Introduction to natural fiber reinforced polymer composites and review of mechanical properties of hemp fibers and hemp/PP composite: effects of chemical surface treatment

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Abstract*—This review article introduced about natural fiber reinforced composite (NFRC) and also study of mechanical properties and effect of surface treatment on hemp fiber and hemp PP composites. In this article we studied about natural fiber, their properties, composition and application in automobile as well as hemp fiber's properties and properties after chemical surface treatment.

Keywords -- low density, high strength, recyclability renewable, biodegradable,

INTRODUCTION

Synthetic polymer composite materials are currently used in industries to meet light-weight and high strength requirements (4, 5, 6). By increasing quantities of synthetic polymer in industries, environmental issues like disposal treatment waste disposal services, and pollution problems are increased (4, 5, 6). Many researchers have studied about composite based on fibers (4, 5, 6). Compared with synthetic fibers, the advantages of natural fiber are low density, less expensive, more availability, recyclable, renewable, biodegradable (4, 5, 6). In some investigation it found that natural fibers have the potential to replace glass fiber in polymer composite materials (4, 5, 6). natural fibers are ecofriendly material which get attention from researchers and academicians to utilize in polymer composite (1, 2, 3). The aim of this review article to introduce about natural fiber and study of mechanical properties of hemp fiber and hemp/ PP composite as well as effects of chemical surface treatment. Hemp fiber are getting attention in numerous industries because of their properties. To minimizing the global warming and human hazard from industry natural/ecofriendly materials were used. In automotive industries to reducing weight of vehicle instead of conventional material composites are used (1, 2, 3). Also beneficial for reducing fuel consumption. In this we studied about hemp fiber's properties and properties after chemical surface treatment and also hemp/PP composites.

INTRODUCTION TO NFRC

The natural fiber material are environmentally friendly materials compared to synthetic fiber. It is defined as fiber which are not manmade or synthetic is called natural fiber (1, 2, 3). It comes from both renewable and non-renewable resources. Because of good properties fiber polymer matrix got considerable attention in various application. Natural fiber gives superior advantages over synthetic fiber like relatively low weight, low cost, less damage to processing equipment, good relative mechanical properties such as tensile modulus and flexural modulus, improved surface finish of molded parts composite, biodegradability and less health hazard.

Natural fiber reinforced polymer are not free form problems (1, 2, 3). The natural fiber composites are cellulose, hemicellulose, lignin, pectin and waxy substance which creates problems while binding between fiber and matrix (1, 2, 3). It permits to moisture absorption from the surrounding. Because of dissimilar chemical composition of both fiber and matrix it is challenge to fabrication, that's why before use of fiber for fabricating it chemically treated (1, 2, 3).

Usually, polymers are classified as thermoplastic and thermosets (7). One or two dimensional molecular structure are called thermoplastics, thermoplastics widely used for natural fiber are polyethylene, polypropylene (PP) and polyvinyl chloride (PVC) (1, 2, 3). On the other hand, thermoset polymer having highly cross-linked structure which cured using only heat or using heat and pressure and/or light irradiation. It having good properties such as high flexibility, great strength and modulus. Phenolic, polyester and epoxy resins are thermosetting matrix (1, 2, 3).

Properties of natural fiber natural fiber composites are different to each other. Because of different kinds of fiber, sources and moisture conditions (1, 2, 3). The basic drawback of NFPC is coupling between natural fiber and matrix (1, 2, 3). The chemical structure between these two phase is different to each other. This leads to ineffective stress transfer during the interface of NFPC (1, 2, 3). Thus, the chemical treatment for the natural fiber are necessary to achieve good interface properties (1, 2, 3).

The beneficial properties of natural fiber reinforced polymer composite are low density, less expensive, and reduced solidity when compared to synthetic composites products (1, 2, 3). Thus it used in various application such as automobile industry, buildings, etc. using natural fiber as reinforced polymer composites introduce positive effect on mechanical behavioral of polymer (1, 2, 3).

Table 1: Chemical composition of some common natural fiber(1, 2, 3).

