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Polymer matrix-natural fiber composites: An overview

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Abstract: The study of polymer matrix composites had become an important topic for academic and industrial research. The current thrust for materials which are environmental friendly and biodegradable made researchers to focus on alternate options to synthetic materials. One major area of research in this direction is in the area composites of polymers with natural fibers. These composites exhibit moderate to good mechanical properties. This overview briefs about the use of polymers for different natural fiber composites. This review is expected to provide a general overview for the materials selection for the design of composite materials with improved properties.

Subjects: Chemistry; Materials Science; Composites; Polymers & Plastics

Keywords: natural fibers; thermosets; thermoplastics; composites; mechanical properties

1. Introduction

Due to rapid growth in the manufacturing industries, there is need for materials which have better properties in terms of strength, stiffness, density, lower cost with improved sustainability. The composite materials are one of the materials which possesses such properties. Over the past decades, polymers have replaced many of the conventional materials like metals in various applications. This

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PUBLIC INTEREST STATEMENT

There is an increasing demand for environmentally sustainable materials. Among them biodegradable materials are one area where researcher focusing on bio based materials. Many modern applications require the use of polymers because of obvious benefit it offer, but majority of them are nonbiodegradable and hence there are environmental challenges when used in large quantities. This issue could be partially addressed by making partially biodegradable composites of polymers with natural fibers.

is possible because of the advantages the polymer offer over conventional materials. The most important among them are the ease of processing, lightweight, higher productivity, and in cost reduction. For many of these applications, the properties of polymers are modified using fillers and fibers to suit the high strength modulus requirements. Natural fibers are extracted from various plant and animal sources. Few examples of natural fibers extracted from the plants which are cellulose based include cotton, flax, and jute. The animal fibers are protein based, include wool, mohair, and silk. The use of plant based natural fibers as reinforcement agent in polymer composites has been the one of the focus area. Natural fiber reinforced polymer matrix composites could be cheaper, tougher and environmental friendly, however the potential of such fibers for polymer composites have not been developed fully (Al Maadeed, Kahraman, & Khanam, 2012; Deborah & Chung, 2017; Nilza, Virgo, & Buchanan, 2008; Sreekala, George, Kumaran, & Thomas, 2002; Thakur, Singha, Kaur, Nagarajarao, & Liping, 2010; Venkateshwaran, Ayyasamy, Alavudeen, & Thiruchitrabalam, 2011). The polymer matrix used in the preparation of composites are classified into thermoplastics and thermosetting based on the type of bonding present in them and the detailed classifications are shown in the Table 1.

The polymer matrix composites (PMC) are composed of various types of organic polymers consisting of short or continuous fibers with the variety of reinforcing agents which makes it possible to improve the properties such as fracture toughness, high strength and stiffness. The PMC is made in such a way that the mechanical loads applied are supported by fibers. The function of the matrix is to adhere the fibers together for the efficient transfer of load between them (Cao, Wu, & Cent, 2008). A polymer matrix reinforced with natural fibers consists of a higher resistance and the interfacial bonding between them help to maintain their chemical and mechanical identities. In general, the fibers are the main members of the charge carriers, while the matrix retains them in place and at the desired orientation, it acts as a means of transferring the charge between them and protects them from environmental damage (Akil, Omar, & Mazuki, 2011; Ashori, 2008; Kim, Yang, & Kim, 2004; Leao, Tan, & Caraschi, 1998). The production of simpler and easier polymer matrix composite materials is desirable when compared to that of ceramic matrix composite, carbon matrix or metal matrix composites from viewpoint of easier fabrication. The use of thermoplastic polymers for engineering applications are more common due to their excellent chemical resistance, good mechanical properties and lower cost. One major drawback of such polymers are they are nonbiodegradable after the end use which could be addressed to certain extent by making composite materials of polymers with natural fibers (Deborah & Chung, 2017; Tajvidi, 2005). Both, thermoplastics and thermosets have certain advantages and disadvantages as matrix materials in composite preparation. The role of chemical treatments on composite properties were reviewed in detail in other publications (Kalia, Kaith, & Kaur, 2009; Kabir, Wang, Lau, & Cardona, 2012).

