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NATURAL FIBERS AND ITS COMPOSITES FOR ENGINEERING APPLICATIONS: AN OVERVIEW

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Abstract- In recent days, researchers, engineers and scientists are attracted towards the use of natural fibers in the manufacturing of composites because of their low cost, abundant, renewable, better formability and eco-friendly features. Although, other fibers are explored in lab scales they have not yet found large-scale commercial applications. Natural fibers have good mechanical strength; lesser weight leads to demand for applications in engineering field. Based on the sustainability benefits, natural fibers are now being rapidly replacing synthetic fibers in composites and also finds wide applications ranging from automotive applications to textile manufacturers who are focusing utilizing natural fibers as raw materials to improve their arts and skills in their industries. In this review paper an effort has been made to carry a literature review on natural fibers such as plant, animal and mineral fibers and their properties. Additionally, this review article also discusses the use of natural fibers in composites and in some engineering applications.

Index terms: Natural fibers, Plant fiber, Animal fiber, Mineral fiber, Natural fiber composites

I. INTRODUCTION

Fibers are classified as natural fiber and man-made (synthetic) fibers. Natural fibers are most abundant and renewable sources in the environment. The term "natural fibers" covers a broad range of vegetable, animal and mineral fibers .However in the composites industry, it usually refers to wood fiber and agro based bast, leaf, seed and stem fibers. These fibers often contribute greatly to the structural performance of the plant and when used in plastic composites, can provide significant reinforcement. In recent days growing awareness of environmental issues has led to increase in demand for goods produced from natural products, including natural fibers [1]. They are biodegradable and hence they can easily usable and acceptable in the society. Asian people had been using natural fibers for many years; for instance, jute available in India has been used as reinforcement in many materials. Natural fibers are increasingly used in automotive and packaging material. One of the largest areas of recent growth in natural fiber plastic composites is the automotive industry, particularly in Europe, where natural fibers are advantageously used as a result of their low density and increasing environmental pressures. Most of the composites currently made with natural fibers are press-molded, although a wide range of processes have been investigated. Flax is the most widely used natural fiber in the European automotive industry, comprising 71% of the natural fibers consumed in 2000 [2]. Being one of the fastest developing countries in the world, a great deal of international attention is focused on India. It is the seventh largest country in the world production level of natural fibers in India is compared to previous years. India is the world's second largest producer and consumer of fibers, textiles and manufactured products next to China. Figure1 shows the Fiber and Yarn exports in India [3]. Hence in India more and more research works are going on to utilize natural fibers for engineering applications.

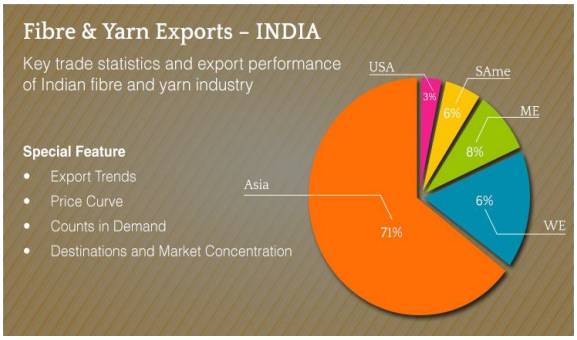

Figure 1: Exports of Fiber and Yarn in India

II. OVERVIEW OF NATURAL FIBERS AND ITS CLASSIFICATIONS

Natural fibers originated in Southeast Asia then spread to China .Reports of the spinning of cotton in India date back to 3000 BC. Natural fibers have great antistatic properties, low thermal conductivity ,moisture regain properties is good enough(about 13.75%) and 100% biodegradable .Hence they can be widely used in agriculture sector, textile sector, woven sector and non-woven sector .On burning the natural fibers we don't get poisonous gas. Natural fiber, any hair like raw material directly obtainable from an animal ,vegetable or mineral source and convertible into non-woven fabrics such as felt or paper or ,after spinning into yarns ,into woven cloth. A natural fiber may be further defined as an agglomeration of cells in which the diameter is negligible in comparison with the length [4]. Although nature abounds in fibrous materials, especially cellulosic types such as cotton, wood,

grains and straw. Only a small number can be used for textile products or other industrial purposes .Apart from economic considerations, the usefulness of a fiber for commercial purposes is determined by such properties as length, strength, pliability, elasticity, abrasion resistance, absorbency and various surface properties. Most textile fibers are slender, flexible and relatively strong. They are elastic in that they stretch when put under tension and then partially or completely return to their original length when the tension is removed .Some of the factors that differentiate between natural and synthetic fibers as shown in Table 1.

