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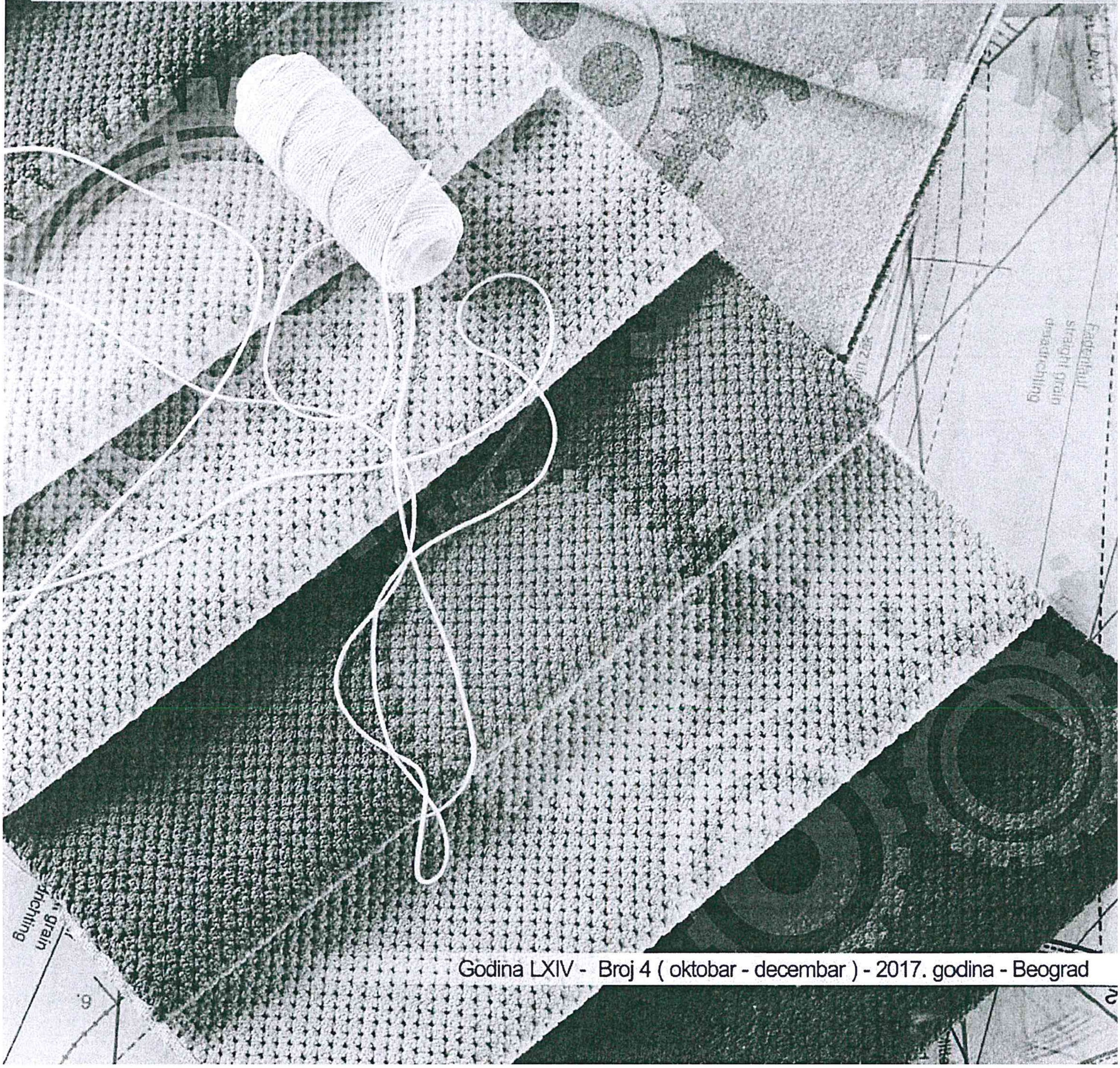

