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PROPERTIES AND POTENTIAL OF BIO FIBRES, BIO BINDERS, AND BIO COMPOSITES

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Abstract. It is imperative to understand about the properties of biodegradable composites and raw materials used in making such composites which are being used for biomedical, automobiles, packaging and other engineering applications. Production of biodegradable composites from renewable sources is a challenging task for researchers to meet the future demand for environmental friendly materials. This review paper addresses the mechanical properties of bio-fiber, bio-binders, and bio-composite that are considered as major thrust for contemporary and future research for bio-composite formation for high value added applications.

1. INTRODUCTION

Bio composites from renewable resources gained much importance universally, because of their biodegradable nature. Bio-composites are most suitable materials profound in nature for their use in various fields due to their eco-friendly advantages [1]. Bio-composites are manufactured using bio-polymer as binder and natural fibre as the reinforcement material. Depending on the origin, natural fibres are classified as leaf, seed, and bast or fruit fibre. Natural **b**io-fibre derived **b**io-**c**omposites (**BBC**) are renewable, light weight, energy proficient, biodegradable, environmental friendly and bio compatible as compared to other binder fabric composites [2]. Now-a-days research in polymer science and technology is mainly focused on composites made from renewable resources [3]. BBC is the challenging issue among researchers all over the world because of the necessity of biodegradable composites at large scale. The major sources of natural fibres are hemp, flax, sisal, jute, coir, banana, bamboo, sun hemp, and pineapple. However, other fibres viz rice, wheat-straw, soybean, sugarcane, and other agricultural residues may also prove to be proficient for use as bio-fibre.

BBC has immense applications in the field of biomedical, agriculture, packaging and other allied engineering fields. The only limitation of BBC is hydrophilicity. The scope of the review is to bring forth the properties of different bio-fibres, bio-binders and bio-binder reinforced fully bio-degradable composites that would attract many researchers attention to focus on future need and importance of fully biodegradable composites.

2. BIO FIBRES AND THEIR MECHANICAL PROPERTIES

Natural fibres are categorised based on their origin which are from plants, animals or mineral sources. However, bio-fibres are purely derived from vegetative sources which are fully biodegradable in nature. The main components of bio- fibres are cellulose, lignin, hemicelluloses, pectin and wax. The beneficial engineering properties of bio-fibres are specific strength, low density, high toughness, good thermal properties as compared to most of the synthetic

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Table 1. Mechanical properties of bio fibres.

Fibre	Density(g/cm^3)	Tensile Strength(MPa)	Tensile Modulus(GPa)	Elongation at Break (%)	Reference
Jute	1.3-1.46	345-1500	2.7-12.6	7.0-8.0	[18-19]
Flax	1.29-1.5	345-1100	27.6-160	1.5-5.0	[18-20]
Sisal	1.35-145	468-640	9.4-24	3-7-4	[19-20, 21]
Banana	1.3-1.35	54-789	3.4-32	2-7	[47,48]
PALF	1.44	170-635	6.26-24.6	3	[18,49]
Hemp	1.0-1.40	310-750	30-60	-	[50]

polymers, reduced tool wear, respiratory irritation and ease of processing. Bio-fibres find many applications in bio medical, food packaging, geotextile, architecture, composites and automotive transportation and general system. Bio- based fibres shows adequate results in terms of mechanical properties. There is the possibility to make composite along with bio-binders to attain requisite materials properties. Some commonly used bio-fibres and their mechanical properties are shown in Table 1.

3. BIO BINDERS AND THEIR APPLICATIONS

Bio-binders commonly known as biopolymer are compounds obtained from natural resources and are consisting of monomeric units that are covalently bonded to form larger structures. Bio-binders vary among their melt flow indices, impact properties, hardness, vapour transmission characteristics, coefficient of friction and decomposition. The engineering properties such as tensile strength, tensile modulus, flexural strength, flexural modulus and density. Water absorption of bio-binders would also vary depending on the chemistry of bio-binder processing condition etc. (Table 2). Bio-binders find many applications in a number of field such as drug delivery system, wound healing, food containers and agricultural films, waste bags, soil retention sheeting, filtration, hygiene and protective clothing, and automobile industries [4-6]. There are many types of bio binders and among them, the most common bio- binders are summarised below.

