Chapter 1

Introductory Chapter: Natural Fiber Plastic Composites - A Brief Review

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1. Introduction

The natural composites are classified mainly in three biomaterial categories: green composites, hybrid biocomposites, and textile biocomposites. In recent times, biological materials have become essential materials for the construction and automotive industry. Natural fibers and particles have been already used in various types of materials such as plastics, concrete, and textile products as strengthening part of the fiber/matrix combination. These composite materials have very good mechanical thermal and acoustical properties; therefore, they have been used in various engineering applications. The wood-plastic composites (WPCs) have been used in many application areas as automotives, constructions, marine, electronic and aerospace areas instead of fiber glass composites and steel materials. As a wood derivative, hemp fibers have been used in generating thermoplastic matrix composites. These composites can find its application area in the following five sectors: the first area is to modify some parts of the internal and external automobile structures and electric cars. The second area is to obtain strong cementation in building construction. Another area is the production of durable clothes for army suppliers. The fourth one is to produce small electric hand tools and the last one is to build supercapacitors in carbon nanosheets which are as strong as graphene. This review covers a general overview of the preparation phase (chemical procedures), test techniques (experiments) and results, and conclusions summaries (the gaining) of current studies on hemp fiber plastic composites. The data obtained by literature search of the 63 publications have been shown in **Table A1** [1–63].

2. Scientific researches about natural hemp composites

The quality of the produced compounds depends on the elastic constants of the natural fibers used in the composition and the shape and size of the fibers as well as the properties of the matrix material. Factors influencing the strength of the composite material can be listed in more detail as follows: Morphic structure, chemical composition, density, thickness of wood plastic composites (WPCs) as well as the type and amount of bonding agent and fiber percentage used in composite material. According to the literature, the usage rate of the herb composites (WPCs) in the industrial areas is stated as follows: in the field of aviation 1%, in the area of consumer products 8%, in various fields 8%, in the field of electronics 10%, in the maritime field 12%, in the construction industry 26%, in the automotive sector 31%, and miscellaneous 4% [46].

2.1. General properties of natural fibers in plastic composites

Interface conditions have been influenced at the nanoscale level depending on the thermal sensitivity and the water content of the green materials in the process of preparing composite material from natural fiber embedded in a polymeric matrix. The natural fiber and the polymeric matrix interface features and the cell wall structure of the natural fibers influence: (i) the mechanical properties, (ii) the durability, and (iii) the recyclability of the

Test type	Experimental methods	Test type	Experimental methods
1	Accelerated weathering testing	20	Microscopy (optical light microscope, SEM, confocal laser scanning microscopy (CLSM))
2	Acoustic emission monitoring	21	Moisture absorption method
3	Biodegradability test	22	Nanoindentation test
4	Chemical techniques	23	Nondestructive longitudinal and flexural free/forced vibration test
5	Compression test	24	Sample thickness measurements
6	Compression molding	25	Shear testing
7	Density measurements	26	Single-fiber pullout test
8	Diffusion measurement	27	Static/dynamic/vibration-damping testing
9	Differential scanning calorimetry (DSC)	28	Surface energy and dynamic contact angle measurement
10	Digital images recording	29	Taguchi's technique
11	Fatigue testing	30	Temperature field measurement
12	Flexural test	31	Tensile testing
13	Fourier transform infrared spectroscopy (FTIR)	32	Thermal techniques (annealing)
14	Fracture toughness	33	Torsion test
15	Growth test	34	Vicat test
16	Impact test	35	Water absorption and volume change test
17	Liquid chromatography (HPLC)	36	Weibull statistics
18	Mass spectrometry	37	X-ray microtomography
19	Microbond test		

Table 1. The list of performed experimental studies on natural fiber plastic composites.

