



Review of Manufacturing Process of Natural Fiber Reinforced Polymer Composites

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Abstract: Lately, natural fibers have been gaining consideration in development of composites due to its biodegradability, availability and low-cost compared to synthetic fibers. Natural fibers are renewable sources, biodegradable, environmentally friendly and effortless in machinery. In this paper, the manufacturing of production for natural fiber reinforced polymer composite (NFRC) will be reviewed. These including injection molding, resin transfer molding (RTM), pultrusion, sheet molding compound (SMC) and compression molding processing technique. Injection molding and compression molding are mostly used in industry. This is due to the machines give a good finishing surface of the products and low cost.

Keywords: Natural Fiber Reinforced Polymer, Composite, Injection Molding, Sheet Molding Compound, Pultrusion

1. Introduction

Fibers are a class of hair-like material that discrete elongated or continuous filaments. It also can be matted into sheets to make a product. Fibers can be divided into two: natural fiber; origins which from animals, plants or mineral and synthetic; man-made fibers from textile industries and petrochemical. The example of synthetic fibers is such as carbon fiber, aramid and glass fiber (Naidu, A.L et al., 2017; Furqan et al., 2015; Husin et al., 2015). Fig. 1 shows the types of commercially natural fiber that have been used. The natural fiber derives from plants, animals and minerals. Kenaf, jute and hemp from stem of plants are widely being used in NFRC (Balla et al., 2019; Mamat. S et al., 2019 ; Rusli et al., 2017 ; Furqan et al., 2015 ; Idicula et al., 2009; Shahidan et al., 2020).

The fibers are usually mixed with polymers, either thermoplastics or thermosets, to form NFRC. This will enhance the properties in final component such as strength and stiffness. Natural fibers are a natural source and the replacement for strengthening and supplementing the polymer-based material. The manufacture of composites from natural fibers became a fascination issue due to the increases of environmental awareness. Natural fibers are competent material compared to synthetic materials because of their related goods for applications with less weight and energy conservation.

The fatal motivations the natural fibers are choose in the polymer composite's applications due to its biodegradability, able to recycle and good properties such as strength and stiffness (Balla et al., 2019; Rusli et al., 2017;

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Shahidan et al., 2020). Then, the natural fiber also could reduce the damage in machinery regarding the physical of natural will deteriorate while in the manufacturing process. Other promising factors are saving production costs, less the usage of the manpower and not complicated machine setting needed.

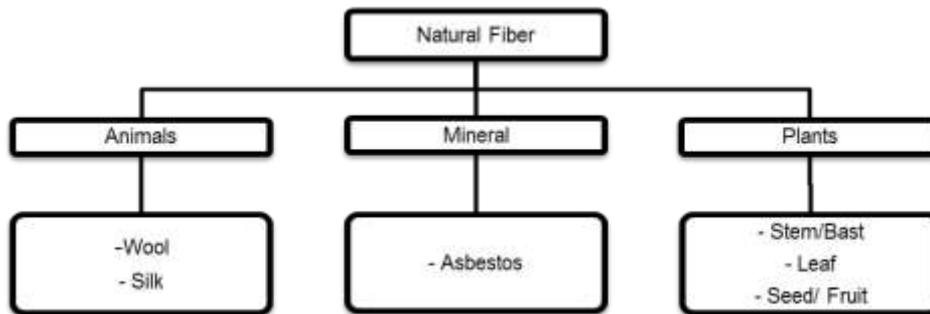


Fig. 1 - Types of family in natural fiber

There are several manufacturing processes to fabricate a product from NFRC's. These include injection molding, pultrusion, sheet molding compound, compression molding and resin transfer molding (Holbery et al., 2006; Oksman, 2001; Furqan et al., 2015). The types of processes are depending on the requirements and will determine the properties of the final product. Compared to the tensile and flexural properties, resin transfer molding is higher than injection compression molding process. Based on research banana/sisal hybrid fiber-reinforced polyester, the tensile strength using resin transfer molding is 1621 MPa which higher than compression molding 1347 MPa. Meanwhile for flexural strength also resin transfer molding is higher than compression molding which 2276 and 2247 MPa, respectively. However, the impact resistance strength of polymer composite made from resin transfer molding is lower than the compression molding process (Maries et al., 2009; Annamalai et al., 2014). The details for the processing are discussed as sub-section follows:

i. Injection Compression Molding

Compression molding by injection is the process of injecting the molten resin (plastic) into the mold and then shaping the injected resin by clamping the compression-closed mold as seen in the molding machine. This technique ensures a uniform distribution of the resin, achieves severe precision in the degree of detail on the surface and gives the finished product extra durability in term of strength.

