AN OVERVIEW: THE PROCESSING METHODS OF FIBER-REINFORCED POLYMERS (FRPS)

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ABSTRACT

A wide range of engineering applications adapts Fiber Reinforced Polymer composite due to its unparalleled advantages. Several promising literature reviews are available on the subject of Fiber-reinforced polymer composite. However, there is no study dedicated to the processing/ fabrication of Fiber-reinforced composite. This article mainly includes various types of processing methods (open and close mold) of FRPs and the future scope of the FRPs. Additionally, destructive, and non-destructive evaluation techniques that are used for conventional composites are included as well. Further, the content of this article reviews some fundamental studies on the subject of FRPs, the established concepts, and some existing contradictions related to the fundamental study that is reported by authors previously.

Keywords: Polymer composites, Fiber-reinforced polymers, Natural fibers, synthetic fibers, open mold techniques, close mold techniques.

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1. INTRODUCTION

Polymer composites are of significant importance due to resistance and low-density stiffness [1]. However, this combination of properties arises from a combination of parent materials in the same polymer composite. The classification of polymer composites is given by the different shapes and orientation of the reinforcement, as shown in Figure Error! No text of specified style in document.. Particle-Reinforced Composites are the most widespread, although less critical than Fiber-reinforcement composites (FRCs). Although high strength, the particles present do not guarantee a significant increase in mechanical characteristics than fiber composites where the fibers bear almost all of the outer load. During the crack propagation, the particles fail to effectively hinder the propagation of any cracks and defects [2]. Fiber-reinforced composites (FRCs) are considered advanced composites based on the concept that

the combination of different materials with fiber can achieve properties that the constituents individually do not present [3]. This concept is applied to create various composite materials with desirable properties superior to conventional ones [4].

Figure Error! No text of specified style in document. Classification of Polymer composites

Figure 1 Classification of Fibers [6].

It is an established fact that the resistance of a given material significantly increases if it is thin fibers. This property is attributed to the high resistance-to-weight ratio (specific resistance) and the high stiffness-to-weight ratio (specific module) combined with the possibility of varying the degree of anisotropy by intervening. The high specific strength of fiber composites is intrinsically linked to the fibers' high strength as shown in **Figure 1** and Table Error! No text of specified style in document. and the low weight of fiber and matrix. Among all FRCs, Fiber-reinforced polymers (FRPs) are one of the largest groups which most commonly used today. FRPs are known for the high rigidity and specific strengths and versatility since different

properties of the final laminate can be obtained by handling the quantity and order of the blades that constitute it. FRPs find applications in structural engineering, with their use ranging from airplanes to sporting goods. The most common FRPs are solid fibers (glass or carbon etc.), fabrics, blankets, or glass rovings soaked in an epoxy thermo-rigid resin matrix or polyester [5].

The literature contains certain good reviews about the subject of polymers or polymer-based nanocomposite. For example, the study of Ahmed et al. [7] counts the tensile and tribological properties. Din et al. [8] and Fu et al. [9] describes the improvement in the strength and stiffness and reduction in fracture toughness by adding polycarbonate and polyamide in glass fiber reinforced composite. Lauke et al. [10], Fu et al. [11]–[14], Mai et al. [15] also discuss the mechanical and physical properties of FRPs. There are two books (Folkes et al. [16]; De et al. [17]) have been published on SFRPs. Folkes et al. [16] wrote the first book with a similar title was published and his book explained some of the principles on which short fiber reinforcements are based and which can be used to produce goods with defined properties. De et al. [17] edited a book on short fiber-polymer composites. Research work on multiple systems that they and other scholars had studied previously was summarized. A special advantage of their book is that it contains valuable discussions on carbon fiber rubber-matrix and components that are frequently used for the manufacture of SFRPs, including fillers, additives, and polymeric materials, were presented and were also short introductions on the choice of raw materials, testing, and assessment of SFRPs.

To the best of our knowledge, the literature has not reviewed dedicated to the study of FRPs processing methods and techniques, therefore this review paper contributes to the literature by reviewing the study of FRPs processing parameters, techniques (open and close molds) and their limitations in the various application sector.

Table Error! No text of specified style in document. Natural fiber Vs Synthetic fiber [6].

