

CHAPTER I

**INTRODUCTION AND
LITERATURE REVIEW.**

1.1 Introduction

Composites are materials consisting of two or more identifiable constituents [1]. In this particular study the type of composites considered are those which consist of a fiber based high modulus reinforcement embedded in a comparatively lower modulus matrix. The matrix here serves two important functions – (i) to hold the reinforcement phase in place and (ii) to deform and distribute the stress to the reinforcement under applied loads [1].

There has been much awareness regarding the harmful effects of polymer materials on the environment. The term ‘*degradable polymers*’ relates to the polymeric materials that disintegrate under environmental conditions in a reasonable and demonstrable period of time [69]. Degradation of polymers may occur by any of the following mechanisms [70].

Biodegradation : It is promoted by enzymes and may be either aerobic or anaerobic and provides for complete removal of the polymer from the environment.

Photodegradation : It is promoted by irradiation, e.g. sunlight, and it rarely leads to complete removal, though small fragments may be produced for subsequent biodegradation.

Environmental Erosion : This is promoted by weather elements such as wind, rain, temperature and larger animals. This also cannot remove the polymer completely.

Chemical Degradation : This is promoted by the chemical reactions through additives, e.g. metals and functional groups, which produces smaller fragments of the polymer.

However, any or all of the above mechanisms may be operative on any degradable polymer, with complete removal from the environment being the ultimate goal, which can only be achieved by biodegradation. Conventional non-degradable polymer systems (e.g. polyethylene, polypropylene etc.) are used for high volume, short-term applications such as packaging, medical, automobile and agricultural areas. These synthetic polymers and composites cannot be degraded easily after their life cycle has been completed and so a portion of this volume ultimately litters the environment. Recycling is obviously a better choice at a higher cost but most countries cannot afford to recycle all its polymer wastes. Moreover, all polymers are not recyclable since their properties after recycling are poor compared to their original ones and they are of less economic value. This leads to the quest for new as well as modified degradable polymers and composites, which can replace existing ones. Replacement of these polymer systems requires that the degradable polymers and composites have properties that are sufficiently comparable to those of the conventional polymers. These desirable properties can be achieved by (i) modifying existing degradable polymers or (ii) creating new environmentally friendly polymers.

Earlier studies were based on the modification of biodegradable polymers to enhance their properties. Specific interactions were observed between two modified biodegradable polymers, esterified cellulose and lignin [55, 68]. In the present study, new biodegradable composites are prepared using high modulus regenerated cellulose fibers (lyocell) as reinforcements and cellulose ester (Cellulose Acetate Butyrate, CAB) as matrix material. These composites are evaluated in regards to the different manufacturing processes and properties.

1.2 Thermoplastic Composites and Processing

Considerable interest has been generated in the manufacture of thermoplastic composites due to their unique properties, such as good fracture toughness and thermal stability [3]. Due to more stringent demands for recycling standards, thermoplastic polymers are substituting thermosetting polymers as matrix materials for high volume consumer-driven composites [47]. Also, there are certain advantages from the processing point of view such as (i) short processing time, (ii) indefinite prepreg shelf life, (iii) no chemical reactions involved and (iv) reprocessibility. However, the thermoplastic composites are limited by the range of temperature above which creep of the matrix increases thus limiting its use [1]. The various common forms of prepregging a fiber with thermoplastics are: hot melt [8], solution [11], dry powder [4, 5, 9, 10] and suspension [2, 5-7, 12-15]. Hot melt prepregging poses disadvantages of polymer degradation due to high processing temperature, fiber breakage due to high melt viscosity as well as poor tack properties of prepreps. In case of solution prepregging, the fiber is dipped in a solution of the matrix material and the solvent is removed at a later stage. Dry powder prepregging has been widely used for thermoplastic polymer composite manufacturing due to the advantages of solvent-free operation, well-controlled polymer particle deposition etc. The fourth prepregging method is an alternative to dry powder prepregging technique by the use of a liquid suspension of polymer particles. This study considered two of these prepregging techniques – the suspension and the solution prepregging. The advantages and disadvantages for both the processes are described below.

