EAN 2017
55th conference on experimental stress analysis

The Proposal of Methodology for Finding of Proper Smoothing Parameters for Stress/Strain Analysis Performed by Digital Image Correlation

HAGARA Martin[1,a], PÁSTOR Miroslav[1,b] and ČARÁK Peter[1,c]

[1]Technical University of Košice, Faculty of Mechanical Engineering, Department of Applied Mechanics and Mechanical Engineering, Letná 9, 040 01 Košice, Slovakia

[a]martin.hagara@tuke.sk, [b]miroslav.pastor@tuke.sk, [c]peter.carak@tuke.sk

Keywords: Digital Image Correlation, Stress/Strain Analysis, Smoothing Parameters, Photoelasticity, Finite Element Analysis.

Abstract. The paper describes the proposal of methodology for finding the most proper smoothing parameters, used by evaluation of full-field stress/strain analysis performed through device working on a principle of digital image correlation method. The proposal for finding of mentioned parameters follows from comparison of the experimentally obtained principal stress difference, whereby the authors did not consider the overlapping of the facets, with the results acquired numerically using finite element method. The correctness of the used numerical model was verified by an experimental analysis performed by transmission photoelasticity method.

Introduction

Digital image correlation is an experimental full-field method based on comparison of digital images obtained during the process of investigated object loading, called correlation. The images are compared along small picture elements, called facets, with size (in square pixels) defined by the user. Typical facet size used is from 15x15 up to 30x30 pixels, whereby using smaller facets the results are influenced by an increasing systematical error [1, 2]. To ensure the comparison of identical image parts it is necessary to create black and white speckle pattern on the object surface, and then each of the facets becomes unique with specific content of black and white color.

The correlation can be carried out using one or more cameras. By the use of one camera, the measurement is 2-D and then it is needful to ensure the parallelism between camera's image plane and object surface (Fig. 1a) during the whole process of measurement. In the case if two (or more) cameras are used, mentioned condition does not exist and the output of the experiment is in the form of 3-D displacements (Fig. 1b).

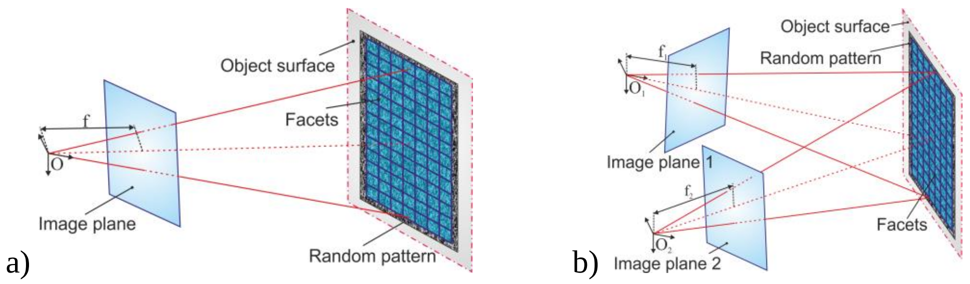

Fig. 1 Basic principle of: a) 2-D digital image correlation, b) 3-D digital image correlation.

The results of the analyses, performed by correlation system Q-400 Dantec Dynamics, are significantly affected by the use of smoothing filters involved in Istra4D software, delivered as a control unit of correlation systems Dantec Dynamics. Istra4D v.4.3.0., which the authors of this contribution work with, evaluate only displacement and strain fields. It comprises two types of smoothing filters – the first one is based on the adaptive spline polynomial algorithm (ACSP) and the second one is denoted as smoothing spline, where Grid reduction factor (GRF) and Smoothing factor (SF) are set for contour and displacement as well [3]. Fig. 2 shows a typical change of the Guest stress field distribution acquired on the rectangle shaped specimen (200x30mm) containing a small hole (diameter of 3 mm) created on the intersection of specimen axis of symmetry, loaded by uniaxial tension loading force using various levels of smoothing filters.

