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SISAL FIBER REINFORCED COMPOSITES BY HOT COMPACTION TECHNIQUE

A PROJECT REPORT

Submitted by

V. ASHOK [71202212003]

M. CHINNUSAMY [71201212008]

R. SRIKANTA [71202212032]

N. VIKNESH [71202212039]

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BONAFIDE CERTIFICATE

Certified that this project report titled "SISAL FIBER REINFORCED COMPOSITES BY HOT COMPACTION TECHNIQUE" is the bonafide work of Mr. V. Ashok [71202212002], Mr. M. Chinnusamy [71201212008], Mr. R. Srikanta [71202212032] & Mr. N. Viknesh [71202212039] who carried out the project under my supervision.

29.4.06

SIGNATURE

Dr. J. Srinivasan

Head of the department

Department of textile technology

Kumaraguru College of Technology

Coimbatore 641 006.

29.4.06

SIGNATURE

Dr. J. Srinivasan

(SUPERVISOR)

Professor

Department of textile technology

Kumaraguru College of Technology

Coimbatore 641 006.

For the viva-voce examination held on: 2/5/06

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EXTERNAL EXAMINER

ABSTRACT

Sisal fiber is a promising reinforcement for use in composites on account of its low cost, low density, high specific strength and modulus, no health risk, easy availability in some countries and renewability. In recent years, there has been an increasing interest in finding new applications for sisal-fiber-reinforced composites that are traditionally used for making ropes, mats, carpets, fancy articles and others.

A composite laminate based on natural sisal fiber and polyolefins was manufactured by compression moulding technique. The mechanical properties of the composite were assessed under tensile, flexural and impact loading. Changes in the stress–strain characteristics, of yield stress, tensile strength, and tensile (Young's) modulus, due to ageing has been analyzed. Optical microscope studies were done to confirm the results behind the changes observed.

Keywords: Sisal, polyolefin, composite, hot press

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

During the past decade, increasing environmental awareness new global agreements, and international governmental policy and regulations have been the driving force behind renewed interest in natural fiber reinforced thermoplastics. The attractiveness of a plant-based fiber as an alternative reinforcement material comes from its high specific strength and stiffness, natural availability, and environmental 'friendliness'.

Though sisal fiber is one of the most widely used natural fibers, a large quantity of this economic and renewable resource is still under-utilized. At present, sisal fiber is mainly used as ropes for the marine and agriculture industry. Other applications of sisal fibers include twines, cords, upholstery, padding and mat making, fishing nets, fancy articles such as purses, wall hangings, table mats, etc. The use of sisal fiber as a reinforcement in composites has raised great interest and expectations amongst materials scientists and engineers.

Natural fibers tend to degrade near the processing temperature of thermoplastics like polyamides and polyesters and thermal degradation during processing limits the number of polymers that can serve as a matrix system and polyolefins remain the choice for experimentation.

CHAPTER 2

LITERATURE REVIEW

Composite materials were principally fabricated using thermosetting matrices. Disadvantages stemming from the use of thermosets include brittleness, lengthy cure cycles and inability to repair and/or recycle damaged or scrapped parts. These disadvantages led to the development of the thermoplastic matrix composite system. Compared with thermosets, composites fabricated from thermoplastic materials typically have a longer shelf life, higher strain to failure, are faster to consolidate and retain the ability to be repaired, reshaped and reused as need arises.

Sisal fiber is one of the most widely used natural fibers and is very easily cultivated. It has short renewal times and grows wild in the hedges of fields and railway tracks [1]. Nearly 4.5 million tons of sisal fibers are produced every year throughout the world. Tanzania and Brazil are the two main producing countries.

Sisal fiber is a hard fiber extracted from the leaves of the sisal plant (Agave Sisalana). Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East [3]. A sketch of a sisal plant is shown in Fig. 2.1 and sisal fibers are extracted from the leaves.

A sisal plant produces about 200-250 leaves and each leaf contains 1000-1200 fiber bundles, which is composed of 4% fiber, 0.75% cuticle, 8% dry matter and 87.25% water [1]. So normally a leaf weighing about 600 g will yield about 3% by weight of fiber with each leaf containing about 1000 fiber.

The sisal leaf contains three types of fiber [3]: mechanical, ribbon and xylem. The mechanical fibers are mostly extracted from the periphery of the leaf. They have a roughly thickened-horseshoe shape and seldom divide during the extraction processes.

They are the most commercially useful of the sisal fiber. Ribbon fiber occurs in association with the conducting tissues in the median line of the leaf.

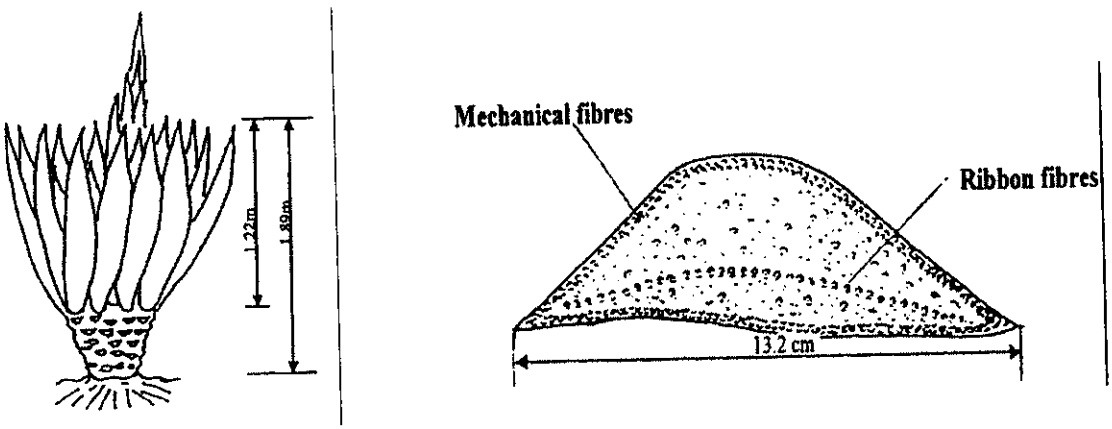


Fig 2.1 A sketch of sisal plant and cross-section of sisal leaf

Fig 2.2 Photograph of sisal plant

Fig 2.1 and 2.2 shows a cross-section of sisal leaf and indicates where mechanical and ribbon fibers are obtained [3]. The related conducting tissue structure of the ribbon fiber gives them considerable mechanical strength. They are the longest fibers and compared with mechanical fibers they can be easily split longitudinally during processing. Xylem fibers have an irregular shape and occur opposite the ribbon fibers through the connection of vascular bundles as shown in Fig. 2. They are composed of thin-walled cells and are therefore easily broken up and lost during the extraction process.

The processing methods for extracting sisal fibers have been described by Chand et al. [2] and Mukherjee and Stayanarayana [1]. The methods include (1) retting followed by scraping and (2) mechanical means using decorticators. It is shown that the mechanical process yields about 2-4% fiber (15 kg per 8 h) with good quality having a lustrous colour while the retting process yields a large quantity of poor quality fibers. After extraction, the fibers are washed thoroughly in plenty of clean water to remove the surplus wastes such as chlorophyll, leaf juices and adhesive solids.

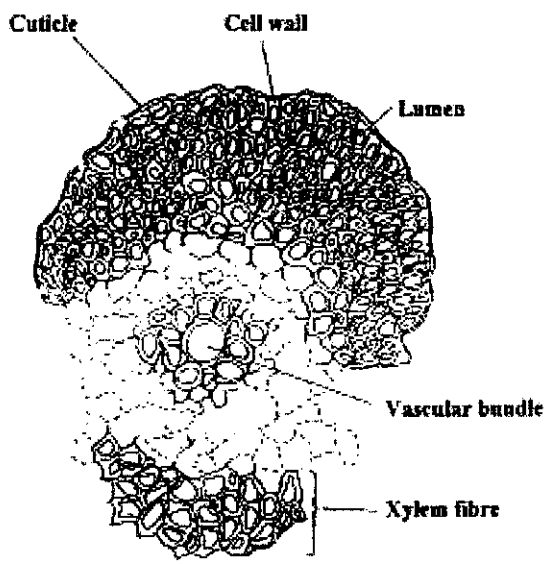


Fig 2.3 Cross section of fiber bundle

The chemical compositions of sisal fibers have been reported by several groups of researchers [4-7]. For example, Wilson [4] indicated that sisal fiber contains 78% cellulose, 8% lignin, 10% hemi-celluloses, 2% waxes and about 1% ash by weight; but Rowell [5] found that sisal contains 43-56% cellulose, 7-9% lignin, 21-24% pentosan and 0.6-1.1% ash. More recently, Joseph et al. [6] reported that sisal contains 85-88% cellulose. These large variations in chemical compositions of sisal fiber are a result of its different source, age, measurement methods, etc.

Indeed, Chand and Hashmi [7] showed that the cellulose and lignin contents of sisal vary from 49.62-60.95 and 3.75-4.40%, respectively, depending on the age of the plant.

The length of sisal fiber is between 1.0 and 1.5 m and the diameter is about 100-300 mm [8]. The fiber is actually a bundle of hollow sub-fibers. Their cell walls are reinforced with spirally oriented cellulose in a hemi-cellulose and lignin matrix. So, the cell wall is a composite structure of lingo cellulosic material reinforced by helical micro fibrillar bands of cellulose. The composition of the external surface of the cell wall is a layer of lignaceous material and waxy substances, which bond the cell to its adjacent neighbours. Hence, this surface will not form a strong bond with a polymer matrix. Also, cellulose is a hydrophilic glucan polymer consisting of a linear chain of 1, 4-b-bonded anhydroglucose units [9] and this large amount of hydroxyl groups will give sisal fiber hydrophilic properties. This will lead to a very poor interface between sisal fiber and the hydrophobic matrix and very poor moisture absorption resistance.

Though sisal fiber is one of the most widely used natural fibers, a large quantity of this economic and renewable resource is still under utilized. At present, sisal fiber is mainly used as ropes for the marine and agriculture industry [1]. Other applications of sisal fibers include twines, cords, upholstery, padding and mat making, fishing nets, fancy articles such as purses, wall hangings, table mats, etc. [10]. A new potential application is for manufacture of corrugated roofing panels that are strong and cheap with good fiber resistance [11].

2.1 PROPERTIES OF SISAL FIBER

2.1.1 Price

Compared to synthetic fibers, the price of sisal fiber (0.36 US$/kg) is very low [3]. It is about one-ninth of that of glass fiber (3.25 US$/kg) and one five hundredth of carbon fiber (500 US$/kg). For specific price (modulus per unit cost), it (41.67 GPakg/$) is almost the best next to jute (43.33 GPakg/$) amongst all the synthetic and cellulosic fibers.

2.1.2. Properties

Generally, the strength and stiffness of plant fibers depend on the cellulose content and the spiral angle, which the bands of micro fibrils in the inner secondary cell wall make with the fiber axis. That is, the structure and properties of natural fibers depend on their source, age, etc. [12]. The tensile properties of sisal fiber are not uniform along its length [3]. The root or lower part has low tensile strength and modulus but high fracture strain. The fiber becomes stronger and stiffer at mid span and the tip has moderate properties.

Table 1 shows the properties of sisal fibers as reported by different researchers. Note that except for the structure and properties of the natural fiber itself, experimental conditions such as fiber length, test speed, etc., all has some effects on the properties of natural fibers [13, 14].

TABLE 2.1.2 Properties of Sisal Fiber

S. No	Density (Kg/m^3)	Moisture content (%)	Tensile strength (Mpa)	Tensile modulus (Gpa)	Diameter (μm)	Elongation (%)	Reference
1.	1450	11	604	9.4-15.8	50-200	-	[14]
2.	1450	11	530-640	9.4-22	50-300	3-7	[2]
3.	1030	11	500-600	16-21	-	3.6-5.1	[28]
4.	1410	11	400-700	9-20	100-300	5-14	[44]
5.	1400	11	450-700	7-13	-	4-9	[43]
6.	1450	11	450-700	7-13	-	4-9	[53]

Mukherjee and Satyanarayana [1] studied the effects of fiber diameter, test length and test speed on the tensile strength, initial modulus and percent elongation at the break of sisal fibers. They concluded that no significant variation of mechanical properties with change in fiber diameter was observed. However, the tensile strength and percent

elongation at the break decrease while Young's modulus increases with fiber length. With increasing speed of testing, Young's modulus and tensile strength both increase but elongation does not show any significant variation. However, at a test speed of 500 mm/min, the tensile strength decreases sharply. These results have been explained in terms of the internal structure of the fiber, such as cell structure, micro fibrillar angle (20-25°), defects, etc. In rapid mechanical testing, the fiber behaves like an elastic body, i.e. the crystalline region shares the major applied load resulting in high values of both modulus and tensile strength. When the testing speed decreases, the applied load will be borne increasingly by the amorphous region. However, at very slow test speeds, the fiber behaves like a viscous liquid. The amorphous regions take up a major portion of the applied load giving a low fiber modulus and a low tensile strength. But at very high strain rates (~500 mm/min), the sudden fall in tensile strength may be a result of the presence of imperfections in the fiber causing immediate failure.