Solution prepregging is commonly used in industrial practices for composite prepregging and provides a uniform and controlled coating of matrix on to the fiber surface. However, it requires the use of organic solvents, which are hazardous and expensive to recover. Suspension prepregging involves impregnating fibers by contacting them, typically in a drumwinding operation, with polymer particles suspended in an appropriate liquid. The advantages of suspension prepregging are: (a) smaller particle sizes (submicron levels) can be used for prepregging as opposed to $\approx 20 \mu\text{m}$ limit for powder prepregging [3,4]; (b) no limitations to polymer solubility as in case of solution prepregging; (c) very low viscosity of aqueous suspensions; (d) ability to include fiber matrix interface material in the composite by using polymer binder mixture in the suspension; (e) easy handling and low cost set-up for prepregging procedure as compared to dry powder prepregging; (f) better sticking of polymer particles to the fibers compared to dry powder and this helps in easier handling of preregs. But there are surely certain disadvantages such as high energy consumption for water removal while consolidation and chances of void formation due to presence of residual water in preregs.

1.3 Composite Properties and Calculations

The composite properties are evaluated in order to predict their performance in real life applications. The properties of the fiber-reinforced composites depend on many factors like fiber-matrix adhesion, volume fraction of fiber, fiber aspect ratio, fiber orientation, and stress transfer efficiency of interface [31-33]. The theories underlying the property evaluation techniques used for this study are briefly discussed here. Detailed analysis can be found in the references mentioned.

The equations presented in this section apply to fiber-reinforced composites only and the other criteria are [1]:

- Composite fracture has to be fiber-controlled.
- Modulus of elasticity of the fiber should be greater than that of the matrix.
- The strain to failure of the matrix is greater than that of the fiber.

In case of unidirectional (or longitudinal) fiber reinforced composites, the stress is transferred from the matrix to the fiber filaments by shear. When stressed in tension, both the fiber and the matrix elongate equally according to the principle of combined action [1]. Hence the mechanical properties of the composite can be evaluated on the basis of the properties of the individual constituents. At a particular elongation of the composite, both the constituents may be in elastic deformation, the fiber may be in elastic deformation whereas the matrix may be in plastic deformation, or both the fiber and the matrix may be in plastic deformation [Fig. 1.1].

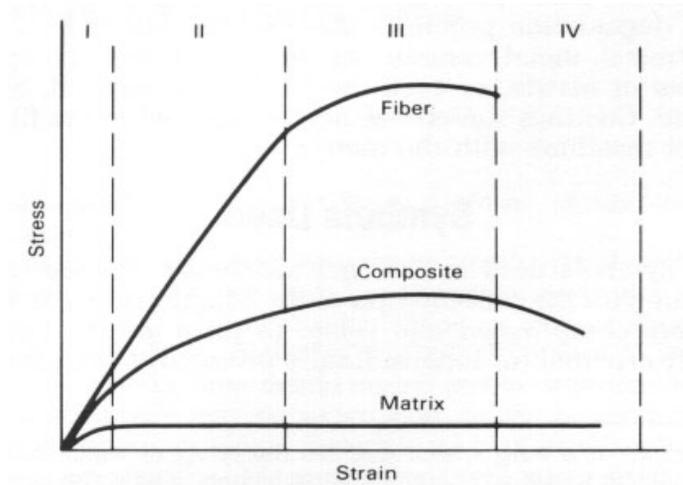


Fig. 1.1: Illustration of four stages of deformation of fibers, matrix and composite. Stage I: elastic deformation of both fibers and matrix, Stage II: elastic deformation of fibers; plastic deformation of matrix, Stage III: plastic deformation of both fibers and matrix, Stage IV: failure of both fibers and matrix [Reproduced from ref. 1].

Rule-of-Mixtures Equations

i. Critical Volume Fraction :

The theory of composites [1] defines the critical volume fraction as the volume fraction of fibers above which the fibers begin to strengthen rather than weaken the matrix [1]. The critical volume fraction may be calculated using the following equation.

$$V_{\text{crit}} = \frac{\sigma_m - \sigma_m^*}{\sigma_f - \sigma_m^*} \quad (1.1)$$

where, σ_m and σ_f are the ultimate tensile strength (UTS) of the matrix and fiber respectively, σ_m^* is the stress on the matrix from the stress-strain curve at a strain

value where the ultimate strength of the fiber is reached. The V_{crit} value for composites decreases with fibers of increasing strength with the other factors remaining the same.

