MICRO-TOMOGRAPHY ANALYSIS OF THE FAILURES IN GLASS FIBER REINFORCED PLASTIC

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Abstract

Computer micro tomography is one of the methods that are used for displaying the structural arrangement of small parts or internal structure of materials (composites). Micro tomograph uses different continuous absorption and dispersion component to detect the internal structure the composites. Computer programs to create the images in 2D and 3D projection also allow mathematical analysis of the individual components. The subject of the article is the analysis the internal structure of the composite reinforced with glass fibers and thermoplastic matrix using software micro CT tomograph.

Key words: glass fiber, failure, micro tomograph, composite, porosity.

INTRODUCTION

Requirements for basic mechanical properties of engineering materials are reduce weight, good stiffness, strength and toughness. Most of the industrial materials are treated as homogeneous and isotropic; they are the basis for the most common technical applications. The composite is a multiphase material consisting of the continuous phase and dispersion. Continuous phase - the matrix may be metallic, ceramic, plastic or special. Dispersion - reinforcement may be fiber or particle. Fiber dispersion is continuous or in different lengths (GAY, SUONG, 2007; SUTCLIFE ET AL., 2012). The fibers are mainly used glass, carbon, basalt lesser extent. Recently, experiments with fibers based on natural (vegetable and animal origin) (GAY, SUONG, 2007). Type of reinforcement definite the arrangement of the fibers in the composite. Unidirectional oriented reinforcing fibers are continuous, infinite and oriented in one direction; ideally tense (AGARWAL ET AL., 2006, REQUENA ET AL., 2009). Properties of lamina in the direction of orientation the fibers are the best. The weave fabric is composed of two layers which are oriented towards the perpendicular direction, the fibers are interlaced. Lamina properties are in the directions of fiber orientation similar. Multiaxial knitted fabric with the desired number of oriented layers has the advantage that the fiber layers are not interconnected, and the fibers in the individual layers are oriented in one direction only. Matrix selected in accordance with the sizing of fibers and composites manufacturing technology have affected the occurrence failures in the internal structure. Mechanical stress leads to crack initiation and irreversible damage to composite structures (GAY, SUONG, 2007). This article describing of measurement with computer micro tomography (CT) as one of the methods that are used for displaying the structural arrangement of small parts or internal structure of materials (composites). Non-Destructive Testing (NDT) is a set of procedures and methods based on physical phenomena, through which it is possible to identify, locate and quantify the defect in the product without damage or destruction. In practice, it uses six basic NDT methods; These include visual inspection (VT), capillary penetration method (PT), the ultrasonic method (UT), radiographic methods (RT), magnetic powder method (MT), the method of eddy current (ET) and the method of acoustic emission (AT) (KARBHARI, 2013). Each method has different physical nature, requires a different approach, hardware and software. Radiographic method uses ionizing radiation to display an object, its internal structure, the separation of its constituents on principle the different radiation absorption and display internal failures. Current radiographic methods processing the image using computer technology; it enables much larger possibilities in image processing and evaluation of the data obtained (HARARA, 2008). The subject of the article is the analysis the internal structure of the composite reinforced with glass fibers and thermoplastic matrix using software micro CT tomograph. We use tomograph for the porosity calculation, quantify failures and for calculation of their distribution.

MATERIALS AND METHODS

Computed tomography (CT) is an advanced method. The device is able to non-destructively analysis and visualization the structure, high-quality 3D visualization and analysis of internal structures (BAKALOVÁ ET AL., 2014, PETRŮ ET AL., 2015).

Computer tomograph Sky Scan1272 (Fig.1) uses different X-ray absorption of individual components of the material. For analysis was chosen purposely defective sample of composite material reinforced with fiberglass. The sample is composed of three layers of unidirectional fibers; layers are not interconnected. The matrix is a thermoplastic resin. Air bubbles were predicted between the individual layers. The aim of the experiment was to identify failures by using computer software; to determine the amount and distribution the failures by 3D analysis, realized 2D analysis and create 3D model (SALABERGER ET AL., 2011). Parameters (conditions) of scanning glass fiber reinforced composite are shown in Tab. 1.