In Ref. [1], the microfibrillar angle and number of strengthening cells in the sisal fibers did not show any appreciable variation in fiber diameter. Hence, no appreciable change in values of Young's modulus and tensile strength were observed. As the test length increases, the number of weak links or imperfections also increases, thus resulting in reduction in tensile strength. However, with increasing fiber length, sisal fibers a higher resistance to applied stress as a result of the involvement of more oriented cellulosic fibers. This probably also accounts for the higher modulus of the fibers at longer test lengths. The reason for such behaviour by the characteristics of natural fiber such as multi-cellular structures, visco-elastic nature and non uniform structural in homogeneity.

Chand et al. [12] reported the effects of testing speed and gauge length on the mechanical properties of other kinds of natural fibers (sun-hemp fibers). Their results support the finding of Ref. [1], though the magnitudes are much lower than those of sisal fibers. (For example, when the gauge length is 50 mm and testing speed is 50 mm/min, the tensile strength of sisal fiber is 759 MPa. However, for sun-hemp fiber, the tensile strength is only 283 MPa.).

The mechanical properties of sisal fibers obtained from different age at three different temperature were investigated by Chand and Hashmi [15]. The tensile strength, modulus and toughness (defined as energy absorption per unit volume) values of sisal fiber decrease with increasing temperature. The relative effect of plant age on these mechanical properties is less prominent at 100°C than at 30°C. This is attributed to the more intense removal of water and/or other volatiles (at 100°C) originally present in the fibers, which otherwise act as plasticizing agents in the chains of the cellulose macromolecules. It is, however, noted that at 80°C both tensile strength and modulus decrease with age of the plant. This trend is different to testing at 100°C. Table 3 shows the results of sisal fibers of different age at different temperature.

For electrical applications, the dielectric properties of sisal fiber at different temperature and frequency have also been studied [16]. Increase of frequency decreases the dielectric constant ? value, while increase of temperature increases ? at all frequencies. Increasing the plant age shifts the dissipation factor (tan d) peak to higher temperature. These phenomena were explained on the basis of structural changes. Water absorbed by sisal fibers has OH^- anions which act as dipoles. Other than OH^- anions, there are several impurities and ions on the fiber. These dipoles and ions contribute to the ? and tan d behaviours of sisal fibers. At low frequencies, high ? and tan d values in sisal fiber are caused by the dipolar contribution of absorbed water molecules. ? values at intermediate frequencies are the result of contributions from space charge polarization. At high frequencies, the contribution of polarization of absorbed water molecules and space charge decreases and electronic and atomic polarization becomes operative. Increase in temperature affects the mobility of ions and consequently changes the ionic contributions.

Yang et al. [17] used IR, X-ray diffraction and TG to study the effect of thermal treatment on the chemical structure and crystallinity of sisal fibers. They concluded that the IR spectrum did not change below 200°C treatment while density and crystallinity increased. This means that the chemical structure of sisal fibers will not change below 200°C while the degree of crystallinity can be increased and hence the density. There was a slight weight loss (~2%) below 200°C probably caused by the evaporation of water

absorbed by sisal fibers, substances of low boiling point and others that can be decomposed below this temperature. However, the large amounts of cellulose, semi-cellulose and glucans were not lost. Also, they found that thermal decomposition of sisal fiber could be divided into three stages. The thermal behaviours are essentially identical for heat treatment between 150 to 200°C. Hence, thermal treatment of sisal fiber can be carried out below 200°C.

TABLE 2.1.2 (a)

Comparisons of mechanical properties of sisal fibers with different age at different temperature [15]

Age of plant	Toughness per unit volume (MJ/m^3)			Tensile strength (Mpa)			Tensile modulus (Gpa)		
	30°c	40°c	50°c	30°c	40°c	50°c	30°c	40°c	50°c
3	4.8	4.9	4.1	452	350	303	26	29	21
5	5.5	7.8	4.3	508	355	300	29	-	22
7	6.0	5.2	4.7	500	300	280	34	22	17
9	7.4	5.4	5.2	581	316	339	37	17.5	21

2.2 DIFFERENT METHODS OF MANUFACTURING COMPOSITES

2.2.1 Hand and Machine Lay-up

This is the simplest way of manufacturing composites; the fiber or fabric layers are placed on a mould with resin applied to successive layers until the desired thickness is reached. A gel coat is applied on the mould for better quality surface. Prepregs are very suitable for hand lay-up techniques to avoid any wet process. Prepregs are yarns and fabrics that are already impregnated or melted with resin. A roller is used to remove the entrapped air, control the thickness, and guarantee good wet out and smooth surface. The curing usually takes place at room temperature or under heat to speed up the process. Usually polyester and epoxy resins are used for hand lay-up.

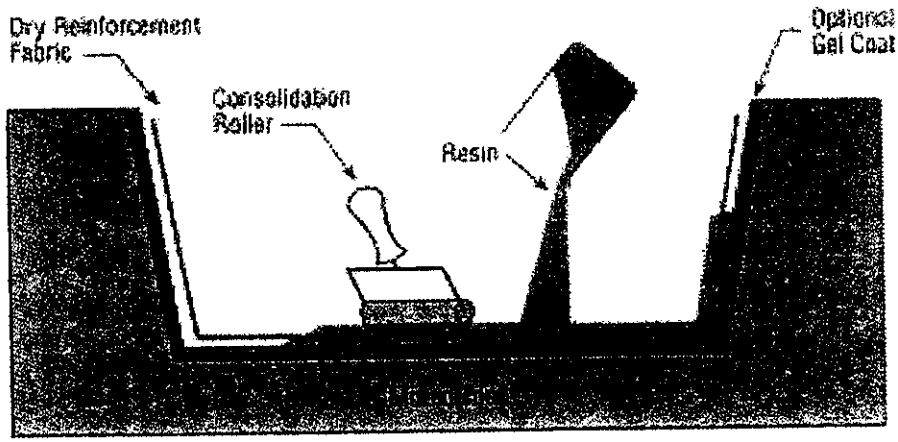


Figure 2.2.1 Hand and Machine Lay-up

Machine lay-up is the automated from the hand lay-up. Computer controlled tape laying machines are used to lay down fiber or fabric. This process provides consistency and increased speed.

2.2.2 Spray-up Moulding

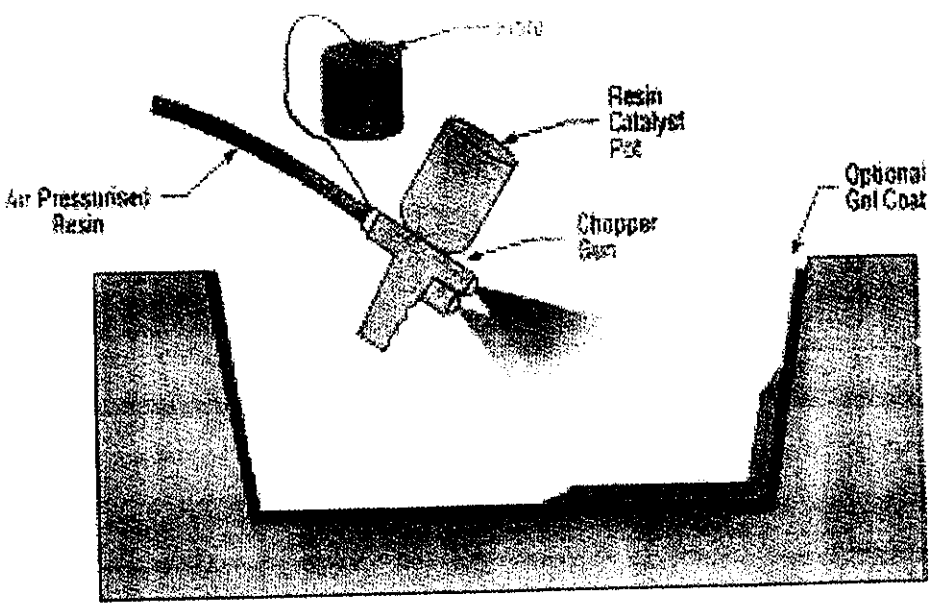


Figure 2.2.2 Spray-up Moulding

Chopped fibers and resins are simultaneously deposited on a mould using spraying equipment. Gel coat is applied by spray gun. Curing takes place at room or elevated temperature. Polyester and epoxy resins are used.

2.2.3 Injection Moulding

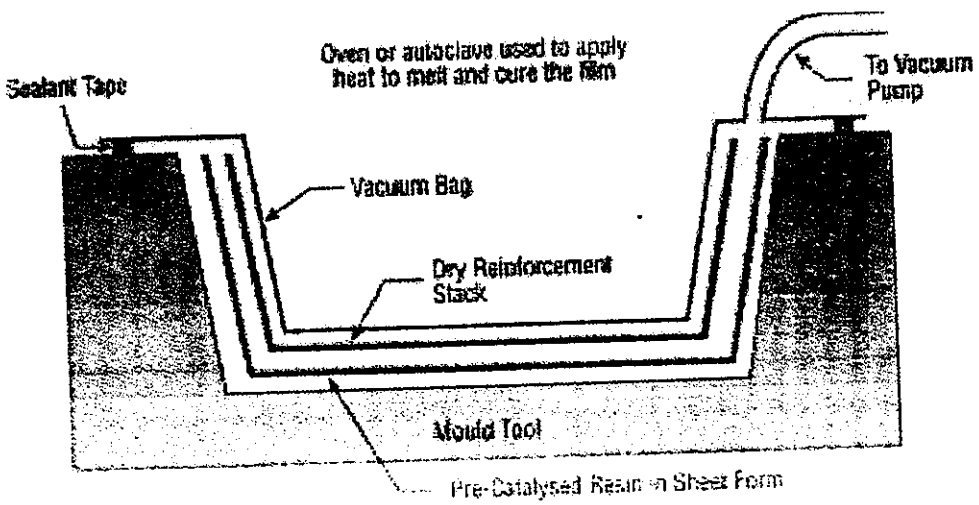


Figure 2.2.3 Injection Moulding

Injection moulding is similar to metal die-casting. It is a high-pressure process to produce thermoplastic and thermo set parts. The matrix is melted and forced in to the mould cavity, where it freezes and is ultimately ejected as a finished part. The injection moulding process permits final part detail and can be easily automated. The part and mould can be designated such that near-net shape parts can be manufactured. There is a limit to the amount and types of fiber reinforcement that can be included in an injection-moulded part. The injection moulding process of thermoplastic and thermo sets is slightly different. In the thermoplastic injection moulding process, molten thermoplastic material is forced through an orifice in to a cold mould where it solidifies. In thermo set injection moulding, a reacting material is forced in to a warm mould where the material further polymerizes or cross-links to a solid part.

2.2.4 Pultrusion Moulding

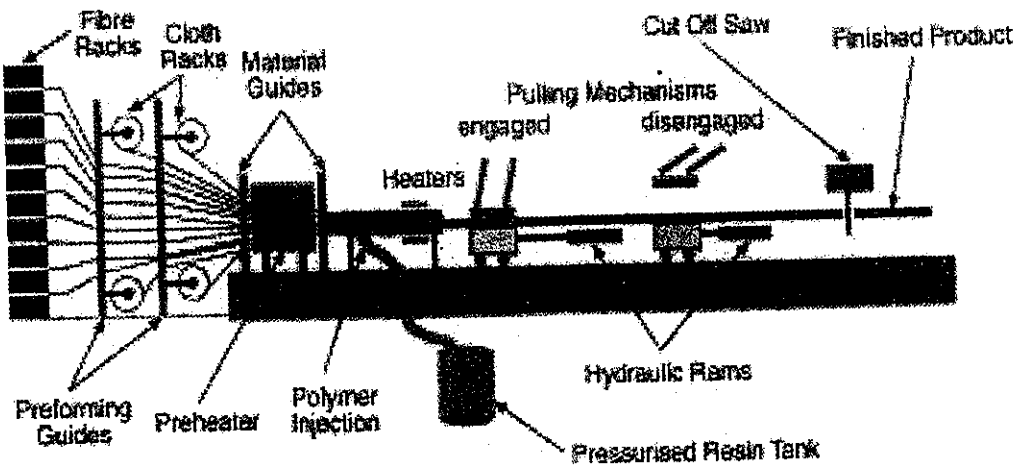


Fig 2.2.4 Pultrusion Moulding

Continuous reinforcement fibers or roving are drawn through a resin bath for impregnation and through a heated die to produce the desired shape and control the resin content in continuous process. Pultrusion is especially suitable for unidirectional reinforcement for simple cross sectional structures such as circular rods, tubes, channel and I beams. Drawing velocity and mould temperature is critical during the process. Polyester and epoxies are commonly used in pultrusion. The resulting composite has excellent mechanical properties due to good fiber alignment and high fiber fraction.