ii. Tensile Strength :

$$\text{For all values of strain} \quad \sigma_c' = \sigma_f' V_f + \sigma_m' V_m \quad (1.2)$$

where σ' s represent the stress values at a particular strain value and V represent the volume fraction of the components in the composite. The subscript c , f and m represent the composite, fiber and matrix respectively [1].

$$\begin{aligned} \text{For } V_f < V_{crit} \quad & \sigma_c = \sigma_m V_m \\ \text{For } V_f > V_{crit} \quad & \sigma_c = \sigma_f V_f + \sigma_m^* V_m \end{aligned}$$

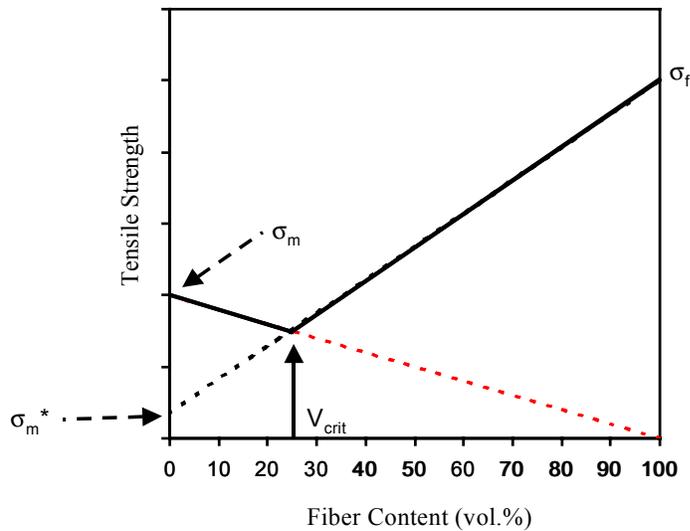


Fig. 1.2: Model for prediction of the ultimate tensile strength of unidirectional fiber reinforced composites where the fracture is fiber controlled.

iii. Ultimate Tensile Strength :

Using the equation (1.2) and the terms for stress specified in part (i), the ultimate tensile strength (UTS) of the composite can be calculated as

$$\sigma_c = \sigma_f V_f + \sigma_m^* V_m \quad (1.3)$$

where, σ_m^* represents the stress on the matrix from the stress-strain curve at a strain value where the ultimate strength of the fiber is reached. This equation is based on the assumption that the composite fractures when the fibers fail (Fig.1.2).

iv. Moduli of Elasticity

Case I – Within strain limits where both the fiber and the matrix are in elastic deformation, the modulus for the composite can be calculated using the rule-of-mixture equation

$$E_c = E_f V_f + E_m V_m \quad (1.4)$$

where E_c , E_f and E_m are the modulus of elasticity of the composite, fiber and matrix respectively, and V_f and V_m are the volume fractions of the fiber and the matrix respectively.

Case II - Within strain limits where the fiber is in elastic whereas the matrix is in plastic deformation, the equation is

$$E_c = E_f V_f + (\sigma_m^* / \epsilon) V_m \quad (1.5)$$

where σ_m^* / ϵ is the slope of the stress-strain curve of the matrix at a given strain beyond the proportional limit of the matrix.

1.4 Cellulose Based Reinforcements in Composites

Cellulose, in its various forms has been one of the commonly used reinforcements for centuries. Mud bricks reinforced with straw and laminated wood were known to be used hundreds of years B.C. [1]. In recent years, cellulosic reinforcements have attracted the attention of researchers for use in thermoplastic composites for high-volume, low cost applications. The advantages of cellulose based reinforcements are: (a) low density,

(b) low cost, (c) high specific properties, (d) biodegradability, (e) renewability, (f) nonabrasive nature to processing equipment, and (g) their organic characteristics, which allows incineration or compostation methods for degradation. However, the primary disadvantages are (a) poor interfacial adhesion and dispersion in olefinic thermoplastic matrix materials due to hydrophilic character of cellulose [39], (b) high moisture absorption leading to dimensional instability [21], and (c) low permissible temperatures of processing and use due to their limited thermal stability. The hydrophilic groups present in unmodified cellulose are detrimental to the performance of the cellulose based composites if the fibers are exposed to the outside atmosphere. Water, in liquid or vapor form, can diffuse into the composite, and the properties (including dimensional stability) are hampered due to hydration. Similar to the study on cellulose based composites by Rowell et al.[38], modification of cellulose by esterification may solve this problem by reduction in hygroscopicity. Also, the processing temperature for cellulose based reinforced composites is limited to 200°C, though higher temperatures can be used for short periods of time [20].