Aspects	Property	Natural fibers	Synthetic fiber
Technical	Mechanical property	Moderate	High
	Moisture sensitivity	High	Low
	Thermal sensitivity	High	Low
Environmental	Resource	Infinite	Limited
	Production	Low	High
	Recyclability	Good	Moderate

Table 1
Comparison between Natural and synthetic fiber

Based on their origins natural fibers can be classified as plant, animal and mineral fibers. Animal fibers such as hair and silk and mineral fibers have not been widely used as a reinforcement fiber. The detailed classification of natural fibers shown in **Figure 2**.But several plants fibers have been used widely in bio-composites field for the applications in the area of automotive, marine and construction [5]. Some of the available plant fibers are seed, bast, leaf, stalk, cane, grass and reed fibers. Available mineral fibers are Asbestos, Fibrous and brucite fibers.

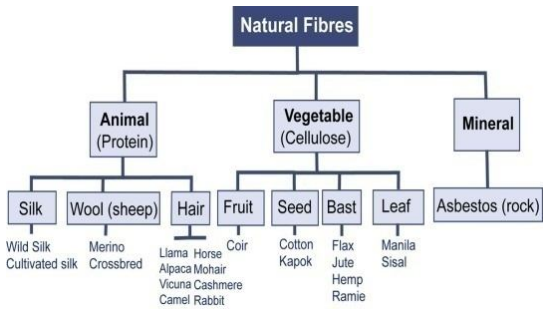

Figure 2: Classification of Natural Fibers

Compared to glass fibers, commonly used in composites, natural fibers have lower tensile strength. However, when the specific tensile strength (tensile strength/density) is considered, some natural fibers have comparable values to that of glass fibers because of their lower density. The properties of natural fibers not only vary depending on origin, quality of the plant, location, weather, age, and pre-conditioning or processing but are also highly influenced by their chemical structure in-terms of degree of polymerization, cellulose content, orientation and crystallinity. The thermal properties of natural fibers are very important since the fibers are likely to be exposed to high curing temperatures used during composite fabrications with thermoset resins. Since natural cellulose fibers are mixture of organic components leads to a variety of chemical and physical changes [6]. By means of dimensional selection of natural lignocellulosic fibers, based on precise diameter measurements, it was recently possible to obtain fibers with relatively higher tensile strength. Natural fibers obtained from vegetables constitute cellulose, a polymer of glucose bound to lignin with varying amounts of other natural materials [7]. Synthetic or man-made fibers are generally obtained from synthetic materials such as petrochemicals, but some types are manufactured from natural cellulose, including rayon model and lyocell. Qualities of Natural fibers are strongly influenced by growing environment, age of plant, species, temperature, humidity and quality of soil. Various fields where natural fibers can be employed are structural composites, automobile, non-structural composites, geo-textiles packaging, molded products, sorbents, filters and in combination with other materials [8]. Currently, plenty of research material is being generated on the potential of cellulose based fibers as reinforcement for plastics.

III. PLANT FIBERS

Plants are the natural sources of many raw materials used to produce textiles, ropes, twine, and similar products. Naturally available fruit fibers are pineapple, banana, coir, and palm fibers; Leaf fibers are manila and sisal fibers; Seed fibers are cotton and kapok fibers and also areca, bamboo, hemp, jute, kenaf and ramie fibers are the major plant fibers commonly used.

Cotton is by far the most important fiber crop in the world. The first evidence of cotton use was found in India and Pakistan, and dates from about 6000 B.C. The industrial revolution brought about the invention of the spinning machine (1738) and cotton gin (1793), providing a great boost to cotton manufacture, first of all in England. Cotton is a soft, fluffy staple fiber that grows in a boll, or protective case, around the seeds of the cotton plants of the genus Gossypium in the mallow family Malvaceae. Cotton mainly contains 94% of cellulose, 8.3% of protein, 0.9% of pectin substance, 0.6% of oil, fat and wax and others [Internet source]. Humans heavily rely on cotton for clothing and other textiles, it enters

the daily lives of more people than any other product except salt.

