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Experimental Stress Analysis

Optical methods in use by experimental strain measurement

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Abstract: In fact, the development costs in the industry raise a lot nowadays. Because of it, it is important to use new innovative and cost-reducing development methods. It is useful not to produce the prototypes for all range of problems considering the expensive price. Instead of this, it is more suitable to use long-range simulations for complex movement and deformation procedures. Using simulations, optimizing of detailed constructions is possible and due to this, reducing the development time and minimizing development iterations is caused. But even if the simulations results are correct, they need to be confirmed in tests and maximum load of components should be verified. For this purpose, non-contact, optical measuring systems are used. The process of using cameras for capturing the coordinates respectively the position and displacement of measuring position can give a large advantage to traditional measuring techniques use electronic sensors by reducing the measuring time. The fast adaptation to new measurement setups and the multitude of easy to apply 3D measurement points allow a precise and efficient strain analysis. Furthermore, optical measurement methods enable a visual presentation of measurement results, which makes a result interpretation easy and intuitive. Examples of new optical measurement systems will be given.

Keywords: Experimental, Photogrammetry, Image correlation, Crack, Strain

1. Introduction

Photogrammetry and image correlation are deeply described in several sources [1],[2]. Therefore only roughly explanation about the theory will be given and the focus an a specific application of use of optical measurement systems will be held.

2. Image correlation

2.1. Principle of image correlation

The basis of image correlation is actually very simple. The measuring object (specimen) is covered by stochastic pattern which is usually done by splashing white spray as a background while the black spray is distributed just partially. Then, the specimen is put under the load and the images of measuring area are recorded

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continuously. Wide range of CMOS cameras are in use, depending on measuring frequency or camera resolution. After the loading is finished and the images are recorded simultaneously by two cameras, the software correlation solution comes to turn. The software solution divides the measurement area into small semi-areas, in which the specific number of white and black pixels is counted *("grey index")* (Fig. 1, Fig. 2). The fact that the pattern was made by hand ensure that *grey index* is a unique number and is not repeated in the whole area. In the very next stage, the position of the same area is investigating according to the *grey index* (Fig. 3, Fig. 4). This workflow is done for all overlapped areas in all stages resulting to a nice overview of the whole measurement are. The following examples were created by using the image correlation system ARAMIS[3].

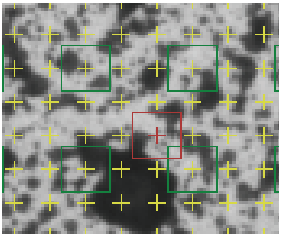

Fig. 1. Undeformed stage – Left camera.

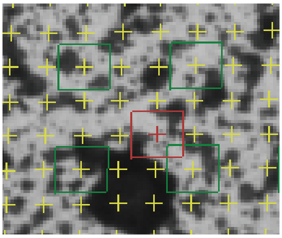

Fig. 2. Undeformed stage –Right camera.

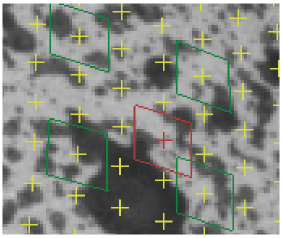

Fig. 3. Deformed stage – Left camera.

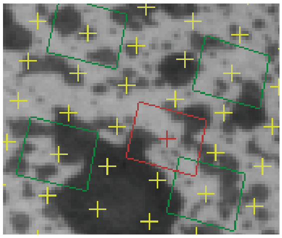

Fig. 4. Deformed stage –Right camera.

2.2. Practical use of image correlation

2.2.1. Fracture mechanics [2]

The forecast of crack propagation and fracture processes requires a high level simulation software and precise definition of boundary conditions. Because of its high lateral and measuring resolution optical measuring system ARAMIS[3] gives an excellent possibility of verifying numerical calculations of fracture processes.

Tests on small specimens (Fig. 5), where grains influence crack propagation, are as applicable as tests with large specimens (CT, SENB, etc.), or furthermore with the inspection of real cracked components.