1.4.1. Discontinuous Fiber Reinforced Composites

Lignocellulosic materials are used as mainly discontinuous short fiber reinforced composites such as wood-based flours as reinforcements [18,19]. Generally, the lignocellulosic materials are ground into fine particles with relatively low aspect ratios [35]. These fillers increase the stiffness of the composites, however, the strength generally declines compared to that of the virgin matrix [36]. On the other hand, stiffness as well as strength of the composites usually increases if the lignocellulosic

material is in fibrous form with a higher aspect ratio. However, according to Klason et al., the aspect ratio of lignocellulosic fibers would not necessarily improve the strength of the composites if the reinforcing material is not dispersed uniformly resulting in fiber agglomeration in the matrix [37].

Thermomechanical pulp fibers obtained from rubber plants were used as a reinforcing agent in high-density polyethylene (HDPE) composites [35]. The effect on composite properties owing to variation in the size of the reinforcing agent (with or without any coupling agent) was studied. The tensile strength decreased whereas modulus increased in both cases of wood fiber and wood powder reinforced composites. The decrease in tensile strength in case of high aspect ratio fiber filled composites has been attributed to non-uniform distribution of the fiber in the matrix.

Renewable natural Kenaf fibers have been used as reinforcing material for polypropylene composites [20]. The tensile strengths of the Kenaf fibers varied from 325 to 450 MPa, while the modulus varied from 27 to 48 GPa [22]. The tensile strength, modulus and elongation at break of the composites at 50 wt.% (39 vol.%) loading of Kenaf fibers are 62 MPa, 7.7 GPa, and 2.2 % respectively [20]. This is approximately equivalent to glass fiber/ABS composites in modulus, and slightly lower in strength (Table 1.3).

Jute fibers have been used as high modulus renewable reinforcements for composites. Considering the low density (1.4 gm/cm^3) of jute fibers, their specific stiffness and strengths are higher compared to glass fibers [23-25]. Jute fibers have been used with thermosets [26] and polypropylene [27, 28]. The tensile strength of the jute reinforced polypropylene composites was not affected by incorporation of 50% of jute in

the composites compared to virgin polypropylene, whereas the modulus increased from 1.23 GPa to 7.48 GPa with 50% jute fibers [28]. Addition of a coupling agent further improved the mechanical properties.

Discontinuous Sisal fibers (Agave-Veracruz) have been used as reinforcement in low-density polyethylene (LDPE) composites [29]. The tensile properties increase with the increase in fiber content as well as with fiber length reaching a maximum at 6 mm fiber length. The maximum tensile strength, modulus and elongation at break achieved in these composites are 31.12 MPa, 3.086 GPa, and 1.8 % respectively at a fiber weight content of 30 %. Compared to the usual melt mixing processing in an internal mixer, the fiber breakage was reduced when the fibers were mixed with LDPE in solution (in toluene) before they were extruded.

Similar studies have been presented by George et al., where short pineapple-leaf-fibers have been used for reinforcement in low-density polyethylene (LDPE) composites [30]. The property comparisons between some natural fiber-LDPE composites are presented in Tables 1.1 and 1.3.

Table 1.1: Comparison of tensile properties for natural fiber reinforced LDPE composites.

<i>Fiber Type</i>	<i>Fiber Loading (Weight %)</i>	<i>Tensile Strength^{iv)} (MPa)</i>	<i>Young's Modulus^{iv)} (MPa)</i>	<i>Elongation at Break^{iv)} (%)</i>
Pineappleⁱ⁾	30	13 (22.5)	570 (1100)	6 (4)
Sisalⁱⁱ⁾	30	14.7 (31.0)	781 (3086)	- (1.8)
Juteⁱⁱⁱ⁾	30	8.03	-	4.9

ⁱ⁾ Ref 30: George et al.

ⁱⁱ⁾ Ref 29: Joseph et al.

ⁱⁱⁱ⁾ Ref 34: Sengupta et al.

^{iv)} Values without parenthesis correspond to randomly oriented composites, values within parenthesis correspond to longitudinally oriented composites.

