MECHANICAL AND PHYSICAL PROPERTIES OF KENAF FIBRE REINFORCED THERMOPLASTIC ELASTOMER COMPOSITES

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ABSTRACT

This research was conducted to study the physical properties, mechanical properties and scanning electron microscope studies of reinforced kenaf fibre with TPE. Generally, the tensile and flexural properties of kenaf reinforced composites, vary depending on the type of fibre, its orientation (random or unidirectional), content and form (fibre or fabric), and the type of blending/plasticizer used. The kenaf fibre reinforced TPE composite developed by using the twin screw extruder with 200 °C and 50 rpm. The experiment for tensile strength, flexural strength, moisture content and water absorption test were conducted according to ASTM D638, ASTM D790, ASTM D1348, and ASTM D5229 respectively. The 30% of kenaf mixture exhibit highest mechanical properties where it has 31 GPa modulus of elasticity, 32 MPa of tensile strength, and 47 MPa of flexural strength. The 30% of kenaf mixture contain moisture of content 4.99%, absorbs 2.99% of water before heat treated, and 1.03% of water after heat treated.
ABSTRAK

Kajian ini telah dijalankan untuk mengkaji ciri-ciri fizikal, mekanikal dan kajian microscope electron, kenaf fibre yang dicampur dengan TPE. Secara umumnya, tegangan dan sifat-sifat lenturan kenaf bertetulang komposit, berbeza-beza mengikut jenis serat, orientasi (rawak atau satu arah), kandungan dan bentuk (gentian atau kain), dan jenis campuran / plasticizer digunakan. Gentian kenaf bertetulang TPE komposit dibangunkan dengan menggunakan skru extruder berkembar dengan 200 C dan 50 rpm. Eksperimen untuk ketegangan, kelenturan, kandungan lembapan, dan penyerepan air dijalankan dengan mengikuti standard ASTM D638, ASTM D790, ASTM D1348, dan ASTM D5229. Kajian SEM dialankan untuk mengkaji struktur campuran kenaf fibre dan TPE. Campuran 30% kenaf dan TPE menunjukkan ciri-cirimekanikal yang tinggi dimana ia mempunyai 31 GPa modulus keanjalan, 32 MPa kekuatan ketegangan, dan 47 MPa kekuatan kelenturan. Campuran 30% kenaf dan TPE mempunyai kandungan lembapan sebanyak 4.99%, menyerap 2.99% air sebelum dirawat dengan haba, dan 1.03% air selepas dirawat haba.
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LIST OF SYMBOLS

\( mc \)  Moisture content  
\( wa \)  Water absorption  
\( w_i \)  Initial weight  
\( w_f \)  Final weight  
\( E \)  Modulus of elasticity

LIST OF ABBREVIATION

ABS  Acrylonitrile Butadiene Styrene  
EFB  Empty Fruit Bunch  
EVA  Ethyl Vinyl Acetate  
GMT  Glass Mat Thermoplastic  
HAC  Honeycomb Air Cushion  
MAPP  Maleated Polypropylene  
NAOH  Natrium Hidroxide  
PLA  Polylactic Acid  
PP  Polypropylene  
SMC  Sheet Molding Compound  
TPE  Thermo Plastic Elastomer  
TPU  Thermo Plastic Poly Urethane
CHAPTER 1

INTRODUCTION

In this chapter the issues related to natural fibres, the potential of natural fibres, advantages over synthetic fibres and the usage of natural fibres in industrial application are discussed. In addition, the availability of natural fibres in Malaysia, and the reinforcement of natural fibres are described. The potential of natural fibres to substitute the present synthetic fibres are discussed in general. Finally, the problem statement, objectives and scope of the study are presented.

