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Experimental Stress Analysis

Experimental Methods for Evaluation of the Energy Balance in Vicinity of the Crack Tip

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Abstract: This paper deals with experimental methodology for comprehensive observation in vicinity of stress concentrator in the high ductile material for the purpose of evaluation of the overall energy balance. The strain and stress fields, level of plasticity and thermal dissipation at the vicinity of the stress concentrator are determined employing combination of simultaneous optical, strain gauge and thermal measurement.

Keywords: Strain and stress measurement, Digital Image Correlation, Thermo vision

1. Introduction

For determination of the fracture toughness of the high ductile metal materials such as aluminum alloys, it is more appropriate to use the energy balance instead of conventional elastic-plastic parameter approaches. For evaluation of the energy balance at the vicinity of sharp notches and cracks, the knowledge of several physical quantities is necessary: distribution of strain and stress, level of elastic and plastic deformation and thermal dissipation. Combination of simultaneous optical, strain gauge and thermal imaging was employed for this purpose. A complex experiment was carried out within thin specimen made of aluminum alloy containing stress concentrator in the form of sharp U-Notch (MT configuration). For precise measurement of full-field strain and stress distribution within overall ligament of the specimen during loading, the enhanced 2D Digital Image Correlation method [1] in conjunction with strain gauge measurement was employed. This combination allows to measure precisely elastic strains, which tend to be very noisy in the case of standard non-contact measurement. Simultaneous observation with the thermal imager allows study the relationship between elastic/plastic deformation and temperature changes of the specimen. The well-known thermo-elastic phenomenon causes the decrease of temperature while thermo-plastic phenomenon causes an increase of temperature.

2. Experiment

The high ductile Al-alloy (ČSN 424415.21) 2 mm thick flat specimen with the central slit, which was pre-machined by spark out technology, was employed for the experiment. The geometry of the specimen is depicted in Fig. 1. The radius of the sharp U-notch was 150 μm. The modulus of elasticity E and Poisson's ratio ν of the material were 70 600 MPa and 0.3, respectively. The yield point of the material was 252 MPa. The speckled pattern (black background, white speckles) was prepared on one side of the specimen using airbrush gun. This pattern is necessary for DIC method. The three strain gauge rosettes (0/45/90) were

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installed in the well-defined positions on the opposite side of the specimen; see Fig. 1. These positions were selected to precise measurement of the nominal strains in sufficient distance away from concentrator, where is the assumption of relatively homogenous strains. The reason for installing strain gauges is that the DIC method is prone to out-of plane rigid body motion and rotation of the specimen during loading. These movements are reflected in measured strains as systematic measurement error. This systematic error has the form of linear surface; therefore the error can be subtracted from the knowledge of the right strains measured at least in three not collinear positions.

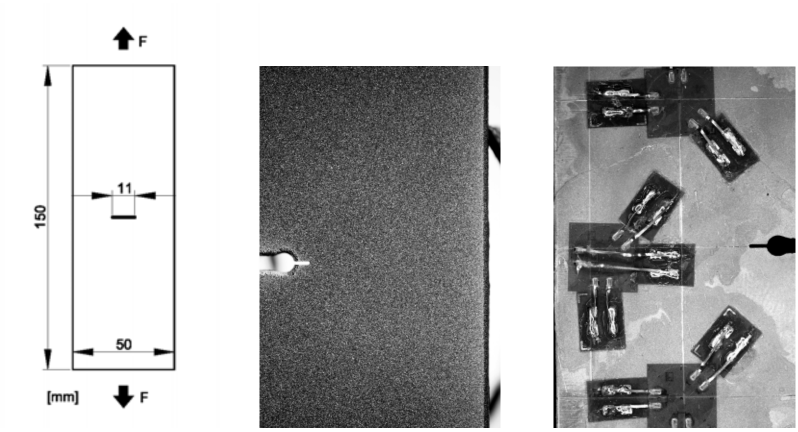

Fig. 1. Geometry of the MT specimen, left. Speckled pattern for DIC measurement on one side of the specimen, middle. Three strain gauge rosettes installed on the other side of the specimen, right.

