Development of Optimal Speckle Patterns Through Digital Image Correlation Technique

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Abstract: -Digital image correlation plays a dynamic role in aerospace industry due to its comparative affluence of application and developments in digital cameras has been the supporting these technologies for this process and full-field optics have played the major tactic. This technique was initially developed in 1980s and various researchers has investigated this procedure in structural analysis of specimens. It is generally used for experimental measurement probably for surface displacement investigation in solid mechanics. The objective of this technique suggests the prospect to control full-field displacement at the surface of specimen during any process of loading. It is designed for ideal usage of the method the objective here is covered with speckle pattern. In this paper, the effectiveness of a random speckle image and its outcome on the measured in full-field displacement with reference to the facet size is optimized for this study each speckle image gets transformed numerically and deformation are measured with open source DIC software.initially the optimal patterns are developed through MATLAB software and gray scaling and noise addition are done to the images to smoothen The calculated displacements are equated and its investigated that the measure of speckle image and its spectral property along with the measure of the used pixel subset impacts accurateness of the calculated displacements.. tensile loading is added to the pre-processed patterns and through high-speed camera the patterns are captured and post-processing of structural analysis is done in GOM correlate software and strain rate are calculated accordingly to increasing rate of strain was observed with different patterns through which the effectiveness of speckle patterns was observed. Characteristics of speckle patterns were also observed and its spectral density was also monitored and it's concluded that maximum deformation occurs when spectral density was increased to optimize the speckle patterns.

Keywords*:* DIC; Speckle pattern; subset size; full-field strain.

1. Introduction

In the last centuries optical measure systems have substantial technology-based advance and accessibility. Many photosensitive procedures have been established for that purpose, such as optical interferometry, high-resolution and coherent gradient sensing digital speckle correlation technique, texture correlation, computer-aided speckle interferometry and electronic speckle photography. This method permits analysing the mechanical behavior of materials through selective loading terms and is been used through many industrial fields. Usually, the DIC procedure have been established in 1980's and meanwhile the procedure is widely been investigated by many researchers. Lately, improvement in pattern optimization is at condensed length measures have oppressed minimal synthesis approaches as computer-generated random speckle patterns produces appropriate surface contrast for DIC. Generally, DIC depend on outcome of extreme correlation subset among pixel range arrangement facets on many equivalent patterns and it obtains the numerical translational modification among them. Its' probable for approximate shifts for better resolution pattern over the resolution of reference patterns,which is frequently known as "sub-pixel" process since the calculated shift is lesser than the numerical pixel unit. This paper presents the work on basis of the effectiveness of a random speckle image and its effect on the calculated full-field displacements along the facet size of the pattern. For obtaining the numerically optimized speckle images to needs to have appropriate surface distinction. Application of finer powdered particles has electrostatic effect observe the surface of image and could be numerically traced in one method. As for alumina surfaces finer alumina coarse enhancing powder was primarily cast-off subsequently the element measures are moderately well controlled, while tendency to Alumina surface were not clear and particles tended to cluster disproportionately. A light alumina particle needs to be applied at rear section of the loaded sample and its observed that bigger elements could be gusted lightly. Enduring elements would have better tendency to the surface. Although the resulting surface contrast is not good for correlation technique, the intensity proportion amid the specimen and offers exclusive opportunity to trace particles among repeated digital patterns obtained. For execution of a DIC measurement, typically the surface of the test patterns prepared with suitable pattern.

From the centre of the subsets in the camera images coordinates are obtained with the help of the standardization data after the DIC sensor. The identification of corresponding subsets in the camera images and through all images over time is done in the sub-pixel range, thus, leading to higher accuracy as related to just the pixel scaling. The spatial tenacity is definite as field of view between the facet point and pixel range at the CMOS sensor captures the specimen accurately with proper time shift. The resolution of the sensor is typically improved through imbrication of the facets resolution. Lens range, lightning are also critical parameters for DIC analysis**.** Larger sized speckle showed narrow deviation so medium sized speckle were preferred here. Numerically simulated speckle patterns are created through mat-lab software by giving set-resolution and subset size of 15 X 15 step size ranges from 5 X 5

