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NDE OF HONEYCOMB STRUCTURE: A COMPARATIVE STUDY OF INFRARED AND TERAHERTZ IMAGING

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ABSTRACT

The honeycomb type material is one of composite materials. This type of material consists of core which is 3-dimansional structure having a form of combined hexagonal cells like the structure of honeycomb. Each side of the core is covered by layers of different material. These composite materials were mainly used in aircraft industry at first but they are also used in following domains now: aerospace, marine, automotive, railways, medical, architectural, electronic engineering, pharmaceutical, food and sport-recreation. These materials can be made both from metal and non-metallic materials. Typical defects are: faults like cracks, destruction in covering layers, destruction of core and separation of covering layers from core.

In the past years, terahertz (THz) technology has received more interest and attention because of its unique properties and capabilities that make it very attractive as a non-destructive evaluation (NDE) tool (Redo-Sanchez, 2006). Most items consisting of dielectrics like plastic, glass fiber reinforced plastics (GFRP), ceramics and certain composites (e.g. GFC) are transparent for THz waves, whereas, metals and other conducting materials such as carbon fiber reinforced plastics (CFRP) are not transparent for THz waves (Ewers, 2010, Jonuscheit, 2010).

This paper presents a comparison results from Terahertz (THz) and IR imaging for non-destructive testing non-metallic composites. The research was carried out by both transmission and reflection mode. Advantages and limitations of these methods are discussed.

Keywords: nondestructive testing, IR thermography, terahertz imaging, honeycomb composite

INTRODUCTION

Composites are a group including a variety of modern construction materials with special, often extreme, properties. They are formed by combining components that differ greatly in their characteristics, and therefore contain defects more often than other materials. These defects can arise during either their manufacture or use (Kurzydłowski, 2005).

Interest in composites results from two important factors. Firstly, they have excellent mechanical strength and, on the other hand, their low weight is of paramount importance for structural applications.

During their use, composites can be exposed to large stresses; these can include high humidity, aggressive chemicals (acid rain), and physical attack (ultraviolet light). Such stresses cause damage to the composite structure.

Microcracks are a type of defect that can be difficult to detect. The presence of moisture or water in the cells of a honeycomb-type composite (Fig.1) with no visible external damage

proves that microcracks are present in the composite. Therefore, the detection of traces of moisture and water inside the composite structure is one method of non-destructive testing.

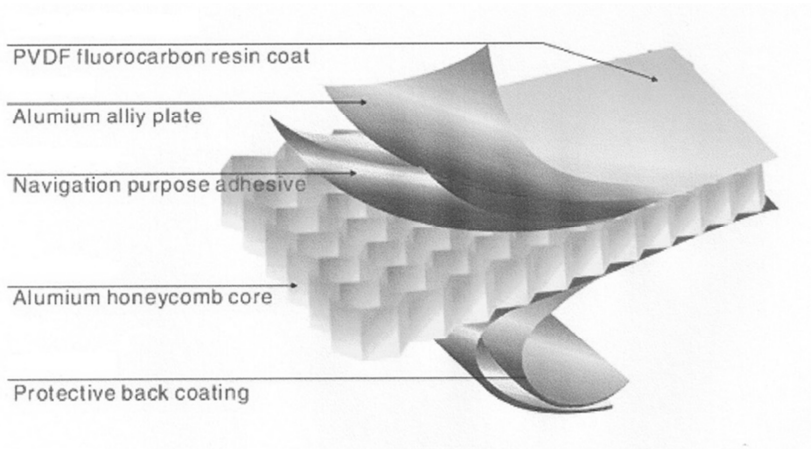


Fig. 1 - Structure of honeycomb composite made by Wxyiming

TESTING METHODS

One of the most effective and widely used methods of NDT of composites is infrared thermography.

NDT procedures using infrared thermography can be divided into passive and active methods. In the passive method, the object of study is characterized by a temperature field created during ordinary functioning. Therefore, passive procedures are primarily used for the non-destructive testing of devices or their components during operation or shortly after, when excessive differences in the temperature distribution on the surface of the examined object may indicate the presence of defects. As a result of mechanical or thermal loads, defects radiate or absorb heat, so they can be diagnosed and identified by passive methods.

Active procedures use a source of thermal stimulation (heating or cooling) of the object. Defects in materials that have a uniform temperature equal to the ambient temperature before testing do not generate "useful" temperature signals, and for this reason require heating or cooling of either the whole object or a part of it. In doing so, a dynamic temperature field is created, and the results of its distribution depend on the observation time. Active methods are also typically used as special procedures for data processing.

