UNIVERSITI TEKNOLOGI MARA

PREDICTIVE MODELLING OF HYBRID COMPOSITE LAMINATES BUCKLING BEHAVIOUR USING RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORK

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ABSTRACT

Accurate prediction of buckling loads in composite structures is essential, as their anisotropic and inhomogeneous properties complicate structural analysis and optimisation. However, traditional predictive models often suffer from limitations such as the inclusion of statistically insignificant polynomial terms in Response Surface Methodology (RSM), or poor learning performance in Artificial Neural Networks (ANN) due to unprocessed and limited data sizes. To address these challenges, this study aims to evaluate and compare the accuracy of predictive models on buckling load in composite laminates by applying model refinement in RSM and input data normalisation in ANN, using Finite Element Analysis (FEA). Two case studies of experimental runs designs were generated using Design of Experiment (DOE) method, incorporating combinations of key factors. Case Study 1 followed a Box-Behnken Design (BBD) statistical design with 17 experimental runs, while Case Study 2 employed a 3-level Full Factorial Design (FFD) statistical design, consisting of 27 experimental runs. All experimental runs were then evaluated through finite element simulation using ANSYS, focusing on graphite/glass epoxy hybrid composites with eight-layer symmetrical sequence [0/+9 /-9 /90]s. The key factors studies were fibre orientation angles of 0° to 45°, plate thicknesses of 0.5 mm, 2 mm and 3 mm, and volume fractions of 100% graphite, 100% glass and a hybrid mix. RSM optimise these factors using Design Expert software which both quadratic and modified polynomial models were developed for each case. ANN models were created in MATLAB using both raw and normalised datasets to analyse the effect of data preprocessing. The performance of both RSM and ANN models was evaluated based on the performance metrics and error analysis was conducted by comparing the predicted buckling loads from both models with the buckling loads obtained from FEA. Findings indicate that the modified polynomial RSM model improved prediction accuracy by 81.2% to 132.4%) compared to the quadratic model, while the normalised ANN models showed improvements ranging from 45.6% to 615.6% over unprocessed ANN models. From the FEA simulation, the range of computed buckling loads was between 3.627 kN and 1730.8 kN. The results also confirmed that increased plate thickness enhances buckling load, and that fibre angle orientation and graphite volume fraction significantly affect structural stability. Statistical analysis using t-tests showed no significant difference between Case Study 1 and Case Study 2, reinforcing the reliability of the results. The highest buckling load was observed at [45, 1, 3], representing 45° fibre orientation, fully graphite composition and a thickness of 3 mm. For hybrid composite laminates, the highest value occurred at [45, 0.5, 3], with 45° fibre angle and 3 mm thickness. These findings provide valuable insights to help engineers design safe graphite/glass epoxy composite laminate structures on vehicles and aircraft under compressive uniaxial loading conditions, while also contribute to the advancement of knowledge in the field of hybrid composite structural analysis and predictive modelling.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

Composite materials are favoured for their strong strength-to-weight ratio, leading to their common use in various industries like automotive, aerospace and shipbuilding (Siengchin, 2023). Composite also have a tailorable property where the properties can be customised according to the application, including the strength, stiffness, thermal properties and corrosion resistance (Zhai et al., 2021). This versatility has led their used across industries. For example, in automotive industry, BMW company apply the used of Carbon Fibre-Reinforced Polymer (CFRP) in their i3 model car bracket to minimise the weight while maintaining the structure strength (Ahmad et al., 2020). Boeing 787 Dreamliner used 50% carbon laminate of the total weight for their fuselage and wings as shown in Figure 1.1 (Rohan Patole et al., 2023). Airbus is one of the aerospace industries that used this combined composite for their A350 XWB aircraft body structure (Nair, 2021). Therefore, studying composites is essential to keep pace with modern engineering demands and advances in material technology.

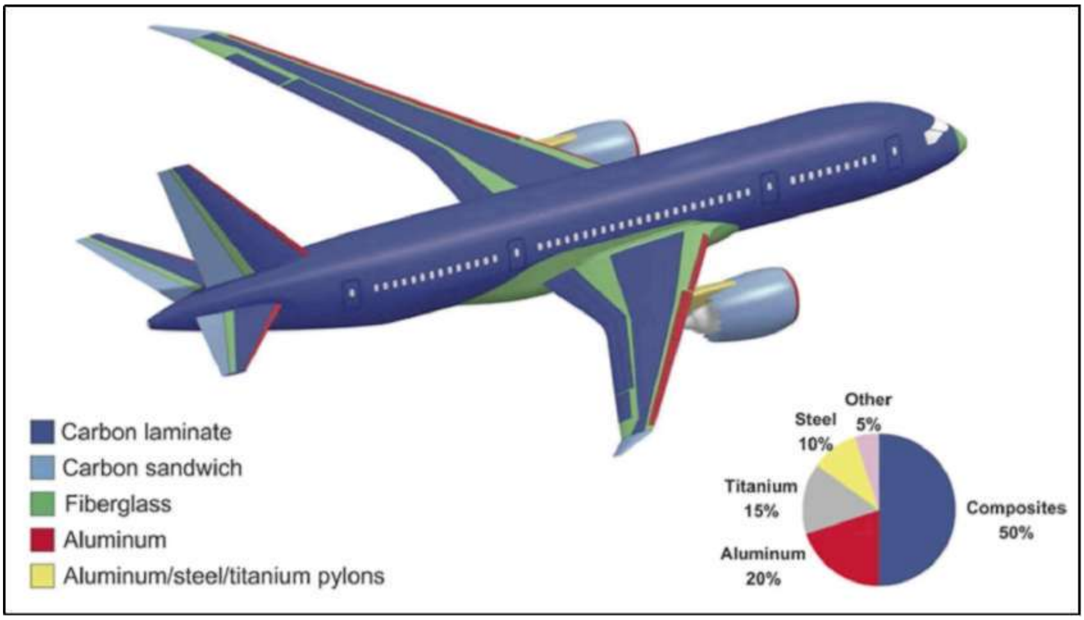

Figure 1.1 Applications of Composites in Boeing Dreamliner (AL-Oqla et al., 2023).