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COMPOSITES THEORY AND PRACTICE

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ANALYSIS OF COMPOSITE STRUCTURE DEFORMATIONS BASED ON 3D LASER SCANNER MEASUREMENTS

Non-contact measuring techniques are nowadays widely used in many applications from industry to the laboratory testing of advanced materials. The present paper is dedicated to the laser measurement scanning technique being one of the 3D active vision measurement non-contact systems. In order to analyze the deformations of a composite structure, 3D virtual models of an unloaded and loaded composite sample are created from 3D scanning data. The results of the deformation analysis are presented in the form of contours of the 3D deviations. Additionally, a comparison between the virtual images of the intact and delaminated areas of the analyzed composite structure is presented.

Keywords: 3D laser measuring scanners, cylindrical composite structures, deformations, inspection techniques

ANALIZA DEFORMACJI STRUKTUR KOMPOZYTOWYCH Z WYKORZYSTANIEM POMIARÓW SKANEREM LASEROWYM 3D

Techniki pomiarów bezstykowych są obecnie szeroko stosowane, od aplikacji przemysłowych po laboratoryjne badania zaawansowanych materiałów. Prezentowana praca dotyczy techniki laserowych pomiarów skaningowych będących jednym z wizyjnych aktywnych systemów pomiarów bezstykowych. W celu analizy deformacji struktur kompozytowych wykonano wirtualne modele 3D nieobciążonej i obciążonej próbki kompozytowej z danych ze skaningu 3D. Wyniki analizy deformacji zaprezentowano w formie map odchyłek 3D. Dodatkowo zaprezentowano porównanie obrazów wirtualnych obszaru nienaruszonego i obszaru z delaminacją dla badanej struktury kompozytowej.

Słowa kluczowe: laserowe skanery pomiarowe 3D, cylindryczne struktury kompozytowe, deformacje, technika inspekcji

INTRODUCTION

Classical deformation measuring techniques are contact measurements with high precession that are good for tiny deformations of measured points of a structure. The main disadvantages of such methods are limits due to the necessity of contact with the measured surfaces and increasing the number of measurement points. Monitoring a large number of measuring points on surfaces having complex shapes becomes a time-consuming challenge [1].

There are two types of vision measurement systems: passive and active. On one hand, passive vision systems give very high accuracy, on the other hand, their using is cumbersome in unstructured environments due to the high dependence of ambient light. In active 3D systems, the object coordinates are received from external information such as scanning angles, time of flight, shape etc. Laser measurement scanners and structural light systems belong to 3D active vision systems. The main advantage of active systems is their own illumination which allows one to measure in most environments [2, 3]. The measurement errors in passive vision systems are caused by the 2D image coordinate measurement and the 3D object coordinate computation, whereas in active visions, the major source of measurement error is in the 3D coordinate measurement (Tab. 1) [3].

Currently, a huge number of research papers as well as commercial applications of measurement solutions is evidence of the development in optical shape measurement techniques [4]. The rapid development of technology entails the use of new, accurate and fast techniques of optical measurement such as 3D measurement scanning. The capabilities and high accuracy of 3D measurement scanners, especially hand-held 3D measuring scanners, gives new possibilities for a wide range of applications (data acquisition, rapid prototyping, reverse engineering inspections and analysis of deformations) [5, 6]. There are two main types of scan measurement techniques based on projected structured light and the laser scanning method [2, 4]. The simple procedures as well as high density of acquisition in a single scan give the possibility to observe the deformations of composite structures [6].

TABLE 1. **Major sources of measurement errors in 3D vision systems**
TABELA 1. **Główne źródła błędów pomiarowych w systemach wizyjnych 3D**

Source of measurement error	Passive systems		Active systems
	2D image coordinate measurement	3D object coordinate computation	3D object coordinate measurement
sensor	+	-	+
feature	+	-	+
ambient light	+	-	-
method	+	-	+
calibration	-	+	+
geometry	-	+	-

METHODOLOGY OF 3D SCANNING PROCESS

3D scanning measurement may be used to observe model deformation defined as a change in the shape of an analyzed structure under loading. Measurement scanners are used to capture the object shape and to generate a virtual model. The irregularities in 3D data scans make it necessary to use additional software for data processing. A 3D scanner measurement produces a set of 3D points with high density from the object surfaces in the form of a range image $z = f(x,y)$, where z is the object depth for an (x,y) location in the sensor image plane. The depth is recovered by triangulation. Next, the data are transformed into a geometrical virtual model of the object [7]. The data from 3D scanning have huge density and are independent from the complex shapes of the measured structures. Simplification algorithms of 3D scanner data processing are now being widely developed [8].

