CHAPTER – II

REVIEW OF LITERATURE

A comprehensive review of relevant research work and literature is of utmost necessity in any research endeavour. It is an evaluative report of information in the literature related to a selected study area. Thus, this chapter is devoted to a review of the literature relevant to the study. An attempt has been made to discover specific literature materials likely to have a direct or indirect bearing on the study.

This chapter deals with the theoretical and research knowledge of the relevant study. The investigator visited and collected the literature through books, journals and thesis through various libraries from different universities of India, such as the Central Library, Delhi University, Lady Irwin College Library, Delhi University, Central Library, Indian Institute of Technology (IIT), Delhi, College Library, Avinashilingam Institute for Home Science and higher education for Women, and Smt. Hansa Mehta Library (Central Library), T.K. Gajjar Library at the Faculty of Technology and Engineering, and the library of Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara.

The researcher visited various Centre of Excellence to collect literature, viz. SITRA (South India Textile Research Association), Coimbatore, BTRA (Bombay Textile Research Association) Mumbai, ATIRA (Ahmadabad Textile Industry's Research Association), ICAR-CIRCOT (Central Institute for Research on Cotton Technology) Mumbai, DKTE Central Library, Icchalkaranji, DKTE centre of excellence in nonwovens, Ichalkaranji, Maharashtra, CICT(Central Institute of Coir Technology), Bangalore, Sugarcane Research Station, Navsari Agricultural University, Gujarat, Indian Institute of Sugarcane Research (ICAR-IISR), Lucknow, Uttar Pradesh. Another important secondary source of collecting information was shodhganga, e-books and various online web sources.

Keeping in mind the purpose of the study, the review of literature of relevance concerning the present study is arranged in this chapter under the following subheadings:

2.1 Theoretical Review: It has been discussed under the following sub-heads:

2.1.1 Agro-waste

2.1.2 Technical textiles

2.1.3 Structural modification of fibre

2.1.4 Oil spill and its environmental hazardous

2.2 Research Review: The research review has been discussed under the following sub-heads:

2.2.1 Cellulosic minor fibres

2.2.2 Chemical modification treatments

2.2.3 Sorbents for specific end-use

2.2.4 Sugarcane bagasse fibre

2.1.1 Agro-waste

Agro-waste is a term used to describe the waste produced during farming practices, whether chemical, pesticide, or fertilizer. These materials are typically hazardous and must be reduced in usage, but they are needed in more significant quantities to obtain optimum crop products (Zamare et al., 2016). Agro-waste contains even pieces of plants that are not used as food. Once crops are grown, there are other similar problems, such as farm waste, which accounts for about 80% of agricultural biomass. This waste that causes the release of gasses into the atmosphere in bulk amounts is often burned by farmers (Bhuvaneshwari et al., 2019). Nowadays, it is the most significant source of smog (fog + smoke) and poses a significant threat to the common man's safety. Therefore, It is essential to take the time to handle the waste strategically to save, recycle and reuse it (Krishnaswamy et al., 2014). Agro-waste has various forms. These can primarily be divided into two major groups, i.e., crop residues and residues from the agricultural industry. There are two more agricultural residue categories: field residues (stem, seeds, stalks, etc.) and process residues (Husk, Bagasse, Molasses).

Sengupta et al. (2003), conducted a study on betel-nut fibre extracted from betel nutshell, an agro-waste. It is estimated that in India, the land available for cultivation of betel nut plants is about 250,000 hectares. Therefore, the total fibre available in India alone is approximately 1,300,000 metric tons annually. Betel-nut plants are abundant in different parts of the world, particularly in tropical countries. In addition to extraction procedures and nonwoven fabric preparation, the study takes a deep insight into some of the physical and chemical properties of betel nut fibre and nonwoven fabrics prepared from these. The researcher concluded that the fibres are suitable for agro-tech protective clothing as an alternative to polyolefin and polyamide nets.

According to Reddy et al. (2005), lignocellulosic agricultural by-products are a promising and beneficial source for cellulose fibres. Due to the chemical and physical properties, composition, and sustainable agro-based bio fibres represent potential use in the textile and paper industry for fibres, chemicals, enzymes, and other industrial products. Annually renewable resources, e.g. corn, wheat, rice, sorghum, barley, sugarcane, pineapple, banana, coconut, etc., by-products are utilized as agro-based biofibres.

Pineapple fibre is one of the natural sources of minor fibres. Pineapple, an edible fruit with medicinal value, now finds another usage in textiles. "Pina" is a leaf fibre obtained from the pineapple plant (Ananas comosus) leaves from the family of Bromiliaceae (or multiple fruit bearing) plants which is tropical, herbaceous, perennial that grows in countries near the equator. The Philippines and Thailand are the chief producers of pineapple leaf fibre, followed by Brazil, Hawaii, Indonesia, the West Indies and India. Only in India could the yield of fibres be about six lakh tons a year if a proper extraction method is adopted. However, the pineapple leaves are mostly agricultural waste at present.

Pineapple grows abundantly in regions that receive high rainfall, like West Bengal, Assam, and north-eastern states, the Western Ghats, and coastal areas like Goa, Kerala, and Karnataka. The major pineapple producers are Brazil, Thailand, the Philippines, Costa Rica, China, India, and Indonesia. India is the sixth largest pineapple producer in the world. Karnataka, West Bengal, and Bihar are the three states in the country with high productivity.

According to Dittenber and Gangarao (2012), agriculture generates a lot of waste. The different wastes obtained from agriculture can be used to make various products that can help agriculturists, the common man, and researchers to a large extent. Using agro-industrial wastes as raw materials can help reduce production costs and the environmental pollution load. Forty per cent of the production is available as waste, and at least 10 per cent of the waste by weight is obtained as fibre; millions of metric tons of fibre are available every year, and the amount will increase annually. This waste could be a potential resource for reinforcing materials in bio-composite applications. Utilizing such resources will not only provide sustainable and less expensive materials but, at the same time, will contribute to waste disposal management and overcoming environmental problems. However, various factors include plant growth, harvesting stage and fibre extraction process. It affects the fibre quality. Therefore, a good understanding of the fundamental properties of agricultural waste fibre is a must.

Agriculture produces all-natural fibres, and the majority are harvested in the developing world. Globally, some 30 million tons of natural fibres are produced annually, largely by economically backward countries.

Coir is a coarse, short fibre extracted from the outer shell of coconuts. There are two types of coir, namely brown fibre, obtained from mature coconuts, and finer white fibre, extracted from immature green coconuts. Coir fibres measure up to 35cm in length with a diameter of 12-25 microns. It has one of the highest concentrations of lignin, making it stronger, but it has good resistance to microbial action and saltwater damage. It is used in ropes, mattresses, brushes, geotextiles and automobile seats. (Kanimozhi, 2012)

Bos and Hamelinck (2014), stated that Agricultural-based industries produce a vast amount of residues yearly. If these residues are released into the environment without proper disposal, they may cause environmental pollution and harm human and animal health. Most of the agro-industrial wastes are untreated and underutilized; therefore, in maximum reports, they are disposed of either by burning, dumping or unplanned landfilling. These untreated wastes create different problems with climate change by increasing the number of greenhouse gases. Besides this, the use of fossil fuels also contributes to the effect of greenhouse gas (GHG) emissions.

