APPLICATION OF ULTRASONIC IMAGING TECHNIQUE AS STRUCTURAL HEALTH MONITORING TOOL FOR ASSESSMENT OF DEFECTS IN GLASS FIBER COMPOSITE STRUCTURES

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ABSTRACT

Structural Health Monitoring (SHM) is non-destructive testing technique which implements a damage detection and characterization strategy for engineering structures. It is widely applied for rapid condition screening with the aim to provide reliable information regarding the integrity of composite structures. Key elements of the system's functionalities include detection of unanticipated structural damage events, damage location identification and characterization through images, monitoring damage growth and enabling a feedback action/alarm mechanism. Fiberglass composite materials are becoming widely utilised in the design of wind energy structures because of their performance in terms of high moduli, high corrosion and fatigue resistance, and low weight. Nevertheless the damage assessment by means of ply delamination causing stiffness and strength reduction is required by both industry and certification societies. In current research the ultrasonic imaging technique is considered as the most efficient method employed for quality control and damage growth inspection by means of ultrasound B - and C - scans for visualization and direct estimation of the nature, structure and spatial distribution of the defects in GFRP structures. More than fifty impact caused damage GFRP samples with artificial damage have been produced for the assessment study. A current research resulted in systemisation of damage and delamination identification means in glass fibre reinforced composite panels.

Key words: ultrasonic imaging technique, glass fiber reinforced composites, defects visualization, structure analysis

INTRODUCTION

Due to high cost/performance properties glass fibre reinforced plastics (GFRP) are becoming more popular in civil engineering. Areas of application include aircraft, car and marine industries. GFRP main advantages are their low cost, low weight, good thermal and acoustic insulation, low fatigue and corrosion levels (Hasiotis et al., 2011). Damage in composite structures in the form of cracks or delamination will lead to a significant loss in strength and failures in performance of the structures.

There is a large number of non-destructive testing and non-destructive inspection techniques for identifying local damage and detecting incipient failures in critical structures. Among them, ultrasonic inspection is well established and has been used in the engineering community for several decades (Giurgiutiu, Cuc, 2005). The ultrasonic method as non-destructive analysis method is very important in many industries because it allows detecting defects inside the material. SHM is extremely important and essential in various areas, including aerospace, automotive, energy, civil and mechanical engineering. Ultrasonic inspection is frequently applied in electrical and electronic components manufacturing, in powder metallurgy, production of metallic and composite materials and in the fabrication of structures such as airframes, piping and pressure vessels, ships, bridges, motor vehicles, machinery and jet engines (Hasiotis et al., 2011; Turo et al., 2013). Ultrasonic tests even can be applicable for archaeological purposes (El-Gohary, 2013).

There have been several ultrasound technologies developed recently, which can be employed for both in the laboratory and in-service inspections. For example, Zike et.al. (Zike et al., 2011) applied ultrasonic inspections to evaluate rupture and delamination and also to compare experimental and simulation results, whereas Bartoli G. with a team applied ultrasonic tests to measure high propagation velocity in stone columns, which allowed them to judge the internal damage and evaluate the dynamic modulus of elasticity of the columns (Bartoli et al., 2012). This makes the ultrasound structural health monitoring one of most effective tool`s in the market. Key elements of SHM system functionalities include detection of unanticipated structural damage events, damage location identification and characterization through images, monitoring damage growth and enabling feedback action/alarm mechanism. SHM is extremely important and essential in various areas, including aerospace, automotive, energy, civil and mechanical engineering (Pisupati, 2009).

The pulse-echo method is the most widely used ultrasonic method. A pulse of ultrasonic energy is transmitted into the specimen, and then the energy is transmitted from the specimen into the transducer an echo. The pulse is reflected from good matrix reinforcement boundaries and also from boundaries associated with flaws. Those signals which travel back towards the probe are detected and the position and size of a flaw is determined from the total pulse travel time and detected amplitude respectively. This method is very often used for flaw location and thickness measurements. The B-scan display, a 2D slice through a specimen, is produced by scanning the probe along the surface. The C-scan display records echoes from the internal portions of test pieces as a function of the position of each reflecting interface within an area (Hasiotis et al., 2011; Shull, 2002; Kapadia..., 2013).

In the present paper, the size of the damage and damage propogation at different plies among thicknesses in glass fibre reinforced composites were inspected and visualized with the ultrasonic technique.