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SADRŽAJ

U FINANSIRANJU ČASOPISA UČESTVOVALO MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA REPUBLIKE SRBIJE

FIBROUS STRUCTURES AS A REINFORCEMENT FOR POLYMER COMPOSITE MATERIALS

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Abstract: *Composites with reinforcing textile fibers are defined as textile composites. Textile composite materials find their use in a range of commercial products thanks to their most important properties, which is the achievement of characteristics that exceed the characteristics of individual constitutive phases. The properties of the composite material depends on the properties of the constitutive phases, their proportions, the reinforcement geometry and the adhesion between the reinforcement and the matrix. Textile reinforced composites have been shown to be competitive materials thanks to certain advantages, in addition to their strength (as a result of the presence of fiber or fibrous structure) and their unique ability to transmit the load (which makes it possible to polymer matrix). The properties of the textile composites are anisotropic and non-homogeneous, and therefore the parameters that control the mechanical properties depend primarily of the fiber reinforcement, generally of the fibers structure and their properties, orientation of the fibers, content of the fibers, etc. This paper presents an overview of the types of textile structure that are most often used as reinforcement in the composite industry. Three main synthetic fibers used in textile composites are analyzed: glass, aramid and carbon.*

Key words: *textile composite, textile preforms, synthetic fibers, 3D fabrics.*

VLAKNASTE STRUKTURE KAO OJAČIVAČ KOD POLIMERNIH KOMPOZITNIH MATERIJALA

Apstrakt: *Kompoziti sa ojačavajućim tekstilnim vlaknima nazivaju se tekstilni kompoziti. Tekstilni kompozitni materijali pronalaze svoju upotrebu u nizu komercijalnih proizvoda zahvaljujući njihovom najvažnijem svojstvu, a to je postizanje karakteristika koje prevazilaze karakteristike individualnih komponenti. Osobine kompozitnog materijala zavise od osobina konstitutivnih faza, njihov saodnos, geometrije ojačivača i adhezije između ojačivača i matrice. Tekstilni ojačani kompoziti pokazali su se kao konkurentni materijali zahvaljujući izvesnim prednostima, pored njihove jačine (kao rezultat prisustva vlakana ili vlaknaste structure) i jedinstvu i sposobnosti da prenose opterećenje (što omogućava polimerna matrica). Kako su osobine kompozitnih materijala anizotropne i nehomogene po prirodi, parametri koji kontrolišu mehaničke sposobnosti zavise generalno od ojačanja vlakana, od strukture vlakana, osobina vlakana, orijentacijom vlakana, sadržajem vlakana, itd. U ovom radu predstavljen je pregled tipova vlaknaste strukture koji se najčešće koriste kao ojačanje u kompozitnoj industriji. U ovome trudu analiziraju se tri glavna sintetička vlakna koja se koriste u tekstilni kompoziti: staklena, aramidna i karbonska.*

Ključne reči: *tekstilni kompoziti, tekstilne predforme, sinteticke vlakna, 3D tkanine.*

1. INTRODUCTION

Composites are materials that consists of two or more constituent elements with outstandingly different physical and chemical properties, which in the structure of the new material remain macroscopically separate and different, that indicate their physical rather than chemical bonding. The constitutive phases of the composite keep their individual, physical and chemical properties, but with their mutual interaction, the obtained composite materials have properties that are superior in relation to the individual constituents. Compared to conventional materials, composites have notable mechanical and thermal properties, such as high strength, low density, hardness, impact resistance, abrasion and corrosion resistance, etc. [1, 2]. The fibrous reinforcement (glass, carbon, aramid, polyethylene etc.) gives the required strength and rigidity of the composite material, while the polymer matrix (epoxy, polyester, polypropylene, nylon etc.) is necessary for connecting, maintaining the position, orientation of the reinforcement and for transmitting the load between the reinforcements in all directions.

Textile composites are made of fibrous structure (reinforcement phase) and polymer (matrix phase). The mechanical properties of the composite strongly depends on mechanical properties of each constitute phase. Generally matrixes are isotropic while the fibers are highly anisotropic [3]. The reinforcing material plays a key role in the composite's properties. With use of different fibers arrangements various properties of composite materials can be achieved.

