Contemporary Development on the Mechanical Properties of HDPE/Natural Fiber Composites

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Abstract

In today's world, with the critical impact caused due to manufacturing and disposal of man-made fiber reinforced polymer composite, there is always a scope for producing eco-friendly composite. It has vast applications opportunities in the manufacturing sector, such as automobiles, marine, piping, and grocery items. Several natural fibers such as banana, rice, sisal, oil palm, coconut, and kenaf are looked up to nowadays because they are readily available, environment friendly, and have better mechanical properties. Natural fiber will always stand out in developing several industrial products with various polymer matrices. High-density polyethylene (HDPE) plays a key role among many polymers as it acquires numerous benefits such as strength and excellent chemical stability. HDPE has several other advantages, such as being durable, lightweight, and easily machinable, making it usable in medical, construction, maritime, and food. This review article proposed with an objective of mechanical properties of natural fiber reinforced in HDPE and various parameters affecting the structural features of polymer composite, like loading, fiber dimensions, and fiber structure. A critical observation is also done to understand the broader effect of the mechanical properties on varying the fiber wt.% and loading. This review article outlined to survey and collect the earlier works demonstrating the mechanical properties of natural fiber and its polymer composite to give a well-made source of information for performing future research to clarify the properties of synthetic fibers.

Keywords. HDPE, Natural fiber, Processing techniques, Mechanical Properties.

1. Introduction

High-density polyethylene (HDPE) was not discovered till the 1950s. Low-density polyethylene (LDPE) was more utilized [1]. But a requirement of the more strengthened polymer was in demand. Thus, several scientists were much interested in the production of denser polyethylene. The difference between the high density and low-density polyethylene is that HDPE is of higher molecular weight and has less molecular chain branching. The mechanical properties acquired by HDPE are much better than other polyethylene. HDPE has carbon and hydrogen as its main constituent. The higher density of HDPE is due to its long-linear molecular arrangement. HDPE was found to have high temperature-resistant properties[1]. HDPE acquiring certain unique features has vast applications, including grocery items, pipes, fuel tanks, cable insulators. HDPE is mostly used as a base material or so-called matrix because of its greater strength to density ratio. It is also equipped with a better specific strength. It is also very cheap and readily available in the market.

A fiber-reinforced polymer (FRP) has its constituents as a polymer matrix reinforced with strengthened fiber like glass, and carbon forms a composite material. Polymers are basically divided into two groups, thermosetting plastic and thermoplastics. Thermoplastic materials nowadays play a prominent part in bio-fibers; the most widely used thermoplastics are PE, PVC, and PP, whereas epoxy and polyester resins are the most widely used thermosetting matrices [2]. In the recent past, natural fibers as a substitute for additives in polymer composites have gained the attention of several researchers and scholars because of their uniqueness over conventional glass and carbon fibers [3]. The natural fibers are sisal, hemp, kenaf, jute, coir, banana, and many others [4]. Natural fibers have various benefits over the synthetic glass and carbon fibers: low cost, low density, good tensile properties, not hazardous to the body, renewable, recyclable, and biodegradable nature [2]. The polymer composite thus developed has a vast application which includes aerospace, construction, sport, automotive industry, and packaging industry. However, natural fibers are a few limitations reinforced in a polymer composite, which could be the instability between the hydrophobic thermoplastic matrices and natural hydrophilic fibers. This may be a cause for the unfavorable properties of the composite. Hence, there is a requirement to improve the fiber interface by modifying the chemical composition of the surface between fiber and matrix.Many parameters can impact the performance of natural fiber impregnated composite. Hydrophilic behavior is not the only property that affects, but the proportion of additive added a significant effect. There is always a need for more excellent fiber content for acquiring better mechanical properties of the composite. This illustrates the importance of fiber amount added to the matrix. Several works have improved the mechanical properties by increasing the fiber loading [5]. This comparative study highlights the effect of different natural fibers with HDPE as a polymer matrix. It also makes us understand the physical and mechanical characteristics of different natural fiber reinforced HDPE composites in various aspects such as industrial, biomedical, structural, etc.

Thus, the following study provides a basic understanding of the relationship between natural fiber and polymer matrix. Natural fiber has vast application due to its better properties and superior advantages over synthetic fiber in terms of lower cost, weight, and less fiber content.

2. FEATURES OF NATURAL FIBER POLYMER COMPOSITE

There is much variation in the mechanical properties of the reinforcement of different kinds of fibers reinforcement. Certain factors affect the properties: composition, structure, defects, and behavior with the base material. There are certain limitations as mixing natural fiber and polymer has certain ill behavior. It is due to the chemical structure of the matrix and reinforcement. This can be a significant cause of misleading the stress transfers. Hence, there is always a need for chemical treatment for the natural fiber to get an excellent interfacial property. While developing natural fiber polymer composites, there is a creation of a weak bond between the hydrophobic polymer and hydrophilic fiber. This hydrophilic property in the natural fiber is due to a functional group known as the hydroxyl group. This results in inferior mechanical properties.

