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Review of the Compression Moulding of Natural Fiber-Reinforced Thermoset Composites: Material Processing and Characterisations

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ABSTRACT

Compression moulding is generally applied to thermoset-based polymer material composites (PMCs), which consist of a reinforcement phase embedded in a polymer matrix to strengthen the polymer. Thermoset compression-moulded composites have advantageous thermal and mechanical properties. Natural fibres are typically used in composites as a reinforcing material either as continuous (very long) or discontinuous (chopped) fibres. Interest in using natural fibres to make high-performance engineering products is increasing because their mechanical properties are better than those of synthetic fibres. The types of matrix, types of fibre, chemical treatment of fibre, orientation of fibre and processing parameters that reveal converging problems, which can be studied in future research, are still being investigated. This work intends to review current studies on material processing and characterisations in terms of the thermal and mechanical properties of thermoset composites reinforced with natural fibres by compression moulding.

Keywords: Kenaf, thermoset, material processing, mechanical and physical properties

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INTRODUCTION

Research into the use of natural resources has tremendously increased over the past few years (Amel *et al*., 2013). Its applications increase because of its good mechanical and physical properties. Mechanical and physical properties are typically important in engineering because they determine the durability and cost efficiency of the product.

Synthetic fibres, such as aramid, carbon fibre and glass fibre (Hariharan *et al*., 2005; Ahmed *et al*., 2008) from petroleum also have good mechanical properties but they are not renewable and are tied to the world market. The cost of the composite reinforced with synthetic fibre, therefore, increases (Fulton *et al*., 2011). Natural fibres clearly have potential to replace synthetic fibres.

Plant fibres effectively reinforce thermoplastic and thermoset polymer composites. Polymers (plastic) are generally unsuitable for load-bearing applications because such applications require sufficient stiffness, strength and stable dimension. Natural fibres must thus be embedded in a polymer matrix to strengthen the polymer composite. The polymer matrix typically enables the fibres to adhere in place and reinforce the structural component of the fibre-reinforced polymer composite (Mohanty *et al*., 2005).

Plant fibres have been used in recent years to reinforce polymer composites in various applications, such as automotives, construction, marine and electronic components (Mohanty *et al*., 2005). Its applications increase because its properties, which are light-weight, high specific stiffness and strength, easy production and extensive resistance to fatigue and corrosion, are better than those of synthetic fibres.

The good performance of natural fibre-reinforced composites is typically affected by various factors such as fibre composition, fibre preparation and extraction process. Performance includes thermal, physical and mechanical properties. The physical and mechanical properties of fibres typically depend on the structural and chemical composition, type of fibre, fibre modification etc. during processing (Mohanty *et al*., 2005). This paper, therefore, aims to review current research into material processing and the characterisations of compression-moulded natural fibre-reinforced thermoset composites. This work also aimed to study the material processing and characterisations (mechanical and thermal properties) of polymers reinforced with some of the most popular natural fibres: kenaf, sisal, abaca and pineapple.

NATURAL FIBRE-REINFORCED POLYMER COMPOSITES

Composite materials, also known as engineered materials, are generally fabricated with two or more constituent materials. These constituents have significantly different chemical and physical properties. Constituents are categorised into two groups i.e. matrix and the reinforcement phase, which exist in the form of fibre, particle or flakes.

Types of Natural Fibres(Reinforcement)

Interest in the use of natural fibres as a reinforcement in composite applications has been growing. Composites are basically reinforced with either continuous or discontinuous natural fibres. Natural fibre materials are abundant. Natural fibres are generally classified into three groups based on their sources: plant, animal and mineral (Nguong *et al*., 2013). Plant fibres are widely accepted as reinforcement materials among these natural fibre groups. A few groups of fibre exist, namely, bast fibre, leaf fibre, seed fibre, fruit fibre, wood fibre, stalk fibre and grass fibre. Common commercially used plant fibres include kenaf, sisal, hemp, flax, abaca, pineapple leaf, and ramie (Aji *et al*., 2009; Akil *et al*., 2011; Nguong *et al*., 2013).

