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Experimental investigation of notch effect and ply number on mechanical behavior of interply hybrid laminates (glass/carbon/epoxy)

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ABSTRACT

The great advantages of hybrid composite materials reside in the synergistic effect of their constituent materials and that make them very attractive for advanced applications. Nevertheless, the interactive effect of the intrinsic properties of each element further complicates understanding of their behavior. In this study, an experimental analysis of the mechanical behavior of interply hybrid laminates (glass/carbon/epoxy) and the estimation of the hybridization effect with respect to mono-reinforced laminates were carried out. It has been found that the incorporation of 25% carbon fibers in the glass/epoxy laminates contributes significantly to improving their tensile mechanical properties but they degrade as the number of glass plies increase. In addition, investigations were carried out on the sensitivity of these materials to geometric imperfections. To this end, the influence of a circular notch has been highlighted. From the results obtained, it was found that the greatest loss of properties is recorded for the hybrid materials; however, they remain the most resistant.

1. Introduction

High performance composite materials such as reinforced by carbon fibers are mainly used in high-tech fields. However, many drawbacks hinder their employment in many areas, such as, sudden failure, low damage tolerance, low residual strength as well as their high cost and limited production.

The resort to hybridization has allowed to overcome some limitations of these materials and to extend their applications in more diverse sectors, from where a significant improvement in their performance has been proved, justified by the synergistic effect of intrinsic properties of different constituents. In fact it consists by using at least two reinforcements having different properties (physical, mechanical … etc.) in the same matrix and it is distinguished by the layout fibers configuration (interply, intraply or intermingled).

It has been proven that the combination of glass fibers and carbon fibers have important considerations, because coupling of high specific strength and stiffness reinforcements to those having high elongation is very advantageous, allowing improvement in strain failure, as demonstrated by Manders et al. [1].

In fact, the incorporation of carbon fibers with GFRP (glass fiber reinforced polymer) is one of the techniques adopted in the automotive industry to reduce the weight without a significant increase of the cost. Also, carbon/glass hybrid polymer composite can be applied in the construction of wind turbine rotor blades [2].

A great interest has been given to the determination of mechanical response of these materials under various loading, whence experimental, numerical and analytical investigations have been retained in many references [3–18]. It was reported that several factors can affect their mechanical performance, such us ratio of reinforcement, stacking sequences, orientation of plies and imposed loading.

Different glass/carbon ratios and stacking sequences were investigated analytically and experimentally against the tensile, compressive and flexural responses of hybrid composite laminates made of epoxy matrix [3]. The main observations are that the hybridization provides the best flexural properties when the carbon layers are at the exterior, while the highest compressive strength is achieved by an alternating carbon/glass lay-up.

Another experimental study was carried out on mechanical behavior of hybrid composite based on carbon fabrics and E-glass fabrics with epoxy resin. It was found that the tensile properties can be improved by placing glass fabric layers in the exterior and carbon fabric layers in the interior [4] which is in good accordance with the results obtained by Syed et al. [5].

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Song [6] have demonstrated that the stacking sequence is the main factor that affect the performance of hybrid materials. He investigated the pairing effect of two types of hybrid composites (carbon/aramid and carbon/glass). It was shown that in spite of the different properties of the reinforcements no increased effect caused by their coupling with carbon and only the arrangement of layers governs the tensile properties. Muñoz et al. [7] were found that the premature fracture of the carbon fibers hinder the full employment of glass fibers to the composite strength, on the other hand, they contribute to enhance the fracture strain and to increase the energy dissipated during fracture.

Also, it was be noticed that the stacking sequence is the important parameter which affect strongly the flexural properties of the interply hybrid composite and all the stacking sequences showed a positive hybridization effect [8]. In fact, the hybridization effect can be evaluated by the positive or negative deviation of the experimental mechanical properties compared to those predicted by the classic rule of mixture (ROM) approach, and this difference has been found by several researchers [9–11].

Dong and Davies [11] was reported that a positive or negative hybrid effect occurs is dependent on the fibre volume fractions of the carbon/epoxy and glass/epoxy. It was concluded in a recent study, that typical rule of mixture is not compatible to be applied in Glass/Carbon and Aramid/Carbon composites studied by Song [6], because by varying stacking sequence, the mechanical properties were different from the same fibre fraction.

Another parameter that can effectively affect the performance of hybrid composites is the presence of geometric discontinuities such as notches which are inevitable for some applications to facilitate the assembly operation. The residual properties in terms of strength and stiffness were evaluated experimentally by many researchers [19–23]. As retained results, the effect of geometrical discontinuity on the polymer composites is depend of the type of reinforcement, sequence staking and particularly of the environmental conditioning service which eventually decrease the overall performance of composites [2,24].