3.1. Poly lactic acid (PLA)

Polylactic acid is a biodegradable polymer obtained from natural resources (renewable sources) via ring opening polymerization of lactides, where the lactic acid monomers are obtained through fermentation process [7]. Due to the biodegradable nature of PLA, the annual demand of PLA is increasing day by day. Presently, a number of industries are involved in production of PLA and mostly pronounced in USA, Germany ang China [8].

3.2. Polyhydroxyalkanoates (PHA)

Polyhydroxyalkanoates are biopolysters synthesized as carbon and energy reserves by a wide variety of microorganism [9]. In Polyhydroxyalkanoates, polyhydroxy butyrate (PHB) is frequently used, which is composed of monomeric units of 3-hydroxybutyric acid. Owing to the fully biodegradable nature of PHB, it has high demand in the market for the purpose of packaging material, disposable items and special devices for medical application. Presently, Imperial Chemical Industries (ICI) produce this biodegradable polymer on a large scale under trade name Biopol [10]. Biopol is the copolymer of polyhydroxy butyrate (PHB) and polyhydroxyvariate (PHBV).

3.3. Polycaprolactone

Polycaprolactone is prepared by ring opening polymerization of caprolactone and is obtained from petroleum resources [11]. Polycaprolactone also posses biodegradable nature and is used for controlled release of drugs and packaging [12]. Many industries and pharmaceutical companies such as Solvay, Union carbide etc. use polycaprolactone for different commercial purposes. In spite of its importance, little is known about polycaprolactone and its blends. The mechanical properties of bio-binders are discussed below.

4. PROPERTIES OF BIO BINDERS

Materials made from composite are used for variety of applications and density is one of the important parameter to consider the material for a specific application. The density of commercially available bio-polymer varies from 0.25-1.26 g/cm^3 [13,14, 16].

Table 2. Mechanical properties of bio-binders.

Types of Bio-binder	Density (g/cm^3)	Tensile properties		Elongation(%)	Source
		Tensile Strength(MPa)	Tensile Modulus(GPa)		
1. PLA	1.26	5.9-72	1.08-3.61	2.1- 30.7	[14,17,22-27]
2. Polyhydroxyalkanoates					
(a) Polyhydroxybutyrate (PHB)	1.2-1.5	24-40	3-5-7.7	1.56-6	[28-32]
(b) Poly-3-hydroxybutyrate (P-3-Hb)	1.28	40	3.5	0.4-6	[33-35]
(c) Poly-3-hydroxybutyrate-co-3-hydroxyvalerate (P-3-Hb-3-Hv)	0.22-0.25	23-40	3.5	1.6-20	[13,32,34,36]
(d) Poly-4-hydroxybutyrate (P-4-Hb)	1.22	104		1000	[34,37]
3. Polycaprolactone (PCL)	1.13	16-23	0.4	>700	[26,28,34,38]

Table 3. Mechanical properties of bio-binders augmented with fibres.

Types of polymer	Tensile properties		Flexural properties		Elongation(%)	Impact Strength(kj/m^2)	Source
	Tensile Strength(Mpa)	Tensile Modulus(Gpa)	Flexural Strength(Mpa)	Flexural Modulus(Gpa)			
PLA/Hemp fibre (PLAHF)	73±1	5.89±0.12	102±2	5.78±0.09	3.0±0.1	14±2	[25]
PLA/Flax fibre (PLAFF)	50-55	6.31-6.52			1.0	10-69	[17,39-41]
PLA/Sisal fibre (PLASF)	56.68±3.51	20	80-100	18-19		3-3.5	[23,42-43]
PLA/Jute fibre (PLAJF)	55.27-72.7	1.71-8.5	75.9-84.5	7.0-7.3	1.5-4.71	15.80	[22,24,44-45]
PHB/Flax fibre (PHBFF)	40-42	8-10				60-70	[46]
Polycaprolactone/Flax fibre (PCLFF)	20-25	0.8-0.9	30-35	1.8-1.9			[15]

