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Digital Image Correlation in Ioscipescu Shear Test

Michał GRZESIAK*, Michał KOWALIK, Karol SUPRYNOWICZ*****
Warsaw University of Technology, plac Politechniki 1, 00-665 Warszawa, Poland, E-mail: mgrzesiak@meil.pw.edu.pl
***Warsaw University of Technology, plac Politechniki 1, 00-665 Warszawa, Poland, E-mail: mkowalik@meil.pw.edu.pl*
****Warsaw University of Technology, plac Politechniki 1, 00-665 Warszawa, Poland,*
E-mail: ksuprynowicz@meil.pw.edu.pl

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1. Introduction

The Goal of the following paper is to determine the best approach for a future testing of 3-D printed materials. The structure of the Fused Material strongly suggests, that its physical properties are orthotropic. Shear tests are necessary to determine properties of any non-isotropic material or structure. While tensile testing of any material is rather simple matter, determining shear modulus is a little bit more complicated [1].

There are several different methods for shear testing of materials. The methods are designed for different types of materials or the size of the sample. Method to choose has to be a good compromise between accuracy of results and ability of testing large quantity of specimen in short period of time. What's more it required to be easily fitted into Instron 8516 static machine standard jaws.

The Traditional method is: the shear frame. Although it gives plain pure shear stress state, it is best suited for large sized specimens therefore it would require a lot of time to prepare specimens and to test them [2].

The 10° Off-Axis Test is a simple method for unidirectional composites, however getting a strain reading is complicated due lack of pure stress state [3].

The another one is Ioscipescu shear test. It's the most popular and widespread method. While stress uniformization is not perfect, this method enables to test large number of specimen in quite short amount of time. Next is the short 3-point bending test – fast quality control method for industry. Due to a complex stress state it's not accurate enough for a planned purpose. Double notched compression test is also fairy simple but it suffers from stress concentration in notches. It's the improved version - Inclined double notched shear test- gives much more reliable results, however it's application is more complicated [1].

Both Inclined Waisted Test and Arcan test are accurate methods, but their application into static machine seemed to be difficult at the time of method selection [1].

The chosen method was Ioscipescu shear test. This method allows to test of a large number of specimens in a relatively short period of time. It's primarily designed for testing different types of composites such as unidirectional, woven or short fibre reinforced laminates. Due to similarity FDM prints to unidirectional composites, it seems to be a good choice for such structures [4].

According to ASTM D5379 the test requires strain gauges for the test, as there is no clear correlation between displacement of static machine traverse and shear strain in specimen. However due to accessibility of Digital Image Correlation during the test, it was chosen for strain measurement. Also, the advantage of this method is possibility of obtaining full image of deformation, next to discrete values of a strain gauge. On the other hand, this method is not supported by the standard, and therefore requires a reference test to confirm its reliability [4].

To confirm reliability of this new approach, test was conducted on isotropic material. Through the experiment shear modulus was determined and then compared with the value calculated from results of tensile test.

2. Method

The principle of Ioscipescu method is antisymmetric flexure of a beam in a jaw designed for this method (Fig. 1). Specimen is material coupon formed into rectangular beam, with two symmetrical notches in centre of the specimen, that helps uniform shear stress. Antisymmetric loading limits influence of bending stress for shear stress. The reading is obtained via 2 strain gauges, set symmetrically in the centre of specimen, oriented at ±45º to the loading direction (Fig. 2).

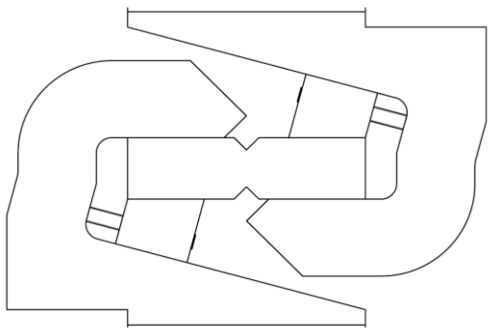


Fig. 1 The Ioscipescu jaw fixture with specimen

The jaw fixture consists of 2 frames which and a wedge for holding specimen. Wedge angle is 20 degrees and it is pressed against a frame wall and the specimen by a screw. Frames are put into static machine jaws, to create an antisymmetric load.