The specimen was subjected to uni-axial tension loading (opening mode I) under the condition of constant grip displacement velocity 1 mm/min. The remote force *F* was measured by the load cell with frequency 1 read-out/sec. The load vs. grip displacement diagram is show in Fig 2. The surface of the specimen was illuminated by circular diffusion light due to avoidance of reflection artefacts. The images were acquired by the 15 MPixel Canon EOS500D camera and macro-lens with frequency 1 image per 5 sec. during loading until the macroscopic fracture occurred. The images of temperature field were acquired simultaneously by thermal imager with frequency 1 image per 2 sec. The experimental setup is shown in Fig. 2.

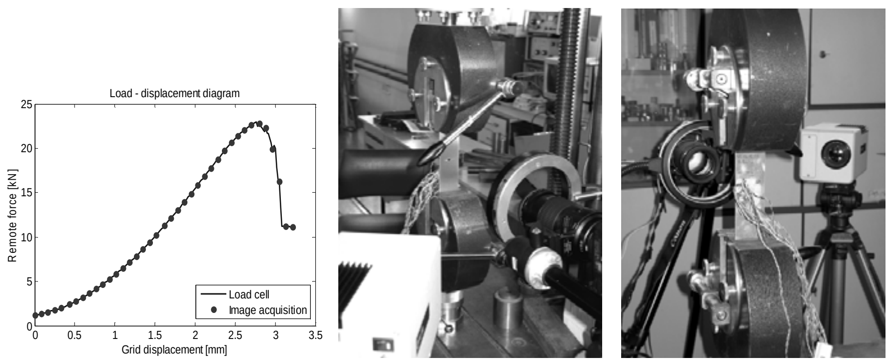

Fig. 2. The loading diagram, left. Experimental setup from the front and back view, right.

3. Results

The own Digital Image Correlation system was employed for evaluation of displacement vector field. The displacements were measured within 42 x 25 points of the regular orthogonal grid with 100 pixel pitch (0.83 mm). When displacements are known, related strain tensor can be computed. For more accurate evaluation of the strains from measured displacements which are unavoidable noisy, the smoothing procedure based on spline function approximation was used. Due to presence of relatively large strains at the vicinity of the notch tip, the finite Green-Lagrange strain tensor was used instead of conventional infinitesimal (small) strain tensor. The Green-Lagrange strain tensor was computed using deformation gradient obtained from afinne transformation of particular triangles of the orthogonal grid. The full-field nominal strains ε_1, ε_2 were than corrected using values of measured strains from the strain gauge rosettes. The stress fields were computed from known strains using incremental plasticity using power law hardening of the material. The example of the nominal strains ε_1, ε_2, and the nominal stress σ_1, σ_2 plots at the remote force F = 14.9 kN, when the strains are more elastic and only small-scale yielding is observed, are shown in Fig. 3.

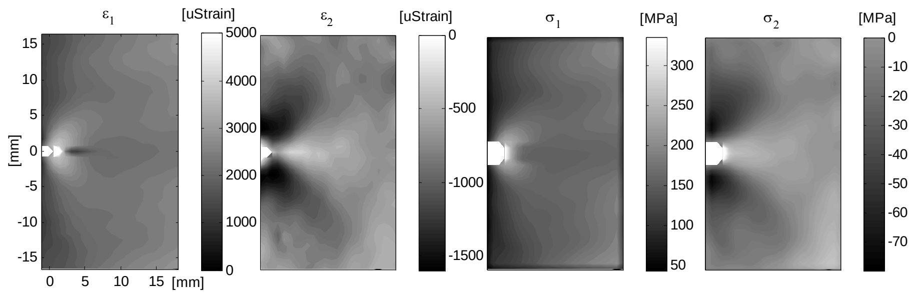

Fig. 3. The plots of nominal strains and stresses at the remote force F = 14,9 kN, when the state is more elastic and only small-scale yielding is observed.

The equivalent stress intensity based on the von Misses yield criterion was used for the plasticity region evolution. The plots of the equivalent stress intensity at four measured increasing loading states and the evolution of the plastic region shape is shown in Fig. 4.