1.1 BACKGROUND

Malaysia is rich with natural fibres such as kenaf, palm oil fruit, pineapple and coconut fibre. Million tons of these fibres had been produced and these fibres can be transforming to useful materials. Composite manufacturing industries have been looking for plant based natural fibre reinforcements, such as flax, hemp, jute, sisal, kenaf, banana as an alternative material which in order to replace solid wood. Natural fibres have the advantage that they are renewable resources and have marketing appeal. Natural fibre reinforced polymer composites have been used for many applications such as automotive components, aerospace parts, sporting goods and building industry (Rowell, 2008).

Natural fibres have been used as reinforcing materials for over 3000 years, in combination with polymeric materials. In the course of nature life, composite materials were subjected to both mechanical loading and exposed to severe environmental conditions. The natural fibre reinforced composite are lightweight and free from health hazard, reasonably strong, and hence it’s have the potential to be used as material for strong components such as building materials, shipping, and automotive. Despite the advantages, they suffer from some limitations such as poor moisture resistance especially absorption and low strength compared to synthetic fibre such as glass (Abdul Khalil et.al., 2009).
Humans have continued to domesticate the natural fibres crops over time and extensively developed through breeding and selection according to societies’ needs and values. The availability of natural fibres in worldwide is the cause for the new polymer science and engineering research and the search for sustainable technology. The study of fibre reinforced plastics began in 1908 with cellulose material in phenolics, later extending to urea and melamine and reaching commodity status with glass fibre reinforced plastics. Cotton–polymer composites are reported to be the first fibre reinforced plastics used by the military for radar aircraft (Lubin, 1982; Piggot, 1980). One of the earliest examples (1950) was the East German Trabant car, the frame was constructed from polyester reinforced with cotton fibres. As a consequence, a balance in cost and performance could be achieved through proper material design (John & Thomas, 2008).

The strength of the fibre reinforced composites is dependent on the properties of fibre, the aspect ratio of fibre content, length of individual fibre, orientation of fibre, extent of intermingling of fibres, fibre to matrix interface bonding and arrangement of both the fibres and also on failure strain of individual fibres. Maximum results are obtained when the fibres are highly strain compatible (Sreekala, George, Kumaran, & Thomas, 2002).

1.2 PROBLEM STATEMENT

The most crucial problems of current plastic materials are heavy in weight, non-biodegradable and expensive. Although natural fibres have similar properties to the synthetic fibres there are still several other challenges presented by natural fibres. Such as large variability of mechanical properties, lower ultimate strength, lower elongation, problems with nozzle flow in injection molding machines, and poor resistance to weathering. The major challenge is the water absorption of natural fibres.
1.3 OBJECTIVES OF THE STUDY

The objectives of research are as follows;

(i) To develop kenaf fibre composite.
   - Kenaf fibre mixed with TPE.
   - Kenaf fiber extruded with TPE using twin screw extruder.

(ii) To investigate mechanical properties of kenaf fibre composite.
    - Tensile strength of the kenaf fibre composite.
    - Flexural strength of the kenaf fibre composite.

(iii) To investigate physical properties of kenaf fibre composite.
     - Moisture content of the kenaf fibre composite.
     - Water absorption of the kenaf fibre composite.

1.4 SCOPE OF THE STUDY

The scope of this study is to develop a reinforced kenaf fiber composite. Then conduct investigation on the mechanical and physical properties of kenaf fibre composite. Finally, conduct studies on the SEM of the composite. The experiments were conducted in Gambang and Pekan, Pahang. The research scopes are as follows:

(i) Mechanical properties study in terms of tensile strength, and flexural strength.
(ii) Physical properties study in terms of the water absorption and moisture content.
(iii) Scanning electron microscopy studies on the reinforced kenaf fibre composite.

1.5 THESIS OUTLINE

The first chapter of the thesis presents the introduction part. In the introduction part the background and availability of natural fibres in Malaysia, fundamentals on natural fibres are described. Next, natural fibres potential to be used as alternative in
industries are discussed in general. The objectives and scope of the study are presented in the first chapter.

