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Optical Measurement of the Springback Angle of Composite Plates

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Abstract: Presented paper describes measurement of the angular change (springback) of composite part with thermoplastic matrix (C/PPS composite) caused by the thermal load. Twelve contactless measurements (used devices were optical distance measurement CHRocodile M4 and laser profilometer ScanControl LLT 2800-25) in four modes were carried out. Measured springback angle was evaluated and compared with the values computed analytically by the Classical Lamination Theory (CLT) + equations for through thickness characteristics and the values computed numerically by using FE software ABAQUS. The results of the measurement show large range of the experimental data and very good agreement of the analytical solution with FE results.

Keywords: Springback, experiment, optical measurement, composites

1. Introduction

Change in composite dimensions is related to many parameters such as: part angles, thicknesses, lay-ups, flange length, but also tool materials, tool surface or cure cycles [1]. When the composite L (or U) section is extracted from the form that was cooled to the room temperature, the change in the angle of the part (Fig.1) can be observed and that´s why tool angles have to be modified to affect this problem. The tool design is based on either the “rules of thumb”, from the past experience, or on the trial-and-error method. For the angular parts, the compensation is normally between 1 and 2,5°. The most common problem found, using a standard factor, is that the springback may vary with the lay-up, material, cure temperature, etc. Therefore, what worked once does not necessarily work next time. The main cause

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of springback was the mismatch in thermal expansion along and across the fibers in a laminate [2].

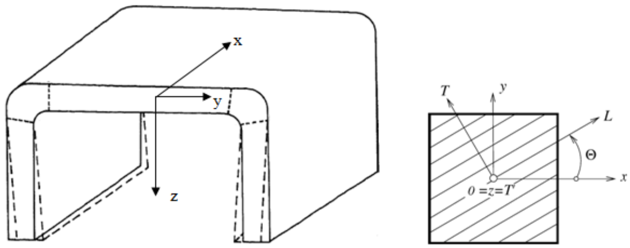

Fig. 1. Distortion of moulded U section.

The main part in our previous works [3,4] was comparison of the analytical and numerical model with the measured data from the manufacturing company Letov Letecká Výroba, s.r.o. In this paper the experiment which was done in our laboratories is described and compared with theoretical data obtained by the analytical and numerical models described in [3,4].

2. Experiment

The main goal of the experiment was to assess the strain of carbon composite (T600 fiber) with PPS matrix due to a temperature change. The lay-up of composite was $[[(0,90)/(\pm 45)]_4/(0,90)]_s$, the fiber volume content V_f is 49%. The devices (see Fig.2 used for measuring were

- Temperature sensor: PT100, CRZ Platinium Thin Film Element
- Contactless infrared thermometer FLUKE 574
- Laser profilometer ScanControl LLT 2800-25
- Optical distance measurement CHRocodile M4

2.1. Description of the experiment

The specimen was heated up about 100° C in an oven and then cooled down to the room temperature (25-27° C). The measurement starts mainly at the temperature of 95° C and ends at 35° C after 30 min. Twelve measurements in four modes were carried out. The sampling rate of the laser was 20 Hz and optical distance measurements 32 Hz. Relative displacements between the points scanned by laser were evaluated as angular displacements of the specimen vertical part in each time step. Then the springback values were calculated and compared with the analytical and numerical solution. Measurement modes with short description and measured specimen can be seen in Fig.3, 4, 5 and 6.

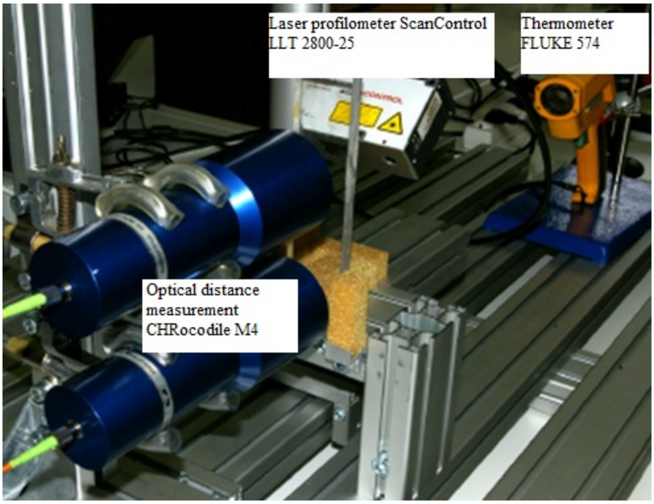

Fig. 2. Arrangement of the experiment.

