

Development, Characterization and Application Potential of Bio-composites: A Review

Mohammad Zahid Rayaz Khan¹ and S K Srivastava²

¹Research Scholar, MED, M. M. M. University of Technology, Gorakhpur, UP 273010, INDIA

²Professor, MED, M. M. M. University of Technology, Gorakhpur, UP 273010, INDIA

E-mail: zahidkhan010@gmail.com

Abstract. Sustainable development of bio-composites is the solution for current ecological imbalance caused by the petroleum based synthetic materials. Synthetic fibers of conventional polymer composites are replaced by natural/biodegradable fiber resulting into bio-composites. The paper presents an overview about the development steps, manufacturing methods and characterization parameters of bio-composites. Popular manufacturing methods of bio-composites such as hand layup, injection molding, compression molding etc. have been covered briefly. It includes characterization based on mechanical, thermal and morphological parameters. The commercial and industrial application potential of bio-composites is also included.

1. Introduction

The conventional fiber reinforced polymer composites are generally made up of inorganic and organic materials reinforced into thermosetting and thermoplastic polymers. These composites had high application potential due to its better mechanical, morphological, thermal properties. However, their usage and disposal are major challenges because they are non-biodegradable. In recent years, this problem has been overcome by using fully/partial biodegradable composite materials reinforced with the natural fiber in place of conventional fossil based fiber[1]. The researches are being carried out in this area for the sustainable development of bio-composites which fulfill the demands of legislative authorities related to their recycling and environmental friendly products.

Natural fibers such as kenaf, sisal, jute, banana, rice hucks are used as reinforcement in the polymers for the development of bio-composites. Bio-composites are fully green, if polymer and fiber both are derived from plant or biodegradable material; however, composites are partial green if anyone out of polymer/fiber is biodegradable or obtained from the natural plant. Natural fibers are economical, low density, good specific strength properties, and biodegradability. Bio composites are suitable for delicate consumer products, packaging, disposable consumer products, and suitable for light weight applications[2][3][4][5].

In this paper, a brief review on the recent research and development carried out, characterization and application of bio-composites is presented. It includes a brief description on the various manufacturing methods based on the types of natural fibers, polymers, their geometrical properties, mechanical properties etc. A brief discussion on the characterization of bio-composites based on different destructive and non-destructive testing methods is also included. Bio-composites have



shown wide potential in the development of automotive components, agricultural equipment, cabinet and cosine of different electrical and electronic equipment, and packaging etc.

2. Development of Bio-composites

The processes involved in the development of NFRP composites are: fiber and polymer preparation and amalgamation of prepared fiber and polymer by different fabrication techniques. Several methods can be used for the processing of natural fibers such as mechanical processing (for stiff and rough fibers), chemical processing (for soft, contains property of both synthetic and natural), & biological degumming[6] etc.

2.1. Basic Steps

The following four steps are generally used in the development of bio-composites such as impregnation, layup, consolidation and solidification [7].

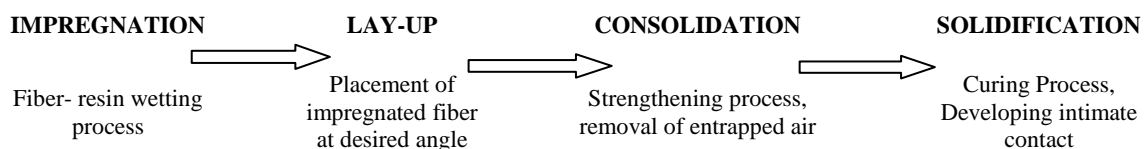


Figure 1: Steps for Development of Bio-Composites

2.2. Manufacturing Methods

There are different manufacturing methods for the successful development of NFRP composites such as injection molding for short fiber reinforced thermoplastics, open mold process (spray and hand layup), liquid composite molding process, compression molding including film staking, automated process[8][9]. The selection of particular manufacturing process depends upon the type of polymers (whether thermoplastic or thermosets) used for the development of NFRP composites [10]. Thermosets are firstly used around 1940s. Fabrication of thermosetting composite is easy because of the low tooling cost, better wettability of fiber, less heat and pressure required during curing process. In 1998, thermoplastic polymer based composite products capture around 25% markets of polymer-based composites. Thermoplastic composites are very popular in the field of aerospace and automobile industries. Few manufacturing processes are common for both types of polymers like pultrusion process, compression molding, injection molding, autoclave process, etc. Table 1 shows different manufacturing methods, processing techniques and characteristics of bio-composites.