2.2.5 Compression Moulding

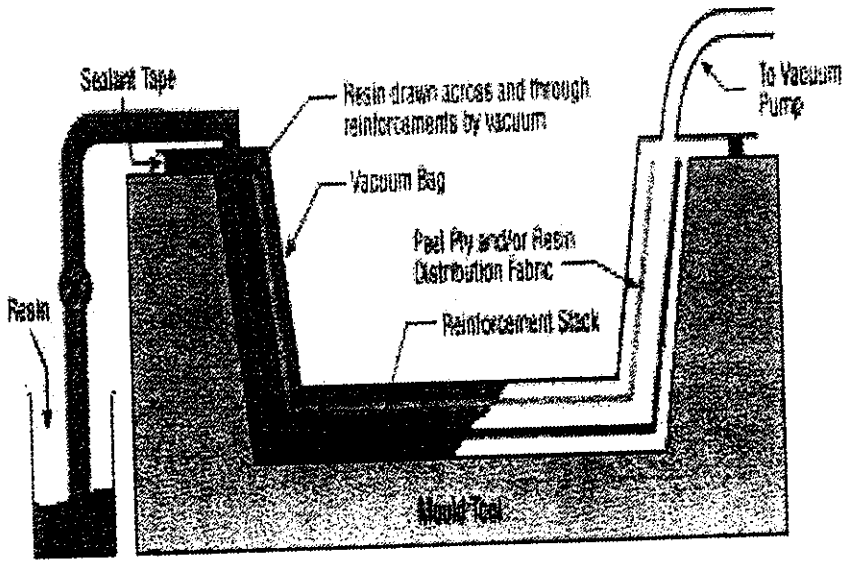


Fig 2.2.5 Compression Moulding

In this method, prepregs or wet impregnated textile performs are placed in to an open mould. The mould is closed and heat and pressure are applied until the structure is formed and cured. Adjusting the final distance between the press platens can control the laminate thickness. Excess resin is usually allowed to escape. Both thermosetting and thermoplastic polymers are suitable for compression moulding. The textile performs can be vacuumed before moulding to eliminate air bubbles in the composite. Compression moulding is especially suitable for manufacturing flat or slightly curved planes or laminates. The advantage of compression moulding includes low cost, little mineral waste with close tolerance, part-to-part uniformity and reproducibility, good control of fiber to resin ratios and void content, and shorter cycle times. The compound can be heavily filled with little orientation of resins or additives.

2.2.6 Resin Transfer Moulding

Resin transfer moulding also called resin injection moulding, is suitable for manufacturing of high fiber volume fraction (up to 70%) composite structures. In the RTM process, the resin system is transferred, at low viscosity and pressure, in to the textile perform already placed in the closed mould. The resin system may consists of resins, curing agents, catalysts, promoters, inhibitors, etc., which may be premixed or mixed during the process using an on-line static mixer.

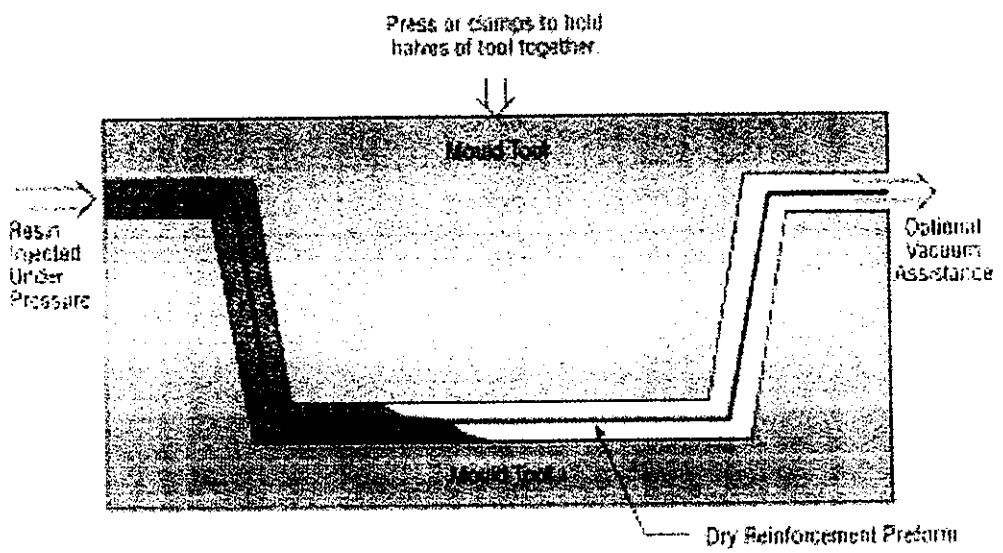


Fig 2.2.6 Resin Transfer Moulding

The resin system is then injected in to the mould. The resin is transferred at the pressure of 20-80 psi and/or with a vacuum in the range of 26-29 inch Hg. For good filling and wetting characteristic, viscosity of the resin should be less than 100 cP at injection temperature. After filling with resin, the mould is sealed and heated for curing. Boron, Kevlar, Glass, Ceramic and graphite textile reinforcement structures are suitable for RTM. Woven, stitched, braided, knit and other performs can be consolidated in the RTM process. Typical resin materials are polyester and epoxy. RTM offers high production rates, more consistent parts, material and labor savings.

2.3 EXPERIMENTAL

2.3.1 Manufacturing composites through film stacking technique

The composites were made by Film stacking is a third technique with which to prepare thermoplastic composites. In this case, fiber tows arranged in sheet form are sandwiched between matrix polymer films. This assembly is then placed within a press where temperature transforms the film into a polymer melt. Pressure is then applied and forces the melt to impregnate the fiber tow. Appropriate process conditions must be used in order to sufficiently reduce the matrix viscosity without thermally degrading the actual composite or de-align the fibrous reinforcement. Insufficient heat input and/or pressure will typically result in unwetted fiber and a high void content within the final material.

2.3.2 Optimisation of temperature, time and pressure

With most thermoplastic composite materials, **temperature** considerably affects the mechanical properties of the composite produced. In addition, the use of thermoplastics introduces the problem of adequate fiber tow penetration. Thermoplastic melts, as opposed to thermosetting resins, have a substantially higher viscosity. Thermoplastic matrices must be able to withstand high temperatures in order to effect a sufficient reduction in viscosity. Thus optimisation of temperature is very important. Bulk resin movement (in order to fill voids, penetrate between unwetted fibers, etc.) favours the use of a high temperature pressing scheme. In contrast, the thermal stability of the materials may favour moderate temperature usage. Therefore, an optimum will exist in which adequate resin flow is manifested during consolidation (i.e., good composite quality) and thermal degradation of the constituents is kept at a minimum.

Time will also be expected to have a similar effect, given that resin flow requires a finite time frame. A high amount of wetting requires an adequate residence time within the press, while the prevention of thermal degradation demands a minimal amount of time in melt consolidation.

Pressure also affects fiber-matrix wetting, given that it is a major driving force in determining resin flow.

2.4 PROPERTIES OF SISAL FIBER REINFORCED COMPOSITES

According to the types of matrices used in sisal-fiber-reinforced composites, they can be divided into the following categories:

- Sisal-fiber-reinforced thermosets
- Sisal-fiber-reinforced thermoplastics
- Sisal-fiber-reinforced rubbers
- Sisal-fiber-reinforced cement and gypsum

2.4.1 Sisal-fiber-reinforced thermoset matrices

The most widely used thermosetting matrix reinforced by natural fibers is polyester [27-30]. Compression moulding is the most widely used and convenient method to make these composites, whether the fiber is long or short. The tensile and impact properties of this kind of composites have been obtained by Sanadi et al. [27].

It is shown that the tensile strength and elastic modulus of the composites containing up to 40% fiber-volume fraction (Vf) increase linearly with Vf in good agreement with the rule of mixtures. The work of fracture, as determined by Izod impact test, also increases linearly with Vf. Analysis of the energy-absorption mechanisms during impact fracture shows that fiber pull-out and interface fracture are the major contributors to the high toughness of these composites. This result indicates that sisal fibers have potential to produce inexpensive materials with high toughness.

Comparison of the impact properties of different natural fiber-reinforced composites, including sisal, pineapple, banana and coir shows that sisal-fiber composites possess the highest impact toughness owing to the optimal micro-fibrillar angle of the fiber (21° for sisal, 12°for banana, 14° for pineapple and 45° for coir). It has been proven by Gordon and Jeronimidis [31] that the toughness of composites increases with the

micro-fibrillar angle of the fibers and reaches a maximum at 15-20°. It will then decrease with increasing angle. The optimal micro-fibrillar angle of sisal fiber (21°) leads to better impact resistance with a work of fracture of 98.7 KJ/m^2 when the fiber-volume fraction is 50%. For the same volume fraction of pineapple fibers, this is 79.5 KJ/m^2; for banana and coir fibers, they are 51.6 and 43.5 KJ/m^2, respectively. When compared to synthetic fiber composites, the specific impact work of fracture for the natural fiber composites is not much worse. The specific work of fracture (i.e. toughness per unit density) of 60% volume fraction sisal fiber/polyester composites is 115 KJ m^{-2}/g, while for ultra-high-modulus polyethylene (UHMPE) and E-glass fibers, these values are 125 and 165 KJ m^{-2}/g, respectively.

Rong et al. studied the effect of fiber pre-treatment and water absorption on the impact properties of sisal fiber reinforced polyester and epoxy matrices [32, 33]. Three fiber-surface treatment methods including alkali treatment, coupling agent treatment and heat treatment were used. They indicated that fiber-surface treatment has a strong effect on the impact behaviour of the composites and the effects are different for different matrices. It is observed that fiber pull-out is the major contributor to the energy absorption. Increased fiber-tensile strength promoted by thermal treatment can increase the impact performance of the composites. Water absorption in sisal fiber composites is mainly caused by the fibers and leads to a very poor interface between the sisal fiber and the matrix. Different matrix systems have different interface characteristics. Generally, water absorption in sisal/polyester composite is two to three times that in sisal/epoxy composite and this leads to their different impact properties. For sisal/epoxy composite, the impact strength improves with water absorption as a result of an acceptable level of interface debonding, but for sisal/polyester composites, the impact strength decreases through the complete destruction of the interface.

From the viewpoint of interface enhancement, Bisanda and Ansell [8] studied the mechanical and physical properties of sisal/epoxy composites and Yang et al. [26] investigated sisal/phenol formaldehyde composites.

2.4.2 Sisal-fiber-reinforced thermoplastics matrices

In recent years, sisal-fiber-reinforced thermoplastics composites have gained much more interest among materials scientists and engineers than thermosets because of their low cost and recyclable properties. Many papers have now been published to study the properties of these composites rather than sisal-fiber-reinforced thermosets. Such properties include mechanical, environmental, electrical and dynamic.

2.4.2.1 Processing methods

The mixing methods so far used are: melt mixing and solution mixing. In melt mixing, the fiber is added to a melt of thermoplastics and mixing is performed using a mixer at a specified temperature and speed for a specified time. Then the mix is taken out from the mixer while hot and is extruded using an injection moulding machine as long and thick rods.

In the solution mixing method, the fibers are added to a viscous solution of thermoplastics in a solvent in a stainless-steel beaker with a stainless-steel stirrer. The temperature is maintained for some time and the mix transferred to a flat tray and kept in a vacuum oven to remove the solvent. The solution-mixing procedure avoids fiber damage that normally occurs during blending of fiber and thermoplastics by melt-mixing [34].

Generally, randomly oriented sisal-fiber-reinforced composites are prepared by standard injection moulding of the blends. Oriented sisal composites are processed by aligning the long extruded rods with compression molding.

Polyethylene is the most widely used thermoplastics matrix [34-37]. For other natural fiber composites, polypropylene is also a major matrix material [38-41]. Recently, sisal fiber reinforced polystyrene and PVC have also been studied [42, 43].

2.4.2.2 Properties of sisal fiber reinforced polyethylene

2.4.2.2.1 Mechanical properties

Joseph et al. [35] studied the tensile properties of short sisal fiber/polyethylene composites in relation to processing methods and the effects of fiber content; length and orientation. As expected, the tensile properties show a gradual increase with fiber length reaching a maximum at about 6 mm (12.5 MPa) and then decrease (e.g. 10.24 MPa at 10 mm). Unidirectional short fibers achieved by extrusion enhance the tensile strength and elastic modulus of the composites along the axis of fiber alignment by more than two-fold compared to randomly oriented fiber composites.

Different processing methods lead to different extent of fiber damage, different fiber-length distribution and hence different mechanical properties. The effect of fiber length on the mechanical properties can be explained by the fact that long fibers tend to bend or curl during moulding. This causes a reduction in the effective length of the fiber below the critical fiber length in a particular direction and hence a decrease of mechanical properties.