Table 1. Major polymers used as matrix for composites

Polymers	
Thermoplastics	Thermosets
Nylon	Phenolic
Cellulose acetate	Epoxy
Polystyrene (PS)	Polyester
Polypropylene (PP)	Polymide
Polyethylene (PE)	Polyurethane
Polycarbonate (PC)	
Polyvinyl chloride (PVC)	
Polyether-ether ketone (PEEK)	
Acrylonitrille-butadiene-styrene (ABS)	

2. Thermoplastic based natural fiber composites

2.1. Polypropylene (PP) based composites

Among various thermoplastic polymers, polypropylene is perhaps one of the most widely used because of its moderate to good mechanical properties. Hence, it is an obvious choice as the matrix material in the preparation of natural fiber-reinforced composites. These materials possess moderate dimensional stability, high temperature of thermal deformation and flame resistance. The recyclability of these materials is an advantage which will reduce disposable waste and therefore economical. The recovered polypropylene showed higher density, lower porosity and water absorption property with a high dimensional stability relative to the composites and native polypropylene, which also showed excellent mechanical properties such as strength and tensile strength (Berglund, Ericson, & Karger-Kocsis, 1995; Butylina, Martikka, & Kärki, 2011; Chattopadhyay, Khandal, Uppaluri, & Goshal, 2011; Shubhra, Alam, & Quaiyyum, 2011). These composite materials based on polypropylene showed higher flexural strength when compared with polypropylene. Mechanical properties such as tensile strength, tensile modulus and impact strength of the unidirectional composites based on polypropylene reinforced coconut fibers reported to increase with higher fiber loading. The composite reinforced with up to 30% by weight have an ideal set of mechanical properties. The chemical treatment of coir fiber showed improved mechanical properties and lesser water absorption tendency in composite materials which is attributed to the improved adhesion between coconut fiber and polypropylene matrix material (Cruz-Ramos, 1986; Espert, Camacho, & Karlson, 2003; Haydar & Beg, 2014).

In general adhesion between thermoplastic polymers and bamboo, sisal fibers were also reported to improve on treatment of the fibers with sodium hydroxide. To improve the adhesion between hydrophilic cellulosic fibers with hydrophobic polypropylene matrix, the natural fibers were treated with maleic anhydride, maleic anhydride copolymer and vinyltriethoxysilane. These treatments were reported as beneficial in improving mechanical properties. The composites based on natural fibers with thermoplastic materials such as polyphenylene oxide (PPO) were also reported (Bajpai, Singh, & Madaan, 2012; Cantero, Arbelaz, Llano-Ponte, & Mondragon, 2003; Trigui et al., 2013). The natural fiber reinforced polypropylene thermoplastic composites were prepared to study the sliding wear and frictional characteristics. The pin on disc apparatus was used for the study which revealed that wear resistance was better with natural fiber with polypropylene as matrix (Arrakhiz et al., 2013).

2.2. Polyethylene (PE) as matrix material

The advantages of using PE as the thermoplastic matrix was studied by fabricating the PE -maize fiber composites. This material presented the reasonable thermal and mechanical properties. Furthermore, the use of maize fibers, as reinforcements in HDPE, gave the affinity of the maize fibers for HDPE; it also contributed to the decrease in the thermal diffusivity and thermal conductivity with the fiber content (Trigui et al., 2013). The tensile, flexural and impact strength of hybridized kenaf and pineapple leaf fiber (PALF) reinforced high-density polyethylene composites were also reported. The observation was made that the tensile strength of the PALF was superior to that of kenaf because of higher cellulose content which increased the tensile strength and Young's modulus. Similarly, Kenaf fiber improved impact and water absorption properties of the composites. Thus the hybridization had its effect where the PALF and kenaf helped in tremendous improvement in mechanical as well as water absorption property (Aji, Zainudin, Abdan, Sapuan, & Khairul, 2012). The effect of the thermoplastic/bagasse fiber ratio on the physical and mechanical properties of low density polyethylene (LDPE) and high-density polyethylene (HDPE) composites was investigated. It was observed that the mechanical and physical properties deteriorated significantly when the bagasse fiber beyond 50% in both LDPE and HDPE composites (Youssef, Ismail, Ali, & Zahran, 2009).