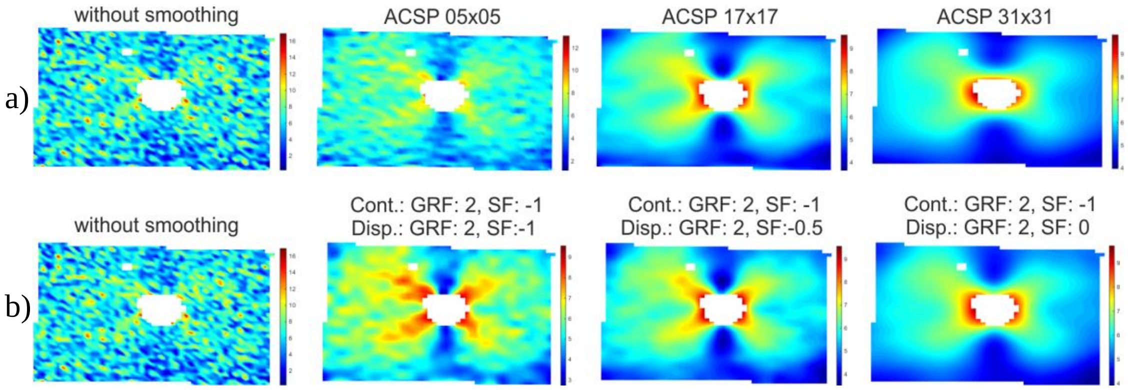

Fig. 2 The influence of: a) ACSP, b) Smoothing spline on the distribution of Guest stress fields acquired by the loading of rectangle shaped specimen with a hole through tension force.

According to information available to authors, there is no instruction how to set the smoothing parameters to get the proper results, which correspond to the real stress/strain state of the structure at most. For that reason, they decided to realize such analyses, which could lead to find the proper values of ACSP smoothing used for evaluation of measurements on the specimen with common size.

Methodology for finding of proper values of ACSP smoothing used in Istra4D

The analyses was realize on the specimen with a shape and dimensions, adjustment to the realization of measurements in laboratory conditions, depicted in Fig. 3.

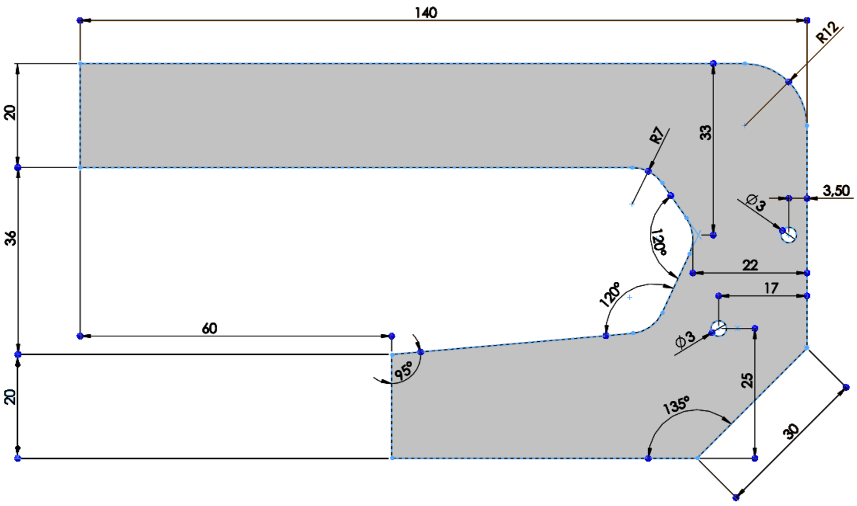

Fig. 3 Shape and dimensions of the specimen.

Such shape of the specimen was chosen to ensure its in-plane bending behavior (without out-of-plane deformation) through the experimental analysis and several stress concentrators served for creation of necessary stress gradient.

The PSM-1 material, used in transmission photoelasticity method and which the specimen was made from, has a thickness of 3.05 mm. Such material has the following mechanical properties: Young modulus E = 2500 MPa and Poisson ration μ = 0.38.