2.4.2.2.2 Dynamic mechanical properties

The effects of fiber length, orientation, volume fraction and fiber surface treatment on the dynamic mechanical properties of sisal-fiber-reinforced PE including storage modulus, loss modulus and damping characteristics have also been studied [34]. It is found that addition of 10% of short sisal fibers into LDPE increases the storage moduli and loss moduli of the composites, leveling off at higher volume fraction. This is believed to be caused by the increasing fiber-to-fiber interaction at high volume fractions resulting in poor dispersion. Both storage and loss moduli decrease with increase of temperature. The damping properties of the composites decrease with addition of fibers and are strongly influenced by fiber orientation. The storage and loss moduli of randomly oriented composites were intermediate between those of longitudinally and transversely oriented composites. The influence of fiber length indicates that a critical length of 6 mm is needed to obtain maximum dynamic moduli. This suggests that a critical length exists for maximum stress transfer between fiber and matrix. The storage and loss moduli of the

isocyanate-treated composites are higher than those of the untreated composites as a result of the improved fiber/matrix interface adhesion.

2.4.2.2.3 Ageing properties

The environmental properties of sisal-fiber composites are very important because, as a natural fiber, sisal ages and causes degradation. The effects of aging on the physical and mechanical properties of sisal-fiber-reinforced polyethylene composites have been studied [52]. The tensile properties and dimensional stability are evaluated under two different ageing conditions: one is by immersing samples in boiling water for 7 h under atmospheric pressure; and the other is by heating the samples at 70°C in an air circulating oven for 7 days. Both cardanol derivative of toluene di-isocyanate (CTDIC) treated and untreated sisal-fiber-reinforced composites have been studied. The ageing properties of the sisal composites are also compared to those of glass-fiber composites aged under identical conditions. It is concluded that CTDIC-treated composites showed better mechanical properties and dimensional stability as compared to untreated composites as a result of the existence of an effective interfacial bond between fiber and matrix. Better dimensional stability is offered by glass/LDPE composite because of the hydrophobic nature of the glass fiber. With suitable fiber-surface treatment, mechanical properties such as strength and elastic modulus of sisal/LDPE composites can be improved to comparable levels as those of glass/ LDPE.

2.4.2.3 Properties of sisal fiber-reinforced polystyrene composite

For other thermoplastics matrices, Manikandan et al. [43] studied the tensile properties of short sisal-fiber-reinforced polystyrene composites. Untreated and benzoylated sisal fibers were used to produce the composites and the influences of fiber length, fiber content, fiber orientation and fiber benzoylation were investigated.

Variation in fiber length produces no considerable change in the modulus of the composites but gives maximum tensile strength (25 MPa) at a fiber length of about 10 mm (aspect ratio=82). This critical fiber length is quite different to the sisal/PE composite which is 6 mm. Table 11 shows the effect of fiber-volume fraction on the mechanical

properties. There is an initial reduction in tensile strength at Vf. 10% followed by an increase to Vf. 20% and remains constant at even higher Vf. These results are also different to sisal/PE composites, which conform to the rule of mixtures.

2.4.2.4 Properties of sisal-fiber-reinforced PVC composite

Yang et al. [42] studied sisal/PVC composites with respect to the effects of fiber and matrix modification, processing parameters on the mechanical and water resistance properties. Their main objective is to obtain the best processing parameters and interface modification to make novel sisal/PVC composites. To make good use of sisal fiber and PVC, it is important to improve the interface so that better mechanical properties of the composite can be obtained. But, unfortunately, their results show that thermal treatment, acetylation and coupling agent improve neither the interface nor the mechanical properties. On the contrary, the untreated sisal-fiber-reinforced PVC composite possesses better mechanical properties. These results have been explained by the small fiber-volume fraction (18.5%) of their composites and the melting processing method that leads to the poor immersion of fibers in the PVC matrix. Also, both treated and untreated sisal/PVC composites have quite good moisture resistance.

2.4.3 Sisal-fiber-reinforced rubber matrix

Rubber is the second most widely used matrix for sisal fiber composites behind polyethylene [53-59]. Rubber matrices include natural rubber and styrene-butadiene rubber. The main research areas concern the effect of fiber length, orientation, loading, type of bonding agent and fiber/matrix interaction on the properties of the composites which include mechanical properties, rheological behaviour, thermal ageing, gamma-radiation and ozone resistance.

Experimental results show that, for best balance of properties, the fiber length is about 6 mm. This is the same as the sisal/PE composites. Orientation effects are as expected. Addition of short sisal fibers to rubber offers good reinforcement, which can be

further strengthened by a suitable coupling agent such as a resorcinol/heca bonding system.

A two-stage stress relaxation has been observed in acetylated sisal-fiber-reinforced natural rubber composites. Initial relaxation occurs at short times (200 s), and second-stage relaxation takes much longer to complete. The initial mechanism is a result of the fiber/rubber attachments and the latter to the physical and chemical relaxation processes of the natural rubber molecules. The relaxation is influenced by the coupling agent indicating that the fiber/rubber interface is involved. Gum vulcanite shows only one relaxation process, the rate of which is almost independent of the strain level. For the composite without a coupling agent, the rate of relaxation increases with strain level and vice versa. The initial rate of the stress-relaxation process diminishes after ageing (at 70 and 100°C for 4 days).

Varghese et al. [57] studied the effect of acetylation and bonding agent on the ageing properties of sisal-fiber-reinforced natural rubber composites which include thermal ageing, gamma radiation and ozone resistance. High fiber-volume fraction shows better resistance to ageing, especially with fiber-surface treatment. Fiber orientation is also found to reduce the extent of degradation under these ageing conditions. Increasing the dosage of gamma radiation was found to increase the extent of the ageing process.

2.4.4 Sisal-fiber-reinforced gypsum and cement matrices

For applications as building materials, sisal-fiber-reinforced gypsum and cement composites have long been studied before 1994 [60±65]. The majority of these works are focused on interface, mechanical, fire and environmental properties and their applications. Bessell and Mutuli [65] studied the interfacial bond strength of sisal/cement composites using a tensile specimen containing a single filament in the brittle matrix. The crack spacing in the matrix was measured and used to evaluate the fiber/matrix bonding strength. It is shown that the interfacial bond of sisal/cement composite is lower than that of other composites because sisal fiber absorbs moisture from cement thus leading to a very poor interface.

The following aspects of sisal-fiber-reinforced cement or gypsum composites have also been studied previously. For example, Hernandez et al. [61] studied the fire behaviour of sisal short-fiber-reinforced gypsum using specially designed testing equipment. Though gypsum itself has good combustion-resistance, with increasing water reduction as a result of increasing temperature, there is a progressive shrinkage process that promotes surface fissuration. Adding sisal fibers into the gypsum matrix increases the fire insulating performance and delays the occurrence of surface fissuration.

Swift [66] studied sisal/cement composites and their potential for rural Africa. He studied the mechanical properties including flexural, energy absorption and pointed out that a composite material formed by sisal fiber and cement is suitable for applications in several structures. For example, cladding walls to produce earthquake-resistant adobe structures for houses, roofing sheets and tiles, grain storage bins and water ducts.

2.4.5 Other matrix systems

Bisanda and Ansell [3] used cashew nut shell liquid (CNSL) as a matrix to make sisal-fiber-reinforced composites. CNSL is a natural monomer blend that has been condensation polymerized with formaldehyde in the presence of an alkaline catalyst to produce a thermosetting resin. It can be used to bind sisal fibers to produce a cheap and useful composite. The resin is thermally stable up to 230_C and is further cross-linked when exposed to simulated sunlight. The plain woven mats of mercerized sisal fiber when impregnated with CNSL/formaldehyde resin produced plain and corrugated laminated composites showing mean tensile strength of 94.5 MPa and Young's modulus of 8.8 Gpa [3]. It is recommended that these low-cost corrugated panels can be used for roofing applications as a result of their adequate crush bending strength (13.9 MPa).

2.4.6 Sisal and synthetic hybrid-fiber composites

Reinforcement by two or more fibers in a single matrix leads to hybrid composites with a great diversity of material properties. It appears that the behaviour of hybrid composites is simply a weighted sum of the individual components so that there is a more favourable balance of properties in the resultant composite material. Sisal and glass fibers are one good example of hybrid composites [67-69] possessing very good combined properties.

For sisal/glass-fiber-reinforced LDPE hybrid composites, the effects of fiber orientation, composition and fiber-surface treatment on the mechanical properties have been studied and the results are shown in Table 12. Owing to the superior properties of glass fibers the mechanical properties of the hybrid composites increase with increasing volume fraction of glass fibers. `Positive' or `negative' hybrid effect is defined as `larger' or `smaller' than the properties calculated from the rule of mixtures of the two constituent fiber-reinforced composites. A positive hybrid effect has been observed for all mechanical properties except elongation at break. This effect is a consequence of increased fiber dispersion and orientation with increasing volume fraction of glass fibers.

The effect of chemical modification (alkali treatment) of sisal fibers on the mechanical properties of a 50:50 sisal/glass hybrid composite is shown in Table 13 and the improvement is generally less than 10%. Water absorption of the composite is reduced from 11.6 to 3.1% compared to the non-hybridized sisal-fiber composite.

Yang et al. [69] studied the mechanical and interface properties of sisal/glass-fiber-reinforced PVC hybrid composites before and after immersion in water. It is found that there exists a `positive' hybrid effect for the flexural modulus and unnotched impact strength but a `negative' hybrid effect for the flexural strength. It is suggested that the `negative' hybrid effect is caused by the poor interface between sisal, glass fibers and PVC matrix. They also suggested that water will have a detrimental effect on the fiber/matrix interface leading to reduced properties.

CHAPTER 3

OBJECTIVE

The main objective in this project is

- To produce aged and fresh sisal fiber composites with polypropylene sheet [1mm] thickness as a matrix through compression moulding technique.

- To study the effect of ageing between aged and fresh sisal fiber composites

- To compare the mechanical properties of aged and fresh sisal fiber composites under tensile, flexural & impact loading.

- To study the fractured samples obtained from the mechanical testing were subjected to morphological analysis with the help of an optical microscope. Images were observed at 40 x magnification.

CHAPTER 4

MATERIAL FABRICATION, EXPERIMENTAL AND SPECIMEN DESIGN

4.1 FIBER EXTRACTION

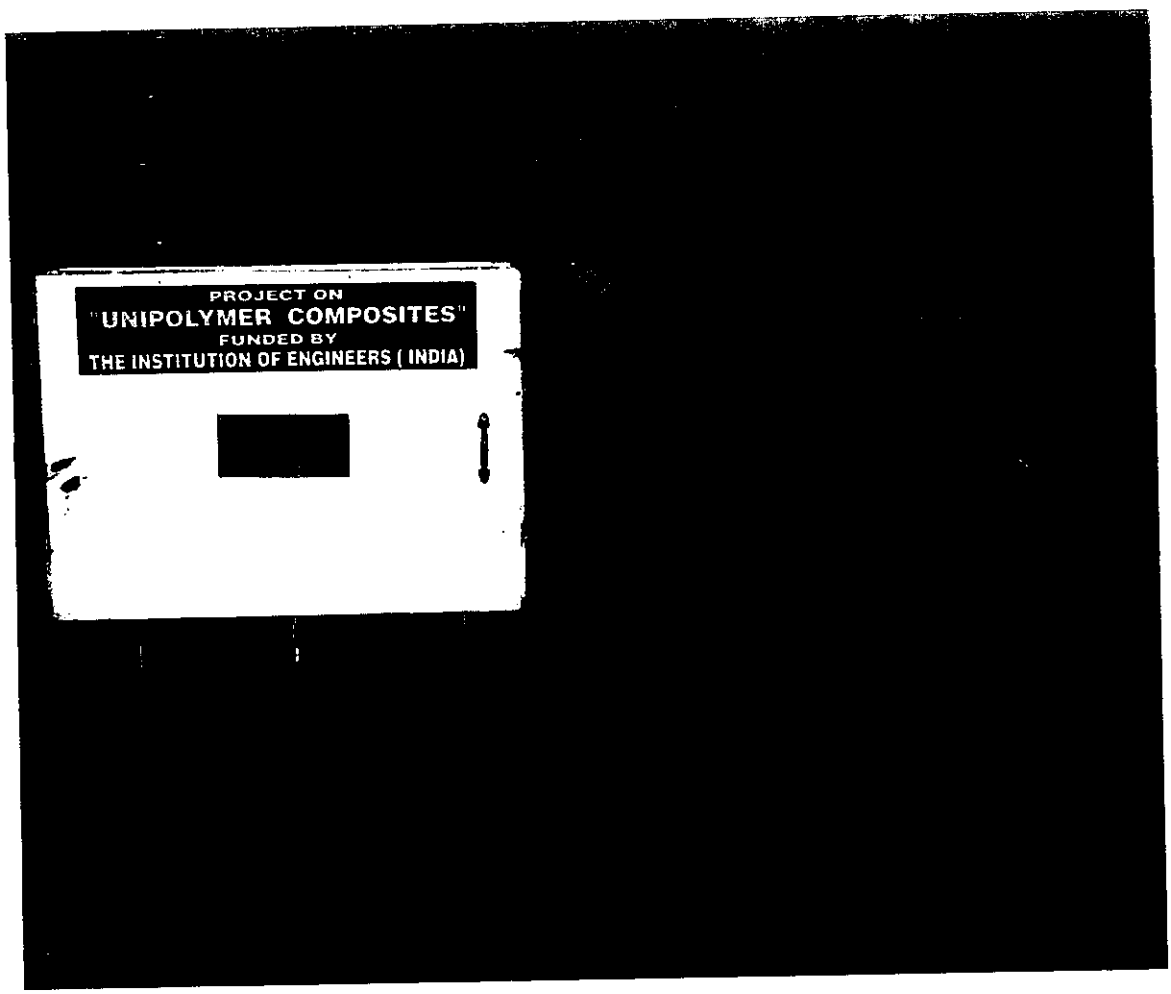
Sisal fiber is a hard fiber extracted from the leaves of the sisal plant *AGAVE SISALANA*. The sisal leaves are fed one by one to the fast rotating roller type mechanical machine. Due to the fast rotating rollers the fleshy part from the leaves is removed and the fiber part is separated. The process of removing the fibers from the leaves is known as retting.