The pineapple leaf fiber (PALF) with different length (long and short fibers) and fiber content (0 to 25%) were prepared and characterized. This study revealed the longer fibers were stronger than shorter fibers and also the tensile strength increased with increase in the fiber content. This was

mainly due to the interfacial bonding between the PALF and polymers which lead to the higher strength of the composites. The scanning electron micrograph (SEM) of the fractured samples revealed that the longer fiber were dispersed homogeneously in the polymer matrices better than shorter fibers (Chollakup et al., 2011). The composites were laminated by employing different process steps namely drying, cutting, mixing, compounding, pelletizing and injection moulding. These composite samples with 10–40% weight percentage of the fibers were selected to study their thermal and mechanical properties. The material characterization was performed on a temperature range that extends from 0 to 120°C. The results revealed the decrease in the thermal diffusivity and thermal conductivity due to incorporation of the maize fiber (Trigui et al., 2013). The coconut fiber reinforced with HDPE without using any compatibilizer and modification of the fiber when fabricated showed higher mechanical properties in comparison to HDPE matrix. The mechanical properties were reported to increase with increase in the coconut fiber content (Singh & Palsule, 2013).

Doim fibers reinforced with LDPE composite were chemically treated and the continuous strands of these fibers were extruded and evaluated for their thermal and mechanical properties. The enhancement of the mechanical properties of composites were reported, however at higher loading the results show a slight decrease in the properties (Zarate, Aranguren, & Reboledo, 2003).

2.3. Polystyrene (PS) based composites

Sapuan et al., studied mechanical properties of sugar palm fiber reinforced high impact polystyrene. The fiber loading was made with five different weight percentages mixed with high impact polystyrene to form the composites. The method adopted for composite fabrication involved melt mixing and hot press. The tensile property evaluation revealed that increase of sugar palm fiber content in high impact polystyrene matrix showed better tensile strength and modulus (Leong, Thitithanasarn, Yamada, & Hamada, 2014; Sapuan & Bachtiar, 2012). The modification of the fiber surface was done using rather difficult graft copolymerization of methyl methacrylate onto the fiber surface. The samples of prepared composites were subjected to mechanical and thermal studies which revealed that composites reinforced with grafted fiber showed better properties than the pure polystyrene. The untreated and treated sisal fibers reinforced with polystyrene was analysed for dynamic and thermal stability which revealed that the sisal fiber degraded before polystyrene matrix and the composites are more stable than both composites (Hujuri, Chattopadhyay, Uppaluri, & Goshal, 2008; Thejvidi, Shekaraby, Motiee, & Najafi, 2006).

2.4. Polycarbonates (PC) based composites

Polycarbonate (PC) is a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonate is used in engineering applications which require strength and also with added advantage of transparency. They are easy to mold and get thermoformed. The extracted tamarind fruit fibers were chemically treated and then the fibers were coated with the polycarbonate for surface treatment and polymer coating were found to improve the tensile and thermal stability of the fibers. The moisture content of the polycarbonate-coated fibers was lower than that of the uncoated fibers. These materials are of important because the PC is likely to be one of the largest volume engineering thermoplastic surpassing the nylon, because of the excellent toughness, high thermal resistance, glass-like clarity, and good processability of polymer composites (Freitag, Fengler, & Morbitzer, 1991; Maheswari, Reddy, Muzenda, & Rajulu, 2012; Schnell, 1964; Wood, 1989).