Selecting fibres not only depends on material properties, but also on economic factors and local availability (Fulton *et al*., 2011). Table 1 shows that natural fibres have advantages over the other reinforcement materials in terms of density, tensile strength, Young's modulus etc. A detailed description of the properties of the natural and synthetic fibres is summarised in the table below. The structure and chemical composition of natural fibres depend on their source, processing and growth application. Natural fibres are generally composed of cellulose (51 wt%), hemicelluloses (21 wt%), lignin (10.5 wt%) and pectin (3 wt% to 5 wt%). The major constituents of natural fibres are cellulose, hemicelluloses and lignin. Higher cellulose content generally contributes to higher stiffness.

The utilisation of natural fibres as a reinforcement material in polymer composite is currently gaining interest due to its high strength and stiffness. The properties of the composite are influenced by the fibre itself and by the interfacial adhesion between the fibre and the matrix (Shanmugam *et al*., 2013). The use of the hydrophilic natural fibres in polymers can generally produce bad properties for the composite (Saheb & Jog, 1999) because of the lack of adhesion between the fibre and the matrix in the composite system. Kenaf fibre is usually treated with chemicals to improve interfacial bonding between the fibre and the matrix. Using alkali-treated fibres improves the properties of the fabricated composite and also reduces water absorption of the composite. The orientation of the fibre also affects the mechanical properties of the composite (Aji

TABLE 1
Physical and Mechanical Properties of Natural And Synthetic Fibres (Mohanty *et al.,* 2005)

Fibre	Density (g/cm^3)	Tensile strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
Flax	1.5	345-1500	27.6	2.7-3.2
Hemp	1.47	690	70	1.6
Jute	1.3	393-800	13-26.5	1.16-1.5
Kenaf	1.22-1.44	930	53	1.6
Ramie	1.55	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-700	9.4-22	3-7
Coir	1.15-1.46	131-220	4-6	15
E-glass (synthetic)	2.55	3400	73	2.5
Kevlar (synthetic)	1.44	3000	60	2.5-3.7
Carbon (synthetic)	1.78	3400-4800	230-240	1.4-1.8

et al., 2009) because the fibres are difficult to evenly distribute and manually separate during processing. Orientating the fibres in a parallel direction increases Young's modulus and tensile strength.

Kenaf

Kenaf, or *Hibiscus cannabinus* L. Family Malvaceaeis, is planted once a year under a wide range of weather conditions. Kenaf has been cultivated in Asia and Africa a few years ago (Mohanty *et al*., 2005). Kenaf plants were extensively planted in Malaysia by the Tobacco Board of Malaysia (LKTN). The kenaf plant contains two fibre types: long and short fibres. Kenaf plants generally have pale fibres and smaller amounts of noncellullosic materials than jute. These plants have similar breaking strength to low-grade jute and slightly weakens in wet conditions.

Kenaf plant has single and straight stems without branches. Harvested kenaf stems are usually decorticated to separate the stem from the core in producing the kenaf bast fibres (single and bundle bast fibre). The kenaf plantgenerally consists of an inner core and an outer fibrous bark surrounding the core (kenaf bast), as illustrated in Fig.1. Kenaf fibre is typically used for extruded, moulded and nonwoven products because of its higher flexural strength and tensile strength. Kenaf fibre is extensively applied as a reinforcement in door panels, mats, headliners, dashboards, furniture etc. (Ishak *et al*., 2010). Kenaf fibres also have the advantages of biodegradability and renewability, which are essential for making environmentally-friendly products.

Sisal

Sisal, *Agave sisalana*, is widely grown in tropical countries in Africa, Western India and the Far East. Fibres are extracted from the fresh leaves using a decorticator followed by washing and drying under the sun (Mohanty *et al*., 2005). The hard fibre, sisal, is typically extracted from the leaves.