industrially produced green composites. The literature survey results both on mechanical and chemical properties of the hemp fiber plastic composites and their usage in industrial areas have been listed in **Table A1**. **Table A1** gives brief information on: (i) the aim of this research, (ii) the experimental methods used in compound production, and (iii) conclusions according to the obtained results. In **Table A1**; 63 research articles have been listed according to the fiber/matrix material characteristics. Of these 63 studies, 59 were related to fiber composites, while only 4 of them were related to particle composites. In the literature survey, the investigations were carried out in two groups: (a) original research articles and (b) review articles. The 52 articles of the 63 articles were original research articles. Researchers performed a series of experimental studies to obtain the information about the following main subjects related with the natural fibers and plastic matrices in biocomposites: (a) mechanical elastic constants, (b) strength, (c) failure stages, (d) the effect of moisture content, (e) biodegradability, (f) fiber matrix interface stresses, (g) cell wall properties, (h) hardness, and (i) the effect of chemical processing. The statistical information according to the performed experiments has been presented in **Table 1** and **Figure 1**. The basic tests have been performed by tensile loading (23%) to obtain the Young's modulus and tensile strength of the composite material in addition to the microscopic visualizations (optical light microscope, SEM) (17%) to observe deformation patterns of the loaded specimens in micro and nanoscales.

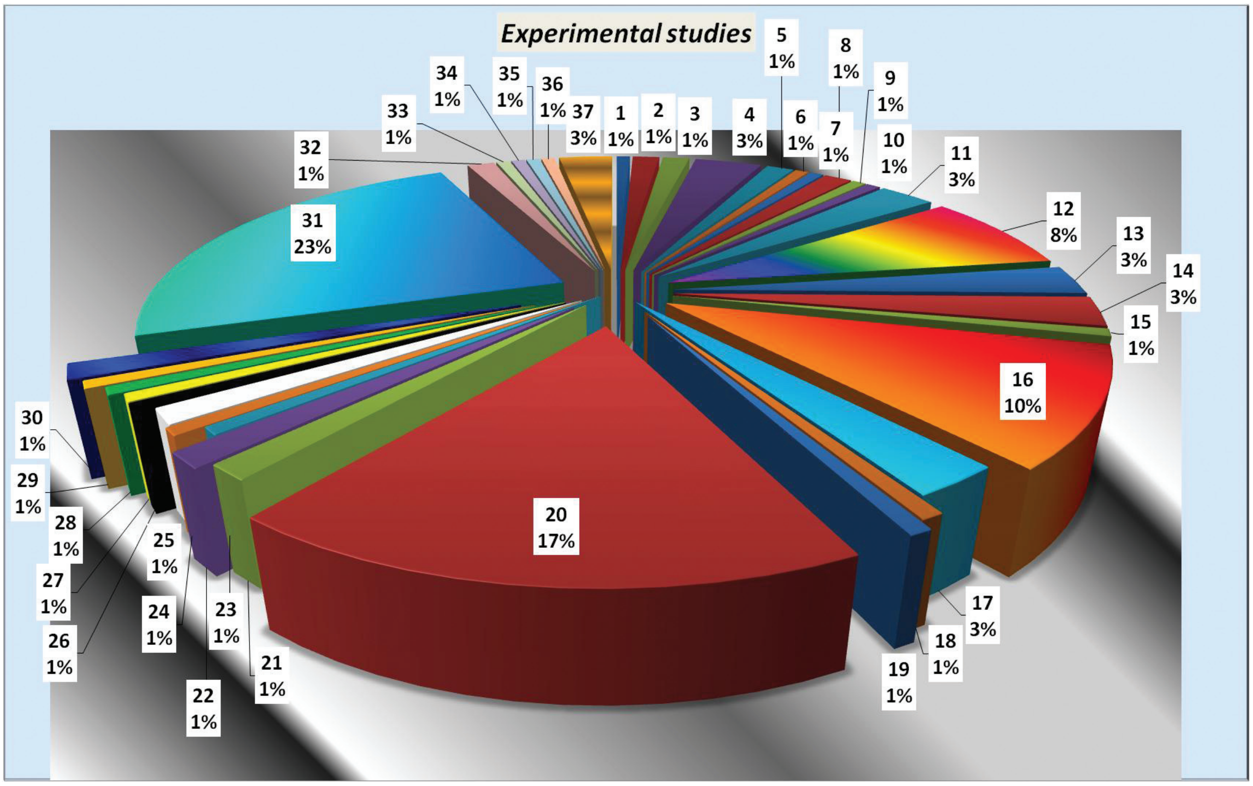

Figure 1. Curve represents the hemp fiber plastic composites and percentage distributions of the performed experimental studies in literature survey.

