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USE OF NATURAL FIBERS IN 3D PREFORMS OF COMPOSITE MATERIALS: A REVIEW

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Abstract. *Composite materials are types of advanced materials used in various engineering applications. Polymeric composites reinforced with synthetic fibers are quite common, but concerns about their cost, recyclability and the energy spent on their manufacturing lead researchers to investigate the feasibility of using natural fibers instead. Natural fibers, however, have some limitations in their mechanical properties and durability. A common solution to improve the mechanical properties of natural fiber reinforced composites is to change the quality of the fiber matrix interface, but another solution can bring improvements, which is the change in the reinforcement shapes. This review aimed to study the fibers and the differences between 2D fabrics and 3D preforms used as composites reinforcements. In the first part, the main natural fibers used today as composites reinforcements are presented, focusing on bast fibers, which are the type of fiber mostly used as polymeric composite reinforcement. The review goes on to analyze 3D fabrics preforms and compare them to 2D fabrics, since depending on the way the fibers are sewn, some of their mechanical properties can be improved. The composites reinforced with 3D preforms show better resistance to delamination and impact, but all research studied were done over synthetic fibers. For this reason the last section of this article reviews how natural fibers react to impact tests, to see if it is feasible to use them, shaped as 3D preforms, as reinforcement in polymeric matrix composites. The review showed good resistance to impact of natural fibers, especially after chemical treatment and with the increment of their volume fraction. The conclusion of this review is that both 3D preforms and natural fibers show good resistance to impact and that using natural fibers shaped as 3D preforms can be a way to create composites reinforced with natural fibers that can withstand impact loads.*

Keywords: *natural fibers, impact test, 3D preforms, laminate composites, polymeric matrix composites.*

1. INTRODUCTION

Composites are materials made up of two or more components of different types of materials (such as metals, polymers and ceramics), developed with the objective of making the properties of each component compensate for the deficiencies of the others, making the composite a material which properties are superior to those of each individual component (Dixit et al., 2017).

A very common type of composite is the fiber reinforced polymer composite (FRPC), whose matrices can be made from either thermoplastic or thermoset polymers. The first FRPCs developed for engineering applications were reinforced with synthetic fibers such as fiberglass, carbon fiber and aramid. Synthetic fibers have good mechanical properties, such as rigidity and mechanical strength, but they pose problems to the environment, both because of the amount of energy used in their production and because of the difficulty in recycling them (Pickering et al., 2017).

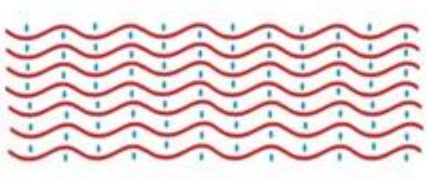
Due to these problems, natural fibers began to be researched as potential substitutes for synthetic fibers. Some natural fibers are able to replace fiberglass in non-structural applications, and are already being used especially by the automotive industry in panels. In addition to this application, natural fiber reinforced polymer composites (NFRPC) also show promise in non-structural applications in the aerospace and construction industries (such as panels and windows), and in the sports equipment industry, in which the loads the materials are subjected to are not very high (Jariwala and Jain, 2019; Sanjay et al., 2018).

The challenges in the use of natural fibers are: the presence of impurities, the variability in their compositions, their hygroscopicity and mechanical properties that are inferior to those of synthetic fibers (Jariwala and Jain, 2019). Note, however, that the specific mechanical properties – that is, the modulus of elasticity and the tensile and bending strengths divided by density – of natural fibers are superior to those of synthetic fibers, which makes polymer composites reinforced by natural fibers (NFRPC) lighter (Pickering et al., 2017).

Reinforcement fibers can appear in different ways in the composite. A common classification is the division of fibers into discontinuous and continuous. In the first case the fibers are relatively short and do not woven into fabrics. In the second type, the fibers are long and usually processed as unidirectional or bidirectional fabrics (Rajak et al., 2019).

Unidirectional or bidirectional fabrics are reinforced only in the plane where the fibers are and composites are manufactured by stacking these fabrics, which adhere to each other through the action of resin, forming composite laminates.