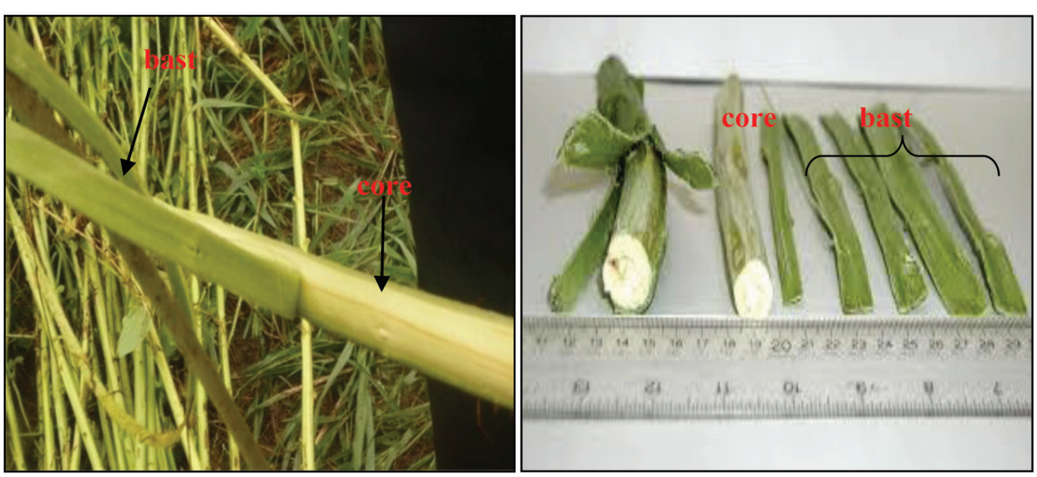

Fig.1: Schematic picture of kenaf plant

The sisal fibre is a bundle of hollow sub-fibres. The cell walls are typically reinforced by spirally orientating a hemicelluloses and lignin matrix. The surface does not form strong bonds with polymer matrices because the external surface of the cell wall is composed of ligninaceous materials and waxy substances that bond the cell to its adjacent neighbours. The strong sisal fibre is traditionally used for making rope, fabrics, rugs, carpet, handicraft etc. The paper industry has become interested in sisal (Saxena *et al*., 2011).

Banana/Abaca

Banana fibre currently is a waste product of cultivation. It is native to the Philippines, and currently is widely planted in Ecuador (Mukhopadhyay *et al*., 2008). The banana plant is durable and resistant to wear. Abaca is used mainly to manufacture rope and handicraft such as bags, doormats and slippers. The banana fibre can be used for various industrial purposes, for instance, in the automotive and construction industries (Samal *et al*., 2009). Various researchers have worked on banana-reinforced polymer composites (Sumaila *et al*., 2013), and most of the research shows that banana fibre can be used as reinforcement, especially in thermoset polymer. Previous studies show that banana is a good reinforcement in polyester resin (Mukhopadhyay *et al*., 2008)

Pineapple leaf

Pineapple fibre (*Ananas comosus*) is typically extracted from the leaves of the tropical pineapple (Shyamraj *et al*., 2013). This fibre is rich in cellulose, and is abundant in Brazil (Faruk *et al*., 2012). The pineapple leaf currently is the most popular waste product from pineapple cultivation, and is relatively cheaper for industrial purposes such as bags, mats and table linen. Pineapple fibre has good potential as reinforcement in thermoset composites. The results of a previous work show that the pineapple leaf strongly influences the tensile properties of the reinforced composite (Vinod & Sudev, 2013). The quality of a pineapple-reinforced composite can generally be improved by surface modification (Vinod & Sudev, 2013). The previous results prove that the modified pineapple leaf fibre composite has the highest tensile and impact strength.

Thermoset Polymer Composite

The matrix phase is important to the performance of polymer composites. The reinforcement materials in the polymer matrix are typically supported and surrounded by the matrix materials to maintain their relative positions. The matrix holds the fibres together. The fibre is embedded in the matrix, such as thermoset and thermoplastic, to make the matrix hold the fibres together and thus strengthen them. Thermosetting plastics are synthetic polymer whose molecules cross-link during processes, and therefore cannot be recycled or reprocessed (Mohanty et al., 2005). Thermoset polymers form three-dimensional molecular chains during cross linking. Thermoset polymer formulations, such as epoxy and polyester, are very complex due to the large number of components involved, such as the base resin, curing agent, catalyst, flowing agent and hardener.

Chemical curing of the highly cross linked, three-dimensional and network structure of the thermoset polymer increases the toughness and solvent and creep resistance. Thermoset materials, such as epoxy resin, vinylester resin and polyester resin, are generally stronger than thermoplastic polymers due to their 3-D network of bonds. These materials are suitable for high-temperature applications, and then followed to the decomposition temperature of the material. These polymers, therefore, cannot be recycled like thermoplastic polymers, which can be melted and re-molded. Epoxy has unique properties, such as high strength, low creep, low shrinkage and low warping. This material also offers high performance and resistance to environmental degradation. The common properties of thermoset polymers are listed in Table 2.