The proposal of methodology leading for finding proper smoothing levels in Istra4D software consists in a comparison of strains and stresses acquired in several chosen points by digital image correlation and finite element method. The numerical model with boundary conditions, used in numerical analyses, is depicted in Fig. 4. The size of the finite element used for calculation was set to 0.3 mm. The mesh was refined in the curved parts of specimen. The study was solved as a static one with consideration of plane model with thickness of 3.05 mm and plane stress state. The loading force, act on the perpendicular edge of specimen lower part, was set to 20 N.

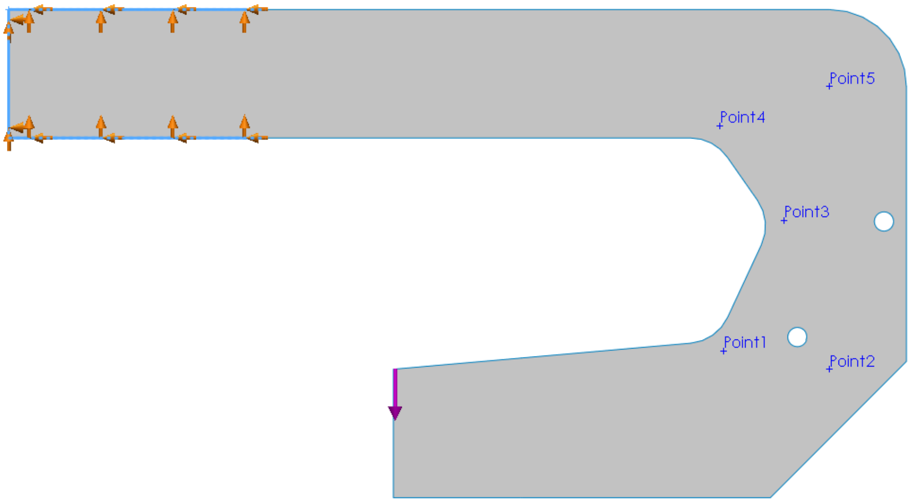

Fig. 4 Boundary conditions used by the solving of numerical analyses and five chosen points which the difference of principal stresses was analyzed in.

The obtained results has to be compared to be sure that the numerical model is correct. The comparison was realized experimentally using Model 060 polariscope working on the principle of transmission photoleasticity [4]. On the specimen surface five points was labeled, which the difference of principal stress was determined in and compared with the results obtained numerically. The pictures, present in Fig. 5, show the shift of fringes caused by the use of compensator Model 067. The obtained results are shown in Table. 1.

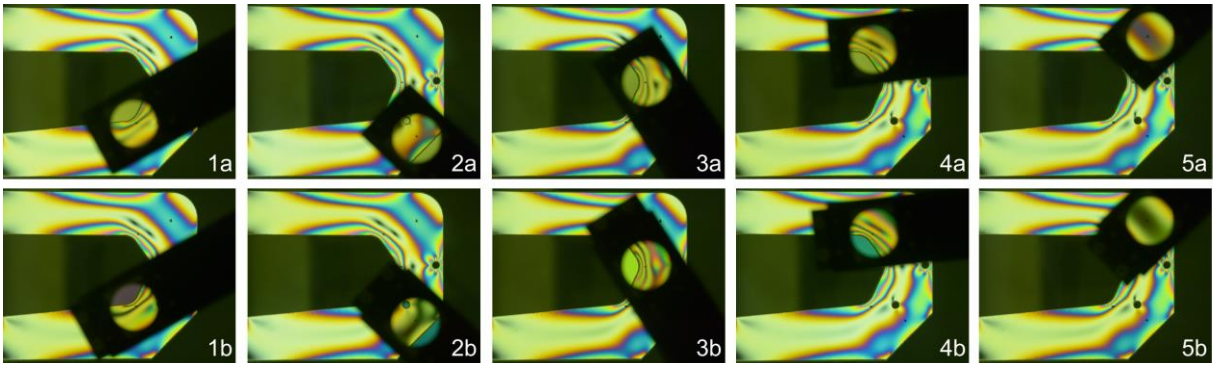

Fig. 5 The use of compensator for determination of fringe order in five chosen points: a) state before its using, b) state after its using.

