CONCEPTUAL DESIGN FEATURES AND ECO-METHODS FOR THE EXTRACTION OF NATURAL FIBERS IN THE MATERIALISTIC EARTH

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Natural fibers are the most common fibers available on earth in various forms such as plant fibers, animal fibers and mineral fibers. Plant fibers are the upcoming novel fibers used in composites as a reinforcement material. Natural fibers have lot of potential in the materials field due to its immense advantage and its low cost availability. Certain mechanisms are to be developed to extract these fibers mechanically without losing its natural properties. This paper is concerned with the design features along with fabricated decorticator to extract the natural fibers from the resources in an eco-naturalistic mechanical manner. Conceptual novel design is been carried out and its features are discussed. This design of extracting natural fiber is done by manually-hand operated method. A view of other methods adopted, features involved in extraction, design of the product and interesting keen ideas are been included.

Keywords: Natural fibers, Extraction, Mechanical method, Design features.

1. INTRODUCTION

Natural fibers are the upcoming promising fibers in the area of composites. It had its presence from the Egyptian period of civilization and still popularly used especially in western countries [1]. India has the ability to produce vast amount of natural fibers because of the favorable climate for its growth and its eco-system. There are several methods of extracting natural fibers from its source, but the mechanical way of extracting fibers are the most commonly used. The mechanisms and the design features for extracting fibers should be developed in such a manner that the natural properties of the fibers are not lost and also comprising the cost factor suitable for the present system.

Natural fibers are advantageous when compared to synthetic fibers in terms of low cost, low density, renewability, non-hazardous and easily available because of these factors they are well known to the composites field [1–3]. One of the most disadvantages of natural fibers is the moisture absorption and the poor compatibility between fiber and the matrix.

1.1. Classification of natural fibers

Fibers can be classified as plant/vegetable fibers, animal fibers and mineral fibers. In the composite and other industries it usually refers to wood fiber and agro based such as bast, leaf, seed and stalk fibers [1–3]. Fibers obtained from the parts of the plants are named as plant/vegetable fibers. These are further classified in to three categories depending on the source of extraction as shown in Figure 1.

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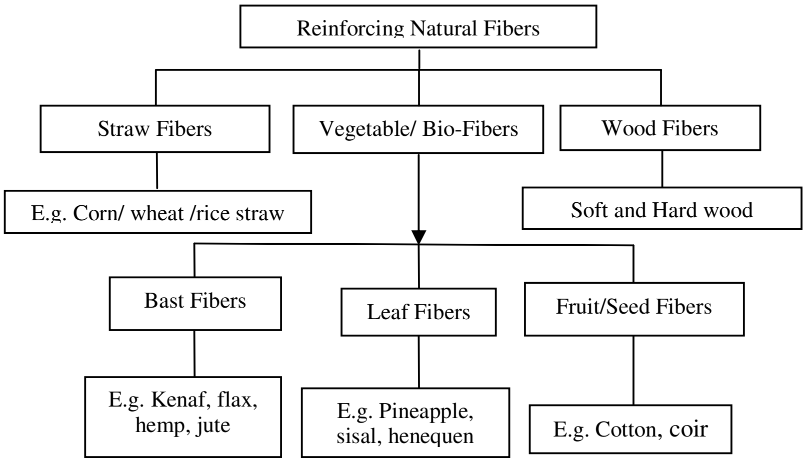


Figure 1. Classification of reinforcing fibers [2].

(i) Bast fibers (e.g. kenaf, flax, hemp, jute), (ii) Leaf fibers (e.g. pine apple, sisal, henequen) (iii) Fruit /seed fibers (e.g. cotton, coir).

1.2. Importance of natural fibers

Natural fibers are primarily important for their low density property, excellent tensile strength and modulus, high durability, and biodegrability. Properties such as ultimate tensile strength, modulus, and density depend upon the internal structure and chemical composition of fibers [1–3]. Natural fibers with combination of resins are ready to have a product of biocomposite material which is widely used in automobile industry for interior parts and also in exterior parts of the vehicle, structural constructions, and electronics industries.

