Consolidated Composites with Natural Textile Fabrics

MP Todor\textsuperscript{1}, C Bulei\textsuperscript{1}, T Heput\textsuperscript{2} and I Kiss\textsuperscript{2,*}

\textsuperscript{1}University Politehnica Timisoara, Doctoral School, Timisoara / Hunedoara, Romania
\textsuperscript{2}University Politehnica Timisoara, Faculty of Engineering Hunedoara, Department of Engineering and Management, Hunedoara, Romania

*Corresponding author: imre.kiss@fih.upt.ro

Abstract. The problems raised by the usage and manufacturing of composite materials are numerous, starting from the prediction of the properties of a new material and going to the determination of some procedures, methods or materials that will eliminate some disadvantages. Because there is a wide variety of the materials already used, with a great diversity of characteristics and properties in a wide range of combinations involving various effects (mechanical, physical, chemical and so on), there have also been a number of issues that need to be addressed differently. The general properties of the composites are decisively influenced by the nature and proportions of constituents, by the nature of the matrix–reinforcement interface, the volume fraction of reinforcement in the composite and its orientation, and the reinforcing component architecture. This paper addresses a major research area of great interest and relevant in the present context, the emphasis is increasingly on environmental protection, saving material resources by developing and creating new manufacturing and execution technologies to be used in composite materials. The paper presents the ways of producing composite materials reinforced with textile materials made of natural fibres, as matrix being used polyester resins. Considering the quantitative availability of these textile fabrics, the experiments take into consideration variants of the bast fibers (flax, hemp and/or jute) for the reinforcement component.

1. Introductory notes

Within the generation of new materials that replace classical and deficient materials, considering their characteristics and prospects for the future, a special attention should be given to composites, recently referred to as reinforced materials.\cite{1} Representing the most well–known category and marking the beginning of an industrial scale use of new materials, fiber composites are mainly imagined as long fiber–reinforced polymer matrix, which for a long period of time had been the only type of wide–spread composites. This explains the fact that, even today, this class of materials is often identified in specialty literature with the very notion of composites.\cite{1,2} By definition, the concept of “composite” is assigned to a complex system composed of many different kind of materials. This is due to the fact that the possibilities of modifying the basic constituents, of the techniques of “assembly” and manufacturing, the level of the performance and the cost are practically infinite.\cite{1–5}

The problems that have arisen in trying to define as much possible exactly the composite materials are a proof of the extremely wide field of this type of material, a field in a continuous and rapid expansion. As a general definition, composite materials are systems of two or more components whose properties complement each other, resulting in a material with superior properties to those specific to each component.\cite{1–5} Thus, these components will cooperate, the deficiencies of some being supplemented by the qualities of others, conferring to the assembly, properties that no component can
have alone. As a result, composites are a category of multi–phasic materials, characterized by the fact that the qualities of each component are combined. [1–5]

For fiber composite materials in a polymeric matrix, the following constituents are considered:[1–5]
— the reinforcement, which constitutes the reinforcement or skeleton of the composite, providing mechanical resistance (it is of a lamellar nature, made up of fibers or fiber cloth);
— the matrix, linking the reinforcement, distributing the efforts and ensuring both the protection of the reinforcement and the shape of the piece (it is by definition a polymer or an organic resin);
— the interface, assures the reinforcement–to–matrix compatibility, ensuring the transmission of the efforts from one to the other without a relative displacement (having a good thin layer adhesion, of the micron order).

Figure 1. The composite’s constituents

In a broad sense, a composite material is a combination of two or more chemically different materials with an interface between them (Figure 1).[1–5] The fiber can be inserted and mixed into matrices or it can be impregnated with a susceptible binder in order to solidify after the parts are configured. Technically, they are considered to be composite materials, continuous or discontinuous fiber arrangements disposed in a form of reinforcement which is immersed in a matrix whose mechanical strength is much lower. The possibility to use very diverse combinations of raw materials in a great variety of combinations results in a wide range of composites. [2,4]

The design of fiber composite materials is based on the concurrent use of two criteria, namely:[1–5]
— the geometrical features of the reinforcement, and
— the way to orient or arrange it in the matrix.

