The use of the experimental optical technique for investigation of shear strains of the samples exposed to shear stress beyond the yield point

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Abstract

Objective of the article is option use utilization experimental DIC - Digital Image Correlation method for strain fields detection. For experiment execution was used Dantec Dynamics Q 400 system. Article describes in brief system characteristic in necessary parameter settings for successful measurement execution. For strain fields detection was used three different geometry samples with reference to rise stress in the most stressed cross-section where samples effect shear strain. Samples load tension machine were evaluated by ISTRA 4D program. Goal of article is to point to shear strain evaluation in large plastic deformation execution with restriction by failure stochastic pattern required for point correlation at structural element deformation. There is many elements stressed in manufacturing practice by shear strain where numeric methods are heavy-handedness realised mainly for difficult geometric shape and impossibility of use in real condition.

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Keywords: Shear strain, DIC - Digital Image Correlation, Yield point

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₈₀</td>
<td>ductility (%)</td>
</tr>
<tr>
<td>Fₛ</td>
<td>shear force (N)</td>
</tr>
<tr>
<td>RₑH</td>
<td>lower yield stress (MPa)</td>
</tr>
<tr>
<td>RₑL</td>
<td>upper yield stress (MPa)</td>
</tr>
<tr>
<td>Rₑ₀,₂</td>
<td>conventional yield stress (MPa)</td>
</tr>
</tbody>
</table>

1. Introduction

Simple shear rise in case exterior forces affect to solid generate inside cross force $Fₛ$ affect in intersection plain intersecting centre of solid. Shear stress affect most commonly cooperating with other stress types. Simple shear can be considered in case we do ignore influence of cooperating stresses. In manufacturing practice this stress type exists most in construction connections as firm riveted joints, screw connections, wood structure connections and application of fillet welds [1-3]. Experimental approach of problem solutions has a foundation in many cases. In the matter of cause, where analytic or numeric approach is not sufficient.

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In the matter of cause, where analytic or numeric approach is not sufficient. That kind of situation emerges, if there is no possibility to specify sufficient quality of character of a solved problem. In the area of IT technology development increasingly occur varieties of experimental methods are used. Without today’s IT possibilities, these experimental methods could not be able to accomplish.

There is very important disputableness in experimental mechanics, quality and quantity displacement analysis, deformation and strain originate from various materials and constructions analysis. Existences of many contactless optical methods allow of measure and visualize of deformations and displacement. Deformations and strains are computed in consequence.

Absolute shape measuring or relative reference shape comparison can be on principle executed with the aid of modern measuring method. Single methods work with different physical-technical principles. Many times we use interferometric methods for this disputableness. These methods use optical interferometry principles with the aid of monochromatic or polychromatic optical device. It is possible to measure optical smooth surfaced alike optical ragged surface [4-6].

Brief characterization of use experimental optical methods: ESPI - (Electronic Speckle Pattern Interferometry) is interferometric real time method enabling static and dynamic measures of solids. DIC - (Digital Image Correlation) is characteristic by using correlative methods and high speed digital cameras. Evaluation of shift is based on digital image recordings correlation analysis. Methods are appropriate not only to for static but also for dynamic measurements. Therefore also they allow real-time vibration of elements analysis. Moiré methods are based on Moiré effect by superposition of the periodic structures (grids). Les used method is photoelasticimetry, which allows you to analyze and to quantify also strains emerging in constructions. For the purposes of strain testing we can be used laser extensometers. These measure very accurate and contactless length variation of an examined sample. Holographic interferometry belongs to older methods. It allows you to quantitative analyze static and dynamic deformations of solids by using the holographic principle [7-10].

All this methods belongs to contactless methods of measurements and so there is no direct contact between measuring machine and examined object. From this comes great advantage. Mostly measuring some parameters, as for example in examination of oscillation is inadmissible to transfer vibration from test subject to very sensitive optical system of measuring machine. If we can’t ensure contactless at all times, then measuring parameters can show biased results. In extreme case can be all measuring process compromised.