Another, less conventional way of arranging continuous fibers is through 3D fabrics. In these fabrics, in addition to the fibers being arranged in a plane like a two-dimensional fabric, another set of fibers reinforces through the thickness of the composite, across its layers, in what is conventionally called the Z direction. Due to this fibers arrangement in the composite, the composites made of 3D fabrics (3DFC) have some advantages over laminated composites of two-dimensional fabrics (2DLC), the main ones being: increased impact strength, resilience to the point of fracture, damage tolerance, and elimination of delamination [6]. The difference in the structure of 2DLC and 3DFC is shown in Figure 1 (Huang et al., 2018).


a)

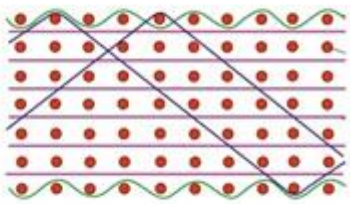

b)

Figure 1. Longitudinal sections of a) a pile of 2D fabrics in a 2D laminated composite (2DLC) and b) a 3D preform (3DFC). In a) the red lines represent warp threads and the blue dots weft threads. In b) greens lines are warp, reds dots are weft and blues lines are binding threads.

This article aims to present the main types of vegetable fibers used in polymer composites reinforced with natural fibers, and also to discuss the types of 3D fabrics and their mechanical properties. At the end of this literature review, natural fibers impact resistance and their potential to be used in 3D fabrics for impact bearing parts will also be discussed.

2. VEGETABLE FIBERS USED IN COMPOSITE MATERIALS

Vegetable fibers are basically composed of cellulose, hemicellulose and lignin. Cellulose has a crystalline structure and is organized in the form of fibrils that are oriented between 10º and 20º in relation to the axis of the fiber. Hemicellulose and lignin have an amorphous structure and bind cellulose fibrils. Cellulose, which is the main component of vegetable fibers, accounts for about 60 to 80% of the fiber by weight and, in general, the more cellulose and the better aligned its fibrils are in relation to the fiber, the better the vegetable fibers mechanical properties will be. Lignin makes up about 20% of the fiber and hemicellulose makes up from 5 to 20% of vegetable fiber by weight (Dixit et al., 2017; Verma and Jain., 2017). The compositions of the main vegetable fibers used in NFRPC are presented in Table 1 (Verma and Jain., 2017; Mohammmed et al., 2015) and their mechanical properties are presented in Table 2 (Dixit et al., 2017; Pickering et al., 2017; Sanjay et al., 2018; Mohammmed et al., 2015).

Table 1. Composition of the main vegetable fibers used in NFRPC.

Fiber	**Cellulose (%)**	**Hemicellulose (%)**	**Lignin (%)**	**Waxes (%)**	**Pectin (%)**	**Humidity (%)**
Rami	68.6-76.2	13-16	0.6-0.7	0.3	-	-
Flax	71	18.6-20.6	2.2	1.5-1.7	2.3	8-12
Hemp	68-74	15-22.4	3.7-10	0.8	0.9	6.2-12
Jute	61-71.5	14-20.4	12-13	0.5	0.2	12.5-13.7
Sisal	65-78	10-14	10-14	2	10	10-22

Table 2. Mechanical properties of the main fibers used in NFRPC.

Fiber	Density (g/cm³)	Length (mm)	Ultimate strain (%)	Tensile strength (MPa)	Young modulus (GPa)	Specific tensile strength (MPacm^3/g)	Specific Young modulus (GPacm^3/g)
Rami	1.5-3.8	900-1200	2-3.8	220-938	44-128	270-620	29-85
Flax	1.4-1.5	5-900	1.2-3.2	88-1830	27-80	230-1220	18-53
Hemp	1.48-1.5	5-55	1.6-4	550-1100	58-70	370-740	39-47
Jute	1.3-1.5	1.5-120	1.5-1.8	393-800	10-55	300-610	7.1-39
Sisal	1.3-1.5	900	2-14	227-855	9.4-38	362-610	6.7-20

Cellulose is the most important structural component of natural fibers, being made of hydrogen, oxygen and carbon, put into a long, linear molecule with no ramifications. Cellulose is estimated to have a 140 GPa Young modulus when X-ray diffraction (XRD) is used to determine its deformation (Summerscales et al., 2010).

2.1 Fibers used as reinforcement in composites

Most plant fibers researched and used as composite materials reinforcement are bast fibers, obtained from the outer layers of plants stem cells, as shown in Figure 2 (Baley et al., 2020). In this section, the bast fibers mostly used in industrial applications will be presented; these fibers are jute, ramie, flax and hemp. Another fiber widely used and presented here, but which comes from the plant leaf is sisal (Summerscales et al., 2010).

