Non-destructive evaluation of dissimilar material joints

Damira Smagulova[1], Elena Jasiuniene[1,2]
1 prof. K. Barsauskas Ultrasound Research Institute, Kaunas University of Technology, Lithuania, damira.smagulova@ktu.edu
2 Department of Electronics Engineering, Kaunas University of Technology, Lithuania, elena.jasiuniene@ktu.lt

Abstract

The aim of this research was to find the most suitable ultrasonic non-destructive technique that would enable to find defects in dissimilar material joints made of steel and Glass Fiber Reinforced Polymer (GFRP). The selection of appropriate technique was performed by analysis of sample, ultrasound methods, types of transducers as well as ultrasonic wave propagation characteristic, paths, amplitude value of peaks. Firstly the sample was designed in CIVA software where different solutions were used to compare the results of investigations. It was determined that inspection is most effective from metal side since the attenuation in steel is 3 time less than in GFRP. Pulse-echo technique and phased array transducers were selected as the most suitable configuration for inspection of the sample. By comparing amplitudes of signal reflected from the defect area and interface without defect it was determined that the difference is very low and it leads to the fact that it can be difficult to locate delaminations experimentally. To avoid this complication comparison of multiple reflections from defect and interface without defect was performed. In experimental part all delaminations as well as their dimensions were determined. As a result of this research, the best configuration for the delamination detection in dissimilar steel and GFRP sample was found.

1. Introduction

Technology of adhesive bonding of metal and composite materials is becoming more popular due to ability to reduce the weight and increase stiffness and strength of the structure. Usually joints of dissimilar materials are used in expensive structures which operation interruption can make quite big effect for safety, health as well as economically. Common defects in adhesively bonded materials are delaminations, voids, porosity and others. The objective of this research is to analyse ultrasonic techniques and wave characteristics which will be most suitable for location of delaminations in dissimilar material joints. Complexity of the inspection of joint of dissimilar materials is that each dissimilar material can have very different material properties on which ultrasonic wave propagation depends (1), (2).

2. Sample characteristics and method selection

2.1 Sample characteristics

The sample under investigation is a planar object of jointed steel and GFRP. The thickness of sample is 10.42 mm, composite layer is 4.12 mm and steel is 6.30 mm.

There are 3 artificial rectangular delaminations of different dimensions from 5 to 25mm between steel and composite layers made of polyethylene (PE) tape with oil to prevent bonding between layers.

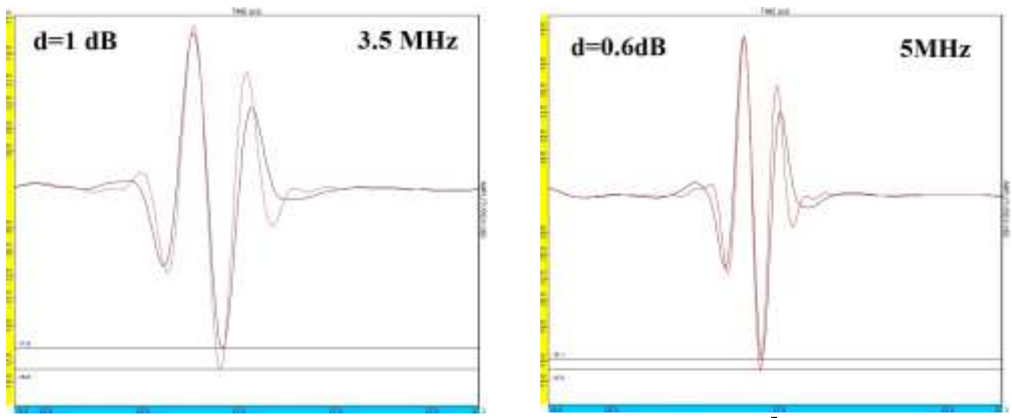
2.2 Method selection

The sample can be inspected from both sides due to construction and geometry. The comparison of attenuation of ultrasonic signal in steel and GFRP was performed using CIVA software. 5 MHz transducer was selected. It was determined that ultrasonic signal is attenuated 3 times more in GFRP compared to steel. Therefore inspection from the metal side was selected.

Phased array transducers were selected for the inspection of delaminations due to ability to cover large surface of the sample, electronic scanning, focusing and steering. The frequencies for inspection were selected taking into account that wavelength should not be higher than the thickness of layer (3). As a result 3.5 MHz and 5MHz frequencies were selected for the inspection.

3. Inspection using CIVA software

Signal amplitudes reflected from the area with defect and without were compared in CIVA software using 3.5MHz and 5MHz phased array transducers (Figure 1).