Textile reinforced composites have been shown to be competitive materials thanks to certain advantages, in addition to their strength (as a result of the presence of fiber or fibrous structure) and their unique ability to transmit the load (which makes it possible to polymer matrix) [4].

The development of textile composite materials, their design and production technology is one of the most important achievements in material engineering. They are used in many fields because of their unique mechanical and physical properties. They find numerous applications in many industries such as: aerospace, automobile, marine, railway etc. [5]. Also today are used for energy production (wind mills), civil buildings (wall reinforcement), protective equipment (helmets, plates), sport equipment etc. [4, 6, 7].

2. TYPES OF FIBROUS STRUCTURES

Textile preforms can be classified according to different criteria, such as: macro and micro geometry and the method of production. The macro geometry refers to orientation and shape of the textile structure, while the micro geometry take in linearity and reinforcement directions, linear density of fiber, the number of yarns in both directions (weft and wrap) etc. [4, 8, 9].

Textile structural reinforcements can be classified according to the direction of fibers or yarns orientation and their specific geometry. According to Fukuta et al., (1984) [4, 10], classified textile structures as follows:

1. one-dimensional (1-D) - (monoaxial - roving yarns),
2. two-dimensional (2-D) (non-oriented – sheets, monoaxial - chopped mat; twoaxial-woven with plain structure, triaxial -triaxially and multiaxial woven and knitted structures)
3. tridimensional (3-D):
   - with linear element – 3D solid braiding, multiple weave, triaxial and multiaxial 3D weave;
   - with plane element – beams, laminates, honeycombs).

Contrary to this classification Scardino [11, 12] listed four various level of fibrous structure for composite, fibers, yarns, 2D fabrics (laminar structures), and 3D fabrics (fully integrated structures).

From the point of view of used weaving process, configurations and geometries, interlacements of yarns there are different classification [13, 14, 15]. According to Khokar [13, 15] woven fabrics can be classified in six categories as follows:

1. interlaced 2D fabric,
2. interlaced 3D fabric,
3. 2.5D fabric,
4. non interlaced 3D fabric,
5. fully interlaced 3D fabric and
6. non-woven, non-interlaced 3D fabric.

Soden and Hill [16] edited Khokar's classification with a new subcategory for the fabrics that can be placed between categories 4 and 5, where are used three sets of yarns (warp, weft and through-the-thickness directions), for obtaining 3D interlaced fabric with use of 2D weaving process. For production of 3D woven fabrics different types of weaving machines (conventional or special) can be used. Different machine types are capable to produce 3D fabrics with various geometrical shapes. According to Chen 3D woven fabrics are classified into four categories as follows: solid, hollow, shell, and nodal [17].

For production of complex textile structures the most commonly textile processes can be used: weaving, braiding, knitting and non-woven (Figure1) [17, 18]. As a result of their specific geometry and characteristics they have different behavior and can be used in various applications. Woven fabric is a textile product obtained in the weaving process by intermingling at least two sets of yarns (warp and weft). The warp is placed along the direction of weaving machine, while the weft is positioned perpendicaly (at an angle of 90°). There are many possibilities for interlacing the weft and warp yarns, and the way it is done gives the structure of the woven fabric. There are many types of weave patterns such as: plain, twill, satin, basket and etc. The most commonly used weave pattern is plain [19]. Knitting is a technique of making a textile structure in transversal and vertical direction, composed of elementary units-loops, twisted from yarns with a certain length. There are two types of knitted structures: weft and warp-knitted fabrics. In the weft knitted structure the loops in one row are made from the same yarn, while in the warp knitted fabrics every loop is made from a separate yarn (warp) [19]. Non –woven fabrics are made by entangling fibers in various ways (mechanically, chemically or thermally). Braiding is a technique for producing braids from two or more yarn sets interlaced and twisted in clockwise and counter-clockwise directions.