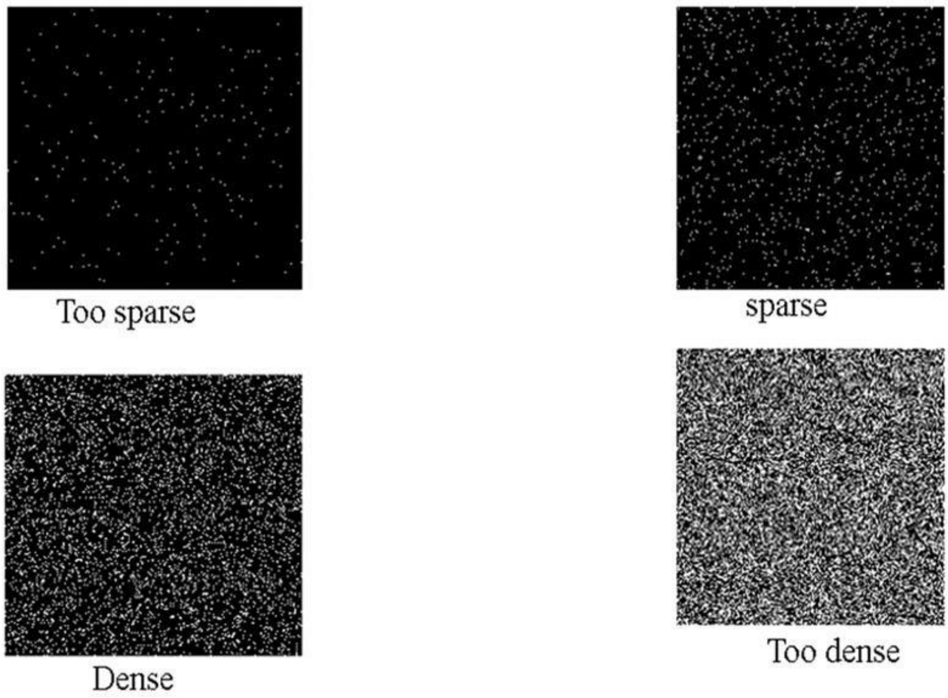


Figure 1 Numerically generated speckle pattern

Figure 1 depicts randomly simulated speckle patterns, in too-sparse pattern the deviation is more as the speckle are widely placed might result in noisy data. Dense pattern medium speckles are placed and spatial distribution is good in sparse patterns small sized speckles gives better displacement contour

2. DIC Overview

Initial hypothesis of correlation measurement is to determine whether captured patterns are attained instantaneously. To carry the experimental procedure selection of camera is important criteria. The c-mount lens has strong camera mounting facility which is essential for DIC process as the camera would be positioned in either direction and it procures out of plane displacement. The light sensitivity of the camera depends on the pixel magnitude and sensor. Enlarged pixels will be excessive light-penetrating and have lesser disruption.

Though, with bigger pixels, as the tenacity rises the intensity becomes huge for most typical lens. The lenses are designed on basis of their attributes where field of view is prime factor in lens selection, if the field of view is no proper it might lead to lens distortion. For 2D procedure mostly tele- centric lens which possess high quality is better option as it calculates Z-plane displacement. But it mostly results in displacement error as it has camera on either positions. Typically, the field of view could be increased through zoom lens which is important measure for resolution purpose.Every speckle pattern has its own lightning criterion as due to over heating the pattern could get disrupted. Lightning mostly depends on its grey level intensity added to pattern. Through CMOS camera this could be identified. It also depends on pattern contrast and mostly LED

lightning is preferred for speckle measurement as it produces low heat**.** Grey level distribution is major factor in this process as it also depends on pattern contrast. By filtering process, the speckle size could be measured as the pattern contrast is quite visible. Here the directionality of speckle plays major role as it affects the subset size during surface creation. Contrast region needs to be corrected for analysing the speckle for better displacement contour. During the experimental procedure likely when spray painting is used the contrast vary significantly due to its pain coat as finer speckle coating is suggested for better contrast of pattern. Based on the number of pixel arrangement the contrast vary as when open-source software is used for post- processing process the contrast vary more as the subset could be increased or reduced based on type of testing calculation. Likely for tensile testing procedure high contrast of pattern is suggested. The contrast could be increased by addition of speckle noise to the pattern as each type of noise has its own variance the pixel dimension also varies by addition of nozse variance to pattern.

