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STRAIN FIELD MEASUREMENT USING IMAGE PROCESSING APPLICATIONS IN DAMAGE AND FRACTURE TESTING

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Abstract

Accurate experimental observations of the strain field are important in the damage and fracture tests. The measuring technique based on the image processing has been developed and it has been shown useful.

This paper presents recent improvements of this measuring technique. From images taken during loading, homologue points in different images corresponding to the same material point can be determined using the presented method with a sub-pixel precision. It allows for an accurate determination of displacement and strain fields. A series of validating tests show that the presented method offers a precision comparable to that of strain gages.

Two applications in fracture and damage problem are also presented. The strain field at the tip of the crack is measured in the CT (Compact Tension) test for an aluminium specimen. It is also used to measure the strain localisation in a concrete specimen under compressive loading. The comparison between current results with previous ones obtained manually illustrates the pertinence of this method.

Key words: Image processing, experimental measurement, fracture, strain localisation

1 Introduction

Adequate optical methods are often used to observe the strain fields of a specimen or of a structure under loading. The main advantage of those methods lies in the possibility to get a global view of the whole specimen and in their insensibility to the high temperature, to the high pressure, and to the chemical attack. Some optical methods determine the displacement field with the aid of a matching technique between two images. For example, a technique called stereophotogrammetry was successfully applied to measure the displacement fields of concrete specimens subjected to compressive loading (Torrenti and al., 1989). It uses nevertheless the human-vision for the matching.

One of the important goals is to develop an automatic method. For this purpose, an image processing technique based on the normalised correlation has been applied (Franke et al., 1991). However, it fails in many real situations because its precision decreases dramatically whenever the images are quite auto-correlated.

A new image processing method offering a better precision is presented in this paper. Such an automatic method becomes then more robust to be applied to determine the strain fields in the damage or fracture problems.

2 Matching

The main difficulty of those optical methods is to find the matching points corresponding to the same materiel point in two images. Once the matching is found, the relative position of each pair of homologue points indicates displacement field, which allows afterwards for the determination of the strain field.

For a given point in the reference image, the image processing technique based on the normalised correlation defines its homologue point as that having the maximum correlation coefficient. It gives wrong homologue point for very auto-correlated images because the correlation coefficients in this case have not an evident maximum (Pratt, 1974). A new processing technique is proposed to improve the precision of the matching. It consists of three principal steps: images pre-treatment, pixels matching and sub-pixel displacement determination.

2.1 Images pre-treatment

A very auto-correlated image contains often the repetition of the small structures or the great structures which hide the useful details. There exist then a lot of similar pixels in the image, which give the similar values of correlation coefficient.

In order to improve the technique of normalised correlation, it is interesting to eliminate those undesired structures. High-pass filters can be used to eliminate low frequency components, which correspond to great structures, whereas low-pass filters allow for the cuts of the high frequency components which correspond to those repetitive small structures. A pass-band Gaussian-Laplacian filter is adopted in our procedure (Yang, 1992). It gives a much more sharp correlation function. The auto-correlation function before and after the treatment for one image of the concrete (Fig. 1) shows the efficiency of this pre-treatment.

a. before the treatment b. after the treatment

Fig. 1. Auto-correlation function

As the Gaussian-Laplacian filter is in fact an edge localisation operator, the zero-crossing points in the filtered image give the edge points. It is then interesting to convert the filtered images to binary image. The grey value 0 is then used as a threshold. Such a binary image gives an even better auto-correlation function (Nishihara, 1983) and it allows for a more rapid calculation.

2.2 Pixels Matching

In order to find the homologue pixel in the second image for a given pixel **p**(x,y) in the reference image, the correlation coefficients are calculated using two windows of the same size of HxL, focused respectively on **p**(x,y) in the reference image and on the candidate pixel in the second image (Fig. 2).

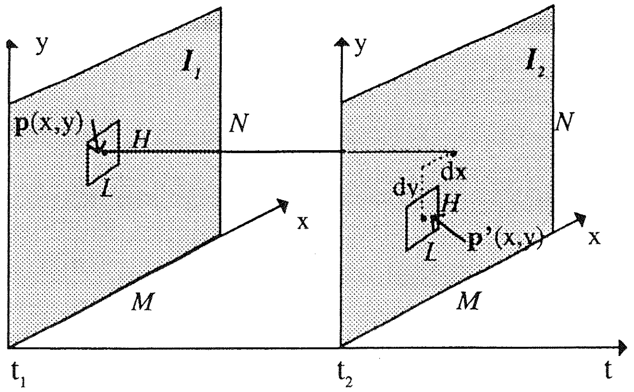


Fig. 2. Pixel matching

The size of those windows should be chosen according to the standard deviation of the Gaussian filter. An important window size would be necessary whenever a great standard deviation is chosen. In our processing a standard deviation $\sqrt{2}$ and a window of 65x65 pixels is proposed.