Addition of henequen cellulosic fibers in a low-density polyethylene (LDPE) matrix increased the tensile strength by 50% (from 9.2 MPa to 14 MPa) at a fiber loading of 30% by volume [43]. The modulus increased from 275 MPa for pure HDPE to 860 MPa for 30% fiber loading though the strain at failure decreased from 42% to 5%.

1.4.2. Continuous Fiber Reinforced Composites

Continuous regenerated cellulose fibers are extensively used for reinforcements in composites such as tires for automobiles and bicycles. However, very few studies have been found for the use of continuous cellulose fibers as reinforcement for thermoplastic composites [48, 66].

A new high modulus regenerated cellulose fiber is produced on a commercial scale by Courtaulds (presently Acordis, The Netherlands). The fiber has been given the generic name "Lyocell" [65]. The lyocell fibers are spun from a solution of cellulose in

N-methylmorpholine-N-oxide/water system [58, 65]. The mechanical properties of the fiber are dependent on the draw ratio as mentioned by Mortimer et al. [58]. The modulus ranges from 6.2 to 20.4 GPa depending on the draw ratios (1.0 to 10.4) when the fibers are spun from a 100 μm spinneret. Other properties and processing details are mentioned in studies by Mortimer et al. [58, 65, and 67].

Lyocell fibers from an unknown manufacturing source were used for reinforcements in poly(3-hydroxybutyrate)-co-poly(3-hydroxyvalerate) (PHB/V) composites [48]. The lyocell fibers had a modulus of 36 GPa, a tensile strength of 1400 MPa, density of 1.52 gm/cc^3 , a filament diameter of 12.4 μm and crystallinity of 60% [48]. The fibers were impregnated with PHB/V powder in a fluidization chamber. The impregnated rovings consisting of 3500 filaments, each, resulted in unidirectional composites having a modulus of 5.8 GPa (10 vol.% fiber) and 11.4 GPa (27 vol.% fiber) after consolidation, versus 1 GPa for the matrix. The fiber content of 10 vol. % and 28 vol. % (as determined by volumetric analysis), was low as compared to the desired value of 60% fiber content in continuous fiber composites. Porosity of the composites ranged between 2.6 and 55 %. SEM images revealed a poor fiber-matrix adhesion because of the clean and smooth topography of the fibers after failure. The reason for weak interfacial adhesion was attributed to the hydrophilic fiber and hydrophobic matrix characteristics.

1.5 Compatibility Issues in Biobased Composites

One of the significant drawbacks in cellulose reinforced thermoplastic composites is the poor compatibility of cellulose with other conventional thermoplastic polymers like polyethylene and polypropylene [39]. The hydrophilic character of cellulose is usually

incompatible with hydrophobic matrix material unless a compatibilizer or coupling agent is used [40]. This leads to poor interfacial adhesion between the fiber and matrix as well as poor fiber dispersion. Various coupling or compatibilizing agents are used for improving the interfacial adhesion, dispersion within the matrix and compatibility of the system.

Surface modification of cellulose fibers with polypropylene-maleic anhydride copolymer resulted in improved mechanical properties of the cellulose-polypropylene composites as shown by Felix and Gatenholm [40, 46]. Scanning electron microscopy (SEM) studies revealed improved dispersion and adhesion when the fibers were surface modified. Similar studies were reported by Karmaker and Youngquist for jute fiber reinforced polypropylene composites [28], and by Chen et al. for bamboo fiber reinforced polypropylene composites [44]. Both these studies used maleic anhydride-grafted polypropylene as coupling agent.

A study by Hendenberg and Gatenholm showed improved stiffness in cellulose-thermoplastic composites containing polyethylene-polystyrene blend (70:30 proportion) as a matrix material when a functionalized copolymer (maleic acid anhydride grafted styrene-ethylene/butylene-styrene block copolymer) was used [42].

