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FAILURE PREDICTION OF COMPOSITE LAMINATE BASED ON MULTITUDINOUS COMBINED LAMINATION AND FAILURE THEORIES

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ABSTRACT

Composite laminates could offer excellent material properties due to their high stiffness and high strength-to-weight ratio. However, its trend of failure could lead to catastrophy due to the lack of understanding of its failure behaviour. Moreover, the accurate failure prediction of composites laminate is still yet to be established. Therefore, this study aims to predict failure of composite laminates based on multitudinous combined lamination and failure theories. The work has been conducted in five phases to cover these specific objectives; (i) to develop a MATLAB programme for failure analysis based on multitudinous combined lamination and failure theories; (ii) to compare simulated and measured extension based on ASTM D3039 (numerical versus experimental approaches) of a Carbon-Epoxy laminate under uniaxial tension; (iii) to assess the effect of different lamination scheme on the failure behaviour and mode of failure of composite laminates; (iv) to assess the effect of different lamination theories on the simulated failure behaviour of composite laminates; and finally, (v) to assess the effect of selected failure theories and determine the best fit failure theory for composite laminates. A programme was developed using MATLAB to compute the displacements, strains and stresses of the laminates based on multitudinous lamination theories (Classical Lamination Theory (CLT), First Order Shear Deformation Theory (FSDT) and High Order Shear Deformation Theory (HSDT)). For failure analysis, Maximum Stress (MS), Tsai-Wu (TW), modified Tsai-Wu (mTW), Hashin, Hoffman, Lee and Mall (MT) failure theories were employed into a programme (MATLAB) to determine the failure loads. Finite element (FE) programming (FORTRAN-90) based on HSDT was upgraded by employing the six failure theories to determine the failure loads. Failure curves are plotted and analysed. It was observed that the results from finite element simulation (ANSYS) were closer to the experimental results. However, the average difference between ANSYS and MATLAB does not exceed 1%. Deformation behaviour between lamination scheme show significant different where it was found that symmetric laminate experience elongation while anti-symmetric laminate experience twisting deformation and angle-ply laminate experience bending deformation. Determination of mode of failure using MS and mTW failure theories does not show significant different except for matrix mode of failures (anti-symmetric laminate). Comparing the FE simulation and analytical approaches, the results for uniaxial tension load (symmetric laminate) are close to each other, with a difference less than 3%. This study has proven that the developed MATLAB programme is found to be very useful for predicting failure load of composite laminate. Other than that, it is also interesting to highlight that MT failure criterion predicts smoother curve and closer to the experimental curve compared to the other five failure theories. Therefore, it can be concluded that this study has contributed significantly to enhancing knowledge about the failure prediction of composite laminates based on multitudinous combined lamination and failure theories.

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CHAPTER ONE
INTRODUCTION

1.1 Background of Study

In conventional structures, it is sufficient to have the members that are made only of materials, which are usually considered as homogeneous and isotropic in design. However, modern structures such as aircrafts would require more than that. Soriano et al. [1] stated that 50% of the components of a commercial aircraft is made out of composite materials. Such composite material idealised from orthotropic laminas, are bonded together to form a laminate. These laminates are preferably used as structural components due to their high stiffness that come with high specific strength and these exceed the advantages of existing metals [2-4]. Due to these advantages, composite materials are rapidly emerging as a primary material for the use in near-term and next-generation aircraft, transportation, construction and various other applications [5-7].

The concept of composite materials has been known to mankind since as early as 1500 B.C. when composites existed in various forms, for example mud walls reinforced by bamboo or use of laminated metals in forging swords later in 1800 A.D [5]. Unlike isotropic material which has identical mechanical, physical, thermal and electrical properties in every direction [8, 9], composite materials are not isotropic. Figure 1.1 shows the comparison between conventional monolithic materials and composite materials. It can be seen that composite materials have high stiffness, high strength and high fatigue resistance compared to steel and aluminium. However, damage mechanism involved in composite materials are unlike that of conventional materials. Due to their complex mechanical characteristic, composite materials are prone to wide range of defects and damages that can cause significant reductions in stiffness and strength [4]. The most common types of damage encountered are fibre breakage, matrix cracking, shear failure and delamination which often is difficult to detect by simple visual inspection [10]. There are several failure theories that could predict failure of composite laminate such as Maximum Stress, Tsai-Wu, Hashin, Hoffman and Lee. These failure theories will be paired with lamination theories (Classical Lamination Theory, First Order Shear Deformation Theory and High Order