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3D SCANNING INSPECTION OF THE COMPOSITE STRUCTURES

Agnieszka Bondyra, Przemysław Pastuszak

Krakow University of Technology
Faculty of Mechanical Engineering
Warszawska Street 24, 31-155 Krakow, Poland
tel.: +48 12 374-33-85, +48 12 374-33-07, fax: +48 12 6282071
e-mail: abondyra@mech.pk.edu.pl, ppastuszak@pk.edu.pl

Abstract

Wide range of different visual measurement techniques, which are used nowadays, shows the need of the development of geometry description possibilities. New applications of advanced materials require measurement methods, which can be used in the areas of reverse engineering, FEA modelling validation, rapid prototyping and analysis of structure deformations. Light and laser-based techniques such as photogrammetry, laser triangulation, Moire and optical coherence tomography allow for analysing geometry of the specimens. Widely used optical methods take into account the global and local coordinate translation, sensitivity, resolution, and measurement uncertainty. They are used in the respect to research trends such as direct shape measurement from surfaces, system calibration and optimization methods.

In this paper, composite specimens' geometries with artificial delamination inside and structures without delamination are analysed. Rectangular, curved and cylindrical shapes are investigated by 3D scanning technique. The measured composite structures are manufactured with autoclave and vacuum bag methods. Results presented in this paper, shows geometries different between composites manufactured by using these methods.

Inspection process was executed in two steps. First, virtual models of the composite specimens are used to determine main geometry dimensions. Second, their curvatures and GD&T are determined. Additional, the thickness change connected with delamination is revealed. Used method gives an opportunity of observing specimens curving radius and manufacturing defects. Presented results shows that use of additional aluminum plate in vacuum bag method allowed to get specimens with high level of flatness and parallelism in the case of rectangular structures and cylindricity in case of the curved shells. Presented methodology of the inspection is simply, give multidimensional results and its application are not limited to laboratory conditions.

Keywords: *non-destructive inspection, 3D scanning, composites, vacuum bag technology, autoclave technology*

1. Introduction

One of the key issue in the many industry areas is composite structures manufacturing. Main difficulties in the production process are connected with quality of the various geometries the structures. Geometries change in the working conditions and besides in the experimental and numerical tests [12]. In some cases, the present expansion of composite structures requires the structure state analysing in on-line conditions. A number of non-destructive inspection techniques such as tomography or 3D scanning are used currently to inspect quality of surfaces after manufacturing processes or to detect the defects in the real structures [3-5, 7-9]. On one hand, visual inspection methods have advantages such as fast data acquisition and low costs of processing, but on the other hand, these techniques are very sensitive to operator errors. It can be partially eliminate by calibration and configuration before measurements. However, inspection tests of composite structures in environment conditions are widely recommended in literature [2].

In our work, the composites structures with various geometries and with additional defects are inspected in order to autoclave and vacuum bag manufacture method comparison. 3D scanning method was used to done this process. This method is helpful to measure the geometries and some type defects detection [1]. This consideration is limited to small composite structures, but presented method can be used also to large constructional composite elements with using of segmentation of scanning measurement process [1].

In the inspection process, portable 3D scanner was used for measured points' acquisition. In the present analysis, the 3D scanning process was executed with a portable laser scanner REVscan manufactured by Creaform company [6]. The main features of the scanner are following:

- weight: 980 grams,
- dimensions: 160×260×210 mm,
- measurement: 18 000 measurements/sec,
- accuracy: up to 0.05 mm,
- resolution in z axis: 0.1 mm,
- laser cross area: 210 mm×210 mm.

3D scanning measurements are made with using "black box" technique, which give opportunity to the geometries measure without additional thickness values. The positioning targets were placed on the environment of the composites structures. The measurements were conducted after the calibration and configuration process. The 3D scanning process was considered the external and internal surfaces of the composite structures. The measurements were done with 0.05 mm resolution. In all presented cases, a total number of 500 000-measurement points were acquired in order to structure geometries reconstruction.

2. Composites manufacturing processes

High fibre volume content in fibre raisin combination is achieving in the modern manufacture processes for example as the results of the vacuum bag or autoclave using. In order to high quality composites obtaining, laminas in form of the prepress are combined with raisins polymerization process with additional compression [10].

Vacuum bag method connected with resin infusion allowed to manufacture even large size composite parts have two stages. In first, reinforcement layers in the preform are impregnated by liquid polymers. Afterwards, composite is subjected to compression with vacuum pump. Pressure distribution has significant influence to process parameters. The first proposition of this application manufacture method have place in 1978 by Gotch. The mathematical models, which described parameters of the process, are wide shown in the literature [13].