In the present analysis, 3D scanning was executed with a portable 3D laser scanner - REVscan manufactured by the Creaform company [3]. The main features of the scanner are the following: weight: 980 grams, dimensions: 160×260×210 mm, measurement: 18 000 measurements/s, accuracy: up to 0.05 mm, resolution in the z axis: 0.1 mm, laser cross area: 210 mm× ×210 mm.

Generally, the procedure for 3D scanning is as follows: sensor calibration, preparation of the scanned structure, implementing the scanning process, cleaning noise data, translation to STL format, and data analysis [9].

It is necessary to stick position targets on the measured surfaces or environment before the scanning process, which make the scanner a self-positioning device. Positioning target systems allow for using laser beams to identify the target to the reference system which is attached to the model [11, 12].

The parameters of the 3D scanning process, e.g. data acquisition speed, spatial resolution and accuracy are connected with the number and shape of light sources, which can vary from a single point to measurement lines [2, 4]. The way of acquisitioning data by means of a portable 3D measurement laser scanner is presented in Figure 1.

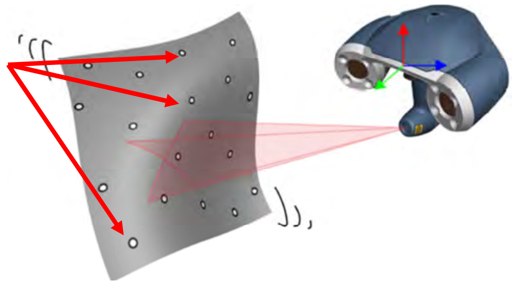


Fig. 1. Data acquisition in 3D scanning process [10]

Rys. 1. Akwizycja danych w trakcie procesu skanowania 3D [10]

The results of the scanning process are presented in the form of point clouds, which may be transformed to a polygon editable mesh (facet mesh) by triangulation (Fig. 2).

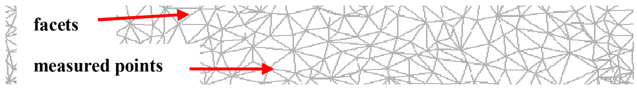


Fig. 2. 3D mesh file in STL format - facet mesh

Rys. 2. Siatka 3D w formacie STL - siatka fasetek

Geometrical models which are built on the basis of the scanning results can be used in FEM software or to compare with a CAD model in the inspection technique. The 3D scanning method allows one to analyze the real data, however, it gives the opportunity to carry out quality control, e.g. measuring changes in a surface shape due to damage or construction errors [13]. The additional advantage of the triangulation of measuring points is the capability of eliminating problems such a Gaussian point disappearance on sharp object edges [4]. A 3D scanning measurement laser allows for registering surface shapes by using a number of algorithms. The widely-used iterative closest point (ICP) algorithms applied to register 3D shapes are based on Euclidean distance [14]:

$$D = \|\bar{r}_1 - \bar{r}_2\| = \sqrt{(dx_2 - dx_1)^2 + (dy_2 - dy_1)^2 + (dz_2 - dz_1)^2} \tag{1}$$

The inspection technique is a method that helps to approximate depth, dimensions and positions of the measured objects. Manual inspection is dependent on the inspector's skills, though in combination with 3D imaging techniques, it gives results with good accuracy, repeatability and data processing speed [12, 15-17].

MATERIAL AND METHOD

The geometry of a measured cylindrical composite structure is presented in Figure 3. An artificial delamination is located in the central part of the cylinder. During the measurement process, 3D scans of the external surface of the studied structure were produced that allowed us to analyze the deformations.