With continuous use of man-made fibers, which are the sources from the petroleum products there is a chance of depletion of the resources. Hence we need to find an alternative source of fibers which does not affect the environment but also eco-friendly. These natural fibers have the equivalent properties of man-made fibers in some aspects. The entire plant (leaves, pith, stock, roots) can be used directly/indirectly to produce structural, non-structural composites and other materials as shown in Figure 2 [4].

1.3. Properties of natural fibers

Natural fibers have a hollow space called lumen, with nodes and inter nodes at irregular distances that divide the fiber into individual cells. The surface is rough, uneven and provides good adhesion to the matrix in a composite structure [1, 4]. Some of the plant fiber dimensions are shown in Table 3.1..

The Criteria for the choice of reinforcing fibers include: Elongation at failure, dynamic behavior, thermal stability, adhesion of the fibers and matrix [4]. The amount of cellulose and other non-cellulosic constituents in a fiber determines the structure and properties and also influences the crystalline and moisture regain. Natural fibers are hydrophilic and they are not easily wetted or bonded well with many matrix materials, like in the case of thermoplastics. Coupling agents, like maleated polyolefins, isocyanates and silanes are used to increase the performance properties of fibers [1].

1.3.1. Mechanical properties

The mechanical properties of natural fibers are shown in Table 4.1., which are mainly influenced by the composition and structure. Natural plant fibers with high cellulose content, high degree of polymerization of cellulose and low microfibrillar angle give better mechanical properties [1, 2].

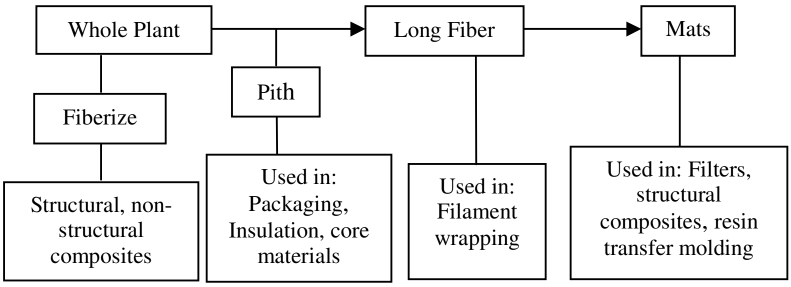


Figure 2. Importance and uses of various parts of plant [4].

Table 1. Some of the plant fiber average dimensions (mm).

Type of fiber	Average length	Length	Diameter
Cotton	10–60	18	0.02
Cereal straw	1–3.4	1.5	0.023
Flax	5–60	25–30	0.012–0.027
Jute	1.5–5	2	0.02

Note: *Source*: Ref. [3].

Table 2. Mechanical property of natural fibers.

Natural fiber	Density(g/cm^3)	Tensile strength (MPa)	Youngs modulus (GPa)
Cotton	1.5–1.6	287–597	5.5–12.6
Jute	1.3–1.46	393–800	10–30
Sisal	1.33–1.5	400–700	9.0–38.0
Coir	1.2	175–220	4.0–6.0

Note: *Source*: Ref. [1, 2].

Cellulosic fibers have high Young's modulus as compared to commodity thermoplastics there by contributing to the higher stiffness of the composites.

1.4. Quantitative analysis of natural fiber

Extracting natural fibre usually starts from the farm then follows retting process [5]. Usually water retting process takes place in ponds, causing inconvenient to humans and thus polluting the water. Traditionally decorticating process is carried by hand, which is here currently replaced by semi-mechanized decorticators, resulting in time saving. Eco friendly method of retting such as green fiber retting can also be carried out.

Considering the fiber such as areca, the first step is to separate the husk from the nut, and then soak the fiber for few days to extract the fiber from the pith. The residual pith, a by-product of decortication, also constitutes waste. For each tonne of areca fibre few tones of areca pith is produced and the waste is re-used as a substitute for horticultural field. However natural fibers are renewable resources and they are biodegradable material thus the ecological implications of the entire life cycle of a product from raw material to processing and to final product disposal are maintained.

