*Research Article*

# Effect of Stacking Sequence on The Mechanical Performance of Hybrid Fiber Reinforced Epoxy-Polyester Composites

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## *ABSTRACT*

*The main aim of this present investigation is to evaluate mechanical properties of different hybrid laminates prepared with different combinations of fiber and resin. The impregnation of laminates is done by epoxy and polyester resin as matrix material. Various structures under tensile strength were considered with different combinations glass, carbon fibers reinforced epoxy-polyester resin laminates. The current research work reveals the effect of stacking sequence on the mechanical behavior of symmetric laminated composites. They are composed ofthree layers alternated between +□/-□, +□/0° and +□/90° forming respectively balanced and angle ply laminates. Thus, it is important to study the performance of this composites in order to assess their failure mechanism. In this paper, analytical predictions were performed based in developing failure criteria for unidirectional fiber composites. The changes of stacking sequences have significant effect on the tensile properties and on the development of cracks likewise. The analysis reveals that the net effect is dependent on the anisotropy of the fiber. Under evaluation of the mechanical behavior of the combined matrix materials, the fibers may have a detrimental effect on strength.*

***Keywords:*** *Composite, Hybrid, Combined Matrix, Tensile, Failure.*

## 1.INTRODUCTION

Composite materials have been widely utilized in many industries, due to their high strength and stiffness to weight ratios. As the reinforcement was the strength source, it is preferable in certain applications to combine several fibers of various natures to constitute hybrid materials. Knowledge of the mechanical behavior of the composite material prevents its failure, improves its manufacturing processes and solves its life problems.

Hybrid composite materials not only represent a new field of fundamental research in which the creativity of the mechanic can be fully expressed to develop new materials, but they also allow, through their new and remarkable properties associated with their multi-functionality, the emergence innovative industrial applications in extremely varied fields. In terms of applications, hybrids are invading the field of transport. Their use has permitted to optimize the mechanical performance of vehicles and therefore reduce their fuel consumption. Consideration of the layer stacking sequence has a significant influence on the behavior and properties of hybrid laminates.

Theoretical and experimental research on the mechanics of composite materials have permitted to propose resistance criteria developed either by the approach of micromechanics [1,2], or by that of macromechanics [3,4]. In the first, the failure criteria are established by considering the mechanical properties of the constituents of the material and of the interfaces. Nalla Mohamed and Praveen Kumar [5] have varied the mixed fiber volume fraction (carbon-glass) of a composite structure in order to obtain a gain on the failure strength, a stiffness increase and a noticeable lightening for a reduced cost. A Numerical study (Finite Element Method) is developed for fiber reinforced composite tubes using Hashin's criteria and the initiations of intra-laminar failures are identified. On the other hand, experimental studies are carried by Pandya et al. [6] under both tensile and compressive in-plane quasi- static loading for two types of hybrid composites made by using satin weave carbon fabrics and plain weave E-glass fabrics with epoxy resin. Furthermore, Abedi et al. [7] have used finite element modeling to investigate the energy absorption mechanism in the hybrid composites.

The aim of this study is to predict the tensile strength of the hybrid fiber reinforced epoxy-polyester composites. The structural material is reinforced by [□/-□]2s, [□/0°]2s and [□/90°]2s, symmetrical laminates made up of E-glass or carbon fibers. A particular attention was given to the examination of the damage modes of each component layer will be also determined when a ply crack was formed.

## 2.THEORY

The theory of the composite plates is different from that of a traditional material because of existence of coupling between bending and extension. The process of identification of elastic constants of material is based by the development of an homogenization method based on the law of mixtures [8-11]:

$$E_1 = E_f V_f + E_m(1 - V_f) \tag{1}$$

The prediction of the elastic characteristics of composite materials is done starting from the knowledge of the properties of the basic components: Ef values modulates fibers and Em modulates matrix. $V_f$ is the voluminal fraction of fibers (Figure 1).