It has been estimated that the agricultural sector provides about 24 million tons of food globally, with accompanying health risks and threats to ecosystems. People cannot do without agriculture because food is a necessity across the globe, but the impact of agriculture on the environment is also evident. For example, it has been documented that about 21% of greenhouse gas emissions come from agriculture. The negative influence of agriculture on the environment, aquatic life, and human health has necessitated improvement in agricultural production, which involves effective and efficient ways of handling agricultural solid wastes.

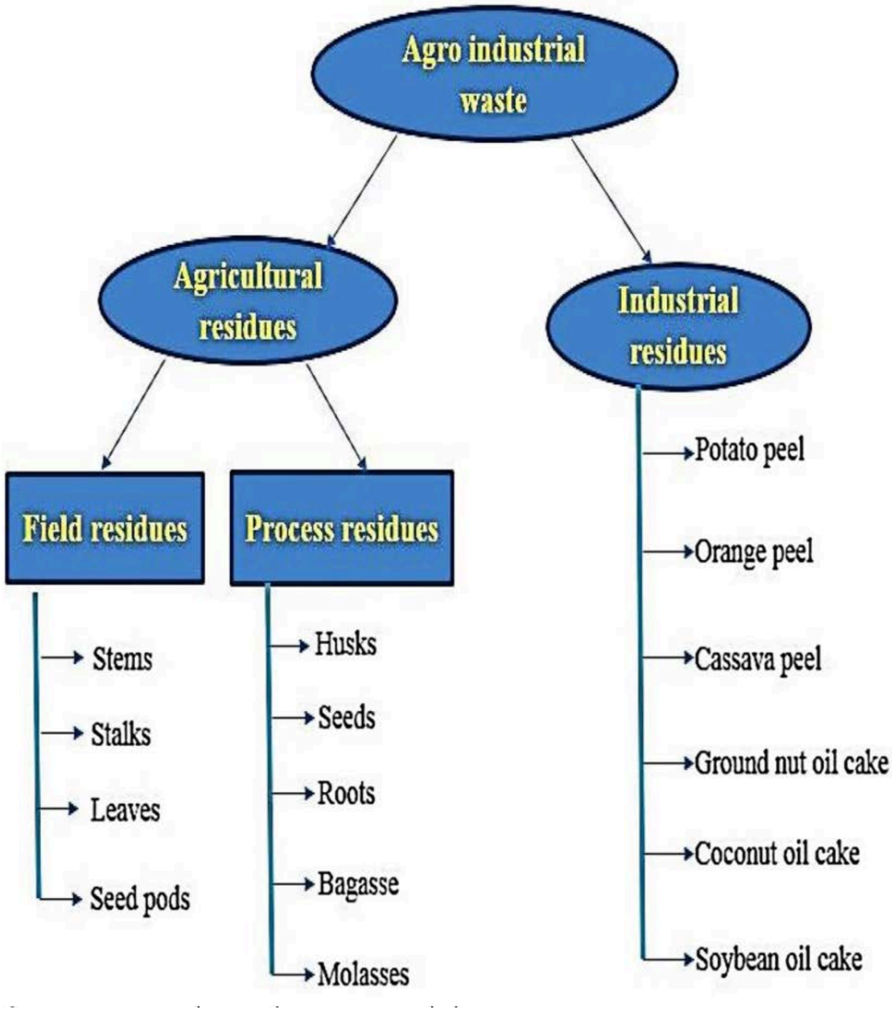

Plate 2.1: Agro-industrial wastes and their types
(Source: https://bioresourcesbioprocessing.springeropen.com/articles/10.1186/s40643-017-0187-z/figures/1)

Dungani et al. (2016), stated that agricultural waste fibres are of notable economic and cultural significance worldwide and are used for building materials, as a decorative product and as a versatile raw material. These fibres also have significant potential in composite due to their high strength, environment-friendly nature, low cost, availability and sustainability. The potential properties of agricultural waste fibres have sparked a lot of research on using these fibres as an alternative to man-made fibres for safe and environmentally friendly products. It can be obtained from oil palm plantations and other agricultural industries such as rice husk, rice straw, sugarcane, pineapple, banana and coconut. Agricultural waste produces large amounts of biomass that are classified as natural fibres, of which until now, only 10 % were used as alternative raw materials for several industries, such as biocomposites, automotive components, biomedical and others.

Maity (2016), states that Akund floss, also called calotropis floss, is a yellowish, thin, hollow seed cellulosic fibre. The Akund plants are native to Southern Asia and Africa and were introduced to South America and the islands of the Caribbean. Rajasthan, Karnataka and Tamilnadu are the states where it is found. With the increasing demand for natural fibre and the limitation of supply of cotton, it is very much necessary to develop other natural fibres as substitutes for cotton. Akund is filling material for jackets, comforters, pillows, etc. It can be used as a substitute for stuffing soft toys, etc.

Plate 2.2: Akund floss fibre: Plant and fibre

Corn or maize is the second largest agricultural crop grown globally, second only to sugarcane, with 875 million tons produced worldwide. The USA, China, Brazil, Mexico, India and Indonesia are major producing countries. In India, maize is cultivated in all the states except Kerala. The major maize-growing states in India are Andhra Pradesh, Karnataka, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh, and Himachal Pradesh. Due to the large availability and low cost, the potential of obtaining fibres from cornhusks and cornstalks has been explored for textile and composite applications. Youssef et al. (2015), evaluated cornhusk fibres reinforced with recycled low-density polyethene composites and suggested their applicability in packaging.

According to Sadh et al. (2018), a huge amount of agricultural waste is produced during the cultivation of crops; this waste can be used for energy production and can cater to the energy demands in rural areas of the surrounding region. Sustainable use of resources is the best way to reduce global environmental issues. The use of agro-waste for power generation is the new eco-friendly resource for sustainability. Power generation from agro waste is a less polluting resource in comparison to conventional energy resources (coal); for power generation, agricultural residues like Maize Cobs, Wheat Straw and Rice Husks are collected at a place from where they can easily be used for energy generation. It helps to fulfil the world's energy demand and conserve natural resources sustainably. The world will need to live within a set carbon budget that can be achieved by sustainable agro-waste management.

2.1.2 Technical textiles

India has tremendous potential for producing, consuming and exporting technical textiles. Technical textiles is a vast and rapidly developing sector supporting many industries. Technical textiles, directly or indirectly, play an important role in making our lives much more comfortable. Right from the time we wake up in the morning to the time we go back to bed, we constantly come across technical textiles in some form or another. For example, bedding might be made of a particular technical textile; these days, food items are packed in technical textiles, nearly 15 parts of automobiles contain technical textiles, and our stain-free clothes are also technical textiles.

The National Technology Mission on Technical Textiles (NTMTT) defines technical textiles as "Textile materials and products used primarily for their technical performance and functional properties rather than aesthetic value." They are used individually or as a product component to enhance their functional properties (Mahapatra, 2015).

Technical textiles are functional fabrics used in multiple industries, such as automobiles, construction and agriculture. The sector has been on the government's policy for ten years for its high growth potential and capacity for job creation and is divided into 12 industries.