Furthermore, to allow compounding using injection compression molding, the feedstocks must be in granule shape which is from short fibers bundles due to the tendency of the natural fiber in absorbing moisture, the feedstocks must be dried before being processed in the machine. The granules are poured through the chamber. Then, the granules are compressed, heated, and then pressed into the mold with a twin-screw or single-screw extruder. Once an enough quantity of material is collected, the molten materials are poured into the preheated mold to form a composite component through the nozzle. The molten material will fill the cavity of the mold as shown in Fig. 2.

Pressure and temperature should be maintained in the mold until the product is solidified and cooled. The products are trimmed before running a test. This process is required for around 3 to 5 minutes per product. To get a right finishing product, the first three products are rejected. This is because the first three products usually do not fill the cavity and a few bubbles of air can be detected on the surface of the product. Before and after using injection molding, the screw extruder must be cleaned using a purging compound such as polypropylene (PP) to avoid contaminants for the other products.

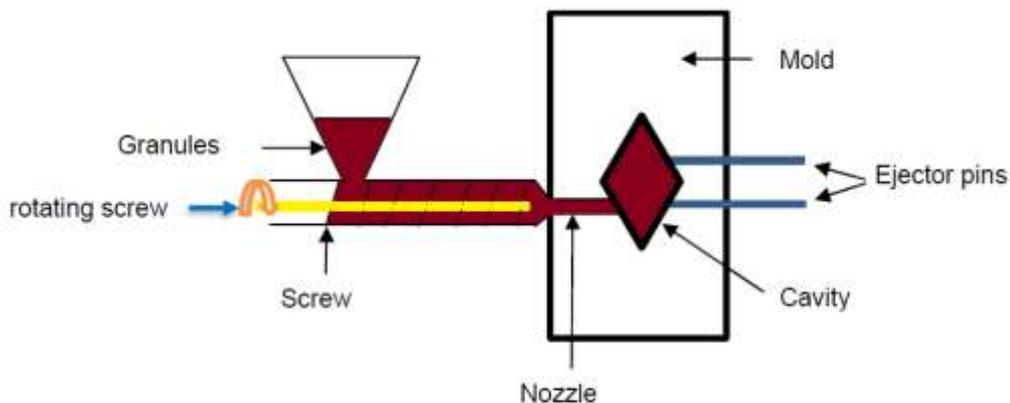


Fig. 2 - Injection molding machine

Next, the important parameters of injection compression molding during the process are melt temperature, screw speed and pressure. Injection molding provides a few advantages such as good finishing surface, high repeatability and less material loss (Balla et al., 2019). The disadvantage of the injection molding process is lower tensile strength than most thermoset systems. Nevertheless, the most expensive mold and some injection molding polymer requires sealing the surface after molding to prevent oxidation.

Furthermore, the challenges of injection molding are the processing time largely depends on the cooling period and thus a low temperature of the mold must be taken to ensure a limited processing time. It is necessary to follow temperatures largely below the glass transition temperature (most of the polymers) is a constraint in the manufacture of very thin parts (in the micrometric range) where the rapid cooling of the product leads to a significant increase in viscosity preventing the complete filling of the cavity. In addition, rapid cooling cannot produce uniform and efficient cooling output if the shape of the molded component is free of charge (Liparoti et al., 2019; Park et al., 2020).

ii. Pultrusion

Pultrusion is a continuous process that creates a constant cross-section profile, a variant known as pulforming which allows some variance to be incorporated into the cross-section. Pultrusion is a continuous production process for composite production by molding die using continuous reinforced fiber impregnated with a thermosetting matrix to form a composite profile. The pultrusion technique restricts the form of materials which can be produced using the method. Only materials with a cross-section of a consistent thickness can be formed by pultrusion (Fairuz et al., 2014; Memon & Nakai, 2013).