2.1. *Mechanical Properties of natural fiber polymer Composite*

There are many efficient methods for the natural fiber that can be performed to improve the mechanical properties. Once the foundation is made strong, the polymers can easily have high strength and improvement. Many things have impacted the performance level, such as the position of fiber [6]., fiber strength, physical properties of fibers, etc. Natural fiber Polymer composite is a type of composite with a mechanical efficiency that depends on the interface made by fiber and matrix. Due to this, the stress is transferred from fiber to matrix [7]. Different aspects of natural fibers such as position, moisture absorption, impurities, and volume fraction are several properties that play a role in finding mechanical properties. Natural fiber polymer composites show good mechanical properties compared to a pristine matrix where jute fibers are involved in polylactic acid (PLA). Till now, mostly, there has been a growth in composites where jute is reinforced and showed 121% improvement is found in comparison to pristine polyester [8]. Essabir et al. developed a composite with the inclusion of oil palm fiber and clay particles as reinforcement with HDPE. Clay as reinforced material reduces thermal interruption and with better mechanical properties. Oil palm fiber is hard. Several tests were performed to analyze the properties, The result observed was satisfying, with a hike of 11% in tensile strength. Elastic properties were also enhanced.[9]. Mazur et al. carried out the inclusion of NF with HDPE matrix to assess the effect on the composite. Wood flour, flax fiber, and wall nutshell flour was used with 40% wt.%. The performance was assessed with several tests, namely Differential Scanning Calorimetry (DSC), and roughness test. Growth in density and reduction in impact strength was improved. Significant flexural strength was found with 262% growth. Composites with NF showed a par level of tensile strength of 156% with basalt and 16% with flax fiber [10]. Savini and Orifice studied on the composite produced by HDPE mixed with micro talc. Thermogravimetric analysis, DSC was carried out to check the variability of the composite's nature. ANOVA was also performed for statistical analysis. The elastic property got enhanced. There was a little drop in tensile strength. Hence, talc showed a better composite improvement with increased ductility, toughness, and rigidity [11]. Li et al. developed a composite reinforced with sisal fiber with an HDPE matrix. Sisal fiber possesses high strength and durability, and its composite is also environmentally friendly. The interfacial shear strength of sisal fiber, including the HDPE matrix, was improved.[12]. Yao et al. developed a composite by reinforcing four rice straw components and wood fiber with an HDPE matrix.The result showed a larger storage modulus and a decrease in tensile and impact strength. Heat flow rate also showed variation. The recycled HDPE and its derivative had much better moduli with respect to virgin HDPE [13]. Mohanty and Nayak developed a composite of bamboo fiber reinforced HDPE. Tensile, flexural, SEM, and heat deflection temperature tests were carried out. The tensile strength was found to be 25.27MPa and flexural strength 27.86 MPa.[14]. Panthapulakkal and Sain prepared a composite with agro-based residue as reinforcement material in the HDPE matrix. Tensile strength showed an improvement. The percentage improvement in strength and stiffness of wheat straw is 47% and 36%, respectively [15]. Table 1 depicts much improvement in tensile properties and flexural and impact strength of HDPE on being reinforced with different natural fibers.

Table 1. Natural fiber reinforcement-based HDPE composites

Matrix	Reinforcement	Matrix Size	Reinforcement Size	Result	Ref.
HDPE	Char	Density = 0.957 g/cm^3	-	32 % rise in tensile properties.	[16]
HDPE	Oil Palm Fiber	Grade HD-6705	10 cm in length	11% rise in tensile strength	[9]
HDPE	Basalt Fiber	94% Biobased Content	40 wt. %	590% rise in young modulus	[10]
HDPE	Micro Talc	Density of 0.957 g/cm^3	60 wt.%	200 % rise tensile strength	[11]
HDPE	Sisal Fiber	Density of 0.96 g/cm^3	100-300 µm	Significant Increase in IFSS.	[12]

3. PROCESSING TECHNIQUES FOR THERMOPLASTIC MATERIALS

The processing of natural fiber composites is affected by several variables, including the kind of fiber, the volume fraction of the fibers, and the temperature. The moistening effect between the fiber and matrix must be reduced before processing. Other factors affecting composite performance are length, aspect ratio, and chemical proportion. The temperature that must be maintained while processing should also be addressed. Temperatures beyond 200°C should be avoided if the product is not to disintegrate prematurely. The most used methods are compression, injection, and extrusion molding [17-19].

3.1. Compression molding

Since the 1990s, compression molding has been the most common method of processing thermoplastic materials. As time went on, demand for lightweight and high-performance materials grew steadily. In this method, materials are heated to a high temperature before being poured into a mound hole. Afterward, these are squeezed and warped by the mold's middle portion while the cavity is subjected to high pressure [17]. It should be subjected to significant pressure until the mold is released and the composite formed reaches a solid-state. For the mechanism to perform well, the heating time, the pressure exerted, and the cooling period must all be regulated. Sheet molding, which is a kind of compression molding, is among the essential processing procedures for the production of polymer composites [18]. It is necessary to inject a fluid mass of a specific resin into the plastic film before it can be used to cut the fibers. Figure 1 illustrates a clear visualization of each component of the compression molding press. The charge or resin is placed in the mold as shown below, giving the final composite the required shape to be developed.

