HYBRID REINFORCING FABRICS FOR ADVANCED POLYMERIC COMPOSITES

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Textile structural composites identify a class of advanced materials utilizing fiber preforms produced by textile forming techniques, for structural applications. One of the major textile forming techniques for composites reinforcement is weaving, leading to woven products which exhibit good dimensional stability in the warp and weft directions. Woven fabrics provide the unique capability that the microstructure of fibre preforms can be designed to meet the needs of the performance of composite structures, in a single layer. In this paper we explore ways of designing woven hybrid materials emphasizing the choice of components and their shape allowing the creation of new “materials” with specific property profiles. Three types of fibres (E-glass, S-glass and Basalt) have been analyzed in woven fabrics embedded in an epoxy matrix with different elastic moduli to obtain the appropriate stiffness properties in the required directions.

Keywords: hybrid composite, woven fabric, woven composites.

INTRODUCTION

Composite materials have been successfully used since the 1960s for structural applications, because of their structural advantages of high specific strength, high specific stiffness and tailored properties with controlled anisotropy. In fibre reinforced polymeric (FRP) composites, fibres with high strength and high stiffness are embedded in and bonded together by the low modulus continuous polymeric matrix [1]. The layers may be composed of short fibres and long fibres embedded in a matrix under different architectures, exhibiting isotropic or anisotropic behaviour, Figure 1 [1, 2, 3].

Figure 1. Variation of FRP mechanical properties with loading direction
Textiles are fibrous materials which are obtained by assembling the filaments into yarns and fibrous plies, and then into textiles. They are materials with a hierarchical nature with three hierarchical levels and the corresponding associated scales: Textiles are structured materials and their diversity comes from special technologies resulting in a large variety of available structures that are widely used as reinforcements for composites. The properties of a fabric are determined by the properties of fibres transformed by the textile structure [1].

In contrast to composites reinforced with unidirectional fibres the geometry and structure of textile composites is much more complex [5, 6, 7]. Mechanical properties of textile polymeric composites are influenced by several parameters and phenomena e.g. fiber architecture or internal geometry of fabric, the linear density, number of counts, size of gap and plastic flow of polymeric resin. Each of these can influence the structural behaviour, but can only be modelled on its specific length scale. Weaving is one of the major textile forming techniques for composites reinforcement. A woven fabric is made by interlacing warp and fills yarns and it is characterized by linear densities of warp and fill yarns, the weave pattern, the number of warp yarns and fill yarns per unit width or unit length, warp and fill yarn crimp, and surface density.

ELASTIC ANALYSIS OF A PLAIN WEAVE FABRIC LAMINA

Hybrid Reinforcement

The in-plane mechanical properties of fibrous composites may be easier controlled and tailored through the number of counts, the gap size between warp fibres and fill fibres as well as and crimps of the pattern. Nowadays these characteristics may be diversified using different fibre materials in one or two directions, leading to hybrid textile reinforcements. The advantage of hybrids is that the superior properties of each fibre material can be utilized to optimize the composite product. Depending on the application requirements the hybrid textile reinforcements can be optimized using two different isotropic materials in the orthogonal directions or combinations of different anisotropic materials [2].

Lamina Configuration

Orthogonal fabrics exhibit good dimensional stability in the warp and fill directions. Woven fabrics, Figure 2, offer the highest yarn packing density in relation to fabric thickness. The pure and hybrid woven fabrics used in composites are mostly in the form of plain, basket, twill and satin weaves.
Plain weave (orthogonal fabrics) is the simplest fundamental weave with repeat size \( N=2 \) and step \( s=1 \), and consists of two sets of interlaced yarns, Figure 2. The lengthwise set is called warp, and the crosswise set is termed fill (weft). Any weave repeats on certain number of warp and fill yarns is defined by geometrical quantities \( n_w \) and \( n_f \) respectively. The repeat is a complete representative unit cell of weave, Figure 3 [1, 5, 6, 7].

