Application of Ultrasonic Guided Waves for NDE of Composite Structures

R. Kazys, L. Mazeika, R. Raisutis, E. Zukauskas and R. Sliteris
Ultrasound Institute, Kaunas University of Technology, Studentu str.50, LT-51368, Lithuania

Abstract
Engineering constructions made of composite materials must be non-destructively tested during manufacturing or/and exploitation in order to ensure the necessary reliability of the whole construction. This paper is devoted to a brief overview of ultrasonic NDT techniques developed and used for inspection of various composite materials, which are mainly based on application of guided ultrasonic waves.

1. Introduction
Nowadays, composite materials of various types are used in many areas. First of all they are used in aerospace industry. Recently, the composite materials are increasingly used in other industrial sectors such as wind energy (wind turbine blades), transport (busses, ships, and trains), etc. In many cases more complicated engineering constructions are manufactured manually. As a consequence, construction elements made of composites must be non-destructively tested during manufacturing or/and exploitation in order to ensure the necessary reliability of the whole construction. Due to the complexity of the material and usually a big size of the construction not all non-destructive testing (NDT) techniques are applicable for inspections. Ultrasonic technique is one of those which can be efficiently used of inspection and investigation of composite materials. However, application of ultrasonic techniques requires solution of many problems caused by attenuation or/and scattering of ultrasonic waves, especially at higher frequencies, multiple reflections due to presence of many layers with different physical properties, anisotropy and a complex geometry of the object under a test.

On the other hand, during the last years a new field of ultrasonic inspection, based on the application of ultrasonic guided waves, is developing very fast. The parameters of propagating guided waves depend essentially on elastic properties of the material. Any spatial non-uniformity of these properties affects propagation of guided waves what enables to detect defects or to reconstruct elastic constants of the composite material. This paper is devoted to a brief overview of ultrasonic NDT techniques developed and used for inspection of various composite materials in the Ultrasound Institute of Kaunas University of Technology, which are mainly based on application of guided ultrasonic waves.

2. Air coupled ultrasonic inspection of aluminium/composites laminates
In modern aircrafts fibber metal laminates are widely used such as the GLARE composite material which consists of multiple aluminium layers glued together using glass fibre composite. The most dangerous defects in such materials are delaminations between adjacent layers. For detection of such defects the most attractive is the air-coupled ultrasonic technique which does not require acoustic coupling between material and ultrasonic transducers. This technique may be implemented using two-side or single-side access and exploiting bulk or Lamb ultrasonic waves (Fig.1) [1-3]. From a practical point of a view a more attractive is single-side access air-coupled ultrasonic technique.

The experiments were carried out on the GLARE-3/2 sample with artificial defects. In the experiments air-coupled

![Fig. 1 : Investigated ultrasonic inspection techniques: a - through transmission using bulk waves; b - through transmission using Lamb waves; c – one side access using leaky Lamb waves (pitch-catch configuration); d – one side access using backscattered leaky Lamb waves; UW- ultrasonic wave in air; LW- Lamb wave.]

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unfocused planar transducers, designed and manufactured at the Ultrasound Institute (UI) of Kaunas University of Technology were used. The ultrasonic images of the 25mm delamination defect obtained using different techniques are presented in Fig.2. Measurements, carried out using through-transmission and pitch-catch techniques, are based on shielding of the propagating bulk or Lamb wave, in this case \( A_0 \) mode, by non-uniformity in the material (Fig.2 a,b). The pitch-catch configuration is usually suitable for testing of thin objects and the spatial resolution depends on a distance between transducers and dimensions of the transducers. Therefore a true geometry of defects in B and C-scan images usually is distorted (Fig. 2c).

The interaction of the Lamb waves with a defect results in three phenomena: scattering, reflection and mode conversion of the incident Lamb waves. A detailed analysis of the Lamb wave interaction with a delamination type defect using a numerical simulation has shown that a strong energy leaking of the \( A_0 \) Lamb wave mode into air occurs over the damage [1-3]. The C-scan image obtained using backscattered leaky Lamb waves technique is presented in Fig. 2d.