2.5. Polyvinyl chloride (PVC) based composites

The need for more economical and biodegradable materials which have better properties like mechanical strength, good durability, low maintenance, resistance to termites, and better fire resistance over traditional materials. Wood plastic composite materials are such materials which are used extensively in the building industries. PVC due to its compactibility with the natural fibers, less cost, durability, chemical and flame resistance has become more appropriate material to build structures and in other construction works. The coconut fiber-filled polyvinyl chloride/acrylonitrile styrene acrylate blends had the higher impact strength and thermal properties than that of the wood-PVC composites when fiber content was not varied. The tensile property of the polyvinyl

Table 2. Some major properties of thermoplastics matrix materials

Thermoplastics	Density (g/cm ³)	Tensile modulus (GPa)	Tensile strength (Mpa)	Melting temperature (°C)
Polypropylene (PP)	0.90–0.91	1.1–1.6	20–40	175
Polyethylene (PE)	0.91–0.95	0.3–0.5	25–45	115
Polyvinyl chloride (PVC)	1.38	3.0	53	212
Polystyrene (PS)	1.04–1.05	2.5–3.5	35–60	240
High density PP	0.94–0.97	0.5–1.1	30–40	137

chloride/acrylonitrile styrene acrylate blend reported to decrease with decrease in the fiber content (Cappucci, 2009; Jiang & Kamdem, 2004; Klyosov, 2007;). Some of the main physical and mechanical properties of thermoplastics used in the natural fiber composite preparation are presented in Table 2 (Cantero et al., 2003; Freitag et al., 1991; Hujuri et al., 2008; Jiang & Kamdem, 2004; Klyosov, 2007; Maheswari et al., 2012; Rimdusit, Damrongsakkul, Wongmanit, Saramas, & Tiptipakorn, 2011; Schnell, 1964; Thejvidi et al., 2006; Trigui et al., 2013; Wood, 1989; Zarate et al., 2003).

3. Thermoset based natural fiber composites

Thermoset polymers are also used as a matrix material for most structural composite materials. The single biggest advantage of thermoset polymers is that they have a very low viscosity and can thus be introduced into fibers at low pressures. Thermosets are processed by simple processing techniques such as hand lay-up and spraying, compression, transfer, resin transfer, injection, compression injection, and pressure bag moulding operations. The use of a few other methods, such as cold press moulding, filament winding, pultrusion, reinforced reaction injection moulding, and vacuum forming, is hardly reported in the case of composites (Corrales et al., 2015; Deepa, Laly, Pothan, & Thomas, 2011). The natural fiber-reinforced composites using kenaf, coir, coconut fiber, banana, sisal, jute, flax, vakka, and pineapple leaf have shown better mechanical properties with a thermoset matrix, thus making them attractive in low load carrying applications including furniture, food packaging, and automotive applications (Devi, Bhagawan, & Thomas, 1997; Hepworth, Hobson, & Bruce, 2000; John & Thomas, 2008; Joseph, Kuruvilla, & Thomas, 1997; Rao, Rao, & Prasad, 2010).