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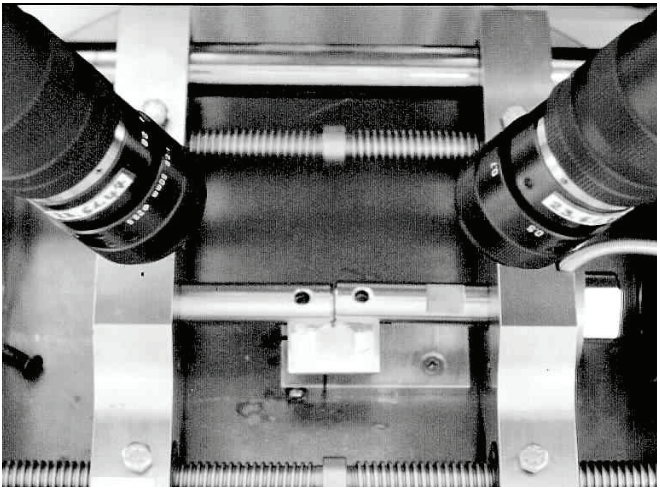

Fig. 5. Set up, (Cameras, specimen W=20mm).

The measuring results are the three dimensional displacements x,y,z (Fig. 7) and the strain tensor. Out of it the distributions epsilon X and epsilon Y can be calculated and graphically shown or exported in an user specific ASCII-format.

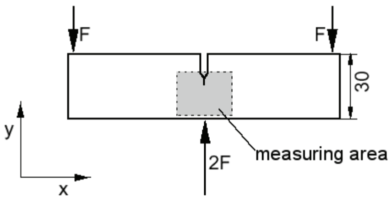

Fig. 6. Specimen with measuring area.

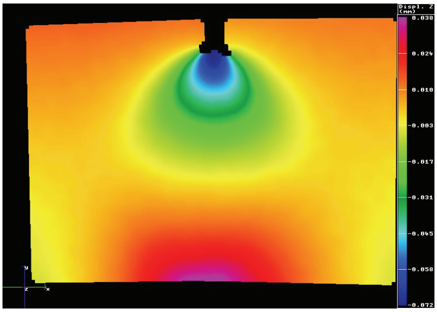

Fig. 7. Z-Displacement.

Fig. 7 shows the displacement distribution in z direction. Direct beneath the crack there is a thinning of material, above the punch the specimen gets thicker.

Fig. 8 and Fig. 9 describe the strain distribution in x perpendicular to ligament. In front of the crack tip a strain maximum occurs. The strain distribution suit to the shear fracture while crack propagation. According to this the strain in y (parallel to ligament) concentrates in front of the tips of crack. Along the ligament compression strain appears in y direction.

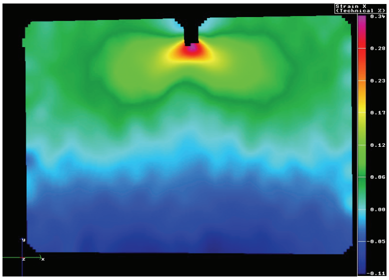

Fig. 8. Strain distribution epsilon X, without crack propagation.

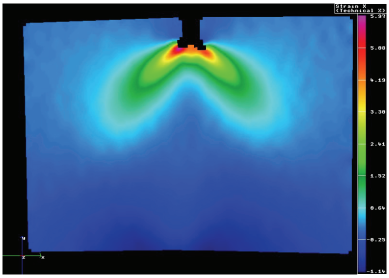

Fig. 9. Strain distribution epsilon X, with crack propagation.

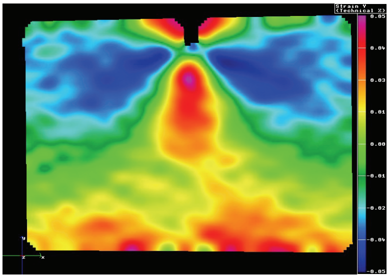

Fig. 10. Strain distribution epsilon Y, without crack propagation.

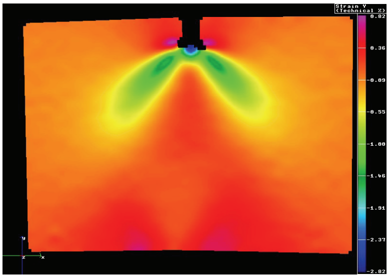

Fig. 11. Strain distribution epsilon Y, with crack propagation.

