Challenges on the synthesis, characterization and machining of green fiber plastics: A review

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Abstract. The need of composite material in industries is increasing day by day due to its competent characteristics with the traditional materials. The plastic composite materials made of polymers are used as structural elements in different fields. The present day polymeric composites are made by mainly focussing the natural fibers as reinforcements because of their usability, properties and cost. While preparing these new composites, utmost care must be taken for synthesizing the natural fibers and polymers before fabrication. Also, during the fabrication of a new composite the process and parameter selection plays a vital role. Once the composites are fabricated, it needs several machining operations as secondary processing. This paper gives a detailed review of different challenges during the synthesis, fabrication, characterization and machining of natural fiber reinforced plastic composites.

1. Introduction

A composite material is prepared by adding two different elements together in the form of a solid shape. The two elements are the matrix which provides the shape and the reinforcements which gives the characteristics [1, 2]. During the initial stage artificial reinforcements are used but later, due to the usability, characteristics and cost green fibers obtained various natural sources are utilized for reinforcements and are said to be green fiber plastics (GFP) [3-4]. The green fibers cannot be used in the original form. It requires some kind of synthesis in order to exhaust the useless substances possessed by it and this may be achieved by using suitable pre-treatments [5-9]. Polymer composites are widely utilised as structural and supporting components in automobile, railway, aircraft and marine industries. They are majorly used in making bodies for boats and radial fan blades [10, 11]. On the other hand, in view of the weight reduction of automobile parts, the GFP is superior to conventional material and therefore, the fuel consumption and efficiency may also be enhanced [12].

Fabrication of GFP is also a big challenge as the operating conditions majorly influences the properties of the composite. Among the several methods, wet layup is a mostly used fabrication technique to prepare the material in the form of slabs [13, 14]. Filament winding process, pultrusion and resin transfer moulding are other techniques to make the composites in different shapes. Once a GFP is fabricated, it requires some secondary operations to bring it in the exact size and shape [15, 16]. At the time of machining, the GFP is prone to damage in many ways and these damages affect the characteristics of the composite. Considering the machinability, a GFP must adapt itself to easily
machine and also with lesser damages. Hence, this review presents the outcome of synthesis, characterization and machining of GFP carried out by the researchers.

2. Green fibers and their properties

Natural fibers are taken from three bases. They are plant, animal and mineral. Fibers from plants are obtained from its stem, leaves, fruits, seeds and roots. In the same way the fibers from animals are extracted from hair, leather, internal organs etc. Mineral fibers are derived from the earth and are pre-treated before usage. Some important natural fibers with their properties and chemical compositions are listed in Table 1.

| Fiber        | Density (g/cm³) | Diameter (µm) | Tensile Strength (MPa) | Young’s Modulus (GPa) | Failure strain (%) | Chemical Composition (%) |
|--------------|----------------|---------------|------------------------|-----------------------|--------------------|--------------------------|
| Sisal        | 1.5            | 50-80         | 511-635                | 9.4-22                | 2.0-2.5            | 84.93                    |
| Nettle       | 1.5            | 20-80         | 650                    | 38                    | 1.7                | 53.826                   |
| Banana       | 1.35           | 50-250        | 500-550                | 12-20                 | 5.6                | 63.64                    |
| Coir         | 1.2            | 10-16         | 175                    | 4-6                   | 30                 | 43                       |
| Cotton       | 1.5-1.6        | 20            | 287-597                | 5-13                  | 7-8                | 92.95                    |
| Flax         | 1.5            | 50-100        | 345-1035               | 50-70                 | 2.7-3.2            | 62.71                    |
| Hemp         | 1.1            | 120           | 389-900                | 35                    | 1.6                | 77.07                    |
| Jute         | 1.3            | 260           | 393-773                | 23-27                 | 1.4                | 63.24                    |
| Kenaf        | 1.31           | 106           | 427-519                | 23-27                 | 1.8                | 65.7                     |
| Pineapple    | 0.8-1.6        | 25-34         | 400-627                | 14.5                  | 1.44               | 71.6                     |
| Linen        | 1.4            | 12-60         | 800                    | 50-70                 | 2.7-3.5            | 82                       |
| Abaca        | 1.5            | 10-30         | 400                    | 12                    | 3-10               | 56.63                    |
| Henequen     | 1.49           | 180           | 430-580                | 10.1-14.5             | 1.6                | 77.6                     |
| Ramie        | 1.5            | 34            | 560                    | 24.5                  | 2.5                | 91                       |
| Oil Palm     | 0.7-1.55       | 150-250       | 248                    | 25                    | 3.2                | 65                       |
| Isora        | 1.2-1.3        | 10            | 500-600                | -                     | 5-6                | 74                       |