3.1. Polyesters based composites

The mechanical properties of the short randomly oriented banana and sisal hybrid fiber reinforced polyester composites, banana/polyester composites, and sisal/polyester composites at different fiber loadings were investigated. Here, tensile and flexural properties showed a positive hybrid effect while impact performance showed a negative hybrid effect (Idicula et al., 2006). Sisal-jute-glass fiber reinforced polyester composites according to the fibers used (sisal-jute-glass, sisal-glass, jute-glass) was developed and evaluated for their mechanical properties. The results indicated that the incorporation of sisal-jute-glass fiber combination can improve the properties and used as alternate material for pure glass fiber reinforced polymer composites (Ramesh, Palanikumar, & Hemachandra Reddy, 2013). In this study, the woven banana fiber-reinforced polyester composites were prepared and the properties were measured. The fiber content varied from 0–20 vol% and its effects on flexural, impact, and water absorption properties were examined. Banana fibers were treated with two chemical treatments; 1% sodium hydroxide (NaOH) and 1% acrylic acid (AA) solution, in order to improve adhesion between the fiber and the matrix (Cao, Shibata, & Fukumoto, 2006). These studies pointed out that banana (*Musa acuminata*) fibers can be used as alternative fiber reinforcement in the composite materials. The reinforcement of unsaturated polyester with banana fibers has been reported by other researchers as well (Idicula et al., 2006; Mariatti, Jannah, Abu Bakar, & Abdul Khalil, 2007). Much of efforts have been focussed finding biodegradable composites with similar properties to synthetic materials. The date palm fibers extracted from date palm tree was used as fiber and polyester resin as the matrix to prepare the composites. These composites were analysed for different physical and mechanical properties where it was found that the material possessed reasonable

properties which can be used in low cost applications. Further work may be essential to enhance the bonding between fiber and matrix (Al Kaabi, Al-Khanbashi, & Hammami, 2005). Thermoset resins such as epoxy, polyester, and vinyl ester are most commonly used with those natural fibers to produce low-strength materials. These resins have good dimensional stability and are easily manufactured, and limit the moisture absorption. The major drawback of thermosets is the fact that they cannot be recycled or reshaped after being cured. Thermoplastics are more attractive due to their potential recyclability. Affordable manufacturing processes such as injection molding or compression, in turn allow for high volume production. However, thermoset materials as matrix could be limited by their high melting point (Zaid & Jimenez, 1999).

The chemically treated (alkaline and saline) unsaturated polyester based sisal-glass hybrid composite were tested for various flexural strength and modulus as a function of fiber content. It is observed that there has been an enhancement in the flexural properties with increased glass fiber content and the total fiber content in the hybrid composites. But these hybrid materials showed lower flexural properties than the matrix when the glass fiber content was low. The effects of alkali and silane treatments of fibers on the flexural properties have also been investigated and found that silane treatment had no significant effect on the flexural properties of sisal/glass hybrid composites. However, there was a small increase in flexural properties on alkali treatment (John & Venkata Naidu, 2004). The advantages of hybrid composites involving both natural and synthetic fibers, they can be combined in the same matrix to produce hybrid composites that the best properties of the constituents and thereby a superior, but economical composite can be obtained. Various reports on hybrid composites reveal reduction in the material cost due to the low cost of the natural fibers used. Yang et al. studied the mechanical and interface properties of sisal/glass-fiber-reinforced PVC hybrid composites (Yang, Zeng, Jian, & Li, 1996). Kalaprasad et al. studied the low-density polyethylene-based short sisal/glass hybrid composites and found a considerable enhancement in the mechanical properties (Kalaprasad, Joseph, & Thomas, 1997; Kalaprasad, Thomas, Pavithran, Neelakantan, & Balakrishnan, 1996). Polymer composites reinforced with short, natural fibers have gained importance due to the advantages they impart during processing, their low cost and their high strength (Cruz-Ramos, 1986). The properties of short fiber composites are strongly influenced by the fiber length, fiber orientation and fiber weight percent. Manikandan et al. studied the mechanical properties of randomly oriented short palmyra fiber-reinforced composites and identified the critical fiber length and optimum fiber weight percent of short palmyra fiber polyester composites as 50 mm and 53%, respectively (Manikandan, Ponnambalam, & Sabu Thomas, 2004; Ramesh et al., 2013). The mechanical properties of short sisal and kapok fabric reinforced polymer hybrid composites were studied with reference to hybridization, fabric content, and surface treatment of fabrics. Since natural fibers are biodegradable, the composites of natural fibers and their hybrid composites may offer a class of materials that may provide environmental protection. It was found that the mechanical performance was lower due to high level moisture absorption by natural fibers, and the insufficient adhesion between untreated fibers and the polymeric matrix, leading to debonding with age (Matthews & Rawlings, 2005).