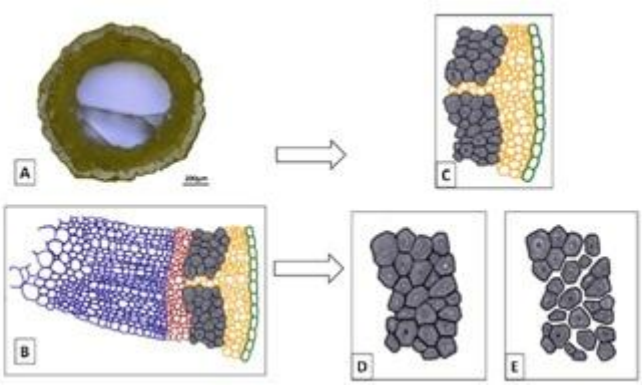


Figure 2. Bast fibers location (in grey) in the stem (A, B and C); fiber bundles (D) and individual fibers (E).

2.1.1 Jute

The jute species mostly used in industries are *Corchorus capsularis* and *Corchorus olitorius*. Jute is the second most cultivated vegetable fiber in the world, only behind cotton. Jute is typical of tropical rainy places and its cultivation takes place during the rainy seasons. Its main producers are Bangladesh, Brazil, China, India and Indonesia (Summerscales et al., 2010; Ashraf et al., 2019).

Jute can be obtained at a low cost and has good mechanical properties for a natural fiber, in addition to low density. These two properties are related to the structure of its fibrils, the name given to areas where cellulose has high crystallinity and packing, and to the lumen, which is an empty region in the central part of the fiber cells, which gives them low weight (Ashraf et al., 2019).

Jute is applied in several different industries such as textiles, where it is used in the production of clothes, ropes, bags, shoelaces etc.; in the civil industry, where it is used as reinforcement in windows, doors and internal partitions; and in the automotive industry, where it is used primarily as a reinforcement for thermoset polymers in the manufacture of door panels, instrument panels, and cup holders. Despite being a tropical plant, it is widely used in the German automotive market, a country where the most common natural reinforcement fiber in plantations is flax (Summerscales et al., 2010; Ashraf et al., 2019).

2.1.2. Hemp

The main species used in fiber production is *Cannabis sativa*, originating in Central Asia and typical of temperate climates. This species can grow to about 4m in 12 weeks. The fiber extracted from its stem is long, reaching almost 2.5

meters. Hemp does not require fertilizers, herbicides and pesticides, making it cheaper to grow and causing less environmental impact (Summerscales et al., 2010; Liu et al., 2017).

Hemp has some advantages over other plants used to obtain fibers. Its rapid growth causes it to produce more fiber per hectare than other bast fiber plants such as flax. Hemp also suppresses weeds and leaves the soil in good condition for other crops. Varieties used for fiber extraction have less than 0.3 percent tetrahydrocannabinol (THC) by weight, which is too low for the production of narcotics (Liu et al., 2017).

Hemp fibers are long and contain highly crystalline cellulose fibrils, which is why they are so widely used in composite materials. The mechanical performance of the fiber can still be improved through proper fiber cultivation, in addition to its selection and extraction method (Liu et al., 2017). Hemp is widely used as polymeric matrices reinforcement in the automotive industry to manufacture internal door panels (Summerscales et al., 2010; Liu et al., 2017).

2.1.3 Flax

The plant is sown in the northern hemisphere between March and May and can grow to around 1m. Flax is a plant of the genus Linum, and the most common species used in industrial applications (such as in the production of fabrics and linseed oil) is Linum usitatissimum. Linen fibers are also bast fibers and have high Young's modulus and high tensile strength in relation to their density. The good mechanical properties of flax fibers are due to the cellulose high content and the small fibril angles in these molecules. Flax fibers form a layer of unidirectional bundles on the periphery of the stem that absorb tensile and compressive loads, and which contribute about 71% of the stem's bending stiffness. Its porous core also contributes to the fiber's flexural strength (Baley et al., 2020).

Flax fibers have been used in the automotive industry since the 1940s, when it was used together with polymeric resins to repair sheet metal. Today, the fiber is used in polymer composites to manufacture internal door panels and headliners (Huang et al., 2018).

