THEORETICAL ANALYSIS AND MODELING OF TEXTILE REINFORCED COMPOSITES

BY

ADRIAN BUHU, LILIANA BUHU and CRISTINA RACU

Abstract. Composites material reinforced with woven fabrics are becoming increasingly popular for various structural applications in industrial sectors. The mechanical properties of textile reinforced composites can be predicted with knowledge of the fibres properties, matrix properties and fabric structures.

Key words: composites, woven fabrics, reinforced.

1. Introduction

Composite materials reinforced with textile (woven, knitted and braided fabrics) are very popular because it’s used for various applications in automotive, aerospace and other industries. Typical processing techniques include variations of layers manufacturing and contact lamination technologies, resin transfer moulding, vacuum/pressure bag moulding and autoclaving of fabric based thermosetting preregs and compression/perform moulding of thermoplastic and thermosetting composites [1].

The purpose of the paper is to discuss the developments in the modeling and characterization of fabric reinforcement’s composite materials and structural components. This is necessary because the textile preforming is the method of placing reinforcing fibers in a desired arrangement prior to formation of a composite structure. Starting with linear assemblies of fibers in continuous or discrete form, this fibers can be organized into two-dimensional (2-D) and three-dimensional (3-D) structures by means of textile processes such as interlacing, interlooping or weaving [2]. Properly selecting the geometry and the method of placement or geometric arrangement of the fibers or fabric can tailor the resulting structural performance of the composite. The shape and geometry of the structural components implies an application of the approaches developed
for thin-walled plates and shells. The particular geometry and material structure of the shell reinforced with carbon fabric pattern have been used as an example of the application of the general approach.

2. Fabric Reinforcement Layers

The textile preforming plays an important role in composite technology providing glass, aramid, carbon and hybrid fabrics that are used as reinforcing materials. A fabric is defined as an integrated fibrous structure produced by fiber entanglement of yarn interlacing, interloping, intertwining or multiaxial placement. In this paper research is concentrated on yarn to fabric structures which are presented in Table 1.

<table>
<thead>
<tr>
<th>Basic direction of yarn introduction</th>
<th>Basic fabric formation technique</th>
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<tbody>
<tr>
<td>Weaving Two (0°/90°, warp and weft)</td>
<td>Interlacing (by selective insertion of 90° yarns into 0° yarn system)</td>
</tr>
<tr>
<td>Braiding One (machine direction)</td>
<td>Intertwining (position displacement)</td>
</tr>
<tr>
<td>Knitting One (0° or 90°, warp or weft)</td>
<td>Interlooping (by drawing loops of yarns over previous loops)</td>
</tr>
<tr>
<td>Nonwoven Three or more (orthogonal)</td>
<td>Mutual fiber placement</td>
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</table>

While the weaving, braiding and knitting can produce planar or 3-D structures, the nonwoven fabrics are mainly for 3-D systems. Yarn orientation distribution and the number of yarn diameters in the thickness direction distinguish 2-D and 3-D fabrics. The key criteria for selecting the fiber architecture for structural composites are: the capability for in-plane multiaxial reinforcement, and the capability for formed shape and/or net-shape manufacturing. Depending on these processing and end-use requirements, some or all of these features are required.

This paper is studying the composites with textile woven reinforcements. The main advantages of woven composites are their cost efficiency and high processability, particularly in layer manufacturing of large scale structures. At the same time, fibers bending in the process of fabric weaving results in substantial reduction of material strength and stiffness. In Fig. 1 is presented a plain woven structure. This structure is shown the warp (lengthwise) and weft (crosswise) yarns forming the fabric make the angle $\alpha \geq 0$ with the plane of the fabric layer.
To demonstrate how this angle influences material stiffness, consider tension in the warp direction and modulus of elasticity can be expressed as [1]:

\[ E_a \cdot A_a = E_{we} \cdot A_{we} + E_{wa} \cdot A_{wa} \]  

where: \( E_a, E_{we}, E_{wa} \) is apparent modulus of elasticity for composite material, respectively for weft (\( E_{we} \)) and warp (\( E_{wa} \)) yarns; \( A_a, A_{we}, A_{wa} \) – apparent cross-sectional area for composite material, respectively the areas of weft and warp yarns in cross section.

\[ A_{we} = \frac{h \cdot (2 \cdot l_1 + l_2)}{2}, A_{wa} = \frac{h \cdot (4 \cdot l_1 + l_2)}{4} \]

where: \( h \) is the thickness of warp or weft yarn; \( l_1, l_2 \) – length of weft yarn in elementary cell.