The second chapter covers the reviews of literature that have been extracted from journals, books and web site which is relevant to the scopes desired in this study. The development on natural fibres and reinforced fibres are discussed. The reviews on performance of natural fibres as an alternative are discussed. The reviews on previous research on using natural fibres as an alternative provide the desired findings and rational of the study, methodology and theoretical background.

The third chapter presents the methodology of the research. In this chapter the methods of kenaf fibre preparation are covered. In addition, testing methods and the instruments used for experiment of kenaf fibre and reinforced composite of kenaf and thermoplastic elastomer are described. The procedures applied for the selection of kenaf fibre also explained in detail. Lastly, the experiments design used for the planning of the experimental runs and for analyzing of experimental results are presented.

The fourth chapter of the thesis covers the results and discussion part. The first four sections focus on the characterization results of kenaf fibre and TPE’s properties evaluation. The remaining sections focus on results obtained from several of experiments. The comparison of the present results and the results reported in the literature which were obtained from other investigators are also presented. Lastly, the fifth chapter covers the conclusion, recommendations for future work and significance of the research to local community, manufacturer and future researcher.
CHAPTER 2

LITERATURE REVIEW

In this chapter type, mechanical properties, physical properties, advantages, and application of natural fibres are reviewed. Next, the potential of reinforced natural fibres in industrial application is reviewed. A detailed review is done on the kenaf fibre composites which are in line with the scope of this research. Lastly, the physical properties and mechanical properties of kenaf fibre composites reviewed as it is mainly investigated in this research.

2.1 NATURAL FIBRES AND CLASSIFICATION

Natural fibres have attracted the attention of scientists and technologists because of the advantages that these fibres provide over conventional materials. These natural fibres are low-cost fibres with low density and high specific properties. Unlike other materials they are biodegradable, nonabrasive and readily available. The tendency to form aggregates during processing and poor resistance to moisture is the factor that becomes a barrier for the natural fibres to be used commercially in manufacturing sector. Natural fibres are low cost, recyclable, low density and eco-friendly material. Their tensile properties are very good. The utilization of natural fibres in industrial application provides challenges for researcher to development suitable techniques to obtain good quality fibres for use as reinforcement for polymer composites (Wambua et. al., 2003).

2.1.1 Kenaf Fibre

Kenaf is known as Hibiscus cannabinus L has a cellulosic source with both economic and ecological advantages. It is a warm season annual fibre crop closely related to cotton and jute. Kenaf has been used as a cordage crop to produce twine, rope and sackcloth. Kenaf has good mechanical properties and can grow quickly as it takes only 150 days to harvest. The kenaf comprises 35-40% bast fibre and 60-65% core
fibres by weight of the kenaf’s stalk. Kenaf contains approximately 65.7% cellulose, 21.6% lignin and pectin and other composition. It could grow under wide range of weather condition, to a height of more than 3m and a base diameter of 3-5cm. Kenaf has a single, straight, unbranched stem consisting of two parts, namely outer fibrous bark and inner woody core (Mohanty et. al., 2002).

Nowadays, there are various new applications for kenaf including paper products, building materials, absorbents and animal feeds. In Malaysia, realizing the diverse possibilities of commercially exploitable derived products from kenaf, the National Kenaf Research and Development Program has been formed in an effort to develop kenaf as a possible new industrial crop for Malaysia. The government has allocated RM12 million for research and further development of the kenaf-based industry under the 9th Malaysia Plan (2006–2010) in recognition of kenaf as a commercially viable crop (Salleh et. al., 2012).

Whole stalk kenaf can also be used in corrugated medium. The whole stalk plant material can also be used in non-pulping products such as building materials such as particleboard and within injection molded and extruded plastics. Unlike the pulping process with whole stalk plant material which yields fewer than 46% by weight, the use of non-pulped whole stalk material yields nearly 100% usable materials. The difference is the result of the intentional removal of non-fibrous materials such as lignins and sugars during the pulping process, whereas the removal of these intercellular materials is not required for the non-pulped products (Anuar and Zuraida, 2011).