Digital Image Correlation is a method of determining the field of displacement and strain of a stress tested subject. It utilizes series of photos prepared surface, before and throughout specimen loading. Inspected surface is covered with random pattern dots on the contrasting background (most common are black dots, on white surface). The spots are keypoints for which displacement is calculated. The algorithm recognizes and tracks a movement of them through all given frames, first frame is the reference one. From discrete values of keypoints displacement, it can be interpolated to a whole inspected specimen and thus full image of deformation.

In comparison to the gauges this method requires painting the specimen surface for testing. However, after setting camera for shooting, the process becomes much simpler, as there is no need of adjusting measuring equipment as a next specimen. What's more, gathered data, can be analysed, for more information after the test [5].

The Material selected for testing was a plate of Polymethyl methacrylate (PMMA), from which the test specimens were milled. It was chosen for reference test, due to comparable level of Young's [6].

To retain compliance with standard, strain measurement was executed via extensometer set according to the standard [4].

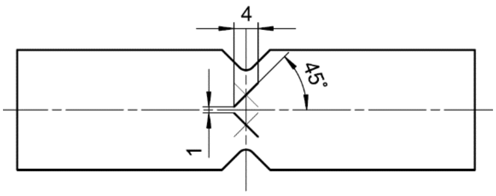


Fig. 2 Extensometers placement on the specimens

Additionally, 2 dots were put on the jaw, to track the displacement of static machine. From this readings characteristic of strain in a function of displacement was derived. For further calculation linear part of characteristic was chosen, as for plastic materials limiting strain value, for modulus, is 1%.

From the static machine force as a function of traverse position is obtained. It can be easily transferred to mean stress in relation to displacement. Matching those characteristic can give searched stress as a function of strain characteristic. Its linear part is used to determine shear modulus value.

Overall 7 specimens were exanimated and their results calculated.

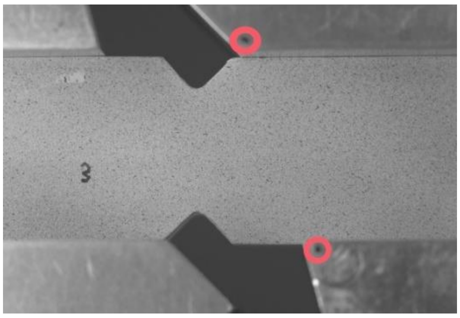


Fig. 3 Specimen during testing. Dots used for displacement reading are marked with red circle

The Reference value was obtained via tensile test. B1 test sample was tested. Reading was also obtained via DIC, with 5 extensometers in longitudinal direction and 5 transverse direction, evenly distributed in a test area (Fig. 4). Poisson ratio was obtained by comparing (strain/displacement) in both directions. Young modulus was later calculated in similar manner that one in the shear test. Knowing Poisson ratio and Young modulus, shear modulus can be calculated, form the formula below [7]:

$$G = \frac{E}{2(1+\nu)} \tag{1}$$

Just like in the shear test, also 7 specimens were exanimated.

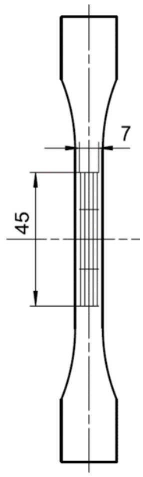
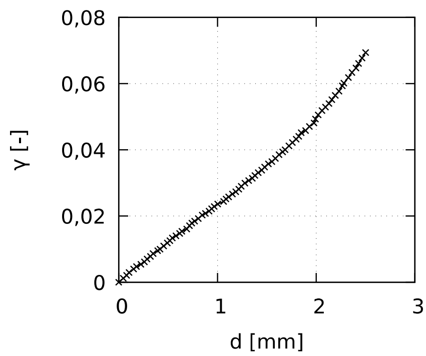
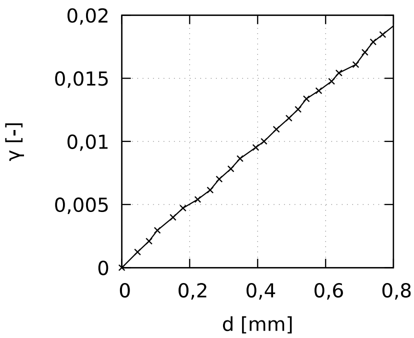