After extraction, the fibers are washed thoroughly in plenty of clean water to remove surplus wastes such as chlorophyll, leaf juices and adhesive solids.

4.2 METHOD

4.2.1 COMPRESSION MOULDING TECHNIQUE

Compression moulding is a powerful tool to manufacture composites though it has not been used with conjunction with sisal fibers. The production cost of composites will be cheaper than other natural composites. Compression moulding is especially suitable for manufacturing flat or slightly curved planes or laminates. The advantage of compression moulding includes low cost, little mineral waste with close tolerance, part to part uniformity and reproducibility, good control of fiber to resin ratios and void content, and shorter cycle times. The compound can be heavily filled with little orientation of resins or additives.



4.2.1 Schematic Diagram of Compression Moulding Machine

4.3 METHODOLOGY

Optimised Curing Cycle

The Mould is taken at room temperature

⇩

Placement of sisal fibres + Polymer matrices in mould

⇩

Placement of Mould in the Hot press

⇩

Application of heat without Pressure over the mould

⇩

Temperature raised to 176, 179 & 182 ° C

⇩

Application of load of 200 Psi for 10 minutes

⇩

Cooling the mould in the open air until the temperature reaches the desired level

⇩

Extraction of composite from mould plates.

The aged fiber and fresh fiber composites are prepared at three different process parameters.

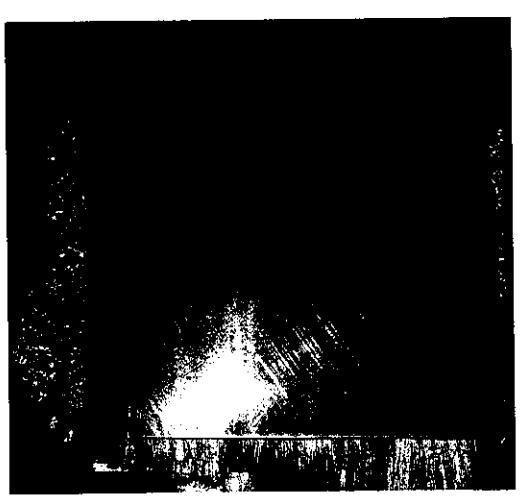
- Temperature [176, 179 & 182 ° C]
- Pressure [200 psi]
- Time of contact [10 minutes]

4.4 COMPOSITE FABRICATION

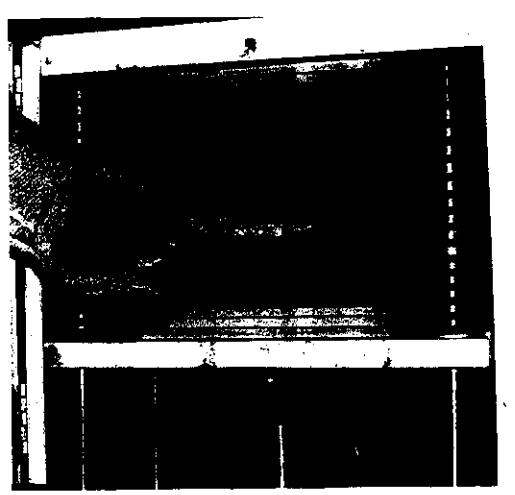
Fabrication of the sisal fiber mat/ Polypropylene composite is by film stacking and compression moulding. Then thin sheets of polypropylene of specified thickness (Table 1) taken. These sheets are combined with the required number of layers of sisal fiber. To encourage impregnation of the fiber mat by the polymer during moulding, the two outer layers of the stack were always of the polymer. The stack, consisting of layers of fiber and polymer, are compressed in a rectangular-shaped mould (200 mm by 200 mm) under a pressure of 200 Psi and at a temperature of 176, 179 & 182° C sustained for 10 min. The pressure is maintained during the final cooling phase, which lasts for 10 min.

Parameters	Polypropylene
Thickness (mm)	1 mm
Peak Melting temperature	176, 179 & 182 ° C

Table 4.4 Composite Fabrication



4.4 (a)



4.4 (b)

4.4 (a) Placement of fibers inside the matrix
(b) Placement of specimen inside the compression moulding machine

CHAPTER 5

RESULTS & DISCUSSIONS

5.1 FIBER TESTING RESULTS

SPECIFICATION	AGED FIBER	FRESH FIBER
Tex	48.27	27.1
Mean length	100.42 cms	116.53 cms
Length S.D	10.33	18.62
Length CV%	10.29	15.984
Mean diameter	0.2388 mm	0.163 mm
Diameter S.D	0.114351	0.0447
Diameter CV	47.88	27.424
Breaking strength	601.7 gms	679.1 gms
Strength CV%	46.43	40.34
Tenacity	12.46 gms/tex	25.05 gms/tex
Initial modulus		
At 0.5%	348.91 gms/tex	851.66 gms/tex
At 1%	397.55 gms/tex	730.62 gms/tex
At 1.5%	386.29 gms/tex	658.97 gms/tex
At 2%	356.22 gms/tex	609.77 gms/tex
Elongation	5.164 %	5.977 %
Elongation CV%	38.94	32.57