COMPRESSION MOULDING OF NATURAL FIBRE THERMOSET COMPOSITES

Selecting the suitable processing method for natural composite materials is crucial for the form, performance attributes, cost and ease of manufacturing of the final desired product to obtain the quality, robust and repeatable manufacturing process. Composite processing generally involves equipment with a simple operation, or needs special equipment. There are several types of processing techniques for natural composite materials, such as compression moulding, injection moulding, resin transfer moulding and thermoforming. Compression is widely used among these techniques to manufacture natural fibre composites because of its high reproducibility and low cycle time.

Compression moulding is a conventional processing technique used to manufacture polymer matrix composites under specific temperatures and pressures (Groover, 2007). This technique is commonly used in manufacturing due to its simplicity. The process has advantages in terms of low fibre attrition and speed. Many variations of compression moulding have been developed, including a combination of compression with extrusion and sheet moulding compound (SMC) processes in order to reduce the cost by decreasing the cycle time (Faruk *et al*., 2012). Compression moulding using the thermoset polymer matrix is another major platform used for

TABLE 2
Properties of Typical Thermoset Polymer for Natural fibre Composites

Property	Polyester	Vinylester	Epoxy
Density (g/cm^3)	1.2-1.5	1.2-1.4	1.1-1.4
Tensile strength (MPa)	40-90	69-83	35-100
Compressive strength (MPa)	90-250	100	100-200
Izod Impact Strength (J/m)	0.15-3.2	2.5	0.3

manufacturing in the automotive industry in producing strong, light and thin panels and structures, as shown in Fig.2.

The distribution of the filler for the compression technique is far better than the other techniques because kenaf fibre is difficult to homogeneously distribute in reinforced composites. Compression moulding reduces the changes in the physical properties, and can help retain the isotropic properties of the composites (Aji *et al*., 2009) because it does not change fibre orientation. The mechanical properties of natural fibre composites are basically influenced by the moulding conditions, such as moulding pressure and temperature. The optimum pressure and temperature should therefore be applied to produce good mechanical products because of the problem of assurance of the adhesion of the fibre matrix in manufacturing natural fibre-reinforced composites.

All the previous studies concluded that natural fibre composites may be produced in various ways to gain different thermal and mechanical properties. The compression moulding process produces compression moulded composites with high strengths and impact strengths (Aji *et al*., 2009). The compression moulding process has been tested in some studies on woven jute and jute glass fabric reinforced polyester (Ahmed *et al*., 2008), hybrid kenaf/glass reinforced composite (Ahmed *et al*, 2008) and kenaf fibre with polyurethane (Sapuan *et al*., 2011) to evaluate its tensile, flexural and impact strength.

PROPERTIES OF NATURAL FIBRE-REINFORCED COMPOSITES

Thermal Properties

The thermal properties of natural fibre-reinforced composites were studied. The analyses were essential for distinguishing the behaviour of the fibre-reinforced composite. Three regular characterisation methods, thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA) and differential