In problematic of testing and the evaluation of the measurements of shear stress was number of articles published [11-14]. In each of the articles are discussed mutual comparisons of optical methods with numerical method FEM (finite elements method) for stress of samples by shear [15-16]. Individual authors propose and optimize the shapes of the samples for the best layout of shear stress fields, shifts and deformations [17-18]. And so use different materials as medals, plastics or composite materials [19-20].

The aim of this article is therefore to point to the utilizing of DIC method for specimens which are in some areas shear deformed. Therefore, we did use three samples with different shape geometry for sufficient comparison. Samples are made of heat rolled steel, thickness 3,5 mm. Condition of shape geometry is to happen straining and failure of the samples loaded with tensile machine by shear deformation effect in consequence. The best case scenario is these samples would be stressed shear only with exclusion of another stress possibility. Purpose was also theoretical analysis for determination of optimum geometry shape of a sample dedicated for this testing. Consequently it would provide a basis for more effective measurement evaluation for shear loaded specimens and remove potential stress concentration locations with option of the most convenient notch sizes with given material thickness of used specimen and to acquire information about evaluation possibilities of sufficiently quality results when big plastic deformations are achieved.

2. Experimental optical DIC technique with Q 400 system

The Digital Image Correlation is one of the modern experimental optical techniques. The Digital 3D correlation system Q 400- Dantec Dynamics is used mainly for the assessment of displacement and shear deformations of both planar and three-dimensional mechanical elements. It allows to perform measurements in any type of material such as metal, rubber, composites, wood and many others. This system can be used for testing Young’s Modulus and Poisson ratio. It also finds its application in fracture mechanics. The major advantage of this optical non-contact technique is that it allows three-dimensional analyses of displacements and shear deformations. The Q 400 system is used for determination of material parameters in tensile, torsion, bending or combined strain. The assessed area can be from some mm² up to m². It’s another big advantage is the export of the recorded sample geometry and its subsequent application and verification using the FEM method.
2.1 Principle of Digital Image Correlation

The DIC principle is based on generation of a random speckle pattern on the observed surface of the sample that is captured with a CCD camera. The investigated part of the sample is automatically divided by the program using virtual grating into smaller areas, the so-called facets (Fig. 1.). Each of these facets has its characteristic stochastic pattern with the required contrast of the background and the stochastic speckle pattern generated on it.

![Fig. 1. Generation of virtual grating and facets in the observed surface](image)

In case of planar objects it is possible to observe the surface of the test element using one camera pointed vertically to the surface of the examined area. In case of three-dimensional objects, stereoscopic mounting of sensors is used enabling 3D vision. In the case presented here, the measured surface is observed with two and more cameras from different directions and places. Positions of individual points are related to a particular pixel in the image plane of a particular camera (Fig. 2 a).

Before the measurement itself, cameras have to be calibrated to identify the size of the object. As a result, an object of the size of a few “cm” may seem to be as big as an object that is several times bigger. It is performed using calibration plates (Fig. 2 b). In this way, the necessary information about the measured object such as geometrical properties and the relative position of the cameras can be obtained. Calibration provides a way to identify three-dimensional coordinates of each surface point.

Virtual three-dimensional contour of the examined surface is determined from the 3D coordinates. The whole process of loading is divided into a certain number of steps. Due to the influence of the acting forces individual observed points of the random pattern make a precise copy of the object contour lines and therefore the position of these points is changed. The movement of points results in a change in the intensity of light reflected from the sample surface. Consequently, in the process of correlation these digitized images are compared with the selected reference point. The result of that are strain forces and displacements in individual time steps of the measurement [21-24].

![Fig. 2. a) Principle of scanning surface points using 3D- DIC system, b) Calibration plate](image)

3 Performance of the experiment

For the purpose of this measurement, three different sample shapes (Fig. 3) were used. The pattern geometry was selected in such a way as to ensure that the samples were distorted by shear stress during their loading in the tension machine [7-9]. As the shape of the samples was complex, the samples were cut by the water jet that allowed for very delicate contour lines. The advantage of this technique is that there is no thermal influence on the surface and it is not necessary to exert any substantial force on the material as a result of which no plastic deformation occurs.
The measurement was performed using a TIRA TEST 2300 tension machine. The tension machine was controlled by a microprocessor for strength tests with maximum testing force 100 kN. Mechanical properties of the material used for manufacturing of steel samples are given in Table 1. Four tensile tests were carried out with respect to the direction of rolling. Test_1, Test_2 - mechanical properties of the material in the direction of rolling. Test_3, Test_4 - mechanical properties of the material in the direction vertical to the direction of rolling. Fig. 4 a) shows the diagrams of individual tensile tests.