Table 1. Principal stress difference (σ_1 - σ_2) obtained by FEA and transmission photoelasticity

Finite element analysis	Point 1	Point 2	Point 3	Point 4	Point 5
Principal Stress 1 [MPa]	1.564	0.321	1.936	1.599	0.566
Principal Stress 2 [MPa]	0.617	-0.731	0.495	0.497	-0.613
σ_1 - σ_2 [MPa]	0.947	1.052	1.441	1.102	1.179

Transmission photoelasticity	Point 1	Point 2	Point 3	Point 4	Point 5
Fringe order	0.833	0.938	1.250	0.979	1.042
σ_1 - σ_2 [MPa]	0.972	1.094	1.458	1.142	1.215

As can be seen the values of principal stress difference acquired numerically and experimentally via transmission photoelasticity are nearly the same (the data correspond to the comparison of results acquired numerically and experimentally). For that reason, it can be stated that the numerical model should be correct and the obtained results can be used for comparison with the results obtained by digital image correlation.

On the specimen surface, a vinyl foil with printed random speckle pattern was attached. The specimen was constrained and loaded in the same way as by experimental analysis performed by transmission photoelasticity. The fields of view from two cameras with 5 Mpx resolution, creating the correlation system Q-400 Dantec Dynamics, can be seen in Fig. 6. By the capturing of images, the whole resolution of the cameras (2452 x 2056 px) was used. For the evaluation of the measurement using digital image correlation, the facet size was changing from the value 15x15 px up to 30x30 px with increment 1. Moreover, the evaluation was realized in such a way, that the facets did not overlap themselves.

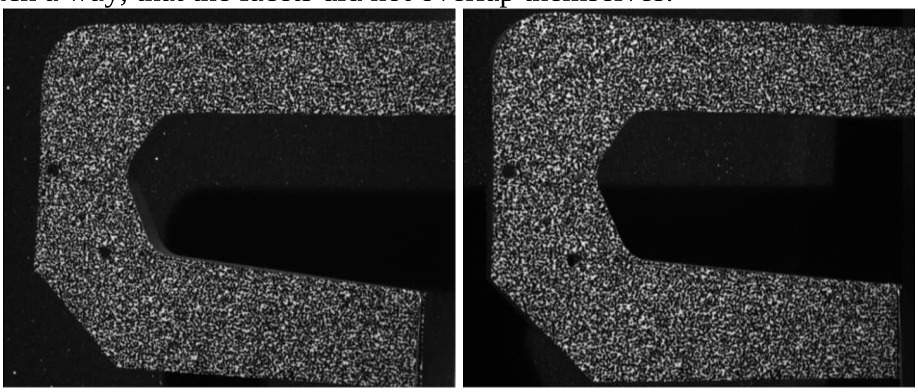

Fig. 6 Fields of view captured by two cameras of correlation system Q-400 Dantec Dynamics.

As the Istra4D allows only visualization of displacement and strain fields, it was necessary to export these data from the numerical analyses. The normal strains, calculated via FEA in analyzed points, are present in Table 2.

Table 2. The values of tangential strains obtained in analyzed points via FEA

Finite element analysis	Point 1	Point 2	Point 3	Point 4	Point 5
Normal strain ε_x [-]	0.000363	0.000087	-0.000096	0.000513	0.0000075
Normal strain ε_y [-]	0.000178	-0.000189	0.000699	0.0000067	-0.000019

Smoothing in Istra4D is performed on contour and displacements particularly, whereby for smoothing of strain fields it is necessary to filter both quantities simultaneously, otherwise the strain fields will be calculated just from the facet deformation (convenient rather for large deformation). Using local regression (ACSP), the strains are computed not only from facet deformation, but also from deformation gradient. The higher the level of smoothing, the higher the influence of deformation gradient on the quality of obtained results. Practically only the deformation gradient is used for the computation of strains using ACSP smoothing level of 7x7 and higher. Higher filter makes the results more smoothed and should decrease the standard deviation of the obtained results, however, it also decreases the spatial resolution of the image. There are fifteen levels of ACSP in Istra4D, starting with 3x3 and ending with 31x31 of increment two. The second type of smoothing used in Istra4D is Smoothing spline, a global filter used commonly in cases when homogenous results on the whole object surface are expected.