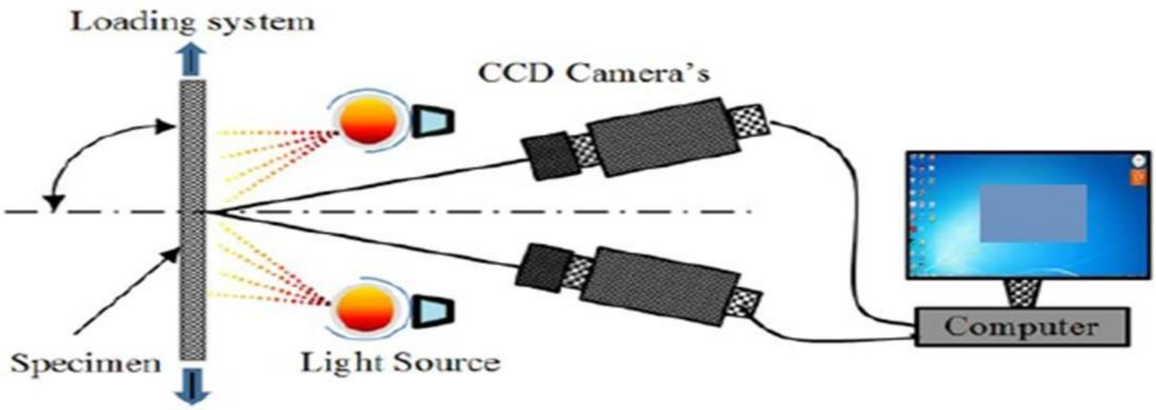


Figure 2 experimental DIC setup

3. Image transformation

Figure 3 depicts fast Fourier transform is applied to transform images spatial and frequency domain for improved computational speed. By doing the Fourier transform identify the deviations in image processing operations in terms frequencies contained in the image. As the images are in their spatial domain initially after applying the fast – Fourier 2D technique / shift and analyze the image in its frequency domain space as it has a greater computational speed and provides better displacement results in post – processing stage.13 translated images were obtained with standard deviation of various subset size 7 X 7, 13 X 13, 27 X 27 pixel dimension.

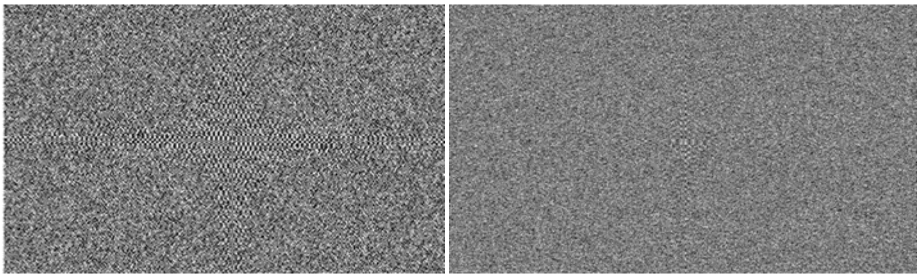


Figure 3 fourier translated images of sparse and dense pattern

To enhance the patterns further grey-scaling and noise addition are done as the contrast of the pattern improve, the speckle sharpness increases for edge detection the grey level indicates brightness of pixel and gives luminance to each of the pixel. Using the matrix to grey scale conversion method gives the grey level images filter does the smoothing of the images which reduces the amount of intensity variation between the neighboring pixels. The contrast varies from black at the lowest intensity to white at the strongest. The grey level to Color Transformations of each color can be a dependent/independent function of grey level. Grey range resolution implies to the probable variation in the shades or levels of grey in an pattern as grey level resolution is equivalent to the amount of bits per pixel. Grey scale conversion to images gives great brightness and increases luminance and makes the pattern quality better for post – processing. Mostly preferred grey image over RGB because due to complexity over the model. In greyscale image value of individual pixel represents a single sample the quantity of light which, it carries the intensity data.

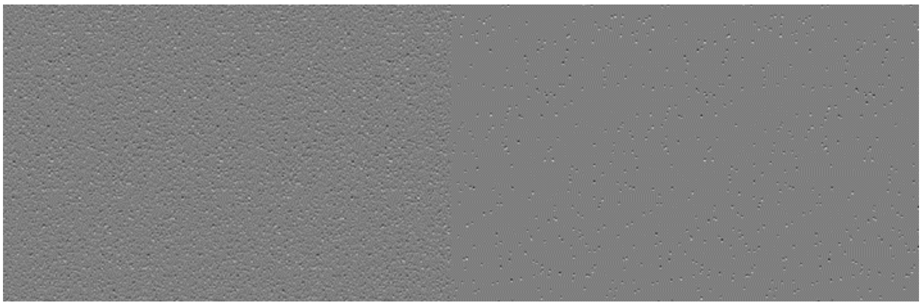


Figure 4 grey level added images

4. Analysis of speckle pattern

Usually in experimental procedure the deformed images are obtained by adding load step at every stage and through CMOS camera the images would be captures. For numerical obtained patterns the deformed images could be created by image acquisition process where the deformed images are created through reference patterns. Through geometric transformation the deformed images are created. The transformation of reference image to deformed image is done.