Polycaprolactone was used for preparing the composites, it is made of a synthetic semi crystalline biodegradable polyester, thermoplastic starch (TPS), Biocomposites of blends TPS/PCL containing 5 and 10% of sisal fibers were prepared by extrusion. Lack of adhesion at the matrix-fiber interface was observed by fibers pull-out and fiber-matrix debonding. After the extrusion process, reduction in fiber length and diameter was observed which resulted in degradation of the mechanical properties such as modulus and strength. The kenaf glass fibers reinforced unsaturated polyester hybrid composites were prepared using sheet moulding process. The ratio of 70:30 was maintained with unsaturated polyester (UPE) resin and kenaf glass (KG) fibers with treated and untreated kenaf. The chemical treatment of fibers were carried out for 3 h in 6% NaOH solution. The mechanical characterization revealed that treated kenaf with 15/15 v/v KG fibers reinforced UPE hybrid composite possessed the highest flexural, tensile and impact strength (Atiqah, Maleque, Jawaid, & Iqbal, 2014; Campos et al., 2012)

3.2. Epoxy based composites

Epoxy resins have excellent mechanical and chemical properties and corrosion resistance, good thermal and dimensional stability, and are widely used in lamination, adhesives, coatings, and advanced composite surfaces (Ren, Sun, Zhao, & Zhou, 2008). Researchers are working in this area to prepare the composite material with unique properties, cost effectiveness and environment friendly nature. For advanced composite materials, an epoxy resin is an obvious choice due to its good stiffness, dimensional stability and the characteristics of chemical resistance (Liu, Qiu, & Wang, 2009; Ren et al., 2008). The epoxy composites of natural fibers of different materials are used for newer applications (Jawaid, Khalil, & Abu Bakar, 2011a, 2011b). The study of mechanical properties of oil palm empty fruit bunches (EFB)/jute fibers reinforced epoxy hybrid composites revealed that the hybrid composite materials have much more strength than the synthetic composites. The hybrid composites made from natural fibers/epoxy constituents showed better mechanical and environmental advantage and with flexural strength of hybrid composites are slightly higher than pure EFB composites and lower than pure jute composites. The same trend is also observed in flexural modulus with respect to layering pattern of fibers. The tensile properties of these hybrid composites were also examined and it was reported that the increase in jute fiber content imparted higher strength than the oil palm-epoxy composites. The nature of the fracture revealed that the addition of the jute to oil palm composite increases the storage modulus while damping factor shifts towards higher temperature region. The tensile and dynamic properties of the hybrid composites were improved by addition of jute to oil palm epoxy composites, which was mainly due to the enhanced bonding between the fiber-matrix interphase. The effect of different fiber loads in terms of % by weight was studied on the mechanical, thermal and morphological properties of the resulting composites. It has been noted that different mechanical properties such as tensile strength, flexural strength, compressive strength and increased wear at 30% and above loading have decreased properties. The surface modification of these fibers was also carried out using silane treatment and subjected to an evaluation of the morphological properties (Oliveira, Gardrat, Enjalbal, Frollini, & Castellan, 2008). Polymer composites prepared by using direct mixing processes, and polymerization filling and their impact and bending properties were studied in depth. It was observed under the compression molding conditions, the silane treated polymer composites showed superior mechanical properties over untreated composite materials. The effect of different treatments on fibers was studied and found that SF-treated reinforced composite materials exhibited better mechanical properties compared to that of reinforced SF-crude composites. Sisal fiber reinforced polymer composites are prepared using phenol-furfural resins as matrix materials. Polymer composites were also prepared using jute/hybrid bagasse as reinforcement and epoxy as the matrix. These fibers were then treated with furfuryl alcohol to increase the adhesion between the matrix and the fibers. It was confirmed by surface modification techniques that reduce the hydrophilic character of composite materials and significant increase in the overall mechanical properties of the composites (Liu et al., 2009; Maleque, Belal, & Saupam, 2007).