The relative positions of the source of heat stimulation and the temperature recording equipment (thermal camera) depend largely on the detection of defects and the practical implementation of the test. The simplest method consists of heating the surface of objects using an electric incandescent lamp. The achievable heating density, which is easily adjustable, can be up to several kW / m^2 in a zone 1 m in diameter.

In recent years, terahertz (THz) technology has received more interest and attention, because its unique properties and capabilities make it very attractive as a non-destructive evaluation (NDE) tool [2]. Most items consisting of dielectrics, such as plastic, glass fiber reinforced plastics (GFRP), ceramics, and certain composites (e.g. GFC), are transparent to THz waves,

whereas metals and other conducting materials, such as carbon fiber reinforced plastics (CFRP), are opaque to them (Maldague, 2001, Dragan, 2010).

The paper presents a comparison of the results of terahertz (THz) and IR imaging for non-destructive testing of non-metallic composites.

EXPERIMENTAL TESTING

In order to assess the possibility of using infrared thermography non-destructive testing methods to detect defaults in conventional honeycomb composite materials, samples of materials made by Nida-Core Corporation were used. In these samples, the core was made from polypropylene. Thanks to its physical and chemical properties, polypropylene is resistant to water and does not absorb it. For this reason, these honeycomb materials are ideal for numerous areas of industry, such as (www. nida-core.com):

- boat-construction: hull, deck, flybridge, sole, door, stringer, hatch, interior;
- equipment specific to marine construction, such as floating docks;
- swimming pool construction, either for the swimming pool itself (when used for this purpose, honeycomb materials act as thermal insulation to maintain the water temperature) or for accessory elements such as staircases or annex premises;
- features connected with sanitary arrangements, such as shower tubs or bathroom fittings in general.

In order to achieve a reasonable estimation and identification of areas in honeycomb composite materials containing water, the following four test-samples of different honeycomb materials were prepared for non-destructive testing:

- sample 1 - a polypropylene core (hexagonal cell size 8 mm) covered with polyester scrim and 50 microns polypropylene film, total thickness 20 mm (Fig.2);
- sample 2 - a polypropylene core (hexagonal cell size 8 mm) covered with wet laminated fiberglass, total thickness 11.2 mm (Fig.3);
- sample 3 - a polypropylene core (hexagonal cell size 8 mm) covered with wet laminated fiberglass, total thickness 21.5 mm;
- sample 4 - a fiberglass core covered with glass fabric, total thickness 10.8 mm (Fig.4).

Water was introduced into four cells in each of the above samples.

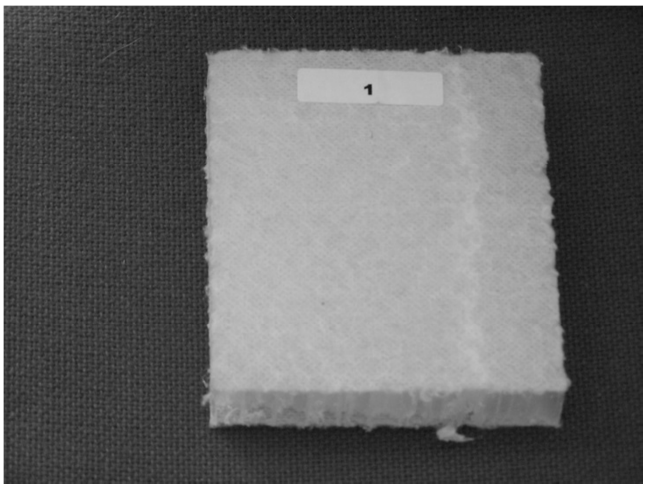


Fig. 2 - Sample 1

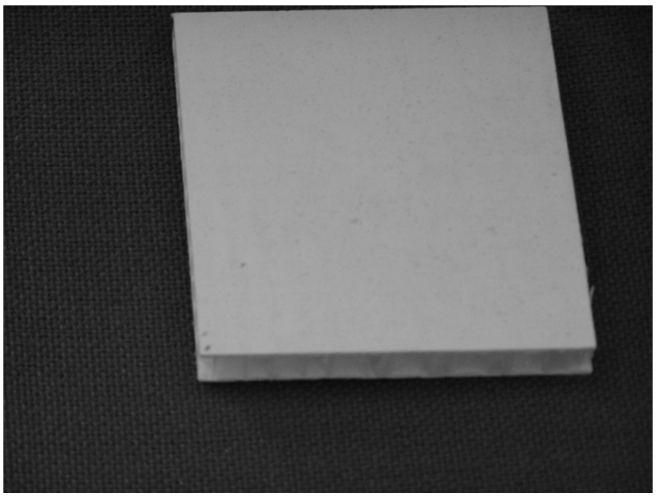


Fig. 3 - Sample 2

Damage in sample 4 was due to the cut glass fibers of the core, an area of about 4 cm^2.