3. Conclusions

The results obtained by the literature search were summarized below and very important keypoints about fiber and matrix compositions, the physical features of the hemp fibers and hemp fiber plastic composites were emphasized. The main results were as follows.

(1) It was found that tensile strength, Young's modulus, and impact strength of the hemp short fiber reinforced composites were increased in proportion to the increase in fiber content. (2) Flexural strength of the hemp fiber reinforced polylactide and unsaturated polyester composites were found to be decreased with increased fiber content. Additionally, flexural modulus was found to be increased in proportion to the increased fiber content. (3) The impact energy required to damage hemp composites was higher than in conventional laminates. (4) The deformation characterization of hemp/epoxy composites has been developed in three stages. (5) It was shown that natural fibers when compared to flexible fibers showed scattered and lower mechanical properties. (6) Minor variations in terms of the mechanical properties of the woody hemp core (WHC) cell walls were investigated at the nanoscale level. (7) The fiber/polymer interface was modified by using two functionalized chemical procedures simultaneously, and in this way, better adhesion capacity was obtained at the interface (between hemp fibers and thermoplastic matrix).

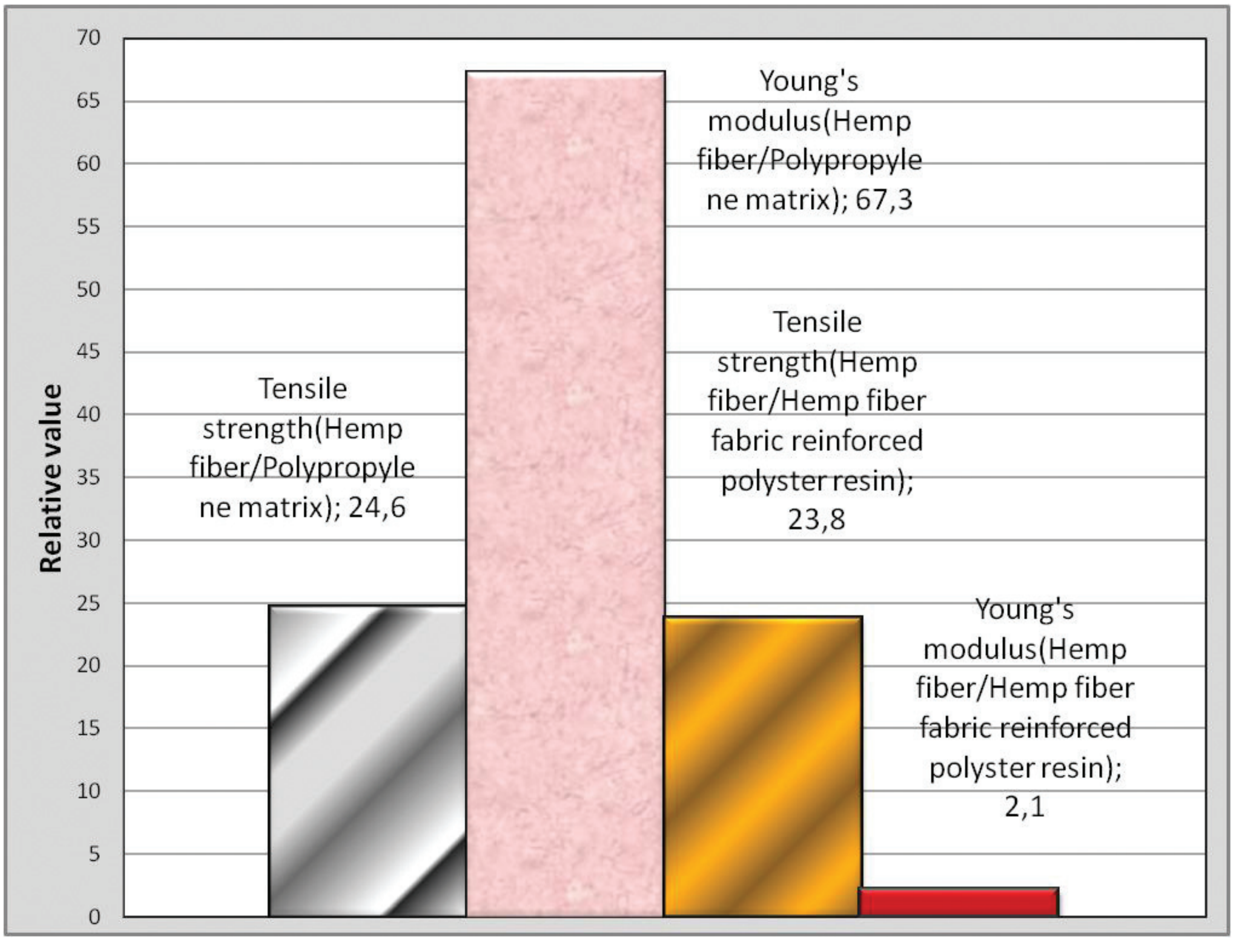

Figure 2. The comparison for the hemp fiber, polypropylene and polyester resin materials according to the tensile strength and Young's modulus.

(8) Variations obtained using nanodrawing tests showed slight variation in the cell wall properties, while the polymer composition was more variable. (9) Hemp fiber composites showed a greater resistance to crack formation and growth than glass fiber composites, although they had lower fatigue strength. (10) Testing natural fiber composites under low impact loading provides important information on the failure mechanisms of hemp (*Cannabis sativa* L.) fiber epoxy composites.