For these reasons, for various facet sizes used for evaluation of measurement ACSP smoothing filter was determined, in order to find the results which correspond with numerical model at most. From the evaluated data, the dependence depicted in Fig. 7 was achieved.

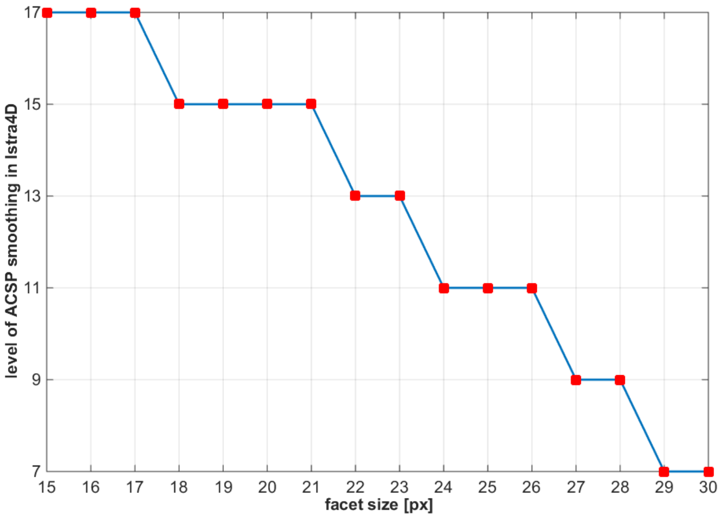

Fig. 7 Dependence of the ACSP smoothing level on the facet size used for evaluation of the measurement.

Principal stress differences (σ_1 - σ_2) acquired by DIC were compared to the results acquired in five chosen points by numerical analysis. The relative differences between both methods are depicted in Fig. 8-10 particularly for the facet sizes set to from 15x15 px up to 19x19 px, from 20x20 up to 24x24 px as well as from 25x25 px up to 30x30 px.

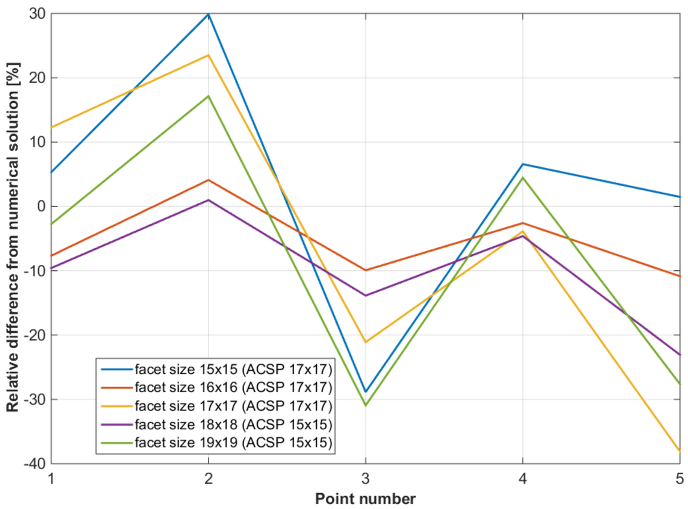

Fig. 8 The relative difference of (σ_1 - σ_2) acquired by DIC by facet sizes from 15x15 px up to 19x19 px with corresponding ACSP from the results obtained in chosen points numerically.