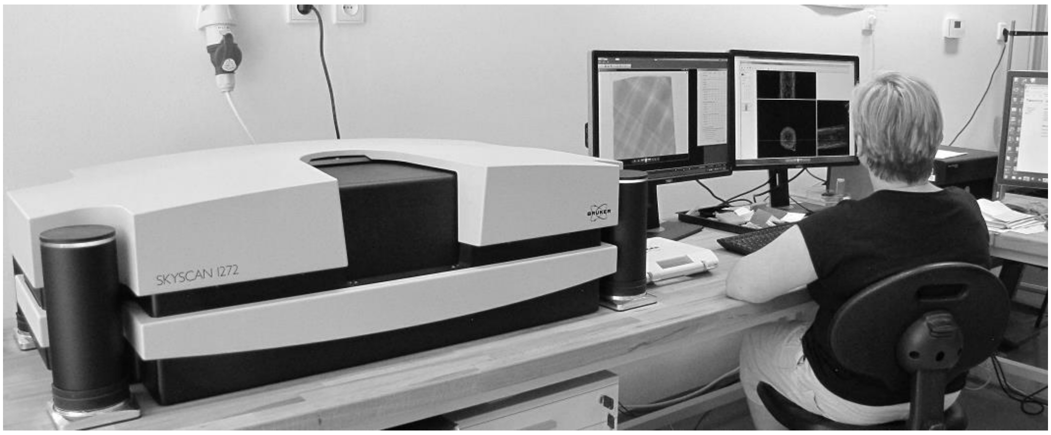

Fig. 1. – High-Resolution X-Ray Microtomograph Skyscan 1272 ; Institute for Nanomaterials, Advanced Technologies and Innovation, TU in Liberec

Tab. 1. – Scan parameters

Sample	GF
Source voltage (kV)	80
Number of rows and columns (pixel)	1640 x 2450
Scaled image pixel size (μm)	5
Exposure (ms)	1085
Rotation step (°)	0.2
Averaging	3
Filter	no filter

Reconstruction of dataset followed after scanning. Special software for the micro CT continues operates of dataset. The program DataViewer displays reconstructed results as a slice-by-slice movie or as three orthogonal sections (Fig. 2). 3D visualization of the sample in program CTVox showed the same material in 3D image (Fig.3a), the failures found in the sample are marked in red Fig.3b). CTAn allows accurate and detailed study of micro-CT results for morphometry and densitometry. The special software counts of porosity: identification of air pores, the calculation of the total volume of pores, their size and distribution, calculation of the volume fraction of open and closed pores. The calculation result is given in percentage of volume of the selected part of the sample. Monitored fiber-reinforced composite is defective. It contains a large amount of air bubbles. For their identification, calculation of volume fraction and distribution of defects was used calculation of porosity by using the software CTAn. Analysis of the sample was performed three times under the same conditions and only the number of slices differed, i.e. the volume of the select part of sample. The result was evaluated by a comparative method. It was performed 2D analysis. The result of this method is the porosity of the each slice of GFRP. CTVol uses surface trangulated models from CTAn and provides a virtual 3D viewing environment, flexible and rich features, to give you a wide range of options for 3D presentation of micro-CT results.

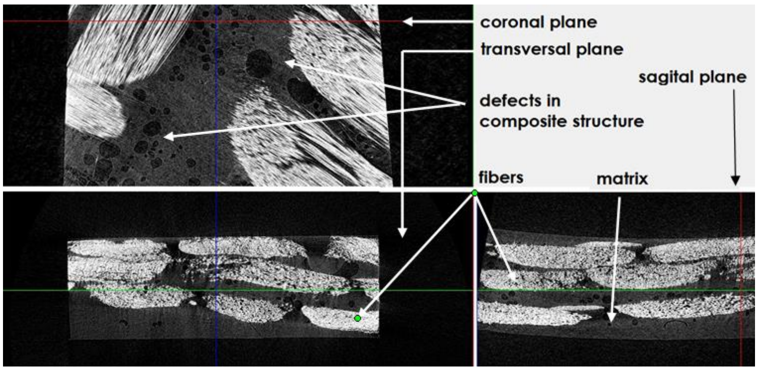

Fig. 2. – Software DataViewer – reconstructed results of composite sample in three orthogonal sections