Through inverse transform function and likewise several deformed images could be obtained in MATLAB software this is also called as inverse mapping function. To obtain the translation matrix, we need to assign the matrix subset with affine2d properties for geometric transformation of the object the translation matrix will change the pattern in horizontal arrangement of pixels. Then to obtain a rotation matrix, it has to store the affine2d inverse transformation object. The translation matrix will rotate the pattern to around 30 degrees and initially deformed image could be obtained. Apply the inverse geometric transformation, inverse form the image will be rotated. Black padding is done to obtain final transformed image.GOM correlate software post-processing is done. Through the surface component creation, the identification of the square subsets could be obtained in a stereo camera setup. The software finds all subsets in the stochastic pattern in all deformation stages. To identify the facets in other camera images (different camera or different stages), the facets must have exclusive grey level arrangement which can be evidently recognized. From each valid computed subset results a measurement point after the calculation of the surface component. The software combines all computed calculated points & track in every deformation stage. The brightness of the pattern quality depends on the brightness of the pattern mapping. the stochastic pattern increases the accurateness can decrease the calculation time by using a varying size. The deformation gradient tensor is separated into a stretch part and a rotational part. The polar decomposing 'F= R.U' offers the two new tensors R and U.R comprises the rotation and U comprehends the stretch. U is called also known as stretch tensor. The stretch tensor comprises the stretch ratios and thus likewise the strains.

The strain ε designates the comparative length alteration of an element. The strains in X and Y directions are always calculated in material coordinates. Material coordinates are 'local coordinate systems' which move organized with the material. Thus, each point the material has its individual coordinate system, the spatial and the temporal filter for an element can be computed. Relative strain check is done. we can optimize how fast the strain is varying over time. the displacement rate conferring to which the object elongates over a certain period of For computing the strain rate, the stages with precise stage times involving to the measurement. Generally, the strain rate is calculated through the time derivative of the strain shown in figure 5.

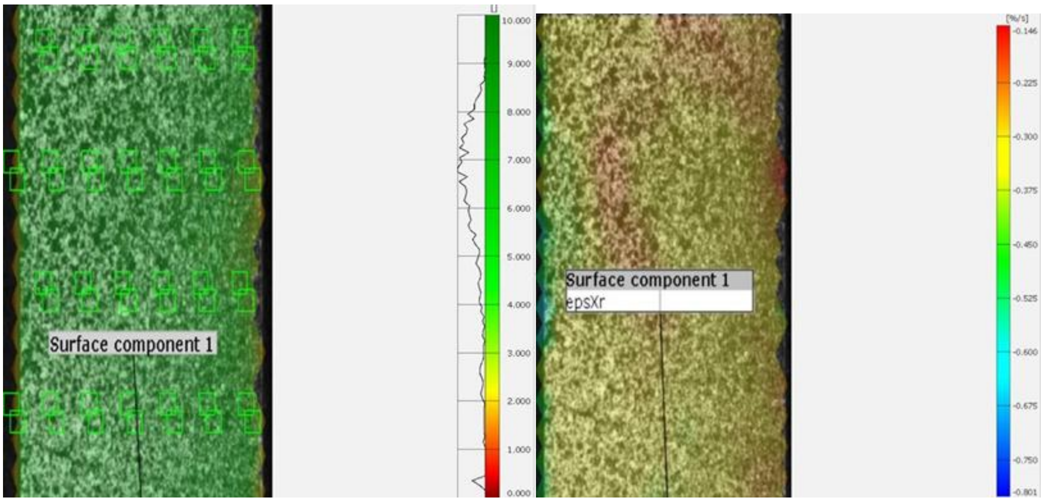
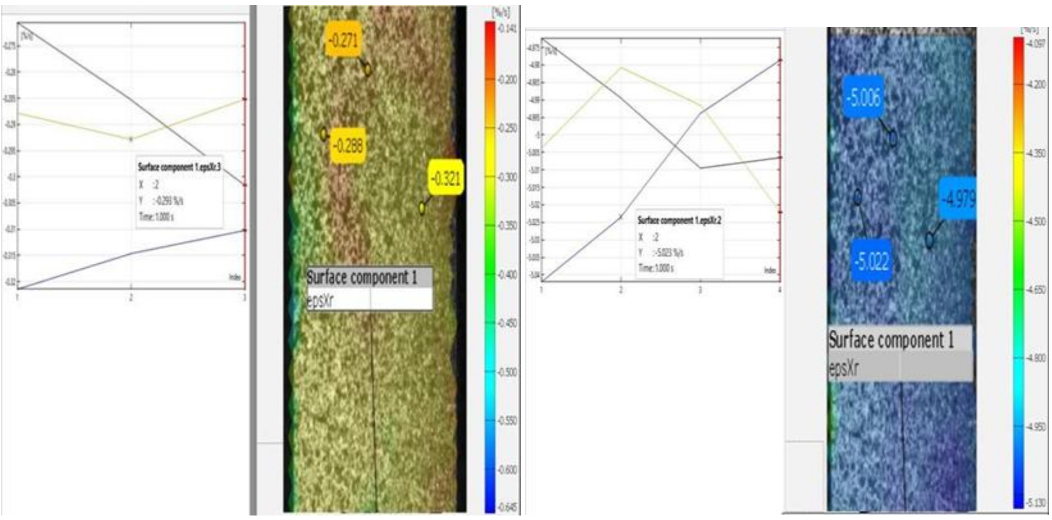


