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Non-destructive characterization and evaluation of adhesive joints using artificial intelligence tools

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1 Abstract

This investigation examined the potential of artificial intelligence tools for detecting defects in adhesively bonded samples. Adhesive bonds are widely used in various sectors such as aviation, modern transport including buses, trams, pleasure boats, etc. One of the main quality assurance procedures is the non-destructive evaluation of adhesive joints.

The aim of the work is to improve non-destructive sample characterization and evaluation of adhesive joints using artificial intelligence tools.

C-scan images of aluminum CFRP bonded joints with non-uniform defects ranging from 5 to 15 mm were used during ultrasonic measurement. The study was conducted in two stages, first, 4 different computational model architectures were applied, data were organized, processed and as a result, defects in bonded joints were identified. In the next stage, all data were randomly cropped in order to have more diverse data and trained using the most reliable model architecture to describe and classify different defects in aluminum CFRP plate bonded joints. During model training, defect detection was achieved with an accuracy of almost 95%, and after testing, the defect detection accuracy exceeded 97%.

Keywords: adhesive joints; artificial intelligence, ultrasonic measurement.

2 Introduction

The operational requirements of various complex materials and structures in various fields are increasingly demanding, as a result, science and technology are developing at a fairly rapid pace [1]. Bonding technology is an advanced way to connect different sheets of materials, and to provide and ensure better electrical and mechanical properties to the structure. This is inevitable in order to create durable, long-lasting, lightweight, corrosion-resistant, high-temperature and other electrical and mechanical properties of materials. Such a bonded layer, such materials are heterogeneous and complex structures, but inseparable in the fields of aviation and aerospace, wind power plants, oil, sonar, ships [2].

2.1 A Sub Section Sample

For this study, an aluminum–CFRP specimen was used, containing nine artificial rectangular defects with sizes ranging from 5 to 15 mm, located at three different depths within the adhesive layer (top, middle, and bottom interfaces). Double-folded rectangular pieces of solid A5000RED film were used to create separation and delamination-type defects. The specimen consisted of aluminum (1.82 mm), CFRP (1.6 mm), and an adhesive layer (0.18 mm), forming a heterogeneous interface that affects ultrasonic wave propagation and amplitude response. Ultrasonic pulse-echo inspection was performed using a *TecScan*

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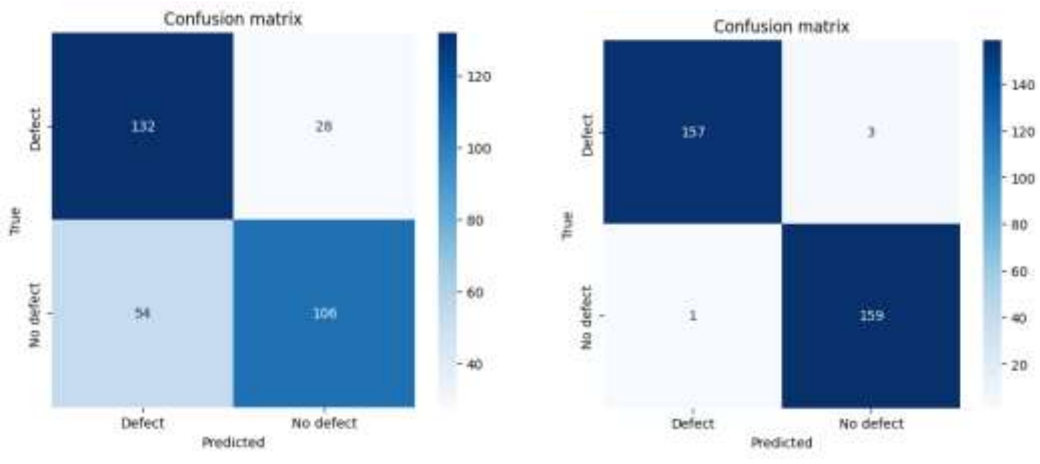
measurement system with a 15 MHz focused transducer in immersion mode, where the specimen was placed in a water-filled tank. Scanning was performed along the z and y axes with a step of 0.2 mm and a sampling rate of 200 MHz, providing sufficient spatial resolution and sensitivity for detecting small interface defects in adhesively bonded joints. Separate ultrasonic measurements were performed for each zone with individually adjusted transducer alignment to optimize wave incidence, signal stability, and defect detectability. In total, more than 600 ultrasonic C-scan images were collected and used to form the dataset for training and evaluation of convolutional neural network (CNN) models.

Table 1. The parameter counts and test metrics.

cnn_baseline	23,714 params	test acc 0.7438, macro F1 0.7420
cnn_bn_dropout	389,410 params	test acc 0.9812, macro F1 0.9812
tinyresnet	1,226,914 params	test acc 0.9875, macro F1 0.9875
mobilenetv3	1,519,906 params	test acc 0.9938, macro F1 0.9937



(a) (b)

Fig. 1. Models Confusio matrix: cnn_baseline (a), tinyresnet (b).

The baseline CNN is clearly insufficient, achieving only ~74% test accuracy and showing class-dependent precision/recall imbalance. Introducing normalization/regularization (cnn_bn_dropout) yields a dramatic jump to ~98% test accuracy, indicating the task benefits strongly from improved training stability and regularization. *TinyResNet* and *MobileNetV3* both achieve near-ceiling performance; *MobileNetV3* provides the top test accuracy/F1, supporting the use of pretrained lightweight CNN backbones for high-accuracy defect detection.

References

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