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Review paper

POLYMER COMPOSITE BASED OF TEXTILES IN VARIOUS GEOMETRY

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Abstract

The development of textile composite materials and their design and manufacturing technologies is one of the most important advances in the materials engineering. Textile reinforced composites proved to be competitive materials due to certain advantages, in addition to their strength (given by the fiber/yarn structure) and unity and ability to transmit strains (ensured by the polymeric matrix). Wide choice of matrices and fibers give good opportunities to choose an appropriate combination for the given application. Since the composite material properties are anisotropic and inhomogeneous in nature, parameters that are controlling mechanical properties depend of the fiber reinforcement, generally of the fiber architecture, fiber properties, etc. In this paper a types of textile structure used as reinforcement in composite industry is presented. The main three fibers used in textile composite: glass, aramids and carbon are discussed. These fibers are usually used to weave 3D orthogonal woven composites' preforms.

Keywords: *textile composite, textile structures, fibers, 3D fabrics.*

Introduction

Composite materials, herein defined as the combination of two or more interfacial bonded micro constituents that differ in form and chemical composition and which are insoluble in each other. However, many composite materials are composed of only two phases: one termed as matrix, which is continuous and surrounds the other phase, often termed as dispersed phase. The dispersed phase also known as reinforcement is usually strong and hard than the continuous phase. The matrix can be polymeric, metallic or ceramic. Reinforcing elements can be either particulate or fibrous. Fibers are

the load bearing elements in a composite and occupy a considerable volume fraction in a composite. The matrix fixes them and keeps them at desired position and direction. It also facilitates load transfer between them and protects them from adverse environment and mechanical abrasion [1, 2].
Composites with reinforcing textile fibers are called textile composites. If they are designed for primary and secondary load-bearing applications, they are defined as textile structural composites [3]. Textile reinforced composites proved to be competitive materials due to certain advantages, in addition to their strength (given by the fiber/yarn structure) and unity and ability to transmit strains (ensured by the polymeric matrix).
Textile composites are being widely used in advanced structures in many industrial applications as storage and transport structures (tanks, pipes, hoses, etc.) [4], geotechnical, aerospace, automotive and marine industries. One application of great interest nowadays is the energy production management, especially when it comes to wind energy (wind mills) [5]. Also, high amounts of textile reinforced composites is used in the production of sporting goods and protective equipment (helmets, etc.). An interesting application is in civil buildings, as walls reinforcement [6]. This is because they possess outstanding physical, thermal and favorable mechanical properties, particularly light weight, high stiffness and strength, good fatigue resistance, excellent corrosion resistance and dimensional stability [7] and attractive reinforcing materials with low production cost and easy handing [8]**.**
Characterization of textile composites becomes very important to structural design. Wide choice of matrices and fibers give good opportunities to choose an appropriate combination for the given application. However, since the composite material properties are anisotropic and inhomogeneous in nature, parameters controlling mechanical properties are numerous, such as fiber architecture, fiber properties, matrix properties, etc.[9]**.**

Classifications of textile preforms

Textile preforms can be classified according to different criteria, such as the macro, method of production of the textiles, and the resulting structural micro geometry. The micro geometry should include directions of reinforcement, linearity of reinforcement in each direction, continuity of reinforcement, fiber packing density, fiber bundle size in each direction etc. [10]
Depending on their structure, Scardino [11] listed the hierarchy of the fiber assemblies into four levels, fibers, yarns, 2D fabrics, and 3D fabrics, as shown in Table 1. The textile component may be represented by short fibers, filaments or yarns, fabrics or complex structures, continuous or not, with

controlled or uncontrolled orientation.
Considering the significant dimension of the textile material structure and the methods of manufacture, including the fabric structure, yarn dimensions, and directions within the preform Fukuta and al. [12], define structures as: unidimensional (non-axial – roving yarns), bidimensional (monoaxial – chopped strand mats; non-axial – sheets; biaxial – plain weave; triaxial – triaxial weave; multiaxial) and tridimensional (linear element – 3D solid braiding, multiple weave, triaxial and multiaxial 3D weave; plane element – laminates, beams, honeycombs).

