ULTRASONIC INSPECTION OF DAMAGE IN IMPACTED COMPOSITE PANELS

TRIECIENA IEDARBĪBAI PAKĻAUTU KOMPOZĪTMATERIĀLA PANEĻU ULTRASKAŅAS TESTĒŠANA SABRUKUMA NOVĒRTĒŠANAI

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Introduction

Composite materials, such as carbon-fibre-reinforced plastics (CFRP), are increasingly being used in the fabrication of high-performance structures. Composites often show considerable advantages of stiffness and strength over homogeneous materials, and this is particularly evident when these properties are considered on a unit weight basis. However, these advantages are counterbalanced by a lower impact damage tolerance [1-3]. An impact-induced damage in composite materials may grow as a combination of different failure modes and thus may significantly reduce the mechanical properties of composites, leading to a sudden and unexpected failure of the component. Typical failure modes are: matrix cracks, fibre fracture, fibre-matrix debonding, and delamination between plies [4-5]. For these reasons, the elaboration of the methods for non-destructive evaluation and defectoscopy of composite materials is of great importance.

A number of various inspection techniques (acoustic emission, thermography, stereo X-ray radiography, and ultrasonics) have been proposed for non-destructive evaluation of composite laminates [6-9].

The ultrasonic non-destructive testing which utilises high-frequency sound waves is a widely accepted technique for damage detection. Either through-transmission or pulse-echo techniques are used to determine the presence, location, relative size, or severity of flaws. By measuring the signal amplitude and the time-of-flight of the ultrasonic signal, the location and size of the defects can be estimated [10-13]. Many authors [14-22] have utilised ultrasonic non-destructive testing for detecting the defects like debondings and delaminations.

In this study, a pulse-echo ultrasonic imaging technique is used to produce high-resolution images of internal defects arising as a result of low-velocity impacts on composite laminates.

Materials

The specimens used in impact tests were curved one-stringer stiffened panels cut from a carbon/epoxy three-stringer panel (see *Fig. 1*). The original panel was one-sixth (60°) of a cylinder 580 mm high and 415 mm wide, with a 1000-mm internal panel radius. This panel was cut into six smaller panels with the following dimensions: four panels of length 290 mm, width 139 mm, and rib height 14.8 mm and two panels of length 290 mm, width 137 mm, and rib height 14.8 mm. For the skin, $[+45/-45/0]_s$ laminate was considered. The ply thickness $t = 0.125$ mm was fixed due to the manufacturing technology. Therefore, the skin thickness was $h = 0.75$ mm. The laminate lay-up for the blade-type stringer was $[(+45/-45)_3/0_6]_s$, i.e., the stringer consisted of 24 single layers, and the thickness of the stringer was $b_w = 3$ mm. For a better matching with the contour of the skin, the stringer flange was stepwise flattened and consisted of three steps: the inner flange step – laminate stacking sequence $[+45/-45]_3$, i.e., six layers of thickness $h_i = 0.75$ mm, the middle flange step – laminate stacking sequence $[+45/-45]_2$, i.e., four layers of thickness $h_m= 0.5$ mm, and the outer flange step – laminate stacking sequence [+45/-45], i.e., two layers of thickness $h_o= 0.25$ mm.

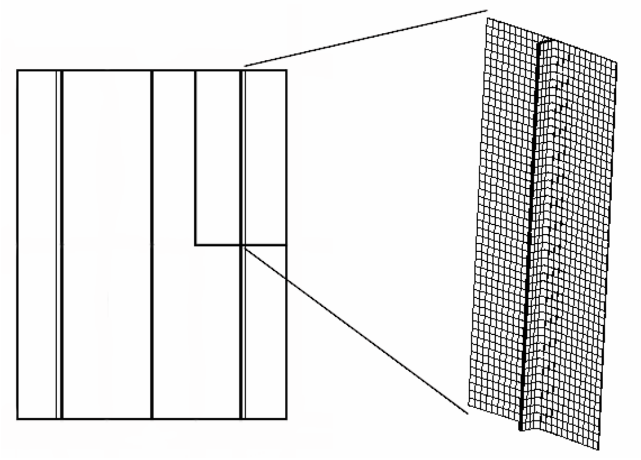

Fig. 1. Curved one-stringer panel

Impact Testing

Impact tests were performed on a pendulum hammer-type impact testing machine (see *Fig. 2*). By varying the drop height, different impact energies and velocities were obtained. The impactor had a hemispherical nose of 20 mm in diameter. Re-strike of the hammer was prevented by capturing it after the first impact.