Our work aims to analyze the mechanical behavior and to estimate the properties at failure of inter-ply hybrid composite subjected to uniaxial tensile loading. Carbon fabric and glass fabric were used as reinforcement within epoxy matrix to produce laminates panels through hand lay-up process. The effect of central circular notch as well as the number of plies of glass fabrics has also investigated. It's important to underscore that the results of hybridization had compared with those of the full carbon and glass configurations. Finally, analyses of final fracture characteristics at macroscopic and microscopic levels were performed in order to understand the effects of holes and the contribution of carbon fibres into glass laminates on the strength of our materials studied.

2. Materials and manufacturing process

The materials used in this study are composite laminates based on an epoxy matrix reinforced by two types of reinforcements (carbon and glass). These constituents are intended for aeronautical applications, they are delivered by the Boeing company and their high performances justify the reason of their choice in this work.

The carbon and glass reinforcements are plain fabric and woven satin fabric respectively (Figs. 1 and 2), their areal weight are 193 g/m^2 and 106 g/m^2. SEM micrographs of the type of warp and weft yarns interlacing are illustrated in Figs. 3 and 4. The matrix is Epocast 50-A1/946 that is referred to as BMS 8–201 and it is obtained by mixed with a hardener at a rate of 15%, according to the indications of the supplier.

Three systems C/E (carbon/epoxy), G/E (glass/epoxy) and C/G/E (glass/carbon/epoxy) were manufactured by hand lay-up process (Figs. 5 and 6). It consists of superimposing the plies, by depositing the reinforcing fabrics individually in an open mold and impregnating them with resin. A vacuum pump is used to remove the air bubbles and to extract the excess resin after careful covering of the stack and finally the curing takes place in ambient air. This process allows to obtain plates with a reduced porosity rate and controlled amount of resin.

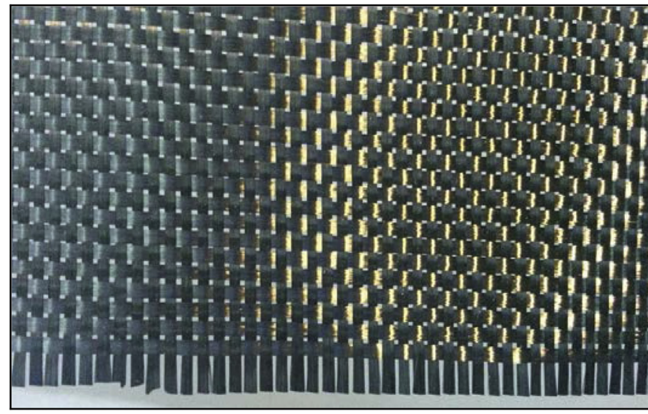

Fig. 1. Woven carbon fabric.

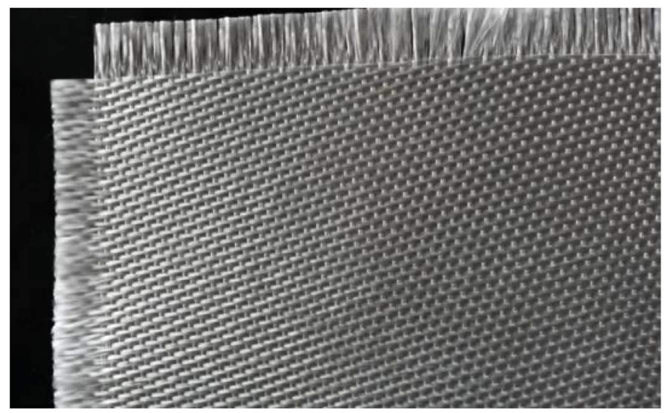

Fig. 2. Woven glass fabric.

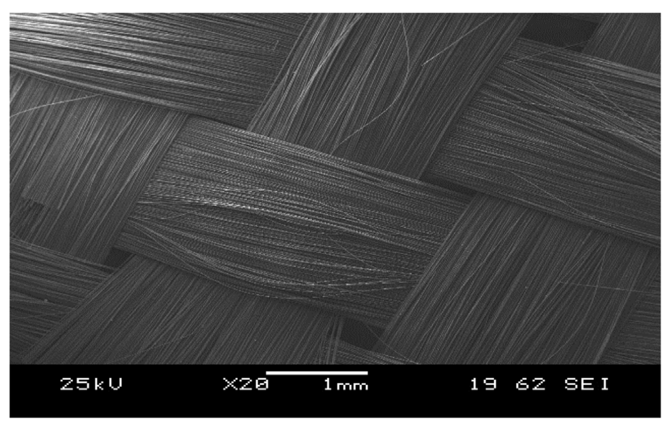

Fig. 3. SEM micrograph of Carbon fabric.

The laminates are oriented in the same direction (0°), which are parallel to the loading axis. An illustrative scheme of the stacking sequence of hybrid laminates composed of eight plies is shown in Fig. 7. The thickness and fibers volume fraction of the laminates studied are summarized in Table 1.

The dimensions of manufactured plates are 300mmx300 mm; they are cut out by a diamond disc under jet of water. Drying of the test specimens is important before mechanical test in order to eliminate any traces of moisture which can consequently affect the properties of our materials.