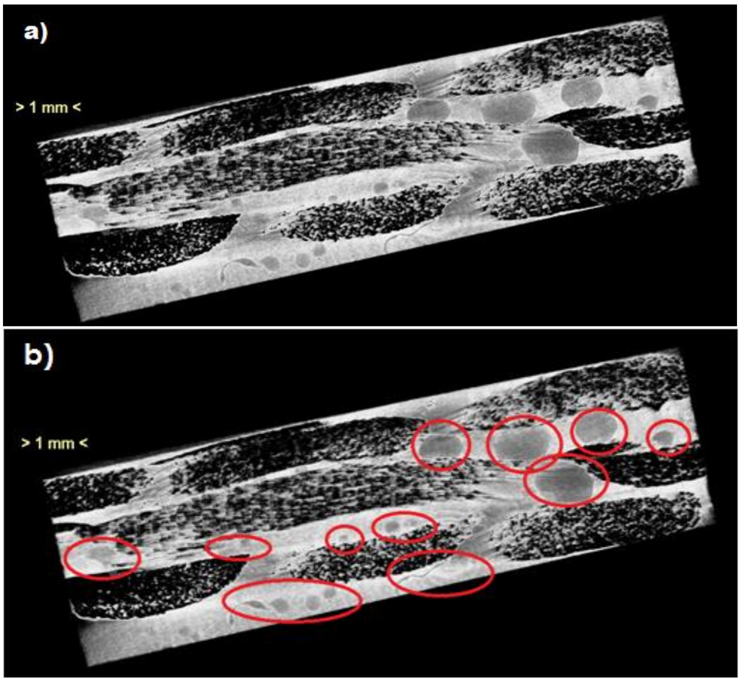

Fig. 3. – Software CTVox – 3Dvisualization of composite sample; a) internal structure of sample; b) failures in the internal structure of sample

RESULTS AND DISCUSSION

To determine the porosity of the fiber-reinforced composite using the CT is not necessary to know their characteristics. The value of porosity is not dependent on the shape and distribution of the pores (as with other methods). For application of CT for determining porosity is the most accurate and reproducible detection of interface between air and other materials - reinforcement and matrix (KASTNER ET AL., 2010). Micro tomography is used as a nondestructive method for determining the distribution of dispersed particles of the composite material (KASTNER ET AL., 2012), and search for defects (Scott A. E., et al). Ct analysis can be used also for the characterization of damage mechanisms in fiber composites (SALABERGER ET AL., 2012). For the experiment was selected composite in which has been supposed very numerous occurrences of defects of different sizes. The selected parameters of the three measurements are summarized in Tab. 2. Average of volume defects (air bubbles) is 29.45 % in the researched sample volume. The result was compared with the porosity (the occurrence frequency of defects) composite with the same properties and composition without the expected defects. Average of porosity was measured and calculated 10.21%, the difference is about 20% (Fig.4). It means approximately a third of the volume of the selected sample. The total porosity values are completed by a percentage of open and closed porosity values. The graph on Fig.5 shows the distribution of the pores (in this case defects - air bubbles) and comparison of results of individual intervals. The 2D analysis of porosity was performed on 900 slices. The interval of porosity was for all slices from 24.8 to 38.8%. The arithmetic average of 2D porosity is 27.7%. The result is graphically interpreted on the Fig.6.Virtual 3D viewing of the sample (Fig.7) and results of the calculation of the 3D porosity were used for visualization of pores (defects) in the program CTVol.

Setting the correct thresholding between the air and the other components of the composite has not been verified by another method.

