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A Review Of Failure Of Composite Materials

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Abstract

Composite materials are ideal for aerospace applications due to their high strength to weight ratio and their excellent fatigue resistance. Fiber reinforced Composite is widely used in light weight structures for different applications. The main properties that describe a composite material are the engineering constants and the strength properties of a single unidirectional lamina that make the laminated structure. The experimental evaluation of these properties is quite costly and time consuming because they are functions of several variables such as the individual constituents of the composite, fiber volume fraction, packing geometry and fabrication processes. Hence, analytical models to predict these properties were developed by researchers to aid the design of composites. In recent years numerous failure theories have been proposed and are available to the composite structural designer. Object of this review is to gather the available guide lines for theoretical models of failure analysis of fiber reinforced Composite.

1. Introduction

Over the last four decades, there have been continuous efforts in developing failure criteria for unidirectional fiber composites and their laminates. The failure of composites has been investigated extensively from the micromechanical and macromechanical points of view. On the micromechanical scale, failure mechanisms and processes vary widely with type of loading and are intimately related to the properties of the constituent phases, i.e., matrix, reinforcement, and interface-interphase. Failure predictions based on micromechanics, even when they are accurate with regard to failure initiation at critical points, are only approximate with regard to global failure of a lamina and failure progression to ultimate failure of a multi-directional laminate. For these reasons a macromechanical approach to failure analysis is preferred.

2. Review of Different theoretical models.

Numerous failure theories have been proposed and are available to the composite structural designer [1].They are classified into three groups, *limit or noninteractive theories* (maximum stress, maximum strain); *interactive theories* (Tsai-Hill, Tsai-Wu); and *partially interactive or failure mode based theories* (Hashin-Rotem, Puck). The validity and applicability of a given theory depend on the convenience of application and agreement with experimental results. The plethora of theories is accompanied by a dearth of suitable and reliable experimental data, which makes the selection of one theory over another rather difficult. Considerable effort has been devoted recently to alleviate this difficulty. The problem can be divided in two parts, one being the prediction of failure of a single lamina and the second dealing with prediction of first-ply-failure and damage progression leading to ultimate failure of a multi-directional laminate.

C. T. Sun [2] reviewed six failure theories and showed comparisons of theoretical predictions with experimental results. Existing lamina and laminate strength data are used to evaluate these failure criteria. For some laminates under certain loading conditions, all six criteria may predict similar results, and their performance cannot be ranked. Therefore, a number of laminates are identified for which the strength predictions according to these six criteria are substantially different. The validity and applicability of a given theory depend on the convenience of application and agreement with experimental results.

In an AIAA Failure Criteria Survey [3], 80% of the respondents said they utilized one of these four lamina failure criteria. Maximum Strain is most commonly used at 30% with Maximum Stress next at 22%. Hill-Tsai and Tsai-Wu usage came in at 17% and 12% respectively. Figure 1 shows the breakdown for each criterion.

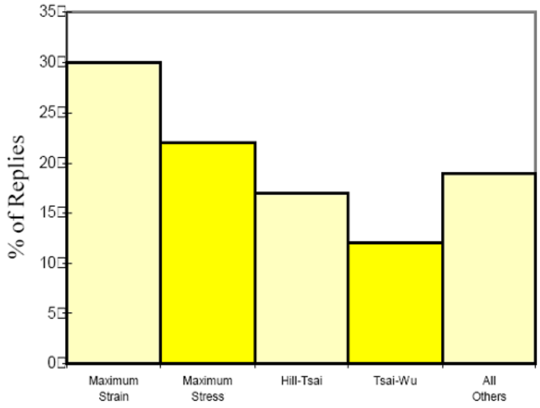

Fig 1. Results of AIAA failure criteria survey

Muhannad Z. Khelifa [4] evaluated the mechanical properties of artificial E-glass reinforced polyester composite for angle ply laminates.

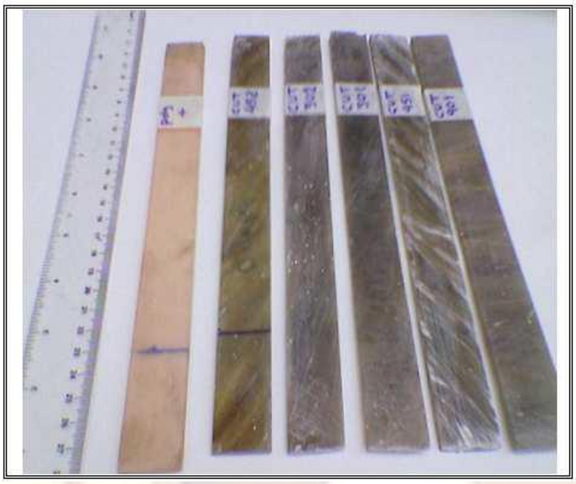

Fig 2. E-glass reinforced polyester composite Specimens

The elastic properties and the strength of the composite were measured experimentally by tensile tests and then compared with the predicted values by theoretical micromechanical constitutive models. The theoretical models showed that the composite stiffness increases with increasing the fibre volume fraction and the volume fraction which gave the best fit to the experimental results of elastic modulus (E1) corresponds to volume fraction (Vf) equal 0.37. Figure 3 shows the Models prediction of E_1 and E_2 and experimental results of unidirectional lamina