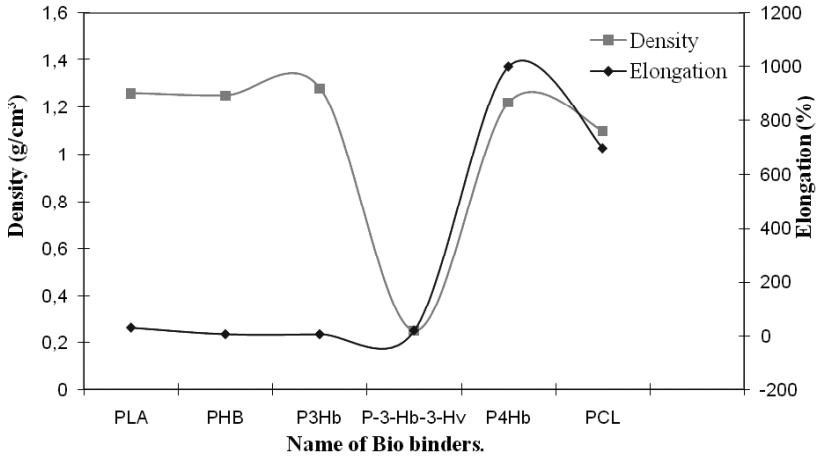

Fig. 1. Mechanical properties of Bio-binders.

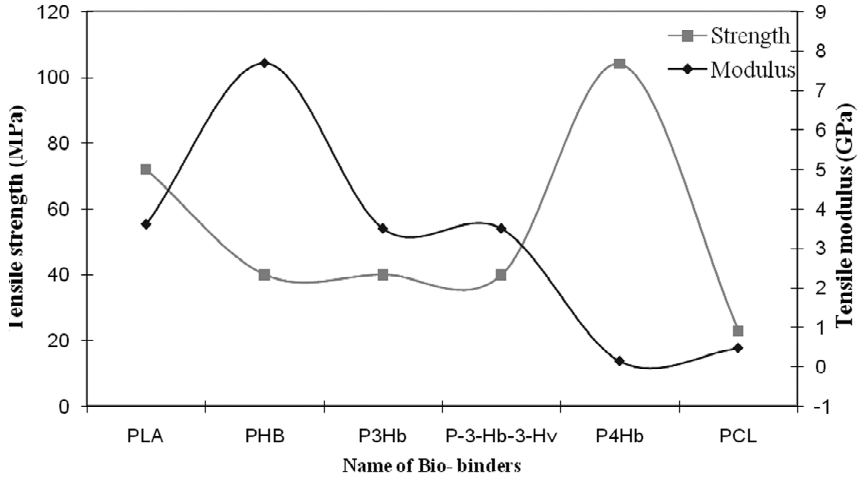

Fig. 2. Mechanical properties of Bio-binders.

Low density materials is preferred, because of several reasons viz energy efficient, easy handling and low cost. As shown in Fig. 1, the highest density of bio-binder was found in Poly-3-hydroxybutyrate (P-3-Hb) followed by Polylactide (PLA), Polyhydroxybutyrate (PHB), Poly-4-hydroxybutyrate (P-4-Hb), Polycaprolactone (PCL) and Poly-3-hydroxybutyrate-co-3 hydroxyvalerate (P-3-Hb-3-Hv).

Tensile strength of different bio polymer is reported in Fig. 2, Table 2. The highest tensile strength (104 MPa) was recorded in Poly - 4-hydroxybutyrate (P-4-Hb) followed by Polylactide (PLA). But Poly-3-hydroxybutyrate-co-3 hydroxyvalerate (P-3-Hb-3-Hv), Poly-3-hydroxybutyrate (P-3-Hb) and Polyhydroxybutyrate (PHB) show almost similar tensile strength. Polycaprolactone (PCL) exhibit minimum tensile strength 23 MPa.

Tensile modulus is another important mechanical property of bio-binder which measures stiffness of materials. Fig. 2 shows the tensile modulus of different biobinders. Among the reported modulus of different bio-binders, Polyhydroxybutyrate (PHB) showed maximum tensile modulus 7.7 GPa followed by Polylactide (PLA) but, Poly -3-hydroxybutyrate (P-3-Hb), Poly-3-hydroxybutyrate-co-3 hydroxyvalerate (P-3-Hb-3-Hv) have similar tensile modulus 3.5 GPa each.

Very limited work is reported the flexural properties of PLA, Fig. 3. As reported so for the flexural strength of neat PLA was 95-105 MPa and the flexural modulus was about 3.4 MPa [14,23,25]. The impact strength of PLA was reported to be 16.66-30 Kj/m^2 [22,23,25].