A study by Trejo-O'Reilly and Cavaille revealed the possible use of grafting agents bearing anhydride or isocyanate reactive groups for introducing non-polar characteristics to the surface of cellulose fiber in view of improving interfacial wetting with polymeric matrices [45]. The interactions of various oligomeric (e.g. oligomeric isocyanate) and polymeric reagents, such as polystyrene-co-maleic anhydride and polystyrene-co-3-isopopenyl- α,α' -dimethylbenzyl isocyanate (PSTMI), with the OH

groups on the surface of different cellulose materials were studied using Fourier-transform Infrared Spectroscopy (FTIR), Scanning electron microscopy (SEM), X-ray photoelectron microscopy and elemental analysis. The accessibility of the OH groups varied as a function of the coupling agent in terms of molecular size and chemical nature. Fiber surface property studies revealed considerable changes in contact angle of water when the appended moieties were long-chain hydrophobic structures like PSTMI.

Improvement in mechanical properties and interfacial wetting was noted for steam-exploded fiber from Yellow poplar (*Liriodendron tulipifera*) when the fibers were acetylated [41]. The thermal stability of the fibers also improved when the fibers were extracted with water and alkali and later acetylated.

Cellulose fiber surface treatment by preimpregnation of henequen cellulosic fibers in LDPE-xylene solution improved the interfacial adhesion between the fiber and matrix as well as the shear properties of the composites [43]. Also a silane coupling agent (A-172 Union Carbide) improved the properties of these henequen cellulosic fiber composites [43].

1.6 Property Comparison of Fibers and Matrices (Table 1.2).

<i>Fiber / Matrix Type</i>	<i>Tensile Strength (MPa)</i>	<i>Young's Modulus (GPa)</i>	<i>Elong. at Break (%)</i>	<i>Notched Izod Impact (J/cm)</i>	<i>Water Absorption* (%)</i>	<i>Sp. Gravity</i>
FIBERS (Reinforcements)						
E-Glass ⁱ⁾	3450	72.4	4.8	-	-	2.60
S-Glass ⁱ⁾	4580	86.8	5.4	-	-	2.49
Aramid (Kevlar 29) ⁱ⁾	3620	124	2.5	-	-	1.44
Graphite (T-300) ⁱ⁾	3243	231	1.5	-	-	0.18
Graphite (IM-6) ⁱ⁾	4278	289	1.7	-	-	0.17
Ceramics (Nicalon) ⁱ⁾	2484	179	1.5	-	-	2.55
Hydro-carbon (Spectra 1000) ⁱ⁾	3001	173	2.7	-	-	0.97
Cellulose ^{vi)}	860	11	10.0	-	-	1.36
Lyocell ^{v)}	1400	36	6.0	-	-	1.52
POLYMERS (Resins/Matrices)						
ABS ⁱⁱ⁾	55	2.8	10	1.9	-	1.05
Polycarbonate ⁱⁱ⁾	62	2.3	100	1.4	-	1.20
Polyetherimide ⁱⁱ⁾	105	2.8	-	0.53	-	-
Nylon ⁱⁱ⁾	66	3.5	29	>21	-	1.12
Polyethylene (HDPE) ⁱⁱ⁾	28	1.04	30	-	-	0.95
Polypropylene ⁱⁱ⁾	35	0.83	200	-	-	0.90
Polystyrene (high impact) ⁱⁱ⁾	35	2.76	15	-	-	1.05
Epoxy Resin ⁱⁱⁱ⁾	32	0.5	6.2	-	-	-
CAB 381-20 ^{iv)}	76	0.8	27	-	-	1.20
PHB/V ^{v)}	20	1.0	27	-	-	-

* Water absorption based on 24 hrs immersion in water (ASTM D570).

ⁱ⁾ From Leslie [62]

ⁱⁱ⁾ From Weeton et al, pp 6-34 and 6-56 [1].

ⁱⁱⁱ⁾ From Hoffman and Glasser [63]

^{iv)} From Ghosh et al [55].

^{v)} From Bourban et al [48].

^{vi)} From Maloney, pp.212 [57].

1.7 Property Comparison of Composites.

Table 1.3: Comparison of properties for fiber reinforced composites.