Areca fiber is being a very high potential perennial crop, abundantly available and also inexpensive among all the natural fiber reinforcing materials. Areca is genus of about 50 species of palms in the family Arecaceae, found in humid tropical forests from China and India .Areca fibers consists of alpha cellulose 53.20%, hemicellulose 30-64.8%, lignin 7-24.8%, 4.4-4.8% of ash, 11.7% of moisture, and very negligible percentage of the pectin and wax [9]. It is estimated that about 6 lakh tonnes of areca husk is available in south West-India. Banana is one of the oldest cultivated plants in the world. Banana farming generates huge quantity of biomass all of which goes as waste and the above ground parts like pseudostem and peduncle are the major source of fiber [10]. Banana fiber can be used as raw material for industry for production of range of products like paper, cardboards, tea bags, currency notes and reinforced as polymer composite in high quality dress materials. The highest pseudostem and peduncle fiber recovery were obtained from Poovan (2.71% and 1.09%, respectively) and the lowest from Grand Naine (1.07% and 0.63%, respectively). Cellulose is the major component of the fiber. The highest cellulose content was recorded in Nendran peduncle fiber (60.27%) followed by Nendran pseudostem fiber (59.23%). The other non- cellulosic substances like hemicelluloses, lignin and pectin were high in Monthan pseudostem fiber (15.75, 21.56 and 4.08%, respectively).Banana fiber is a natural bast fiber which has wide range of uses handicraft product development such as mat, rope and twines, but only 10% of its pseudo stem is being used for making products and remaining is used as fertilizers. Bamboo fiber is the easily available with lowest possible cost. Bamboo fibers are all cellulose fiber extracted or fabricated from natural bamboo, but they vary widely. Textiles labeled as being made from bamboo are usually not made by mechanical crushing and retting. They are generally synthetic rayon made from cellulose extracted from bamboo. Bamboo is used whole and in strips; these strips may be considered stiff fibers. In China and Japan, thin strips of bamboo were woven together into hats and shoes. Chemical composition of bamboo fibers are cellulose (45-50%), Hemicelluloses (20-25%), Lignin (20-30%) and Extractives (2.5-5%) [11]. Majority we use bamboo fabric because of its Anti bacterial; highly sweat absorbent and powerfully insulating properties.

Hemp is one of the oldest and naturally most ecologically friendly fibers. The scientific name of the hemp is Cannabis Sativa L. The Columbia History of the World (1996) states that weaving of hemp fiber began over 10,000 years ago, Carbon tests have suggested that the use of wild hemp dates as far back as 8000 B.C. In Great Britain, hemp cultivation dates back to 800AD. In the 16th Century, Henry VIII encouraged farmers to plant the crop extensively to provide materials for the British Naval fleet. The chemical composition of hemp fiber is Cellulose (77.5%), Hemicellulose (10%), Lignin (6.8%),Fat and Wax(0.9%) and water soluble materials(1.8%). A steady supply of hemp was needed for the construction of battleships and their components. Riggings, pendants, pennants, sails, and oakum were all made from hemp fiber and oil. Hemp paper was used for maps, logs, and even for the Bibles that sailors may have brought on board. The most affordable Natural fibers and it is second only to cotton in amount produced and variety of uses of vegetable fibers is the Jute fiber. Jute fibers are composed primarily of the plant materials cellulose and lignin. It falls into the bast fiber category. The scientific name of jute fiber is Corchorus capsularis of Tiliaceae family [12]. Historical documents (including Ain-e-Akbari by Abul Fazal in 1590) state that the poor villagers of India used to wear clothes made of jute. Simple handlooms and hand spinning wheels were used by the weavers, who used to spin cotton yarns as well. History also suggests that Indians, especially Bengalis, used ropes and twines made of white jute from ancient times for household and other uses. It is highly functional in carrying grains or other agricultural products.