Fiber	Cellulose (wt%)	Hemicellul;ose (wt%)	Ligning (wt%)	Waxes(wt%)
Bagasse	55.2	16.8	25.3	-
Bamboo	26-43	30	21-31	-
Flax	71	18.6-20.6	2.2	1.5
Kenef	72	20.3	9	0.5
Jute	61-71	14-20	12-13	0.8
Hemp	68	15	10	0.3
Ramie	68.6-76.2	13-16	0.6-0.7	3
Abaca	56-63	20-25	7-9	2
Sisal	65	12	9.9	-
Coir	32-43	0.15-0.25	40-45	-
Oil plam	65	-	29	-
Pineapple	81	-	12.7	-
Curaua	73.6	9.9	7.5	-
Wheat straw	38-45	15-31	12-20	-
Rice husk	35-45	19-25	20	-
Rice straw	41-57	33	8-19	8-38

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NATURAL FIBER POLYMER COMPOSITE APPLICATION

Natural fiber polymer composite are used in various application. According to its properties over the synthetic reinforced polymer, natural fiber reinforced polymer are used in automotive application structural component, packing and construction fields the different kinds of natural fibers such as jute, hemp, kenaf, oil plam and bamboo reinforced polymer composite have received importance in various application of engineering field (1, 2, 3) .

Table no. 2 shows application of NFPC in automobile industry (1, 2, 3)

Table no.2: application of natural fiber polymer composite in automobile industry.

Manufacturer	Model	Application
Rover	2000 And Others	Rear storage shelf/panel, and insulations
Opel	Vectra, Astra, zafira	Door panels, pillar cover panel, head-liner panel, and instrumental panel
Volkswagen	Passant variant, Golf, A4, bora	Seat back, door panel, boot-lid finish panel, and boot-liner
Audi	A2, a3, a4, a4 avant, a6, a8, Roadstar, coupe	Boot-liner,sparetire-lining,sideandbackdoorpanel,seatback,andhat rack
Daimler Chrysler	A, C, E, and S class, EvoBus (exterior)	Pillarcoverpanel,doorpanels,carwindshield/cardashboard,andbusiness table
BMW	3, 5 and 7 series and other Pilot	Seat back, head liner panel, boot-lining, door panels, noise insulation panels, and moulded foot well linings
Peugeot	406	Front and rear door panels, seat backs, and parcel shelf
Fiat	Punto, Brava, Marea, Alfa	Door panel

	Romeo 146, 156, 159	
General Motors	Cadillac De Ville, Chevrolet Trail Blazer	Seat backs, cargo area floor mat
Toyota	ES3	Pillar garnish and other interior parts
Saturn	L300	Package trays and door panel
Volvo	V70,C70	Seat padding, natural foams, and cargo floor tray
Ford	MondeoCD162,Focus	Floor trays, door inserts, door panels, B-pillar, and boot-liner
Saab	9S	Door panels
Renault	Clio, Twingo	Rear parcel shelf
Toyota	Raum, Brevis, Harrier, Celsior	Floor mats, spare tire cover, door panels, and seat backs
Mitsubishi		Cargo area floor,door panels, and instrumental panel
Mercedes Benz	C, S, E, and A classes Trucks	Door panels (flax/sisal/wood fibers with epoxy resin / UP matrix), glovebox (cotton fibers / wood molded, flax / sisal) , instrument panel support, insulation (cotton fiber), molding rod / apertures, seat back rest panel (cotton fiber) ,trunk panel (cotton with PP / PET fibers), and seat surface / back rest (coconut fiber/natural rubber) Internal engine cover, engine insulation, sun visor, interior insulation, bumper, wheel box, and roof cover
Citroen	C5	Interior door paneling
Lotus	Eco Elise (July2008)	Body panels, spoiler, seats, and interior carpets
Rover	2000 and others	Insulation, rear storage shelf/panel
VAUXHALL	Corsa, Astra, Vectra, Zafira	Head liner panel, interior door panels, pillar cover panel, and instrument panel