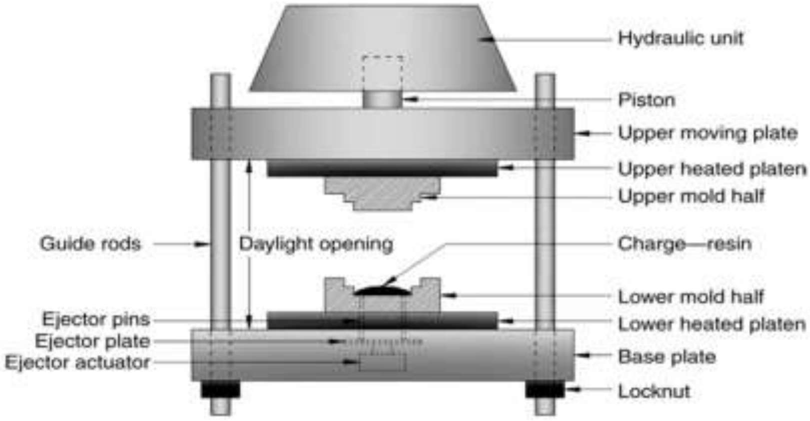

Figure 1. Major parts of a compression molding press [19].

3.2. Injection molding

When mass manufacturing of polymer composites is required, this is one of the processing methods used. The process initiates with feeding the granules of polymers in the hopper. After that, the melting process is completed by a heating procedure done at high temperatures. The liquid components are then pumped into an empty cavity. In the mold, the molten shape solidifies and is extracted using a split die mold [20].

3.3. Extrusion molding

Extrusion molding could be a widely used manufacturing industry procedure to produce or develop natural fiber composites. The reason behind its importance is the high stiffness and strength of the polymer composite. This process gets started by keeping the polymer material in the shape of pellets [21]. After which, they are given heat to get converted into a molten state. Hence it gets heated up, so it is made to cool down.

Figure 2 exemplifies a brief description of the life cycle of natural fiber. Initially, the raw fiber gets processed into intermediate products like fiber mats, fleece, etc., then into the final product. The final product after usage, when it becomes of no use and is referred to as waste, gets decomposed into fiber crops after several chemical processes. Hence, fiber extraction is finally done. This process continues cyclically.

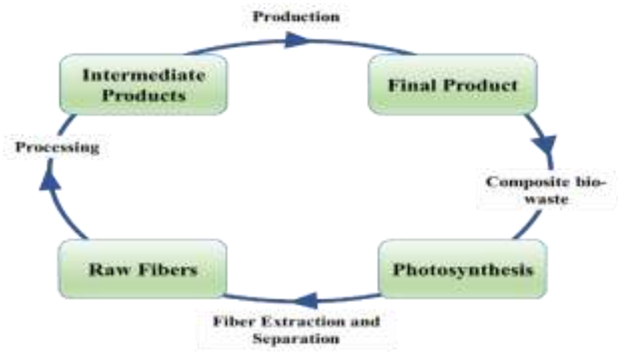

Figure 2. Life cycle of natural fiber.

4. Applications of Natural Fiber Reinforced Polymer Composites

Natural fiber composites have been reported to be primarily employed in the automotive, construction, aviation components, packaging, electrical parts, and biomedical sectors due to their eco-friendly nature, superior mechanical qualities, and lightweight nature, among other factors. Due to a few drawbacks, such as a lack of endurance in wet environments, such as piping and boats may eventually be replaced with glass fiber reinforced composite (GFRC) [22]. In 1941, Henry Ford was the first person to use flax and hemp fibers in the automobile industry [23]. In the construction area, natural fibers are employed to produce load-carrying elements such as beams, roofs, walls, and bridges. For safety purposes, jute fiber composites are used in indoor parts housing and outdoor housing [24].

5. Conclusion

The most striking features of natural fiber are cost-effective and environment-friendly, making it a better option and replacing conventional fibers like glass and carbon as an additive in the polymer matrix. HDPE stands out to be a better matrix than other polymer matrices such as LDPE, Polypropylene and Polyester because of its high strength and hardness. HDPE could be utilized for pipes, biomedical implantation, packaging and sporting equipment etc. One of the major concerns encountered in today's world is solid waste management. HDPE-based composite reinforced with natural fiber is most effective due to its eco-friendly behavior and is easily decomposable. Various natural fibers can be added for developing new and advanced composites, such as sisal, wheat, rice etc. There are many processing techniques available for the development of the composite, under which some are discussed as per the requirement. The above discussions in this review article had already shown that natural fibers reinforced with HDPE have greater tensile strength, modulus of elasticity, and bending strength. The strength of the HDPE-based composite is also much dependent on the fiber loading, which shows improvement up to a certain level on increasing the wt. %.

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Biographies

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