Table 1. Mechanical properties of the steel used for the test

<table>
<thead>
<tr>
<th>Test</th>
<th>$R_{el}$ [MPa]</th>
<th>$R_{eu}$ [MPa]</th>
<th>$R_{p0,2}$ [MPa]</th>
<th>$R_{m}$ [MPa]</th>
<th>$A_{80}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test_1</td>
<td>339,830</td>
<td>361,570</td>
<td>348</td>
<td>411</td>
<td>27,470</td>
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<tr>
<td>Test_2</td>
<td>336,122</td>
<td>348,716</td>
<td>346</td>
<td>412</td>
<td>28,755</td>
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<tr>
<td>Test_3</td>
<td>320,181</td>
<td>328,378</td>
<td>328</td>
<td>406</td>
<td>31,286</td>
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<tr>
<td>Test_4</td>
<td>316,887</td>
<td>324,346</td>
<td>324</td>
<td>403</td>
<td>33,194</td>
</tr>
</tbody>
</table>

Once the mechanical properties of steel were obtained, it was possible to perform the measurement itself using Q 400 system Fig. 4 b. The straining speed used was the same for each sample and was as the speed used for common tensile tests, i.e. 10 mm/60 s. Also the same number of time steps for Q 400, i.e. 2 steps/1 sec., was selected for all the tests.

4 Experiment results

When performing individual measurements, the character of dependencies of tensile machine traverse displacement (mm) due to loading force (kN) (Fig. 5, Fig. 6.) was obtained. As far as plastic deformations were investigated, the first step for depicting the obtained plastic deformations in each sample was to select a point close to the yield point. Further points or steps were selected randomly demonstrating the fields of plastic deformations in samples stressed by shear forces. The horizontal axis presents a shift of movable girder.
Table 2. Chosen spots where relative deformations used to be detected.

<table>
<thead>
<tr>
<th>sample</th>
<th>point</th>
<th>time [s]</th>
<th>force [kN]</th>
<th>displacement [mm]</th>
<th>nominal shear stress [MPa]</th>
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<tr>
<td>1</td>
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<td>10,02</td>
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<td>2</td>
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<td>49,96</td>
<td>12,23</td>
<td>7,52</td>
<td>349,4</td>
</tr>
</tbody>
</table>

4.1 Sample 1

Sample 1 was evaluated in the 20th, 70th and 100th step. Individual images illustrate the process of principal strains with depiction of principal stress direction (Fig. 7 a)). Fig. 7 b) illustrate the process of tangential shear strain in the 20th step; Fig. 7 c) illustrate the process of tangential shear strain in the 70th step and the process of tangential shear strain in the 100th step (Fig. 7 d). The field of strain increased with the increasing loading force. In case of evaluation of tangential shear strain, the increase of shear strain from the value 1,8 mm/m in the 20th step to the value 48 mm/m in the 100th step was achieved. Step 145 is limiting step to strain field evaluation. By effect of great damage of random pattern program lost half evaluated field. This is the reason why there is impossible to evaluate strain with increasing loading.
4.2 Sample 2

Sample 2 was evaluated in the 12th, 50th and 77th step. Individual images illustrate the process of principal strains with depiction of principal stress direction (Fig. 8 a)). Fig. 7 b) illustrate the process of tangential shear strain in the 12th step; Fig. 7 c) illustrate the process of tangential shear strain in the 50th step and the process of tangential shear strain in the 77th step (Fig. 7 d). The field of strain increased with the increasing loading force. In case of evaluation of tangential shear strain, the increase of shear strain from the value -9.5 mm/m in the 12th step to the value -380 mm/m in the 77th step was achieved. Step 81 is limiting step to strain field evaluation. By effect of great damage of random pattern program lost half evaluated field. This is the reason why there is impossible to evaluate strain with increasing loading.