Elongation determines how much deformation occurs in the materials under stress. The highest elongation is found in Poly - 4-hydroxybutyrate (P-4-Hb) (Fig. 1). Polycaprolactone (PCL), Polylactide (PLA), Poly-3-hydroxybutyrate-co-3 hydroxyvalerate (P-3-Hb-3-Hv). However Poly -3-hydroxybutyrate (P-3-Hb) and Polyhydroxybutyrate (PHB) showed similar elongation. It is observed that there is considerable variation in densities and elongation of different bio-binders and there is considerable scope for syn-

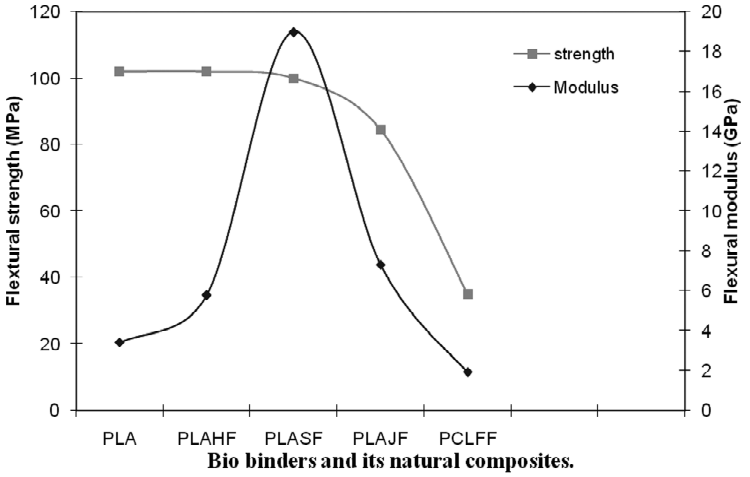

Fig. 3. Mechanical properties of Bio-binders and their composites.

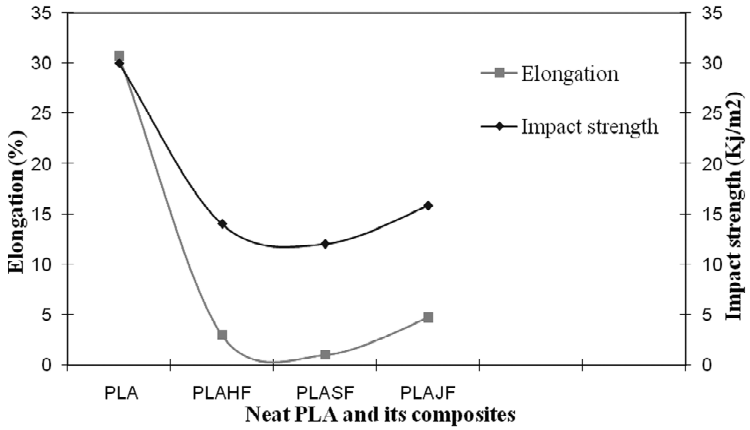

Fig. 4. Mechanical properties of PLA and its composites.

thesizing of further improved quality of bio binder to meet the needs of tomorrow world.

5. BIO COMPOSITES AND THEIR ADVANTAGES

Biocomposites are manufactured using bio binder and bio fibre which are fully bio degradable, Table 3. Biocomposites has many advantages, they are relatively cost effective, exhibit good thermal and dimensional stability, low coefficient of friction and low density. Bio composites are mainly used in high end use applications such as tissue engineering, automotive industries and aeronautical engineering, etc.

It has been reported that bio-binders reinforced with bio fibres showed considerable improvement in tensile properties of biocomposites [25]. It is apparent from the work done so far on biodegradable composites that the tensile strength of fully biodegradable composites varied from 20-73 MPa and maximum tensile strength 73 MPa was recorded when the composites fabricated using PLA reinforced with Hemp and minimum tensile strength was found when Polycaprolactone bio binder was reinforced with flax fibre [15].

The tensile modulus of biocomposites varied with addiction of different bio binders and bio fibres. The tensile modulus of such composites are shown in Fig. 3, where the maximum tensile modulus was 20 GPa reported in PLA with sisal fibre and lowest modulus reported in Polycaprolactone bio-binder reinforced with flax fibre [15].

Modulus of rupture or flexural strength shows the materials ability to resist deformation under load. Work done by several researchers revealed that there is considerable variation in flexural strength of BBC and is depends on the properties of bio-fibres, bio-binders and fabrication techniques (Fig. 4). It is to note that highest strength is reported in PLA reinforced with hemp fibre and lowest modulus is reported in Polycaprolactone bio-binder reinforced with flax fibre.