3.3. Polyurethanes based composites

Atiqah et al. studied the density and water absorption property of sugar palm fiber thermoplastic composites which were fabricated by using Haake Polydrive R600 internal mixer and followed by hot pressing. The different fiber loading (weight %) was adopted for fabrication. The density increased with increase in sugar palm fiber content. It has been reported that water absorption and swelling thickness increase the fiber content and immersion time in water. It was noted that the water diffusion occurred in blends, depending on the fiber content (Atiqah, Jawaid, Ishak, & Sapuan, 2017). The behavior of polyurethane plates based on castor oil resin with coconut and sisal unidirectional short fibers (10 mm) and unidirectional long fibers. The results show sisal fibers have the best results over coconut fibers. With the increase the fraction of fiber content, the increase in tensile strength, rigidity and water absorption observed, but reduction in bending strength. Layered polymer polyurethane resins, epoxy-based and castor oil reinforced unidirectional sisal fibers reinforced by wood timber were also explored. The use of these materials was reported to be technically feasible for use

Table 3. Some major properties of thermoplastic matrix

Thermosets	Density (g/cm ³)	Tensile modulus (GPa)	Tensile strength (Mpa)	Elongation at break (%)	Compression strength (Mpa)
Polyester	1.0-1.5	2.0-4.5	40-90	< 2.6	90-250
Epoxy	1.1-1.6	3.0-6.0	28-100	1-6	100-200
Vinyl ester	1.2-1.4	3.1-3.8	69-86	4-7	86
Phenolic	1.29	2.8-4.8	35-62	1.5-2.0	210-360

as reinforcement. The mercerizing treatment (10% NaOH) on the sisal woven fabric for an hour reduces the composites variability on tensile behavior, however decreases stiffness and tensile strength (Favaro, Ganzerli, & Carvalho, 2010; Silva, 2003). Some of the main physical and mechanical properties of thermosets used as matrix are presented in Table 3. The Table 4 presents examples for natural fibers reinforced with various thermoplastic and thermoset to form polymer composite materials. Further details on preparation, properties and limitations of such materials may be obtained from the original literature (Atiqah et al., 2017; Campos et al., 2012; Cantero et al., 2003; Carvalho, 2005; Devi et al., 1997; Hepworth et al., 2000; Hujuri et al., 2008; Jiang & Kamdem, 2004; John & Thomas, 2008; Klyosov, 2007; Maheswari et al., 2012; Oliveira et al., 2008; Silva, 2003; Thejvidi et al., 2006; Trigui et al., 2013; Zarate et al., 2003).

4. General applications of polymer matrix composites

The composite materials are one of such materials that the property of the resulting materials could be altered by changing the constituents involved in it. This helps to build stronger, lighter and cost effective composite materials which could be used in the applications like aerospace, automobiles, roofing structures and interiors. They are potentially user friendly and proven to be a good reinforcement in polymer matrices. The polymer matrix composites have several advantages, such as low cost, low density, less abrasiveness (Alvarez, Fraga, & Vazquez, 2004; Beldzki & Gassan, 1999; Favaro et al., 2010; Garkhail, Heijenrath, & Peijs, 2000; Sreekumar, Thomas, & Saiter, 2009). Even they are used in building applications, automobiles, marine environments, highway structures, aerospace, construction, medical field, recreation, and sports tools, furniture, door panels, trunk liners, parcel shelves, upholstery, rear parcel shelf, seat cushion parts, consumer goods, low-cost housing and high-end applications (Cui, Wang, Xu, & Xia, 2011; Faruk, Bledzki, Fink, & Sain, 2014; Gowda, Naidu, & Chhaya, 1999; Holbery & Houston, 2006; Sreekala et al., 2002; Zah, Hirschier, & Leao, 2007). Some typical applications of thermoplastics and thermosets are listed in Tables 5 and 6 (Alvarez et al., 2004; Beldzki & Gassan, 1999; Cui et al., 2011; Faruk et al., 2014; Garkhail et al., 2000; Gowda et al., 1999; Holbery & Houston, 2006; Liao, Huang, & Cong, 1997; Singha, Rana, & Rana, 2010; Sreekala et al., 2002, 2009; Zah et al., 2007). There is an ample scope for exploring the potential applications of natural fiber composites for such applications if cost benefit analysis is favourable or acceptable.