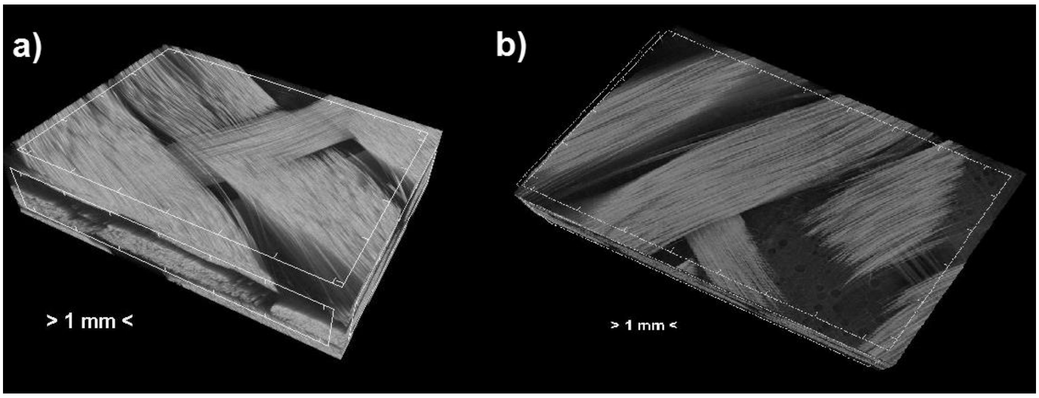

Fig. 4. – Comparison of samples: a) 10% of failures, b) 30% of failures

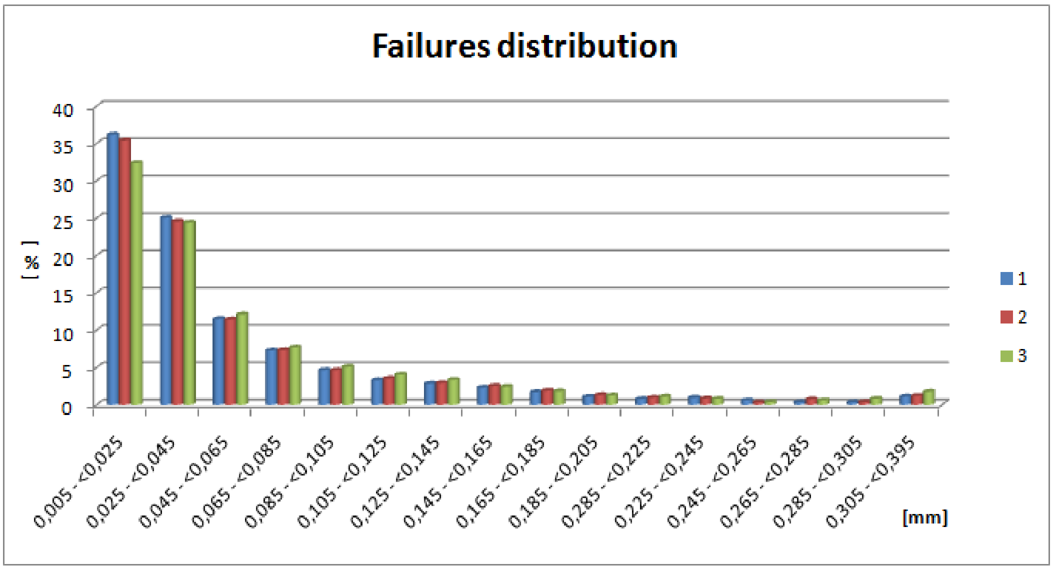

Fig. 5. – Graph of structure separation (failures distribution)

Tab. 2. – 3D analysis of structure GFRP

	Number of layers	Object volume	Open porosity [%]	Closed porosity [%]	Total porosity [%]	Degree of anisotrophy
1	701	54.86463	27.60	1.45	28.65	0.363
2	601	51.35300	27.52	1.43	28.56	0.368
3	651	56.18543	30.28	1.23	31.13	0.362
Average			28.47	1.37	29.45	0.364