Among these, an official said that medical textiles such as implants, geotextiles used in the reinforcement of river embankments and rocky cliff sides, and agro-textiles for crop protection have been earmarked by the government as significant growth creators. Based on the usage, Technical Textiles are divided into 12 segments: Agrotech, Meditech, Buildtech, Mobiltech, Clothtech, Oekotech, Geotech, Packtech, Hometech, Protech, Indutech and Sportech.

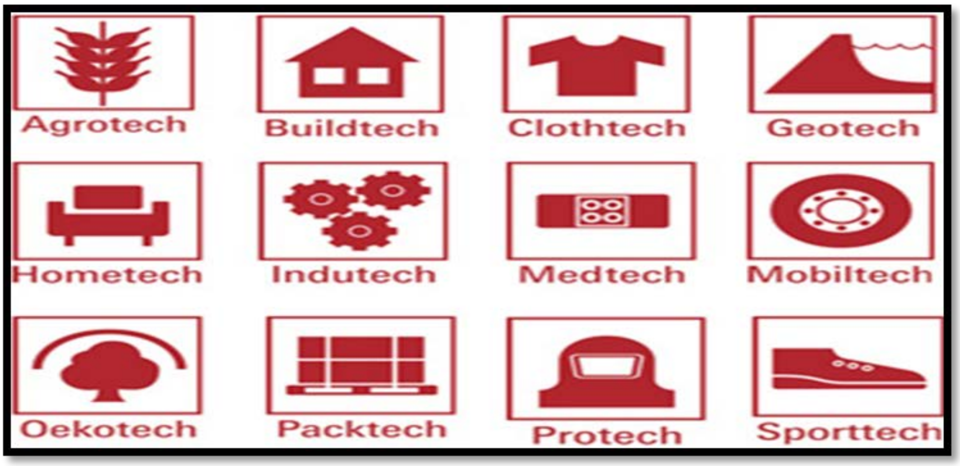

Plate 2.3: Technical Textile Segments

Plate 2.4: Applications of Meditech, Agrotech and Mobitech

Plate 2.5: Applications of Packtech, Geotech and Sportech

Plate 2.6: Applications of Buildtech, Oekotech and Clothtech

Plate 2.7: Applications of Indutech, Hometech and Protech

For years, agro-based bio-composite material has been used for many applications. Some common applications include using natural fibre composites for automotive and building components. Another unique application uses nano-cellulose fibre biocomposites to create loose-fill packing and biomedical applications.

Natural fibre composites were being used for manufacturing many components in the automotive sector. Typical market specification natural fibre composites include elongation and ultimate breaking force, flexural properties, impact strength, acoustic absorption, suitability for processing and crash behavior. The plants, which produce natural fibres, were classified as primary and secondary depending on their utilisation. Primary plants were those grown for their fibre content while secondary plants were plants in which the fibres were produced as a by-product. Jute, hemp, kenaf, and sisal are examples of primary plants. Pineapple, Bagasse, oil palm and coir are examples of secondary plants. Plant fibres are mainly used in the part of car interior and truck cabins. The use of plant fibre based automotive parts such as various panels, shelves, trim parts and brake shoes are attractive for automotive industries worldwide because of its reduction in weight about 10%, energy production of 80% and cost reduction of 5% (Balaji et al., 2015).

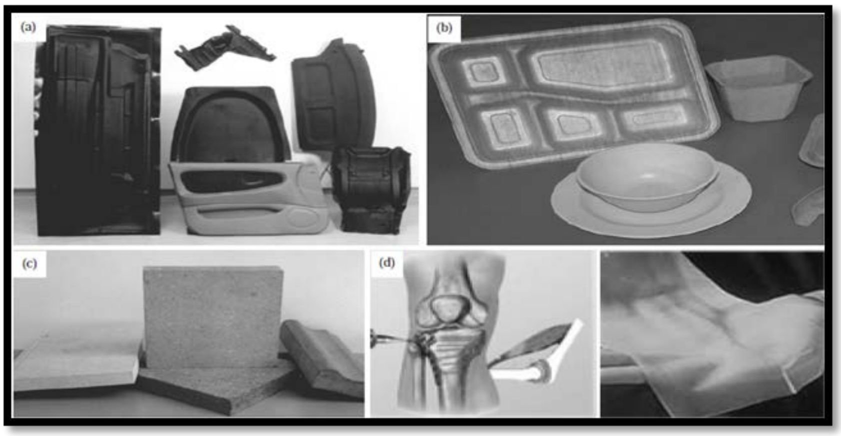

Plate 2.8: Various applications of agro-based biocomposite, (a) Automotive component, (b) Food packaging, (c) Building component and (d) Medical applications.

According to Horrocks and Anand (2004), Industrial textiles are now more often viewed as a subgroup of a broader category of technical textiles, referring specifically to those textile products used in the course of manufacturing operations (such as filters, machine clothing, conveyor belts and abrasive substrates) which are incorporated into other industrial products (such as electrical components and cables, flexible seals and diaphragms or acoustic and thermal insulation of domestic and industrial appliances).

Despite the high-tech allure of futuristic fabrics, the appeal of natural fibres promises to be sustained. New generations of textiles may surpass them in performance, but the fibres that have dressed the human race for several millennia have a feel-good factor that is likely to persist. Natural fibres are almost as ancient as the earth and are inextricably linked to humanity's long history. Fibres are nourished by the earth and nurtured by the sun, and their growth reflects the processes that sustain human life. Natural textiles bring nature's bounty to man's artificial environments, where they remind us of our connections to the earth (Quinn, 2010).

According to the New policy to make technical textiles must for industries, "As many as 92 categories of technical textiles including fire-resistant curtains, geo-grids for railways, bulletproof jackets, leno bags for transporting Agri commodities, and architectural membranes for tents, have been identified for mandatory use, according to senior government sources. Seven ministries that undertake major infrastructure and public works will lead the initiative. These are the railways, road transport, jal shakti, agriculture, urban development, health and defence.

Automotive textile is an integral aspect of technical textiles. Since it cannot be classified as apparel textiles, it is more of a techno-mechanical application of textiles. Automotive textile refers to all textile components, such as fibres, filaments, yarns, and fabrics used in automobiles. Some of these components are visible, while others are concealed. Examples are Truck covers (polyvinyl-coated polyester fabrics), car trunk coverings (often needle felts), seat covers (knitted materials), seat belts, nonwovens for cabin air filtration (also covered in indutech) and airbags (Kanimozhi, 2012).

Ortega et al. (2016), stated that fibers had been extracted by mechanical means from banana tree pseudostems to valorize banana crop residues. To increase the mechanical properties of the composite, technical textiles can be used as reinforcement, instead of short fibers. To do so, fibres must be spun and woven. This paper aims to show the viability of using banana fibres to obtain a yarn that is more environmentally friendly to be woven after an enzymatic treatment. Extracted long fibres are cut to 50 mm length and then immersed into an enzymatic bath for their refining. Conditions of enzymatic treatment have been optimized to produce a textile grade of banana fibres, which have then been characterized. The optimum treatment conditions were found using Biopectinase K (100% related to fibre weight) at 45℃, pH 4.5 for six h, with bath renewal after three hours. The first spinning trials show that these fibres are suitable for producing yarns. The next step is the weaving process to obtain a technical fabric for composite production.

