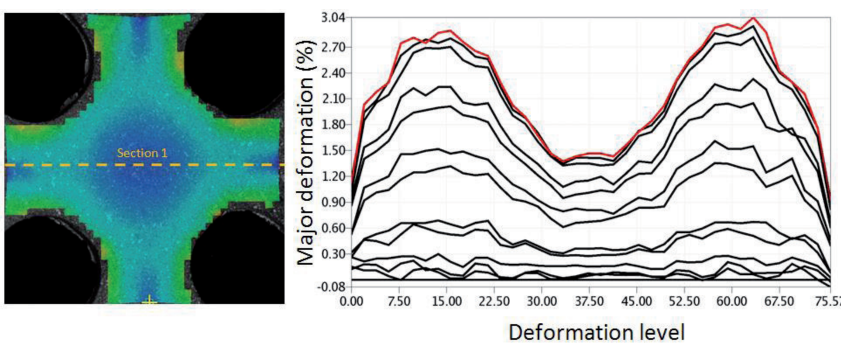

Fig. 12. Distribution of major deformation (%) along Section 1

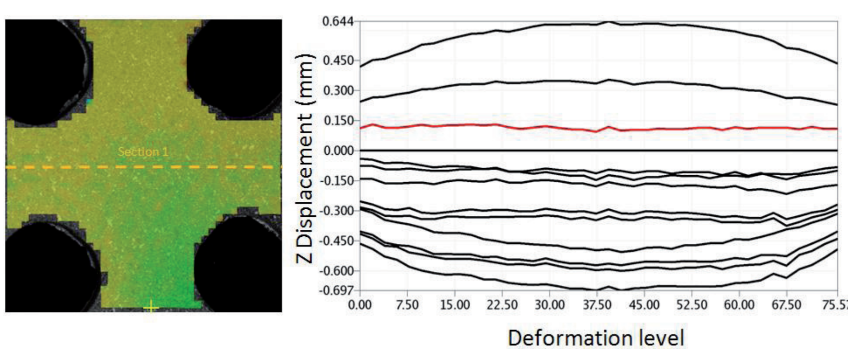

Fig. 13. Distribution of out of plane Z displacement (mm) along Section 1

4 Conclusions

An experimental method has been developed to make displacement and deformation measurements with the DIC technique during a dynamic sinusoidal fatigue test. This method uses the capacity of stereo correlation equipment to be trigger on a bi-axial tensile machine. A stroboscopic light was used to be able to make measurements at a very accurate position on a sinusoidal displacement. A work was made on the synchronization between DIC software, tensile machine and stroboscope, to determine the phase shift imposed on the stroboscope flash to make measurements at the good cycle position. Thus, the following of the maximum position, or any other, during a very long time test is possible. Perspectives of this study are the determination of fatigue life properties of a specimen with a bi-axial solicitation. The quality of DIC results will be very useful to create a numerical model and to correlate it with these experimental results.

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