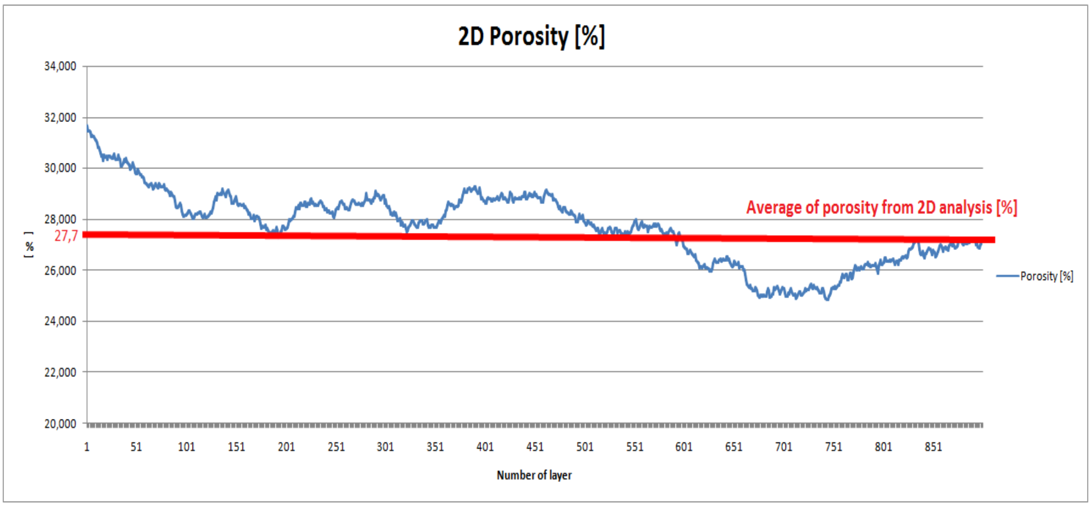

Fig. 6. – 2D porosity single slices

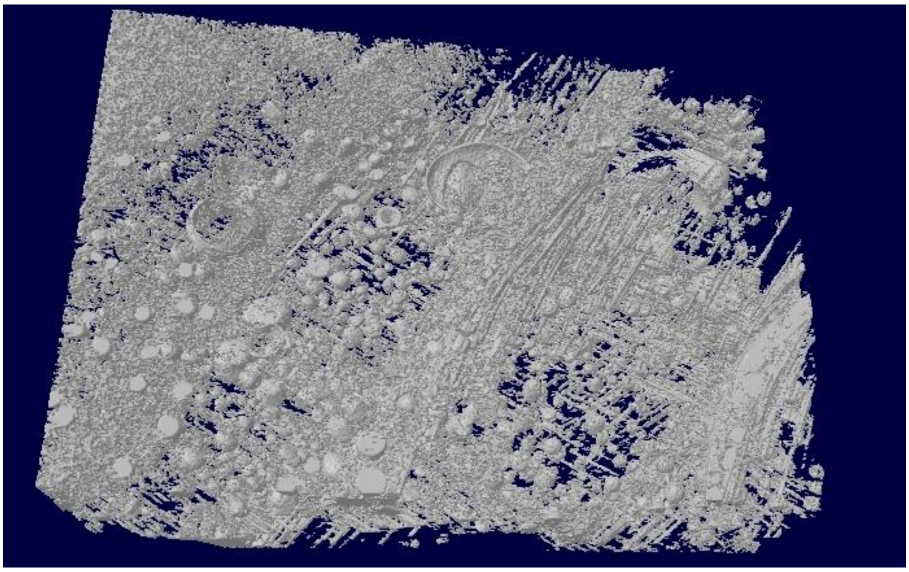

Fig. 7. – Virtual 3D viewing of the pores (failures) in CTVol program

CONCLUSIONS

Computer micro tomography is one of non-destructive methods of examining the internal structure of multi component materials. By using the programs that are part of the equipment micro tomograph is possible to visualize, simulate and implement calculations corre-sponded the properties of individual components. Calculating porosity was used for identifying and quantifying defects in glass fiber reinforced compo-site. The resulting porosity, respectively, the volume fraction of defects has a value of 29, 45%. It was visu-alized virtual 3D viewing of the pores (Fig.5). Setting the correct resolution of interface between the pores (defects - air bubbles) and matrix has proven very important. The visualization showed air bubbles (round objects on Fig.5) and minor micro cracks in the close proximity to the fibers. These micro defects copy fibers tightly and create the impression that the fibers are displayed in the model. The biggest defects are not displayed in the all volume. The degree of anisotrophy approaches 0, the structure is isotropic means properties of this material are the same in all directions.

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