INTRODUCTION TO HEMP FIBER

hemp fibers are traditionally known as fiber plant (8). Basically from hemp fiber are collected from its steam and converted into stalk (8). This stalk having two types long (Bast) and short (Core). Mainly long (bast) is used (8). Hemp fiber contained following composition like cellulose, pectin, hemicellulose, lignin, waxes and oil (4, 5, 6). Cellulose is an organic compound in hemp fiber. A hemicellulose is present along with cellulose in almost all plant cell. While cellulose is crystalline, strong, and resistant to hydrolysis, hemicellulose has a random, amorphous structure with little strength. It is easily hydrolyzed by dilute acid or base. Lignin is important in the formation of cell walls, because they lend rigidity and do not rot (break down) easily (7).

Table no. 3: chemical composition of hemp fibers (4, 5, 6).

Composition	cellulose	pectin	Hemicellulose	lignin	Waxes &oils
Wt.%	70.2-76.12	0.9-1.55	12.28-22.4	3.7-5.7	0.8-1.59

WHY HEMP FIBER / NATURAL FIBERS CHEMICALLY TREATED

untreated natural fiber- reinforced thermoplastic composites include poor interfacial adhesion between the cellulose fiber and thermoplastic matrix, limited thermal stability of the composites (1,2,3). All plant-derived cellulose fibers are polar and hydrophilic in nature, mainly as a consequence of their chemical structure(4, 5, 6). On the other hand, Polypropylene (thermoplastics) are non-polar and hydrophobic(4, 5, 6). These incompatibility of polar cellulose fibers and non-polar thermoplastic matrix leads to poor adhesion which result in poor mechanical properties (2). That's why hemp fiber or natural fiber are chemically treated.

EFFECTS ON CHEMICAL TREATMENT ON MECHANICAL PROPERTIES OF HEMP FIBER

The effects of chemical surface treatment on the hemp fiber were investigated (4, 5, 6). After chemical treatment of the fibers, the density and weight loss was measured (4, 5, 6). And also found surface morphologies of fibers were observed using scanning electronic microscope SEM (4, 5, 6). In this review article we were studied about what effect of chemical surface treatment on hemp fiber. And how it beneficial for us. The hemp plant, high quality natural fiber that are inexpensive and excellent mechanical properties when compared to other natural fiber

Figure no. 1: Bundle of natural fiber (4, 5, 6)

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EXPERIMENTAL RESEARCH (4, 5, 6).

1. Introduction to experiment

The experiment performed by chonbuk national university, republic of Korea. In which they conclude that after chemical surface treatment on hemp fiber and hemp/PP composite they get change in its properties. Naturally hemp fiber are hydrophilic in nature. After chemical treatment it get converts into hydrophobic which useful to fabrication with PP (polypropylene) matrix to form a meaningful composite product.

2. Material used

In this experiment hemp is used in study was produced in Hubei province of china. The above table no. 3 and figure no. 1 shows chemical composition and bundle if hemp fibers. Composition of hemp are led important role in their properties in experiment the fiber are free from ash and dust by washing them. Then, they were free from bacteria by sterilized in boiling distilled water in oven at 100 °C at 1 hour period of time. After these fibers were rinsed/ clean in tap water and again dried in oven at 70 °C for 12 hours. The total length of hemp fiber is in 2,500 mm and it cut by scissor in 5-10 mm in length to convert in short length.

3. Surface treatment performed on hemp fiber

The experiment used a sodium hydroxide (NaOH) and silane coupling agent at 2%, 4%, 6% concentration. In this experiment first hemp fiber were treated by sodium hydroxide concentration. First fibers are submerged in sodium hydroxide solution at oven 95 °C for 1 hour. Then fiber were rinsed with tap water to eliminate any NaOH which sticked on fiber surface. Then they dried for 24 hours oven at 70 °C. thus the process was completed. Silane coupling agent used was γ-glycidoxypropyltrimethoxy-silane with chemical constitute of $H_2COCHCH_2O(CH_2)_3Si(OCH_3)_3$. Then process is repeated as sodium hydroxide was implemented.