Furthermore not only the strain distribution also crack propagation on the specimen surface and macro specific values as crack opening displacement (CTOD, CMOD, COD) (fig. 8) can be calculated.

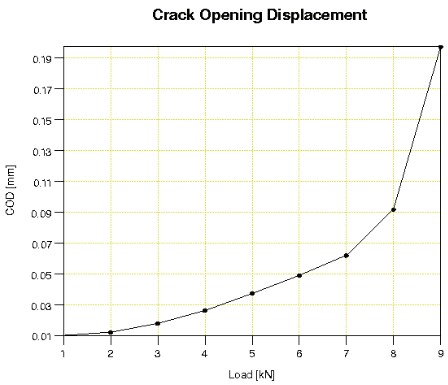

Fig. 12. Set up, (Cameras, specimen W=20mm).

The lateral resolution of the results allows for the assessment of the mesh used for simulation. In addition, tests for linear and non-linear processes are possible because of the high measuring resolution.

2.2.2. Rivet joins under load [4]

Rivets are proven to join aluminum sheets or fasten them to the support structure in light weight constructions.

To install and test a new ordered ARAMIS system in the Testing Technology laboratory of AIRBUS, Bremen, Mr. Torben Kluwe prepared a simple test set-up, consisting of two aluminum sheets (material 3.1364-T3), joined together using three rows of rivets and put under the load in the tensile machine. 90 stages were captured in order to catch the reaction of the jointed sheets.

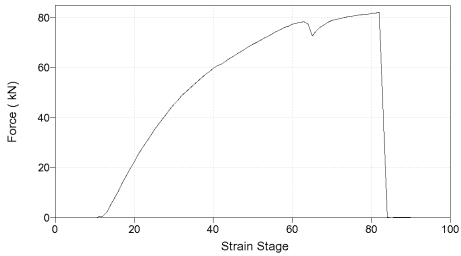

Fig. 13. Load displacement diagram during 90 captured stages.

Fig. 13 shows the resulting load displacement diagram. Immediately visible is the shearing of the rivets shortly after load step 60 and the total failure shortly after load step 80. The deformation of the sample is visible in the captured image series (Fig. 14). However, to get detailed results, the graphical plot of the measured deformation is used. First, the coordinate system of the gathered data was adjusted to the actual measuring set-up and the lower end of the front sheet was used to define the location of zero movement.

Fig. 15 shows the local deformation of the rivets and the asymmetrical and non-uniform displacement of the sheet.

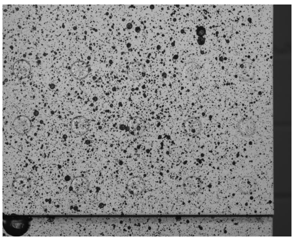

Fig. 14. Sample loaded with 77kN, load stage 60.

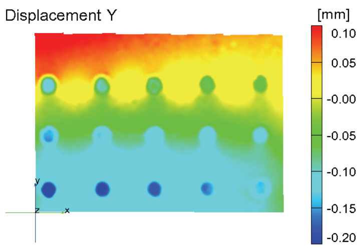

Fig. 15. Relative displacement in tensile direction (Y-displacement), load stage 60.

Masking the rivets shows the deformation of the sheet very clearly. As often in tensile tests of riveted sheet metals, the sample under load starts tilting in Z-direction (vertical to the sheet surface). In vertical direction, only small displacements are measured.

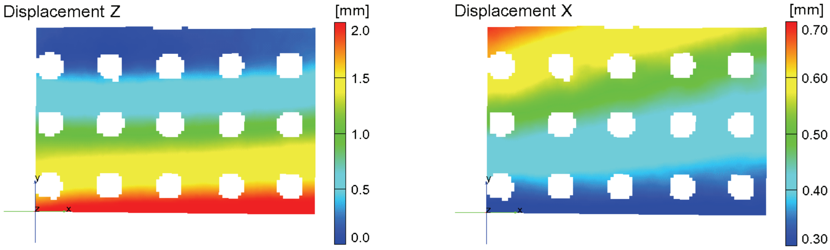

Fig. 16. Deformation values of the load stage 60, referenced to load stage 0. Visible in the left image is the Z-movement (in viewing direction) and in the right image the vertical displacement, in X direction.