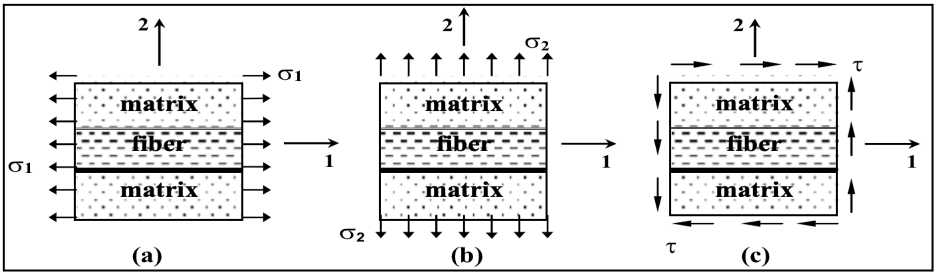

**Figure 1.** Various states of simple loading of a composite material: (a) longitudinal tensile, (b) transversal tensile, (c) longitudinal Shearing.

According to the Kirchhoff hypothesis for plates [8,12], the laminate is presumed to consist of perfectly bonded laminae. The bonds are presumed to be infinitesimally thin as well non-shear-deformable. Moreover, the displacements are continuous across lamina boundaries so that no lamina can slip relative to another. The Hooke law permit to calculate the membrane efforts in function of the extensional stiffnesses Aij and the total in-plane strains $\square^0$ of the laminate:

$$[N]_{x,y} = [A]\{\square^0\}_{x,y} \tag{2}$$

The prediction of limiting strengths is determinated by Tsai-Hill criterion. It depends of strain modes related to the distortion energy; and maximum longitudinal and transversal tensile stresses (X and Y) of the [0°] ply and the maximum shear stress (S) in 1-2 plane [13,14] :

$$\left(\frac{\sigma1}{X}\right)^{\sim} + \left(\frac{\sigma2}{Y}\right)^{\sim} - \frac{\sigma1\sigma2}{X^2} + \left(\frac{c12}{S}\right)^{\sim} \leq 1 \qquad (3)$$

There is therefore no rupture of the material as long as the stresses prevailing in the latter do not exceed the ultimate stresses.

The prediction of the different failure modes and damage zones of this least resistant ply is determined by the theory of maximum stress [9,14]:

$$\sigma_1 < X \quad , \quad \sigma_2 < Y \quad , \quad r_{12} < S \qquad (4)$$

If one of the inequalities is not verified, the limit state is reached, the failure then being attributed to the stress corresponding to this inequality.

## 2.RESULTS AND DISCUSSION

The considered composite materials are reinforced with 60% of unidirectional E-glass or carbon fibers. Reinforced resins are combinations of epoxy and polyester forming hybrid materials. Epoxy matrix layers are placed in the exterior and polyester matrix layers in the interior. The four layers constituting the laminates are alternated between +θ/-θ, +□/0° and +□/90°, symmetrically disposed about the middle surface (Figure 2).

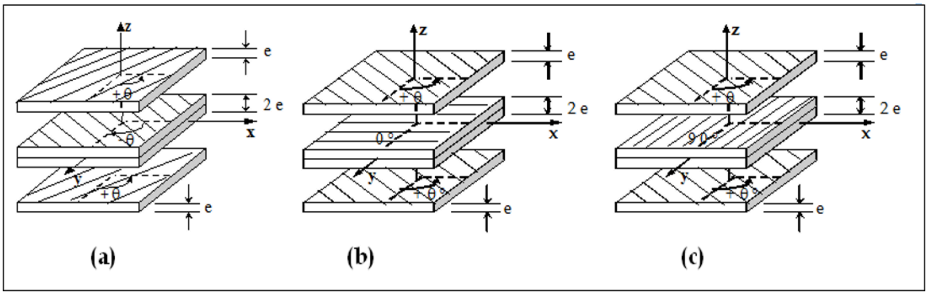

**Figure 2.** Definition of axis systems for symmetrical laminate: (a) [□/-□], (b) [□/0] and (c) [□/90]

Elastic constants of the basic components are illustrated in table 1. The ultimate mechanical properties of the considered composite plies are presented in table 2.