Table 1. Various level of fiber structure for composite

Level	*Reinforcement system*	*Textile construction*	*Fiber length*	*Fiber orientation*	*Fiber entanglement*
I	*Discrete*	*Chopped fiber*	*Discontinuou s*	*Uncontroll ed*	*None*
II	*Linear*	*Filament yarn*	*Continuous*	*Linear*	*None*
III	*Laminar*	*Simple fabric*	*Continuous*	*Planar*	*Planar*
IV	*Integrated*	*Advanced fabric*	*Continuous*	*3-D*	*3-D*

Contrary to Fukuta's classification and in accordance with most researchers in the composite field, 3D textile fabrics arc defined as fully integrated structures, having multi-axial in-plane and out-of-plane fiber orientations [10, 13]. Ko [10] excludes two dimensional (2D) textile fabrics sewed together after formation of the fabric from these integrated 3D textiles, which are all manufactured with an inherent through-the-thickness yarn component. 2D fabrics are defined as flat textile fabrics with most of the fibers oriented in the plane of the fabric.
When the classification of 3D woven fabrics are examined, it is observed that there are several classifications based on the shedding mechanisms, weaving process, geometries and configurations, interlacements and fiber axis according to the different researches [14, 15, 16].
Khokar [14, 15] reported on a type of 3D woven fabrics that require shedding in yarns in the fabric length direction and in the through-the-thickness direction, which permits the weft yarns to be inserted in two directions into the fabric. Based on that, he classified the woven fabrics, in six categories:

- interlaced 2D fabric,
- interlaced 3D fabric,
- 2.5D fabric,
- non interlaced 3D fabric,
- fully interlaced 3D fabric and
- non-woven, non-interlaced 3D fabric.

The key criterion for 2D and 3D woven fabrics according to this classification is shedding. Solden and Hill [17] classified the woven fabrics by the weaving process, which comprises the warp binder, warp interlinked, in-plane interlacing yarns, and stuffing warp yarns to produce an integrated structure.

Regardless of the types of machines used, it is fair to say that the weaving technology is capable of constructing 3D fabrics with many different geometrical shapes. Chen [18] studied the configurations and geometries of the 3D woven fabrics and classified 3D woven fabrics into four different categories, that is, solid, hollow, shell, and nodal.

In terms of technology, all specific processes from textile industries may be used to produce complex structures, but, due to their characteristics and the material geometry that results, they lead to different behavior and recommend materials for various applications. The main production processes employed in textile reinforcements are weaving, braiding, knitting and non-woven production. Other processes, such as filament winding and poltrusion, which process filaments, are also applied. The selection of a specific technological process takes into account its architectural capabilities, the material characteristics and behavior (dimensional stability, mechanic strength, drapability and formability, etc.), as well as its suitability for the composite processing and application. Table 2 provides a comparative account of different preforming techniques with respect to yarn direction and fabric formation principles [19].

Table 2. A comparison among different production techniques of textile material

Parameter	*Direction of yarn introduction*	*Fabric formation principle*
Weaving	*Two (0°/90°) (warp and weft)*	*Interlacing*
Knitting	*One (0°/90°) (warp or weft)*	*Interloping*
Braiding	*One (machine direction)*	*Intertwining (position displacement)*
Nonwoven	*Three or more (orthogonal)*	*Mutual fiber placement*

Fibers used for complex textile structures

Fiber reinforcement became dominant in many engineering applications due to the possibilities of designing various properties of composite materials by changing the arrangements of different fibers. According to Carlson (20), not all types of fibers can be used as reinforcement of textile composites. Fibers to be utilized in composites should have specific properties, such as high modulus of elasticity, high ultimate strength, uniform cross section, low variation of properties between individual fibers, and the ability to withstand fabrication without significant property loss. Textile reinforcements are using high performance fibers such as glass, carbon/graphite, aromatic polyamides (aramides – Kevlar), polyesters (HM/HT PES), ceramic fibers, boron and silicon carbide fibers, etc. They have superior mechanical characteristics, as presented in Table 3, so that can meet the specific demands of advanced composite applications. Each fiber has its own advantages and disadvantages.

