

UNIVERSITI TEKNOLOGI MARA

**PREDICTIVE MODELLING OF THE
HYBRID COMPOSITES FAILURE
UNDER BIAXIAL TENSION USING
INTEGRATED FINITE ELEMENT
ANALYSIS WITH VARIOUS
STATISTICAL DESIGN MODELS**

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ABSTRACT

Due to their exceptional strength-to-weight ratio, composite laminates reinforced with boron and glass fibres are widely used in civil, aerospace and automotive applications. The hybridisation of these fibres provides improved mechanical strength, better durability and longer fatigue life. Predictive modelling is increasingly used to estimate the failure response of hybrid composites, reducing the need for extensive physical testing. These models help evaluate multiple design parameters more efficiently and support better decision-making in structural design. Analysing the failure behaviour of hybrid composites becomes challenging due to their unpredictable response under complex loading conditions, especially biaxial tension. The main aim in this study is to formulate a reliable predictive framework for the failure behaviour of hybrid boron/glass epoxy composite laminates under biaxial tension through the integration of Finite Element Analysis (FEA), Response Surface Methodology (RSM) regression functions and an optimised Artificial Neural Network (ANN) model using normalised datasets. FEA was conducted to validate the model, involving mesh sensitivity analysis, numerical validation against past studies and the prediction of failure load values. Design of Experiment (DOE) was used to set up the selected parameters involving two RSM statistical design models, Box-Behnken Design (BBD) and Full Factorial Design (FFD), generating 17 and 27 datasets, respectively. Analysis of Variance (ANOVA) was utilised to investigate the interactions between the selected parameters and the influence of each parameter on the failure behaviour of hybrid boron/glass epoxy composite laminates. In addition, the modified regression function-modified cubic polynomials was selected for the optimisation analysis and the prediction of the failure load. Then, an ANN was employed as a predictive model for failure load prediction, based on the combination of the modified regression function and normalised datasets. Finally, the accuracy of the prediction models was compared, while an independent t-test was utilised to assess the significant differences between 17 and 27 datasets. Based on the results obtained from the FEA, the failure load values ranged from 384.83 N to 4180.20 N across both statistical design models. RSM optimisation predicted a maximum failure load of 3637.42 N for the BBD, with an optimal setting of 3625.25 N at 11.82° angle orientation, fully glass volume fraction and 0.003 m thickness. For the FFD, the predicted maximum failure load was 4180.20 N, with an optimal setting of 4150.46 N at 0° angle orientation, fully glass volume fraction and the same thickness. The prediction of failure load values demonstrated a low error margin with errors recorded below 7% for BBD and below 10% for FFD. Among the four models evaluated, the BBD model achieved the highest prediction accuracy at 97.84%, while statistical comparison revealed no significant difference between all models. The findings indicate that plate thickness is the most influential parameter affecting the failure behaviour, whereas angle orientation exhibits the least impact. Additionally, the interaction between plate thickness and volume fraction is shown to be significant and plays a dominant role in analysing the failure behaviour.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Composite materials have gained widespread attention across various engineering fields and are now regarded as a core foundation for the advancement of structural engineering design. The combination of two or more different elements at the macroscopic level enables the new materials to be produced with improved mechanical properties that surpass the individual components (Abdalla, 2025). One of the main advantages of composite materials is their excellent strength-to-weight ratio. In research and development field, composites remain an important topic due to their cost-effectiveness, desirable mechanical properties, lightweight and high fatigue performance (Ajayi et al., 2025). Despite their wide range applications, composite materials often fail to meet several performance standards, such as strength, stiffness and durability. Thus, hybrid composite materials have been developed as an alternative to overcome these limitations.

Hybrid composites are advanced materials that combine two or more different fibre types, such as boron, carbon, glass and Kevlar, within a single matrix (Dong, 2025). They can be tailored to provide various advantageous properties, including improved thermal performance, stiffness, strength-to-weight ratio and wear resistance, which surpass those of conventional composite materials (Mateen et al., 2018). This hybridisation allows the material to address the weaknesses of each fibre while taking advantage of their strengths. A wide range of engineering industries such as marine, automotive, aeronautical and biomedical, utilise hybrid composite materials due to their beneficial combination of mechanical performance, durability and design flexibility (Parkunam et al., 2020).

Therefore, this study suggests hybridising boron and glass fibre composites to gain the benefits of their combination. Boron fibre composites are famous by their higher compressive strength compared to tensile strength, however, their high production cost has limited their widespread use in practical applications (Garulli et al., 2025). In contrast, glass fibre is well-known for its high durability and tensile strength. However, its relatively high density can increase the total weight of the composite