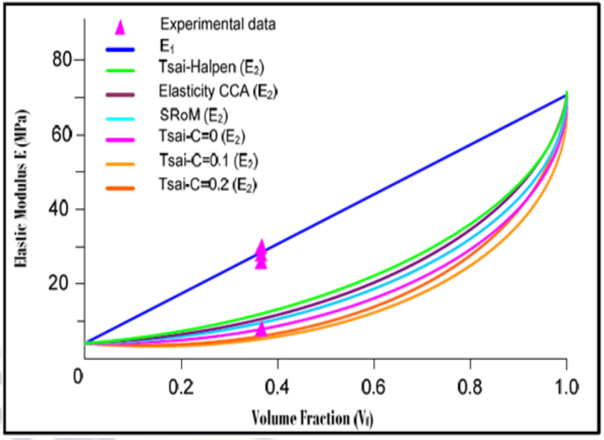

Fig 3. Models prediction of E_1 and E_2 and experimental results of unidirectional lamina

He also compared the experimental results of stiffness of a unidirectional lamina with the results of theoretical models. It was found that the stiffness depends on the fiber orientation relative to the off-axis load direction, and it drops sharply as the fiber alignment angle increases. In general, a wide variation has been observed in the prediction of laminate stiffness by the various theories. Figure 4 shows the Models prediction of stiffness and experimental results of unidirectional lamina.

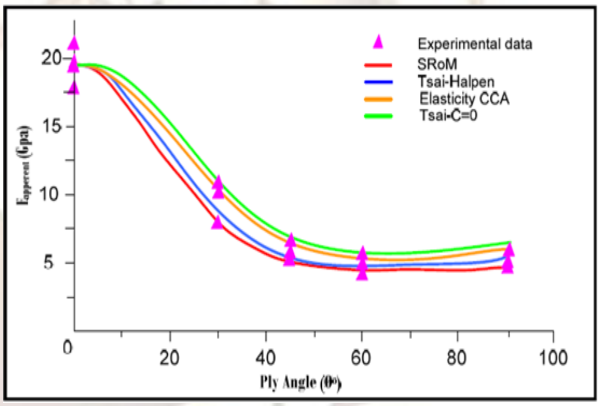

Fig 4 Models prediction of stiffness and experimental results of unidirectional lamina

The strength of the composite lamina and laminates were also determined experimentally and compared with five widely used failure theories. It was found that Tsai-Hill, Tsai-Wu and Hashin failure theories give best fit with the experimental results. Figure 5 compare the results of failure theories with experimental results.

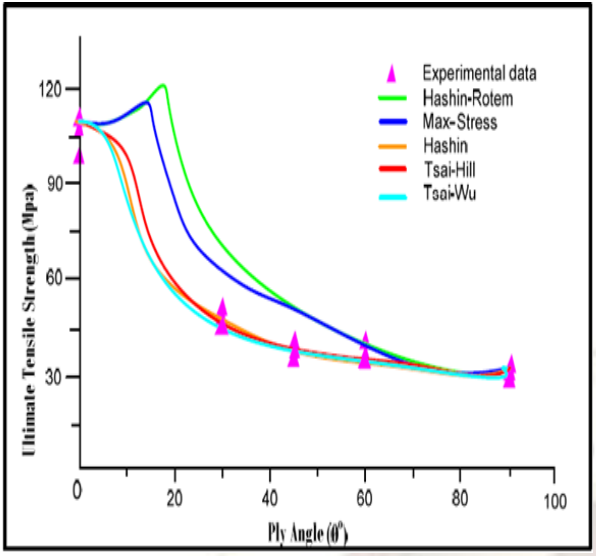

Fig 5. The comparison results of failure theories with experimental results

3. Conclusion:

In general, one observation of this exercise was that, even for the unidirectional lamina, predictions of the various theories differed from each other. The divergence observed may be attributed primarily to the following factors:

1. The different ways in which curing residual stresses are introduced in the predictions, especially in the case of first-ply-failure.
2. The concept of in-situ behavior of a lamina within the laminate which is still debated.
3. The different methods of modeling the progressive failure process and the definition of ultimate laminate failure.
4. The nonlinear behavior of matrix-dominated laminates, e.g., angle-ply laminates.

It is difficult to reach definitive conclusions on the applicability of the various theories based on comparison with the limited experimental data available. Hence in view of the multitude of failure theories, the divergence of their predictions and the lack of definitive general conclusions regarding their applicability, a practical approach is recommended as follows.

1. Select a classical representative theory from each category, i.e., non-interactive (maximum stress), fully interactive (Tsai-Wu), and partly interactive (Hashin-Rotem).
2. Compute and plot stress-strain relations of the laminate under representative mechanical and hygrothermal loading.
3. Use a newly proposed failure mode discrimination rule.
4. Select prediction according to degree of conservatism desired. For the most conservative approach, limit the state of stress (loading) to within the common domain of the selected failure envelopes.

The approach above is adequate for conservative structural design.All computations and plots can be performed by a newly developed computer program.

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