![Figure 3. The unit cell of plain weave fabric](image)

In this paper, the authors analyze a hybrid 2D orthogonal plain weave lamina i.e. the warp and fill fibers materials are different. Combinations of three isotropic fibres (E-glass, S-glass and Basalt) in a plane wave embedded in an epoxy resin are studied. The main properties of the fibres and matrix utilized for hybrid textiles composite lamina are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>( E ) (GPa)</th>
<th>( G ) (GPa)</th>
<th>( \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix-epoxy</td>
<td>3.4</td>
<td>1.08…1.43</td>
<td>0.38…0.40</td>
</tr>
<tr>
<td>Basalt fiber</td>
<td>89</td>
<td>37.08</td>
<td>0.20</td>
</tr>
<tr>
<td>Glass E fiber</td>
<td>72.4</td>
<td>29.67</td>
<td>0.22</td>
</tr>
<tr>
<td>Glass S fiber</td>
<td>85.5</td>
<td>35.0</td>
<td>0.22</td>
</tr>
</tbody>
</table>

The fabric was assumed to be a closely woven plain weave with an overall fiber volume fraction equal to 0.39. The geometrical characteristics of composite lamina are given in Table 2.

<table>
<thead>
<tr>
<th>( h_0 )</th>
<th>( u_w / u_t )</th>
<th>( a_w / a_t )</th>
<th>( g_w / g_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.68 / 0.89</td>
<td>1.44/1.12</td>
<td>0.12/0.6</td>
</tr>
</tbody>
</table>

where

- \( h_0 \) represents fabric thickness and lamina thickness,
- \( a_{w, f} \) represent dimensions of warp and fill yarn in the unit cell,
- \( g_{w, f} \) represent the gap between two adjacent yarns,
- \( u_{w, f} \) represent the undulation of fiber in warp and fill directions.
The number of counts \( n_w \) of warp has been considered variable, from 3 to 7, while the number of fill counts \( n_f \) has been kept constant and equal to 3 [6, 7].

The objectives consisted in analyzing the influence of different types of isotropic fibres on the lamina stiffness with respect to various parameters such as matrix stiffness, as well as the number of counts in warp and fill directions.

**Case Studies**

The composite lamina with an epoxy matrix has been successively reinforced with three fibre combinations as following:

- **Case 1**: warp (S-glass) and fill (E-glass);
- **Case 2**: warp (Basalt) and fill (E-glass);
- **Case 3**: warp (Basalt) and fill (S-glass).

Many analytical models exist for the calculation of average stiffness matrices of textile laminates, but almost all of them do not consider the effect of crimp [8]. In this paper the utilized model transforms the unit cell in two elementary sub-lamina that take into account the undulation on both directions. The main results are illustrated in Figures 4-8.

In Figures 4 and 5 the influence of the matrix modulus and the fibres material on the stiffness along warp direction is presented. Two types of plain wave textiles have been analyzed: one unbalanced fabric with the warp number of counts equal to 7 and a constant fill number of counts equal to 3, Figure 4; the second type of reinforcement is a balanced fabric with 3 counts in both directions.

![Figure 4. Variation of \( E_y \) for unbalanced fabric](image)

![Figure 5. Variation of \( E_y \) for balanced fabric](image)
The Figures 6, 7 and 8 illustrate the influence of the warp number of counts on the stiffness in the principal directions. The results refer to the same value of the matrix elastic modulus, $E_m=4$ GPa.

**Figure 6.** Fabric with warp S-glass and fill E-glass

**Figure 7.** Fabric with warp Basalt and fill E-glass

**Figure 8.** Fabric with warp Basalt and fill S-glass
CONCLUSIONS

The textile FRP composites are valuable composite products with significant advantages in different areas of utilization.

The nature of material for reinforcing fibres has a substantial effect on the stiffness properties of textile composites.

Depending on the product requirements the stiffness can be modified in the main geometric directions by the pattern of the fabric and/or the types of fiber material.

In addition, a certain modification in stiffness characteristic may be obtained through variation of the matrix material and its elastic moduli.

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REFERENCES