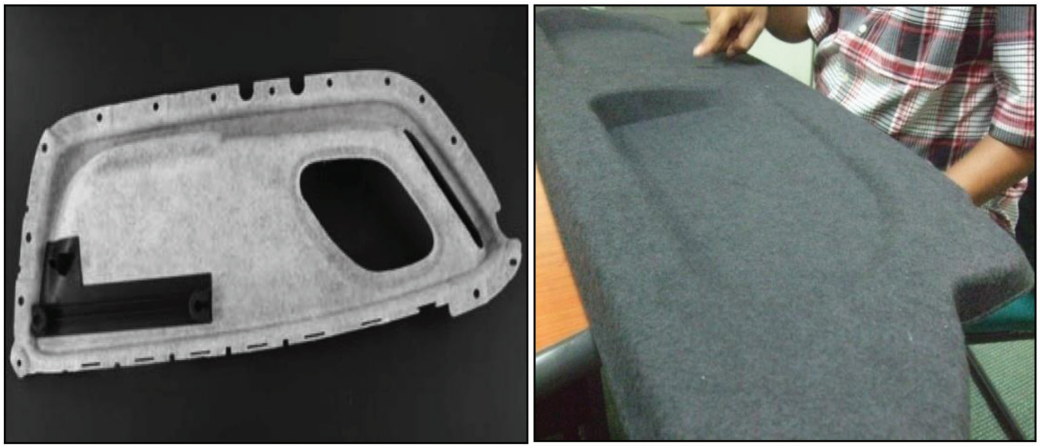

Fig.2: Kenaf natural fibre composite fabricated by compression moulding.

scanning calorimetry (DSC), were used. Several crucial parameters, such as the glass transition temperature (T_g), melting temperature, crystalline level and oxidation, were estimated from the DSC scan. TGA is an experimental technique for determining material stability, in which the weight or the mass of the sample is measured based on temperature changes. This technique is performed in air or at inert temperatures (H_2 and Ag), and the weight is recorded as the temperature increases (Azwa *et al*., 2013). Sublimation, evaporation, decomposition, chemical reaction and the magnetic or electrical transformation of the material usually change the mass, and these are related to thermal stability (Akil *et al*., 2011). The thermomechanical properties of the materials as a function of temperature and deformation can be measured by DMA.

Researchers have studied the thermal properties of the laminate obtained from thermal gravity using differential scanning calorimetry (TG-DSC), showing that the melting point (T_m) of the polypropylene (PP) film laminate decreases and the crystallisation peak increases as the fibre content in the laminates increases (Fulton *et al*., 2011). The DSC analyses of Muhd *et al*. (2010) showed that the endothermic transition temperature of kenaf filled with chitosan biocomposite increases with increasing kenaf content. The TGA result showed that the addition of kenaf dust in the chitosan film did not significantly change the thermal stability of chitosan films. *Samal et al.* (2009) studied the fabrication and performance evaluation of banana/glass fibre-reinforced polypropylene hybrid composites. The results showed that the thermal stability and crystallisation temperature of polypropylene incorporated with maleic anhydride grafted polypropylene (MAPP)-treated banana and glass fibres decreased in contrast to the banana fibre-reinforced polymer composite. The investigation done by Jawaid *et al*. (2012) demonstrated that the incorporation of jute fibres increased the thermal stability of the hybrid composite because the jute fibre had higher thermal stability compared to the empty oil palm fruit bunch. Azwa *et al*. (2013) compared the degradation behaviour of kenaf/epoxy composite and neat epoxy exposed to high temperatures. The investigation revealed that the addition of fibre into the epoxy improved the thermal stability and charring capability of the samples.

Mechanical Properties

Mechanical properties, such as tensile properties, flexural properties and impact properties, are crucial to the performance of materials. Mechanical properties are important in determining the ability of materials, especially under critical conditions. Most studies on natural fibre composites involve mechanical properties. The fibre content, the use of external coupling agents and the effects of various treatments change mechanical properties. Many studies on kenaf fibre-reinforced composites have been conducted during the past few years to study mechanical behaviour. Matrix and reinforcement typically are important in improving the mechanical properties of the composites (Saheb & Jog, 1999). Some of the mechanical properties of natural fibre-reinforced composites that have been studied include tensile strength, flexural strength and impact strength. The details of the discussion on the mechanical properties are discussed in the following section and are summarised in Table 3.

Tensile Strength

The tensile test predicts the behaviour of materials under different loadings other than uniaxial tension. This test also determines the maximum engineering stress in tension that may be sustained without fracture (Akil *et al*., 2011). Tensile strength is generally more sensitive to the matrix properties, whereas the modulus depends on the fibre properties. The strong interface, low stress concentration, fibre orientation and fibre volume can basically improve tensile strength (Saheb & Jog, 1999).