The correlation coefficient between **p**(x,y) and the pixel having a displacement of (dx, dy) in the second image is defined as follows (Eqn.1):

$$C(x,y,dx,dy) = \sum_{i=-H/2}^{i=H/2} \sum_{j=-L/2}^{j=L/2} (I_1(x+i,y+j) I_2(x+dx+i,y+dy+j)) \quad (1)$$

It is noted that, for a binary image, the realisation of formula (1) is just to count the number of the same sign pixels in two windows. It makes the coefficient calculation very efficient.

2.3 Sub-pixel Displacement Determination

In order to have a better displacement precision; it is supposed that there exists a continuous function of correlation coefficient in the neighbour of the homologue pixel.

The following interpolating function is used in our processing.

$$f(x,y) = a(x-u)^2 + b(y-v)^2 + c \quad (2)$$

With the value of the correlation coefficient at the homologue pixel (**p**') and those at 4 connected pixels (Fig. 3), the location of the maximum of supposed continuous function (u,v) are found. It gives then a sub-pixel matching.

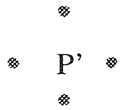


Fig. 3. Interpolation of the correlation function

3 Evaluation of the precision of this technique

A comparison between the presented method and the strain gage is realised to evaluate the precision of the presented technique in the measurement of the strain field.

Tension tests are performed on the specimens of carbon-epoxy composites (T300-174) and of commercial aluminium, using an INSTRON 6022 test machine for the loading. An electronic tube camera is fixed such that the image plan is parallel to the specimen surface (Fig. 4).

The specimen dimension is about 1mm of thickness, 10cm of length and 1cm of width. A strain gage is pasted in the middle and connected to an extensometer that are connected with a printer. The camera is adjusted to get the images of the exact verso-zone where strain gage is cemented.

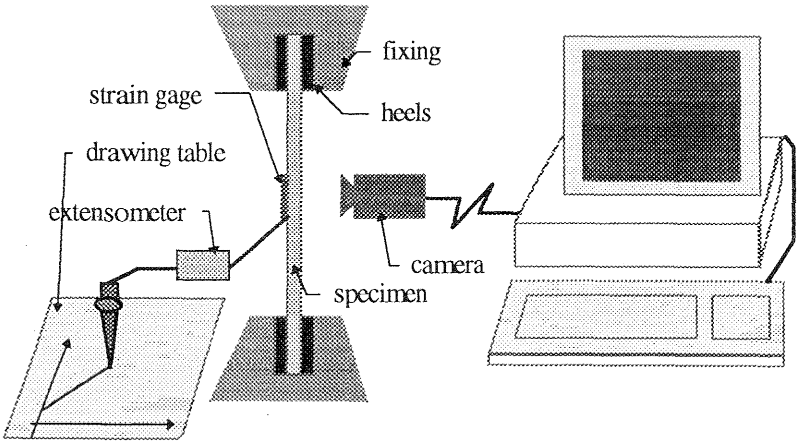


Fig. 4. Experimental arrangement for validation tests

The present image processing technique is applied for a group of 20x20 points, distributed regularly in a rectangular within the image.

Displacements are measured and then used to calculate the average strain of this rectangular. The comparison between the image results and that of strain gage is shown in Fig. 5a and Fig. 5b.