The pultrusion process is shown in Fig. 3. First, fibers with the necessary resin viscosity are removed from the creel into a resin tub. Next, polymer solution is put in the resin bath containing the, pigment, filler, catalyst, polymer resin and releasing agent. The fibers are then led through a guide plate with impregnation of fiber and resin. Upon reaching a heated die, fibers are curing to remove excess resin. The heating process takes place with a pultrusion die around 150°C and the temperatures are controlled by a thermal couple sensor that interacts with the heaters. This is to ensure that the temperature is sufficiently good and to avoid overheating which may cause defects in the pultruded profile.

The puller clamped the fibers with the rubber clamp, and the profiles are drawn across the cutter and cut according to the required lengths. The pultrusion's product can generate higher strength parts with fiber content of up to 80 wt%. This process also allows the continuous production of the composite material in the form of long sections (Chen et al., 2019; Fairuz et al., 2014; Ojha et al., 2019; Zoller et al., 2019).

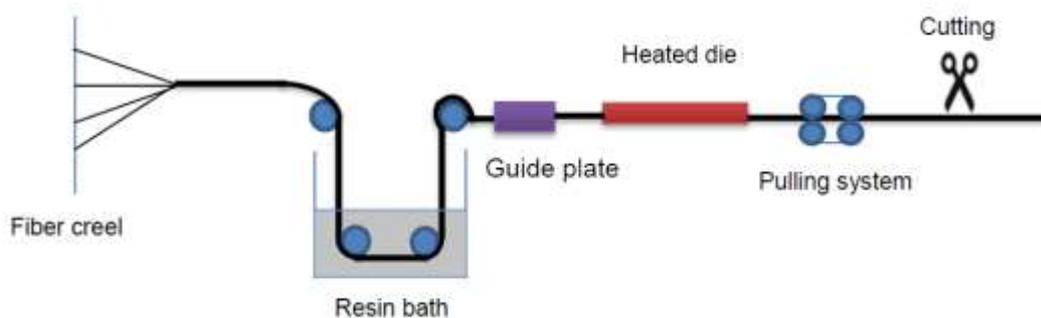


Fig. 3 - Illustration of pultrusion process

A few factors that need to be considered during pultrusion process to make a high-quality product are die temperature, pulling speed and resin viscosity. However, the most important factor during the process is curing temperature. Furthermore, this manufacturing process can fabricate high-performance products which commonly produce in aircraft, aerospace and corrosion resistance parts (Fairuz et al., 2014). Thermosetting resins have dominated the pultrusion industry due to their rapid curing and effective low viscosity impregnation.

However, it has many drawbacks, which are fragile, prone to effects, and cannot be recycled. Besides, several thermosetting resins will be released during the pultrusion process, which is contrary to environmental protection policies. Thermoplastic polymers are environmentally friendly, and it can improve impact strength, damage tolerance, durability, and repair capability. However, the relatively high viscosity (100–10,000 Pa.s) of molten thermoplastics limits the impregnation capability, resulting in poor product quality (Chen et al., 2019; Zoller et al., 2019).

One of the challenges of manufacturing process using pultrusion is aramid, carbon and glass fiber reinforced polymer indicated that fiber damage occurred only during the manufacture of carbon fibers. This is because carbon fibers exhibit high modulus strength and low ultimate strain, rendering them fragile and vulnerable to injury. Next, the pultrusion problem arises in the impregnation of the fiber layer with viscous thermoplastic melts. Many researchers

found out that using carbon reinforced thermoplastic held in blends yarns showed a lack of impregnation. Then, thermodynamic problems need to be resolved to achieve a reproducible, safe impregnation method with high-quality reinforcements. Since carbon fibers are generally hydrophobic, they are usually not compatible with water-based systems. There are several types of treatment, such as plasma treatment, silica deposition and calcite coating, can be used to increase the wettability of carbon fiber and to enhance adhesion between the fibers and the matrix (Lapointe & Laberge Lebel, 2019; Mechtcherine, et al., 2020).

iii. Resin Transfer Molding

Resin transfer molding (RTM) is a composite manufacturing process by which a preformed stack of fibers or dry woven fibers is put in a mold cavity, which is then sealed. The resulting polymeric materials are also used in carbon and glass fiber reinforced composites (FRPs), epoxy laminates and nanoparticle reinforced polymer structures. RTM has also been operated at lower pressures and temperatures. By monitoring the polymerization rate by means of the resin injection rate, the monomer rate, the activator rate and the catalyst rate, rapid cycle time can be achieved, resulting in a double to triple increase in productivity (Choi et al., 2019; Dammann & Mahnken., 2019).