Davoodi *et al*. (2010) studied the tensile properties of kenaf reinforced with different polymer composites known as polypropylene (thermoplastic) and epoxy (thermoset). The tensile test was performed according to the guidelines of the American Society of Testing Method Standard (ASTM) 3039. Their research shows that fibres reinforced with epoxy are far better because of the unity of the plies and the adhesion between the fibres. The results show that epoxy has higher strength (71.68 MPa) than polypropylene. Saxena *et al*. (2011) proved that the mechanical properties of the polymer composite are more enhanced than the neat polyester composites. The incorporation of the sisal

TABLE 3
Mechanical Properties of Natural Fibre Composites

Reinforcement	Composition (wt %)	Matrix	Tensile (MPa)	Flexural (MPa)	Impact (J/m)	Reference
Kenaf bast fibre	0-50	Poly-lactic acid	223	254	-	(Ochi, 2008)
Kenaf bast fibre	-	Epoxy Polypropylene	71.68 37.2	200-240	20-40	(Davoodi *et al*., 2010)
Coconut particle	5-15	Epoxy	35.48	-	-	(Sapuan *et al*., 2003)
Coconut spathe and coconut fibre	30	Polyester	7.9-11.6 (coconut spathe)	25.6-67.2	-	(Sapuan *et al*., 2005)
Kenaf bast fibre	10-60	Thermoplastic Polyurethane	32-37 (30 wt%)	-	-	(El-Shekeil *et al*., 2011)
Kenaf derived cellulose	40-60	Poly-lactic acid		63.4-98.8	35.3	(Syafinaz *et al*., 2010)
Banana fibre and glass fibre	0-45	Phenol formaldehyde	28 42	50 73	30-40 40	(Joseph *et al*., 2011)

was found to increase the tensile strength and Young's modulus of the epoxy resin.

Sapuan *et al*. (2005) studied the mechanical properties of unsaturated polyester composites reinforced with different percentage weights of kenaf fibre. The results showed that tensile strength increased as the fibre content increased. In another research done by Sapuan *et al*. (2003), the mechanical properties of composites with filler epoxy/coconut particle were studied. The tensile strength of the composites reportedly increased with increasing filler content because coconut filler particle strengthened the interface of the resin matrix and filler materials. The composite with 15% filler showed the highest tensile strength, 35.48 MPa, compared with the other two combinations (5% and 10%).

Sapuan *et al*. (2005) also compared the flexural and tensile strength of epoxy composites reinforced with coconut spathe and coconut fibre. The results showed that the coconut spathe-reinforced composite had higher tensile strength than those reinforced with coconut fibre. The incorporation of spathe fibre within the epoxy thus enhanced the strength of the matrix. Girisha *et al*. (2012) investigated the tensile properties of the epoxy composite reinforced with different types of fibre, coconut spathe, sisal and ridge gourd, with different fractions of fibre loading from 5% to 30%. The results showed that the tensile properties were best at approximately 25% of the weight fraction of the fibres. The values decreased further with increased weight fraction. Research into mechanical properties of polyurethane composites reinforced with different weight percentages of kenaf fibre loading was performed by El-Shekeil *et al*. (2011). Their result showed that the higher strength of 30% contributed to the strong bonding between the fibre and the matrix.

The fibre volume strongly influenced the tensile and Young's modulus of the polymer composite. Saxena *et al*. (2011) found that the tensile and Young's modulus increased with fibre volume increase due to the fibre interaction. The effects of the single and bundle fibre on the tensile modulus were also compared. The results showed that the tensile properties of a single fibre of sisal were better than those of the bundle fibre because the load on the single fibre was not uniform. Saxena *et al.* (2011) also investigated the effect of fibre length on the composite polymer and found that the tensile length increased with the increasing sisal fibre length. This result is consistent with the result obtained by Sumaila *et al.* (2013). The observation on the effect of fibre length with different diameters on the tensile properties of the banana/epoxy composite showed that the percentage elongation increased with increasing fibre length from 5 mm to 15 mm. The tensile strength decreased with increasing fibre length of up to 25 mm afterwards. Vinod and Sudev (2013) also studied the effect of fibre length on the tensile properties of pineapple leaf fibre (PALF). The results revealed that the tensile strength of the fibre increased with increasing fibre length.