Table 5.1 Fiber Testing results

5.1.1 OPTIMIZATION OF FIBER LENGTH

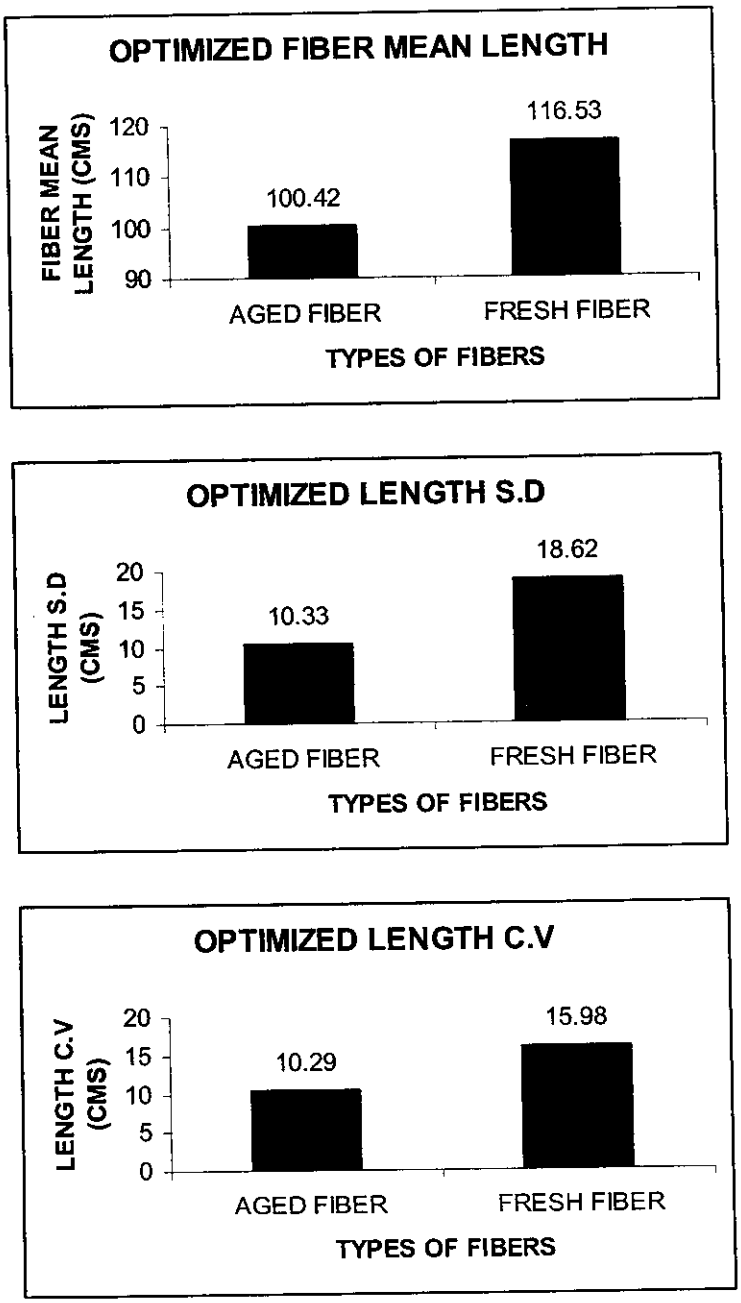


Fig 5.1.1 Optimization of fiber length

5.1.2 OPTIMIZATION OF FIBER DIAMETER

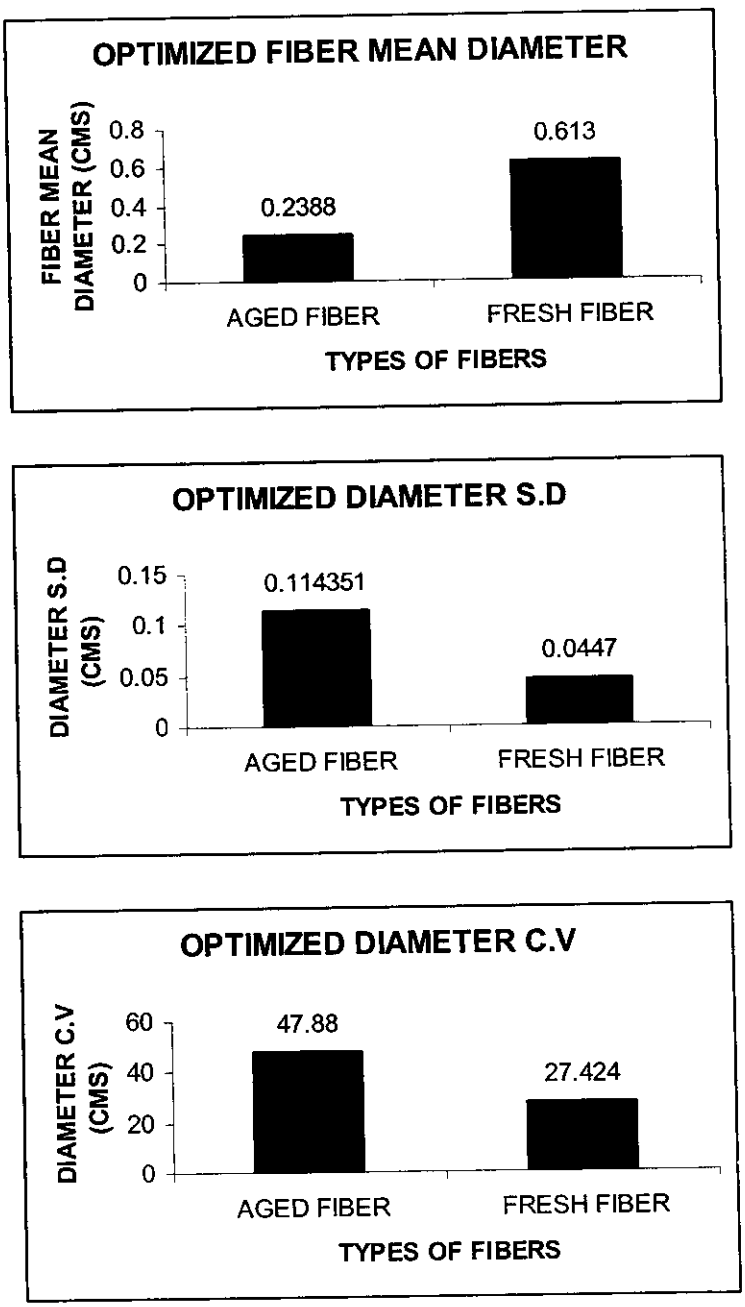


Fig 5.1.2 Optimization of fiber diameter

5.1.3 BREAKING STRENGTH

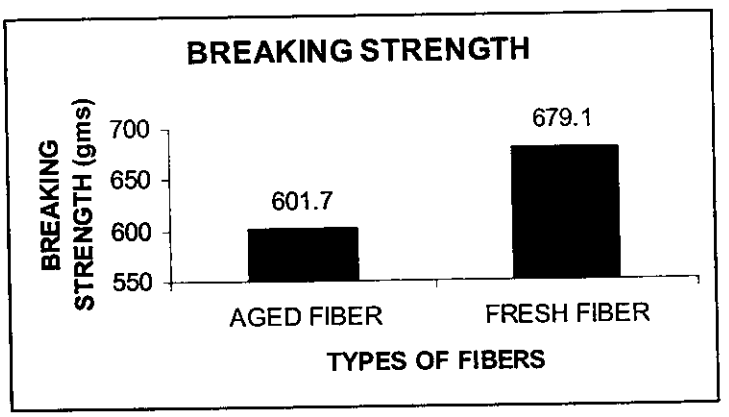


Fig 5.1.3 Breaking Strength Results

5.1.4 STRENGTH C.V %

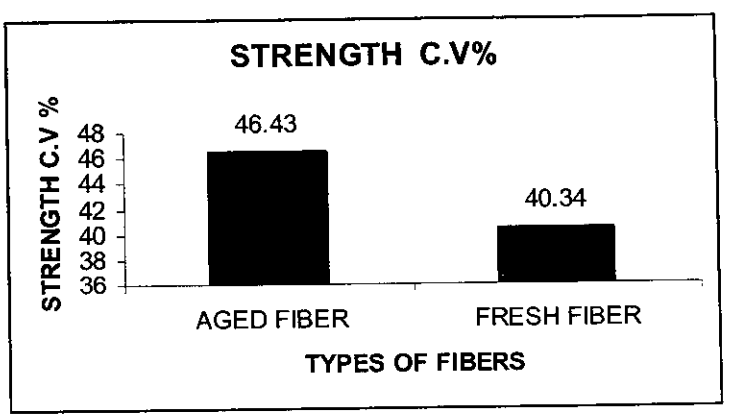
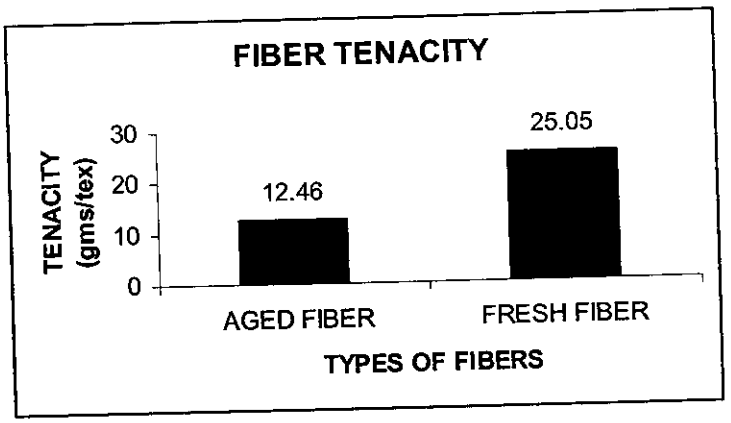


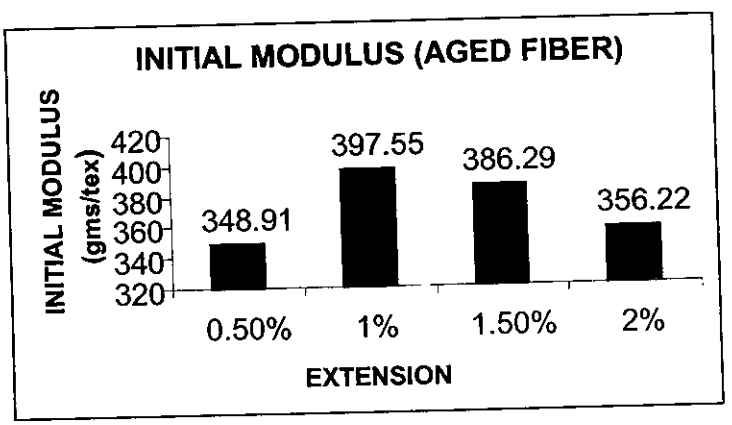
Fig 5.1.4 Strength C.V % Results

5.1.5 FIBER TENACITY RESULTS



5.1.5 Fiber Tenacity Results

5.1.6 INITIAL MODULUS RESULTS



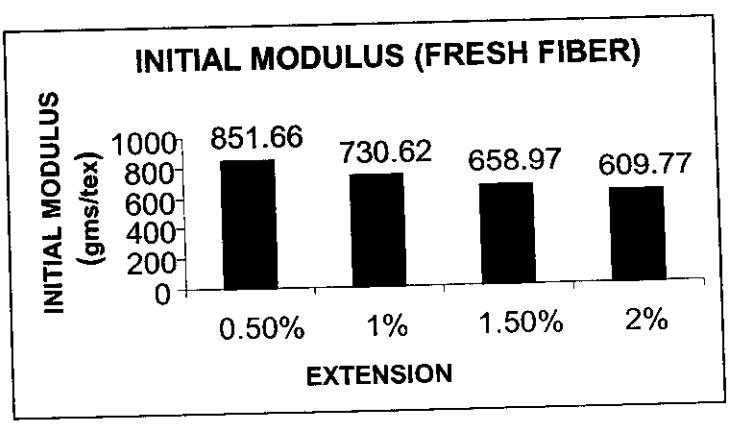


Fig 5.1.6 Initial Modulus Results

5.1.7 FIBER ELONGATION

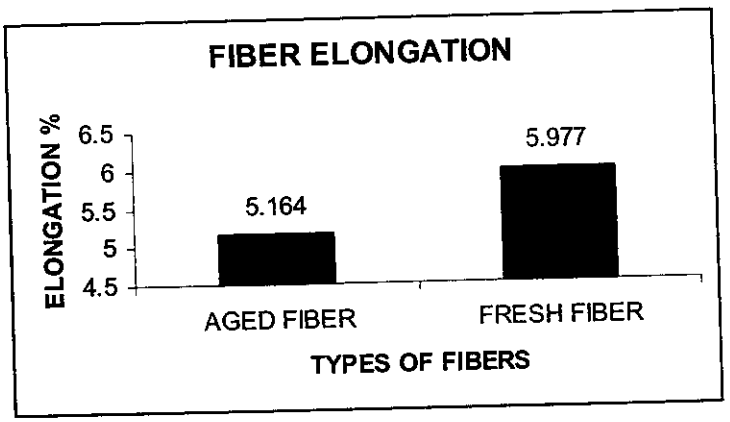


Fig 5.1.7 Fiber Elongation Results

5.1.8 ELONGATION C.V%

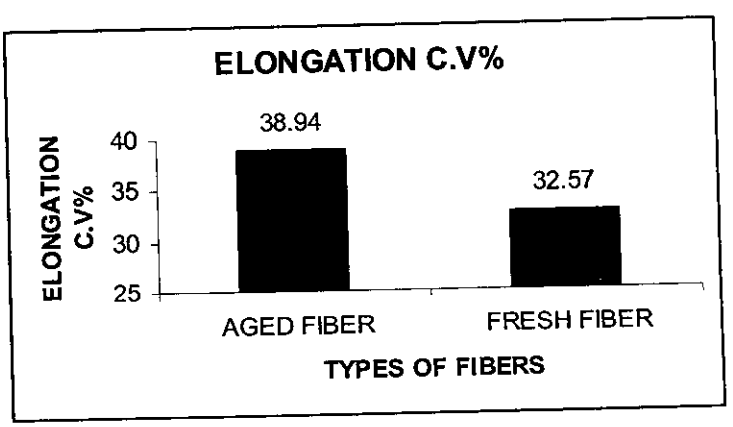


Fig 5.1.8 Elongation C.V% Results

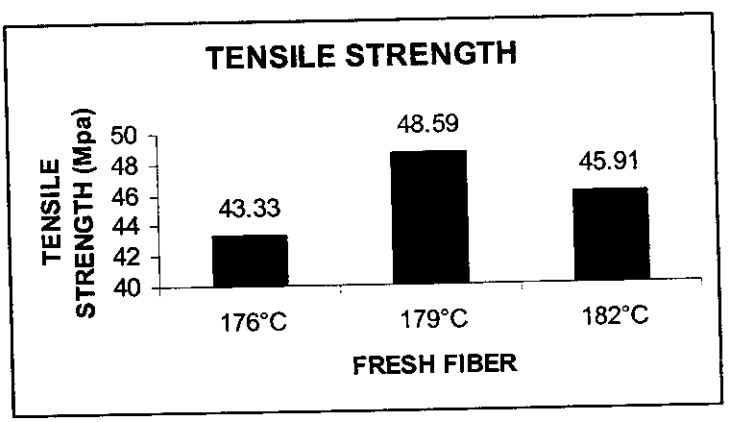
5.2 MECHANICAL PROPERTIES RESULTS

SPECIFICATION	AGED FIBER COMPOSITES	FRESH FIBER COMPOSITES
Tensile strength		
[176°C]	44.98 Mpa	43.33 Mpa
[179°C]	41.92 Mpa	48.59 Mpa
[182°C]	50.18 Mpa	45.91 Mpa
Tensile modulus		
[176°C]	1.053 Gpa	1.035 Gpa
[179°C]	1.006 Gpa	0.843 Gpa
[182°C]	1.066 Gpa	0.90 Gpa
Flexural strength		
[176°C]	40.56 Mpa	37.28 Mpa
[179°C]	36.47 Mpa	37.09 Mpa
[182°C]	50.05 Mpa	46.80 Mpa
Flexural modulus		
[176°C]	1.335 Gpa	1.231 Gpa
[179°C]	1.233 Gpa	1.360 Gpa
[182°C]	1.703 Gpa	2.078 Gpa
Impact strength		
[176°C]	6.3 J/cm	7.36 J/cm
[179°C]	7.065 J/cm	6.04 J/cm
[182°C]	5.95 J/cm	7.613 J/cm

Table 5.2 Mechanical Properties Results

5.2.1 TENSILE STRENGTH RESULTS

The tensile test was carried out in INSTRON 4301 tester according to ASTM D 3039 standards. The dimensions of the specimen are 25 x 150 mm. The crosshead speed was kept at 2mm per minute.



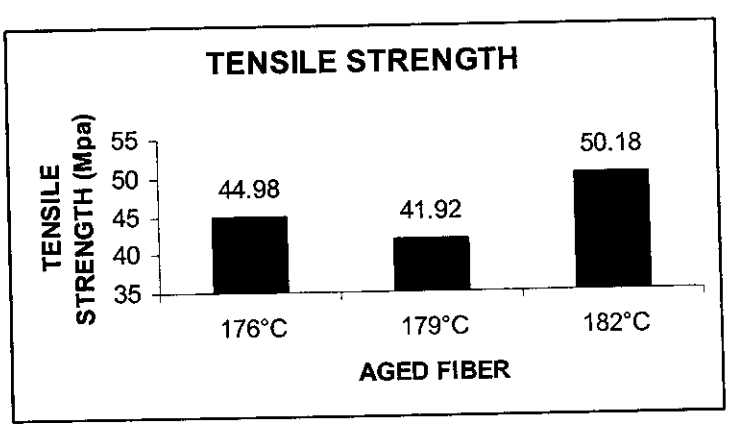
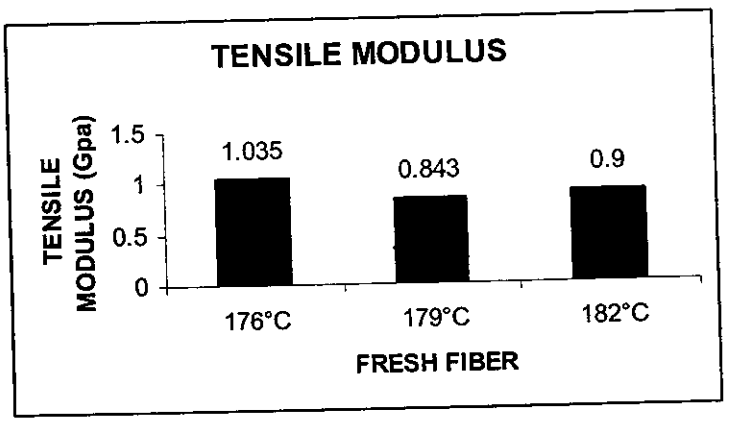