The resin flow rate j in composite manufacture processes is described by Darcy's law:

$$j = \frac{-D}{\eta} \nabla P, \tag{1}$$

where:

D – permeability of the preform,

η – viscosity of the resin,

P – hydrostatic pressure.

Energy release G is described by proportion of the product of the energy density and the thickness of the infused layer [13]:

$$G = \xi \frac{(h-b)}{E_w} (\sigma_{\parallel}^{w})^2, \tag{2}$$

where:

h – thickness of the perform layer,

b – thickness of the "un-infused" section of the preform layer,

E_w – Young's modulus of the saturated zone,

$\sigma_{\parallel}^{w}$ – Component of the stress tensor perpendicular to the flow direction,

ξ – experimental constant.

If the *G>Gc* in the unsaturated region than catastrophic crack growth occurs, else if the *G=Gc* than stable crack growth have place.

Autoclave process have two mains steps: temperature (heating, cooling) and pressure changes [12]. Autoclaving manufacturing method guaranteed highest quality of composite structures, especially in aviation. In this process, individual prepreg layers are brought together and made them in one laminated material in the pressure vessel [11].

3. Inspection results

In this paper, specimens, made with vacuum bag method or autoclave using are considered. We examined three types of the structures with various geometries: rectangular, curved (Fig. 1) and full cylinder, made from R-glass reinforced composite. Artificial delamination are made with using the Teflon film. Other defects were created in the production process. Geometries features were observed and main typical defects in structures manufactured with autoclave and vacuum bag are defined. Furthermore, influence of additional elements in vacuum process was analysed.

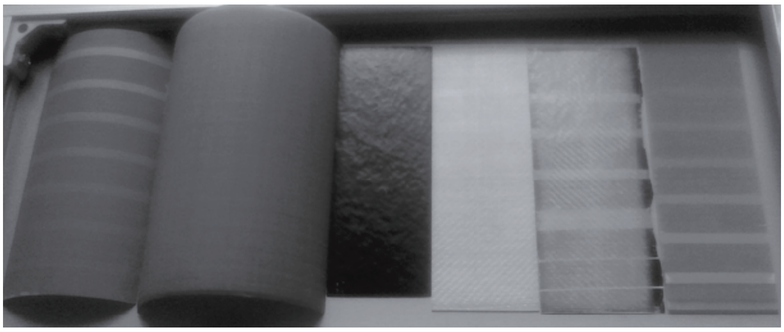

Fig. 1. Scanned structures – selected specimens

Specimens were scanned and virtual models were prepared. The geometry measurement and inspection was done with Geomagic Control 2014 software using. With 3D scanning measurement method we localized some defects in structures such as structure deformation or wrong raisin saturation, which are provide by manufacturing technology. In some cases, artificial delaminations are made in composites structures with using Teflon film.

Before analysis of particular specimens, we compared 3D deviation for autoclave and vacuum manufactured specimens (Fig. 2). Specimen done with autoclave was reference object. This result show curvature of the vacuum manufactured object in the central part. Next, in order to analysing specimens, wall thickness evaluation and GD&T were done.

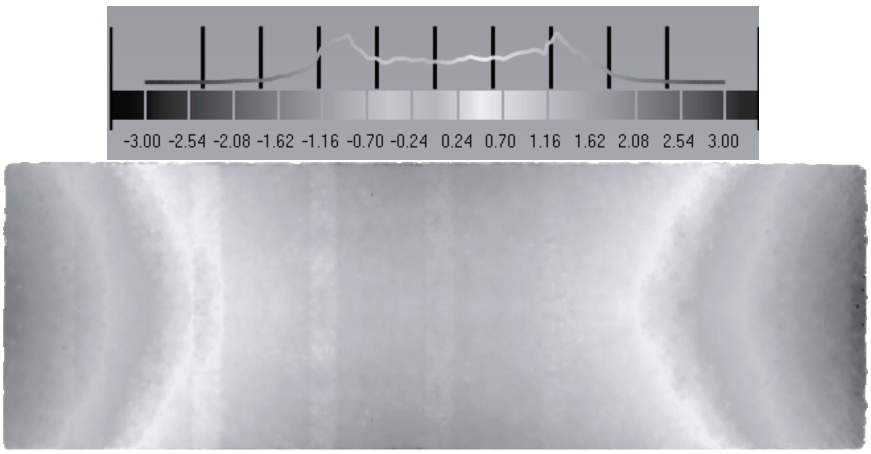

Fig. 2. Comparison of the autoclave and vacuum technology manufactured composite structure