MATERIALS AND METHODS

Glass fibre/epoxy composite materials were used in the present investigation. Specimens were prepared with two manufacturing methods: hand lay-up (HL) method and vacuum infusion (VI) method. Laminates were manufactured with different thickness and directions of fibre in order to assess the difference both from textile procession and specimen preparation technology. The INSTRON Dynatup 9250 HV impact tower was employed to cause artificial impact defects in composite materials. The impact nozzle used in investigation has a 20 mm diameter.

The ultrasonic inspection of specimens was made by applying the Pulse-Echo method. A 3 mm diameter pulse-receiver flat transducer of 20 MHz from PANAMETRICS was applied and the inspection was made with the specimens fully immersed in water. The ultrasonic device utilised for NDT inspection was HILLGUS USPC 3010HF. Oculus software was also used for data acquisition, control and imaging. A current Ultrasonic transducer has the ability to record 20,000 amplitudes of signal and 10,000 travel time values per second.

RESULTS AND DISCUSSION

To measure impact defect distribution in composite materials ply by ply analysis was carried using the ultrasonic imaging technique. Achieved images of selected layers of specimen 1 are shown in Figure 1. Images show a complex layer characterization of the impact defect. With the Oculus software it is possible to evaluate the size of the defect. For specimen 1, overall size of the impact is 24.4 x 24.7 mm. Defect shape and size distribution in different layers shown in Figure 2. From this image it can be seen, that the diameter of the flaw increases towards the back side of the impact for about 10 mm. This behaviour is noticeable in all specimens.

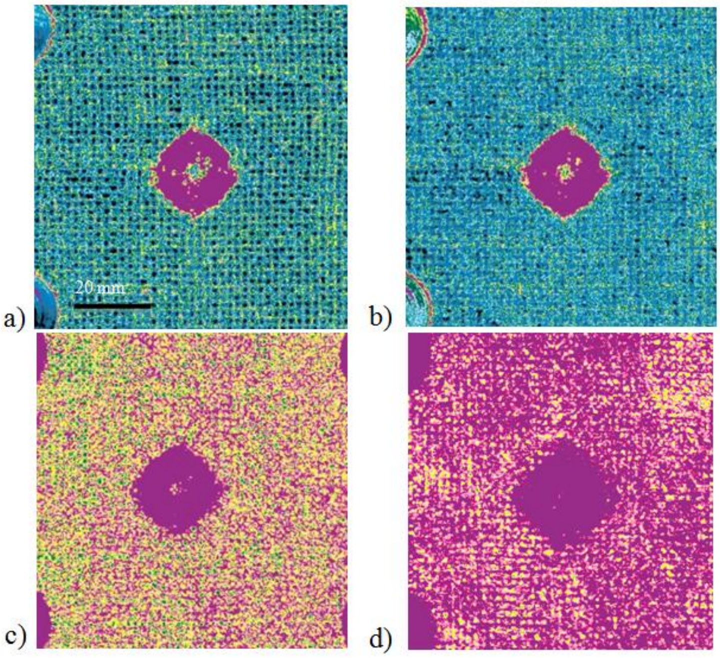

Figure 1. C-scan image of impact defects distribution on different depth of specimen 1. a) C-scan at 0.15 mm depth; b) C-scan at 0.32 mm; c) C-scan at 0.87 mm; d) C-scan at 1.31 mm depth

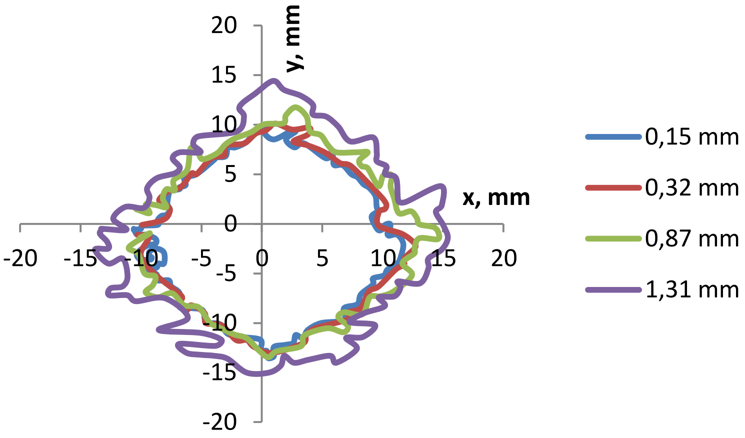

Figure 2. Distribution of defect at different depths of specimen

B-scan of the ultrasonic method can also be applied to investigate the distribution of defect in the specimen depth. Figure 3 shows distribution of the defect in specimen 1. Here it is also noticeable that the defect size increases towards the lower part of the specimen. Combining B-scan and C-scan images, the three-dimensional structure of the impact area can be reconstructed.