Characteristics of the deformed material such as matrix cracking, delamination, fiber breakage, and fiber pullout phenomenon were examined microscopically [15, 16, 25, 44, 58]. In literature, there were rare experimental studies on the characteristic determination of hemp cell wall structures. In a study on this subject, minor variations at the nanoscale level related to the mechanical properties of the cell wall have been identified [19]. The comparison between the hemp fiber-polypropylene matrix and hemp fiber-fabric reinforced polyester resin in terms of material properties were summarized in Refs. [30, 46, 47, 60, 62]. The graphical results on mentioned values were given in **Figure 2**.

A. Appendix

Author, Reference number	**Research subject**	**Testing methods**	**Results**
Moyeenuddin et al. [1]	Mechanical properties of hemp fiber reinforced composites	Tensile testing, impact testing, and fracture toughness testing	Tensile strength, Young's modulus, and impact strength
Summerscales et al. [2]	A review to obtain high quality fiber	Growth, harvesting, and fiber separation techniques	A review
Summerscales et al. [3]	Properties of natural fiber reinforced composites	Microscopy, mechanical, chemical, and thermal techniques	A review
Pickering et al. [4]	Plane-strain fracture toughness (KIc)	Heat treatment "annealing"	KQ of random short hemp fiber reinforced (PLA).
Sawpan et al. [5]	Flexural strength and flexural modulus	Flexural test	Flexural strength of the composites increased with fiber content
Summerscales et al. [6]	The rules-of-mixture (effects of porosity)	Weibull statistics	A review
Newman et al. [7]	Wood fiber reinforced in polypropylene	Tensile testing	Micromechanical models predicted the tensile modulus
Rachini et al. [8]	Characteristics for hemp fibers and thermoplastic matrix	Chemical process, tensile and impact testing, and SEM	Organosilane coupling agents affecting the tensile strength
Michel et al. [9]	Failure modes of (PHB) and PHB-hemp fiber reinforced composites	Tensile testing and accelerated weathering testing	Changes in the mechanical properties
Vasconcellos et al. [10]	Typical tests of a woven hemp fiber reinforced epoxy composite	Tensile and fatigue testing, optical microscopic, X-ray micro-tomography,	Three stages of damage mechanisms