3. Synthesis of green fibers and fabrication of composites

In order to enhance the surface properties of a natural fiber, it is subjected to a series of pre-treatment. These pre-treatments include, cleaning of fibers with distilled water, soaking of fibers in chemicals followed by heat treatment. A research work studied the influence of three different chemical namely sodium hydroxide, hydrogen peroxide and benzoyl chloride on vetiver fibers and proved that all chemicals have the capacity to improve the properties of the natural fibers [22]. Silane treatment is also a treatment method which helps to improve the tensile strength of the natural fibers and in turn the GFP [23]. Each chemical treatment has a different effect and as a result, it will enhance the characteristics of the reinforcement. Treating with acetic anhydride is a good way to improve the fiber-matrix bonding strength and thereby enhance the tensile strength and thermal stability of the GFP [24]. Several research works are carried out by giving different chemical treatments to green fibers and some of them are listed in Table 2.

A GFP may be fabricated in different ways. Hand Layup or wet layup is the oldest and easiest technique for fabricating parts like bath tubs, bodies of simple boats and furniture. This method has been used by many researchers due to its simplicity [25-27]. Compression moulding is the next level to the hand layup method in which, the load is applied by the ram after layering the composite
constituents in the mould. This method has got several advantages over the hand layup method like, uniform resin coverage, good bonding and compaction [28]. Automobile components are manufactured using press moulding technique in which the vacuum pressure level decides the quality of component. A nominal range of pressure creates products with high strengths whereas high pressure decreases the strengths of the composite [29]. Vacuum bag moulding is another important method which suits well for preparation of hybrid composites. It has been proved that, this method promotes the cross linking of fiber and resin when a setting time of more than 70 hours is maintained [30]. Composite tubes and rods are manufactured by using filament winding method and resin transfer moulding is highly suitable for producing GFP [31].

Table 2. Chemical treatments and their influence in research

| S. No | Green fiber | Chemical for treatment | Properties achieved                          | Ref  |
|-------|-------------|------------------------|----------------------------------------------|------|
| 1.    | Vetiver     | Sodium hydroxide       | Tensile, flexural, compression and impact strengths | 3    |
| 2.    | Luffa       | Sodium hydroxide       | Tensile, flexural, compression and impact strengths | 7, 14|
| 3.    | Kenaf       | Sodium hydroxide       | Tensile, flexural and impact strengths         | 32   |
| 4.    | Date palm   | Sodium hydroxide       | Tensile strength                             | 33   |
| 5.    | Kapok       | Sodium hydroxide       | Tensile strength and chemical resistance      | 34   |
| 6.    | Banana      | Acrylic acid           | Flexural and impact strengths and water absorption   | 35   |
| 7.    | Kenaf       | Maleic anhydride       | Tensile and impact strength                   | 36   |
| 8.    | Hemp        | Sodium hydroxide       | Bonding strength                             | 37   |
| 9.    | Basalt      | Silane                 | Tensile strength                             | 38   |

4. Characterization of GFP

Green fibers are used majorly with artificial fibers in order to enhance the characteristics of the composite material. Thus they work effectively in hybrid form and this has been proved by several researchers. It has been proved that, the composition of all fibers must be equal in order to get a maximum strength of the hybrid composite material [7]. As each fiber has its own best property, the use of multiple fibers improves majority of the composite properties. Hence, the advantage of hybrid composite is that, a design engineer may decide well in advance about the property of the composite by properly selecting the fiber [9]. In an experimental study, it has been reported that the use of sisal fiber along with glass increased the impact strength and tensile strength of the composite. Also, it is concluded that, a combined use of green fiber and artificial fiber is more advantageous than the green fiber and green fiber combination [39].