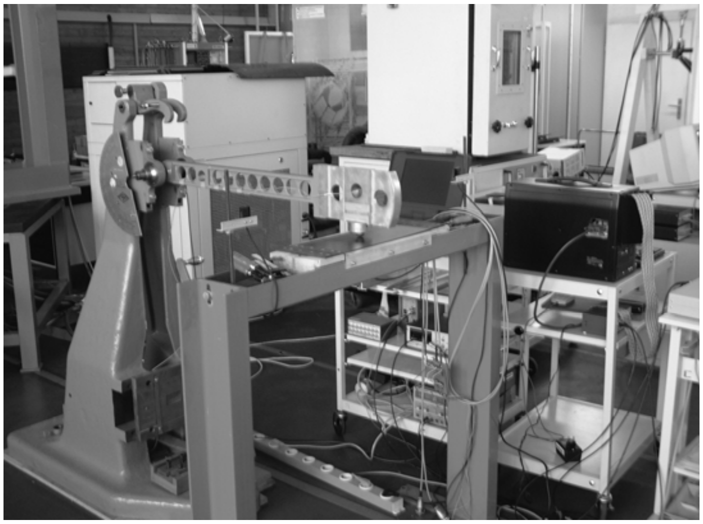

Fig. 2. Pendulum hammer-type impact testing machine

In this study, three different impact energies (10, 15, and 20 J) were selected. Since the specimens were curved one-stringer stiffened panels, it was of interest to see the impact responses in three critical locations of the panels: on the skin only, on the edge of stringer flange, and directly above the stringer (see *Fig. 3*).

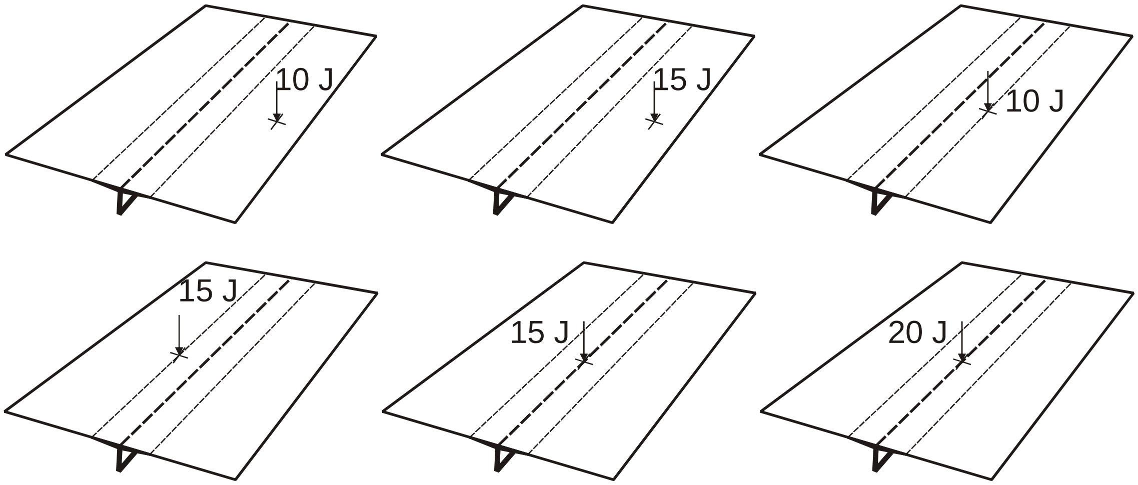

Fig. 3. Impact scheme

Ultrasonic Imaging Test Procedure

Ultrasonic imaging system

An experimental set-up (see *Fig. 4*) considered in this study consists of a computer-controlled ultrasonic flaw detector USPC 3010 Industrial, an immersion probe of 10 MHz, a glass water tank, and a stepper motor-controlled XYZ-manipulator.

Fig. 4. Experimental set-up

An industrial PC with *Hilgus* software provides manipulation and settings of the ultrasonic flaw detector, the storage of data, and imaging of test results in A-, B-, C-, and D-scans. The scanning system measures up to 20000 amplitudes and up to 10000 time-of-flight values per second.