Flexural modulus represents the ability of bend. This is an important property of any composite. As shown in Fig. 4, maximum flexural modulus (19 GPa)

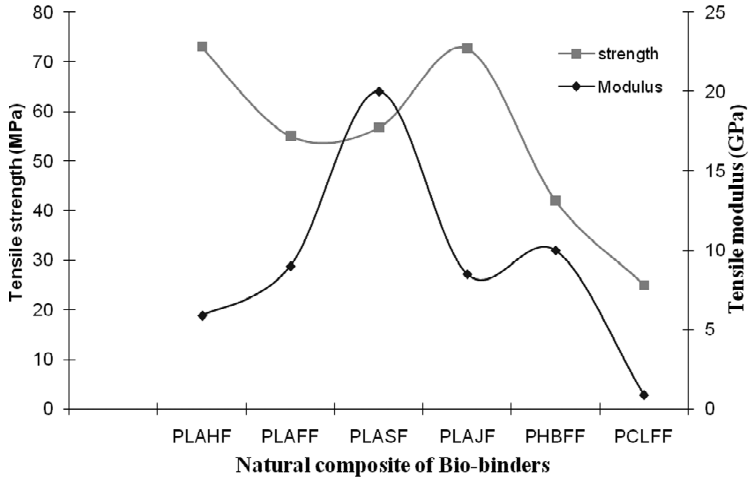

Fig. 5. Mechanical properties of Bio composites.

is reported with PLA reinforced with sisal fibre and lowest (1.9 GPa) in Polycaprolactone bio-binder reinforced with flax fibre.

Similarly, highest elongation of BBC was found to be in PLA reinforced with jute fibre (Fig. 5). Whereas the lowest is in PLA reinforced with flax fibre [17].The impact properties help us to determine the toughening of a material. Work done by several researchers showed that highest impact strength was reported in PLA reinforced with jute fibre (Fig. 5). Lowest impact strength [3.5 kj/m^2] was in PLA reinforced with flax composite.

Bio composites cater to the needs of several industries including automobile, biomedical and allied engineering industries. We should strive to make bio-composites having high tensile strength and flexural strength and lower elongation and density so that it becomes eco-compatible polymer composite. Especially, it will help to reduce the cost and increase eco-friendless along with best composite products used in daily life.

6. CONCLUSIONS

It is evident from the present study that there is a wide variation in the mechanical properties of bio fibres. Jute fibre and banana fibre showed much variation in their tensile strength than that of other bio fibres. It is perceptible that the properties of bio fibres depend on the plant variety, growing conditions, age of the plant and fibre extraction process. Bio-binder or biodegradable plastic is mostly synthesised from bio-resources such as corn, wheat, rice, potato, soybean, sunflower, blood meals and its properties varies significantly depending on their chemical structure, grade and quality. Work done so far revealed that maximum tensile strength (104 MPa) was found to be in poly-4- hydroxybutyrate with a tensile modulus of 7.7 GPa. But, minimum elongation (0.4%) was found in poly-3-hydroxybutyrate. The mechanical properties of bio composites were significantly influenced by the reinforcement of bio fibres combined with bio binder. As reported, maximum tensile strength (73 MPa) and flexural strength (102 MPa) were found in hemp fibre reinforced PLA composites. Nevertheless, impact strength was found to be highest in PHB-flax fibre composites (70 kj/m^2) but the flexural modulus (100 MPa) and tensile modulus (20 GPa) of composite was reported as maximum in PLA reinforced with sisal fibre.

In many polymer matrix composites, glass fibre, carbon fibre and petroleum based synthetic fibres have been frequently used. Universally, environmental threat due to exploitation of non renewable resources become a prime concerns which prioritizes the need of exploitation of renewable resources for the development of new materials that could be used as an alternative to the conventionally used composite materials for construction, automotive, locomotive, aerospace, biomedical, packaging and other commercial purposes. Bio-fibres are traditionally used for making rope, cordage, twines, cables, anchors, binders, nets, textiles, door mats, rugs, carpets, hats, sandals, and brushes but not exploited for effective utility in engineering application as reinforcing materials in bio composites. Bio-fibres are eco-friendly, cost-effective, lighter in weight and renewable and have potential to use in composites. Such renewable natural resources can be beneficially exploited to engender innovative bio-composites for dual benefit. The present study revealed that there is a wide variation in the mechanical properties of biocomposites and therefore, it is

imperative to carry out advanced research on the engineering chemistry of bio fibres, bio binders and the influence of different fibre and matrix on different properties of bio composites for targeted applications.

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