Type	Fibers	Densities (g/cm ³)	Tensile strength (MPa)	Young's Modulus (GPa)	Elongation (%)
Synthetic Fibers	Glass	2.5-2.6	2200-3600	65-75	3
	Carbon	1.4-1.8	3000-4000	250-500	1-1.5
	Aramid	1.4	3000-3150	63-67	3.3-3.7
Natural Fibers	Hemp	1.4-1.6	550-900	70	1.6
	Sisal	1.3-1.5	600-700	38	2-3
	Jute	1.3-1.5	200-800	10-30	1.8
	Ramie	1.5	500	44	2
	Cotton	1.5-1.6	290-490	12	3-10
	Flax	1.4-1.5	800-1500	60-80	1.2-1.6
	Coir	1.2-1.5	180-220	6	15-25
	Pineapple	0.8-1.6	400-627	1.44	14.5
	Kenaf	1.45	930	53	1.6
	Bagasse	1.25	290	17	1.8-2
	Bamboo	0.6-1.1	140-230	11-17	5.2
	Abaca	1.5	400	12	3-10

2. PROCESSING METHODS OF FRP COMPOSITES

To manufacture FRPs that meet the design requirements, the distribution of fibers must be uniform within the matrix. In polymer matrices, fiber reinforcement is an efficient method of producing tribologically significant composites. There are different forms of fiber reinforcement available, such as discontinuous or short (chopped) fiber reinforcement, continuous or long (unidirectional) fiber reinforcement, and woven or bidirectional fabric

reinforcement, and these provide a great deal of scope to configure a variety of properties. This is since the high fiber content with resins and the preferential load bearing of the fibers mean that tribological properties are regulated by fiber reinforcement. Besides the type of reinforcement, the orientation of the fiber (parallel, anti-parallel, and natural to the sliding plane) also influences the mechanical properties of FRP composites. Figure elaborates the classification of processing methods of FRPs.

Figure 3 Classification of manufacturing processes for FRPs

2.1 Processing Methods for Continuous Fiber-Reinforced Polymer Composites

Continuous profiles are among the most common semi-finished products used in different manufacturing sectors. They provide the foundation for buildings that deliver high strength, rigidity, and low cost. For example, they can be easily reshaped into various geometries. Furthermore, when they are made of continuous reinforcement fibers with defined orientation, there are some additional advantages, particularly profiles made of fiber-reinforced polymers (FRPs), such as they can be easily reshaped into different geometries. Also, when they are made of continuous reinforcement fibers with a given orientation, they give a much greater ratio of weight/length than profiles made up of others. While in support of FRP profiles, there are compelling aspects. Only a few technologies with a given fiber orientation can generate continuous FRP profiles. Furthermore, they are divided into open and close mold techniques.

2.1.1 Open-Mold Techniques

Open-mold processes are well-established techniques for molding, that are used to manufacture, boats, RV components, truck cabs and fenders, spas, tubs, showers, and other fiberglass composite products. In the matter of part size and design options, open molding is the most versatile, flexible, and virtually limitless in all composite manufacturing techniques. Typically,

the open molding approach is usually used for a wide variety of items that cannot be manufactured in more automated processes e.g. large size, or for parts manufactured in limited amounts that are unable to justify the higher mold costs of automated processes.

2.1.1.1 Hand lay-up

It is the most basic and cheapest process of manufacturing FRPs when we consider the equipment used. The quality of the parts depends on the skill of the operator, which means that the labor has to be qualified. Reinforcement is usually some fiber tissue from one of the materials mentioned above. This fabric is applied to a mold of only one side, usually the female part, carefully adapted to the contours of the cavity, so that the operator then impregnates the resin, sometimes with the help of rollers. In this process, it is difficult to obtain a large volume of parts produced because of the long curing time, and manual processing decreases their speed [18]. Another negative aspect is that because the air trapped in the resin is removed manually, and it is difficult to obtain low levels of Porosity. Besides, the production of the part in harsh environments can lead to the degradation of its mechanical properties due to its exposure. An example of this degradation is the corrosion of glass fibers in the polyester matrix when exposed to NaOH [19]. The most used matrices are epoxy and polyester because they cure at room temperature. To maintain a high-quality surface, a layer of pigmented gel is usually used in the mold [20].