4.3 Sample 3

Sample 3 was evaluated in the 20th, 80th and 100th step. Individual images illustrate the process of principal strains with depiction of principal stress direction (Fig. 9 a)). Fig. 9 b) illustrate the process of tangential shear strain in the 20th step; Fig. 9 c) illustrate the process of tangential shear strain in the 80th step and the process of tangential shear strain in the 100th step (Fig. 9 d). The field of strain increased with the increasing loading force. In case of evaluation of tangential strain, the increase of shear strain from the value -50 mm/m in the 20th step to the value -300 mm/m in the 100th step was achieved. Random pattern by step 145 is fairly disrupted, as same as by 1st sample. There is impossible to qualitative evaluate reached strain.
There are tangential shear strains depicted on element in the middle area of shear zone of particular specimens in dependence on girder movement on the fig.10a and there is also dependence of nominal shear stress in the middle area of shear zone on girder movement the fig.10 b.

As it results from the fig.10 a) for the specimen 2 the maximal shear strain with value of 400mm/m was reached while minimal value of shear strain was reached for the specimen 1 with value of 140 mm/m which was loaded with general planar stress. Maximal nominal shear stress is for the specimen 2 with value of 389,3 MPa.

5 Conclusion

With the development of computer technology, experimental optical techniques are becoming more widely used for the evaluation of displacements, deformation fields and strains. The advantage of optical methods is especially based on contactless measurement of displacement fields on the investigated object surface. In this paper is for shear deformation analysis applied optical method which uses digital image correlation-DIC on chosen specimen types.

From the presented results are evident different shear deformation fields of specimens in investigated areas. When load increased the specimen 1 was plastically deformed also out of the investigated area and caused its disruption by general planar stress. From fig.7 also results that in rounded notches areas come to concentration of deformation what created premature cracking of applied stochastic pattern. Maximal reached shear deformation was 400 mm/m. Specimens 2 and 3 (fig.8, fig.9) were predominantly deformed in investigated areas by shear with maximal values of shear strains 400 mm/m (specimen 2) and 300 mm/m (specimen 3). Plastic deformation was concentrated only in area of expected shear deformations. It shows evidence of that geometry and shape of specimens 2 and 3 are suitable for this type tests.
The problems with application of the system Q-400 by such type tests can be caused by quality of applied stochastic pattern on investigated surface. In this case white spray was used in which a speckle pattern was created using black spray. Paint tends to be damaged at higher loadings. It causes incompact contour lines of the investigated area. From this reason the little cracks are created on applied stochastic pattern in the area of maximal strains. The increase of loading results in constant growth of these cracks and for extreme case impossibility to evaluate results in investigated area.

Presented facts occurred especially on specimen 1 on which during the test the preliminary cracking of applied layer emerged in consequence of the general planar stress on the specimen surface. The specimens 2 and 3 which had more convenient geometry showed during the all loading process stable surface layer but in the case of specimen 3 the preliminary growth of cracks occurred in surface layer in the surrounding of notches.

Experiments with the improved geometry of samples exposed to shear stress are planned for the future as well as reciprocal verification of the results of shear deformations obtained using the FEM in program ANSYS. ANSYS enables to define convenient boundary conditions for the best mutual comparison with experiment. The aim is also to improve properties of stochastic pattern painting to not cracking during the big loading. It would enable to evaluate the measurement to the point of specimen disruption. For this reason it is planned a creation of stochastic pattern not with paint coating but with utilizing of some elasto- plastic material (thin foil precisely copying deformation of the specimen) on which the needed pattern is consequently coated or printed. The solution could be also the using of paints with better deformation characteristics. These steps together with using of FEM or other experimental method (e.g. ESPI-Electronic Speckle Pattern Interferometry) could help to increase the deformation analysis quality of specimens measured in plastic area.

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References