Figure 5 surface component creation and strain check for pattern

5. Results

The statistical values show the mean & standard deviation of pattern could be analysed through calculate the transformation. The Strain representation describes the unit against fixed range the software basically uses a fixed value. Coordinated to the check describes above, there are further checks with which could be determined through statistical values (maximum deviation, arithmetic mean, etc. for a component or a surface component region. In a similar way iteration could be done by varying facets by adding the deformation stages and by gradually increasing the fixed value of the epsilon rate. The strain rates are varied from 3% to 9% and we could see how fast strain travels at 0.1s time shift. Figure 6 shows the various deformation contour of numerical controlled patterns pattern created & as the strain rates are varied its observed at 3% and 5% rate how fast strain travel at 0.1s time shift and less deviation occurs as the spatial distribution is uniform with small sized speckle and at 7% and 9% strain rate maximum deformation occurs as medium sized speckles are used.



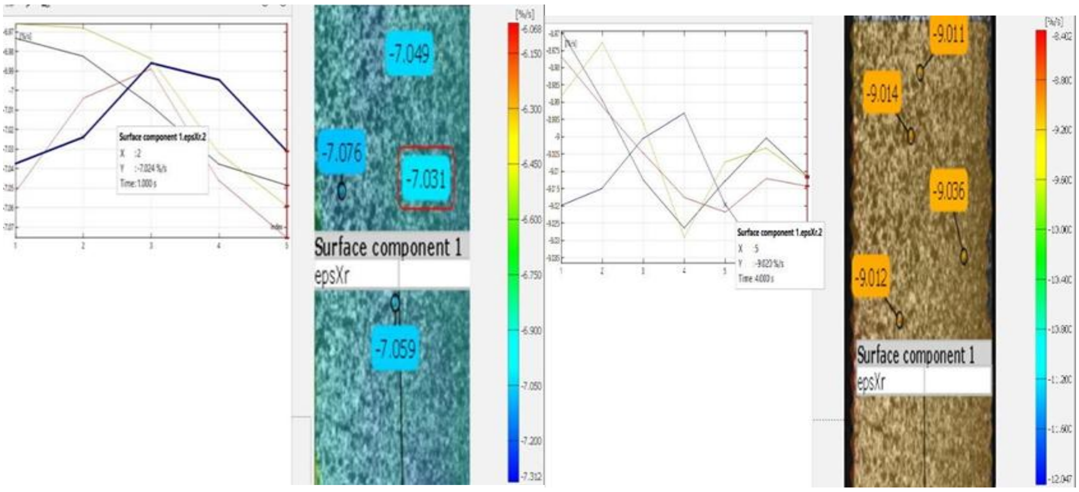


Figure 6 deformation contour of pattern at 3%, 5%, 9% & 10%

6 Discussion

From this paper it's studied about the fundamentals of DIC like stereo camera rig set-up, lens selection, camera selection, speckle optimization through MATLAB Software. It's also learnt about how numerical transformation is done through image by Fourier transform and adding grey level to patterns. It's also analyzed how deformation images are created through the reference images and also of post-processing is done through GOM correlate software. Strain contour is obtained through post – processing of these images and some iterations are done by varying the subset or facets points, epsilon rate against the fixed value and by adding deformation stages and it's observed that how fast the strain travels in each stage and length changes against the time and maximum deformation occur when strain rate increased to 9%.which implies that spectral density needs to be increased to optimize the speckle pattern for better enhancement. These patterns could be further used in surface testing in laboratory purposes as the strain rate increases materials like polymer would harden and it may reduce the plastic deformation.