2.1.1.2 Automated tape laying

25 years ago, ATL was first invented with machines lay continuous fiber strips with width varying from 70-300 mm on to a flat surface in different orientations [21]–[23]. In ATL, thermoset and thermoplastic materials will also be used. Prepreg tape creels are stored near or on the layup machine head for use during development. The ATL unit head usually consists of tape spools, a winder, winder manuals, a compaction shoe or roller, a tape cutter, and a location sensor [21], [24] To keep the ATL head, a multi-axis articulating robot can be used or it can be suspended on a gantry over the tool. The ATL head will have up to 10 degrees of freedom if used on a gantry, with 5 axes on the head and 5 on the gantry [25]. The first step to composite development is to use a soft silicone roller to inject a starting volume of prepreg tape on the mold. After this is completed, according to CNC paths that describe the geometry of the component, the computer deposits the tape. The tape is automatically sliced by spinning or pinching blades at the end of the lay-up. Depending on the size of the component being made, the velocity at which the system does this is variable. This process is similar to conventional AM technologies where the material is deposited in compliance with a given CNC path. ATL is an important means of manufacturing composite structures for large non-complex sections (flat or single curvature) [23]. A second shaping stage is used to mold the ATL laminate sheet to manufacture non-flat structures [22]. The biggest problem with this is that the laminate tends to warp and buckle during the forming process if the curvature is too large [23], [26], [27]. The study has shown that the tackiness of the prepreg and the tow distance are the two key components that affect buckling [23]. The way to combat buckling is to impose a minimum machine turning radius based on the material and tow width used [28].

2.1.1.3 Filament winding

Filament winding is a type of composite processing, in which controlled amounts of resin and fibers are rolled with the desired orientation along with a rotating chuck and cured to produce the FRP. This process is widely used to produce high-quality structural FRPs since the deposition of continuous fibers is controlled with reproducible precision [29]. This technique was initially used to produce pressure vessels, water tanks, and chemicals. Nowadays, applications include aircraft fuselage, wing sections, radomes, helicopter rotor shafts, high-

pressure pipes, sporting goods, and structural applications of all kinds [30]. The winding operation is a primary manufacturing technique to produce structural elements in fibrous composites of the polymer matrix, which have the form of a revolution surface. A semi-manufactured product (uncured preform) of filaments, yarns, tapes, or impregnated fabrics is rolled layer by layer with controlled tension on the chuck or in previous layers. By varying the angle of winding or deposition of the tape, it is possible to control the angle of reinforcement of the fibers in the FRP in each layer [31]. The desired winding angle of the fibers is reached by controlling the displacement speed of the transverse car and the rotation speed of the chuck [32]. The fibers can be impregnated with resin before they are rolled, and the tension applied to them in the winding can be adjusted to control the compaction of the FRP. The shift of the eye and the rotation of the chuck are synchronized by numerical control equipment similar to those used in machining lathes [33]. The composite is then cured, and the chuck is removed later. Kaynak et al. [34] investigated the processing parameters of FRP pipes reinforced with continuous fibers produced by the filament winding technique. For the work, the "split-disc" tests were performed for the samples produced with two epoxy resin systems, five types of fibers (three glass fibers and two carbon fibers), and five different angles. When determining the tensile strength and elastic modulus of these samples, three process parameters were evaluated: resin type, fiber type, and winding angle. It was found that the use of different epoxy resin systems did not significantly influence, while the use of carbon fibers compared to glass fibers and the use of winding angles greater than 60° increased the performance of the FRP considerably for cross-loading. Hernández-Moreno et al. [33] studied the influence of the number of layers in the filament winding on the mechanical response of composite cylinders manufactured glass/epoxy fibers. They evaluated tubular samples with coincident winding angles in the center ($\pm 55^\circ$) and at the ends (90°), and thickness variation between samples (4.4 mm for thin wall and 12.6 mm for thick wall ones). The samples were exposed to external pressure in the hyperbaric test chamber. Different analytical models were evaluated to predict pressure buckling for thin-walled cylinders (diameter-to-thickness ratio, d/t , 25), and the modeling had satisfactory results of the same order of magnitude as the results obtained experimentally. Mertiny et al. [35] experimentally analyzed the influence of the applied tension during the filament winding process (26.7 and 44.5 N) on the physical and mechanical properties for the manufacture of FRP pipes glass/epoxy fibers, being the pipes with the same programming of winding angles at $[\pm 60^\circ/3]_T$ and six layers. The samples were tested with internal pressure application utilizing a fluid, to analyze the biaxial loading and create the functional and structural failure envelopes of the sample. The results showed that the mechanical strength of the material depends on the degree of tension of the fiber, and higher winding stresses led to more excellent resistance against pipe failure under loading conditions dominated by fibers, while the loading dominated by the matrix phase is reduced by the reduction of tensioning in the winding. Mertiny et al. [35] also produced FRP tubular structures with variations in the winding angle and compared them with a basic winding configuration in terms of rupture stress and stress-strain curves. They concluded that multi-angle composite structures provided considerable advantages over a single winding angle.