Author, Reference number	**Research subject**	**Testing methods**	**Results**
		temperature field measurement, and acoustic emission monitoring (AE)	
John et al. [11]	The classification of composites	–	A review
Ude et al. [12]	A summary about *Bombyx mori* woven silk fiber and its composite	–	A review
Misnon et al. [13]	An overview of describing natural textile materials	–	A review
Shah [14]	Ashby-type materials selection charts	Tensile testing	A review
Caprino et al. [15]	Natural composites in applications	Impact loading, optical microscope, penetration test, and indentation test	An higher impact energy is necessary to obtain damage inside hemp composites
Kim et al. [16]	The effect of pH on the tensile properties	Tensile testing, microbond test, SEM.	The fracture toughness of the composites
Shah et al. [17]	The mechanical properties of silk	Charpy impact testing and short beam shear testing	Silk fiber composites (SFRPs) offer advantages
Marrot et al. [18]	The mechanical properties of hemp fibers (Fedora 17)	Tensile testing, nanoindentation test, and X-ray diffraction test	Plant fibers showed low mechanical properties
Beaugrand et al. [19]	The micromechanical properties (WHC) cell walls	Nanoindentation test, density measurements, flexural tests, and biochemical analysis	The mechanical properties of the cell walls
Salentijn et al. [20]	Fiber hemp (*Cannabis sativa* L.) breeding programs	–	A review
Liu et al. [21]	The mechanical properties of hemp fibers	Tensile testing, chemical analysis, microscopic tests, and digital images recording	Less variable and high strength fibers
Almusawi et al. [22]	The particle sizes, the moisture content, and the heating temperatures	Three point flexural testing and tensile testing	The importance of particle size
Christian et al. [23]	Diffusion properties and mechanical properties	Tensile testing and diffusion measurement	Larger change in properties of the hemp/cellulose
Yan et al. [24]	The effect of fibers (MAPP)	Tensile testing, flexure testing, and impact testing	(MAPP) improved the fiber-PP adhesion
Lu et al. [25]	The improvement of the fiber-matrix interface by 5 wt% NaOH treatment	SEM and Fourier transform infrared spectroscopy	Mechanical and thermo-mechanical properties
Shah et al. [26]	Investigation of the mechanical testing cases	Tensile testing and fatigue testing	Flax is a potential structural replacement to E-glass
Kabir et al. [27]	The tensile properties of single hemp fibers	Optical microscopy (OM) measuring and tensile testing	The tensile strength of chemically-treated fibers

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Author, Reference number	Research subject	Testing methods	Results
Vasconcellos et al. [28]	The resistance for low velocity impact of hemp/ epoxy	Tensile testing, impact testing, fatigue testing, acoustic, emission (AE) monitoring, and microscopic observations	A decrease of the residual tensile strength
Landro et al. [29]	The characteristics and performance of a thermoset bioepoxy resin	Static/dynamic/vibration-damping testing	Laminated composites reinforced with hemp fibers
Sukmawan et al. [30]	Steam exploded bamboo (SEB) fibers	Tensile testing	The tensile strength of alkali treated bamboo fiber
Vukcevic et al. [31]	The optimal production of hemp fibers (ACh)	SEM, mass spectrometry, and temperature programmed chemical reaction	High efficiency in pesticides removal on hemp fibers
Kord [32]	Mechanical properties of (PP)/hemp fiber	Tensile and impact testing, and X-ray diffraction (XRD) testing	The PP/hemp fiber composites
Kavianiboroujeni et al. [33]	The effects of different design parameters	Three-point bending flexural testing, and SEM	Hemp content parameters
Alhuthali et al. [34]	A new infiltration method	Three point bending testing, impact testing, and fracture testing	The development of new composite materials
Saikia [35]	The mechanical properties of the composite	SEM, the gravimetric moisture absorption method, and three point bending test	The thermodynamic parameters of the absorption process
Dalmay et al. [36]	The effects of adding natural fibers	SEM, Vicat test, and three point bending testing.	Flax, lowered the crack propagation
Wretfors et al. [37]	The improvement of fiber-matrix interactions	Tensile testing, SEM, (HPLC), (CLSM)	Getting a better fiber distribution
Erchiqui et al. [38]	The mechanical and structural properties	–	The variations of the process parameters
Etaati et al. [39]	The distribution and effects of the interfacial shear strength (IFSS)	Tensile testing	The hemp fibers had lower tensile properties
Fotouh et al. [40]	The effect of strain rate	Tensile testing, (SEM)	The mechanical behavior is dominated by the matrix
Han et al. [41]	Surface treatment effects	(FTIR), moisture analysis, (DSC), and Tensile testing	Improvement of the thermal stability of hemp fiber
Sawpan et al. [42]	Mechanical properties of chemically treated random short fiber	Impact testing and fracture testing	Mechanical properties of (PLA) increased
Mantia et al. [43]	Polymer composites filled with natural-organic fillers.	–	A review
Sawpan et al. [44]	The interfacial shear strength (IFSS)	Optical light microscope, Fourier transform infrared spectroscopy (FT-IR), scanning electron microscope (SEM).	(IFSS) of PLA/hemp and UPE/hemp fiber samples
John et al. [45]	Cellulosic fiber reinforced polymeric composites	–	A review
Ashori et al. [46]	Wood-plastic composites (WPC).	–	A review