4. Result of surface treatment of hemp fiber

The density, weight loss and tensile strength of surface-treated and untreated hemp fiber shows in table no. 4. The fiber density was measured according to ASTM D 3800-99. Density hemp fiber decreased after hemp fiber treated by Alkali and silane coupling agent. In the alkali-treated fiber lignin, pectin, hemicellulose removed and weight loosed. In other hand, weight of hemp fiber slightly increased in silane treated fiber.

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Table no. 4: weight loss density and tensile strength of hemp fiber after treatment (4, 5, 6).

Hemp fiber	Untreated	NaOH			Silane		
		2%	4%	6%	2%	4%	6%
Density (g/cm^3)	1.249	1.203	1.160	1.127	1.216	1.170	1.150
Weight loss (%)		-7.99%	-9.78%	-13.58%	+0.6%	+1.08%	+2.17%
Tensile strength (MPa)	962.5	905.63	866	670.75	976.67	986	1025.2

5. SEM (scanning electron microscope) observation of single fiber.

By using scanning electron microscope SEM NaOH-treated fiber were observed in experiment. Untreated fibers were covered with a membrane layer (pellicle). Membrane were removed by increasing concentration of NaOH alkali. In figure no.(2a) were seen that untreated hemp fiber was covered with layer like pectin, lignin and other impurities. After NaOH treatment at 2%, 4%, 6% concentration in figure no. (2b-d) these impurities were removed. Resulting in rougher surface of hemp fiber remained. Thus tensile strength of single hemp fiber decreased by alkali treatment (Table no. 2). In figure no. 3 it shows after silane treatment fiber get coated by silane and the tensile strength after silane treatment shown in table no. 4

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Figure no. 2: SEM image of surfaces of (a) untreated, (b) 2% NaOH-treated, (c) 4% NaOH-treated and (d)6% NaOH-treated hemp fiber (4, 5, 6).

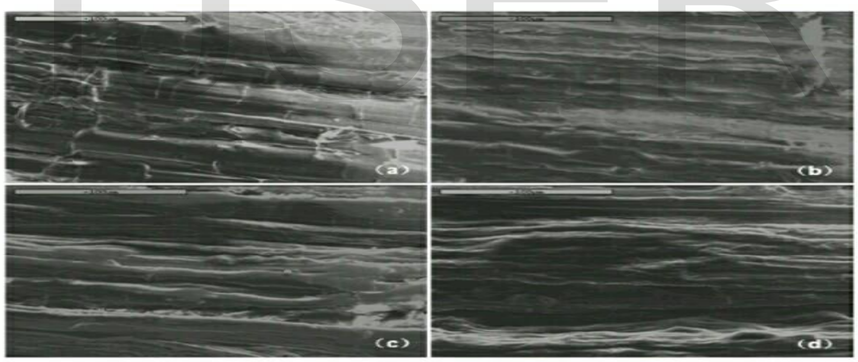
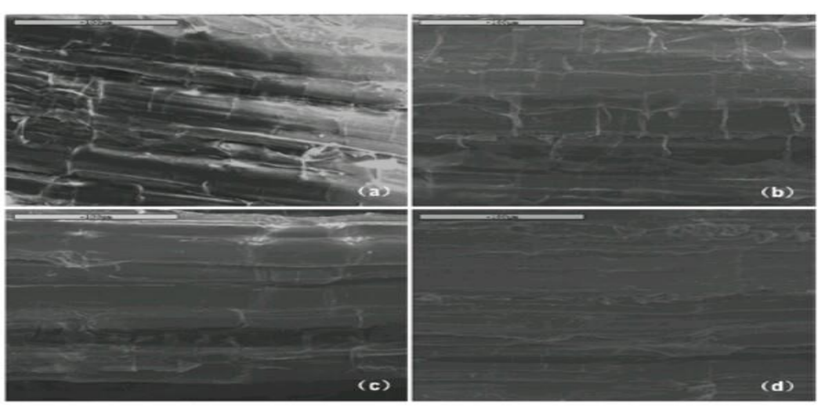


Figure no. 3: SEM image of surface of (a) untreated, (b) 2% silane-treated, (c) 4% silane-treated and (c) 6% silane-treated hemp fiber (4, 5, 6).