Plant fibers are complex, three dimensional, polymer composites consisting of cellulose, hemi-celluloses, and lignin of major portion and minor portion consist of pectin, water soluble, moisture, and wax [6, 7]. However, chemical analysis can be carried out to find the constituents for a particular fiber but is time-consuming and requires the use of solvents. Differential scanning calorimetry (DSC), Thermal gravimetric analysis can be used as a technique for thermal analysis of polymers in natural

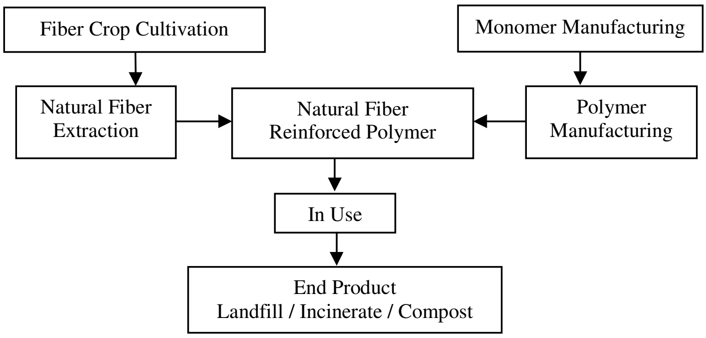


Figure 3. Processing stages of Natural fibers [8].

fibers, because it is quite fast and well-established technique, which requires neither the use of solvent nor a lengthy sample preparation to perform it.

2. EXTRACTION OF NATURAL FIBERS

Fiber extraction procedures depend on the type, kind of plant and portion from which the fibers are derived such as bast, leaves, stem, fruit, wood, and other factors such as fiber performance and economics. But separation of the fibers from the original plant source is always an important step to obtain the high quality of fibers. Natural plant fibers are extracted and processed by various means that include methods like retting, breaking, scutching, hackling, and combing [5, 6].

Cellulosic fibers are extracted from lignocellulosic byproducts naturally using bacteria and fungi. Physical, chemical and mechanical methods are also followed to extract the fiber. These methods are carried out in such a manner that the morphological features are improved and processing way is done in a better way and chemical composition is not altered [7]. Physical methods such as stretching, calendaring, thermal treatment can also be carried out. Processing stages of natural fibers is shown in Figure 3.

Long and short fibers separation depends upon the method adopted by harvesting, extraction conditions, such as water pretreatment, alkaline treatment, mechanical action, time, and properties of fiber bundle [5].

The eco-method of extraction of natural fiber is taken into account of the environmental impact of a product throughout its lifecycle, ranging from extraction of raw materials to production, use, recycle and final disposal.

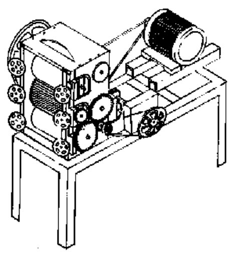
2.1. Traditional and natural method of extraction

Retting, the traditional process to extract fibers uses bacteria and fungi in the environment to remove lignin, pectin and other substances [8]. Bacteria and fungi play an important role in water retting and dew retting. Bacteria retting are based on the natural action of anaerobic bacterior aerobic fungi. Bacillus and Clostridium bacteria are used in water retting, Rhizomucor pusillus and Fusarium lateritium fungi are used in dew retting [9, 10]. Atmospheric retting also provides better quality fibers, but the time required is more and relatively longer duration which also makes the fiber difficult in processing.

In the case of traditional method to obtain coir fiber, the first step is to cure the coconut husks in water for 6–7 months. Large curing pits are used for it. Curing of husks in water increases the flexibility of fibers and increases their durability. Husks are added in one end and the cured husks are taken at the other end. The soaked husks are machine processed to obtain coir.