Composite materials “associate” chemically different materials in the same mass that exhibit a range of performance, either in terms of the ease of machining or mechanical, physical or chemical resistance. This produces “demand” materials with good stiffness and low density. The association between a matrix and an armature cannot be coincidental and it depends on: [1–5]
— the chemical compatibility of the components which influence the transfer of effort through the interface;
— the obtained technological characteristics and properties;
— the cost of manufacturing.

The matrix–reinforcement mixture does not acquire the properties of the composite materials except in the last manufacturing phase: hardening of the matrix (polymerization in the case of composite materials with the matrix of polyester resin). After hardening, the properties of composite materials can no longer be altered as with metallic alloys by thermal treatments. The connection between the armature and the matrix is created during the composite material manufacturing phase. It has a determining influence on the mechanical properties of the composite material. [1–5]

2. Technical textile materials for reinforcement

Textiles find their applications as reinforcement in composites. The study of some technologies has revealed that they could be applied on an industrial scale for the economic advantages, performance and simplicity of design.[5–9] Textile fibers are the basic raw material of the textile industry but, at the same time, they are also important material for many other areas of the industry. In the modern period, pre–consumer waste textile materials, like those resulting from technological processes, but also from post–consumer waste, i.e. those collected, have been used to obtain a variety of textile products such as yarns, fabrics, knitwear, nonwovens, beds and so on, products used in many sectors. [5] The fibers resulting from the recovery of waste, which serve to obtain nonwoven products, are used in the form of fibrous
layers. These are textile supports, consist of fiber–oriented agglomerations or multidirectional. Practically, all types of fiber, including fibers recovered from reusable materials, can be used as starting materials for technical textiles. Reusable textile materials, also known as textile waste, come primarily from textile processing (spinning, weaving, knitting and so on), fabrication, machining in other textile processing sectors or as a result of physical or moral wear of textile products.

Textiles have the advantage of mass / strength ratio, reducing the time to achieve, eliminating waste resulting from the production and processing process, a better control of the final shape of the product and superior quality. [2,5–9] At the same time, textile materials allow direct control over the material characteristics from the design stage. In the case of textile materials, the architecture is favored by their extreme deformability being possible to obtain knitted fabrics of special complexity. This feature has made textile materials to be regarded as a possible alternative to the production of preforms for advanced composite materials recently. [5–9] Textile materials can also have three–dimensional architectures and the production of some of the most complex fittings eliminates the intermediate stages of preforms (with implications over production time and costs) and the possibility of controlling the final shape from the material design stage. [5–9]

3. The architecture of textiles

The form of textiles / fabrics is an extremely important factor in the design phase as it influences the raw material, structure and technology options. The sum of the qualities of a fabric, which includes flexibility and maneuverability to model, is manifested by the layout of the material to generate a pattern or to obtain a pattern. Textile materials can be defined according to the essential dimensions to the way they are constructed: [2,5,9]

— materials with one–dimensional architectures, for which the length is decisive, in this category being included the textile fibers and yarns (Figure 2a);
— materials with two–dimensional architectures, with a geometry characterized by two dimensions (length and width), the case of knits, fabrics, braids and non–woven materials (Figure 2b);
— materials with three–dimensional architectures, built along the three axes, with knits, fabrics and knitted fabrics with three–dimensional complex shapes (Figure 2c).