When bast material is mechanically pull out from the core, it was chemically pulped without the core, it produce a 57% yield of bast fibre. On a whole stalk dry weight basis, the bast comprises 17.4% to 28.6%. The individual bast fibres are up to 5.0 mm long averaging 2.6 mm in length and 20 mm in width. Chemical bast pulp is well suited for specialty papers, such as high quality stationery or filter paper. Bast pulp, compared to softwood pulp, has a similar tensile strength, but greater tear strength and bulk fibre, thus it could serve as a replacement for softwood pulp. Pulping kenaf bast and core fibres can benefit the environment because the process requires fewer
chemicals and less energy compared to standard pulping processes for wood fibres (Nishino et. al., 2003).

The kenaf fibres can also serve as a virgin fibre for increasing recycled paper quality and paper strength. Although the kenaf bast fibre strands were once only considered for use as a cordage fibre in such products as rope, twine, carpet backing and burlap. A variety of additional uses has developed for the bast fibre strands. These include use in automobile dashboards, carpet padding, corrugated medium as a substitute for fibreglass and other synthetic fibres, textiles and as fibres for injection moulded and extruded plastics. Kenaf bast fibre strands are presently in commercial use in other environmentally friendly products such as fibre lawn mats impregnated with grass seed and spray on soil mulches for use along highway rights of way or construction sites to prevent soil erosion from water and wind (Karimi et. al., 2014).

Chemical pulping of the woody core will yield about 41% core fibre from the original woody portion of a kenaf stalk. The core fibres make up from 20% to 40% of the entire stalk by weight. The core pulp, compared to hardwood pulps, has lower tear strength but greater tensile and burst strength. Due to the high absorbency of the woody core material, researchers have investigated the use of kenaf as an absorbent, as a poultry litter and animal bedding, as a bulking agent form sewage sludge composting and as a potting soil amendment. In addition to the above core products, which are all now available in the market place, several kenaf core products are available which are successfully used for toxic waste clean-up, oil spills on water and the remediation of chemically contaminated soils (Abdul Khalil et. al., 2010).

The stock of kenaf can be used almost entirely. Kenaf leaves and stems have a potential as livestock feed. Dried leaves contain 30% crude protein and are used as vegetables in some part of the world (Ochi, 2008). In recent years, with increasing concerns for environmental protection, kenaf has found more applications. The breakthroughs and advances in environmental technology have resulted from intensive testing and research in the kenaf industry. Kenaf fibre/plastic compounds based on kenaf can replace glass reinforced plastics in many applications such as automotive industry, construction and housing industry, food packaging industry, oil and chemical
absorbents, animal bedding and poultry litter, and soil free potting mix. The compounds have the mechanical and strength characteristics of glass filled plastics but are less expensive and in many instances are completely recyclable (Ochi, 2008).

The Automotive Industry

The 1996 Ford Mondeo which sold abroad features interior automobile panels made of kenaf fibre. Kenaf international supplies the fibre, which is processed by the supplier to Ford. The company expects that sales to European automobile manufacturers will steadily increase as the industry becomes comfortable with the product and the kenaf products from automotive group are capable of meeting required demand (Fuqua et. al., 2012).

Construction and Housing Industry

Kenaf/plastic compounds molded into lightweight panels can replace wood and wood based products in many applications. This product has the potential to be the first economically priced plastic lumber that can be engineered for use as building materials in housing industry. In some cases, emphasis has centered in the utilization of core of the plant. Kenaf core has been used as packaging material, animal bedding, oil absorbents and poultry litter (Akil et. al., 2011).