6. Fabrication of hemp fiber with PP matrix (4, 5, 6).

First take 180 mm × 155 mm sheet of PP film. Then hemp short fiber and PP film uniformly layer by layer placed into mold. In hot press machine (Standard presses, No. 3968, carver, Inc.) mold was placed. After that hot-pressing was performed at 200 °C under 1.3 MPa for 15 minute. Then mold was removed and cooled at room temperature in cold press with load 0.3 MPa. Volume fraction of fiber are 30% in composite.

7. Mechanical property test of composites

The test was conduct to analyze tensile and flexure properties of composite according to ASTM D3039 and D790-03, respectively. The test was performed on universal material testing machine (Instron 4206) a 750 kgf load cell at a crosshead speed of 3 mm/min at room temperature.

8. Result to mechanical properties of composites

The flexural and tensile strength of hemp fiber-reinforced PP composites are shown in figure no. 4. The tensile strength of untreated and neat PP material are same. After NaOH treatment tensile strength is greater than untreated fiber composites which is shown in fig. 4. 4% alkali treated composite having greater tensile and flexural strength than 2% and 6%. 6% having less strength because hemicellulose and lignin present in fiber are substantially removed after 6% alkali treatment. this may cause fibril in fiber are easily pulled out (fibrillation). This observed in SEM shows in figure no. 5. On the other side the tensile and flexural strength of silane-treated fiber composite. Thus the silane treatment not effect on mechanical properties hemp/PP composite

In SEM were observed that untreated hemp fiber and PP resin's interfacial bonding are not good, it indicates that there is gap between them. This because of there is low adhesion between fiber surface and PP resin, hence tensile strength of untreated composite is less. Where NaOH treatment remove membrane from fiber cause proper adhesion and having more strength. Were figure no. 6 shows silane treated hemp fiber composite. In which lack of interfacial bonding between hemp fiber and PP resin. Therefore, the silane treatment does not affect mechanical properties of the composites.

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Figure no. 4: tensile and flexural strength of (a) alkali and (b) silane coupling agent treated hemp fiber PP composites (4, 5, 6).