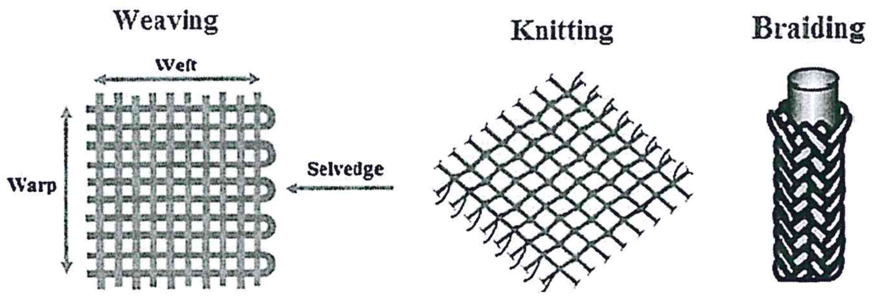

Figure 1. *Different production techniques of textile material*

The choice of the type of textile reinforcement for a given composite material depends primarily on the properties that the composite should possess for a given purpose. Structural potential, the material properties and their behavior under mechanical and other factors have influence on the selection of most suitable technological process [20].

3. TYPES OF FIBERS USED FOR COMPOSITE MATERIALS

There are many fibrous structures that can be used as reinforcements, but in the technology of composites the following fibers have the main role: glass, carbon and aramid. The term "fiber" is defined as a unit for matter and it is characterized by a high difference between length and width (fiber length is at least 100 times bigger than its diameter). The fibers are a significant form of material and possess properties that are superior to the same material in the non-fibrous form. The linear density which is in the range of 10 microns, provides excellent flexibility. The geometry of the fiber, with a length notably greater than the width determines their preferred application for the axial tension load.

The properties of composite materials depends on properties of fibrous reinforcement, polymer matrix and their adhesion. All fibers are not applicative as a reinforcement for composite materials. In order to be used as a reinforcing component, the fibers should possess specific characteristics such as high strength, high modulus of elasticity, uniform cross section and the capacity to hold off the manufacturing processes without significant property failure. All types of fibers, natural, man-made and synthetic fibers can be used as reinforcement for polymer composite materials. Three main synthetic fibers used in textile composites are: glass, aramid and carbon. Depending of the application, each fiber is distinguished by certain advantages and disadvantages. In Table 1 is shown a comparison between the most important reinforcing fibers properties [21, 22].

Fibers can be used in various forms as a reinforcement, for example in the form of chopped fibers, short fibers, continuous filaments or as a planar textile materials (woven or knitted materials with different pattern), etc. One of the most important parameters that influ-

Table 1. *Comparative properties of composite reinforcement fibers [22].*

Property	Glass	Carbon	Aramid
High Tensile Strength	Average	Best	Average
High Tensile Modulus	Poor	Best	Average
High Compressive Strength	Average	Best	Poor
High Compression Modulus	Poor	Best	Average
High Flexural Strength	Average	Best	Poor
High Flexural Modulus	Average	Best	Poor
High Impact Strength	Average	Poor	Best
Low Density	Poor	Average	Best
Low Cost	Best	Poor	Poor

length and orientation of the fibers. Stronger composite materials are produced from longer fibers and simple (2D textile materials) or advanced (3D textile material).

Glass fibers are the most common reinforcements for polymer composite materials. Their large application is primarily due to their low cost, low weight, mid-range tensile strength, low elongation, high bending rigidity, stability, resistance to chemical agents and insulation properties. Glass fiber disadvantages are: low tensile and compression modulus, relatively sensitivity of abrasion during operation, high specific gravity, low fatigue resistance and high rigidity [23, 24].

Generally, glass fibers are divided into two categories: ordinary cheap fiber - for general purpose (90%) also known as E-fibers (glass for electrical applications) and premium fibers (ECR-glass, S-, R- and Te glass, D-glass A-glass, C-glass) for special purpose. The most commonly used glass fibers for fiber composite materials are E-glass and S-glass. E-glass fibers have the lowest price compared to all commercially available reinforcements, which is one of the reason for their widespread use. The S-glass is generally used in aircraft and rocket industry. Glass fibers are available in various forms, such as: continuous roving, woven roving, glass mat, chopped strand yarns, woven structures with different patterns, etc..