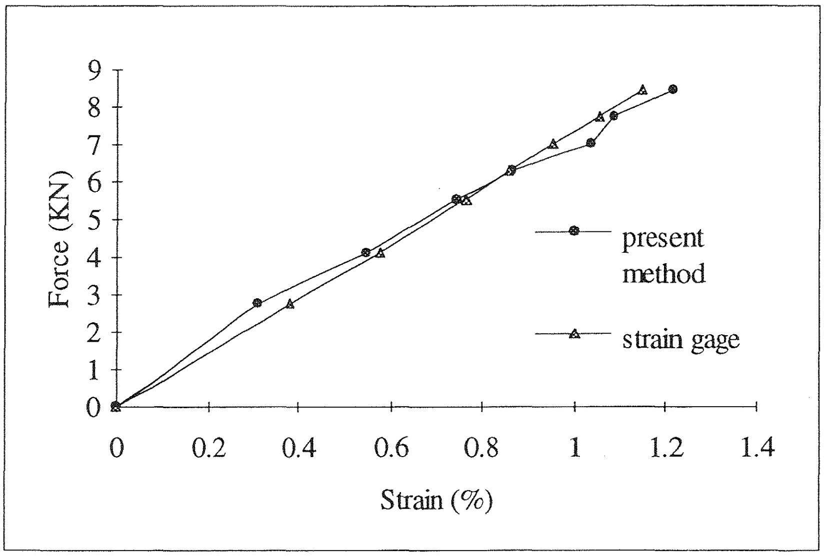


Fig. 5a. Validation test on carbon-epoxy composite specimen

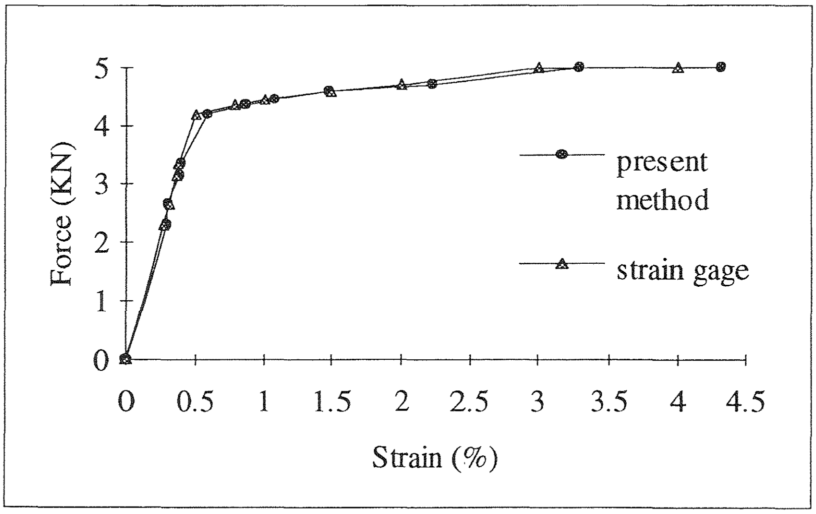


Fig. 5b. Validation test on aluminium specimen

The average difference between the measurement using the present method and that using the gage is 0.038% for the aluminium specimen and

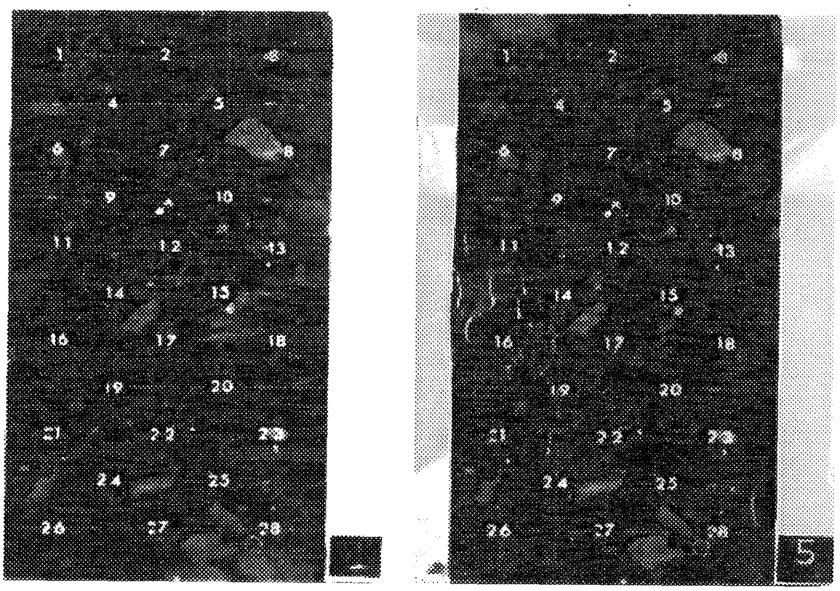
0.0625% for the carbon-epoxy composite specimen, which correspond to a relative difference of 5.57% and 5.97% with respect to the strain gage one.

4 Application to the damage or fracture problems

This technique is firstly applied to study the strain localisation for a concrete specimen under compressive loading. A series of photographs provided by LCPC (Laboratoire Central des Ponts et Chaussées) are digitised in 512x512 pixel and with 256 grey levels. Displacements of regularly distributed points are calculated by the presented image processing method, which allow for the construction of the displacement field. The strain field are then calculated afterwards with a FEM code SAMCEF.