Fig. 4 The tensile test specimen with marked position of extensometers



a)



b)

Fig. 5 Shear strain in a function of traverse displacement (a) and it's linear part (b)

3. FEM model

FEM model was developed in ANSYS APDL software. As all load in the experiment are within specimen plane, 2D model was sufficient to simulate conditions of experiment. Sample was modelled with PLANE 182 with thickness parameter on. Jaw fixture was simulated as 4 rectangles in positions compliant with fixture stetting. Thickness was defined via real constants, their values were set to match sample and fixture. Compression of test specimen ends was emulated with potential force acting on 2 rectangles. Movement of static machine was given as vertical displacement of right upper rectangle. Displacement was given in several loadsteps to get stress reading for multiple points of trial.

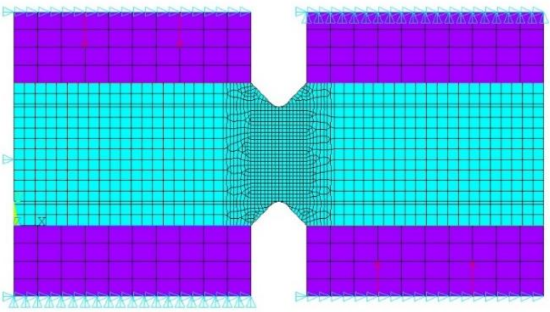


Fig. 6 Specimen and fixture FEM model

Between the specimen and rectangle contact pair was defined. Result was taken as average value of shear stress in cross section between notches. Gap closing setting was used and friction coefficient of 0,3 was set. Using contact model was necessary as model with linear displacement didn't give correct results. What's more due to the fact, that compression force was hard to determine, and finding their values were part of model calibration.

4. Results

4.1. Experimental results

Catalogue gives values for PMMA Young Modulus for 3,3 GPa, Poisson ratio – 0,37, thus giving value for shear modulus –1204 MPa.

From tension test Fig. 7 obtained Young modulus value is 3,05 GPa, Poison ratio – 0,37 and shear modulus of 1116 MPa Eq. (1).

Finally, Iosicipescu test results gives value for shear modulus 1130 MPa.

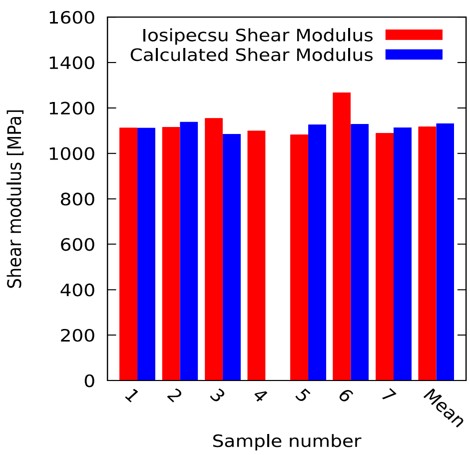


Fig. 7 Results of tensile and shear test. Note: sample no.4 didn't give reading for DIC, therefore it isn't analysed

4.2. FEM model calibration and results

Experiment and FEM stress results in a function of displacement were compared. At first results were not satisfactory (Fig. 8). Constant potential force model was inaccurate; however, it was observed that error level is predictable for each step.

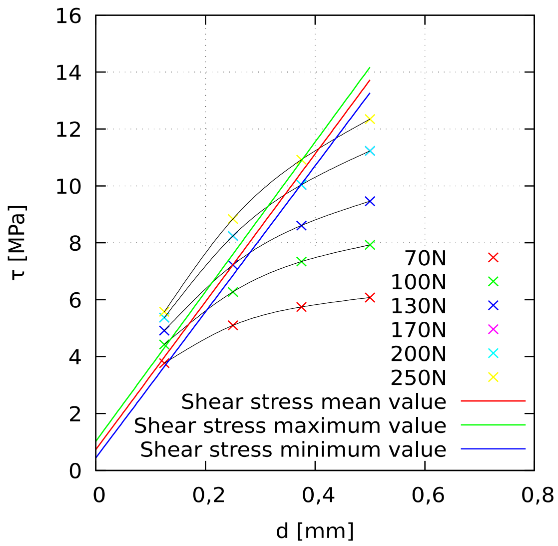


Fig. 8 Initial FEM model response compared with experiment results. Coloured lines are test results data, approximated as linear function, dotted curves presents FEM model response to different fixture compression force

Therefore, after calculating value of error between numerical and presenting its value as function of compression force, treating displacement as parameter. A created transfer functions are used for calculating correct fixture compression values.