![Figure 2. The architecture of textiles: a) vertical fibers (warp)/ horizontal fibers (weft); b) two–dimensional shapes (plain fabrics); c) three–dimensional shapes](image)

The process of increasing the complexity of the shape of the products required the adaptation of the textile materials and led to the emergence of the concept of materials with three–dimensional architecture. [2,5] In the specialty literature, the concept of three–dimensional textile material is still being discussed, with several views on what types of materials can be considered as three–dimensional. In broad sense, three–dimensional architectures are defined as: [2–5]

— multiaxial (multilayer), having a structure in layers of wire systems deposited at different angles, independent of each other, assembled in a unitary knitted structure. The threads are arranged in layers at angles of 0°, 90°, +/- 30° and +/- 45°
— sandwich, consisting of two layers of fabric, knitted or non–knitted.
— three–dimensional contours, the 3D layout of which is achieved by using contour lines, which define structures on incomplete rows, with complex shapes similar to the shape of the finished product.
Reinforcing with threads arranged at different angles improves the mechanical behavior of multiaxial knits on the reinforcement directions as well as the shear properties (Figure 3). In contrast, increased stiffness significantly reduces the formability of these architectures. The shape of composite materials reinforced with sandwich structures can be controlled by varying the structure of the outer layers or layout and structure parameters of the bonding layers.[2–5,9]

Figure 3. The shape of composite materials reinforced with sandwich structures

Three-dimensional preforms are less studied and used, especially due to the following problems related to their production and properties: [2–5]

— the development of these types of architecture is still in the laboratory stage;
— the specific properties and methods of their prediction are not yet well determined;
— the correlation of technological parameters – properties of composite material is not completely defined;
— pre-stretching the fabric before resin impregnation determines the unevenness of the composite behavior due to the random change in the arrangement of the yarns in the fabric. Concluding, the main advantages of textile materials are related to:
— special formability, due mainly to the draping properties;
— the high degree of complexity of the obtained forms;
— the possibility of obtaining composites with superior behavior to impact demands.
These things recommend technical textiles for applications using complex architecture materials, including reinforcements for composite materials.

4. Technologies for obtaining consolidated composites with fabrics
The first problem with the manufacturing of fiber-reinforced composites is the choice of component materials depending on the conditions of use. It is very important that in a composite the mechanical stresses are supported by fibers, the matrix having the role of protecting fibers against oxidation, corrosion, hitting and friction. It is obvious that the manufacturing processes must ensure the exercise of this role from the moment the composite is formed.[2–5] The second problem is the incorporation of fibers into the matrix, which must respond to three fundamental requirements:

— the uniform distribution of fibers
— their alignment in a common direction and
— making a connection between fibers and matrix.

In the case of the fabrics usage, the first two requirements are solved by choosing the type of fabric, the fiber distribution and their alignment being solved by the manufacturing technology. Making a fiber–matrix link remains a difficult problem. The difficulty consists in ensuring that the fibers are “wetted” by the matrix without forming diffusion layers at the interface to alter the characteristics of the fabrics in the fabric.[2,5] This problem is solved by using low surface tension matrix relative to the textile material. Contact formation is the easiest method in the manufacturing of fiber reinforced polymer composite components (fabrics).[1–5] The matrix (resin) and the reinforcement (the textile material) are deposited in layers, and after each deposition it is ensured pressing and adhering the previous layer to the next with a contact roller. Thus, the resin is “buffered” over the fabric which is properly impregnated. In the case of several layers of fabric, for proper adherence, the next layer was laid before the previous one was fully hardened.
The reinforcement systems for composite textiles refer to a wide range of textile surfaces that can be obtained using all textile technologies (weaving, knitting, and sewing) or obtaining nonwoven materials. The characteristics of the resulting composite material depend on the ratio between the volumes and the reinforcement masses and the matrix.[1–5] To these there can be added the processes characterized by the production of reinforcement and composite material at the same stage, such as filament winding and polishing. When choosing the optimal variant of the composite preforms, the strengths and weaknesses of each composite preform must be taken into account. The criteria used in choosing the technological process for the reinforcement manufacture refer to the dimensional stability, to the imposed mechanical properties, and to the draping / forming properties of the reinforcement system.[2–5] For reinforcing we can meet uni–, two– or three–dimensional armatures as it follows:

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- reinforcement of yarn (textile fibers) + matrix;
- fabric (textile surfaces) + matrix;
- fabric systems (3D textile materials) + matrix;

Preparation of the reinforcement is an operation that takes a very important place in the process of obtaining composites and involves knowing all the factors that compete for the building of an appropriate architecture of the reinforcement to a particular type of landmark.[2–5] There are usually used the following basic armatures:

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- unidirectional (support from textile surfaces, in different layouts, in one layer);
- non–woven (non–assembled textile support, layered on several textile layers);
- woven (supported from reinforced textile surfaces, disposed on several textile layers);

Textile supports are textile being made of plain or composite fabrics (stratified supports). Textile fibrous layers and layered supports may be subjected to pre–consolidation processes by simple interlacing and then to mechanical consolidation processes and, more particularly, physic–chemical, with the aid of adhesives.[2,5]

The fabric is the textile product obtained by the right–angled crossing of two yarn systems: a longitudinal system and a transverse system. The obligatory condition for fabrication is the alternate passage of longitudinal threads over and under the transverse threads, and vice versa. Fabric elements are considered to be the crosses of the yarns. The structural characteristics and properties of the fabrics are determined by the links used to obtain the fabrics (basic, derived, combined, multiple or special), the characteristics of the component yarns (nature of the raw material, the process of production, the weaving method) and on the transverse system), the thickness, the degree of corrugation of the yarns in the fabric and its mass.

**Figure 4.** The natural textile fabrics’ densities used in the polymeric matrix: a) 200 gr/m²; b) 250 gr/m²; c) 280 gr/m²; d) 300 gr/m²; e) 330 gr/m²
Fabric of jute, hemp or sack cloth is an ecological and biodegradable natural raw material. For textile inserts in the polymeric matrix we use fabrics with densities between 200–330 gr/m², obtained from the selective collection of textile waste (from textile products that have completed their life cycle) or technological debris from textile factories (Figure 4).

The polyester resin used is an unsaturated, pre–accelerated one getting hardened at the ambient temperature. From the point of view of processability, the polyester resin is easier to use due to higher viscosity and low density. A hardener is added to the base component in a proportion that can vary between 1–3%, depending on the temperature and speed of the desired hardened. The hardener acts quickly and is highly concentrated, so a 2% addition is sufficient in most cases. The addition of hardener depends on the amount of base that is prepared at a single casting.

The working temperature must be between 18–25°C, the higher the temperature, the harder the hardening. Practically, at a temperature of 0°C, hardening does not take place. Working time may vary between 20–40 minutes depending on the amount of the hardener added.

5. Concluding remarks and future works
The main advantage of using composite materials is both qualitative and economical. The natural fibers used as a textile reinforcement favor the improvement of the properties of the made products, which makes them considered a successful alternative. The choice of technical textiles for a domain is made according to the functional characteristics, the reliability and the destination of the products being made. Achieving new performance materials to meet the widest possible range of requirements is a must–have nowadays. The idea of creating new techniques and technologies to improve the traditional and composite materials, the best use of secondary resources, the increase of recycling and the use of waste is becoming increasingly important.

Today, the concept of development means sustainable competitive growth, based on the innovation of technologies, products and processes, under conditions of increased environmental efficiency. In order to find solutions for waste recovery, it is taken into account that technological progress can no longer only follow economic criteria. The objectives include eliminating the concept of waste in product creation using materials, energy and resources that can be immediately recycled, reused and introduced into the circuit.

In the category of waste, an important place belongs to the textile waste, also to the knowledge and studying of the problem regarding their valorization in the industry (own, by recuperation of proper waste or in other industries, in composite products with textile friability). The development of alternative waste disposal solutions in high added value products by producing non–conventional products containing recovered fibers constitutes an ecological alternative to the capitalization of textile waste. Thus, fiber–reinforced composite materials are promising alternatives for reducing environmental problems regarding lightweight construction area.

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