**Table 1.** Elastic constants of the basic components

| | E1 (Gpa) | E2 (Gpa) | G12 (Gpa) | □12 |
|---|---|---|---|---|
| E-Glass fiber | 74 | 74 | 29.9 | 0.25 |
| Carbon fiber | 230 | 15 | 50 | 0.3 |
| Epoxy resin | 4.5 | 4.5 | 1.6 | 0.4 |
| Polyster resin | 4.0 | 4.0 | 1.4 | 0.4 |

**Table 2.** Ultimate mechanical properties of the basic composite plies

| | X (Mpa) | Y (Mpa) | S (Mpa) |
|---|---|---|---|
| E-Glass/epoxy | 1500 | 35 | 60 |
| E-Glass/polyester | 1500 | 35 | 60 |
| Carbon/epoxy | 1920 | 42 | 60 |
| Carbon/polyester | 1920 | 42 | 60 |

The behavior of the hybrid fiber reinforced epoxy-polyester composites with [□/-□]2s stacking sequence under tensile loading is represented on the Figure 3. It is noticed that the ultimate strength of the carbon/epoxy-polyester material is greater than that of E-glass/epoxy-polyester and that it gradually decreases when the fiberorientation □ varies from 0° to 90°. It is the thermosetting resin which is responsible for this degradation. These are the exterior layers which failed first either by tensile failure of the fibers (Mode I) or by shearing of the matrix parallel to the fibers (Mode III) or by traction of the mixed matrix (Mode II). It should be noted that the reinforcement with carbon fibers causes a reduction in the failure modes.

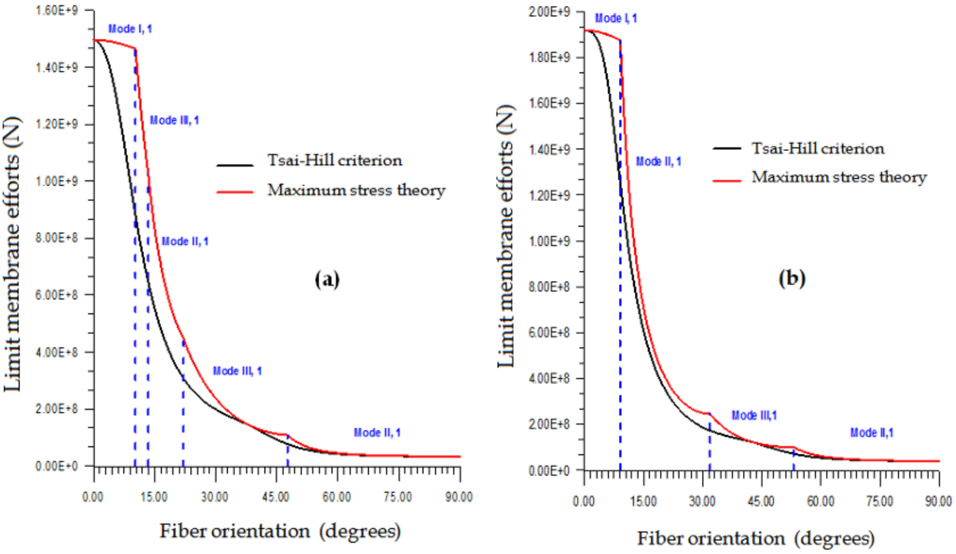

**Figure 3.** Variation of the limit tensile strengths of the [□/-□]2S composites reinforced with: (a) glass fibers and (b) carbon fibers

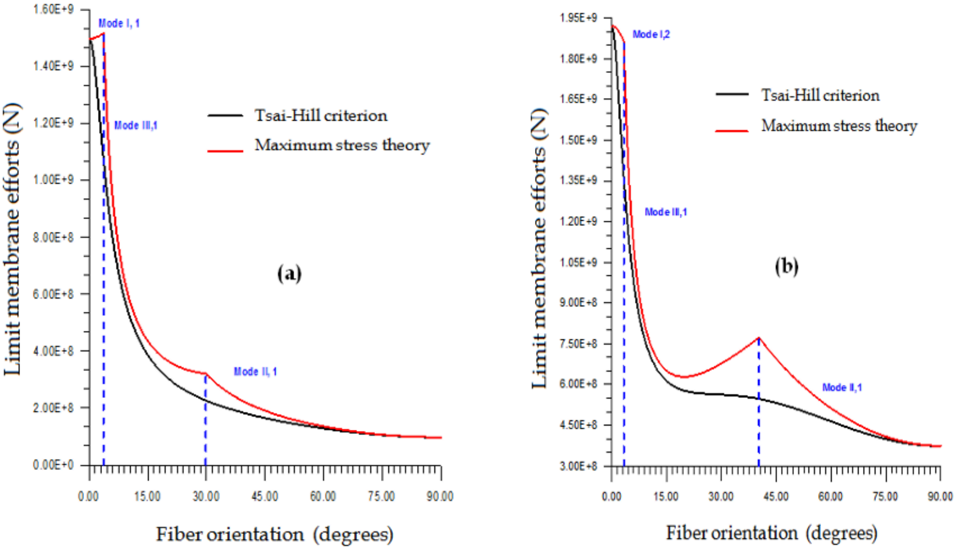

**Figure 4.** Variation of the limit tensile strengths of the [□/0]2S composites reinforced with: (a) glass fibers and (b) carbon fibers