<i>Fiber / Matrix Type</i>	<i>Filler (Wt. %)</i>	<i>Tensile Strength (MPa)</i>	<i>Young's Modulus (GPa)</i>	<i>Elong. at Break (%)</i>	<i>Notched Izod Impact (J/cm)</i>	<i>Water Absorption* (%)</i>	<i>Sp. Gravity</i>
COMPOSITES							
Glass Fiber/ABS ⁱ⁾	30%	100	7.6	-	0.75	-	-
Carbon Fiber / ABS ⁱ⁾	30%	130	12.4	-	0.59	-	-
Glass Fiber/PET ⁱ⁾	30%	159	9.0	2-3	1.0	0.05	1.6
Pineapple/LDPE ⁱⁱ⁾	30	22.5	1.1	4.0	-	-	-
Kenaf/PP ⁱⁱⁱ⁾	50	62	7.7	2.2	32	1.05	1.07
Sisal/LDPE ^{iv)}	30	31	3.1	1.8	-	-	-
Jute/LDPE ^{v)}	30	8.03	-	4.9	-	-	-
Lyocell/PHB/V ^{vi)}	27	278	11.4	4.3	-	-	-
Newspaper/PP ^{vii)}	40	53	4.4	3	-	-	-

ⁱ⁾ From Weeton et al, pp 6-34 and 6-56 [1].

ⁱⁱ⁾ From George et al. [30]

ⁱⁱⁱ⁾ From Sanadi et al. [20-22]

^{iv)} From Joseph et al. [29]

^{v)} From Sengupta et al. [34]

^{vi)} From Bourban et al. [48]

^{vii)} From Sanadi et al. [64]

1.8 Application of Biodegradable Composites

Present applications of the biodegradable composites are in the field of energy and impact absorption, such as car fenders and bicycle helmets [39, 47, 66], and for markets which targets cheaper, renewable and non-recyclable (biodegradable) materials, such as packaging, and structural elements [64]. 20 to 30 pounds of wood based composites are used in cars behind the vinyl and carpeting on the doors, consoles,

headlines, trunkliners, and seat backs (Fig. 1.3) [39]. These composites have 50% wood flour and 50% polypropylene, along with other additives for appearance and performance enhancements. Similar wood fiber-polyethylene composites are used for exterior construction materials, and they often replace lumber based materials. Other uses of wood fiber based composites are deck surface boards, picnic tables, industrial flooring, etc. [39].

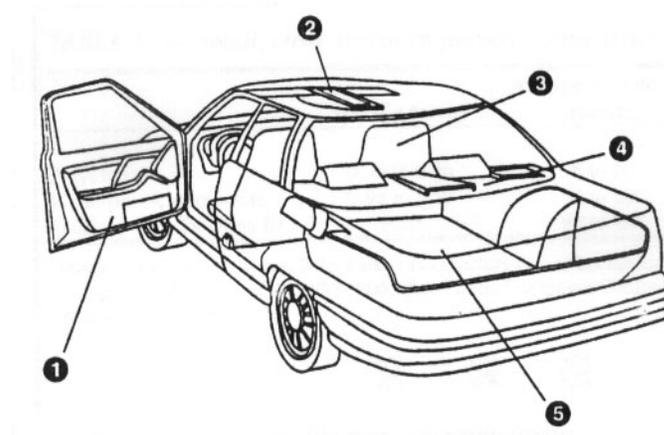


Fig. 1.3: Illustration of application of wood fiber/plastic composites in automobiles for door panels (1), roof headliners (2), seat backs (3), rear decks (4), and trunkliners (5). Reproduced from ref. 39.

1.9 Objectives

This study is based on the evaluation of composites from several different manufacturing processes by their performance. The reinforcement is regenerated cellulose (lyocell) fibers, either in the form of continuous filaments (tows) or woven fabrics, which is spun from a solution of cellulose in N-methylmorpholine-N-oxide [58, 65]. Because biodegradability is a concern for conventional thermoplastic matrix

materials (such as polyethylene and polypropylene), this study will explore the possibility of a biodegradable cellulose ester (cellulose acetate butyrate) as the matrix material. Moreover, both the fiber and the matrix are obtained from renewable resources and there may be a possibility of compatibility between the matrix and fiber owing to their similar conformations. The objectives of the study are as follows:

1. To evaluate commercially available thermoplastic cellulose esters as matrix material for cellulose fiber composites.
2. To screen various options available for composite manufacturing, and to evaluate the final products.
3. To evaluate particle size and particle size distribution of matrix powder for use in suspension prepregging.
4. To compare composite performance for various prepregging technologies and fiber types (fiber mats vs. continuous fibers).
5. To provide relationships between composite properties and fiber loading, fiber orientation, and consolidation conditions.
6. To evaluate water absorption in these composites.