Table 3. Main characteristics of fibers used in textile reinforcements

Fiber	*Relative density (g/cm^3)*	*Young`s modulus (GPa)*	*Tensile strength (GPa)*
Carbon	*2.0*	*400*	*2.0-2.5*
E-glass	*2.5*	*70*	*1.5-2.0*
S-glass	*2.6*	*84*	*4.6*
Kevlar 29	*1.44*	*60*	*2.7*
Kevlar 49	*1.45*	*60*	*2.7*

Glass fibers, are the most common high performance fibers used to reinforce composite materials. They are characterized by mid-range strength, resistance to chemical agents, stability and inertness, low elongation, low weight and processability, high bending rigidity and brittleness [21]. There are more types of glass fibers depending on their chemical composition: E-glass, with good strength, high electrical resistivity, minimal moisture absorption rate, and effective mechanical properties per cost, is the most widely used fiber component in composite materials; S-glass, with high tensile strength modulus and elongation than the E-glass, used mainly in military applications; and C-glass, characterized by chemical stability and corrosion resistance.

Carbon fiber, the most expensive of the composite reinforcement materials, contains the best properties of the materials alternatives and thus, commands high prices. Carbon has some very beneficial properties to the overall structure that makes it unique, such as it's conductive nature, has high fatigue resistance, low impact resistance, a low coefficient of thermal expansion, a range of strengths, and also, low density [22]. Carbon fiber is used for structural aircraft applications, such as floor beams, stabilizers, flight controls, and primary fuselage and wing structure.

Aramid fiber, provide extremely high tensile strength, high abrasion resistance, excellent fatigue and creep resistance. Aramid fibers are stiff, not brittle and highly anisotropic. This fiber has very high strength with excellent temperature resistance with 60 % strength and modulus retention at 260ºC. Aramid fiber is resistant to many solvents and has low water absorbency, but is sensitive to UV light and not easy to dye [23].

Conclusion

Textiles are considered to be among the most effective reinforcements for composites and the successful use of fabrics, based on carbon, glass or aramid fibers, enabled the increase of their use in many industrial applications. These fibers are usually used to weave 3D orthogonal woven composites' preforms. Textile composite materials have innovative features, due to the complex geometry of the reinforcements.
Textile composites are being widely used in advanced structures in many industrial applications, because they possess outstanding physical, thermal and favorable mechanical properties, particularly light weight, high stiffness and strength, good fatigue resistance, excellent corrosion resistance and dimensional stability and attractive reinforcing materials with low production cost and easy handing. A better understanding of the mechanism of fibers reinforcement in composite materials enables the design and production of new high performance textile-based composites for a wide range of applications.

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POLIMERNI KOMPOZITI NA BAZI TEKSTILA RAZLIČITE GEOMETRIJE

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Izvod

Razvoj tekstilnih kompozitnih materijala, njihovog dizajna i proizvodnih tehnologija je jedno od najvažnijih dostignuća u inženjerstvu materijala. Tekstilni ojačani kompoziti su konkurentni materijali, ne samo zbog njihove jačine (kao rezultat prisustva vlakna ili vlaknaste strukture), već i zbog jedinstvene sposobnosti da prenose naprezanje (zahvaljujući polimernoj matrici). Veliki izbor matrica i vlakana daje mogućnost da se izabere odgovarajuća kombinacija za datu primjenu. Zato što su svojstva kompozitnih materijala anizotropne i nehomogene prirode, parametri koji kontrolišu mehanička svojstva zavise od vlakana kao pojačivača, uglavnom od njihove strukture, svojstva vlakana, itd. U radu su prezentovane vrste tekstilnih struktura koje se koriste kao pojačivači u industriji kompozitnih materijala. Diskutovana su vlakna koja se obično koriste u tekstilnim kompozitima: staklena, aramidna i karbonska. Oni se najčešće koriste u tkanju 3D ortogonalne predforme.

Ključne reci: *tekstilni kompoziti, tekstilne strukture, vlakna, 3D tkanine.*