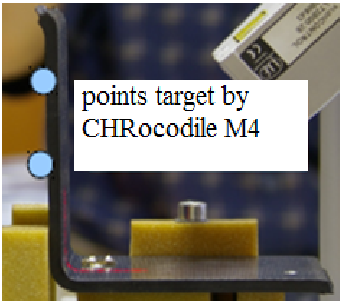

Fig. 3. Measurement by CHRocodile M4.

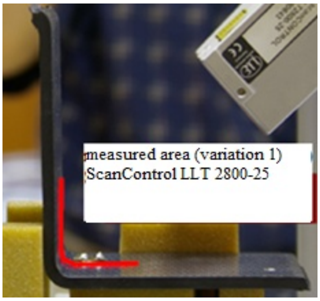

Fig. 4. Measurement by ScanControl, variation 1.

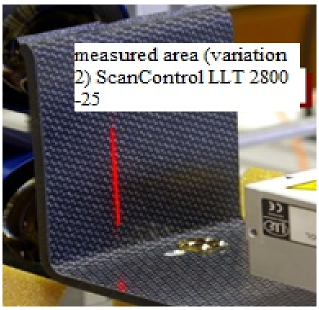

Fig. 5. Measurement by ScanControl, variation 2.

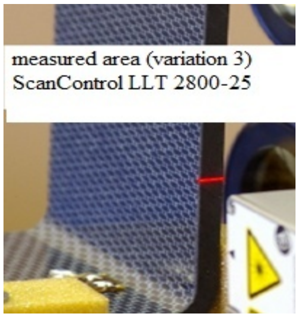

Fig. 6. Measurement by ScanControl, variation 3.

Data obtained from the measurements can be seen in Fig. 7, 8, 9 and 10.

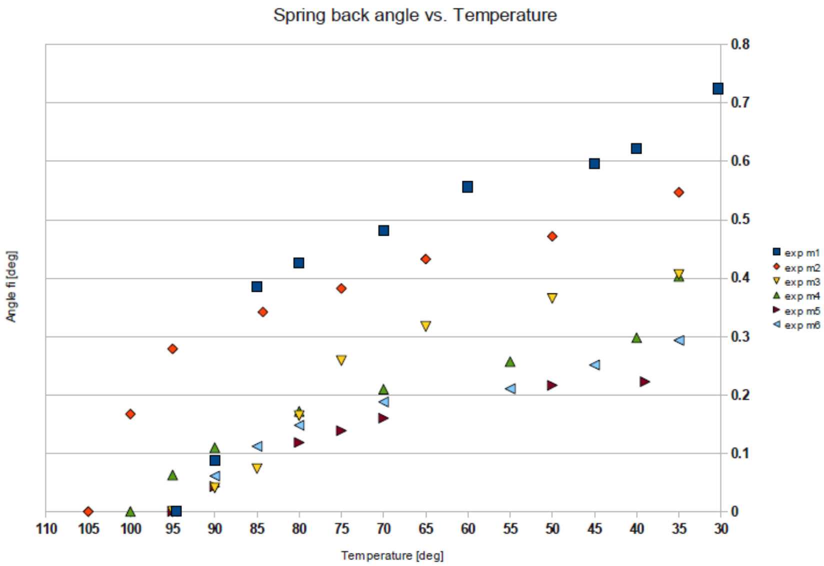

Fig. 7. Obtained data for springback angle for measuring by CHRocodile M4.

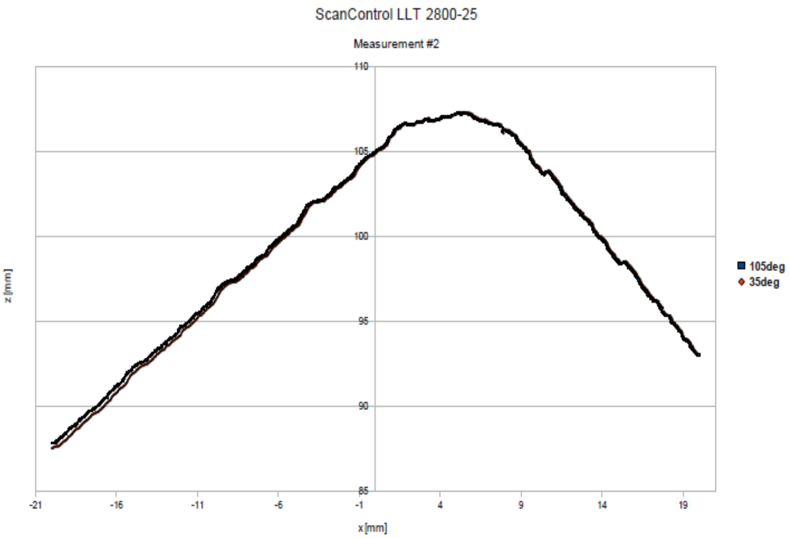

Fig. 8. Obtained data for springback angle for measuring by ScanControl, variation 1 (lines in the figure stand for profile at the beginning and at the end of the measurement).