3. Inspection of carbon fibre rods used in the manufacturing of glider longeron

One of the most important parts of the gliders is a lightweight longeron reinforcement made of carbon fibre reinforced plastics (CFRP) rods. These a few millimetres diameter rods during manufacturing are glued together in epoxy filled matrix in order to build the arbitrary spar profile. However, the defects presenting in the rods such as brake of fibres, lack of bonding, reduction of density affect essentially the strength of the construction. We have developed ultrasonic NDT technique of CFRP rods used for aerospace applications, which is based on air- coupled excitation/reception of guided waves. The effective exploitation of the guided waves requires selecting of an appropriate value of operating frequency and optimal deflection angles of ultrasonic transducers.

In order to determine guided wave modes propagating in CFRP rod the modelling was carried out using semi - analytical finite element method [4-5]. The acoustic properties of the CFRP material used in the modelling were defined by the matrix of elastic coefficients and the anisotropy was taken into account. The obtained dispersion curves of main propagating modes in unloaded the square shaped CFRP rod are shown in Fig. 3. As it can be seen in the frequency range up to 0.5 MHz there are three lowest order modes of propagating guided waves: axially symmetric (\( S_0 \)), torsional (\( S_T \)) and asymmetric (\( A_0 \)).

The regularities of interaction of guided waves with the defects in the case of immersion technique were investigated by modelling using finite difference method and experimentally at the frequency of 400 kHz. The symmetric mode of guided waves was excited by longitudinal mode ultrasonic transducer attached to the edge of the rod. The receiver scanned over the rod enabled to pick up the leaky guided wave signals and to determine whether the parameters of wave modes propagating in the rod will be affected by presence of defects.

The snapshots of the simulated displacement fields in the rod in places with defects and without defects are presented in Fig.4. It can be seen that the leaky wave over the defect is almost completely suppressed. The experimental results (Fig.5) demonstrate similar regularities.

4. Investigation of honeycomb structures

The honeycomb structures are complicated objects for the ultrasonic inspection because from one side they are relatively thick, so only low frequencies should be used. On
The signals were averaged from 8 measurements. In order to get the optimal excitation and reception of the guided Lamb wave the transducers were deflected at 24° angles and the distance between them was 40 mm. The distance between the honeycomb panel and the transducers centres was approximately 3 mm. The scanning step was 1 mm in $x$ and $y$ direction. The obtained results are presented in C-scan image of the time of flight data (Fig. 6a). The defects in the other hand they are covered by thin shells which should be tested using higher frequencies. Additional problems are caused by a complicated character of dispersion curves [1].

The investigations of the 10 mm thickness honeycomb panel from the impact side using the 210 kHz frequency and the air-coupled pitch-catch arrangement of the transducers were performed. The transmitter was excited by the 3 cycles 800V rectangular burst of 210 kHz. The total gain was 53.4 dB. The signals were averaged from 8 measurements. In order to get the optimal excitation and reception of the guided Lamb wave the transducers were deflected at 24° angles and the distance between them was 40 mm. The distance between the honeycomb panel and the transducers centres was approximately 3 mm. The scanning step was 1 mm in $x$ and $y$ direction. The obtained results are presented in C-scan image of the time of flight data (Fig. 6a). The defects in the other hand they are covered by thin shells which should be tested using higher frequencies. Additional problems are caused by a complicated character of dispersion curves [1].

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are not so clear (Fig. 7b). This can be explained by different Lamb wave velocities at the sample zones of the different thickness. Due to the thickness difference, the excitation and reception angles of the Lamb wave signals become non-optimal and therefore the amplitude of the signals reduces [1,3,6].

Conclusions

It was shown that the Lamb waves may be used for air-coupled ultrasonic NDT of multi-layered metal-composite laminates, CFRP and honeycomb structures. The developed single-side access technique is based on interaction of the guided A₀ Lamb wave mode with delamination type defects. Ultrasonic guided waves for detection and investigation of impact type defects in honeycomb samples are suitable also. For NDT of highly anisotropic small lateral dimensions CFRP rods, used in aerospace components, ultrasonic guided waves may be also efficiently exploited.

References