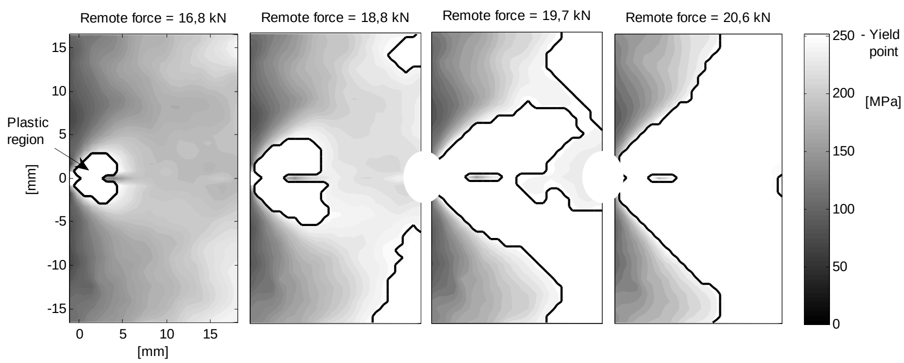

Fig. 4. Evolution of the shape of the plastic region in the means of Von Misses stress. It is clear from the last plot, that overall ligament is plastic even before crack initiation.

The example of resulting images of temperature field evolution during loading is shown in Fig. 5. The most intensive changes in temperature occurred just before fracture. It is well observed thermal dissipation due to large plastic deformation in the direction angle of shear bends from the third image from the left in the Fig. 5. However, it is looks like; there is a time delay of changes in temperature in comparison with plasticity obtained from the stress fields, because the large increase of temperature took a place after macroscopic crack already occurred; see last image in the Fig. 5. This phenomenon is attributed to the conductivity of the material, and will be more studied in the future work.

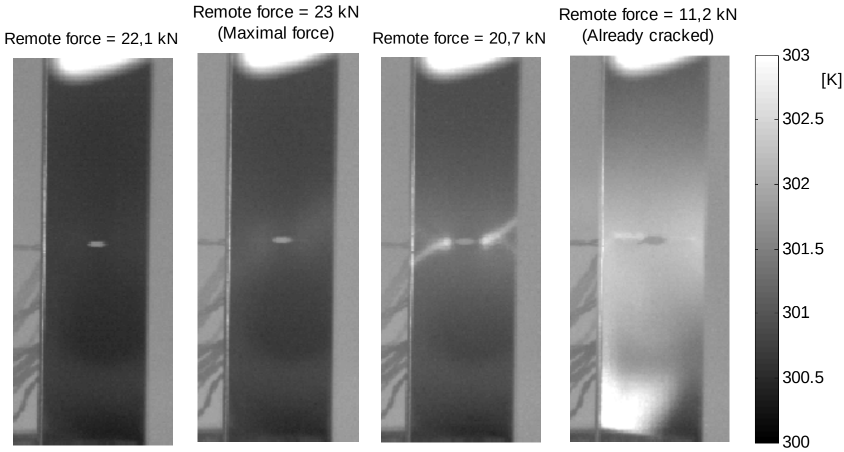

Fig. 5. Evolution of temperature field during cracking acquired by thermo-vision.

4. Conclusion

The complex fracture experiment, measuring fundamental physical quantities necessary for evaluation of energy balance at the vicinity of the stress concentrator was successfully carried out. The enhanced DIC method in conjunction with strain gauge measurement was employed for precise measurement of the strain and stress fields in both elastic and plastic state. It was shown, that ligament of the specimen is fully plasticized before crack initiation. Therefore conventional energetic elastic-plastic parameters such as J integral [2] cannot be used and other approaches will be applied in the future work. However J integral could be probably used if different specimen geometry with higher constrain factor that would not cause such intensive plasticity will be used. Anyway it would be better to have a real sharp crack; although it is very difficult to pre-initiate crack using cycling loading for example in such a ductile material without presence of plastic deformation. The both thermo-elastic and thermo-plastic phenomenon were successfully observed using thermo-vision. The results of temperature fields show a little discrepancy in comparison with stress fields. It looks like the changes in temperature field due to plastic deformation had a time-delay probably caused by conductivity of the material.

Acknowledgements

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References

[1] Sutton M.A., Orteu J.J. and Schreier H.W., Image Correlation for Shape, Motion and Deformation Measurements, Springer, 2009, ISBN 978-0-387-78746-6.

[2] Rice J.R., “A Path independent Integral and the Approximate Analysis of Strain Concentration by Notches and Cracks,” in Journal of Applied Mechanics, Vol. 35, 1968, pp. 379-386.

[3] Jandejsek I. and Vavřík D., “Experimental measurement of the J-integral using Digital Image Correlation,” in European Conference on Fracture 18. Berlin : Deutscher Verband fur Materialforschung und prufung e.V, 2010. pp. 189-194. ISBN 978-80-244-2533-7.