Considering the [□/0]2s laminates in the figure 4, it was noticed that the hybrids become less anisotropic. These materials expose three zones of damage, the fiber tensile failure mode of which relates to the interior layer oriented at 0 °, and the other modes correspond to the exterior plies of □ orientation. The first zone is observed to be very small compared to that of balanced laminates, but the second widens when the reinforcement is provided by carbon fiber. It is the superior mechanical strength of the carbon fiber that causes the shear failure of the matrix along with the reinforcement. We also note that the resin has no influence on the resistance or the change in mechanical behavior of the material.

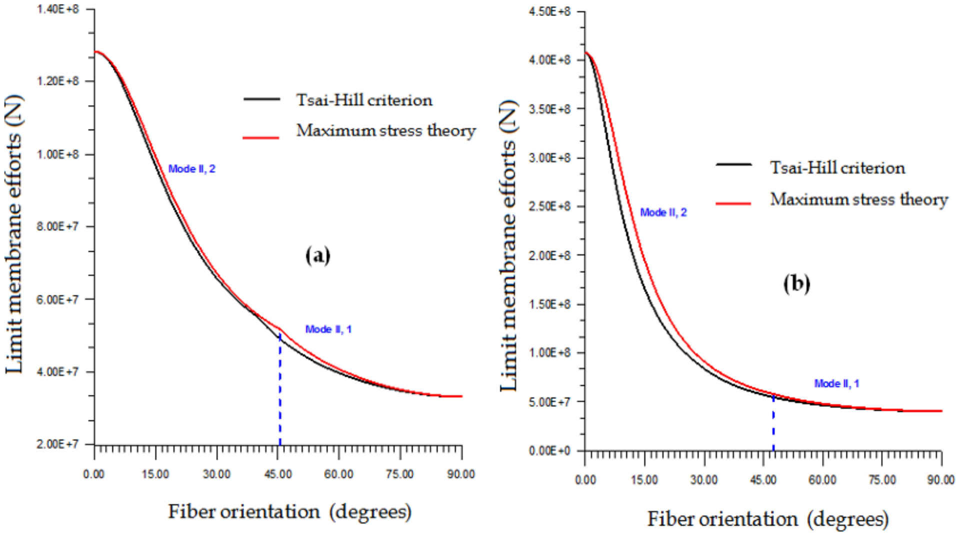

**Figure 5.** Variation of the limit tensile strengths of the [□/90]2S composites reinforced with: (a) glass fibers and (b) carbon fibers

In the [□/90]2S composite materials (Figure 5), there is only one failure mode by tensile of the polyester matrix constituting the interior layer of orientation 90 ° and when the orientation of the exterior plies vary from 0 ° to the vicinity of 45 °. Approaching the □= 90 °orientation, the failure will match the exterior plies with epoxy resin matrix. Reinforcement with E-glass fibers promotes rapid degradation of the strength of the hybrid composite material.

## 3.CONCLUSION

The study of hybrid composite materials with stacking sequence [+□/-□]2S, the mechanical strength of the laminates was not improved. On the other hand, it is noticed that the sequence [+□/0]2S presented a marked improvement in the resistance of the composite material and the profile of its mechanical behavior becomes more or less regular. Moreover, the consideration of laminated composites [□/90]2S shows an improvement in the profile of their mechanical behavior. Therefore, the presence of mixed matrices has no effect on the change in mechanical behavior. Combination of epoxy with polyester does not have a significant effect on the evaluation of the mechanical behavior of the material. Their effect only appears in the last stacking configuration but remains more or less weak. It is only noticed more considerably in the case of reinforcement of the E-glass fiber with the combination of the epoxy and polyester resins.

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