2.2. Chemical method of extraction

The most common methods include alkalis, mild acids and enzymes for fiber extraction. Sodium hydroxide is the most commonly used chemical for fiber extraction. Sulfuric acid and oxalic acid in



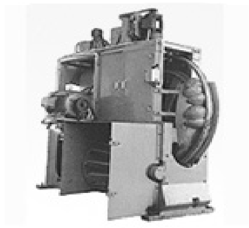


Figure 4. Banana fiber extractor [14]. **Figure 5.** Coir fiber extractor [15].

combination with a detergent have can also been used for fiber extraction [11]. Chemical retting is a low-concentration alkaline solution, and high temperature process. Factors that determine the quality of chemically extracted fibers are the chemical concentration, duration of treatment and temperature. Enzymatic fiber extraction includes a combination of enzymes such as pectinases, hemicellulases and cellulases which are generally used with a pre- or post chemical treatment of fiber [12].

2.3. Mechanical method of extraction

Mechanical separation of fibers is carried out using decorticating machines, steam explosion (STEX), ammonia fiber extraction, Tilby process and other novel methods [12, 13].

Mechanical decorticator, the fiber extracting machine, consists of a pair of feed rollers and a beater as shown in Figure 4. Slices will be fed to the beater between the squeezing roller and the scrapper roller, and where the pulp gets separated and fibers are extracted from the machine and air dried [14].

Decorticating equipment or defibering is used to process the husks which requires few days of immersion in water tanks. Later the husk is allowed to crush into a breaker to open the fibers. Revolving drums are used to separate the fibers from the short woody parts and the pith as shown in Figure 5. The stronger fibers are later washed, cleaned, dried, hackled and combed. Quality of the fibers is taken in account with the adaption of treatment involved [15].

By using the entire plant, processes such as retting, fiber separation, fraction purification, etc. can be eliminated which increases the total yield of plant material and reduces the costs associated with fraction isolation. The plant can be fractionated into fiber types and each type is utilized for different composites.

3. DESIGN FEATURES OF NOVEL DISC-MILL

As mentioned above, there are different ways of extracting natural fibers; each method has some pros and cons. The design of the extracting machine should be nature friendly, less cost, easily operated, processed with time consuming. The design to be discussed is a mechanical decorticator extractor, which is hand-operated.

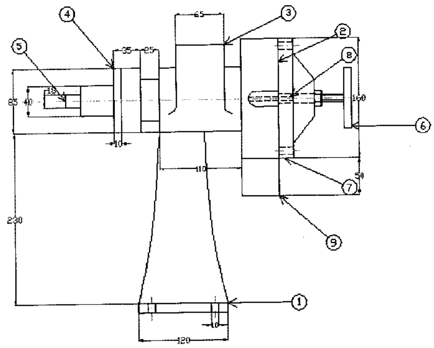
In order to carry out any kind of crushing or grinding operations, mills are commonly used. The commonly used mills are; Hammer mill, ball mill, disc mill. Hammer mill, consists a steel drum containing a vertical or horizontal cross shaped rotor on which pivoting hammers are mounted. The hammers are free to swing on the heads of the cross. And the materials are impacted by the hammers on the ends of the rotating cross. Ball mills are commonly used in extraction of fibers [16].

The design that implemented is disc mill, which involves two discs spinning against each other and crushing substances caught between them.

3.1. Features of Novel Disc–mill design

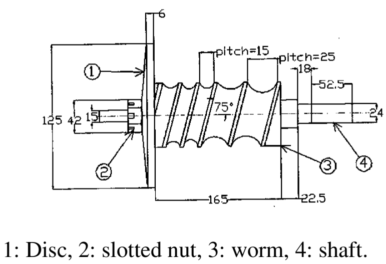
The various parts of the fabricated disc mill design are grooved disk, worm, lid, shaft, bearing, sprockets, chain drive, hand operated lever, casing, and gap-adjustment screw as shown in Figure 6.

The casing was attached with a shaft and a bearing. The disc chosen for this is of 5 inch diameter, which was ideal for opening at the other end of the casing. One of the disc is attached to the inside of



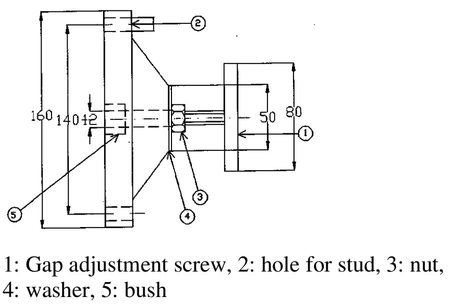
1: Base, 2: disc housing,3: opening for feed, 4:bearing housing, 5: shaft, 6: adjustment screw,7: lid, 8: hole for stud, 9:feed output

Figure 6. Front view of the disk mill casing with lid.