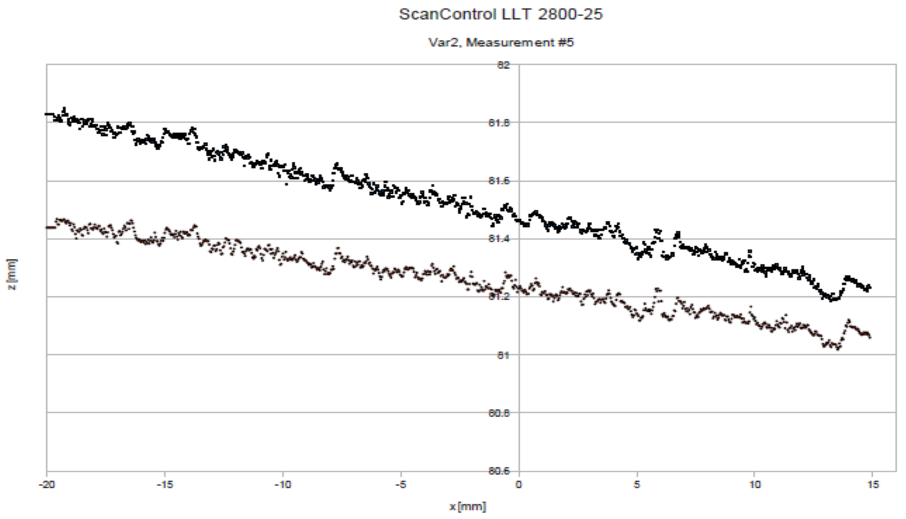

Fig. 9. Obtained data for springback angle for measuring by ScanControl, variation 2 (lines in the figure stand for profile at the beginning and at the end of the measurement).

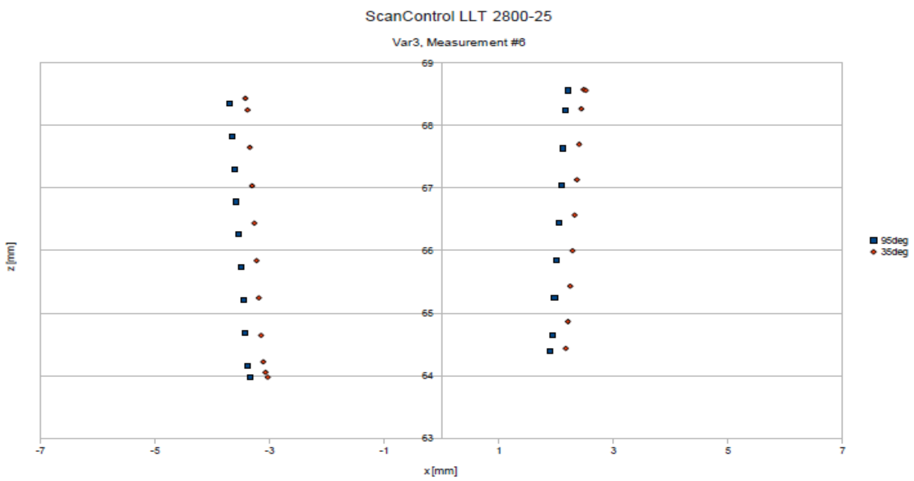

Fig. 10. Obtained data for springback angle for measuring by ScanControl, variation 3 (points in the figure stand for profile at the beginning and at the end of the measurement).

2.2. Interpretation of measured data

The accuracy of measuring device is in µm which means that the measurement took into account also the surface roughness. This accuracy makes the evaluation more complicated because of the volume of measured data and also the fact that the measured points are changing with the deformation of the specimen. Therefore, the results taken are actually average values or regression curves. The angular displacements are measured as the springback of L-profile but also as its volumetric change due to temperature. These two physical effects are difficult to separate. Another point to discussion is the fact that we have no information about temperature inside the specimen (temperature information is taken just from the surface).

3. Analytical and numerical model

Measured data from the chapter above were evaluated and compared with analytical and numerical model.