2.1.2 Close-mold techniques

Close-mold techniques enable more excel polymer composite parts to be produced in a shorter time, with less waste and largely reduced emissions. Not only does the closed-mold process minimize emissions, but it also optimizes the ratio of glass to resin, creating a better quality laminate. To make precision parts, a wide range of industries use closed mold technologies. Aerospace, shipping, and leisure are among the sectors. Closed molding is a viable option when identical parts need to be produced multiple times from composites.

2.1.2.1 Compression mold

In this process, a sheet of FRP with fiber, and resin, or a mass of this material, is positioned inside the heated mold, which closes and due to its pressure and temperature, curing the FRP. When you put a mass of this FRP in the mold, called BMC (bulk molding compounds), it is usually made of chopped fibers and resins and offers mechanical properties limited to the FRP. When using an SMC sheet (sheet molding compound), the resulting FRP has significant improvements due to the possibility of the orientation of the fibers of this [36]. In the case of reinforced thermoplastics, a chap called GMT (glass-mat reinforced thermoplastics) is used similarly. Some FRPs manufactured using SMC can replace metal panels of cars, with the advantage of being lighter and corrosion-resistant [36]. Additionally, SMC compression molding may present fewer problems of homogeneity and dispersion of nanomaterials in the matrix. The dispersion of cellulose nanocrystals, for example, can dispense with the use of part of the fiberglass and reduce the weight of the FRP by up to 7.5% [37].

2.1.2.2 Resin transfer molding (RTM)

It is pointed out as the most appropriate means of mass production of small and medium-sized composites in the FRP system and with complex geometries [38]. In this process, as well as in infusion molding and manual lamination, a fabric is positioned on the female part of a mold. Still, unlike them, the male part of the mold is embedded on the fabric and sealed, which can be preceded by the application of an agent that assists in the extraction of the FRP, or a gel coating that gives a more excellent surface finish. Thus, the resin is injected at high pressure into the heated mold, from 2 to 20 bar. After the resin is cured, the FRP is then extracted from the mold [18]. The difference between process RTM to RIM is that in RTM, the cure is given by thermal activation in the mold while in the RIM, the cure happens by mixing the reagents. Also, the cure in RTM is much slower [39]. In RTM, more complex FRPs with high fiber content can be manufactured, with well-defined surfaces on both sides of the FRP, but it is more costly due to the need for another part of the mold. Some variants of this process are used, such as the auxílio of a vacuum pump, which increases the pressure gradient [18]. It is a process used by BMW to produce reinforced ceilings with carbon fiber M3 and M6. It is also used in the manufacture of components for Mercedes SLR [38]. Due to the drop in the speed of the resin as it flows through the mold, some research is carried out to improve its infusion by the tissue and enable the mass production of large FRPs. Japanese company Toray Industries reports developments in the RTM process that would reduce the molding cycle from 160 to 10 minutes [40]. Another research promises to reduce time in production by changing the direction of resin infusion. Instead of this flowing through the plane of the piece, it would flow through its thickness with the aid of multiple vacuum doors [41].