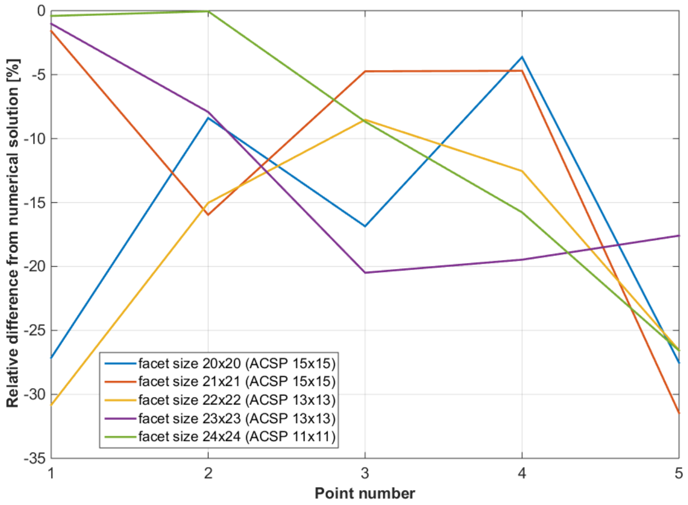

Fig. 9 The relative difference of (σ_1 - σ_2) acquired by DIC by facet sizes from 20x20 px up to 24x24 px with corresponding ACSP from the results obtained in chosen points numerically.

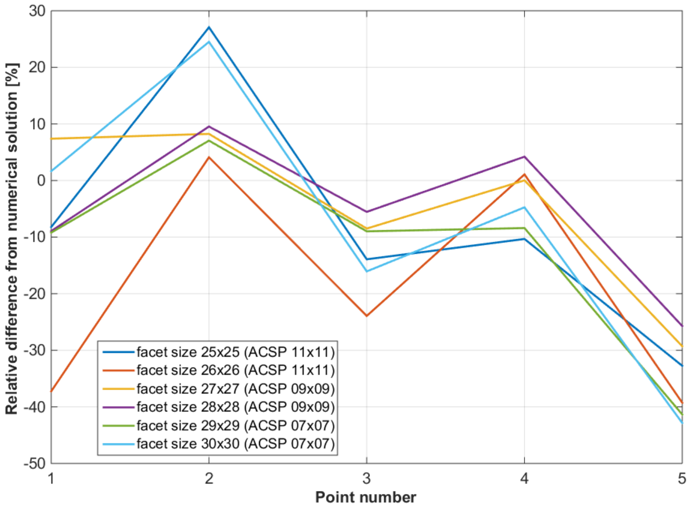

Fig. 10 The relative difference of (σ_1 - σ_2) acquired by DIC by facet sizes from 25x25 px up to 30x30 px with corresponding ACSP from the results obtained in chosen points numerically.

From all the evaluated data, the best correspondence between the numerical and DIC analyses acquired in analyzed points was achieved by the facet size of 16x16 px and level of ACSP set to 17x17 as well as facet size 27x27 px and level of ACSP 9x9. The obtained results in a form of normal strain ε_x, ε_y and shear strain γ_{xy} acquired by the mentioned settings of facet size and ACSP smoothing can be seen in Fig. 11-12.

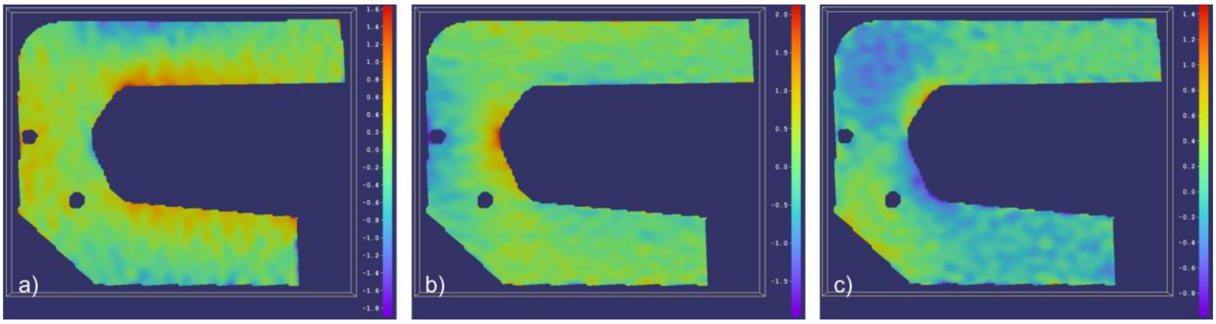

Fig. 11 The fields of: a) normal strain ε_x, b) normal strain ε_y, c) shear strain γ_{xy} acquired in Istra4D by the facet size of 16x16 px and level of ACSP set to 17x17