Carbon fibers are often used to strengthen modern composites with a polymer matrix. The reasons for the wider use of carbon fibers are: the very high values of specific strength and modules among fiber reinforcements, low weight and resistant to moisture, solvents, bases and acids. The disadvantages include small compressive strength, lower conductivity and high price. Carbon fibers are ideal for the production of low-weight composites, especially for high temperature applications. They are increasingly used in various fields of industry (aircraft, automotive, marine, military, construction, sport industry). As a result of increasing application of carbon fibers in different applications, it is necessary further improvements of their properties and in particular decreasing of the production costs [25].

Aramid fiber, were discovered in 1965 as progress in the field of nylon fibers. There are two types of aramide fibers as following:

1. Para - aramide fibers - with much greater toughness and module (developed in 1971). Later, they where commercialized under the trademark Kevlar® (Du Pont).
2. Meta-aramide - (Nomex® - the trade name for Du pont)

Generally the biggest use of these fibers in the composite industry is because of the following properties:

- High tensile strength, high modulus of elasticity, low density.
- Good vibration absorption and high energy absorption
- High impact resistance
- Good chemical resistance
- Low thermal expansion and conductivity.
- Comfortable to wear [26].

Meta - aramide fibers compared with Para- aramide are less rigid and strong. On the other hand, the process of their production is easier, and also they are cheaper. The disadvantages of this fibers is their susceptibility to acids, salts and ultraviolet radiation, and also their hygroscopy. [27].

Based on data from Growth Opportunities in Global Composites Industry 2011-2016, the major fibers used as a reinforcement for manufacture of composites are glass fibers [28].

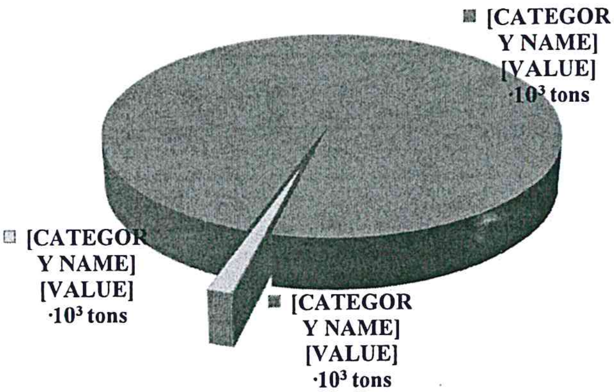

Figure 2. *Global shipments of fibrous materials used as a reinforcement for composites manufacture [28]*

The performance of fiber reinforced polymer composites is affected by many factors such as properties of the fibers, orientation of the fibers, content of the fibers and matrix, properties of the matrix, fiber-matrix interfaces etc. Fiber orientation is an important parameter because it influence on the performance of a composite. By changing the content and orientation of the fibers, composite materials with different mechanical properties can be designed. By increasing the volume content of the fiber, the strength and rigidity of the composite can be increased to a certain point. The polymer matrix in the composite usually consists of 30-40% and it basic function is to keep the reinforcing fibers together and to preserve the shape of the composite. The polymer matrix protects the fibers, which are usually brittle, from abrasion and corrosion under external influences. The thermal behavior of the composite depends mainly on the thermal stability of the polymer. Most importantly, the polymer distributes the applied load and plays the role of the transmitter of the stress, so when the individual fibers break down, the composite structure does not lose its ability to withstand the load. In compression stresses, the matrix plays a critical role in protecting the fibers from bending. The interlayer toughness, shear strength, compression and transverse strength of the composite are also dictated by the matrix. In order to fulfill all these functions, the adhesion between the fiber and the polymer matrix should be as high as possible.

4. 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. Improvements in the field of textile production technique and production of new fibrous structures with better characteristics nowadays is possible to produce composite materials with different properties for various applications. Because of the great significance of the reinforcing components in the composite material, knowing their characteristics and functioning is of great importance for process of designing a new types of textile composite.

Thanks to their outstanding mechanical, physical and thermal properties (high strength and stiffness, light weight, great corrosion resistance, good dimensional stability, average fatigue resistance, etc.) textile composites are being broadly used in advanced structures in many industrial applications.

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