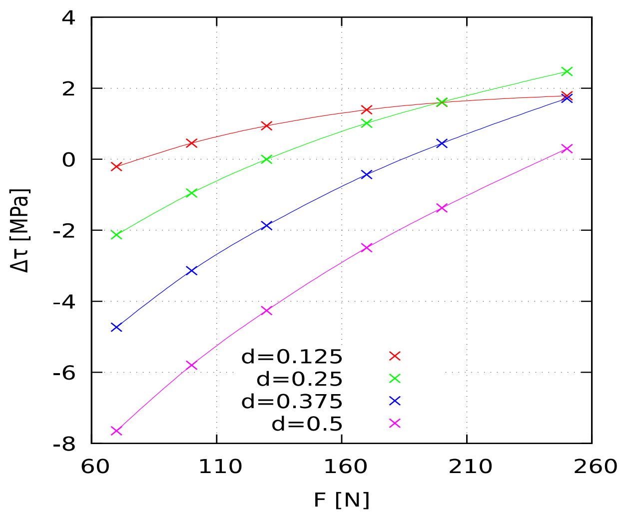


Fig. 9 Transfer functions for different displacement values

From that, compression force values were calculated. Results of the calculation are presented below (Fig. 10).

Calculated forces were put back into FEM model. Giving good accuracy between FEM results and Experiment. However, using this stress for calibrating the model, created a need for another comparing criterion for comparing model with experiment. Due to possibility of graphic images of these two methods it can be compared.

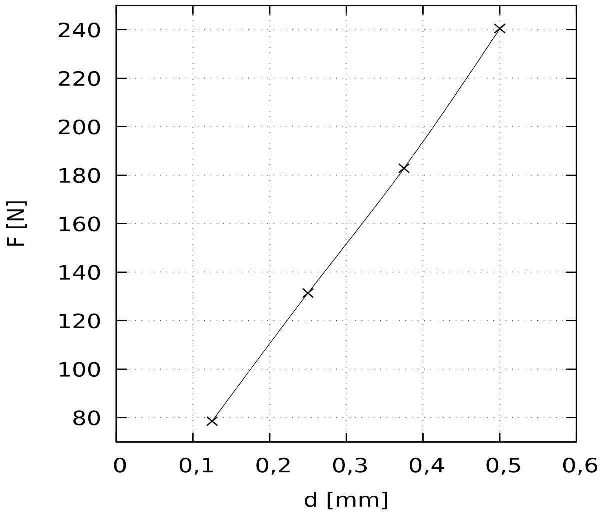
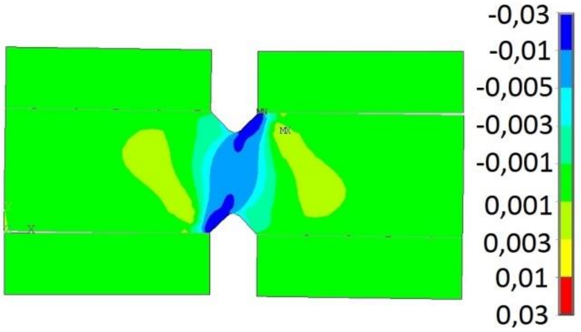


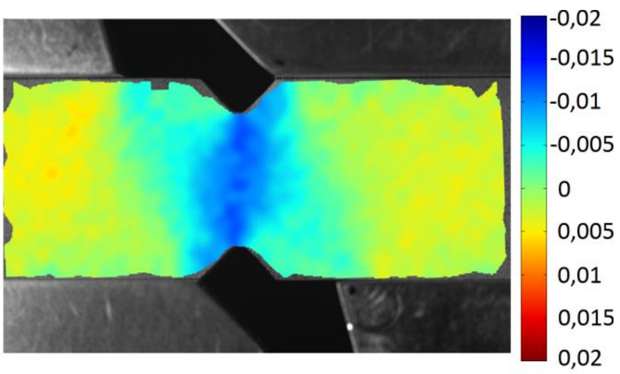
Fig. 10 Calculated values of compression force

Both images bear resemblance to each other, so they indicate similar stress distribution in centre area (Fig. 11). Closer look into the shear strain graph reveals some degree of difference between DIC reading and FEM results (Fig. 12). However, these two function doesn't differ significantly from each other. Furthermore, it can be easily explained by filtering in DIC results.