Fig. 4 shows resin transfer molding (RTM) machine process. Fiber sheets or reinforcement are placed in the mold, and the mixture of epoxy resin and hardener is injected into the fibers and pressurized while a particular gap is maintained. Carbon fibers are commonly used as reinforcement. The resin is injected and pressurized into cavity at high temperature (200°C) and high pressure (160 bar) via a mixing head. Therefore, the impregnation direction of the resin is vertical, and the resistance to resin impregnation occurs in the vertical direction rather than in the horizontal direction.

Thermosetting resins, such as epoxy resins and polyester, which have excellent impact strength and higher fracture capacity, along with better fiber impregnation than other thermosetting resins (Choi et al., 2019; De Farias et al., 2020; Han et al., 2019; Mohamed et al., 2020). As a result, the resin spreads through the mold, impregnating the fibers. To get a right finishing product, there are a few parameters that should be controlled when using RTM, such as injection pressure, temperature, the viscosity of fluid and volumetric fraction of fiber.

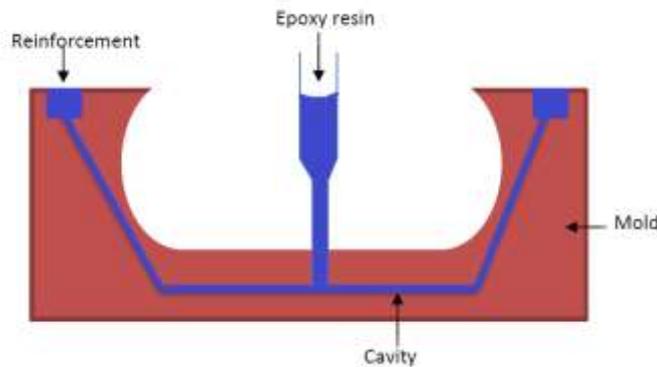


Fig. 4 - Resin transfer molding process

Other than that, the advantages of RTM are good surface finishing of the product, less void content and low tooling costs (Maries et al., 2009). However, the drawback of this method is that the mold cavity restricts the size of the component, the high tooling costs and the restriction of the reinforcing of materials due to the flow and resin saturation of the fiber (Iran et al., 2013). Furthermore, RTM is mostly used in manufacturing industries, such as aerospace, military, automotive, and sports equipment.

The challenges from this manufacturing process is inadequate molding due to the lack of mold design and the forming of so-called 'race tracking channels,' there may be dry spots, void formation, and poor surface quality. Air-leaks are frequently created in welding lines such as in the resin-contact area resulting from the front collision between opposite flows of the resin. Therefore, in order to enhance the consistency of the products, the welding line area must be decreased or removed as both thermoplastic and thermoplastic resins are used (Landi et al., 2020).

iv. Sheet Molding Compound

In the automotive, aerospace, telecommunications, oil, recreational and industrial/consumer industries, SMC is a versatile composite material. SMC can be defined as fiberglass reinforced thermosetting compound in sheet form that usually rolled into coils interleaved with plastic film to prevent self-adhesion. SMC consists of a maturation agent, filler, catalyst, mixed resin and mold release agent on two moving polyethylene film sheets (Asadi et al., 2019; Nony-Davadie et al., 2019). According to Alnersson et al., glass or carbon fibers are widely used as fabrics for reinforcement. These fibers can be grouped into tows and woven or stitched together to form fabrics. Different types of resins, including thermosets such as polyester, vinyl ester and epoxy, and thermoplastics such as nylon, are used as matrixes.