Table 1. Manufacturing methods for bio-composites development

Methods	Operation	Characteristics
Hand Lay-Up Method[11][10]	Mixture of fiber-matrix is placed manually into open mould, mild pressure is applied by roller for the removal of entrapped air, better compatibility with thermosets.	low cost, no size constraints, suitable for academic and R&D work, mild surface finish, air pockets and long curing time are the limitation.
Filament Winding Process[10][12]	Resin impregnated continues fiber are wound on rotating mandrel, manual, computer controlled, controlled fibre orientation.	Hallow Tube like structures, continues fiber and thermoplastic resin are the constraints, high fiber volume fraction.
Pultrusion Process [13]	Resin soaked fibers are pulled out though a die of desired shape, Shape of the product depends on the die cross section.	Overall cost is low, suitable for thermosets and thermoplastics, limited for continues cross section.
Compression Moulding[10]	Fiber- resin mixture is placed into the heated closed mould; compressive load is applied through the upper half of the mould.	High production rate, good Surface finish, multiple part development, thermosets polymer, large automobile parts.

Liquid Transfer Moulding Process[14]	Resin is injected into the fiber carrying closed mould, mould cavity has vacuumed pressure or atmospheric pressure.	product having complex geometry, high fiber volume fraction, good surface finish, Resin injection, curing, and heat transfer are the major constraints.
Hybrid transfer moulding[10]	Mixture of two different resin is injected into mould containing fiber.	Low fiber volume fraction, complex shapes, thermosets polymer.
Injection Moulding[15]	Require amount of fiber resin mixture are injected into mould cavity, extruder is used.	Compatibility with both type of resin, high production rate, less curing time, different automobile parts.
Tape Winding[16][17][18]	Commingle fibers are wound on the heated mandrel for melting and strengthening of thermoplastics.	Suitable for thermoplastics polymers, single step process.
Hot Press [19]	Thermoplastic prepreg are piled up together between the heated moulds and compressed.	No need of secondary operation, popular in R&D.
Autoclave Processing[20][21]	Automatic process, prepreps are lay down in mould and entire assembly vacuumed bagged and placed for curing inside autoclave.	Higher fiber volume fraction, proper amalgamation of composite constituents, no air pockets, good interfacial adhesion, aircraft parts, both type of polymers.
Diaphragm forming [22]	Thermoplastic prepregs sheets are placed between the flexible diaphragms, diaphragms placed into the mould for curing.	only suitable for part having constant thickness and non-uniform fiber distribution.

3.Characterization Parameters

There are different tests for the mechanical characterization of bio-composites such as tensile test, flexural test; impact test, dynamic mechanical analysis etc. The scanning electron microscopy, XRD, EDX, FTIR tests are conducted for the morphology analysis of bio-composites. Table2 shows the possible number of tests, purpose, machine used (brand name), approximate cost along with capacity for the characterization of bio composites.

Table 2: Various tests for Bio -Composites Characterization

Experiments	Properties	Machine, Brands and Capacity (Cost)
Tensile Test [23]	Maximum tensile load carrying capacity, young's modulus	Universal testing machine Brands: Instron, Tinius Olsen, Zwick Capacity: 5, 15, 30, 100 KN Approx. Cost: 10-20 lakhs
Three Point Bending Test[24]	Flexural strength, maximum load at failure, flexural modulus	
Impact Test (Charpy /Izod)[25]	Impact strength	Pendulum impact test machine Brands: Instron, Tinius Olsen, Zwick, WPM Leipzig, Haida Capacity:1J-300J Approx. Cost: 3-10 lakhs
Hardness [26]	Hardness	Hardness testing machine Brands: Instron, Zwick, Buehler Capacity:10 to 150 Kg Approx. Cost: 1.5-4lakhs
Dynamic Mechanical Thermal Analysis (DMA) [27]	Fatigue strength, glass transition temperature, storage modulus	DMA analyser Brands: Instron, NETZSCH Capacity:25N to 500N Approx. Cost:10-25 lakhs
Thermogravimetric Analysis	Thermal properties, thermal	Thermogravimetric analyser