Wall thickness evaluation was done for selected specimens in order to the geometry defect localised. In the vacuum-manufactured rectangular specimens the symmetrical wrinkles, incorrect raisin saturation and shape deformation can be seen (Fig. 3).

a) Wrinkles and delaminations b) Raisin saturation c) Shape deformation

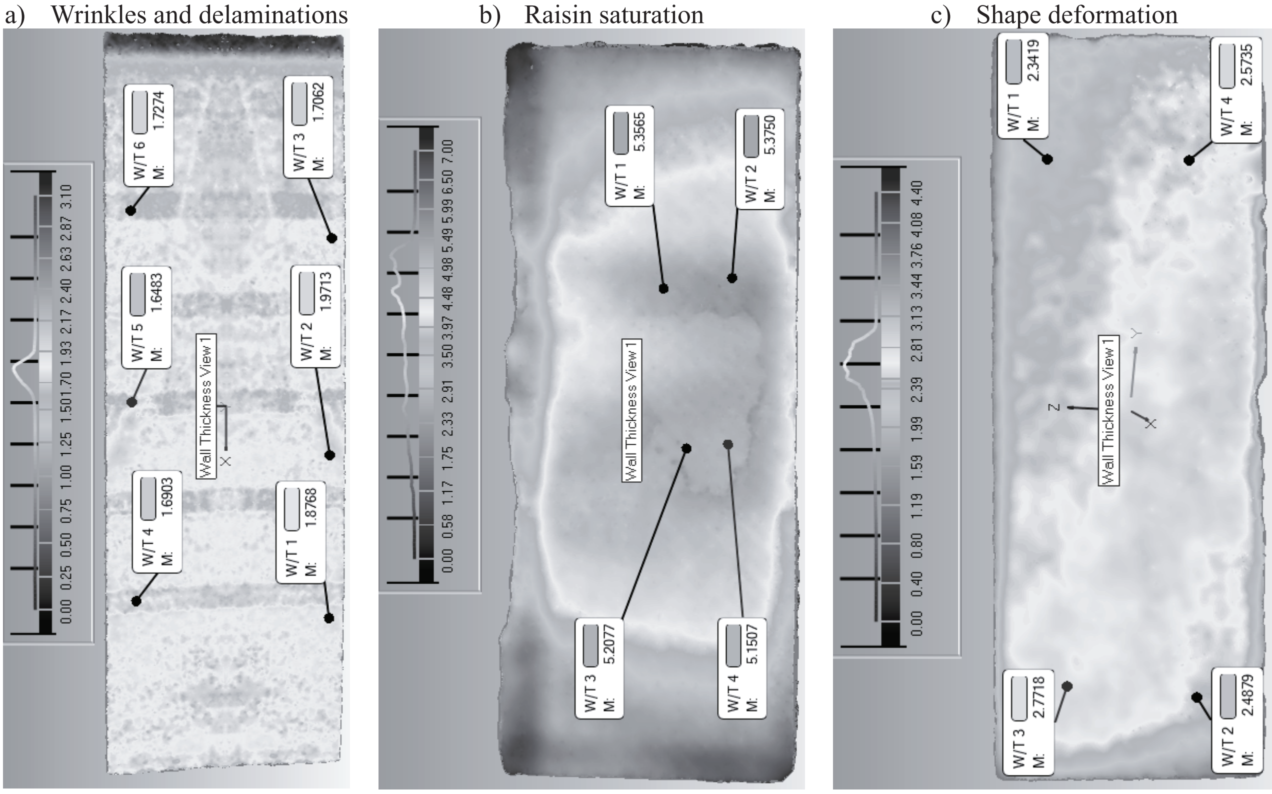

Fig. 3. Vacuum technology manufactured composite specimens – defects

Additional, wall thickness changes connected with artificial delamination were localised in various shapes structures. In case of the specimen with thickness changes in the central part of the top of the specimen, resin saturation is low. The thickness differences in this structure are results of the irregularity of raisin distribution. This disadvantage is eliminated by using additional aluminium plate, but changes in the vacuum manufacture process not eliminate the specimen deformation. In structure with artificial delamination, it can be seen, irregular thickness distribution in places of the defects.

The thickness of the autoclave-made specimens (Fig. 4), have the best compliance with nominal dimensions and the lowest deviations. Specimens given by autoclave manufacturing process haven't production defects such wrinkles and wrong raisin saturation. Thickness values distributions are much regular also in curved composite structures. Additionally, histograms shows thickness distribution, in the case of the autoclave and vacuum bag manufactured specimens. It can be seen that the specimens produced with autoclave using have higher regular thickness distribution (Fig. 4).