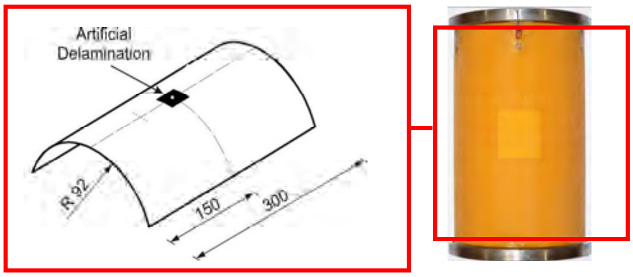


Fig. 3. Geometry of cylindrical composite shell

Rys. 3. Geometria cylindrycznej powłoki kompozytowej

The scanning measurements were done in two steps: on an unloaded structure and on a structure under compression loading. The 3D scan was prepared with a resolution of 1 mm. Therefore, there was need to guarantee that the used 3D scanning method could improve the processing of the data point clouds with an accuracy described by the user, then transform the data point clouds onto the surface, and finally remove the redundant data points. Next, the 3D scanning data were analyzed in Geomagic Qualify 2014 software.

Figure 4 presents a virtual model of the external surfaces of the scanned structure after removing the positioning targets from the scanning surface. The cylindrical composite structure was placed between the top and bottom base in the testing machine.

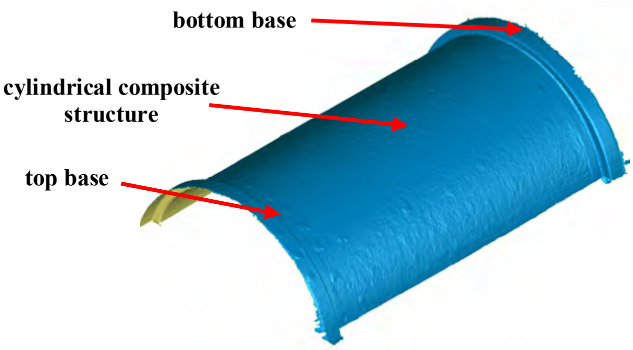


Fig. 4. Virtual model of scanning surface

Rys. 4. Wirtualny model skanowanej powierzchni

Next, virtual models after processing were used to analyze the deformation of the loaded structure and to compare an intact structure with the structure with delamination.

After hole filling and noise reduction, it is possible to obtain virtual models in the form of points, facets, surfaces etc. The data from 3D scanning after processing can be used to measure for example dimensions such as a change in the curvature radius (Fig. 5).

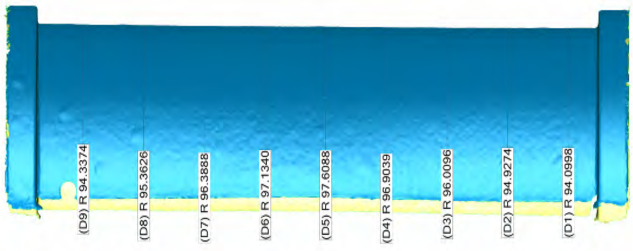


Fig. 5. Curvature radius change

Rys. 5. Zmiana promienia krzywizny

RESULTS

The data after processing were redefined as the distance between the unloaded and compressed structures and next presented in the form of 3D deviation. Two types of analysis were conducted: local comparison between the intact and delaminated area of the structure in the form of a facet mesh and a global comparison between the non-loaded and loaded structures in the form of 3D deviation. Comparisons were made between the *Test* and *Reference* object. The *Test object* means in this example an unloaded structure, and the *Reference object* means a compressed structure. The inspection process with 2D and 3D comparison were done with the help of Geomagic Qualify 2014 software. The *Reference* and *Test* objects were aligned with the Best Fit Alignment tool because the scanned structures lie in spaces where it was scanned with different coordinates.

The comparison of the 2D deviation of the cylindrical composite structure in thesymmetry plane of the composite structure had a maximum of +2.2381 mm and –2.0505 mm, the average was +1.3799 mm and –1.1973 mm, the standard deviation was 1.4136 mm and the RMS (the root mean square) estimate was 1.4183 mm (Fig. 6). In Figure 6, points with the maximum and minimum deviations are presented.