Kenaf is one of the natural plant fibers used as reinforcement in Polymer Matrix Composites. Kenaf having a scientific name Hibiscus cannabinus which belongs to Malvaceae family also called Deccan hemp and Java jute. The kenaf leaves were consumed in human and animal diets, the bast fiber was used for bags, cordage, and the sails for Egyptian boats. Pineapple is a native plant of America, first seen by Columbus and his companion in November 4, 1493, at an island of West Indies. Pineapple leaf fiber has high specific strength and stiffness; it is hydrophilic in nature due to high cellulose content [13]. Sisal fiber is a hard fiber extracted from the leaves of the sisal plant and its scientific name is Agave sisalana. The sisal fiber is traditionally used for rope and twine, and has many other uses including paper, cloth, footwear, hats, bags, carpets, and dartboards.

Figure 3 shows different kinds of mainly available natural fiber plants. A natural fiber extracted from the palm tree was used as reinforcement for acrylonitrile butadiene styrene (ABS) matrix composites. Palm fiber (PF)-reinforced ABS (PF-ABS) composites were prepared via injection molding machine. Three sets of samples were prepared for three different mass% (5, 10 and 20 %) of fiber contents. The effect of fiber addition in composite along with the age and different edges of the palm fiber on thermal properties was evaluated with the help of thermo gravimetric/differential thermo gravimetric, differential thermal analyses and thermo mechanical

analysis. The split leaves of a palm used for thatching, weaving, or rope making.

