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Feature-Based Machine Learning Approach for Adhesive Joint Integrity Assessment

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1 Abstract

Ensuring the integrity of adhesively bonded joints is essential for maintaining structural reliability in aerospace applications. This work presents an approach that integrates ultrasonic pulse-echo testing with machine learning (ML) to enable robust defect detection and bonding-quality classification. Aluminium and composite joints exhibiting a range of bonding conditions—including perfect bonds, interfacial defects such as disbonds and delaminations, as well as weak bonds arising from contamination or improper curing—were inspected using pulse-echo immersion ultrasonic techniques. Following signal preprocessing and time gating, a comprehensive set of ultrasonic features was extracted from both the time and frequency domains. Feature engineering and dimensionality-reduction methods— including tree-based selection, recursive and sequential algorithms, and Linear Discriminant Analysis (LDA)—were applied to optimize model performance. Support Vector Machine (SVM) classifiers demonstrated high accuracy in assessing bonding strength and detecting interfacial defects: over 90% for binary defect detection, up to 99% for weak-bond identification, and up to 97% for defect-depth classification. These results highlight the strong potential of ML-enhanced ultrasonic inspection as an automated, accurate, and efficient solution for assessing the integrity of adhesive joints.
Keywords: Ultrasonic testing, machine learning, adhesive joints, defect classification, defect feature analysis

2 Introduction

Adhesive bonding has become a key joining technology in aerospace and other high-performance industries due to its ability to reduce structural weight, improve fuel efficiency, and enable the joining of dissimilar materials without compromising structural integrity. However, the reliability of adhesive joints can be affected by defects such as disbonds, delaminations, and weak or kissing bonds, many of which are invisible and difficult to detect using conventional ultrasonic inspection techniques. To address these limitations, this work integrates ultrasonic pulse-echo inspection with machine learning (ML) algorithms, employing advanced feature engineering and dimensionality-reduction methods to enhance defect detectability and classification performance. By extracting a comprehensive set of ultrasonic features [1] from both the time and frequency domains—such as peak-to-peak amplitude, time-of-flight, attenuation, and others—ML models can identify subtle signal variations associated with interfacial defects or bond condition [2,3]. The novelty of this approach lies in the combination of ultrasonic NDT with a feature-based machine-learning framework, enabling not only the detection of defects such as disbonds and their classification according to depth within the adhesive layer, but also the identification of different types of weak bonds.

3 Materials & methods

In this study adhesively bonded lap joints (aluminium - aluminium and aluminium-CFRP),

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containing multiple artificial interface defects of different sizes and depths and with controlled variations in bonding quality introduced through surface contamination and faulty curing to create weak bonds were investigated. Samples were measured using ultrasonic pulse-echo immersion techniques. 45 ultrasonic features were initially extracted from pulse-echo A-scans, covering time and frequency domains. These features were analysed employing the statistical significance, cross correlation analysis as well as the performance of different feature subsets extracted tree-based feature selection, recursive, sequential elimination and LDA were evaluated.

4 Results & discussion

SVM classifiers trained on ultrasonic features achieved robust performance across both binary and multi-class tasks. For binary defect detection ("defect" vs. "no defect"), classification accuracy exceeded 90% on training/testing data and remained above 83% on unseen samples. Depth localization within adhesive layers reached up to 97% accuracy for shallow defects, although intermediate depths remained challenging due to low amplitude contrast and signal overlap, leading to occasional misclassification between neighboring classes. In weak-bond detection, models trained on selected feature subsets achieved at least 91% accuracy, while full feature sets produced slightly lower accuracy but improved generalization. Dimensionality-reduction techniques, particularly LDA, offered an effective balance between computational efficiency and predictive performance, reducing training time by approximately 40% while maintaining accuracy above 84%. These findings demonstrate that conventional ultrasonic amplitude or time-of-flight criteria alone are insufficient for reliable defect identification, whereas feature-based, ML-driven approaches substantially enhance detection capability.

5 Conclusions

The research confirms that feature-based machine learning integrated with ultrasonic NDT significantly improves the reliability of adhesive joint quality assessment. Conventional ultrasonic criteria, such as amplitude or time-of-flight, proved insufficient for detecting weak bonds or some interface defects, whereas ML-based approaches achieved classification accuracies exceeding 90% for defect detection and up to 99% for severe weak bonds. Dimensionality reduction techniques, particularly LDA, provided an optimal balance between computational efficiency and predictive performance, reducing training time by approximately 40% while maintaining accuracy above 84%. These results demonstrate that feature-based ML-driven ultrasonic inspection enables precise identification of bonding anomalies, defect depth localization, and differentiation of contamination versus curing-related weakness of the joint.

References

1. Smagulova, D.; Yilmaz, B.; Jasiuniene, E. Ultrasonic Features for Evaluation of Adhesive Joints: A Comparative Study of Interface Defects. *Sensors* 2023, *24*, 176, doi:10.3390/s24010176.
2. Samaitis, V.; Yilmaz, B.; Jasiuniene, E. Adhesive Bond Quality Classification Using Machine Learning Algorithms Based on Ultrasonic Pulse-Echo Immersion Data. *J Sound Vib* 2023, *546*, doi:10.1016/j.jsv.2022.117457.
3. Smagulova, D.; Samaitis, V.; Jasiuniene, E. Machine Learning Based Approach for Automatic Defect Detection and Classification in Adhesive Joints. *NDT & E International* 2024, *148*, 103221, doi:10.1016/j.ndteint.2024.103221.