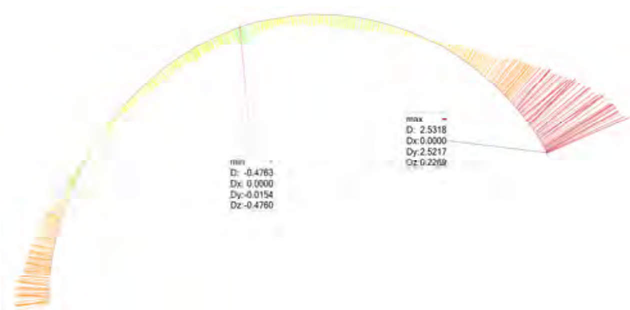
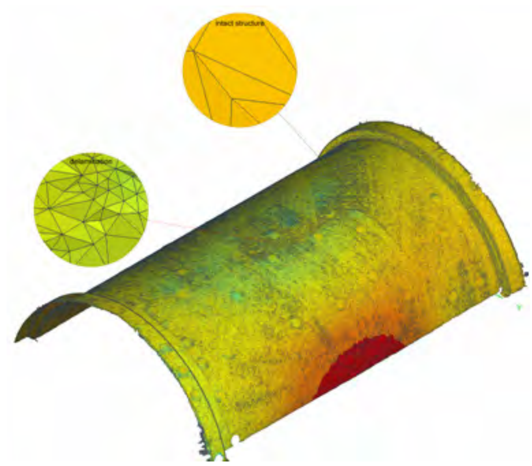


Fig. 6. Comparison of 2D deviation in symmetry plane of analyzed structures

Rys. 6. Porównanie odchyłek w przekrojach 2D w płaszczyźnie symetrii analizowanych struktur

In the 3D comparison analysis, the virtual models were created from 500 000 triangular facets each.

A higher concentration of facet mesh from the 3D scanning process in the central part of structure where the artificial delamination was present compared to the intact structure was observed (Fig. 7).



Rys. 7. Facet mesh refinement

Fig. 7. Gęstość siatki fasetek

The maximum and minimum of the 3D deviations were equal to +4.9355 mm and –4.7199 mm, average +1.2667 mm and –1.1606 mm. The standard deviation was equal to 1.3609 mm and the RMS estimate was equal to 1.43623 mm (Fig. 8).

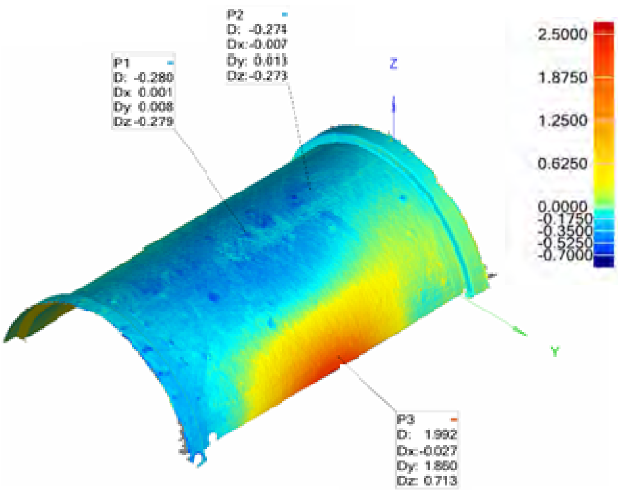


Fig. 8. Comparison of 3D deviation of deformed composite structure

Rys. 8. Porównanie odchyłek 3D zdeformowanej struktury kompozytowej

The comparison between the intact and the deformed structure allowed for observing 3D deviation in the selected points: *P1* in the center of the delamination, *P2* located in the intact structure and *P3* in the area with the highest 3D deviation (Fig. 8).

CONCLUSIONS

A practical technique for measuring the deformation of cylindrical composite structures was discussed in the present paper. It was shown that 3D laser measurement scanners can be useful in the analysis of composite structure deformations. The 2D section comparison in the symmetry plane of the analyzed structures and contours of the 3D deviations were used to elucidate the deformations of the composite structure under compression. The carried global analysis allowed for describing the deformations of the compressed structure by using 3D deviations. Additionally, the 3D scans have revealed changes in the facet mesh density in the intact and delaminated area during local analysis. In future works, we plan to analyze the uncertainty of 3D scanning measurement and structure deformations under fatigue loading.

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