Inspection procedure

The test specimens, immersed in a water tank, were scanned at a normal incidence in pulse-echo mode by means of a focussed 10 MHz broadband transducer (focal length 25.4 mm). The pulse-echo technique consists in generation of a short impulse of the ultrasonic wave by a transmitting transducer. After reflection from the limiting surface, the impulses are recorded by a receiving transducer [a dual transmitting-receiving transducer was used in this study (see *Fig. 5*)]. If there is a defect in the material tested, some part of the ultrasonic wave is reflected from this defect, returns to the receiving transducer, and is recorded as the echo of the defect. Another part of the wave passes by the defect, reaches the opposite wall of the tested material, reflects from it, and returns to the receiver with some delay as the backwall echo. The depth of the defect is determined on the basis of the time-of-flight, i.e., the relation between the travel time of an impulse and the ultrasonic wave velocity. *Figure 6* shows an A-scan recorded from a defect-free region of a specimen. The gate for the defect evaluation is situated between the interface echo and the backwall echo. A typical C-scan image was recorded with a resolution step of 0.25 mm.

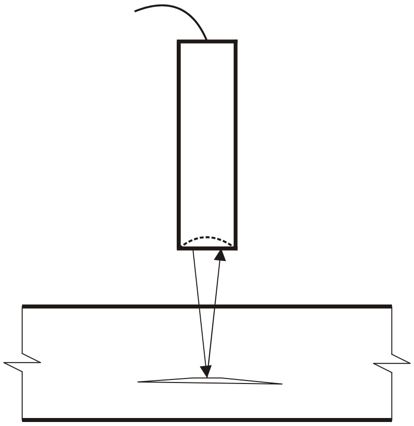

Fig. 5. Ultrasonic pulse-echo technique

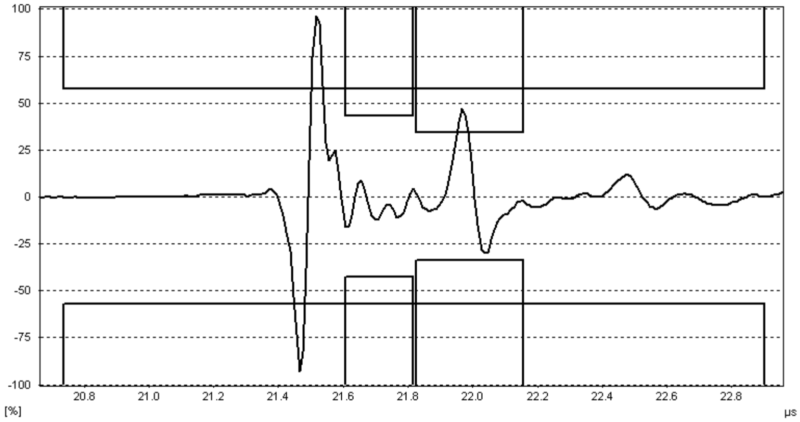

Fig.6. A- scan recorded from a defect-free region of a specimen

Results

For the impact damage evaluation in composite panels, the C-scans of the flaw echo, backwall echo, and flaw depth were recorded. *Figures 7 and 8* show the results of ultrasonic imaging tests on panel 1 impacted at 10 J and panel 2 impacted at 15 J on the skin only. As seen from the C-scans, the damage consists of matrix cracks and delamination areas distributed in the lower layers directly at the point of impact and transfered to the free edge of the panel. The flaw depth image shows that most part of the delamination areas develops at adjacent interfaces of 45^0 ply at the back surface. Additional imaging is possible with B-scans which clearly show the defects at different depth levels of the panels. An example is given in *Fig. 9* in the form of B-scan of panel 1 in the damaged area. A 15 J impact causes many echoes in the skin, which are displayed in the horizontal B-scan.

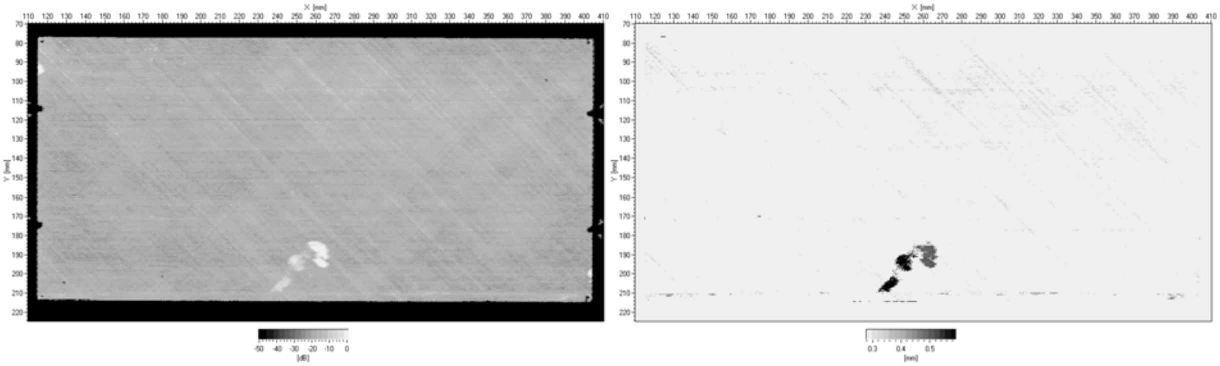

Fig. 7. C-scan images of panel 1: flaw echo (left) and flaw depth (right)