Figure 4 shows B- and C-scans of the specimen after impact. In this case the impact nozzle didn't penetrated through the specimen, but in B-scan (a) of this specimen only some small defects on the interface can be seen, the specimen has a vast amount of cracks and damage accumulated on the outer surface area which is demonstrated in (Figure 4.b) image.

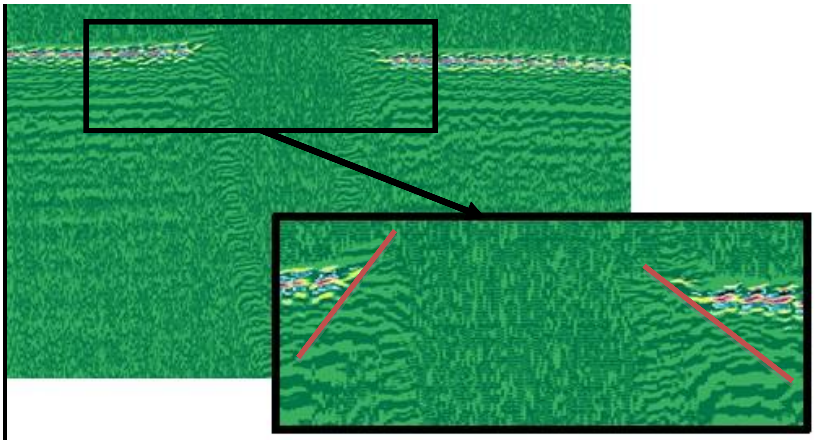

Figure 3. B-scan of specimen 1

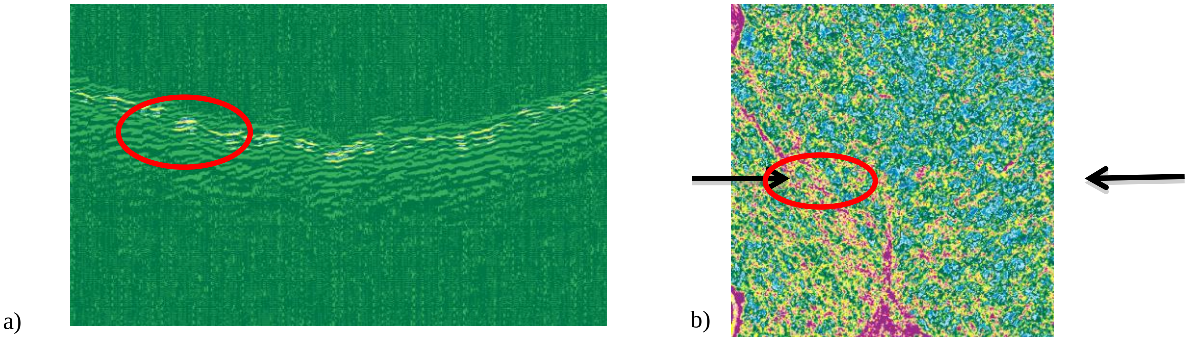

Figure 4. B-scan (a) and C-scan (b) images of the damaged area of the specimens 2. B-scan shows cross section of C-scan marked with arrows

With the ultrasonic technique it is possible to detect delamination inside the specimens. For example, in Figure 5, picture of specimen 3 and its ultrasonic C-scan images are shown. In the picture the depth cannot be identified at which delamination appears in the specimen. Whereas, with ply by ply analysis a particular ply and depth can be found where delamination has appeared. The delamination area seen in picture and in C-scan image is marked with blue colour. Specimen 3 has 2.77 mm thickness and delamination after impact appears at 1.7 mm depth. The size of delamination is from 40.3 to 46 mm.