Table 3. Optimum composition of green fiber arrived in research

| S. No | Green fiber | Optimum composition (%) | Properties achieved                          | Ref  |
|-------|-------------|-------------------------|----------------------------------------------|------|
| 1.    | Flax        | 40                      | Flexural and impact strengths                 | 44   |
| 2.    | Menkuang    | 20                      | Tensile strength                             | 45   |
| 3.    | Aloe vera   | 30                      | Tensile, flexural, compression and impact strengths | 46   |
| 4.    | Bagasse     | 30                      | Tensile strength                             | 47   |
| 5.    | Bamboo      | 50                      | Impact strength                              | 48   |
| 6.    | Coir        | 15                      | Tensile, flexural, compression and impact strengths | 49   |
| 7.    | Sisal       | 40                      | Tensile and flexural strength                 | 50   |
| 8.    | Hemp        | 20                      | Tensile and compressive strengths             | 51   |
| 9.    | Kenaf       | 70                      | Flexural strength                            | 52   |
| 10.   | Oil palm    | 20                      | Tensile, flexural and impact strengths        | 53   |
| 11.   | Jute        | 30                      | Tensile, flexural and impact strengths        | 54   |
| 12.   | Basalt      | 20                      | Compressive strength and Hardness             | 55   |
| 13.   | Pine needle | 30                      | Tensile, flexural, compression and wear resistance | 56   |
The number of laminas used in a GFP has influence on its characteristics. A study reported that, a double fiber layered composite produces a maximum bending and impact strength than a triple fiber layered composite. Also, it is concluded that in order to increase the strength of composite, an appropriate fiber must be used as top and bottom layers in a composite [40]. The use of artificial fiber as top and bottom layers in a composite and a green fiber as a central layer gives highest strength to the hybrid GFP [41]. The fiber and matrix composition in a composite decides majority of the characteristics of the composite material. Many research works have been performed to study the influence of fiber loading on the characteristics of the composite material. A research showed that, 30% okra fiber is the optimum composition for achieving highest bending and tensile strength [42] whereas in another research, it is proved that 20% composition sisal fiber is the apt proportion to acquire maximum mechanical properties [43]. The optimum composition of fiber arrived in some important research works are shown in Table 3.

5. Machinability of GFP

As a GFP after fabrication require few secondary operations to make it suitable for assembly. Therefore machining is mandatory and the ease of machining a GFP is to be studied [57]. The ease of machining a GFP depends upon the property of green fiber present in the composite as well the property of the matrix used. Thermoset matrices are always harder than the thermoplastic matrices thereby hard matrices produces chips in the form of particles and soft matrices produces chips in the form of continuous threads [58]. A study on the vetiver reinforced vinyl ester composite reported that the presence of green fiber reduces the drilling induced damages to a maximum extent [59, 60]. In another study, optimum conditions have been arrived for machining jute reinforced composite and reported that, a high level of spindle speed, medium level of spindle feed and a medium level of drill size as the optimum values for drilling. In order to arrive at the optimum conditions, any one of the tools of design of experiment is used by all researchers working on the machinability [61]. It is also proved that the green fiber present in a composite has two capacities; one is to improve the mechanical characteristics and other if to improve the machinability of the composite [62-64]. Many research studies have used green fibers along with an artificial fiber and some research has also been worked out with a combination of a green fiber and a metal fiber. It has been proven that, the green works well in respect to both properties as well as in terms of machinability. A research utilised steel fibers as reinforcements along with woven jute and made machining studies. The research reported that, only the factors that can be controlled by an operator of the machine affect the damage of hole to a maximum effect whereas the tool diameter does not influences the damage [65, 66]. A recent research on drilling of hybrid composites concluded that a spindle speed of 1450 rpm, a spindle feed of 0.2 mm/rev, a point angle of 60° and a tool diameter of 10 mm are the optimum combinations for drilling [67].

6. Conclusions

This paper has presented a comprehensive review on the literature pertaining to the green fiber reinforced plastic composites. The challenges faced during synthesis of a green fiber, fabrication of green fiber plastics and the ease of machining have been elaborately addressed. Some of the major conclusions obtained are as follows:

- A green fiber may not be used in its native form. A series of pre-treatment methods are to be followed in order to exhaust the unwanted substances present in it and also to make it suitable for usage as reinforcement in composite.
- Among the several pre-treatment methods, alkali treatment and followed by heat treatment is majorly done by many researchers and they proved that alkali treatment is the best method of chemical treatment for green fibers.
- During composite fabrication, a suitable technique must be chosen in order to adapt the size and shape of the component to be manufactured. Hand layup is one the best and easiest method which has been used by many researchers for fabrication of green fiber plastics.
• During characterization of GFP, the influence of fiber loading on the properties has been reported by many researchers. It has been shown that, a fiber loading between 25 % and 35 % will be an optimum value to arrive best properties.

• Machining associated studies have been conducted by several researchers and showed that the presence of green fiber in a GFP improves the ease of machining and reduces the damages in all forms. Working under optimum conditions will be a suitable technique considering the machinability of GFP.

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