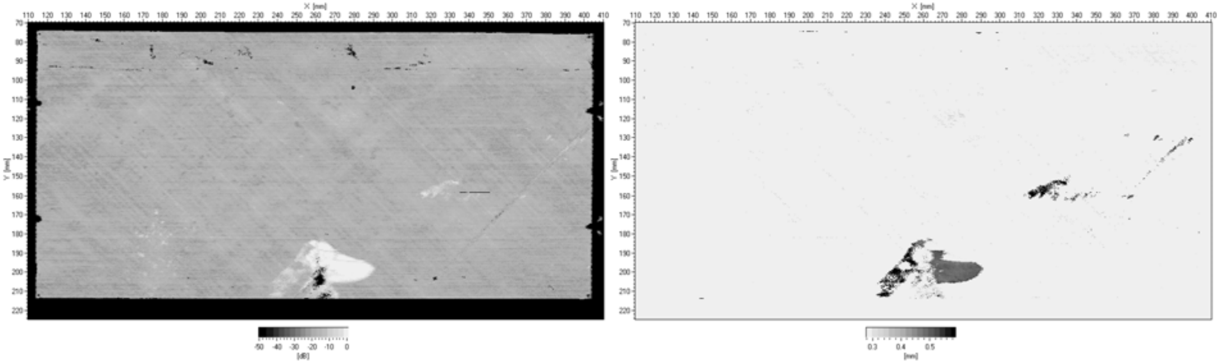

Fig. 8. C-scan images of panel 2: flaw echo (left) and flaw depth (right)

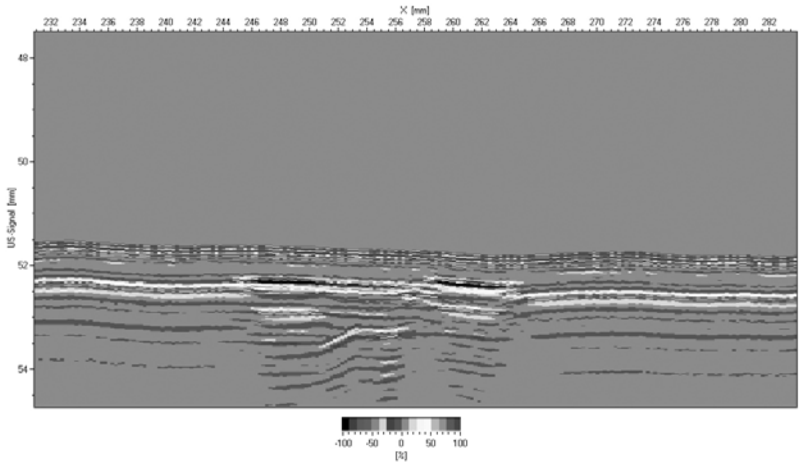

Fig. 9. B-scan image of panel 2

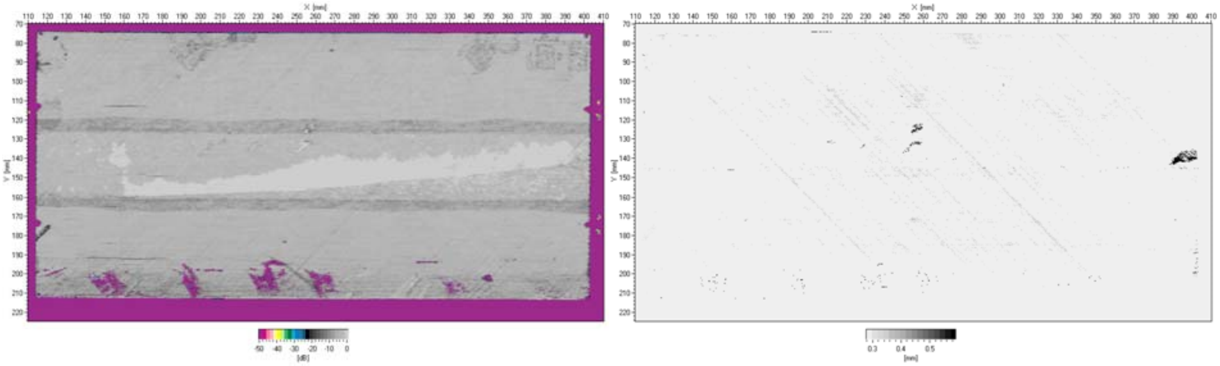

Fig. 10. C-scan images of panel3: backwall echo (left) and flaw depth (right)