2.1.2.3 Pultrusion

The pultrusion process consists of a continuous bundle of impregnated fibers passing through a final heated output of the composite and curing the plunging material. This process is limited to constant cross-sections such as rods, pipes, and gutters. The pultrusion works well with fast curing resins and is a low-cost method for the high production of FRPs with cross-sections. Palanivelu et al. [42] researched the progressive deformation in pultruded FRP pipes in glass/polyester fibers and glass/vinyl ester fibers subject to axial impact load. All samples were manufactured with fibers in the longitudinal direction to extrusion, with the outer and inner layers covered with a blanket of glass fibers for better finishing. The effect of tube geometry, facial cutouts, deformation rates, and resin type was analyzed for energy absorption. In all cases, circular section tubes showed more energy-efficient than squares, and samples of glass fibers/vinyl ester absorbed more energy than those manufactured in polyester. Han et al. [43] investigated by numerical simulation thin-walled pipes (40 mm diameter and thickness of 3.174

mm) by the pultrusion process. The pipes consisted of pultruded FRPs of unidirectional glass fibers and epoxy, covered by braiding (carbon or glass)/epoxy at $\pm 45^\circ$. Results showed that pultruded pipes without the addition of braiding layers showed a higher energy absorption capacity, but exhibited non-symmetric failure mode, while hybrid pipes (glass and carbon fibers) exhibited a more desirable mode of failure, being more efficient candidates for energy absorption structures under service conditions. Hancox [44] produced in his work rods and pipes in FRP pultruded carbon/epoxy fibers. The shear resistance properties were evaluated in the samples containing faults and voids. The author suggests that the effects of failures on the mechanical properties of the samples are dependent on the geometry of the sample and are not significant for rods. He also reported that shear resistance reduces by up to 30% to empty volume values around 5%.

2.1.2.4 Continuous lamination

Composite products such as opaque and transparent flat or corrugated paneling, truck trailer paneling, refrigerator liners, sanitary paneling, road signs, and other related products are developed through continuous lamination. Usually, up to 10 feet (3 meters) wide high production machines mix reinforcement and resin on plastic film that is pulled through the process. To facilitate mixing and exclusion of air that is normally achieved by compaction rollers, a second plastic film is added over the reinforcement and resin. In an oven, the cure is complete. Panels are shortened to the width and sliced to length automatically. A corrugated sheet is created during cure by forming shoes that keep the compacted sheet in the shape needed. By using embossed carrier films that are later removed, special surface effects are produced. In the process, both mat reinforcements and rovings chopped by separate large cutters are used. Polyester and acrylic modified polyester (for better water resistance) are the main resins for ongoing lamination.

2.2 Processing Methods for Short Fiber-Reinforced Polymer Composites

Composites of a short fiber-reinforced polymer (SFRP) have flexible properties and are relatively inexpensive to process. The great interest in composite materials has led to questions regarding the rapid use of global metal capital. In automobile, aerospace, maritime, housing, construction, microelectronics, business equipment, rugged consumer products, athletic goods, household applications, and others, SFRPs represent a large portion of the composites used. Thanks to their low cost, fast processing and superior mechanical properties over the parent polymers, the traditional manufacturing techniques of SFRP make the large-scale manufacture of components simple and affordable. In particular, compared to the production of continuous fiber-reinforced polymer composites produced by time-consuming processes that are not appropriate for high-volume manufacturing, SFRP composites are only one class among a range of composite materials that, due to their broad uses and comparatively simple manufacturing techniques, are experiencing a high growth rate.

2.2.1 Open-Mold Techniques

2.2.1.1 Spray Lamination

Just as in the manual lamination process, spray lamination is applied to a one-sided mold, making the process cheaper. Also, it cures room temperature, taking too long for mass production. Unlike manual lamination, a compressed air gun launches into the mold cavity a mixture of resin with minced fiber, that is, the pre-positioning of a fiber tissue does not occur. Despite the long curing time, the process of deposition of the fiber mixture with resin takes the primary time than that of manual impregnation; however, the fact that the fiber is chopped gives the resulting FRPs limited mechanical properties [18].