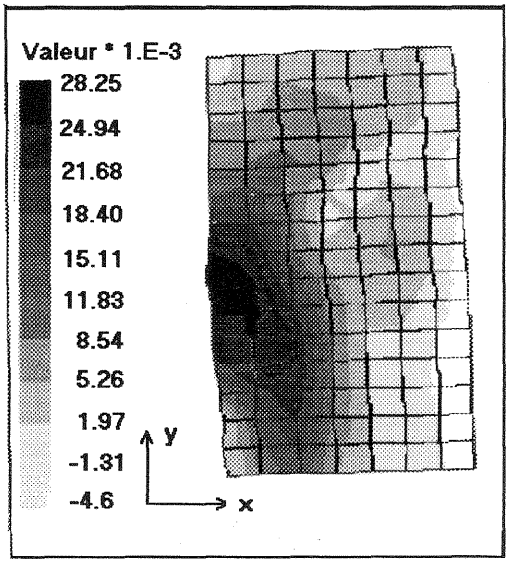
A good coherence has been found between the strain fields given by the stereophotogrammetry and those given by the present method (Yang, 1992). Pair of images where the fracture can be visually observed and the corresponding strain field are illustrated in Fig. 6.

In Fig. 6c, a damage zone in middle left of the specimen has been observed, which correspond to the photograph in Fig. 6b where the fracture can be seen in this zone.



a. Image of reference

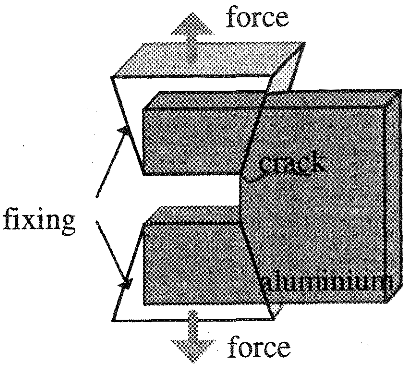
b. Image after loading



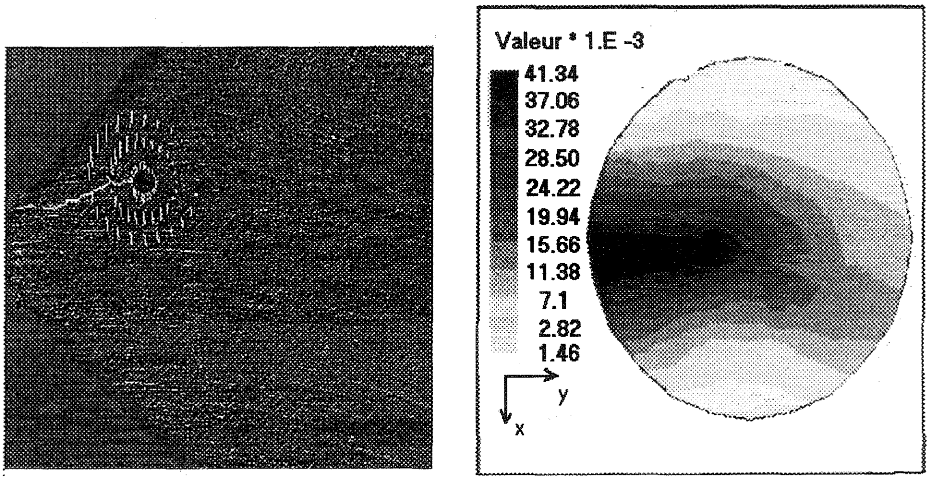
c. Strain field in the x-direction

Fig. 6. Concrete specimen under compressive loading

This method is also applied to measure the strain field at the tip of the crack in a CT (Compact Tension) test for an aluminium specimen. The experimental arrangement is shown in Fig. 7a. Two images were taken before and after the crack appearance in the specimen. The displacement field is superimposed to the image after the crack appearance and shown in Fig. 7b. The strain field in the vertical direction calculated using the code SAMCEF is given in Fig. 7c, where one can see that the crack was detected.



a. Aluminium CT specimen under loading



b. Displacement fields   c. Strain field in the vertical direction

Fig. 7. Aluminium specimen in CT test

5 Conclusion

This paper presents an image processing technique for the measurement of the strain fields. With the images of specimens taken during loading, the displacement field can be automatically determined with a sub-pixel precision, which offers the possibility to measure strain fields in damage or fracture applications.

The validation tests performed in a strain range from 0.1% to 5% show that this technique gives a measuring precision comparable with that of a strain gage. Its applications to a CT test on an aluminium specimen and to the concrete specimen under compressive loading show that this method offers an acceptable strain field measurement in fracture and damage problems.

6 References

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