The SMC process begins when a continuous fiberglass strand or known as 'roving', is chopped to the desired length. The strands are put on the bottom layer of a paste made of resin and filler. The paste and the fiberglass strand are moving through the machine, onto the carrier film. The top layer of the resin and the filler paste sandwiches the fiber to the bottom layer of the paste, and the top layer of the carrier film is covered. Fiber and paste sandwich is then compacted by a series of rollers to form a continuous sheet of molding compound. The SMC paste contains polymerized cross-linking resin, fiber reinforcement, filler, and various additives. Via a continuous line process, this resin paste is combined with fiber reinforcement to create a pre-preg stored between thin, low-temperature plastic sheets for later use in finished parts molding. The SMC structure is shown in Fig. 5. During the molding process, the treatment of the paste is advanced to produce the final rigid product (Orgéas et al., 2011; Han, Q et al., 2019).

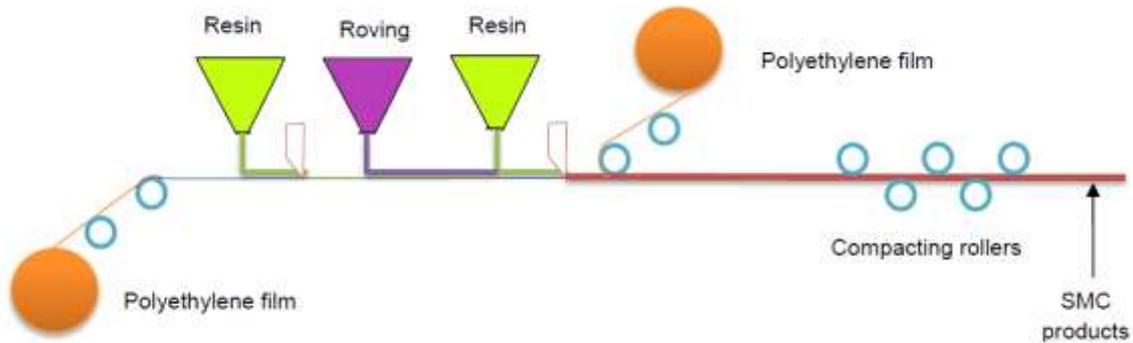


Fig. 5 - Sheet molding compound

SMC has good mechanical properties, environment friendly, and heat resistance compared injection molding. Besides, SMC can give a good surface on finishing products, low cost and it can allow complex and large shapes processing on rapid cycle time. However, it also has certain drawbacks which are the continuous thickening of the paste and the emission of styrene affecting the curing reaction (Hohber et al., 2019; Orgéas et al., 2011).

Next, the amount of small fiber volume and the discontinuity of fibers with a finite fiber length, strength and stiffness of the material are limited and is not adequate for use in structural components for most applications. The solution is the application of carbon fibers to the sheet molding compound matrix. However, the usage of carbon fibers enhances the production costs. Another approach focuses on hybrid sheet molding compounds for which discontinuous glass or carbon fiber sheet molding compounds are locally reinforced and combined with carbon fiber prepreg or dry textiles during compression molding. This combination allows good mechanical properties in highly load-bearing parts of a system or structure, but retains high design flexibility, low manufacturing costs and cycle times (Schäferling et al., 2019).

v. *Compression Molding*

Compression molding is a high-volume and high-pressure method to produce high-strength, fiber-reinforced composites and is widely used to produce automotive parts. This process is suitable for development and preparation of two or more types of polymers.

As seen in Fig. 6, the compress molding process begins with the positioning of composite materials on the cavity of lower mold and then compressed by the mold's core side to deform and fill the cavity. The compression pressure is maintained high until solidified by the component. The mold is then removed, and it extracts the product. The molds are made of hard metal, such as tool steel that can be polished and chromium-plated to achieve a good finishing surface. Before use the compression molding, the mold must be preheated first around 10 to 15 minutes with suitable temperature according the materials that had used to achieve pressure heating curing process (Jaafar et al., 2019; Park & Lee, 2012).