Refrences

[1] E. A. Patterson, E. Hack, P. Brailly, R. L. Burguete, Q. Saleeme, T. Siebert, R. A. Tomlinson, and M. P. Whelan. Calibration and evaluation of optical systems for full-field strain measurement. Opt .las . Eng., doi:10.1016/j. optlaseng.2006.08.012, 2006.

[2] W. G. Knauss, I. Chasiotis, and Y. Huang. Mechanical measurements at the micron and nanometer scales. Mechanics of Materials, Vol.35:217-231, 2003..

[3] N. McCormick, J. Lord, and A. Ive. Towards a fully validated digital image correlation system. In Photo-mechanics 2006, book of abstracts, Clermont-Ferrand, France, July 10-12 2006.

[4] J. Abanto-Bueno and J. Lambros. Investigation of crack growth in functionally graded materials using digital image correlation. Engineering Fracture Mechanics, Vol. 69:1695- 1711, 2002.

[5] S. Yoneyama and H. Kikuta. Lens distortion correction for digital image correlation by measuring rigid body displacement. Optical engineering, Vol. 45(2):1-9, 2006

[6] W. H. Peters and W. F. Ranson. Digital imaging techniques in experimental stress analysis. Optical Engineering, Vol. 21:427-431, 1982

[7] Li EB, Tieu AK, Yuen WYD. Application of digital image correlation technique to dynamic measurement of the velocity field in the deformation zone in cold rolling. Opt Laser Eng 2003;39:479-488

[8] Rae PJ, Palmer SJP, Golrein HT, Lewis AL, Field, JE. White-light digital image cross- correlation (DICC) analysis of the deformation of composite materials with random microstructure. Opt Laser Eng 2004;41:635-648

[9] Lagattu F, Brillaud J, Lafarie-Frenot M. High strain gradient measurements by using digital image correlation technique. Materials characterization 2004;53:17-28

[10] Sun Z, Lyons JS, McNeill SR. Measuring Microscopic Deformations with Digital Image Correlation. Opt Laser Eng 1997;27:409-428

[11] D. Lecompte, S.Bossuyl , S. Cooreman, H. Sol, study and generation of optimal speckle patterns for DIC

[12] Prof. Emanualezappa , Ing paulomazzoleni Novel technique for DIC speckle pattern optimization and generation.

[13] Sutton, M.; Mingqi, C.; Peters, W.; Chao, Y.; McNeill, S. Application of an optimized digital correlation method to planar deformation analysis. Image Vis. Comput. 1986, 4, 143–150.

[14] Chu, T.C.; Ranson, W.F.; Sutton, M.A. Applications of digital-image-correlation techniques to experimental mechanics. Exp. Mech. 1985, 25, 232–244.

[15] Peters, W.H.; Ranson, W.F.; Sutton, M.A.; Chu, T.C.; Anderson, J. Application Of Digital Correlation Methods To Rigid Body Mechanics. Opt. Eng. 1983, 22, 226738

[16] Cofaru, C.; Philips, W.; Van Paepegem, W. Improved Newton–Raphson digital image correlation method for full-field displacement and strain calculation

[17] Hild, F.; Roux, S. Digital Image Correlation: From Displacement Measurement to Identification of Elastic Properties—A Review. Strain 2006, 42, 69–80.

[18] Blenkinsopp, R.; Roberts, J.; Harland, A.; Sherratt, P.; Smith, P.; Lucas, T. A Method for Calibrating a Digital Image Correlation System for Full-Field Strain Measurements during Large Deformations. Appl. Sci. 2019, 9, 2828.

[19] Barranco-Gutiérrez, A.I.; Padilla-Medina, J.A.; Perez-Pinal, F.J.; Prado-Olivares, J.; Martínez-Díaz, S.; Gutiérrez-Frías, O.O. New Four Points Initialization for Digital Image Correlation in Metal-Sheet Strain Measurements. Appl. Sci. 2019, 9, 1619