Table 4. Natural fibers reinforced with polymers

Thermoplastics		Thermosets	
Polymer	Fibers	Resin	Fibers
PP	Curua, coconut husks, hemp, jute, sisal, sugarcane bagasse	Polyester	Bamboo, banana, coconut, flax, pineapple, hemp
PE	Banana, rice husk, sugarcane bagasse	Polyurethane	Coconut, banana, curcua, sisal
HDPE	Banana, curcua, sisal, wood	Epoxy	Cotton, flax, hemp, jute, sisal, pineapple
PS	Coconut husks, sisal, sugarcane bagasse	Phenolic	Flax, sisal, jute, banana
		Vinylester	Pineapple, sisal, jute, coconut, hemp

Table 5. Typical characteristics and applications of some thermoplastics

Thermoplastics	Characteristics	Applications
Acrylics	Exceptional resistance to long-term exposure to sunlight and good light transmission	Swimming pools, skylights, sinks and washbasins and on tail lights on automobiles
Acrylonitrile-Butadiene-Styrene (ABS)	Outstanding impact strength and high mechanical strength	Appliances, automotive parts, telephone components, shower heads, door handles and automotive front grilles
Nylon	High stability and adaptability	Automotive parts, electrical and electronic applications, and packaging
Polycarbonate	Excellent electrical insulating characteristics, strong, and rigid	Electrical and electronic applications
Polyethylene	Rigid and moisture resistant	Packaging films, house wares, toys, containers, pipes, gasoline tanks, and coatings
Polypropylene	Light-weight material and good insulation properties	Packaging and foodservice products, automotive parts, radio and TV housings
Polyamide-Imide	Exceptional mechanical, thermal and chemical resistant properties	Aerospace, heavy equipment and automotive

Table 6. Typical mechanical properties and applications of some thermosets

Thermosets	Characteristics	Applications
Epoxy	Virtually no post-mold shrinkage, resistance to high impact and high temperatures, chemical resistant and fungus resistant	Adhesives, protective coatings in appliances, industrial equipment and aircraft components
Phenolic	Excellent dielectric strength, great mechanical strength and dimensional stability, resistant to high heat, wear resistant, low moisture absorption	Adhesives, casting resins, laminating resins, electrical and electronic Applications
Polyimides	Known for thermal stability, good chemical resistance, excellent mechanical properties, exhibit very low creep and high tensile strength, inherently resistant to flame combustion	Electronics, medical tubing, adhesives, gears, covers, bushings, piston rings, and valve seats
Urea-Formaldehyde	Very hard, scratch-resistant material with good chemical resistance, electrical qualities and heat resistance	Electrical and electronic products, decorative products, laminates, and chemically resistant coatings

5. Conclusions

The extensive research work has been taking place in the field of polymers. Improvements have occurred in the development of composites by selecting different matrices and fibers. This overview given the focusses on research carried out for improvement of the mechanical properties like strength, stiffness and impact strength including the effect of water absorption and weathering on these properties. The incorporation of polymers in the composites has advantage over the natural composites. The polymer matrix composites have several advantages, such as low cost, low density and lesser abrasiveness. The work is still needed to explore the scope and limitations of these materials. So the research must focus on the development of such materials with balance of structure and property of composites having lower cost and manufacturability. One significant limitations would be many of the polymer matrix materials are non biodegradable and at best one could achieve partially degradable composites.

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