2.1.4 Sisal

Sisal fiber is widely available, inexpensive and environmentally friendly. The species used to extract the fiber, which is removed from the leaves, is Agave sisalana, which can be cultivated in various parts of the globe. Its abundance comes from this global presence coupled with a short growing season (Huang et al., 2018).

Sisal has high cellulose content, being responsible for the fiber's good traction properties, in addition to giving it low hygroscopicity in relation to other plants. In addition to good tensile strength, sisal fibers can also be used in situations that demand good impact strength. Its impact strength is close to that of jute fibers, which have similar amounts of cellulose (Senthilkumar et al., 2018).

Sisal fibers are used in the automotive industry and, mainly, in the construction industry in applications were high mechanical stresses are not applied, such as roof tiles and panels that provide acoustic and/or thermal insulation (Huang et al., 2018; Senthilkumar et al., 2018).

2.1.5 Rami

The largest producers of ramie (*Boehmeria nivea* and *Boehmeria tenacissima*) are China and the Philippines, with Brazil in third place [14]. Its fibers stand out among bast fibers due to their high cellulose content, long length and high mechanical strength. They also have antimicrobial properties that make them more resistant to degradation (Xu et a., 2016).

The range of ramie tensile strength can surpass that of jute and flax, which are commonly used in composites. For this reason, ramie fiber can partially replace glass fiber and has already been used in research in combination with aramid fibers for the production of armor materials. This fiber is also efficient in the production of acoustic insulation (Djafar et al., 2020).

2.2 Natural fiber composite applications

The largest consumer market for composites in the world is the United States, which consumes 48% of these materials by weight, followed by Europe, with 28%, and Asia, with 23% of consumption. The industries that most consume this material, in dollars, are the automotive and aerospace industries. More than half of the composite materials industries' earnings come from sales to these two industries, despite them representing only 26% of composites consumption in volume. This is because these industries still mainly use carbon and aramid fibers, which have high mechanical performance and are more expensive. The rest of the consumption is made with cheaper fibers, especially fiberglass. Natural fibers are still incipient and their consumption is well below that of glass fibers (Huang et al., 2018).

The main applications of natural fiber composites in industries today are (Anandjiwala and Blouw, 2007):

Agglomerates: These are traditionally made from sawdust, but non-woven fibers can also be used. The plant material is agglutinated using phenolic resins in the form of hot-pressed sheets. These sheets require the use of some type of flame retardant technology, which can come in the form of a surface layer of flame retardant, the addition of flame retardant materials to the agglomerate, or binder resins that are flame retardant themselves.

Buildings and infrastructure: fibers are mainly used in non-woven form, combined with a polyester matrix, or in a blend of polyester with vegetable oils. Fibers can also be used as reinforcements for cementitious matrices, although in this case wood is used as reinforcement plant material due to its greater resistance to traction and impact.

Automotive components: Most common application in these industries is in the manufacture of internal panels, carpets, and trunk linings, where the fibers are normally used in a non-woven form. These fibers are applied in these places because the demand for mechanical strength is not very high, and they are usually added to meet recyclability demands, which can be defined by legislation in some consumer markets.

A country that uses high quantities of natural fibers in the automotive industry is Germany, where automobiles consume 70% of the natural fiber composites used in the country. The most used fibers there are flax and hemp, which are planted in Europe, and jute, which despite being a plant from tropical climate is imported for composites manufacturing.

Natural fibers, even bast fibers, have low impact resistance compared to synthetic fibers, which limits their use cars interiors. However, fiber treatments are being researched to increase the bond quality at the matrix/fiber interface and its interlaminar strength.

3. TRIDIMENSIONAL FABRICS

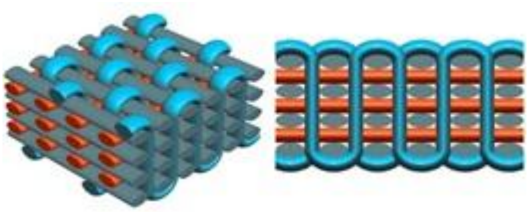
Fibers used in composite materials are manufactured as preforms, which are fibrous materials assembles without the matrix, which is used as a base for composite materials. They can come in the form of yarns, fabrics or in complex shapes (Wambua and Anandjiwala, 2011). Preforms are made to facilitate the handling and transport of fibers and to arrange them in an orderly manner, increasing productivity in the manufacture of composite parts and objects. Preforms with complex geometry are made in formats very close to the final parts, optimizing fiber distribution and reducing the need for final machining adjustments (Gereke and Cherif, 2019).