Fig. 4 - Sample 4

The IR thermography test may be performed by either the reflection or the transmission method.

In the reflection method, also known as the one-sided method, the source of the heat stimulation and the temperature-recording device are located on the same side of the object (Fig. 5a). Its disadvantages are the uneven heating of whole surface of the object (which makes it difficult to detect defects) and disturbances caused by reflected radiation.

In the transmission method, also known as the two-way method, the source of heat stimulation and the temperature-recording device are located on opposite sides of the object (figure 5b). This requires heating the whole object and cannot be used for testing thick objects. The influence of uneven heating on the test results is much smaller than in the reflection method.

During the IR thermography experiments, the test surface of the sample was heated for 1 s by a thermal pulse of 1kW, which was generated by a lamp. Changes in the temperature field on the heated surface of the sample were registered by a FLIR SC7600 IR camera, in sequences consisting of 125 images with a resolution of 512 x 640 pixels, recorded at a frequency of 50 Hz.

Similarly to IR thermography testing, the terahertz method was implemented using reflection and transmission with the use of a terahertz source.

The terahertz testing method used equipment from the company Terasense Development Labs: line scanner - Linear 1024 (256x4 pixels image resolution, pixel size 1.5x1.5 mm, frequency ~ 100 GHz, power 1 nW / Hz) and terahertz source - Generator Sub-THz - IMPATT (frequency 100 GHz ± 5 GHz, power ~ 30 mW).

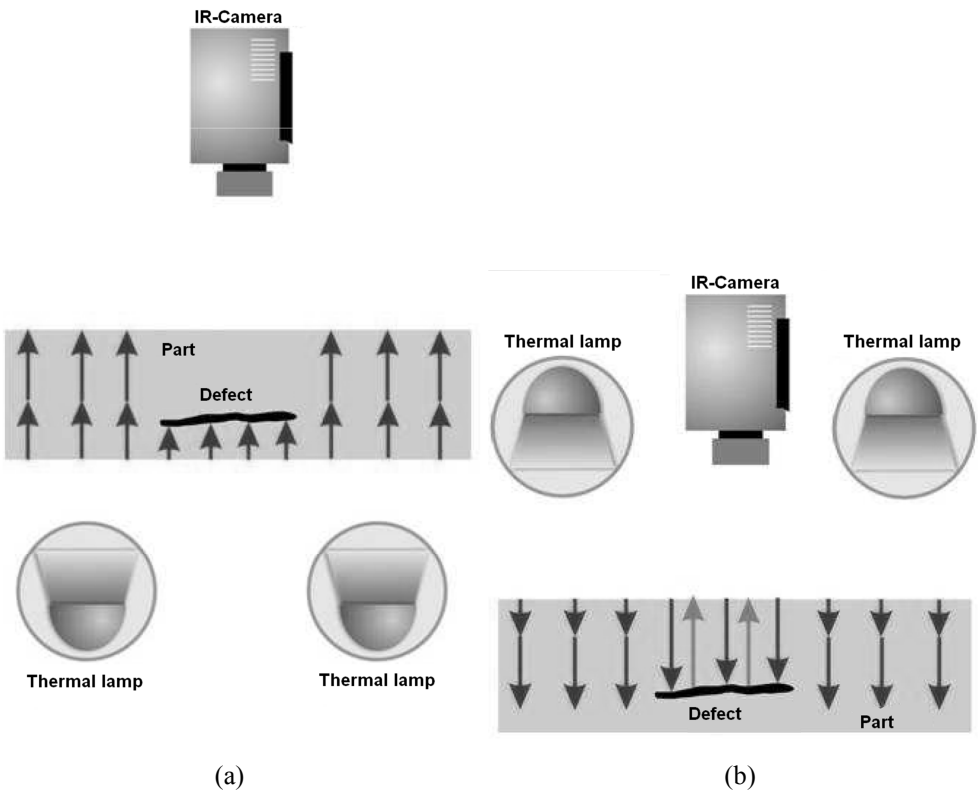
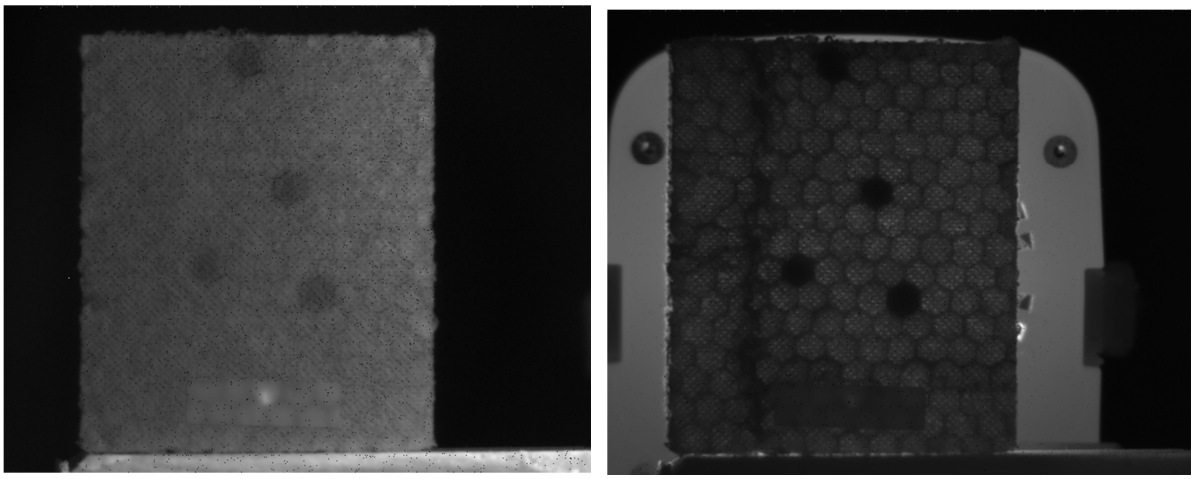