Figure 10 presents the backwall-echo and flaw-depth C-scan images of panel 4 impacted at 15 J on the edge of stringer flange. As seen from the ultrasonic imaging results (flaw depth), matrix cracks and delamination areas arise in the lower skin layers at the point of impact. In this case, the damaged region is considerably smaller compared with the regions in the panels impacted on the skin only. This could be explained by the fact that most of the impact energy has been consumed by the process of skin stringer debonding, as seen from the backwall-echo C-scan image. Similar results were obtained for panels 3, 5, and 6.

Conclusions

The non-destructive ultrasonic imaging technique is utilized to produce high-resolution images of internal defects as those resulting from low-velocity impacts on curved one-stringer stiffened composite panels. The results have shown the good possibilities for detection, localization, and evaluation of matrix cracks and delamination areas by using the ultrasonic imaging technique. Of great importance for the accuracy of experimental results is the choice of both the probe frequency and proper selection of gate settings in terms of width and location.

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Ručevskis S. Trieciena iedarbībai pakļautu kompozītmateriāla paneļu ultraskaņas testēšana sabrukuma novērtēšanai

Rakstā tiek apskatīta ribotu kompozītmateriāla paneļu nesagraujoša ultraskaņas pārbaudes metode bojājumu noteikšanai. Impulss-atbalss ultraskaņas tehnika tika izmantota, lai iegūtu augstas izšķirtspējas attēlus, kas raksturo kompozītmateriāla paneļu trieciena testos radušos iekšējos defektus. Trieciena testi tika veikti izmantojot „pendeļa” tipa trieciena iekārtu. Variējot kritiena augstuma tika pielietoti dažāda lieluma trieciena ātrumi un trieciena enerģijas. Ultraskaņas eksperimenta rezultātā tika ierakstīti ultraskaņas signāla amplitūdas un ceļa ilguma attēli. Pārbaudāmie paraugi tika skenēt impulss-atbalss ultraskaņas tehnikā, izmantojot 10 Mhz platjoslas raidītāju. Impulss-atbalss ultraskaņas tehnikas galvenie sastādošie ir īsu ultraskaņas signālu ģenerējošs raidītājs un atstaroto signālu ierakstošs uztvērējs. Iegūtie rezultāti uzskatāmi rāda izmantotās ultraskaņas metodes iespējas bojājumu noteikšanā, lokalizēšanā un izvērtēšanā.

Ručevskis S. Ultrasonic inspection of damage in impacted composite panels

In the present paper, an ultrasonic non-destructive technique for the evaluation of cracks and delaminations in curved one-stringer stiffened composite panels is described. The pulse-echo ultrasonic imaging technique is used to produce high-resolution images of internal defects in composite panels subjected to low-velocity impact tests. Impact tests were c on a pendulum hammer-type impact testing machine. By varying the drop height, different impact energies and velocities were obtained. Ultrasonic testing was carried out by recording C-scans of the time-of-flight and amplitude of the ultrasonic signal. The test specimens were scanned at a normal incidence in pulse-echo mode by means of a focussed 10 MHz broadband transducer. The pulse-echo technique consists in generation of a short impulse of the ultrasonic wave by a transmitting transducer. After reflection from the limiting surface, the impulses are recorded by a receiving transducer. The results have shown the good capabilities in terms of detection, localization, and evaluation of cracks and delamination.

Ручевскис С. Ультразвуковой контроль повреждений многослойной панели при импульсном нагружении.

В данной статье рассмотрен метод ультразвукового контроля трещин и расслоений в изогнутой многослойной панели, подкрепленной одним стрингером. Для получения изображения с высоким разрешением внутренних дефектов многослойной панели, подвергавшейся низко скоростному импульсному нагружению, был реализован метод обратного импульса. Ударный тест был выполнен с помощью испытательной машины типа маятниковый молоток. Изменяя высоту падения, были получены различные значения ударной энергии и скорости. Тестовые образцы были отсканированы методом обратного импульса с использованием 10 MHz широкополосный датчик. Метод обратного импульса заключается в образование коротких импульсов ультразвуковых волн передающим датчиком.После отражения от поверхности импульс записывается с помощью записывающего датчика. Результаты демонстрируют хорошие возможности выявления, локализации и оценки трещин и расслоений.