3.1. Analytical model

Analytical model was based on classical lamination theory (CLT) and equations for through thickness characteristics of the composite plate (see [5] or [6] for details). Springback angle can be computed as

$$\Delta\gamma = \Delta\gamma_t + \Delta\gamma_h + \Delta\gamma_c = \gamma\frac{\varepsilon_y^t - \varepsilon_z^t}{1+\varepsilon_z^t} + \gamma\frac{\varepsilon_y^h - \varepsilon_z^h}{1+\varepsilon_z^h} + \gamma\frac{\varepsilon_y^c - \varepsilon_z^c}{1+\varepsilon_z^c} \qquad (1)$$

where $\Delta\gamma_t$ is the change in angle due to temperature, $\Delta\gamma_h$ is the change in the angle due to hygroscopic effect and $\Delta\gamma_c$ is the change in the angle due to shrinkage effect during the cure cycle. Strains (from temperature, moisture absorption and shrinkage – superscripts *t*, *h* and *c*) those marked with *y* subscripts stand for longitudinal directions, coefficients marked with *z* stand for transversal (through thickness) direction. In our case just $\Delta\gamma_t$ is relevant. $\Delta\gamma_c$ will be relevant if the matrix went from amorphous to crystalline phase during the cure cycle (the range of temperatures in experiment kept the matrix just in crystalline phase). $\Delta\gamma_h$ will be relevant if there is some kind of the change in moisture (which isn´t).

3.2. Numerical model

A finite element (FE) model was created and analyzed for thermo-elastic strains using ABAQUS solver. The linear elastic material constants were verified on the bone specimen and compared with the experimental data. The model was solved with the hexahedron incompatible mode elements and two types of material properties - orthotropic linear elastic properties and thermal expansion material coefficients for unidirectional lamina and linear elastic material properties and orthotropic thermal expansion for the whole composite. There were two sources of material data – the first are computed by classic lamination theory and the second are data from material sheet AIMS 05-09-002. Numerical model is shown in Fig.11.

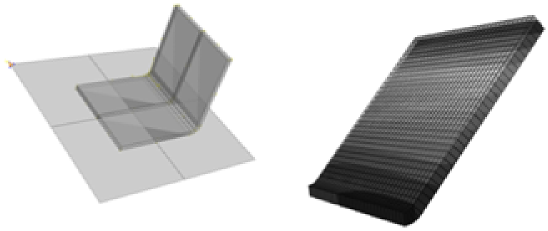

Fig. 11. FE simulation of springback effect.

4. Result comparison and conclusions

The springback angle of C/PPS composite plate was experimentally measured and the measurement results were compared with the analytical ones with a good agreement. Numerical model was created and analyzed for thermo-elastic strains using ABAQUS solver.

The comparison of analytical, experimental and FEM simulation results for the corner section of C/PPS composite is presented in Fig.12. The results show a large range of experimental data and very good agreement of the analytical solution with the FE results of material model with the data from material sheet AIMS 05-09-002. The large range of experimental data can be caused by the fact that the measurement was done repeatedly on one specimen.

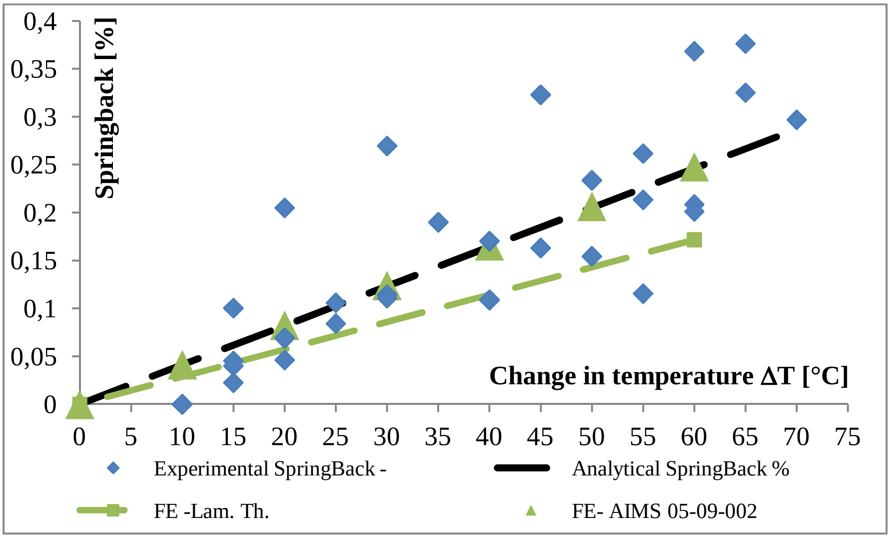

Fig. 12. Comparison of analytical, numerical and experimental data for springback.

Moreover, the results of the FE material model, which were compared with the coefficients solved by the classical lamination theory are conservative.

Acknowledgements

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