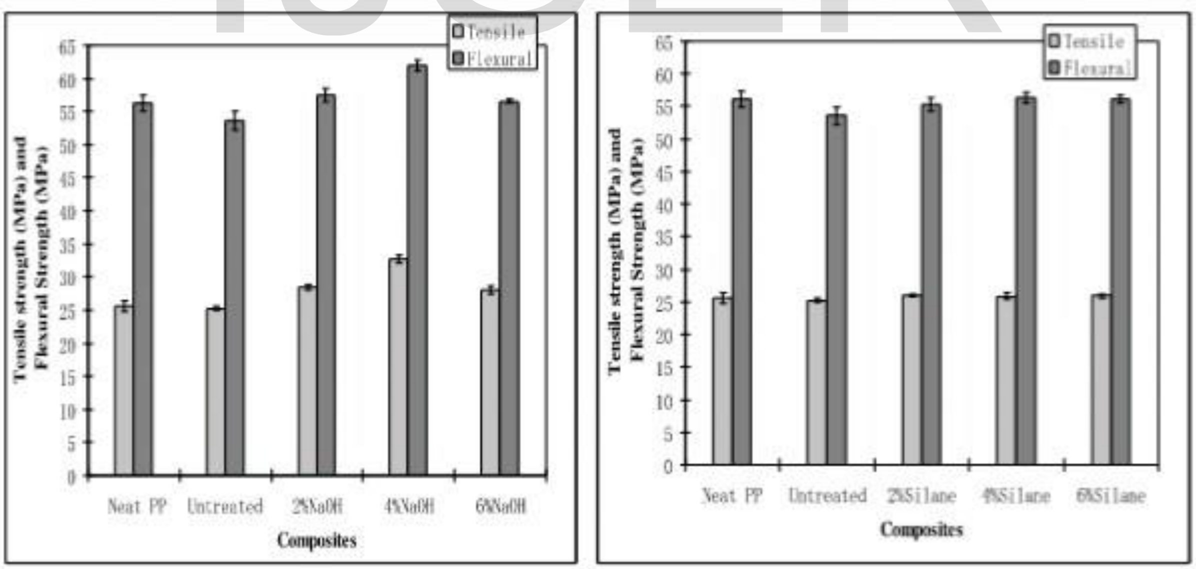


Figure no. 5: SEM observation of tensile fracture surfaces of the (a) untreated fibers composites, (b) 2% NaOH-treated fiber composites, (c) 4% NaOH-treated fiber composites, (d) 6% NaOH-treated fiber composites

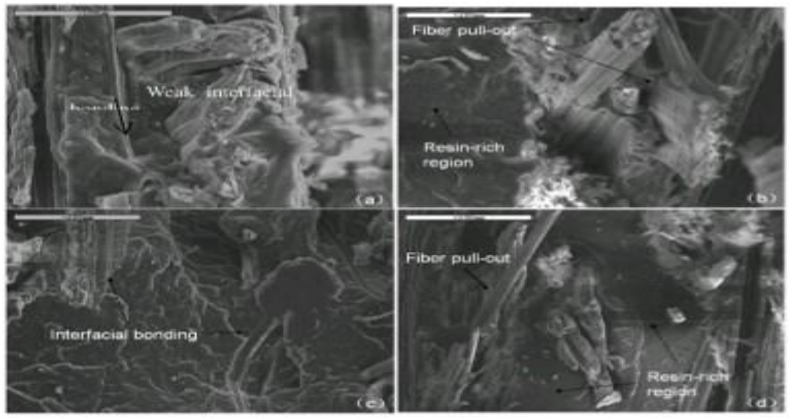
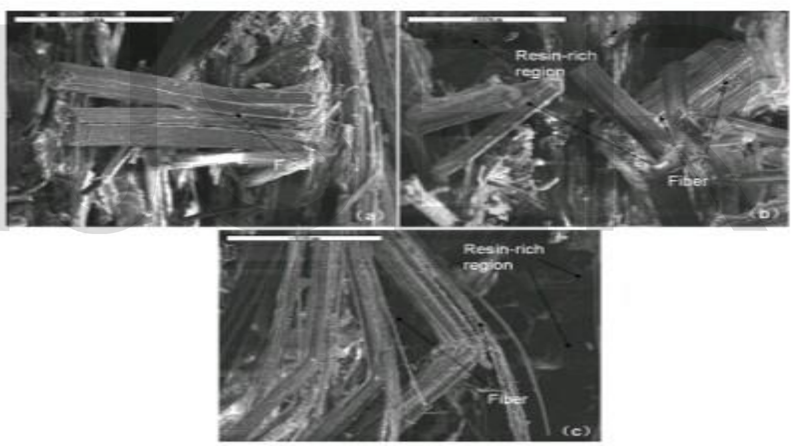


Figure no. 6: SEM observation of tensile fracture surface of the (a) 2% silane-treated fiber composite, (b) 4% silane-treated fiber composites, (c) 6% silane-treated fiber composites.



Conclusion

In this paper we introduced about natural fiber reinforced polymer composites, their application in automotive industry. This review article focused on study on hemp fiber/PP composite in which mechanical properties of untreated hemp fiber were increased by treating them by NaOH (alkali) and silane coupling agent. Also the hemp fiber PP composites can change their property parameter after chemical surface treatment (alkali and silane). After research it get investigated 4% alkali treated hemp/PP composite getting higher tensile and flexural strength than 2% and 6% alkali treatment. after 6% alkali treatment hemicellulose, pectin and other impurities get totally removed cause fibrillation means it get pull out their fibril. On the other side silane coupling agent treated hemp fiber get coated by silane resulting weight increased. By lack of interfacial bonding between silane treated fiber and PP resin observed in SEM, silane treatment not affected on composite.

Acknowledgment

The

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