Flexural Strength

The type of fibre, orientation (either random or unidirectional), content (fibre or fabric) and type of blending or plasticiser typically influence the flexural and tensile properties of the materials. The three-point bending test method also determines the flexural strength and modulus of the composite by following ASTM D790 standard. The research done by Davoodi *et al*. (2010) showed that the flexural modulus and flexural strength of the kenaf hybrid materials (natural fibre) were higher than those of the glass mat thermoplastics (synthetic fibre). Syafinaz *et al*. (2012) studied the effect of kenaf-derived cellulose content on the physical and mechanical properties of kenaf-derived cellulose (KDC)-filled polyactic acid (PLA) composites. The flexural properties of KDC/PLA composite were found to be improved compared to commercial neat PLA composites.

Joseph *et al*. (2002) also investigated the effect of fibre loading and fibre length on the flexural properties of phenol formaldehyde composites reinforced with banana (natural) fibres and glass (synthetic) fibres. The flexural properties of the composite were found to be dependent on fibre length. Both banana and glass fibre increased in flexural strength with increasing fibre loading. Saxena *et al*. (2011) investigated the effect of sisal fibre length reinforcement on different polymer composite bases, epoxy and polyster. The results showed that the flexural strength of the sisal-reinforced epoxy composite increased with increasing fibre length, whereas the polyster composite did not show any changes.

Impact Strength

Impact strength tests the ability of materials to resist fracture under stress applied at high speeds. The impact properties of polymeric materials are generally strongly related to the overall toughness of the materials. Composite fracture toughness is affected by the interfacial and interlaminar strength parameters. The impact performance of fibre-reinforced composites depend on numerous factors, including the nature of constituent, fibre/matrix interface, the construction and geometry of the composite and test conditions. Joseph *et al*. (2002) studied the influence of fibre length on impact strength. The results revealed that the impact strengths of the composite reinforced with glass fibre and banana fibre increased with the increasing fibre length. Davoodi *et al*. (2010) found that the average impact strength of the kenaf-reinforced epoxy composite was 26 J/m, which is nearly half of that of the common glass mat thermoplastic.

Liu *et al*. (2007) showed that compression moulded biocomposites have higher impact strength than injection moulded samples. The impact strength of the composite reinforced with different fibre lengths and contents were also investigated. The strength of the composite was found to increase with fibre length and content. Hariharan and Khalil (2005) showed that the impact strength (18 kJ/m^2) of oil palm fibre composites was lower than that of glass fibre (107 kJ/m^2). However, the tensile and impact properties of palm fibre composites have been improved by the hybridisation of oil palm fibres with glass fibres (El-Shekeil *et al*., 2011). Aji *et al*. (2009) reported that the use of short fibres caused lower impact strength than long fibres.

Fibre treatment can generally increase interphase adhesion and cause the penetration of the matrix resin into the fibre. The impact strength of the alkali sisal-treated composite increased because the alkali treatment removed the waxy materials (Saxena *et al*., 2011).

CONCLUSION

Various studies have been conducted on various types of natural fibres, as summarised in Table 4. Natural fibres have better characteristics than synthetic fibres in reinforcement. Different processing methods can produce different products with different properties. For example, compression method improves the mechanical properties of composites. Compression moulding has the advantage of fibre bridging through fibre pullout. Using epoxy thermoset polymer as matrix for the compression moulding offers high performance to the natural fibre-reinforced composite. Epoxy resin potentially eliminates residual stress and also reduces shrinkage and creep of the final product.

There are some problems in using natural fibres, such as interfacial adhesion and water absorption. These problems must be solved before natural fibre composites become fully competitive with synthetic fibres. Further study must, therefore, be conducted to improve the physical and mechanical properties of the kenaf/thermoset composite to the desired level. Much work must be performed to overcome obstacles, such as moisture absorption, long term performance and toughness, for internal and automotive engine applications.

TABLE 4
Compression Moulded of Thermoset Composite Reinforced with Natural Fibres

Natural Fibre	Matrix	Technique	Tensile Properties (MPa)	Reference
Kenaf fibre	Epoxy Resin	Compression Moulding	71.68	(Davoodi *et al*., 2010)
Kenaf bast fibre	Polyurethane	Compression Moulding	32-37	(El-Shekeil *et al*., 2011)
Banana fibre and glass fibre	Phenol formaldehyde	Compression Moulding	28 & 42	(Joseph *et al*., 2011)
Oil Palm	Epoxy Resin	Compression Moulding	24	(Hariharan & Khalil, 2005)

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