(TGA) [28][29]	degradation temperature, percentage weight loss, variation in chemical and physical properties	Brands: Perkin Elmer, Torbal Approx. Cost: 15-25 lakhs
Differential Scanning Calorimetry (DSC) 23,6 [29][30]	Observe the glass transition temperature of the polymers T _g , crystallization and melting temperatures	Thermo- Modulated calorimeter
Thermal Conductivity Test [31]	Insulation performance of materials	Manually
Thermomechanical Analysis [32]	Thermomechanical stability, coefficient of thermal expansion,	Thermomechanical analyser Brands: Thermo Scientific LTQ, Thermo Finning
Pin-on- Disc Test [33]	Friction and wear properties of material	Tribometer Approx. Cost: 5-8 lakhs
Erosion Test [34]	Erosion wear properties	Air jet erosion test rig
Fragility Test [31]	Mass loss from the surface abrasion and Impact damage	Manually
Scanning Electron Microscopy (SEM) [35][36]	Surface morphology, examine the surface of sample after deformation, physio-mechanical properties, micrographs of fractured surface	Scanning electron microscope Brands: Hitachi, JEOL, ZEISS, FEI Approx. Cost: 25-150 lakhs
X-Ray Photoelectron Spectroscopy [29][28]	Identify the crystal structure and molecule arrangement, strain, composition of material	X-Ray diffractometer Brands: PANalytical, Philips, Siemens Approx. Cost: 30-150 lakhs
FTIR [37][28]	Amount of component in the mixture,	FTIR spectrometer Brands: Nicolet, PerkinElmer, Bruker Approx. Cost: 30-100 lakhs
CT Scan Analysis [38]	Fiber distribution in the matrix	CT Scanner Approx. Cost: 15 lakhs
Elemental Dispersive X-Ray Analysis [39]	Elemental composition of composites	Nano scanning electron microscope Brands: Hitachi, ZEISS Approx. Cost: 100 Lakhs
Transmission electron microscopy Analysis (TEM) [39]	Morphology and particle size distribution in particulate composites	Transmission electron microscope Brands: CRAIC, JEOL Approx. Cost: 10 lakhs
Atomic Force Microscopy [32]	Surface morphology	Atomic force microscope Brands: Veeco, RMC Approx. Cost: 20-100 lakhs
Polarized Optical Microscopy [40]	Crystallization behaviour	Polarized optical microscope Brands: Motic, Olympus, Nikon Approx. Cost: 5-15 lakhs
Soil Burial test [28][41]	Biodegradability of Bio-Composite, weight loss	Manual Process

4. Applications

The bio-composites materials have wide domestic and industrial applications. The different types of natural fibers such as sisal, hemp, wood saw particles, bamboo, kenaf, oil palm, bagasse, animal hair etc. and polymers such as epoxy, polyester, polylactic acid(PLA), etc. are used for the sustainable development of bio-composites. Bio-composites are largely used in automobile industries, structural components, packaging, electronics industries, electrical appliances, sports, aerospace structures, etc. for the last two to three decades because it possesses high strength to weight ratio, substantially low cost, corrosion resistant, high fatigue strength, biodegradability, good surface finish, etc. These composites have the demerits such as poor hydrophilic resistance, moderate temperature sustainability and ageing effect [42]. Major industrial applications of bio-composites are summarized in table 3.

Table 3 : Applications of Bio-Composites

Area	Applications	Company
Automobile Industries[43]	Rear storage shelf/panel, door panels, spare tyre lining, noise insulation panels, boot lining, seat backs, internal engine cover, sun visor, bumper, wheel box and other parts of automobiles	Opel, Volkswagen, Audi, BMW, General Motors, Toyota, Volvo, Mercedes, Renault, Mitsubishi, Rover, Lotus
Packaging[44]	Cosmetics, laptop casings, bottles, food and beverages, mobile casings, electronic goods packaging, laptop and mobile packaging, projector and voltage stabilizer cover	FS Korea, Rexam, hp, Apple, Thomson Lamp Bulb
Sports	Safety helmets, surfing boards, rackets, polo balls, bicycle frame	-
Construction	Door panels, decking, railing, window frames	-

5. Conclusions

The waste disposal problem, limited resources and unbalance among the ecology, technology and economy associated with the conventional polymer composites led to the development of nonconventional, viz. natural and biodegradable composites (bio-composites). The paper describes different manufacturing methods for the sustainable development of bio-composites. It covers the discussion on major characterization parameters and application potential of bio-composites in different areas of engineering components. There is always a good scope for designing and exploring the new biodegradable fiber/polymer which competes with non-biodegradable fiber/polymer.

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