2.1.3 Structural modification of fibre

Fibres are often subjected to chemical and enzyme treatments for various purposes. Such treatment may involve different finishing phases and may affect either the internal structure of the fibre, the surface of the fibre, or both. The cellulose is so modified that the absorption and adsorption properties of the fibre are greatly improved. Chemical modification of the internal structure is of minor importance to surface modification unless the addition of new groups in the inter-regions of the fibre causes physical enlargement of the fibre cross-section. Such additions of the groups would cause changes in the folds (ridge-and-groove system) on the fibre surface.

Alkaline pretreatment of lignocellulosic materials causes cellulose swelling, decrease of polymerisation degree and crystallinity, increase of internal surface area, disruption of the lignin structure, and separation of structural linkages between lignin and carbohydrates. Advantages of Alkaline pre-treatment: - the employment of lower temperatures and pressures than other pre-treatment technologies - in comparison with acid processes, alkaline ones cause less sugar degradation; - many caustic salts can be recovered and regenerated.

Zhang et al. (2014), said that hemp fibre has attracted considerable attention in recent years because of its good antibacterial properties and unique appearance and feel. This study investigated the effects of alkali treatment on hemp fibre qualities, such as chemical compositions, fineness, length, and distribution. The effects of different factors on hemp fibre quality were determined through normalisation and average weight distribution of the multiple indices of hemp fibre quality. The optimum conditions for alkali treatment were also provided, serving as a theoretical basis for hemp fibre processing and manufacturing.

Chung et al. (2011), stated that Sugarcane bagasse was partially acetylated to enhance its oil-wicking ability in saturated environments while holding moisture for hydrocarbon biodegradation. Hydrophobicity (or oleophilicity) is one of the major determinants of sorbent properties influencing the effectiveness of oil sorption in the presence of water. The effectiveness of the sorbent in saturated environments would be enhanced if the density of the hydroxyl functional group decreased. This functional group is the most reactive and abundant site in cell wall polymers of lignocellulosic material such as sugarcane bagasse. The acetylation reaction is one of the most common techniques used for the hydrophobic treatment of lignocellulosic material (e.g., wood) by a substitution reaction of a hydroxyl group (hydrophilic) into an acetyl group (hydrophobic). This reaction is usually carried out by heating lignocellulosic material in the presence of acetic anhydride with or without a catalyst. Various catalysts have been used for enhancing the efficiency of acetylation reactions. Pyridine and 4-dimethylaminopyridine (DMAP) have been commonly applied for acetylation for many years.

Jute and kenaf have been treated with acetic anhydride to give acetylated derivates that show reduced swelling. Due to the conversion of hydrophilic hydroxyl groups to less polar acetyl ester groups, this effect is advantageous when these fibres are incorporated into fibre/board composites. The reaction of jute with acrylonitrile converts the cellulosic hydroxyl groups to cyanoethyl groups. The properties of cyanoethylated cotton are well known and provide improved stability to attack from acids and heat. Cyanoethylation of jute yarns to a total of 2.8% nitrogen improves resistance to heat, acids and rotting. However, the high cost of such a treatment limits its commercial use.

2.1.4 Oil spill and its environmental hazardous

Oil spills are a global concern due to their environmental and economic impact. Crude oil released to the marine environment through accidental spillage or drainage from land causes severe damage to the environment and marine life. Oil spills are of great concern because they threaten the marine ecosystem, including shorelines. Oil from accidental discharges during transportation, tank ruptures, offshore exploration, and leakage from underwater pipelines are known to affect the marine habitat and community adversely. As oil spilt at sea is transported to the shoreline, and after its arrival, its behaviour and physic-chemical characteristics change because of natural weathering phenomena

According to oil spill intelligence reports, major hotspots primarily occurred in the north-eastern USA, the Gulf of Mexico, and the Mediterranean Sea. The intensity of spilt events depends on the type and volume of spilt oil. The "International Tanker Owners Pollution Federation" (ITOPF) categorises spills into small-scale (<7 tonnes), medium-scale (7–700 tonnes), and large-scale (>700 tonnes). With the advent of new ships and improvements in safety protocols, compared to the period 2000–2009, statistics have shown a reduction of 71.7% and 43.75% for medium and large-scale spills from 2010–2019. However, while incidents have declined over the past decades, mitigation and remediation of oil spills remain challenging (Asif et al., 2022).

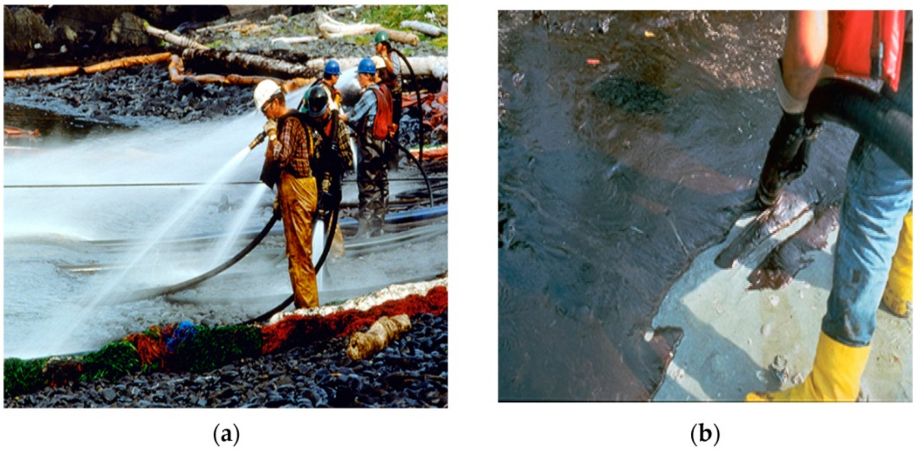

Plate 2.9: Cleaning oiled rocks with (a) high-pressure hoses and (b) Heavy oil vacuumed from a sandy beach (Source: credit to NOAA’s Office of Response and Restoration)

Due to massive shipment of oil across the border, spill disaster occurs, which results in the release of pollutants, posing both short- and long-term threats to the ambient environment. The effects on fish, sea birds, and other marine animals are often noticeable in the immediate aftermath of an oil disaster. Coated in oil, animals can be killed by poisoning or suffocation. Apart from the environment, a country's economy also experiences a severe setback. Losing tons of oil, which is not only a natural source of energy but also a depleting source, severely impacts a country's economy.

Plate 2.10 Oil spill hazards on marine life
(Source: https://www.thoughtco.com/environmental-consequences-of-oil-spills-1204088)

Besides this, the tourism industry is also affected. This is because, after the spill, many recreational activities like scuba diving, boating, snorkeling, and fishing are prohibited until the clean-up is complete. The fisheries bear the maximum brunt of these oil spills. Fish and other seafood sources are contaminated, which poses a health hazard. Also, operations of industries like power plants, desalination plants, and nuclear central stations are poorly affected, as they use seawater for many of their commercial activities.

Oil spill accidents have urged scientists across the world to develop an immediate cleanup technology because the spilled oil significantly affects the ecological and environmental system. Carbon-based sorbents have shown great capabilities in oil-spill cleanup operations owing to their superior properties. Moreover, they are biodegradable and chemically inert which make them superior to polymer-based sorbents. Carbon aerogels, graphene or carbon nanotubes (CNTs) coated sponges, carbon nanotube forests, graphene foams or sponges, carbon coatings, activated carbon, porous carbon nanoparticles and carbon fibres have been widely investigated for water filtration, water/ oil separation, oil-spill cleanup, wastewater treatment, gas separation and purification (Gupta and Tai., 2016).