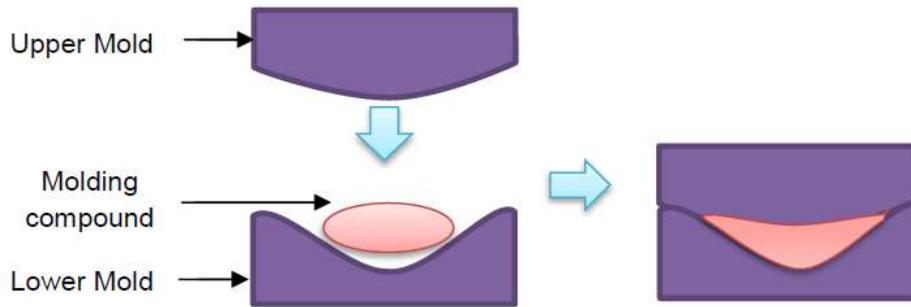


Fig. 6 - Compression molding compound

Next, the important parameters when using compression molding are viscosity and polymer matrix sheets between stacked fibers. This is essential to obtain a good bonding and impregnation of fibers and matrix. Heat and pressure are also important to make sure the fibers do not degrade or break during the process (Balla et al., 2019; Fairuz et al., 2014). Compared to resin transfer molding or injection molding, the advantage of compression molding for large products. Therefore, it is also ideal for high-priced materials and least-cost tooling, extraordinarily little material waste and perfect for most sizes. However, for the disadvantages of compression molding, it does not suit due to the restricted material flow inside the cavity also makes it difficult to remove vacuums, air traps, and knit lines in the development of more complex parts. The mold of compression molding also can be damaged and it takes long time during processing time.

The suitable materials such as glass fiber mat thermoplastics (GMT) are also used in the production of compression molding. Nevertheless, due to the complicated micro-structure of the fiber and fiber-resin matrix interactions, the process of compression molding is still exceedingly difficult to understand, and it is difficult to produce a uniformly compressed GMT product. After pressing, heating, and solidifying, the resin material can be plasticized and dispersed, and the mold cavity can be filled. Hence, compact composite material will finally produce.

The composite materials formed by this manufacturing process have a good microstructure and good strength however the viscous resin has good fluidity when pressed at high temperatures and is easy to adhere to the mold. For example, laminated carbon fiber reinforced matrix composites, which the bonding force between the carbon fiber layers becomes extremely low when the resin is at high temperatures, the isolation of the fibers and the defect of displacement can easily occur. This would have a significant effect on the microstructure and mechanical properties of laminated composite materials (Huang et al., 2019; Ma et al., 2018). Each process has its own advantages and disadvantages when using it in industry. The advantages and disadvantages of each manufacturing process are summarized in Table 1.

Table 1 - Advantage and disadvantage of manufacturing process of composites

	Injection Molding	Pultrusion	RTM	SCM	Compression Molding
Advantages	Good finishing surface. Repeatability. Less material loss.	Environmentally friendly. Can improve impact strength, damage tolerance, durability, and repair capability.	Good surface furnishing. Less void content. Low tooling costs.	Good mechanical properties. Environmentally friendly. Good heat resistance. Good surface furnishing. Low costs. Allow complex and large shapes processing on rapid cycle.	Less tooling costs Suitable for large products only. Ideal for high-priced materials.

Disadvantages	Lower tensile strength than most thermoset systems. The mold is expensive. Some materials require sealing the surface after molding to prevent oxidation.	Fragile. Prone to effects. Cannot be recycle.	The mold cavity restricts the size of component. Restriction of reinforcing of materials due to the resin saturation of the fiber.	Continuous thickening of the paste. Emission of styrene affecting the curing reaction.	Do not suitable for complex products. The mold can be damaged. Long processing time.
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2. Conclusion

The injection molding and SMC are most broadly utilized in manufacturing such as automotive due to the natural fibers form which are short, particle form and granulate size. Furthermore, the RTM and pultrusion can be manufactured for complex shape and mostly used in applications such as boat and table. The long and continuous fibers are preferred to limited design of the shapes such as rectangular, circular circle, hollow pipe, bar, and beam. A natural fiber material has contributed to being environmentally friendly and low cost compared to synthetic fibers. Hence, NFRCs can be developments and discovered in automotive, aerospace and construction industry application with the suitable manufacturing process via the type of natural fibers availability.

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