Substitution into equation (1) yielded:

\[ E_a = \frac{1}{2} \left[ \frac{E_{we} \cdot (4 \cdot l_1 + l_2)}{4 \cdot (2 \cdot l_1 + l_2)} \right] \]

Composite materials has an anisotropic character and because the weft yarns are orthogonal to the stress direction it can take \( E_{we} = E_2 \), where \( E_2 \) is the transverse modulus for a unidirectional composite. According with Hooke’s law the strain of composite can be decomposed into two parts corresponding to \( l_1 \) and \( l_2 \):

\[ \frac{2 \cdot l_1 + l_2}{E_{wa}} = \frac{2 \cdot l_1}{E_1} + \frac{l_2}{E_a} \]

where: \( E_1 \) is the longitudinal modulus of a unidirectional composite.
$E_\alpha$ can be determined with the aid of an equation demonstrated by Vasiliev [3], for the unidirectional anisotropic layer:

\[
\frac{1}{E_\alpha} = \cos^4 \alpha \cdot \frac{E_1}{E_2} + \sin^4 \alpha \cdot \left(1 - \frac{2 \cdot \nu_{21}}{G_{12}} \right) \cdot \sin^2 \alpha \cdot \cos^2 \alpha
\]

where: $\nu_{21}$ is the Poisson ratio; $G_{12}$ shear modulus.

The replacement of $1/E_\alpha$ in eq. (4) with its expression from eq. (5) and subsequent substitution of the result into eq. (3) yields:

\[
E_\alpha = \frac{E_2}{2} + \frac{E_1 \left(4 \cdot l_z + l_2 \right)}{4 \cdot \left[2 \cdot l_1 + l_z \cdot \left(\cos^4 \alpha + \frac{E_1}{E_2} \cdot \sin^4 \alpha + \frac{E_1}{G_{12}} \cdot \sin^2 \alpha \cdot \cos^2 \alpha \right)\right]}
\]

Depending on the structure of woven fabric, if the warp and weft yarns have same density and fineness it can consider that $l_1 = l_2$ and the relation (6) became:

\[
E_\alpha = \frac{E_2}{2} + \frac{5 \cdot E_1}{4 \cdot \left[2 \cdot l_1 + \left(\cos^4 \alpha + \frac{E_1}{E_2} \cdot \sin^4 \alpha + \frac{E_1}{G_{12}} \cdot 2 \cdot \nu_{21} \cdot \sin^2 \alpha \cdot \cos^2 \alpha \right)\right]}
\]

For a composite reinforced with the hemp fabric with the parameters: longitudinal modulus $E_1 = 44.5$ GPa, transverse modulus $E_2 = 5$ GPa, shear modulus $G_{12} = 6$ GPa and Poisson’s ratio $\nu_{21} = 0.35$, the modulus of elasticity $E_\alpha$ depends on the angle $\alpha$. The modulus values for different values of angle $\alpha$ are presented in Table 2.

<table>
<thead>
<tr>
<th>Elasticity Modulus $E_\alpha$ Dependency of Angle $\alpha$</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°</td>
</tr>
<tr>
<td>Elasticity modulus $E_\alpha$ (GPa)</td>
<td>21.4</td>
</tr>
</tbody>
</table>

For different values of angle $\alpha$ the modulus of a woven structure decreases with increase of it. The evolution of modulus influence the variation of stress–strain curves for elastic domain like Fig. 2.
Stiffness and strength of fabric composites depend not only by the yarns and matrix properties, but on material structural parameters like: warp and weft density, yarn strength and pattern. The composite material presents a low strength for the angles greater then 45º, so it is recommend using structures with low weft density. In this case is necessary to use weaves with a smaller number of weft yarns and great number of thick warp yarns. Such weave is called unidirectional.

3. Conclusions

This paper has presented the development in characterization of fabric reinforced composite materials. The relationship between fabric structure and elastic modulus of composite material is presented.

Woven fabrics which can be used like reinforcements for unidirectional composites are made by a great number of warp yarns and a small number of weft yarns.

The composite materials with unidirectional reinforcement weave have high stiffness and strength in one direction.

The weaves fabricated like planar structures can be shaped on shallow surface’s using material’s high stretching ability.

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Materialele compozite cu inserții din țesături sunt foarte utilizate pentru diferite aplicații industriale. Proprietățile mecanice ale compozitelor cu inserții textile pot fi prevăzute prin cunoașterea proprietăților fibrelor, ale matricei polimerice și ale structurii țesăturii.