Strain data often give an easier understanding of the behaviour of a sample under load. Therefore, figure 6 displays the differentiated displacement values (strain values) of the load stage 80 graphically. For the actual calculation of the strain values in the left image, a short base length of 0.57 mm was used, showing local strain maxima and inhomogeneities. To show the averaged deformation in the sheet metal, a longer base length of 1 mm was used.

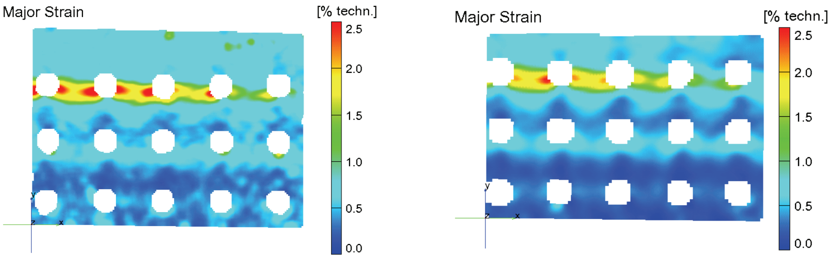

Fig. 17. These images show the major strain at load stage 80, calculated for the left image using a base length of 0.57 mm and for the right image with a base length of 1 mm.

Fig. 18 shows the strain distribution shortly before the failure of the rivets (load stage 80). Clearly visible is pressure-strain in the area of the lower rivets and tensile strain in the area of the other rivets. The area of high strain is caused by the bending of the sheet under load.

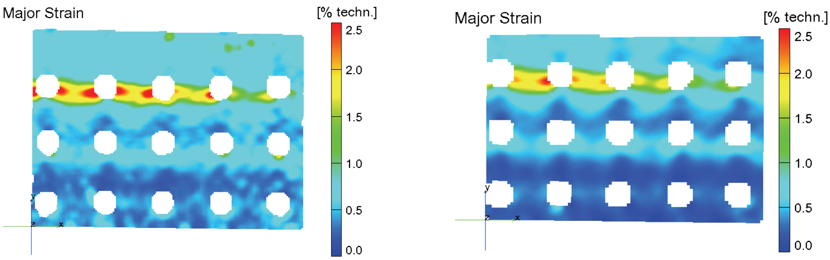

Fig. 18. Graphical display of the epsilon strain values in vertical direction, in the left image at load stage 80 before failure and in the right image, at load stage 84, after failure.

In Fig. 19, the strain values in a section parallel to the tensile direction, as indicated in Fig. 18, is shown. Here, the total strain before the failure and the remaining strain after the complete failure is clearly visible.

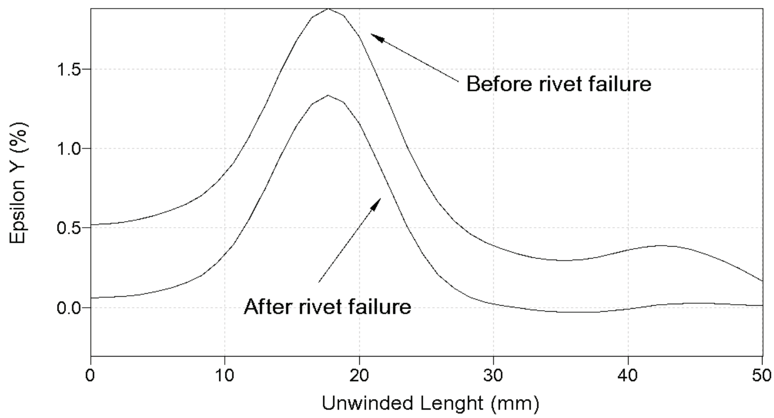

Fig. 19. Plot of the section, shortly before and after the complete failure.

3. Conclusion

The rough principle of image correlation was given and two specific application of the optical measuring system ARAMIS were shown. These technologies are nowadays in use at many places including industry, product development, material testing and last but not least in academic research centers. As was shown it the result examples, it is a reasonable usage of quick-setup and easy-handling tool for wide range of users. According to rapidly developing progress in image capturing devices it is to expect that the optical measuring systems could be an alternative to standard measuring devices.

References

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