In next part our analysis, GD&T of the specimens are determined. At case of the vacuum bag made specimens (Fig. 5) it can be seen curved geometry, which affected to the parallelism error. The lowest values of the flatness and parallelism error can be seen at autoclave made specimen. Error of the cylindricity of the vacuum bag manufactured specimen without delamination is higher than specimen with artificial delamination between subsequent laminas. The cylindricity error of the all specimen is at the similar level in contrast to flatness and parallelism of the rectangular structures.

In some cases, geometry inspection and GD&T can be used prior to carrying out further processing of the composite structures in order to approach to the nominal dimensions. Furthermore, 3D scanning inspection allow to measure geometry at high level of accuracy, which helps gets better results in experimental tests and numerical simulations.

a) delaminations b) nominal geometry

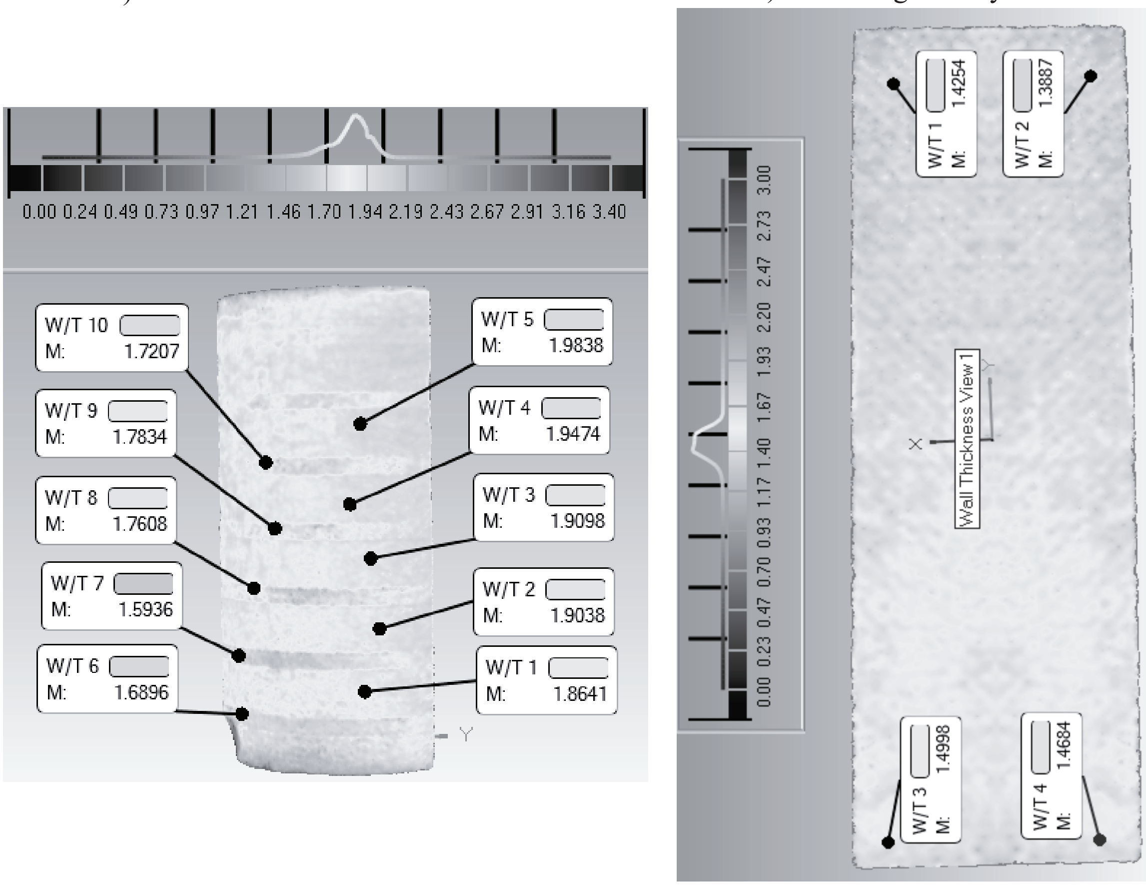

Fig. 4. Autoclave technology manufactured composite specimens

Flatness *Parallelism*

Specimen 1 (vacuum bag)

Specimen 3 (autoclave)