The most common forms of preform, however, are 2D fabrics, which are planar structures formed by crossing two perpendicular sets of textile strands through a loom. In the most common form of weaving, the threads that are laid across the loom are called warp threads and the threads that run across are called weft threads. A schematic of this process is shown in Figure 3 (Boussu et al., 2019):

Figure 3. Fabric production process.

The most common 2D fabric manufacturing processes cited in Figure 3 are weaving, knitting, and braiding.

3D preforms can be made by adding binder yarns that intertwine the warp and weft yarns, traversing them in the thickness direction (also called the Z direction) of the 2D fabric stack. These binding threads can traverse the stack in a direction orthogonal to the plane or at an angle, as shown in Figure 4 (Gereke and Cherif, 2019). The type of preform manufactured in this way is called a 3D solid preform or 3D fabric (Wambua and Anandjiwala, 2011).



a) b)

Figure 4. a) Isometric view of a 3D preform with orthogonal sewing through its thickness and b) its longitudinal section.

We can classify 3D fabrics into four types according to the angle of the binding yarn and how the fabric layers are bonded.

The first two types of 3D fabrics refer to the binding thread angle. Angle sewing happens when the angle of the binding thread is less than 90º, as shown in parts "a" and "b" of Figure 5. Orthogonal sewing happens when this angle is equal to 90º, as shown in parts " c" and "d" of the same figure.

The other two types of fabrics are classified by binding type, which can be through thickness or by layer. In the first type, shown in parts "a" and "c" of Figure 5, the binding thread goes through all the fabric layers in one direction before being sewn in the opposite direction to join the layers. In the second type, shown in parts "b" and "d" of the same figure, a binding wire passes through only two adjacent layers to join them together; thus, the first binding yarn joins the first layer of fabric to the second, the second yarn joins the second layer to the third, and so on (Huang et al., 2018).

These four types exist in combination, and a fabric can be, for example, orthogonal sewn through the thickness or orthogonal sewn by layers. All these combinations are shown in Figure 5 (Huang et al., 2018).

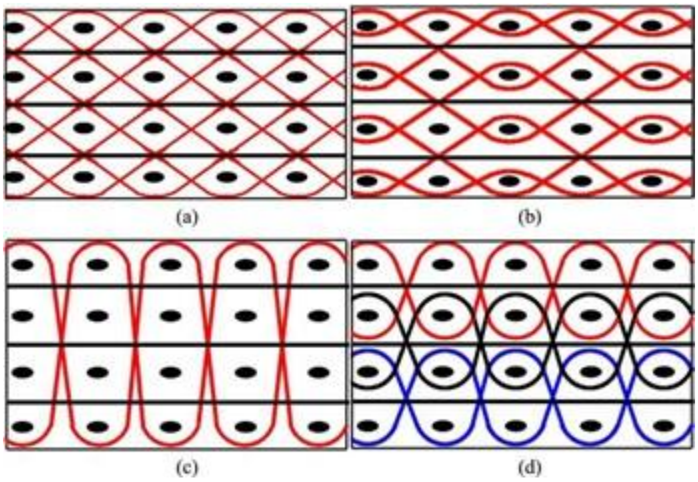


Figure 5. a) angled weave through the thickness, b) angled weave in layers, c) orthogonal weave through the thickness, and d) orthogonal weave in layers.

The most common form of 3D preform is orthogonal fabric, also referred to as block preform. Preform fabrication methods are similar to those for 2D fabrics, with weaving, knitting, braiding and suturing as main examples. The most common method among these is weaving, which is done using modified 2D fabric looms to insert the binding threads in the Z direction, which eliminates the delamination present in laminates made from conventional 2D fabrics (Wambua and Anandjiwala, 2011; Ansar et al., 2011).

3.1 Differences between 3DFC and 2DLC

The main advantages of 3DFC over 2DLC are their resistance to delamination and impact. In addition, 3DFCs have greater rigidity and resistance to traction, bending and compression. 3DFC also has greater dimensional stability and greater restriction on crack propagation. Its tenacity is also greater, and this advantage is even clearer in orthogonal fabrics (Gereke and Cherif, 2019).

