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Evaluation of bonding quality by using ultrasonic waves

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Abstract

Adhesive bonding with substantial weight saving advantage has significant potential for the aerospace industry. An essential step to be able to use this potential is the determination of bonding quality of the adhesive joints by non-destructive testing. Among various NDT methods, the ultrasonic inspection is a well-known and established technique to evaluate bonding quality. Despite the remarkable number of studies has been conducted using ultrasonic inspection, evaluating bonding quality of the adhesive joints is still a challenge. In this work, the propagation of the ultrasonic waves through the single-lap adhesive joints with aluminium alloy and carbon fibre reinforced composite laminate adherends has been investigated. Different case studies, - three different quality interfaces have been analysed. The numerical analysis for each case has been performed by semi analytical finite element method and by finite element method based simulations. The ability of the ultrasonic wave parameters to be used for the evaluation of the bonding quality was evaluated.

1. Introduction

In the emerging industries such as aerospace, the importance of adhesive bonding is rising by its advantages on high load to weight ratio and homogenous load distribution over the joint. However, the usage of the adhesive bonding is limited to secondary load carrier structures due to reliability concerns (1,2). Although the manufacturing techniques are developing day by day, the imperfections such as porosity, delamination, and contamination during manufacturing or on usage of the adhesive bonding structures can occur. Even though there are remarkable studies on the bonding quality of adhesive joints by ultrasonic inspection, it is still a challenge due to unclear multiphysics of the bonding interface (3,4). This study represents an approach to relate the bonding quality with ultrasonic wave parameters.

2. Numerical analysis

2.1 Materials and Model Dimensions

In this study, single lap joints have been simulated with two adherend and one adhesive layer containing two interfaces through bondline. Material properties that have been used in the study are given in table 1. Three different bonding quality conditions are calculated, namely perfectly bonded, delaminated and weak bonded (contaminated with oil). The description of the model dimensions are given in figure 1. Six different cases have been explained in table 2.

Table 1. Material Properties

Material Name	Density [kg /m^3]	Longitudinal sound wave velocity [m/s]	Used as
Aluminum2024	2770	6370	Adherend
CFRP	1494	1480	Adherend
Epoxy	1230	2488	Adhesive
Oil (SAE20)	860	1750	Contamination

Table 2. Case Studies

Case Name	Adherend1	Adhesive	Adherend2	Imperfection (top interface)
A-NON	Aluminum2024	Epoxy	Aluminum2024	None
A-DEL	Aluminum2024	Epoxy	Aluminum2024	Delamination
A-OIL	Aluminum2024	Epoxy	Aluminum2024	Oil-Contamination
C-NON	CFRP	Epoxy	CFRP	None
C-DEL	CFRP	Epoxy	CFRP	Delamination
C-OIL	CFRP	Epoxy	CFRP	Oil-Contamination

2.2 Methodology

The ultrasonic wave propagation through adhesive bonding for six different cases have been modelled with Ultrasonic and Composite modules built in CIVA 2017 by using semi-analytical finite element methodology for numerical simulation. In addition, same configurations have been studied with finite element method with commercial software. Three different cases have been investigated by 5MHz contact-flat transducer in pulse-echo mode. The specimen has been scanned 30 steps in X direction for 15 mm during numerical calculation.

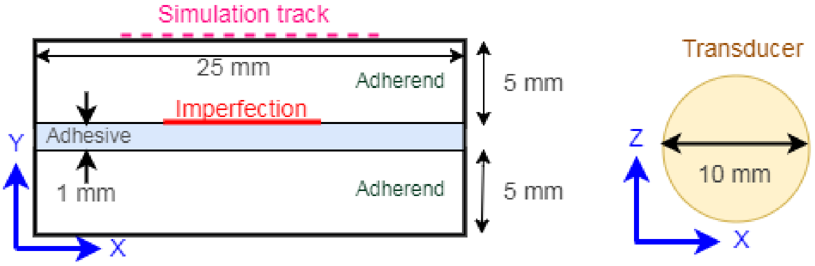

Figure 1. Schematic representation of the model (on the left) with the dimensions. Imperfection stands for delamination or oil-contamination. Transducer size and shape (on the right).

3. Results

The bonding quality of six different cases that are described in table-2 has been investigated using numerical calculation. The A-scan result from the middle step of each inspection has been compared within aluminium (figure2.A) and CFRP (figure2.B) cases separately. Since the imperfections, both delamination and oil-contamination, cause acoustic impedance change at the top layer interface, the received ultrasound signals have changed from the perfectly bonded no-defect case. As it was expected to have perfect reflection from delaminated case, second interface reflection and backwall reflections are zero. On the other hand, for contaminated cases, the amplitude of second interface reflection has decreased in both cases. In the aluminium joint, almost 10 percent is visible whereas in composite joint the decrease is more than 20 percent.

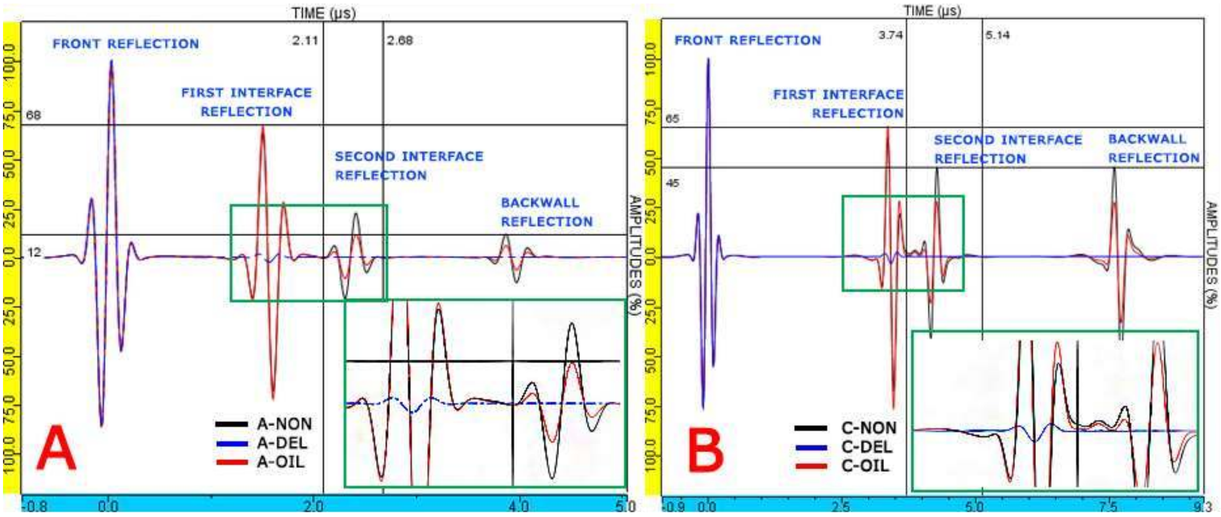

Figure 2. A-Scan results of six different cases calculated by CIVA 2017.

4. Conclusions

The numerical investigations in order to evaluate bonding quality using ultrasonic waves were presented. It was shown that ultrasonic parameters such as reflected amplitude at the interface can be used to evaluate bonding quality. This results suggest that different quality conditions on adhesive bonding can be evaluated by ultrasonic inspection.

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References and footnotes

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