Furthermore, FEM strain reading obtained in as strain reading in DIC is within standard deviation range compared to experimental values (Fig. 13).



a)



b)

Fig. 11 Map of the shear strain form FEM (a), and DIC (b)

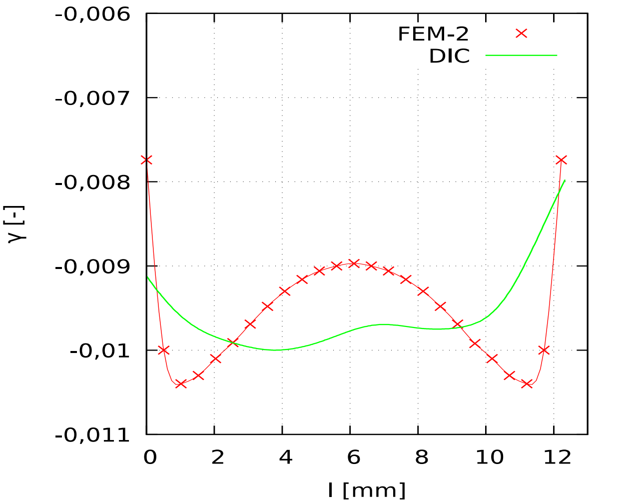


Fig. 12 Graph for shear strain in specimen section located between notches

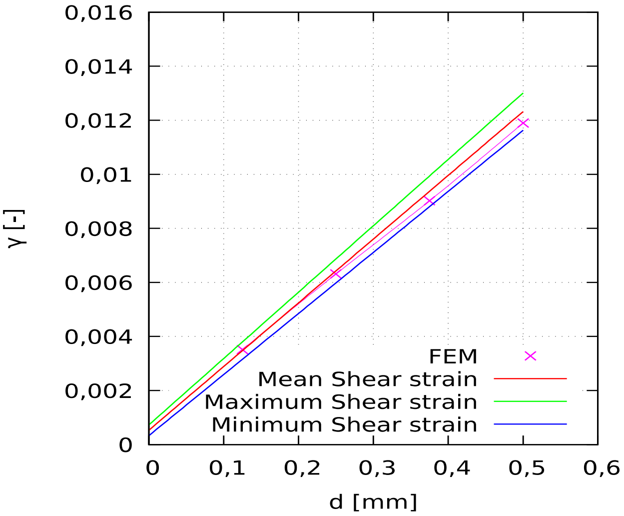


Fig. 13 FEM and DIC strain comparison

5. Conclusion

The results of the test seem to be compliant with values from the tension test. The difference between literature values and experimental ones may be caused by material sample quality.

Overall incorporation DIC into the test seems to be successful idea and can be used in further investigation.

EM model, although not perfect, seems to be fair representation of the experiment. Main sources for difference are an image noise for DIC and the simplification for FEM. However, comparing values obtained through extensometers shows, that FEM model is accurate enough.

To summarize both, the experiment and the FEM model have fulfilled their purpose: DIC can be used for Ioscipescu test and the FEM model represents the experiment.

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M. Grzesiak, M. Kowalik, K. Suprynowicz

DIGITAL IMAGE CORELATION IN IOSCIPESCU METHOD

S u m m a r y

This paper presents investigation of using Digital Image Correlation measurement method in Ioscipescu Shear Test. Additionally a FEM model was developed to further support research and to be used in future investigation. Test specimens were made of Polymethyl methacrylate (PMMA), an isotropic material which shear test results can be compared with calculated shear modulus from the tensile test. FEM model was developed as 2D linear model with thickness as parameter. In development the linear model was dropped in favor of model with contact and friction that gave better results. The results of shear test compared to the shear modulus calculated from tensile test, gave matching results. FEM model due to inclusion friction mechanism required calibration, therefore its accuracy was confirmed by strain measurements. Overall both experiment and FEM model worked its purpose.

Keywords: Ioscipescu Shear Test, Digital Image Correlation, Finite Element Methods, Material Testing, Experimental.

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