3DFCs suffer less impact damage compared to 2DLC and have a smaller deformation area and lower penetration of projectiles in tests. 3DFCs also perform better in low-impact ballistic tests (Boussu et al., 2019).

However, 3DFC also has some disadvantages. Some of its mechanical properties (hardness, modulus of elasticity under tension, and modulus of elasticity and tension under shear) are lower in the planes where the warp and weft yarns are located. This can be a consequence of the abrasion damage the fibers suffer when they are sewn through the thickness, which diminishes their integrity. The fiber fraction by volume in a 3DFC is lower than in a 2DLC, having a maximum fraction of about 55% to 60% of fibers, which leads to many resin-rich areas. 3DFCs also have higher shear deformation and lower fatigue strength (Djafar et al., 2020; Wambua and Anandjiwala, 2011; Ansar et al., 2011).

3.2 Properties differences among distinct

3DFCs, in general, exhibit a linear behavior under tension at first, and then its behavior becomes non-linear. Under compression, its behavior is approximately linear up to the point of failure (Huang et al., 2018).

Angled stitching generates 3DFC with greater impact resistance and type II failure delamination. These composites can also have greater fatigue strength and can withstand more cycles before failure. Composites made with orthogonal fabrics, on the other hand, present greater tenacity and less crack propagation (Boussu et al., 2019).

3D fabrics made by weaving have greater rigidity and tenacity than 3D fabrics made by suturing. The more binding threads are used, the greater the resilience and tensile modulus, flexural strength, and interlaminar shear strength.

Increasing the amount of binding threads also decreases the deformation of the 3DFC subjected to compression. Sewing through the thickness results in a 3DFC with higher interlaminar fracture toughness compared to 3DFC with layer seams (Huang et al., 2018; Boussu et al., 2019).

4. IMPACT RESISTANCE OF NATURAL FIBER REINFORCEMENT

The previous sections showed that improving impact strength is one of the great advantages of making 3DFC. In this part of this literature review, we will see how natural fibers help to increase the impact strength of polymeric materials.

4.1 Researches on natural fiber reinforced composites impact resistance

Dubey and Agnihotri (2015) used the fiber from the coconut midrib to reinforce a polyester matrix. The polymer impact strength increased with the fiber presence and the best result was obtained at 20% volumetric fraction, when the test impact energy reached 64.4kJ/m², a result 23 times greater than that obtained by pure polyester matrix.

Midani *et al.* (2020) performed impact tests to characterize tururi fibers, which are extracted from ubuçu, a palm type of the species Manicaria saccifera. In their work they varied the amount tururi fabric layers to find the optimum impact strength values. At first, a larger number of layers provide better impact resistance, but after a certain amount, the number of layers can hinder resin penetration between the fibers, reducing its impact resistance.

Mishra and Naik (2005) used banana, sisal and hemp fibers treated with maleic anhydride to reinforce polystyrene matrices, varying the fiber volumetric percentage. The composite with sisal fibers proved to be more resistant than the others for all volumetric fractions. Maleic anhydride treatment increased the impact strength of all three composites. The volumetric percentage of fibers ranged from 40% to 55% and with the increase of this percentage, the impact resistance decreased linearly. The impact strength of the composite with 40% treated sisal fibers demonstrated an impact strength of approximately 17 Nm/cm², while the composite with 55% of fibers of this same type obtained an impact strength of approximately 10 Nm/cm².

Premnath (2019) performed an experiment using sisal and jute as reinforcements for an epoxy resin matrix. The sisal percentage was not modified, but the jute percentage varied. In addition, he observed the difference in mechanical strength of composites that underwent treatment with sodium hydroxide solution. It was demonstrated with this research that the impact resistance increased 27.7% with treatment. The greater amount of jute fibers also increased the composite impact strength and the effect of fibers addition was similar to that of the NaOH solution treatment. The composite which contained only 10% untreated jute fiber demonstrated impact strength energy of 19.5J. With an increase in the percentage of jute fiber to 20%, the impact strength improved to 24.84J, while the treatment made this value increase to 22.25J. Combining this same fibers increment with NaOH solution treatment, the impact strength was taken to 33.46J.