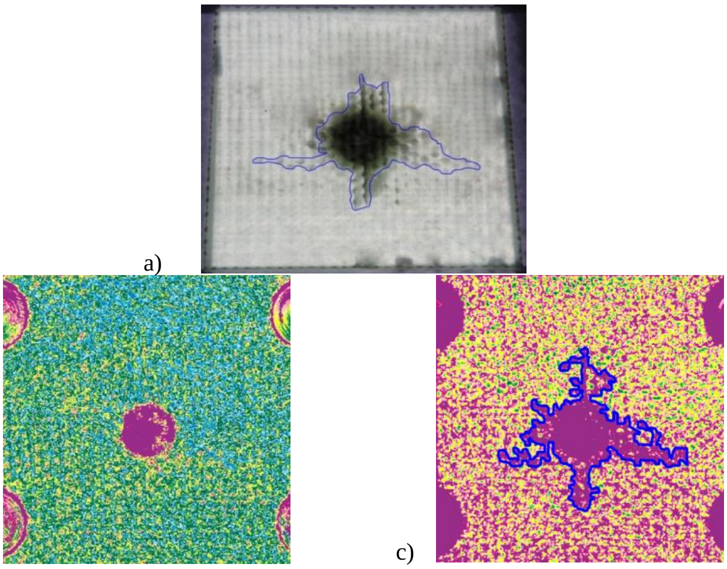

Figure 5. Picture (a) and C-scan (b, c) images of specimen 3; b) specimen at 1 mm depth and c) specimen at 1.7 mm depth

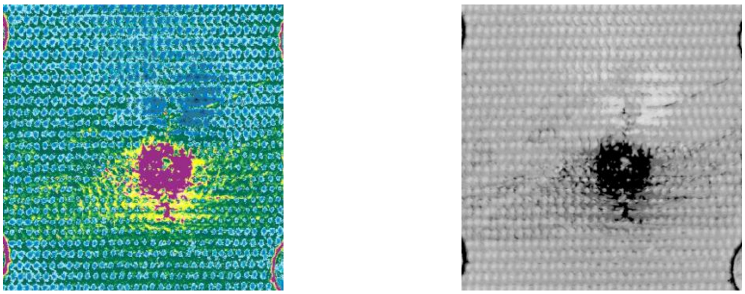

Figure 6. C-scans of specimen 4, where a) C-scan in colourful palette, b) C-scan in gray scale palette

For different applications the ultrasonic software Oculus allows the image's palette to be changed. For example, in Figure 6 specimen's 4 C-scans in different palettes are shown. Colourful palette can be used to analyze signal amplitudes distribution in the specimen. This will allow describing the specimens' composition: concentrating locations of epoxy and glass fibre. Whereas grey scale palettes allow the observer to focus and determine defect extension. In this case the amplitude of distribution doesn't overshadow the scene from defects prospect.

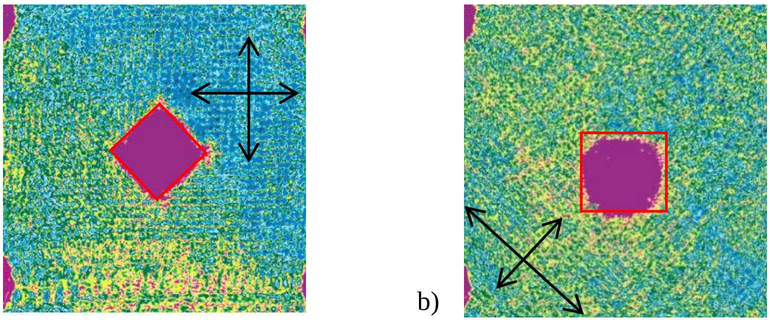

Figure 7. C-scan images of specimens with fibre direction a) 0/90 and b) 45/-45

The shape of impact defects in specimens with different fibre direction varies. In specimen 5 fibre direction is 0/90 and the shape of impact is rhombic, but in specimen 6, the fibre direction is 45/-45 and the shape of impact is close to square. This difference is shown in Figure 7. Similar results were obtained in Zike's et.al. (Zike et al., 2011) study. With the ultrasonic imaging technique it is also possible to visualize the direction of fibre in composite materials. In Figure 7, directions of fibre are shown with arrows.

CONCLUSIONS

The ultrasonic imaging technique was successfully applied to analyse the GFRP composite materials. Our study has shown that the ultrasonic method can work successfully for non-destructive testing of composite materials. The method demonstrates the ability to visualize internal defects in glass fibre reinforced composite and estimate the size and shape of the impact. The ultrasonic method allows the viewer to detect a particular depth of defect and its extend. Additionally by applying the B-scan method it is possible to detect the distribution of defects in the specimen's depth. This method also can be utilised to characterize specimen's structure: orientation of fibre in the specimen, epoxy and fibre concentrations location.

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