Fig. 5 - Testing set-up: (a) transmission IR thermography method, (b) reflection IR thermography method

RESULTS

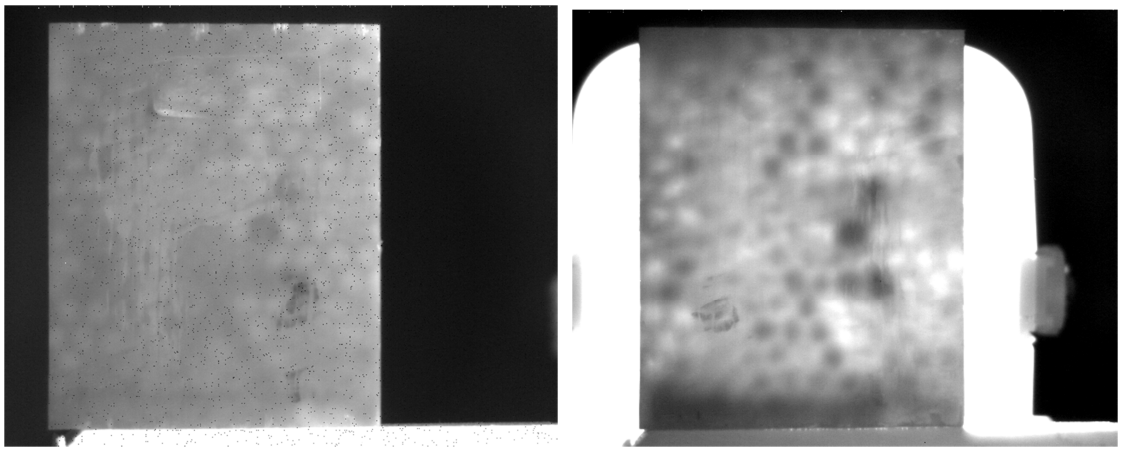
The thermograms shown in Figs. 6-8 are the results obtained by infrared thermography using transmission and reflection methods with the test samples 1-3. Using both the reflection and transmission methods, cells containing water can easily be located.

The analogous results obtained by terahertz imaging are shown in Figs. 9-11. The results obtained by the transmission method are similar to those found with infrared thermography. Using the reflection method, it was not possible to determine which areas contained cells with water.