Food Packaging Industry

Pellets made from a kenaf/plastic compound can be molded into commercial food storage containers and virtually any other product now made of plastic. Non-food related packaging opportunities are also numerous including bulk chemical and pharmaceutical packaging, parts packaging in the electrical and electronics industries and disposable packaging for large consumer appliances. In every instance, fibre composites have distinct technical and pricing advantages over plywood and cardboard and are recyclable as well (Karimi et. al., 2014).
Oil & Chemical Absorbents

The core of kenaf fibre is very absorbent and one of its main uses is to clean up oil spills and similar chemicals. The kenaf fibre product is also non-toxic, non-abrasive and is more effective than traditional remediants like clay and silica. This product is distributed for use in oil fields but the product also absorbs gasoline, diesel, transmission fluid and coolant spills. In addition to use by individuals for personal garages, bulk applications include clean-up operations in refineries, utility companies, land and sea spills, oil rigs, industries that handle bulk storage terminals and for military field refuelling applications (Fuqua et. al., 2012).

Animal Bedding and Poultry Litter

Kenaf bedding is sold in bags to farm and ranch supply stores and in bulk to large buyers such as stables, zoos and poultry farms. This product has superior absorbency, requires fewer changes, is cost competitive with most traditional litter and bedding products comprised of wood shavings, saw dust or shredded paper (Coetzee et. al., 2007).

Soil free Potting Mix

This product competes with commercial potting soils and can also be custom mixed for different horticultural applications. Kenaf has a long term supply arrangement with a nursery products wholesale business. The products are blended and mix with peat moss, compete with commercial mixes containing mostly peat moss or pine bark (Akil et. al., 2011).

2.1.2 Hemp Fibre

Hemp (Cannabis sativa L.) is a fibrous plant, grown in many countries such as China, France, Chile, Russia, Turkey, United States and Canada. The cultivation of hemp is restricted by licensing in most of the countries due to its similarity with marijuana, which belongs to the same Cannabis family. Industrial hemp contains only
0.3–1.5% of tetra-hydro-cannabinol (THC), but marijuana contains about 5–10% of THC, which is the reason why it is used as a psychoactive drug or medicine (Wayne and Wendy, 2000). Hemp has a lot of potential applications in various areas like apparel industries, paper industries and in bio-composites (Ouajai and Shanks, 2005).

The stem is used for fibre, while the seeds used for oil, and leaves and flowers for drugs. The stalks grow 5-7 m tall and 6-16 mm thick. The hollow stems, smooth until the rough foliage at the top, are hand cut and spread on the ground for dew retting for the highest quality product. Water retting is used on sun-dried bundles from which the seeds and leaves have been removed. Strands of hemp fibre can be 2 m in length. The fibres are graded for color, luster, spinning quality, density, cleanliness and strength (Mutje et al., 2006).

The hemp fibres suitable for composites are the primary- and secondary fibres situated in the cortex of the hemp plant stem. The bast fibres encircle the core xylem and originate from the procambium and correspond to sclerenchyma primary cells (Crônier et al., 2005). Their morphological features differ significantly from those of xylem fibres. In addition, the morphology and chemical composition of bast fibres vary with maturity (Charlet et al., 2007, Duval et al., 2011 and Mediavilla et al., 2001). This results in large variations in the mechanical properties of the fibres (Placet et al., 2012), and these variations are generally considered a major barrier for using hemp fibres in composites where high reliability and stability of fibre properties are required.

The main chemical components of hemp fibre cell walls are cellulose, hemicelluloses, lignin and pectin and the fibres are bound together by a pectin and lignin-rich middle lamella (ML) (Love et al., 1994 and Nykter et al., 2008). For high-grade composites, the ML-fibre-fibre bonding are degraded to obtain individual fibres and/or small fibre bundles. Therefore to increase the ease of fibre extraction from plants and reduce fibre breakage, the stems are normally retted before mechanical separation (termed “decortication”). The retting stage is critical for the broad use of hemp fibres with respect to economic aspects and fibre quality (Keller et al., 2001 and Mediavilla et al., 2001).
Hemp contains secondary bast fibres situated outside the vascular cambium. These secondary fibres are shorter (approx. 2 mm long) and thinner (approx. 15 μm in diameter) than primary fibres (i.e., tenths of mm in length and 18–24 μm in diameter) (Mishra, 2009 and Sankari, 2000). According to Amaducci et al. (2008), these secondary fibres are primarily located at the bottom of the plant stem. Their formation has been reported to cause a reduction in both fibre yield and quality after flowering (Mediavilla et al., 2001). Thus, the mechanical properties of hemp fibres are dependent on many parameters such as fibre diameter, defects, chemical composition, and the presence/proportion of secondary fibres.