Author, Reference number	Research subject	Testing methods	Results
Koronis et al. [47]	Green composites	–	A review
Schirp et al. [48]	Wood and hemp fibers	Tensile testing, three-point bending test, Charpy impact testing, water absorption and volume change test, and dynamic mechanical analysis test.	Flexural strength values.
Wretfors et al. [49]	Reinforcing wheat gluten (WG) plastics with hemp fibers	Compression molding, tensile testing, SEM, and sample thickness measurements	Hemp fibers in composite material
Ismail et al. [50]	The influence of drilling parameters and fiber aspect ratios	Taguchi's technique	The delamination factor and surface roughness of drilled holes
Jalili et al. [51]	The acoustic parameters of three different polyester composites	Non-destructive longitudinal and flexural free/forced vibration tests	The results obtained from longitudinal free vibration method
Kakroodi et al. [52]	Hemp fibers and particles, in hybrid composites	Tensile, flexural, three-point bending, torsion and impact tests, and SEM	The mechanical properties of the composites
Ochi, et al. [53]	The hemp fiber reinforced biodegradable plastics	Tensile testing, SEM, and biodegradability test	The tensile strength of the composites
Shahzad et al. [54]	The effects of alkalization surface treatment on hemp fiber properties	Tensile testing, impact testing, fatigue testing, and SEM	The tensile properties, interfacial shear strength
Shahzad et al. [55]	The fatigue properties of nonwoven hemp fiber	Tensile testing and fatigue testing	The hemp fiber composites with less fatigue sensitivity.
Terzopoulou et al. [56]	The study about fully biodegradable ("green") composite materials	Tensile testing, impact testing, Fourier transform, infrared spectroscopy, X-ray diffraction, differential scanning calorimeter, and scanning electron microscopy	Tensile and impact strength
Toupe et al. [57]	Phase compatibilization of four mechanical properties	Tensile testing, flexural testing, and impact testing	Fiber concentration parameter
Kabamba et al. [58]	The effect of hemp fibers.	Shear testing and elongation test.	The rheological properties
Muneer [59]	Hemp fiber reinforced wheat gluten (WG) composites	Biodegradability test using the ASTM D5988-03 standard	A review
Scutaru [60]	The mechanical properties hemp fiber composites	Tensile testing	The measured Young's modulus distribution
Gassan [61]	The elastic properties	Analytical solution, SEM.	The experimental data and calculations

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Author, Reference number	Research subject	Testing methods	Results
Shahzad [62]	Physical and mechanical properties of hemp fibers	Tensile testing, thermal characterization, single fiber pull-out test, surface energy and dynamic contact angle measurement, and SEM	The tensile strength, Young's modulus, and surface energy
Niyigena [63]	The impact properties of hemp concrete	Compression test, impact test	Mechanical behaviors of hemp concrete material

Table A1. Literature survey: the main characteristic properties of the hemp fiber reinforced epoxy composites.

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