2.2 Research Review

2.2.1 Cellulosic minor fibres

Cellulose is one of the most naturally occurring fibrous materials. Strictly speaking, all plant fibres are single-cell materials. Most plant fibres exist in bundles of ultimate fibres except for seed fibres. A fibre is defined as a unit of matter characterised by flexibility, fineness, and a high length ratio to thickness. In contrast, fibre ultimate can be defined as 'one of the unit botanical cells into which leaf and bast fibres can be distinguished'. The use of these naturally occurring cellulosic fibres can be traced back more than 10,000 years. In about 8,000 B.C., in the Middle East and China, cellulosic was used for textiles.

Minor fibres in textiles are those that are limited in production and not available on the economic scale of a mass market. The fibres have limited production and application. Minor fibres like Sunnhemp, Flax, Ramie, Banana, Sisal, Bamboo, Pina, Kenaf, Coir and fibres of similar plants have been used for more than 8,000 years. Sunn hemp (Crotalaria juncea) or, Bombay hemp, or Banaras hemp is a crop grown to produce bast fibres. The fibre is dull yellow, somewhat coarse, strong and durable. The fibre has high cellulose content, low lignin and negligible ash, so the paper industry has identified it as the most suitable indigenous raw material for manufacturing tissue paper and paper for currency. In rural areas, it is used to make ropes, twines, nets, hand-made paper, and tat patties. It is also used to make canvas and screens. The area under this fibre crop is around 28,000 ha, and the annual production of fibres is 20,000 tons.

Among cellulosic minor fibres, ramie possesses excellent absorbency properties. To change tensile strength and stiffness, Gupta (2000), applied resins and softeners individually and in combination. They were applied to 100% ramie and cotton ramie blended fabrics, which were further evaluated for their fixation and surface modification. Combination-treated samples produced smooth, fine, and soft handles, and a decrease in bending rigidity was seen due to the softeners' formation of cross-linkages.

According to Yang (2004), the fibres from corn husks can be made into yarn and woven into a comfortable and easy-to-dye fabric. They have already produced a prototype sweater. About three pounds of husks were needed to extract enough fibre for an average T-shirt. The U.S. produces about 20 million tons of corn husks each year.

Plate 2.11: Cornhusk Fibre, Plant and Product (Sweater developed from a 50/50 blend of corn husk fibres and cotton)

Bhagwate (2006), conducted an experimental study on product development using Kenaf fibres. They studied the Kenaf fibre morphology, extraction and decortication process, structure and properties like scouring and bleaching with hydrogen peroxide and sodium silicate. Four basic dyes were used: Procion Brill Orange H- 2R, Procion Brill Blue H- TGS, Procion Brill Red and Procion Brill Violet for softening and dyeing the fibres. The blending of Kenaf fibre is done with cotton, and the spinning of yarns is done on the Raspador Machine. A diversified line of 20 products was developed, such as a Set of table mats with coasters, shoulder bags, sling purses, lamp shades, ladies' footwear, mobile case, folder, coaster, tea cosy, set of mittens, hanging, wall piece, floor mat, hair band, letterbox, from

Kenaf fibre by using six different techniques and at the end evaluation of preferences are done for the developed products.

Kannojiya et al. (2013), studied the developing trends in extraction methods and economic optimisation of the products in the market obtained from PALF. PALF is leaf fibre obtained from the pineapple plant's leaf after the fruit is harvested. Fibre extraction alone from the leaves is not economically viable, so the utilisation of the residual sludge remains after the process is used for vermicomposting and other applications. India is the sixth largest country in the world to produce pineapple, and Assam has the maximum area for cultivation with a medium productivity scale. Due to natural calamities, other inadequacies of financial sources, and insurgency problems, the growth rate of the pineapple plant has decreased. To overcome this problem, SITRA has fabricated the pineapple leaf fibre extraction plant at the behest of Assam Rifles of Tripura under the Ministry of Civil Action programme, which has sponsored the fibre extraction plant project for the Tripura-based NGO called Mushroom Growers Welfare Society. For the fabrication process of pineapple fibre, it has been modified by alkali, acetylation, and graft copolymerisation, which improves its properties for use in textile applications.

Shroff and Karolia (2014), studied the effect of enzymes on the softening of Banana, Sisal and Ramie and 100% nonwoven fabrics were prepared. A combination of the fabrics was also prepared by blending 50:50% banana and sisal fibre by punching manually because of the lack of cohesiveness property and 40:60% of ramie and banana fibre on the DILO nonwoven machine because ramie had good cohesive properties. The researcher used hemicellulose, pectinase and cellulase enzymes for the softening of the fibres. The fibres were treated with different combinations of the enzymes at 6%, 15%, and 22% concentration for 2, 8, 12 and 16 hours; it was observed that the combination had variation in readings and with the touch and feel method, the researcher could not conclude any final combination, so the fibres were treated individually with the enzymes. Fibres were treated at 10% and12% concentration for 8, 12 and 14 hours, and it was observed that the maximum weight loss of the banana fibre was when treated with cellulase enzyme, sisal was with hemicellulase at 12% concentration for 14 hours, and ramie was with Pectinase enzymes. However, maximum strength loss was observed in sisal fibre due to the hemicellulase enzyme. The result showed that the tensile strength of the three fibres was similar to that of cotton. It was observed that ramie gave the best results for the nonwoven preparation, making it the most compact, smooth, and flexible fabric compared to the fabric prepared with banana and sisal fibre.

Agarwal and Sharan (2016), conducted a study on exploring different minor fibres. The main aim was to document the cellulosic minor fibres and the government, non-government, and other allied agencies/ institute initiatives for the upliftment and popularisation of the cellulosic minor fibres. It was found that they are readily available in fibrous form and can be extracted from leaves, stems, and seeds at meagre costs. Thus, they can be considered a substitute for conventional synthetic polymeric fibre because of the growing environmental concern of global warming. The study was limited to cellulosic minor fibres only, which included flax, ramie, kenaf, sun hemp, banana, bamboo, sisal, pineapple and coir fibre. These fibres were selected based on their sustainability and availability in India for future applications, cultivation, and availability. This study provided data regarding cultivation regions and extraction processes, uses and applications for selected minor fibres, and information about the agencies supporting the development of minor fibres.

Bhoj and Karolia (2015), conducted a comparative study to understand the impact of chemical and enzyme treatment on sisal fibre. The research was conducted with laccase, cellulase, hemicellulase, and pectinase as the enzymes, while sodium hydroxide, hydrogen peroxide and sodium hypochlorite were used for the treatments. The comparative study revealed that enzyme treatment reduced the strength and increased the elongation, and the fibres were swollen and softer. While the strength of the chemically treated fibre was maintained after the treatment, with no elongation and swelling, fibres were less smooth and flexible with more fibril, the whiteness index increased due to bleaching and brightness was increased but reduced the yellowness. The yarns were prepared from untreated, enzyme-treated, and chemically treated fibres, amongst which the finest was untreated fibre yarn, followed by chemically and enzyme-treated ones. Plain weave fabrics were also developed, and the enzyme-treated fibres were rough with uneven textures as the fibres were protruding on the fabric's surface, giving it a rough surface.