Hemp is used for many varieties of products including the manufacture of cordage varying tensile strength, durable clothing and nutritional products. The bast fibres can be used in 100% hemp products, but are commonly blended with other organic fibres such as flax, cotton or silk, for apparel and furnishings, most commonly at a 55%/45% hemp/cotton blend. The inner two fibres of hemp are woodier and are more often used in non-woven items and other industrial applications, such as mulch, animal bedding and litter. The oil from the fruits oxidizes (commonly, though inaccurately, called "drying") to become solid on exposure to air, similar to linseed oil, and is sometimes used in the manufacture of oil-based paints, in creams as a moisturizing agent, for cooking, and in plastics. Hemp seeds have been used in bird feed mix as well (Ranalli and Venturi, 2004).

Hemp used for industrial purpose such as paper, textiles, clothing, biodegradable plastics, and construction. In a new development hemp is being processed relatively inexpensively into electrodes possibly even more efficient than graphene for use in super capacitors.

2.1.3 Pineapple Leaf Fibre

Pineapple is one of the plants available in Tropical countries. Pineapple leaf fibre is a waste product of pineapple cultivation. So, pineapple fibres could be obtained easily without any cost input. Pineapple leaf fibre has some of the highest mechanical properties, such as tensile strength and flexural strength among natural fibres. It is
known as textile materials in many countries. These fibres are multicellular and lignocellulosic. They are extracted from the leaves of the plant Ananus Cosomus belonging to the Bromeliaceae family by retting (Akil et al., 2010).

Pineapple leaf fibre is a high textile grade commercial fibre, generally extracted by water retting. Pineapple leaf contains only 2.5-3.5% fibre, covered by a hydrophobic waxy layer, which remains beneath the waxy layer. Pineapple leaf fibre is graded in between jute and cotton or jute and ramie. It has all textile properties and capable of blending with jute, cotton, ramie, and some other synthetic fibres. So pineapple leaf fibre can capture an important position among natural fibres as potential commercial grade textile fibre, but there is need of its assured supply to processing industry in sufficient quantities (Huda et al., 2008).

Pineapple leaf fibre (PALF) is an important natural fibre that exhibits high specific strength and stiffness. The fibres have a ribbon-like structure and consist of a vascular bundle system present in the form of bunches of fibrous cells, which are obtained after mechanical removal of all the epidermal tissues. PALF is of fine quality and its structure is without mesh. The fibre is very hygroscopic, relatively inexpensive and abundantly available. The superior mechanical properties of PALF are associated with its high cellulose content and comparatively low microfibrillar angle (14°). Due to the unique properties exhibited by pineapple leaf fibre (PALF) they can be used as excellent potential reinforcement in composite matrices (Lopattananon et al., 2006).