2.2.2 Close-Mold Techniques

2.2.2.1 Reactive Injection Molding (RIM)

In this process, monomers and low viscosity oligomers are mixed at high pressure and injected into the mold cavity, where the polymerization process takes place, large parts can be removed from the mold in 1 or 2 minutes [45]. The difference between RIM and injection molding is the fact that a thermosetting polymer is used. Concerning composite materials, when minced fibers are incorporated into the mixture of reagents and injected into the mold next to the mixture, the process is called Reinforced Reactive Injection Molding (RRIM). When pre-formed tissues (mesh) are inserted into the mold before the reagents are injected, the process is called Structural Reactive Injection Molding (SRIM) [18].

2.2.2.2 Long Fiber Injection (LFI)

Traditionally, polyurethane composites reinforced by glass fibers were produced by RIM. This process, however, has some disadvantages such as an excessive number of steps, handling of glass fibers, waste of material, and much time required throughout the process. Driven by these issues, Krauss-Maffei developed the long fiber injection (LFI) process in 1995 [46]. The process consists of mixing chopped fibers up to 100mm with polyurethane during their pouring into the mold cavity by a robotic head. All in one operation, Polymeric reagents are mixed at high pressure in a chamber. They are then transferred to an annular tube, which has a pipe in its center. The reagent mixture is discharged around this pipe by the robotic head. At the same time, the glass fiber is unrolled and chopped when passing through two rollers, one with blades and the other flexible, and then discharged through the tube that passes through the mixture of reagents, mixing with them with the help of an air jet. In the LFI system, the complete mixture of the reagents with the fiber is a fundamental feature for the quality of the FRP. For this, a cleaning system was developed especially for LFI, eliminating any trace of residue that could hinder the flow of reagents and fibers, worsening the quality of the mixture. In this system, the fiber rate introduced into the polymer is controlled by the rolls mentioned above. In this system, different areas of the mold may have different concentrations of fiber, controlling the city fleece of the roller that stings the fibers. The robotic head allows the entire area of the mold to be covered, including the most prone areas, due to its reorientation capacity [47]. Another significant advantage of this process is the elimination of paint technology, which is a problem in FRPs manufactured in compression molding that requires a class A finishing, presenting bubbles in the paint. In the LFI process, a colored thermoplastic film is previously inserted into the mold, over which the mixture of fiberglass and polyurethane will be poured, eliminating the need for painting. Besides, the necessary FRP is more comfortable to obtain directly from primary suppliers, in the case of fiberglass and polyurethane, without the need for pre-formed fabrics or some mixture of components [48].

2.2.2.3 Bladder Molding

Bladder molding allows the production of FRPs with hollow geometries that have high geometric complexity and intrinsic rigidity. The BIM technique uses an external mold and an internal bladder, to define the shape of the required FRP. The low pressure used in the process (~10 bar) allows the use of simple tooling, being a skillful process for producing FRPs in thin-walled composites with revolution surfaces. Works have shown the use of this technique for the manufacture of small components such as bicycle frames, tennis rackets, suspension arms, and pressure vessels [49]. The technique is economically competitive when compared with other processes for manufacturing hollow parts, which overcomes some limitations of some processes such as filament winding, centrifugation, and pultrusion [50]. The technique involves placing the preform around a polymeric chuck, known as the bladder [51]. After the pre-shape