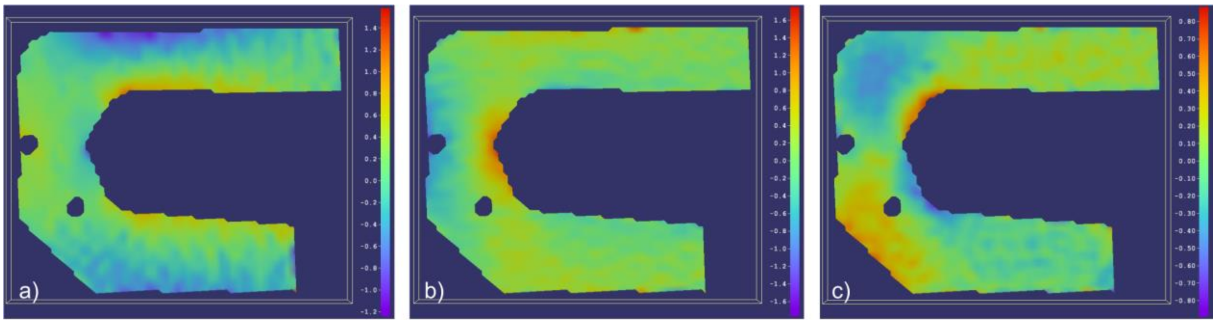

Fig. 12 The fields of: a) normal strain ε_x, b) normal strain ε_y, c) shear strain γ_{xy} acquired in Istra4D by the facet size of 27x27 px and level of ACSP set to 9x9

In Table. 3 the results of principal stress difference (σ_1 - σ_2) obtained in analyzed points via digital image correlation system Q-400 Dantec Dynamics can be found. The first row describes the results obtained by the facet size set to 16x16 px and the second one describes the results obtained by the facet size set to 27x27 px.

Table 3. Principal stress difference (σ_1 - σ_2) obtained by digital image correlation

Digital image correlation	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**
(σ_1 - σ_2) for facet size of 16x16 px [MPa]	1.019	1.009	1.298	1.131	1.307
(σ_1 - σ_2) for facet size of 27x27 px [MPa]	0.877	0.965	1.318	1.102	1.524

Comparing the results of the both evaluations it can be stated, that the differences of DIC analyses from the results of numerical analyses are approximately the same except the fifth point, in which the higher difference was achieved by the use of higher facet size. This phenomenon can be caused by the technical possibilities of the correlation system Q-400 Dantec Dynamics, which is assigned to measure with convenient accuracy deformation of $1e^{-4}$ and higher level. Due to the facet size used for the evaluation of the measurement, it is clear that the evaluated contour does not cover the real shape of the specimen up to the edges, especially in the second case where the spatial resolution of measurement is decreasing with higher facet size. For that reason, that the evaluated contour obtained by the use of facet size of 16x16 px corresponds better with the real surface of the specimen, the maximal values of strains reach higher levels.

Conclusions

The authors introduce a methodology, which can be used for the “calibration” of the ACSP smoothing filter used in Istra4D (software delivered with correlation systems Dantec Dynamics) according to the facet size, which has to be set for the evaluation of the measurement. In the paper, there is a comparison of the results obtained by digital image correlation, transmission photoelasticity and numerical analyses. The authors propose to perform several other measurements, where the effect of higher strain level, size of the specimen cover the spatial resolution of the cameras as well as the overlapping of the facets concerning the level of smoothing, used by the evaluation, will be study.

Acknowledgement

This contribution was created with a support of project *VEGA 1/0751/16* and *APVV 15-0435.*

References

[1] T. Becker, K. Splitthof, T. Siebert, P. Kletting, Error Estimations of 3D Digital Image Correlation Measurements, Technical Note: T-Q-400-Accuracy-3DCORR-003-EN, Dantec Dynamics, 2006.

[2] F. Trebuňa, R. Huňady, M. Hagara, Experimentálne metódy mechaniky – Digitálna obrazová korelácia, Edícia vedeckej a odbornej literatúry, Košice, 2015.

[3] Istra4D v.4.3.0. software manual: Q-400 System

[4] F. Trebuňa, F. Šimčák, Príručka experimentálnej mechaniky, Emilena, Košice, 2012.