Fig 5.2.1 Tensile Strength Results

5.2.2 TENSILE MODULUS RESULTS



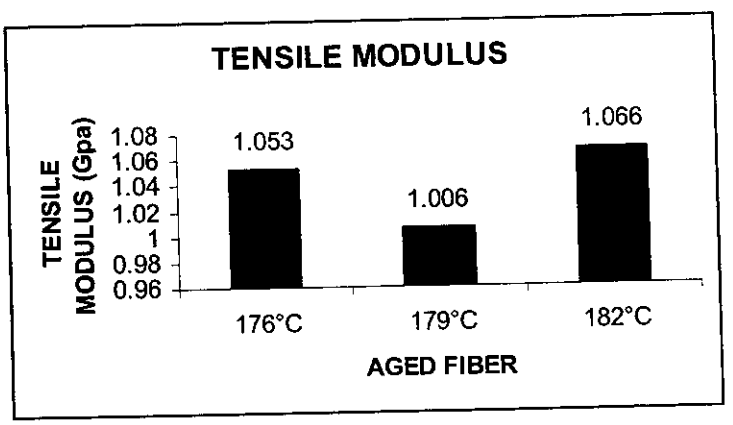
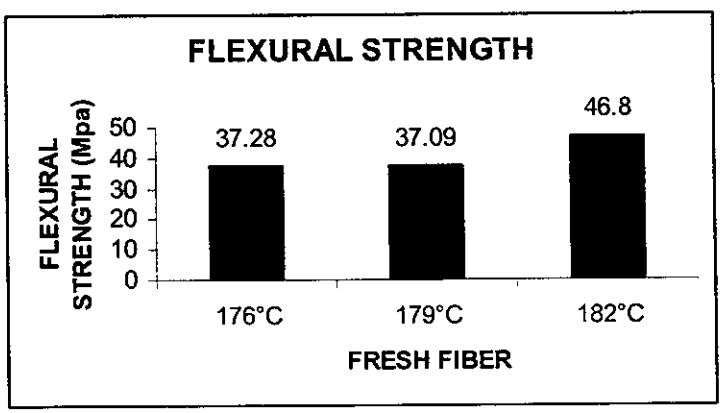


Fig 5.2.2 Tensile Modulus Results

5.2.3 FLEXURAL STRENGTH RESULTS

Flexural test was carried out according to ASTM D970 standards. Flexural test was done in a 3-point bending load using INSTRON 4301 tester. The dimensions of the specimen are 10 x 80 mm.



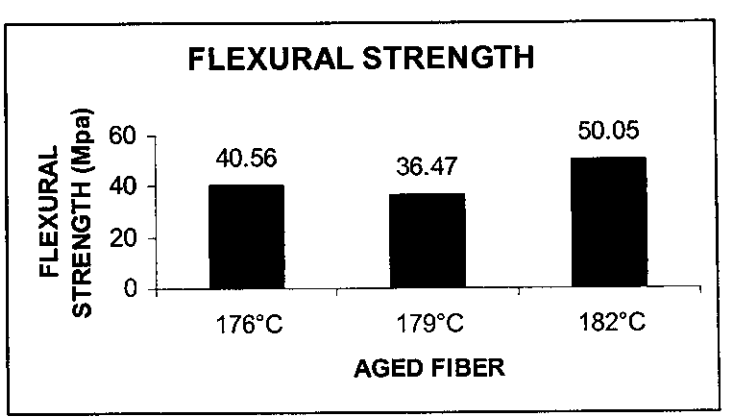
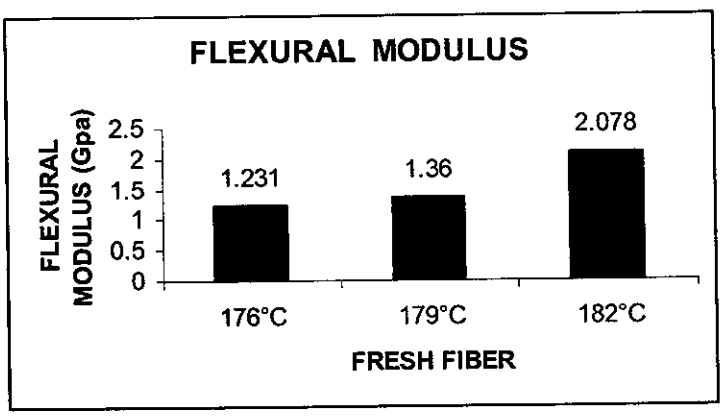


Fig 5.2.3 Flexural Strength Results

5.2.3 FLEXURAL MODULUS RESULTS



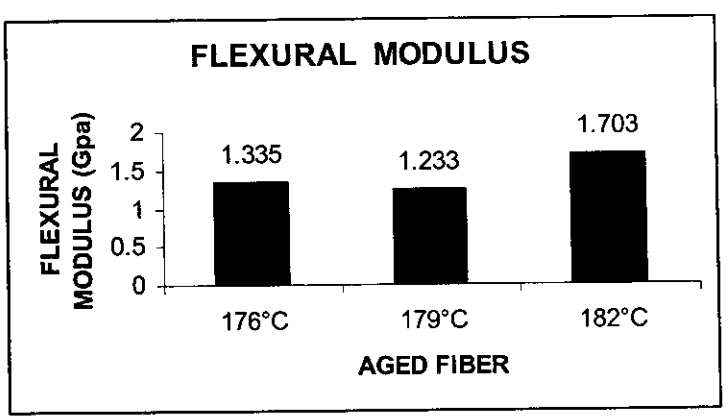
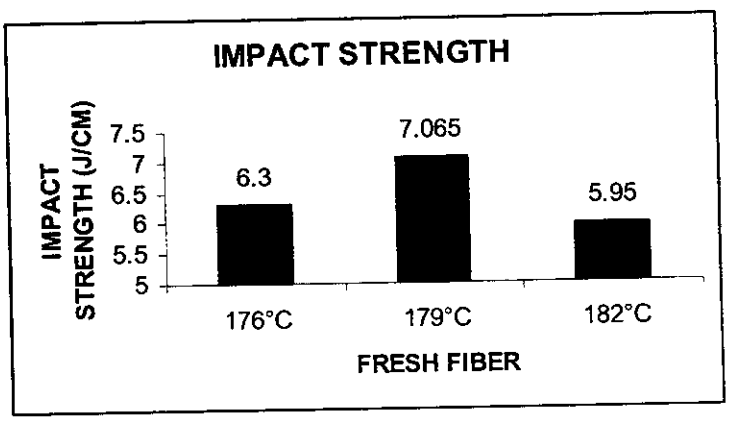


Fig 5.2.3 Flexural Modulus Results

5.2.4 IMPACT STRENGTH RESULTS

Impact strength was carried out according to ASTM D256 standards. The izod method of impact testing is done. The capacity of the machine is 0-50 joules. The dimensions of the specimen are 13 x 65 mm.



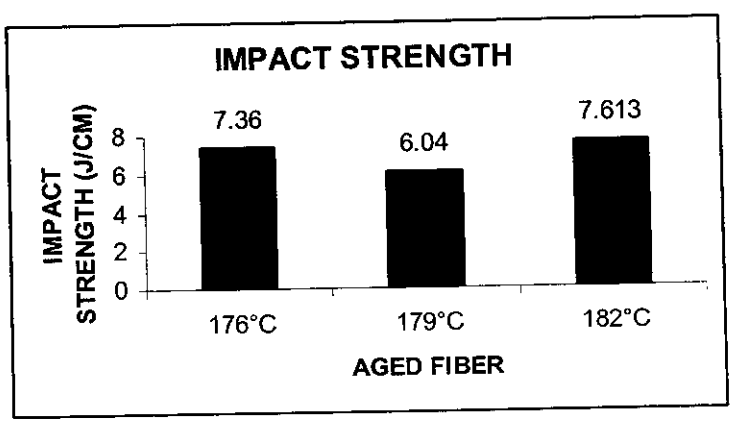


Fig 5.2.3 Impact Strength Results

5.3 OPTICAL MICROSCOPIAL STUDIES

The fractured samples obtained after the mechanical testing were subjected to morphological analysis with the help of an optical microscope. Images were observed at 40x magnification

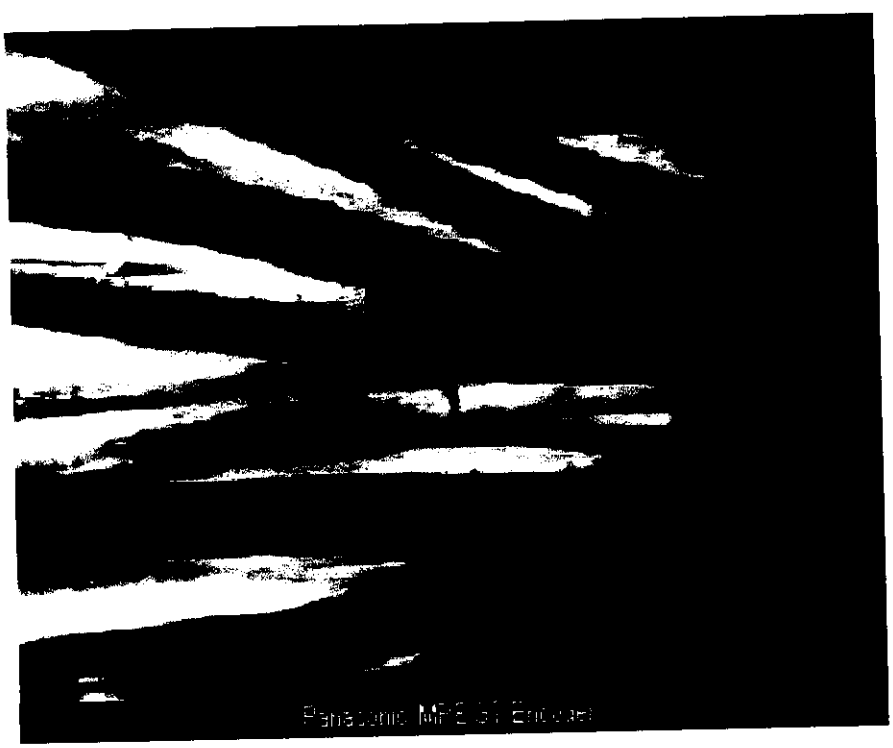


Fig 5.3 (a) Fresh Fiber [176 deg celcius]

Fig 5.3 (b) Fresh Fiber [179 deg celcius]

In both cases of optical micrographs, it shows that good composites have been manufactured. There is minimum fiber pull out from the matrix. The higher temperature [179 deg celcius] composites show there is change in colour. But the optical micrographs show good adhesion between matrix and fibers. Poor adhesion would have resulted in a lot of fiber pull out, which has not been observed

5.4 REASON OF AGED FIBER COMPOSITE BEING SUPERIOR TO FRESH ONE

- It is proposed that in sisal-polypropylene the main interphase mechanism is inter diffusion. When the thermodynamics are favourable, it may be possible for molecules of one surface to diffuse into the bulk of another surface and set up an interphase.
- This interphase represents the elimination of the joining surface and replaces it with a relatively smooth gradient from one bulk material to the other.
- Adhesion by interdiffusion can be seen as mechanical interlocking on a molecular scale. This mechanism of adhesion is applicable to materials whose molecules possess a high degree of mobility as well as affinity toward the opposing molecules.
- In presence of moisture, the molten matrix cannot properly diffuse into the fibers and results in lack of adequate fiber-matrix adhesion. This has resulted in the aged fibers adhering better and securing a better interphase.

5.5 REASON FOR APPLYING TENSION TO FIBERS

- Additional problems which was caused by high matrix viscosity during consolidation was de-alignment of reinforcing fibers during consolidation as well as the introduction of voids within the final composite product.
- All of these problems can be addressed by appropriate application of tension during composite fabrication procedures.
- Composites prepared with satisfactory matrix dispersion within the fiber tows as well as reasonable fiber-matrix adhesive interaction typically resulted in composites with good mechanical properties.

CHAPTER 6

APPLICATIONS

Plant fibers are currently only used in the interior of passenger cars and truck cabins. Besides their use in trim parts such as door panels or cabin linings, plant fibers can be used extensively for thermo-acoustic insulation. Such insulating materials, mainly based on cotton fibers recycled from textiles, have relatively high fiber contents of more than 80% by weight.

Trim parts in Brazilian trucks, made of a mixture of jute coffee bag wastes and polypropylene bags show that recycling sometimes can lead to advanced applications. Another well established field of application is the use of coconut fibers bonded with natural latex for seat cushions.

For this application the ability of plant fibers to absorb large amounts of humidity leads to an increased comfort that cannot be reached with synthetic materials. Aside from this kind of developments, fundamentally new applications have not been realized in recent years.