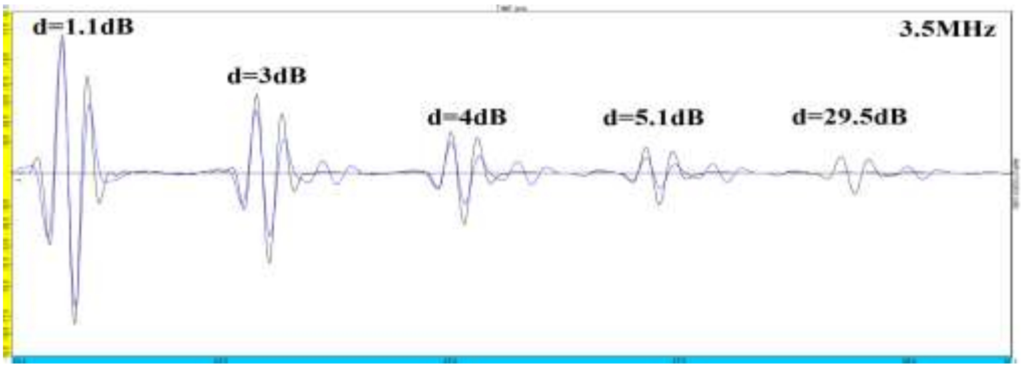
a **b**

Figure 1. Comparison of signal amplitudes reflected from the area with defect (red colour) and without defect (black colour).

In the case of inspection using 3.5 MHz transducer the reflection from defect is 1 dB higher than the reflection from interface without defect. In the case of 5MHz transducer the difference is 0.6 dB. Since the acoustic properties of steel and GFRP are different there is no possibility to avoid reflection of ultrasonic signal from the good joint (4). As a result the possibility to detect delamination using 3.5MHz phased array is a little higher comparing to 5MHz, but in general the small difference in amplitude leads to the fact that it will be hard to locate delaminations experimentally.

In order to improve the probability of detection of delaminations multiple reflections from defect and interface of the sample were analysed (5).

The reflections from defect and from interface using 3.5MHz and 5MHz phased arrays were compared and shown in Figure 2.



a

b

Figure 2. Comparison of amplitudes of multiple reflected signals from the area with defect (black colour signal) and without defect (coloured signal).

Amplitude difference of signals reflected from defect area and interface without defect increases because of signal attenuation in steel and GFRP (5). As a result it is a bigger probability to detect delaminations by analysing multiple reflections from the bonding.

4. Experimental inspection

The Omniscan measurement system and 3.5MHz and 5MHz phased arrays were used. Special gel was used as a coupling media and electronic scanning with 1 mm step was applied. As a result delaminations were located It was hard to locate delaminations from first reflection but easier from subsequent as it was proved in modeling part.
Dimensions determined from the experimental measurements are shown in Table 2.

Table 2. Dimension of delaminations

3.5MHz		5MHz	
Item	Length	Item	Length
Delamination 1	25.62	Delamination 1	25.53
Delamination 2	15.24	Delamination 2	15.22
Delamination 3	20.43	Delamination 3	19.59

5. Conclusions

Detection of delaminations in adhesively bonded joint is the complicated task since the acoustic impedance of adherends differ quite strongly what leads to strong reflection from the bonding between two materials even without any delamination. According to CIVA modelling results the side of sample from which the inspection should be performed as well as frequency and most suitable type of transducer were selected. According to examined characteristics pulse-echo method was selected as the most suitable technique for particular sample of dissimilar materials. Amplitudes of signals reflected from the defect area and interface without defect were compared. As a result better possibility of delamination location is in comparison of multiple reflections. Experimentally all delaminations were located using the selected technique.

Acknowledgements

The research leading to these results has received funding from the European Union Seventh Framework Programme under grant agreement n° 310498, project SAFEJOINT "Enhancing structural efficiency through novel dissimilar material joining techniques".

References and footnotes

1. Josefine Jahna, Max Weebera, Johannes Boehnera and Rolf Steinhilperb, “Assessment strategies for composite-metal joining technologies – A review”, 26th CIRP Design Conference, Procedia CIRP 50, pp 689 – 694, 2016.
2. K. Martinsen (3)a,b,*, S.J. Hu (1)c, B.E. Carlson, “Joining of dissimilar materials”, CIRP Annals - Manufacturing Technology 64, pp 679-699, 2015.
3. L. Satyanarayan, C. Sridhar, C.V. Krishnamurthy, Krishnan Balasubramaniam, “Simulation of ultrasonic phased array technique for imaging and sizing of defects using longitudinal waves”. International Journal of Pressure Vessels and Piping 84, pp 716–729, 2007.
4. Agilent Impedance Measurement Handbook, A guide to measurement technology and techniques, 4th Edition. Agilent Technologies Inc., USA, 140 p, 2013.
5. L. Goglio, M. Rossetto, “Ultrasonic testing of anaerobic bonded joints”, Ultrasonics 40, pp 205–210, 2002.