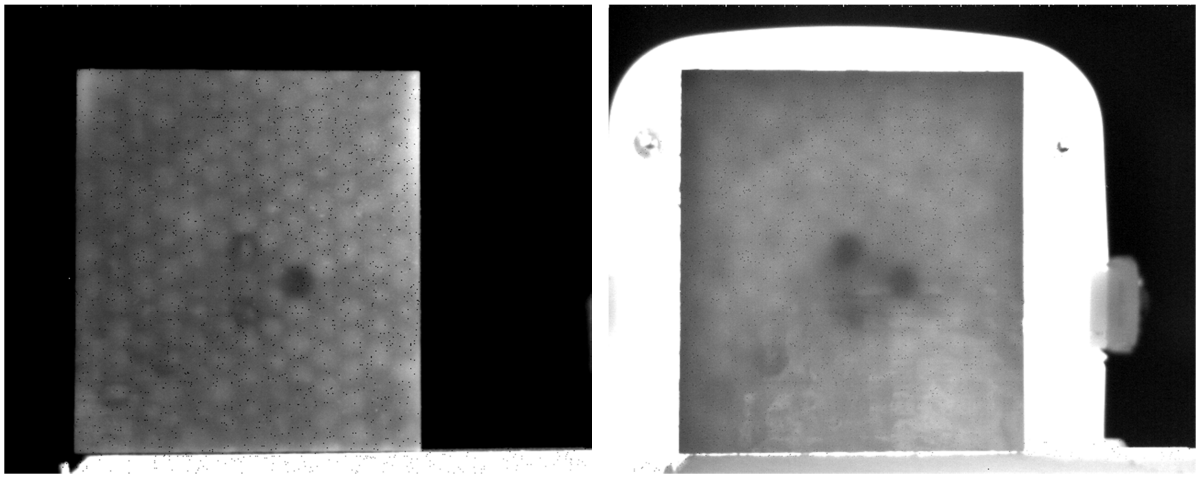
(a) (b)

Fig. 6 - Thermograms of Sample 1: (a) reflection method, (b) transmission method



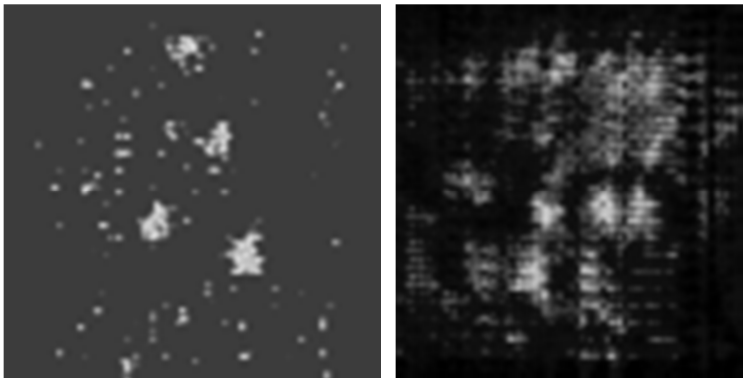
(a) (b)

Fig. 7 - Thermograms of Sample 2: (a) reflection method, (b) transmission method



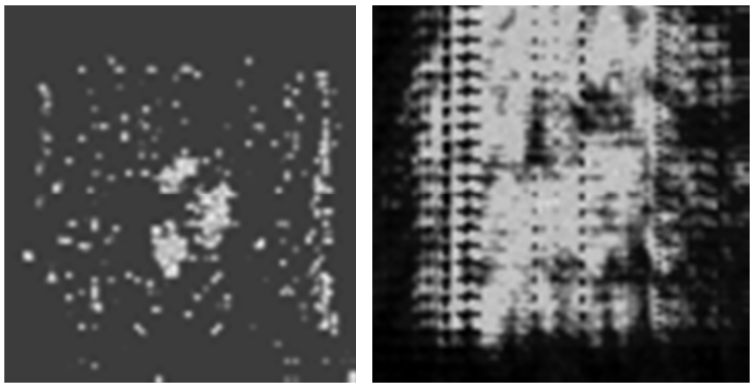
(a) (b)