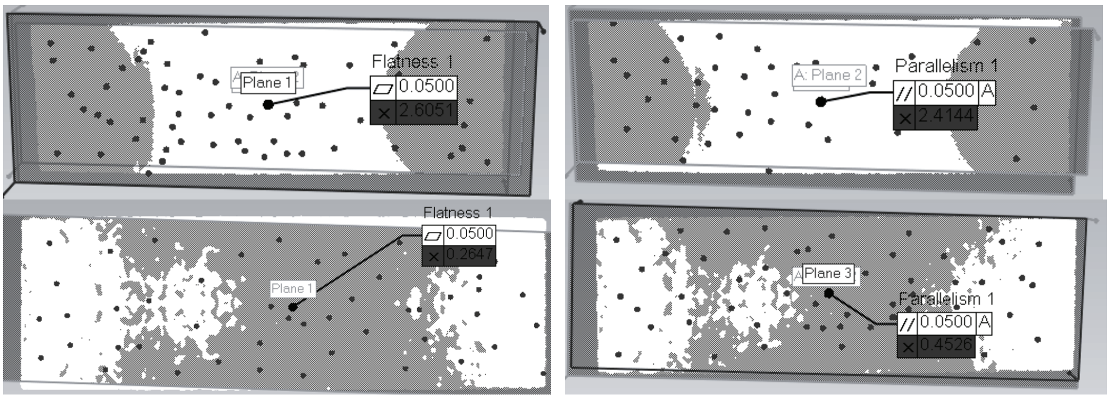

Fig. 5. Geometric dimension and tolerancing (GD&T) – selected specimens

5. Conclusions

In this work, the inspection results of the specimens made by vacuum and autoclave techniques are presented. The 3D scanning measurements of several composite specimens were done and virtual models geometries were built. The comparisons and analysis are included two aspects: various geometries and two-manufactured method: autoclave and vacuum bag. Afterwards, wall thickness evaluation and GD&T were shown in relation to measured structures. The results show the dependences of the structure shape quality from manufacturing method.

Applied measured method allows to get the virtual models (*stl), which analysis can be useful to detected the manufactured defects affecting at the dimension geometry and shape. This data constitute the basis for determining further processing to improve the structure shape and for numerical model creation and validation.

References

[1] Bere, P., Neamtu, C., *Methodology for evaluate the form deviations for formula one nose car*, Central European Journal of Engineering, Vol. 4, Is. 2, pp 148-154, 2014.

[2] Böer P., Holliday L., Kang T. H.-K., *Interaction of environmental factors on fiber-reinforced polymer composites and their inspection and maintenance: A review*, Construction and Building Materials, Vol. 50, pp. 209-218, 2014.

[3] Bondyra, A., Chwał, M., Pastuszak, P. D., *Prospects of laser measuring scanners applications for analysis of the deformation of composite structures*, Przetwórstwo Tworzyw, pp. 4-11, 2014.

[4] Bondyra, A., Chwał, M., Pastuszak, P. D., Stawiarski, A., *Analysis of composite structure deformations based on 3D laser scanner measurements,* Composites Theory and Practice Vol. 1, pp. 38-42, 2014.

[5] Dong, Q. G., Ma, J. F., Lin, H., Chen, Ch. Q., Yang, F., *Precision Analysis of the Surface Model Based on Geomagic Qualify*, Applied Mechanics and Materials, Vol. 490-491, pp. 649-653, 2014.

[6] http://www.creaform3d.com/en

[7] Ibrahim, M. E., Nondestructive evaluation of thick-section composites and sandwich structures: A review, Composites Part A: Applied Science and Manufacturing, Vol. 64, pp. 36-48, 2014.

[8] Lemes, S., *Validation of Numerical Simulations by 3D Scanning: Springback Compensation in 3D Scanning by Finite Element Analysis*, LAP Lambert Academic Publishing, 2012.

[9] Liu, P., Groves, R. M., Benedictus, R., *3D monitoring of delamination growth in a wind turbine blade composite using optical coherence tomography,* NDT & E International, Vol. 64, pp. 52-58, 2014.

[10] Preglej, A., Karba, R., Steiner, I., Škrjanc, I., *Mathematical Model of an Autoclave*, Strojniški vestnik Journal of Mechanical Engineering, Vol. 57, No.6, pp.503-516, 2011.

[11] Sevostianov, I. B., Verijenko, V. E., von Klemperer, C. J., Chevallerea, B*., Mathematical model of stress formation during vacuum resin infusion process,* Composites Part B Engineering, pp. 513-521, 1999.

[12] Short, G. J., Guild, F. J., Pavier M. J., *The effect of delamination geometry on the compressive failure of composite laminate*, Composites Science and Technology, Vol. 61, Is. 14, pp. 2075-2086, 2001.

[13] Vasileios, M. D., Seferis, J. C., Doumanidis, C. C*., Curing Pressure Influence of Out-of-Autoclave,* Processing on Structural Composites for Commercial Aviation, Advances in Materials Science and Engineering, Vol. 2013, pp. 1-14, 2013.