Nayak et al. (2016), researched the extraction process and the mechanical properties of extracted pineapple leaf fibre obtained from the leaves of the pineapple plant (Ananas Cosmosus) from the family Bromeliaceous. Scarping of pineapple leaves was done manually and mechanically with the help of a machine designed and developed at ICAR- NIRJAFT Kolkata. Retting of scratched pineapple leaves was done by making bundles and immersing them in the retting water enriched with two different bacterial cultures. It was observed that the controlled sample took five days, whereas the bacterial culture samples took three days.

The tenacity of fibre obtained in the combination of ICAR-NIRJAFT extractor and both plain water and bacteria-enriched retting was much higher than in comparison to the other combinations. However, the highest fineness (6.50) among all combinations was found in the case of enrichment culture retting, E2. In controlled samples, SEM shows the gummy substance between the individual fibres, whereas the gummy materials are removed after the enrichment of bacterial cultures in the retting process. Therefore, PALF is blended with many other natural and synthetic fibres to develop diversified products such as woven and nonwoven fabrics.

According to Doshi and Karolia (2016), bananas are India's second most important food crop. Every year, around a billion tonnes of banana plant stems are thrown on the roadside after harvesting the fruit. Banana fibres are extracted from this roadside-thrown biomass using the Raspador machine. Being lignocellulosic, banana fibres have excellent strength but are a little brittle. Processing can improve specific properties of any textile fibre. Banana fibres are lustrous fibres, ranging from creamy to off-white. The present study focused on optimising the bleaching recipes for banana fibres. Sodium hypochlorite, Hydrogen peroxide, and a combination of the two bleaches were studied by varying time, temperature, and concentration. Bleaching parameters were optimised based on tensile strength, whiteness index, and weight loss testing results. The combination of hypochlorite and peroxide bleach obtained the best results.

Desai et al. (2020), conducted an experimental study of fabric construction using minor fibres for sound-resistant materials. The study includes an experimental work that aimed to develop sustainable woven sound-resistant materials using two minor cellulosic fibres – Sisal and Ramie. The material application area was for acoustic applications. To improve fibre quality, a commercial bulk enzyme treatment was done. The fibre surface modification was done using four different enzymes. The enzyme treatment of the fibres was to remove the impurities and reduce the stiffness, thereby giving the strength to convert into yarn. Woven and nonwoven fabrics were created using 100% sisal and 100% ramie yarns. The combination of both fabrics will be analysed for absorption or scattering of the sound passing. The results showed that the sound absorption is better with the increasing thickness of the nonwoven and their uneven structure.

2.2.2 Chemical modification treatments

Mohanty et al. (2000), studied that the chemical surface modifications of jute fabrics involving bleaching, dewaxing, alkali treatment, cyanoethylation and vinyl grafting are made in view of their use as reinforcing agents in composites based on a biodegradable polyester amide matrix, BAK 1095. The effect of different fibre surface treatments and fabric amounts on the performance of resulting composites is investigated. The mechanical properties of composites, like tensile and bending strengths, increase due to surface modification. Among all modifications, alkali treatment and cyanoethylation result in improved properties of the composites. The tensile strength of BAK is increased by more than 40% due to reinforcement with alkali-treated jute fabrics. SEM investigations show that the surface modifications improve the fibre–matrix interaction. Degradation studies found that after 15 days of compost burial, about 6% weight loss was observed for BAK, whereas cyanoethylated and alkali-treated jute–BAK composites showed about 10% weight loss. The loss of weight, as well as the decrease in bending strength of degraded composites, is more or less directly related.

Bisanda et al. (2000), studied the effect of alkali treatment on the wetting ability, and the coherence of sisal-epoxy composites was examined. Treatment of sisal fibre in a 0.5N sodium hydroxide solution resulted in more rigid composites with lower porosity and, hence, higher density. The treatment has been shown to improve the adhesion characteristics due to improved work of adhesion because it increases the surface tension and surface roughness. The resulting composites showed improvements in compressive strength and water resistance. The alkali removal of intercrystalline and intercrystalline lignin and other surface waxy substances substantially increases the possibility for mechanical interlocking and chemical bonding. The alkali treatment is simple and is recommended to precede other sophisticated surface modification treatments on plant fibres similar to sisal fibre.

Tserki et al. (2005), Conducted a study on, "A study of the effect of acetylation and propionylation surface treatments on natural fibres”. This study applied two fibre pre-treatment methods, acetylation and propionylation, to flax, hemp, and wood fibres. The effect of esterification between the acetyl/propionyl groups and the hydroxyl groups of the fibre was examined by attenuated total reflectance-Fourier transform infrared (ATR-FTIR) and X-ray photoelectron spectroscopy (XPS). At the same time, its extent was assessed by titration. X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to characterise the crystallinity and the surface morphology of the untreated and esterified fibres. The highest extent of the esterification reaction was achieved for the wood fibres due to their high lignin/hemicellulose content. XPS and FTIR experiments revealed the presence of acetyl/propionyl groups that are involved in an ester bond with the fibre constituents for the treated fibres. Esterification decreased the hydrophilicity of the materials, as indicated by the reduction in moisture adsorption.

In contrast, the fibre crystallinity was slightly decreased as a result of the increase of the amorphous portion due to the esterification reaction. The SEM results revealed that both treatments resulted in the removal of non-crystalline constituents of the fibres, possibly waxy substances, and altered the characteristics of the surface topography. It was found through SEM and XPS analyses that the surface of the untreated fibres is rich in compounds that are of a hydrocarbon nature, such as waxes and wax-like substances, and that the treatments altered the fibre surface characteristics by removing the outer surface layer and producing a smoother fibre surface.

Bledzki et al. (2008), studied "The effects of acetylation on properties of flax fibre and its polypropylene composites". Flax fibre was modified with acetylation. The influence of the acetylation on the structure and properties of flax fibre was investigated, and modified flax fibre-reinforced polypropylene composites were prepared. The catalyst was used to accelerate the acetylation reaction rate. Flax fibre was characterised after modification. Surface morphology, moisture absorption property, components content, degree of polymerisation, the crystallinity of cellulose and thermal stability of flax fibres were studied. Due to acetylation, the flax fibre surface morphology and moisture resistance properties improved remarkably. Flax fibre (modified and unmodified) reinforced polypropylene composites were fabricated with 30 wt% fibre loading. The mechanical properties of those composites were investigated. The tensile and flexural strengths of composites were found to increase with an increasing degree of acetylation of up to 18% and then decreased. Charpy impact strengths of composites were found to decrease with an increasing degree of acetylation. Owing to the addition of a coupling agent (maleated polypropylene -MAH), the tensile and flexural strength properties were found to increase between 20 to 35% depending on the degree of acetylation.