Fig. 8 - Thermograms of Sample 3: (a) reflection method, (b) transmission method



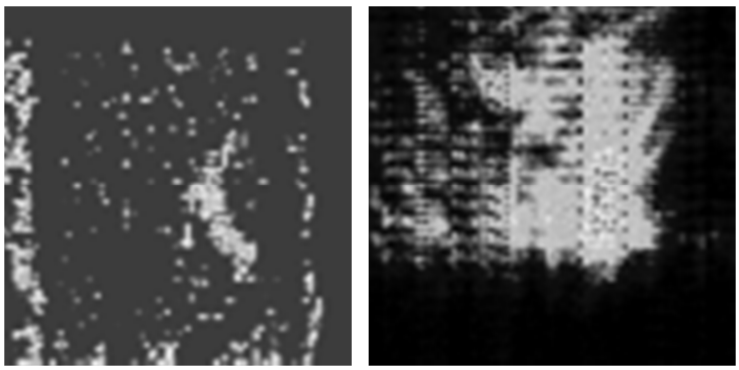
(a) (b)

Fig. 9 -Terahertz imaging Sample 1: (a) transmission method, (b) reflection method



(a) (b)

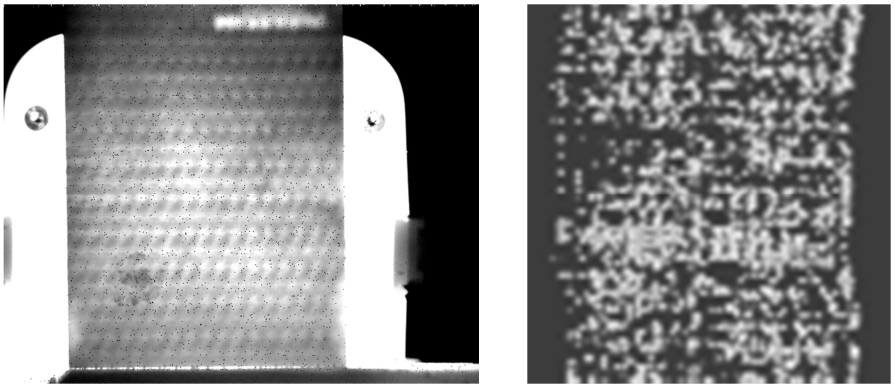
Fig. 10 - Terahertz imaging Sample 2: (a) transmission method, (b) reflection method



(a) (b)

Fig. 11 - Terahertz imaging Sample 3: (a) transmission method, (b) reflection method

Figure 12 shows a comparison of results obtained for sample 4 by the transmission terahertz and infrared thermography method. As shown in the thermogram (Fig. 12a), infrared thermography failed to detect damage to the sample. Only the image obtained by the terahertz method (Fig. 12b) showed the damage.



(a) b)

Fig. 12 Sample 4: a) thermogram of transmission IR thermography method, terahertz imaging transmission method

CONCLUSION

A comparative study between IR thermography and terahertz imaging has shown that it is possible to apply the terahertz method to the detection of moisture and water in non-metallic honeycomb materials. Due their current resolution, terahertz detectors can detect defects whose dimensions exceed the pixel size of the terahertz image obtained using this detector (scanner, camera). As a result of the development of terahertz technology, it is expected that terahertz cameras with a much better image resolution than today will be available in the future.

In some cases, as in test sample 4, the terahertz method can be complementary to IR thermography testing.

In further work, I intend to focus on improving the efficiency of the reflection terahertz method, because the results shown in this paper are below expectations.

REFERENCES

[1]-Redo-Sanchez A, Karpowicz N, Xu J, Zhang X-C. Damage and defect inspection with terahertz waves. Proceedings of the 4th International Workshop on Ultrasonic and Advanced Methods for Nondestructive Testing and Material Characterization, 2006.

[2]-Ewers B, Kupsch A, Lange A, Hentschell PM. Terahertz spectral imaging techniques in NDT: topography and computed tomography Proceedings of ECNDT 2010, Moscow.

[3]-Jonuscheit J, Beigang R, Ellrich F, Klier J, Matheis C, Molter D, Theuer M. Terahertz Imaging for Non-Destructive Testing Proceedings of 2nd International Symposium on NDT in Aerospace 2010, Hamburg.

[4]-Kurzydłowski KJ, *et al.*, Monitoring of failures in the composites by non-destructive methods. Polimery, 2005, Vol. 50. No 4, p.255-261 (*in Polish*).

[5]-Maldague XPV. Theory and practice of infrared technology for nondestructive testing. John Wiley&Sons, Inc. New York, 2001.

[6]-Dragan K, Swiderski W. Multimode NDE approach for structure health assessment of composite elements in aerospace applications. Acta Physica Polonica A, 2010, Vol. 117, Issue: 5, p. 877-882.

[7]-www. nida-core.com.