has been placed, the mold is closed, the bladder is inflated, and presses the composite material against the outer mold, which is sequentially heated in an autoclave or greenhouse for the healing of the piece [52]. Lehmann et al. [53] described the different techniques with nuclei, especially with the use of bladders. Various tests of drapability and impregnation proved that the internal pressure of the bladder strongly affects the permeability of the reinforcement. Different materials can be used for the bladder, giving up a higher, equal, or smaller diameter than the larger diameter of the component to be processed. The materials can be rigid (polyolefins) or flexible (silicone), and an auxiliary core can be used to pre-fix the reinforcement which leads to the possible variations that can be combined for each specific molding design [54]. Unlike relatively thick silicone bladders that have to be removed from the part, thin-walled bladders can remain inside the FRP without adverse effects on properties [55]. The Plastics Processing Institute (IKV) in Aachen, Germany, combined bladder molding with RTM for the manufacture of hollow components with complex geometry. In this process, the disadvantages of the adhesion and low drapability of the pre-impregnated are overcome with RTM. Unimpregnated fabrics are placed around the bladder and preformed into the mold before resin injection to impregnate the reinforcement. A tubular input channel system has proven its value for molding hollow FRPs [55]. Bernet et al. [51] used the bladder molding technique, bladder with commingled yarn, polyamide-12 (PA12) mixed with carbon fibers in braiding preforms. Polyamide-12 thermoplastic threads give speed to the process, as it requires a short time for impregnation and removal of the part and is predicted by a consolidation model. The precision of the model was demonstrated by comparing experimental measurements in pipes processed with braiding commingled in carbon/PA12 fibers. Results showed porosities lower than 0.5% with consolidation times of approximately one minute. Anderson et al. [56] studied a variation of the bladder molding process, an innovative production method known as Bladder Assisted Composite Manufacturing (BACM). Unlike conventional bladder processes, BACM utilizes an internally heated bladder to provide the consolidation pressure at the required curing temperature. The viability of the present process is demonstrated by the manufacture of laminated FRP pipes, using various pressures in curing and number of layers.

2.2.2.4 Vacuum Bagging

It is a curing process in which the FRP obtained has low porosity, allowing higher fiber volume. After the resin manually impregnates the fiber, the piece in the process is inserted into a bag, which is sealed. A vacuum pump takes the air out of this bag, which causes the pressure exerted by the atmosphere to act on the resin and make it impregnate better in the fibers. In this process, the resin curing is faster and can be performed by placing the sealed bag in an oven, further accelerating the process. Although the FRPs produced in this process have better mechanical properties and are a faster process than seen so far, it is more costly due to the acquisition of bags and materials to seal it, as well as the need for a vacuum pump. Besides, the size of the weigh-ins is limited to the bags used. In case the process is carried out in an oven, there will be additional expenses [18]. This technique can be used hybrid with manual lamination, where outer layers of fiber and resin are first applied to the mold manually and cured. Inner layers are applied to the former and cured by vacuum. This hybrid process has the advantage of producing parts with better mechanical properties than manual lamination and lower cost than only in vacuum lamination [57].

2.2.2.5 Resin Infusion Molding

Unlike RTM and RIM processes, Infusion molding uses only a part of a rigid mold, where fiber fabric is positioned. Where the second part of the rigid mold would be positioned, a flexible film is placed. Two doors are included in this film, one for the resin inlet and one where a vacuum pump is connected. The resin process should be of low viscosity [18]. Research shows

that preheating of mold and fibers reduces resin viscosity and does not affect FRP properties, causing the resin to flow faster. There are fewer voids in the material [38]. Some research seeks to demonstrate the use of this technique in the production of large parts of vehicles, seeking to demonstrate the benefit of its use in the manufacture of the structure of a vehicle in a single case of resin infusion, producing an FRP that meets mechanical, impact, low cost, and aerodynamic requirements. The result was a vehicle with remarkable performance in the Euro Eco-marathon, which took place in Malaysia [58]. Laboratory tests point to the sensible improvement of matrix properties in the case of the insertion of nanographene particles and carbon nanotubes; however, the adoption at industrial levels has as one of the obstacles to the effect of filtration in processes such as infusion molding and resin transfer. This filtration is due to the retention of particles by the fibers, increasing their concentration near the resin inlet into the mold [59].

3. CONCLUSION

Thus, FRPs are the future of the modern world and predominant where traditional composites are facing hardship to find their places in engineering industries like aeronautical and aerospace, automotive, racing, cycling, civil construction, marine, etc. Last few decades, FRPs have been playing a vital role in the medical field, especially as Dental material. Most of the research in the dental field has been focusing on particulate filler resin composites and in medical biomaterial research to biodegradable polymers [60]. Over the past 15 years, FRPs designed for reinforcing dental resins have been introduced, such as fiber-reinforcing ropes, braids, ribbons, and bundled fibers. Clinicians and researchers have investigated the embedding of these FRPs into dental resins and found that they provided for an increase in certain physical properties and more durable tooth stabilization and can potentially resolve many of the problems related to traditional isotropic dental and medical materials such as removable dentures, fixed dental prostheses, root canal posts, filling, Facial prostheses, and surgical applications.

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