Wu *et al.* (2019) performed an experiment where they added flax fibers to an epoxy resin composite reinforced with silk fibers. Silk is commonly used to increase the impact strength and flexural properties of epoxy matrices composites. This is because, although silk doesn’t have a very high modulus of elasticity and stiffness, it is able to absorb and dissipate energy well during deformation. On the other hand, flax fibers have good mechanical properties, but their composites have low fracture toughness due to their low adhesion with the matrix. With this work, Wu and his team demonstrated that flax fiber insert increased impact strength when compared to the epoxy/silk fibers composite, and also increased impact energy absorption efficiency.

Wambua *et al.* (2003) carried out a research in which they compared the impact resistance of glass fiber mat reinforced polypropylene composites with natural fibers (sisal, hibiscus, hemp, jute and coconut) reinforced composites. Although the glass fiber composite absolute impact resistance is higher (54kJ/m² against 27kJ/m² of the sisal fiber composite, which registered the best resistance among natural fibers), its specific impact resistance, i.e., energy absorbed divided by density, is smaller. The same research showed that the impact strength increased with the fiber volume fraction for the hibiscus fiber reinforced composite, with the impact strength going from 12.5kJ/m² with 30% fiber to 23kJ/m² in the composite with 50 % fiber.

Jawaid *et al.* (2011) created natural composites using oil palm empty fruit bunches (EFB) and woven jute fabrics to reinforce epoxy. The addition of natural fibers improved the epoxy matrix impact resistance. EFB fibers showed better impact resistance than jute fibers. When the epoxy was reinforced by EFB fibers alone, the composite impact strength was 92.7 J/m. When it is reinforced only with jute fibers, the composite impact strength is only 38.1 J/m.

Braga *et al.* (2017) used curaua fibers to reinforce polyester and performed a ballistic test to assess its suitability to be used as a layer of multilayered armor systems. Despite the absorbed energy of curaua/polyester composites (230J) was lesser than that absorbed by neat polyester (295J), its value was close to that of aramid/polyester composites (239J). Curaua fiber was concluded to have potential to integrate the second layer of multilayered armor systems.

Kommula *et al.* (2014) developed a composite made of epoxy reinforced with Napier grass fibers using hand lay-up technique. The addition of Napier grass fibers improved the epoxy impact resistance, with the best results at 20% of volume fraction. They also compared how treating the fibers with alkali solution (NaOH) could improve impact resistance. Treated fibers showed higher impact strength, with the best results happening when using NaOH solution at 10% concentration.

4.2 Factors that collaborate to improve NFRPC impact resistance

This review section shows that the use of natural fibers as reinforcements for polymeric matrices increases their impact strength. In most of the researches it was shown that with the volume fraction increment, the impact resistance also increased, with the exception of Mishra and Naik research.

It is also important to note that hybridization made with two types of natural fibers can also improve the composites impact resistance, as in the case of adding jute to the sisal composite and flax to the silk composite. However, it should be noted that the jute addition also meant an increase in the natural fibers total volumetric fraction, which went from 30% to 40%.

Finally, surface treatments increased the NFRC impact resistance, both maleic anhydride and sodium hydroxide solution (at 10%) treatments.

Considering these results and that the impact resistance increases when changing the configuration of the composite from 2D fabric laminate to the 3D fabric preform, the use of these preforms manufactured with natural fibers seems to be promising in applications where impact resistance is required.

5. CONCLUSIONS

We saw in this article that natural fibers are increasingly being used as reinforcements in composite materials, and are mainly used in the construction and automotive industries. The fibers that demonstrate the best mechanical performance are bast fibers such as ramie, flax, hemp and jute. Sisal, which is extracted from the leaves, is also extensively used as reinforcement.

3D fabric preforms produce composites that have some mechanical properties superior to laminate composites made from 2D fabrics. Among these advantages, the highlight is the increase in impact resistance and the very low degree of composite delamination.

Several natural fibers have proven to be suitable for use in composites subject to impact loads. The increase in fiber volume seems to improve impact resistance, and care must be taken so that the excess fiber volume does not prevent the resin from completely filling the composite, which reduces the composite resistance. Fiber treatments improved the impact strengths of all researched fibers.

It is concluded with this work that the use of natural fibers in 3D preforms manufacturing is promising in the fabrication of components that are subject to impact loads during service.

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