Barreto et al. (2010), studied the structure characterisation of the banana fibre modified by alkaline treatment was studied. Some essential properties of this fibre changed due to some chemical treatments, such as the crystalline fraction, dielectric behaviour, metal removal (governed by solution pH) and biodegradation. The results showed that treated banana fibre is a low-cost alternative for metal removal in aqueous industry effluents. Thus, for regions with low resources, biosorbents are an alternative to diminish the impact of pollution caused by local industries, besides being a biodegradable product. It was observed by XRD that chemical treatment with NaOH increased the crystalline fraction of the banana fibre due to the partial removal of the lignin (amorphous phase). The vibrational modes obtained by IR spectroscopy did not suffer significant changes after this alkaline process, and the prominent bands appeared to be approximately in the same range of wave number.

Mir et al. (2012), researched coir fibre, which aimed to characterise brown single coir fibre for manufacturing polymer composites reinforced with characterised fibres. Adhesion between the fibre and polymer is one of the factors affecting the strength of manufactured composites. In order to increase the adhesion, the coir fibre was chemically treated separately in single-stage and double-stages. Both the raw and treated fibres were characterised by tensile testing, Fourier transforms infrared (FTIR) spectroscopic analysis, and scanning electron microscopic analysis. The tensile properties of chemically treated coir fibre were found to be higher than raw coir fibre, while the double-stage treated coir fibre had better mechanical properties compared to the single-stage treated coir fibre. Scanning electron micrographs showed a rougher surface in the case of the raw coir fibre. The surface was found to be clean and smooth in the treated coir fibre. Thus, the performance of coir fibre composites in industrial applications can be improved by chemical treatment.

Brindha et al. (2012), experimented with fibres extracted from banana varieties scoured with 2% NaOH solution at 100℃ for 45min and analysed for their physico-chemical and mechanical properties. The moisture regain and the cellulose content, modulus, and tenacity of the fibres of all varieties were increased after the scouring process. The fibre from the variety rasthali had high moisture content (13.21%), cellulose content (83.02%), modulus (3293.16 g/den) and tenacity (48.66 g/den) when treated with 2% NaOH solution. Thus, scouring can increase the fibre quality for use in industries like paper and textiles.

Kalia et al. (2013), compiled various research on surface modifications of plant fibres using various pre-treatment methods. One of the treatment methods was enzyme treatment, which affected the properties of the plant fibre and reinforced polymer composites. The most commonly used enzymes for polymer modification from the class hydrolase are glycosidases, proteases and lipases and from the class of oxidoreductases, tyrosinase, laccase and peroxidase. Enzymes degrade cellulose in the fibre wall structure, which then initiates wall stripping, generates fine fibrils and leaves the fibres less hydrophilic. The advantages of using enzymes were also emphasised, such as milder reaction conditions, non-destructive transformations on the surface of the polymer, environmentally friendly but needing technological ways for commercial application, and thereby, it will also be cost-effective.

Chattopadhyay and Umrigar (2017), studied the possibility of the use of waste cotton linters as oil sorbents by chemical modification such as acetylation and cyanoethylation. Both the chemical modification processes were optimised based on the oil absorption capacity of the chemically modified cotton fibre with the help of MATLAB software. The modified samples were tested for their oleophilicity in terms of oil absorption capacity, oil retention capacity, oil recovery capacity, reusability of sample and water uptake and buoyancy as oil sorbent. The results show that Cotton waste linters were successfully acetylated using acetic anhydride in the presence of either H2SO4 or HClO4 as catalysts and cyanoethylated using acrylonitrile. The modification was characterised by the FTIR spectra and SEM analysis. Maximum oil absorption was achieved at around 39.6% for cotton fibre acetylated using 3% H2SO4 at room temperature for 60 min. Cyanoethylation treatment resulted in about 35% oil absorption for cotton samples pre-treated with 2% NaOH and cyanoethylated at room temperature for 60 min. Oil recovery from the acetylated and cyanoethylated cotton samples was about 85–90% and 80–85%, respectively. It was found that the chemically modified samples can also be reused conveniently at least three times. In addition to oil absorption, the higher sinking time of chemically modified fibres in the water further confirmed the chemical modification. Therefore, acetylated or cyanoethylated waste cotton linters can be suitably used for oil spill clean-up applications.

2.2.3 Sorbents for specific end-use

Sun et al. (2004), conducted a study on "Acetylation of sugarcane bagasse using NBS as a catalyst under mild reaction conditions for the production of oil sorption-active materials”. In this study, Sugarcane bagasse was esterified with acetic anhydride using N-bromosuccinimide as a catalyst under mild conditions in a solvent-free system. The extent of acetylation was measured by weight per cent gain, which varied from 2.1% to 24.7% by changing the reaction temperature (25–130℃) and duration (0.5–6.0 h). N-bromosuccinimide was found to be a novel and highly effective catalyst for the acetylation of hydroxyl groups in bagasse. At a concentration of 1% of the catalyst in acetic anhydride, a weight per cent gain of 24.7% was achieved at 120℃ for one hour, compared with 5.1% for the un-catalyst reaction under the same reaction condition. FT-IR and CP-MAS13C-NMR studies produced evidence for acetylation. The thermal stability of the products decreased slightly upon chemical modification, but no significant decrease in thermal stability was observed for WPG ≥ 24.7%. The oil sorption capacity of the acetylated bagasse obtained at 80℃ for six hours was 1.9 times higher than the commercial synthetic oil sorbents such as polypropylene fibres. The results revealed that the acetylation significantly increased the hydrophobic properties of the bagasse.

They concluded from their research that the acetylated SCB could be used as a natural sorbent in oil spill clean-up. Its oil sorption capacity was much higher than that of the synthetic sorbents, indicating that a total or partial substitution of commercial synthetic oil sorbents by acetylated SCB could be beneficial in oil spill clean-up operations by improving the efficiency of oil sorption and by incorporating other advantages such as biodegradability.

Bayat et al. (2005), studied the performance of three sorbents to determine their potential for oil spill clean-up. The sorbents were selected from natural and synthetic categories. Bagasse and rice hull were used as natural materials, and polypropylene nonwoven web was used as a synthetic sorbent. The results obtained that polypropylene can sorb almost 7 to 9 times its weight from different oils. Bagasse, 18 to 45 mesh size, follows polypropylene as the second sorbent oil spill clean-up. Bagasse, 14 to 18 mesh size, and rice hull have comparable oil sorption capacities, which are lower than those of the two former sorbents. It was found that oil viscosity plays a vital role in oil sorption by sorbents. Bagasse and rice hull are agricultural wastes and pose disposal problems, but they are biodegradable and inexpensive. Also, they are both usually burned as fuels and used as oil sorbents.

Carmody et al. (2007), stated that Spillages of oil and similar petroleum products are costly, common events worldwide. Clean-up operations involve a range of many types of sorbents. The common properties that these sorbent materials possess include hydrophobicity and oleophilicity, high sorption capacity, high rate of uptake, retention over time, oil recovery from sorbents and the reusability or biodegradability of sorbents. The research was an attempt to characterise and provide insight into the adsorption phenomena of selected sorbent materials (sand, SD1 organo-clay and BC cotton fibre) using key analytical techniques. They studied basis for selection of cotton-cellulose fibres compared to common and other novel alternatives such as sand and organo-clays. The study conclude that Cotton fibre was observed to have several key properties such as hydrophobicity, good affinity for hydrocarbons, rapid adsorption on contact, and high adsorption and retention through interfibre capillaries.