1: Disc, 2: slotted nut, 3: worm, 4: shaft.

Figure 7. Diagram of Worm with key.



1: Gap adjustment screw, 2: hole for stud, 3: nut, 4: washer, 5: bush

Figure 8. Diagram of Lid with key.

casing through a nut and bolt fastener. The second disc is kept movable and detachable. The feed is achieved through the worm. The worm, through its helical grooves, brings the feed to the discs for the rubbing action that removes the surface from the husk thus extracting the fiber.

A hole is drilled in to the second disc, into which this worm was inserted. The inserted worm was secured through a castle nut since it locks the position of the worm through a cotter pin as shown in Figure 7. A certain part of the worm extends outside the castle nut in the form of a shaft. A spring is placed around the latter part of the worm. This spring provides the clearance between the two discs and when the disc is pushed back, it acts against the action of this spring.

An opening was made in the centre of the fixed disc to accommodate the worm, which is attached to the movable disc. The gap between the discs is kept flexible by means of an adjustment screw as shown in Figure 8. The lid is attached to the adjustment screw that helps to change the gap between the discs, and to the casing by means of two wing nuts.

A sprocket-chain system is devised to drive this assembly. The sprockets are attached by means of a chain and the larger sprocket is driven by a handle which is manually rotated.

3.2. Advantages of the novel disc mill

The advantages of the current design are low cost and it is operated manually, particularly suited for the rural areas and it is free from power supply. (i) Continuous rubbing action between the discs which obviates the need for high rpm, (ii) all parts are detached and the machine is portable, (iii) The 1:3 transmissions through the sprocket-chain drive make the machine easier to operate, (iv) Due to low rpm requirement of the system, human effort is also considerably reduced.

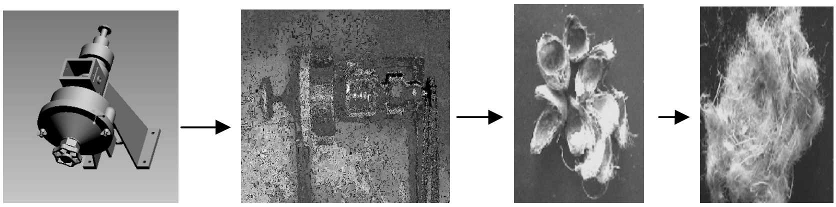


Figure 9. Extracting Areca fibers from the Disc — mill extractor.

3.3. Novel decorticator for extracting natural fiber

The disc mill is initially designed for extracting the fibers from areca husks as shown in Figure 9. With some modification features the mill can be used to extract other natural fibers. These areca husks should be soaked in water for about 2 days. The soaking process loosens the fibers and it can be extracted easily from the disc mill extractor. After extracting it has to be blown through a filter of cyclone separators to remove dust and pith from fibers. Finally the fibers are washed again with fresh water and dried.

3.4. Eco and sustainable development method

Economic growth activities from agriculture to manufacturing must allow the continued production of a commodity without damaging the eco-system. The method adopted must meet the present generations without compromising the ability of future generations. The environmental impact of a product depends on all the life cycle stages of the product. Life cycle assessment is the commonly accepted methodology to systematically test the environmental impact of the product material.

4. CONCLUSIONS

Green fibers are the wave for the future; it has the potential in replacing the man-made fibers. The design of disc mill is more suited to manual operation than a hammer mill. For the future, the mill design can be made smaller and a handle can be provided directly instead of its connection to the sprocket-chain drive. The gap between the discs can be worked out for a further new look. Changes can be done for the existing one for having an electrically driven motor to extract the fiber. Mechanical way of extraction fibers holds good for some aspects but need not follow for all type of fibers. The future generation should be focused on the eco, green, bio, natural fibers for the composite materials world.

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