PALF is being examined with a view to replace glass fibre in low priced products, especially building materials. Profound research has to be done to discover the potential applications of pineapple leaf fibres in high performance polymer composites. Among various natural fibres, pineapple leaf fibres exhibit excellent mechanical properties. These fibres are multi cellular and ligno cellulosic. They are extracted from the leaves of the plant Ananus cosomus belonging to the Bromeliaceae family by retting. The main chemical constituents of pineapple fibres are cellulose (70–82%), lignin (5–12%) and ash (1.1%) (Bledzki and Gassan, 1999). The superior mechanical properties, such as tensile strength of pineapple leaf fibres are associated with their high cellulose content (Bledzki et al., 1996).
As fibre-reinforced composite structures are taking the central stage in almost every sphere of material science, lingo cellulosic natural fibres like pineapple fibres (PALF) come as viable and abundant substitutes for the expensive and non-renewable synthetic fibres. These with high specific strength improved the tensile strength and flexural strength of the polymer matrix such as polypropylene and polyester (Huda, et. al., 2008). In tropical countries, fibrous plants are available in abundance and at least some of them are agricultural crops. Pineapple is among them. PALF at present is a waste product of pineapple cultivation. Hence, without any additional cost input, pineapple fibres can be obtained for industrial purposes (Bledzki et. al., 2006).

2.1.4 Banana Leaf Fibre

Banana plant not only gives the delicious fruit but also provides textile fibre, the banana fibre. It grows easily as it sets out young shoots and is most commonly found in hot tropical climates. All varieties of banana plants have fibres in abundance. These fibres are obtained after the fruit is harvested and fall in the group of bast fibres. This plant has long been a good source for high quality textiles in many parts of the world, especially in Japan and Nepal (Mohanty et. al., 2004).

Bast fibres, like banana, are complex in structure. They are generally lignocellulosic, consisting of helically wound cellulose microfibrils in amorphous matrix of lignin and hemicellulose. The cellulose content serves as a deciding factor for mechanical properties along with microfibril angle. A high cellulose content and low microfibril angle impart desirable mechanical properties for bast fibres. The removal of heavily coated, non-cellulosic gummy material from the cellulosic part of the plant fibres is called degumming (Samal et. al., 2009a).

Banana fibres are obtained from the stem of banana plant (Musa sapientum). Banana fibres can be extracted by utilizing mechanical, chemical or biological methods. Mechanical method does not remove the gummy material from the fibre bundle surface while chemical method causes pollution to the environment. Biological method is most
appropriate because it could produce more fibre bundles than other two methods while being environmental friendly (Jannah et.al., 2009).

The essentially hand driven process of extracting banana fibre is now set to change with the invention of the Banana Fibre Separator Machine. The machine has been developed in India by Tiruchirappalli Regional Engineering College - Science & Technology Entrepreneurs Park (TREC-STEP). One more interesting fact associated with the development of this machine is that it uses the agriculture waste of banana harvests to produce silk grade fibre. These silk grade fibres are of immense help to the handicrafts and textile industry (Murali et. al., 2010).

2.1.5 Sisal Fibre

Sisal fibre is one of the most widely used natural fibre and is very easily cultivated. It is obtained from sisal plant (Agave sisalana). Each leaf contains a number of long, straight fibres which can be removed in a process known as decortication. During decortication, the leaves are beaten to remove the pulp and plant material, leaving the tough fibres behind. Sisal Fibre is exceptionally durable with a low maintenance with minimal wear and tear. Sisal fibres are obtained from the outer leaf skin, removing the inner pulp. Sisal fibres does not attract or trap dust particles and does not absorb moisture or water easily. It exhibits good sound and impact absorbing properties (Koradiya et. al., 2010).

The sisal plant has a 7-10 year life-span (longer in Mexico where growth is slower) and is usually cut first after 2-3 years and then at 6-12 month intervals. A typical plant will produce 200-250 commercially usable leaves in its life-time (hybrid varieties up to 400-450 leaves) and each leaf contains an average of around 1000 fibres. In East Africa, where sisal is produced on an estate basis, the leaves are in the main transported to a central decortication plant after which the fibre is dried, brushed and baled - for export or for use in the domestic mills. In Brazil it is mainly grown by small-holders and the fibre is extracted by teams using portable raspadors. The fibre element, which accounts for only about 4% of the plant by weight, is extracted by a process known as decortication (Beladi et. al., 2013).