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Ultrasonic Inspection and Data Analysis of Glass- and Carbon-Fibre-Reinforced Plastics

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Abstract

Non-destructive testing (NDT) helps to find material defects without having an influence on the material itself. It is applied as a method of quality control, for online structural health monitoring, and for inspection of safety related components. Due to the ability of automation and a simple test setup ultrasonic testing is one major NDT technique next to several existing options. Whereas contact technique allows the use of higher frequencies of some MHz and phased array focusing, air-coupled ultrasonic testing (ACUT) shows different advantages. Most significant for ACUT is the absence of any coupling fluid and an economical test procedure respective time and costs. Both contact technique and ACUT have been improved and enhanced during the past years. One important enhancement is the development of airborne transducers based on ferroelectrets, like charged cellular polypropylene (cpp), which makes the application of any matching layers being mandatory in conventional piezoelectric transducers unnecessary. In this contribution we show ultrasonic inspection results of specimens made of carbon- and glass-fibre-reinforced plastic. These specimens include defects represented by drill holes and artificial delaminations of various size and depth. We compare inspection results achieved by using contact technique to those achieved by ACUT. For ACUT, conventional piezoelectric transducers and transducers based on cpp were used, both focused as well as non-focused types. Contact inspections were performed with a multi-channel matrix array probe. Once the inspection data is recorded it can be analysed in order to detect and evaluate defects in the specimen. We present different analysing strategies and compare these regarding detection rate and sizing of defects.

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1. Non-Destructive Testing of Fibre-Reinforced Plastics

Non-Destructive Testing (NDT) is used for the detection of material defects due to production failure or fatigue. It also may support process and quality control. Various NDT techniques such as radiographic examination, thermography, eddy-current testing or ultrasonic testing represent different ways with distinct advantages and disadvantages depending on actual existing inspection conditions.

Contact ultrasonic technique enables one-sided inspection as it is usually performed in pulse-echo mode. Defects are detected by the occurring reflection of a transmitted ultrasonic pulse. The time of flight provides information about the depth of a detected defect. Furthermore, inspection in contact technique allows the use of frequencies of some megahertz and phased array focusing, which improves the signal-to-noise ratio and the lateral resolution. It may be performed automated or manually but always requires a couplant between probes and inspected material.

In contrast to contact technique, air-coupled ultrasonic testing (ACUT), recently reviewed by Chimenti (2014), is characterized by the absence of any coupling fluid. This makes it suitable for application to porous materials and composite structures, especially those consisting of fibre-reinforced plastics. Most kinds of inspections with ACUT require two-sided access as it is usually performed in transmission mode. Due to high sound attenuation in air, ACUT is limited to frequencies below 500 kHz. Recently developed airborne transducers based on ferroelectrets make the application of matching layers, being mandatory in conventional piezoelectric airborne transducers, unnecessary. For example, cellular polypropylene (cpp) shows excellent properties after a high-voltage corona discharging process, first shown by Paajanen et al. (2000). This material can easily be bent, which enables the production of spherically focussed transducers, as shown by Gaal et at. (2013 and 2016) and Schadow (2016), as well as other forms as reported by Ealo (2008). In a certain range of conditions ACUT represents an economical inspection method respective time and costs.

In this contribution, we compare matrix array testing and ACUT on two specimens made of carbon- and glass-fibre-reinforced polymers including flat bottom holes and artificial delaminations of various sizes.

2. Ultrasonic Inspection of Specimens made of Carbon- and Glass-Fibre-Reinforced Plastic

We inspected two similar specimens of composite material: one made of a carbon-fibre-reinforced plastic (CFRP) and one made of a glass-fibre-reinforced plastic (GFRP). Both CFRP and GFRP are widely used in the field of renewable energy, e.g. in wind energy turbines, in the sector of lightweight transport, e.g. marine and automotive, as well as in oil and gas industries. The thickness of both specimens was 5 mm. A prepreg material consisting of unidirectional glass fibre and epoxy matrix resin was used for the GFRP specimen. Multiple prepreg layers of an orientation of ±55° were then oven cured at 120°C, so that the structure was $[+55, -55]_{9S}$. The CFRP was built using a unidirectional carbon fibre prepreg with epoxy matrix resin. In this case a unidirectional fibre layup was applied and the curing process of 120°C was performed in an autoclave, resulting in structure $[0]_{8S}$. The specimens include defects represented by flat bottom holes and artificial delaminations of various sizes between 1 and 40 mm in diameter. These defects were placed in three different depths: close to the upper surface, in the centre, and close to the lower surface of the specimen as shown in Fig. 1 (b). Table 1 contains the exact positioning of flaws.

Both specimens were inspected by air-coupled ultrasonic testing (ACUT) and contact technique. For ACUT we performed measurements with conventional piezoelectric transducers and transducers based on cpp. Frequencies were applied in the range from 200 kHz to 330 kHz. This inspection was performed in transmission mode, with the specimen's front and back surfaces in their focal points (Fig. 1 (b)). Defect indication occurs due to alteration of the transmitted amplitude when transducers are passing over a defect.

Measurements in contact technique were performed with a multi-channel matrix array probe consisting of 60 elements of an operating frequency of 2.25 MHz. The use of a matrix array probe allows precise focusing to the appropriate depth of the defect. The inspection was performed in pulse-echo mode where a defect can be detected by the occurring reflection of the ultrasonic wave at the defect interface.