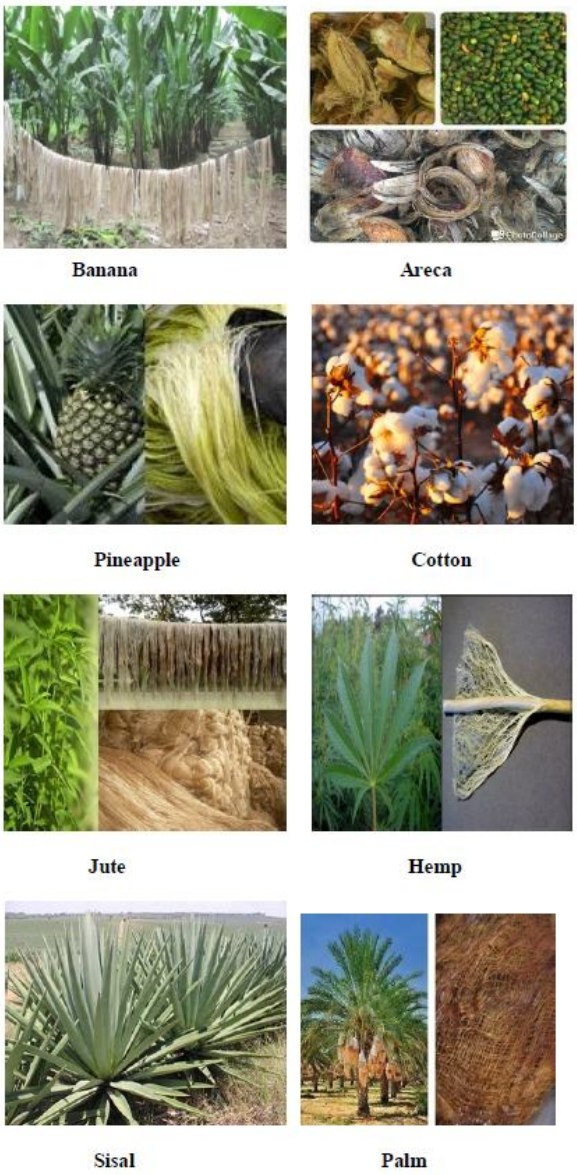

Figure 3: Natural Fiber Plants

IV. ANIMAL FIBERS

Animal fibers are natural fibers that consist largely of particular proteins. Instances are silk, hair/fur (including wool) and feathers .Some animal fibers shown in **Figure 4**. The animal fibers used most commonly both in the manufacturing world as well as by the hand spinners are wool from domestic sheep and silk. Also very popular are alpaca fiber and mohair from Angora goats. Unusual fibers such as Angora wool from rabbits and Chiengora from dogs also exist, but are rarely used for mass production. Wool is the fiber derived from the fur of animals of the Caprinae family, principally sheep, but the hair of certain species of other mammals such as goats, alpacas, and rabbits may also be called wool. Wool fiber contains Keratin (33%), Grease (28%), Suint (12%), Different impurities (28%) and water content (1%) [14]. Wool is dirt and odor resistant. Wool is durable and long lasting. Wool fiber is unsurpassed in flexible strength, shape for a lifetime of use. Silk is a natural protein fiber, some forms of which can be woven into textiles. The protein fiber of silk is composed mainly of fibroin and is produced by certain insect larvae to form cocoons. The best-known silk is obtained from the cocoons of the larvae of the mulberry silkworm Bombyx mori reared in sericulture. The shimmering appearance of silk is due to the triangular prism-like structure of the silk fiber, which allows silk cloth to refract incoming light at different angles, thus producing different colors.

Figure 4: Animal Fibers

V. MINERAL FIBERS

Examples of mineral fibers are asbestos, graphite, and glass. Asbestos occurs naturally as fibers. Asbestos is the only natural fiber obtained from varieties of rocks. It is fibrous form of silicate of magnesium and calcium containing iron and aluminium and other materials. It is acid proof, flame proof and rust proof, its particles are carcinogenic and hence its use is restricted. It can largely used in fire-resistant substances. Graphite is the low cost naturally available mineral fiber. They have higher stiffness and reasonable mechanical properties. It will be having higher thermal conductivity and hence this makes them particularly useful in thermal management system and satellite structures. Glass mineral fibers are light weight easily installed and provides outstanding thermal insulation as well as exceptional acoustic performance. Glass mineral wool is the best example for glass fibers and they can be used in applications from lofts and roofs to HVAC and industrial insulation.

VI. NATURAL FIBER COMPOSITES

The increase in population, natural resources is being exploited substantially as an alternative to synthetic materials. Due to this, the utilization of natural fibers for the reinforcement of the composites has received increasing attention [15]. The strength of natural fibers is not as great as glass, the specific properties are comparable. Natural fiber composite is not a new concept, it has existed since the early 1900's but has not received much attention until late in the 1980's.

Germany is a leader in the use of natural fiber composites. This widespread use of natural fibers in composites comes down to fairly low production cost, low weight, right strength, good mechanical properties and resistance to fatigue. The advantages to using natural fibers in composites are the cost of materials, their sustainability and density [16]. NFCs have low density and high specific strength and stiffness. Fibers are a renewable resource, for which production requires little energy, involves CO2 absorption, whilst returning oxygen to the environment. They have low hazard manufacturing processes and low emission of toxic fumes when subjected to heat and during incineration at end of life. The parameters affecting the mechanical performance of NFCs are fiber selection-including type, harvest time, aspect ratio, method of extraction, treatment and fiber content. Some others are matrix selection, interfacial strength, fiber dispersion, fiber orientation, composite manufacturing process and porosity.

VII. POTENTIAL APPLICATIONS

Fiber reinforced composites have received much attention based on different applications because of the good properties and the advantages found over synthetic fibers. With the use of natural fibers in composites, there exist many possibilities since the number of different application possibilities is rapidly growing within many engineering fields [17]. Natural fiber reinforces composites containing fibers such as bamboo, jute, hemp and kenaf. They have been received in many industries such as packaging, automobile and construction but natural fiber composites are also finding its way into sport, aerospace, boat and electronic industries too. Some of the applications are decking, railing systems, window frames, fencing, panels, furniture's, bicycle manufacturing, mobile cases and laptop cases. Some are shown in the **Figure 5**. They are commonly used in manufacturing of car bodies and sometimes aerospace applications. In the United States, composite building materials are being made from straw. Straw bales are being used in the construction of buildings [18]. Many automotive components are already produced with natural composites, mainly based on polyester or Polypropylene and fibers like flax, hemp, or sisal. The jute composites may be used in everyday applications, such as lampshades, suitcases, paper weights, helmets, shower, and bath units. A sheet and fabric like composites are commonly used in manufacturing of footwear components.

CONCLUSION

The different types of natural fibers, natural fiber composites and their applications are discussed in this paper. This review concludes that the better utilization of available natural fibers and its composites rather than synthetic fibers will be helpful for the economy of the developing countries.

Figure 5: Potential Applications

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