Behnood et al. (2013), stated that natural sorbents are applied as a single solution for oil spills since this technique is effective, rapid and cost-saving for cleaning these pollutions and reducing environmental effects. Thus, for their study, they selected raw sugarcane bagasse as a natural organic sorbent. This sorbent was used in different particle sizes, and the effect of contact time and the existence of water was studied. The results of their study show that the bagasse can be applied to effectively remove crude oil in crude oil layer pollution from marine environments. The maximum adsorption capacity of raw bagasse for the dry system was obtained at about 8 g for raw bagasse mesh number 60. The particle size effect was evaluated, and it was shown that the sorption capacity improved with decreasing particle size due to increased surface area. The maximum adsorption capacity of raw bagasse for the crude oil layer was about 6.6 g crude oil per g sorbent.

Rekha et al. (2013), studied the suitability of the bagasse fibres for use in absorbent hygiene products. The bagasse absorbency was improved by the enzymatic delignification process, which is the main requirement for sanitary napkins. Bagasse fibres were delignified using an eco-friendly method using the laccase enzyme, and the delignification process was optimised using the Box-Behnken experimental design. The delignified fibres resulted in some stiffness and may not be suitable for application in hygiene products. Thus, the researcher converted those fibres into pulp in order to increase their suitability. The pulp stage was found to perform better than the fibre stage. The delignified bagasse fibres and pulp showed the highest absorbency and lowest lignin content when compared to the raw and cleaned stages. Thus, the delignification using laccase enzyme can considerably improve the suitability of bagasse for absorbent hygiene products and help in recycling bagasse to enhance its functionality.

2.2.4 Sugarcane bagasse fibre

In recent years, different groups have reported increasing trends toward a more efficient use of agro-industrial residues. Sugarcane bagasse, an abundant agricultural lignocellulosic byproduct, is a fibrous sugarcane stalk residue - the annual global production of 800 million tonnes of sugarcane results in 240 million tonnes of bagasse. Sugarcane bagasse, lignocellulosic residue from the sugar industry, is an abundant and renewable bioresource on the earth (Chen et al., 2016).

Structurally, the sugarcane (Saccharum Officinarum) stalk comprises an outer rind and an inner pith (Chiparus, 2004). According to Paturau (1989), the majority of sucrose, together with bundles of tiny fibres, is found in the inner pith. The outer rind contains longer and finer fibres in a random arrangement throughout the stem and is bound together by lignin and hemicellulose. Previous studies on the extraction of the fibres from sugar cane rind demonstrated that controlled amounts of lignin and hemicellulose could be removed through alkaline and mechanical treatments, resulting in bundles of relatively thin fibres (Collier et al., 1992).

Research at Louisiana State University (LSU) has been conducted to determine the feasibility of sugar cane rind fibres for textile and geotextile applications (Elsunni and Collier, 1996). A suitable nonwoven mat for geotextiles should sustain or at least prevent erosion. At the same time, it should be penetrable by growing plants, be capable of permitting interaction between air and soil, and allow rain to penetrate the soil and drain excess water (Collier et al., 1995). One product was a nonwoven mat formed by suspending the fibre bundles on a screen in water, then dewatering and drying. The mats have been tested as geotextiles for soil erosion control in civil engineering applications (Romanoschi,1998). Thus, a low-cost, biodegradable geotextile can be produced in local sugar cane mills, providing an economic benefit to both the transportation and sugarcane industries.

Asagekar and Joshi (2014), studied the characteristics of Sugarcane fibres produced from different varieties cultivated in the western part of Maharashtra, India. Sugarcane fibres have been extracted from bagasse by 0.1 (N) NaOH treatment, and their characteristics have been evaluated. They found that there is a difference in properties of fibres between varieties as well as between maturity levels, and as such, no specific trend was observed. The properties of sugarcane fibres are closer to those of cellulosic coir fibres. Hence, this fibre can be used to make nonwoven mats. The nonwoven material can be impregnated in resins to make composites for various applications.

Anggono et al. (2014), conducted a study and evaluated the improved performance of Sugarcane bagasse fibres-polypropylene (PP) composites due to alkali treatment done on Sugarcane bagasse as reinforcing fibres. Alkali solution of 10% NaOH with a temperature of 60-70^{o}C was used to soak the bagasse for 2 to 6 hours. Hot-pressed samples were prepared from a mixture of sugarcane bagasse fibres and PP with fibres/PP weight ratios of 20/80, 25/75, and 30/70. Hot-pressed samples using untreated bagasse fibres were also produced for comparison. A tensile test was performed on all samples, and the fracture surface from tensile test samples was observed using scanning electron microscopy (SEM). The alkali treatment resulted in a relevant increase of tensile strength of the composite to 229, 29 MPa at 20/80 fibres/PP weight ratio or an increase of 43% compared to the composite samples; fibres were untreated with alkali. The Alkali treated-sugarcane bagasse resulted in the best reinforcement for composites after 2 hours of treatment, which resulted in excellent fibre-resin bonding.

Mohit and Selvan (2018), conducted an experimental study, and the characterisation of mechanical and thermal properties of treated and raw sugarcane bagasse fibre has been studied. The bagasse fibres are treated with sodium chloride (NaCl) and sodium hydroxide (NaOH) solutions. The NaOH-treated fibres show better structural and thermal properties than the other two types. SEM image of alkali-treated fibres reveals that the bundles of fibres are mainly composed of thin parenchyma cell walls. The fibres are joined with each other, which improves their mechanical properties. The statistical analysis is also performed using the ANOVA one-factor method. The results show that the NaCl and NaOH treated fibres significantly improve the mechanical properties and thermal stability.

Thilagavathi et al. (2018), conducted research and did extensive work on thermally-bonded, hybrid and oil-sorbent nonwovens from binary and tertiary mixing of cotton, kapok, and three varieties of milkweed fibres (Asclepias syriaca, Calotropis Procera and Calotropis gigantea) and polypropylene fibres. The physical and chemical properties of the fibres were examined for their oleophilic character. The results of the study reported that all the fibre surfaces were covered with natural wax. Further, kapok and milkweed fibres were found to have less cell wall thickness and a high void ratio. Oil sorption and retention characteristics of these fibres were studied in loose fibrous form and structured assembly form (thermally-bonded nonwovens) using high-density oil and diesel oil. The effects of fibre diameter, fibre cross-sectional shape, fibre surface area and porosity on the oil sorption behaviour were also discussed. An excellent and selective oil sorption behaviour of milkweed fibres (Calotropis

Procera and Calotropis gigantea) blended with cotton and polypropylene fibres was observed. The maximum oil sorption capacity of the developed thermal bonded nonwoven was 40.16 g/g for high-density (HD) oil and 23.00 g/g for diesel oil. Further, a high porosity and a high surface area significantly influenced the oil sorption and retention characteristics.

Therefore, It is evident from the above-cited literature that the utilisation of agro-waste for extracting natural minor fibres has a vast scope and applications in different technical textile segments. However, there is a need to develop scientific research based on new natural geotextile products as well as their promotion for commercialisation. These are the only routes for the natural product manufacturing industry to reach the same platform as those already occupied by the synthetic industry. Hence, in the future, the utilisation can be expanded in many fields by considering the essential characteristics and appropriate technologies of natural fibres.