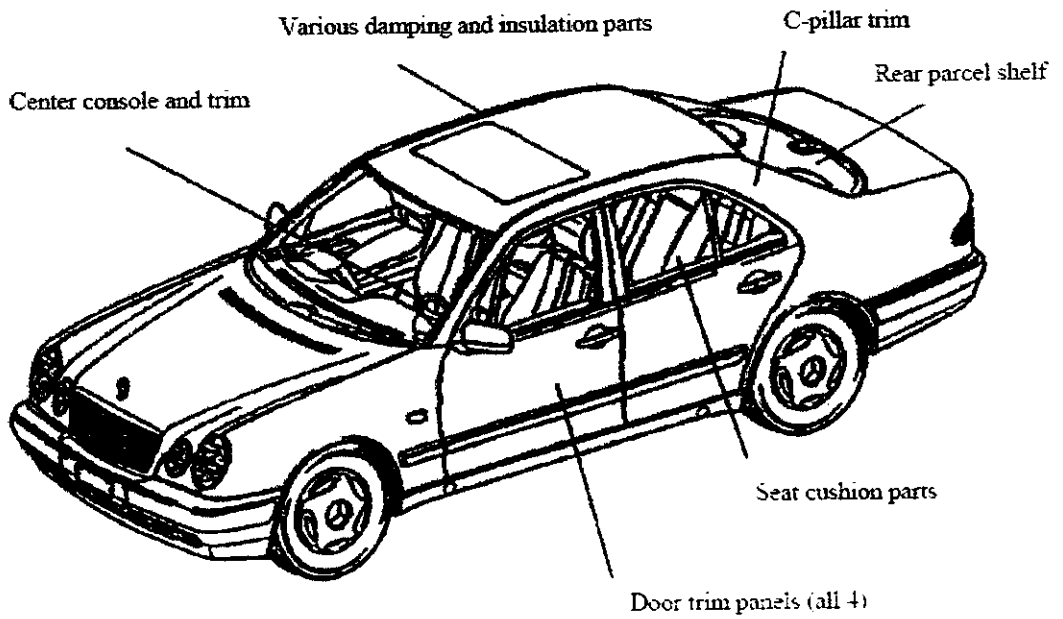


Fig 7.1 Plant fiber Application in the current Mercedes-Benz E-Class.

An important step towards higher performance applications was achieved with the door panels of the Mercedes-Benz E-Class. The wood fiber materials previously used for the door panels can be replaced by sisal fiber-reinforced material with polypropylene sheet as a matrix. A remarkable weight reduction of about 20% can be achieved, and the mechanical properties, important for passenger protection in the event of an accident, were improved. Furthermore, the sisal/polypropylene material can be molded in complicated 3-dimensional shapes, thus making it more suitable for door trim panels than the previously used materials.

CHAPTER 7
SCOPE OF FUTURE WORK

1. Sisal-textile-reinforced composite is an important area in which little work has been done [3]. Sisal fibers can be woven into textile preforms and impregnated with resins by resin transfer moulding (RTM) or resin ®lm infusion (RFI) to make superior but more economical composites.
2. Microstructure of the interface between sisal fiber and matrix still needs to be investigated and the interfacial properties should be studied with more rigorous single fiber pullout and fragmentation tests [70]. The relationship between interface and bulk composite properties should be established.
3. Fracture toughness and fracture mechanisms of sisal-fiber composites do not seem to have been studied in any depth in previous published works. This is important if new improved materials are to be developed for safe usage against crack growth.
4. Mechanical properties of sisal-fiber composites measured from tests quite often disagree with the rule of mixtures. A full explanation can only be obtained if the interface strength and the failure mechanisms are known. Further work is needed particularly to explain `hybrid' effects in sisal/glass composites.
5. Economical processing methods must be developed for the composites because of the very low price of sisal fibers. The relationship between mechanical properties and processing methods should be established.
6. New applications should be found for sisal-fiber-based composites. Hybrid fiber composites with sisal and other fibers rather than glass may open up new applications. For example, from the economics point of view, sisal fibers may be hybridized with carbon or aramid fibers to reduce the costs of these expensive fibers reinforced composites whilst maintaining their good mechanical performance.

CHAPTER 8

CONCLUSION

- In this project natural sisal fiber was used as reinforcement in making composites laminates using compression moulding technique.

- Compression moulding is a powerful tool to manufacture composites though it has not been used with conjunction with sisal fibers.

- From this project the following conclusions are reached.

    1. From the fiber part fresh sisal fiber shows better tenacity, breaking strength and elongation when compared to aged fiber. The reason may be due to oxidation of cellulose in aged fiber, which results in degradation of strength, which doesn't happen for fresh fiber.

    2. In composites, overall aged fiber composite shows better mechanical properties than fresh fiber composites. The reason proposed is that mechanical properties of composites not only rely upon the fiber strength alone which is better in fresh fiber but also on the interfacial adhesion between the fiber and the matrix which assists stress transfer. The adhesion between the fiber and matrix is superior with aged fiber due to the fact that, the aged fiber has less moisture absorption. The adhesion between polyolefinic matrix and natural fiber tends to improve with less moisture. Reduced moisture content also resist degradation of fibers resulting in better strength.

    3. The time, temperature and pressure cycle has been optimized for sisal-polypropylene combination. The overall results demonstrate that aged fiber composites consolidated at 182 deg c [200 psi & 10 min] shows good mechanical properties. They have shown a tensile strength of 50.18 Mpa, tensile modulus of 1.066 Gpa, flexural strength of 50.05 Mpa, flexural modulus of 1.703 Gpa & Impact strength of 7.616 J/cm.

    4. Such composites can be used in various fields, especially in the field of automotive textiles.

CHAPTER 8

REFERENCE

[1] Mukherjee PS, Satyanarayana KG. Structure and properties of some vegetable fibers, part 1. Sisal fiber. Journal of Materials Science 1984; 19:3925-34.

[2] Chand N, Tiwary RK, Rohatgi PK. Bibliography resource structure properties of natural cellulosic fibers - an annotated bibliography. Journal of Materials Science 1988; 23:381-7.

[3] Bisanda ETN, Ansell MP. Properties of sisal-CNSL composites. Journal of Materials Science 1992; 27:1690-700.

[4] Wilson PI. Sisal, vol. II. In Hard fibers research series, no. 8, Rome: FAO, 1971.

[5] Rowell RM. In: Rowell RM, Schultz TP, Narayan R, editors. Emerging technologies for materials & chemicals for biomass, ACS Symposium Ser, 476, 1992. p. 12.

[6] Joseph K, Thomas S, Pavithran C. Effect of chemical treatment on the tensile properties of short sisal fiber-reinforced polyethylene composites. Polymer 1996; 37:5139-49.

[7] Chand N, Hashmi SAR. Metals Materials and Processes 1993; 5:51.

[8] Bisanda ETN, Ansell MP. The effect of silane treatment on the mechanical and physical properties of sisal-epoxy composites. Composites Science and Technology 1991; 41:165-78.

[9] Li H, Zadorecki P, Flodin P. Cellulose fiber-polyester composites with reduced water sensitivity. (1) Chemical treatment and mechanical properties. Polymer Composites 1987; 8:199-207.

[10] Chand N, Sood S, Rohatgi PK, Sayanarayana KG. Resources, structure, properties and uses of natural fibers of madhya pradesh. Journal of Scientific and Industrial Research 1984; 43:489- 99.

[11] Bisanda ETN. The manufacture of roofing panels from sisal fiber reinforced composites. Journal of Materials Processing Technology 1993; 38:369-80.

[12] Chand N, Satyanarayana KG, Rohatgi PK. Mechanical characteristics of sunhemp fibers. Indian Journal of Textile Research 1986; 11:86-9.

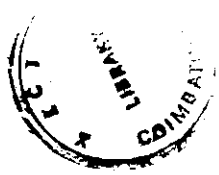
[13] Hornsby PR, Hinrichsen E, Tarverdi K. Preparation and properties of polypropylene composites reinforced with wheat and flax straw fibers. Part 1, fiber characterisation. Journal of Materials Science 1997; 32:443-9.

[14] Satyanarayana KG, Sukumaran K, Mukherjee PS, Pavithran C, Pillai SG. Natural fiber-polymer composites. Cement & Concrete Composites 1990; 12:117-36.

[15] Chand N, Hashmi SAR. Mechanical properties of sisal fiber at elevated temperatures. Journal of Materials Science 1993; 28:6724-8.

[16] Chand N, Joshi SK. Temperature dependence of dielectric behaviour of sisal fiber. Journal of Materials Science Letters 1994; 13:156-8.

[17] Yang GC, Zeng HM, Zhang WB. Thermal treatment and thermal behaviour of sisal fiber. Cellulose Science and Technology 1995; 3:15-19.



P-1619

[18] Zhou LM, Mai Y-W, Ye L, Kim JK. Techniques for evaluating interfacial properties of fiber-matrix composites. Key Engineering Materials 1995; 104±107:549±600.

[19] Kim JK, Zhou LM, Mai Y-W. Interfacial debonding and fiber pull-out stresses. Part III. Interfacial properties of cement matrix composites. Journal of Materials Science 1993; 28:3923-30.

[20] Yang GC, Zeng HM, Li JJ, Jian NB, Zhang WB. Relation of modification and tensile properties of sisal fiber. Acta Scientiarum Naturalium Universitatis Sunyatseni 1996; 35:53-7.

[21] El-Naggar AM, El-Hosamy MB, Zahran AH, Zondy MH. Surface morphology/mechanical/dyeability properties of radiation grafted sisal fibers. American Dyestu. Reporter 1992; 81:40-4.

[22] Sabaa MW. Thermal degradation behaviour of sisal fibers grafted with various vinyl monomers. Polymer Degradation & Stability 1991; 32:209-17.

[23] Chand N, Verma S, Khazanchi AC. SEM and strength characteristics of acetylated sisal fiber. Journal of Materials Science Letters 1989; 8:1307-9.

[24] Singh B, Gupta M, Verma A. Influence of fiber surface treatment on the properties of sisal-polyester composites. Polymer Composites 1996; 17:910-8.

[25] Kim JK, Lu S, Mai Y-W. Interfacial debonding and fiber pullout stresses Part IV: Influence of interface layer on the stress transfer. Journal of Materials Science 1994; 29:554-61.

[26] Yang GC, Zeng HM, Li JJ. Study of sisal fiber/phenol formaldehyde resin composites. Fiber Reinforced Plastics/Composites 1997; 3:12-14.

[27] Sanadi AR, Prasad SV, Rohatgi PK. Sunhemp fiber-reinforced polyester Part 1 Analysis of tensile and impact properties. Journal of Materials Science 1986; 21:4299-304.

[28] Pavithran C, Mukherjee PS, Brahmakumar M, Damodaran AD. Y. Li et al. / Composites Science and Technology 60 (2000) 2037-2055 2053 Impact properties of natural fiber composites. Journal of Materials Science Letters 1987; 6:882-4.

[29] White NM, Ansell MP. Straw-reinforced polyester composites. Journal of Materials Science 1983; 18:1549-56.

[30] Pavithran C, Mukherjee PS, Brahmakumar M, Damodaran AD. Impact performance of sisal-polyester composites. Journal of Materials Science Letters 1988; 7:825-6.

[31] Gordon JE, Jeronimidis. Philosophical Transactions. Royal Society of London, Series A: Mathematical and Physical Sciences 1980; 294:545.

[32] Rong MZ, Li RKY, Ng CN, Tjong SC, Mai Y-W, Zeng HM. Effect of fiber pretreatment on the impact fracture toughness of sisal fiber reinforced polymer composites. In Proc. First Asian - Australian Conference on Composite Materials (ACCM- 1), 7-9 October 1998, Oseka, Japan. p 433-1±4.

[33] Rong MZ, Li RKY, Ng CN, Tjong SC, Mai Y-W, Zeng HM. Effect of water absorption on the impact behaviour of short sisal fiber reinforced polymer composites. In Proc. First Asian-Australian Conference on Composite Materials (ACCM-1), 7-9 October 1998, Oseka, Japan. p 438-1±4.

[34] Joseph K, Thomas S, Pavithran C. Dynamic mechanical properties of short sisal fiber reinforced low-density polyethylene composites. Journal of Reinforced Plastics and Composites 1993; 12:139-55.

[35] Joseph K, Thomas S, Pavithran C, Brahmakumar M. Tensile properties of short sisal fiber-reinforced polyethylene composites. Journal of Applied Polymer Science 1993; 47:1731-9.

[36] Joseph K, Kuriakose B, Premalatha CK, Thomas S. Melt rheological behaviour of short sisal fiber reinforced polyethylene composites. Plastics Rubber & Composites Processing & Applications 1994; 21:237-45.

[37] Joseph K, Thomas S, Pavithran C. Viscoelastic properties of short-sisal-fiber-filled low-density polyethylene composites: effect of fiber length and orientation. Materials Letters 1992; 15:224-8.

[38] Karmaker AC. Effect of water absorption on dimensional stability and impact energy of jute fiber reinforced polypropylene. Journal of Materials Science Letter 1997; 16:462-4.

[39] Garkhail S, Heijenrath R, Oever M, van den, Bos H, Peijs T. Natural-fiber-mat-reinforced thermoplastic composites based on flax fibers and polypropylene. In Scott M, editor. Proceedings of ICCM-11, vol. II, Fatigue, fracture and ceramic matrix composites, Gold Coast, Australia, 14±18 July 1997. p. 794-803.

[40] Park BD, Balatinecz JJ. Effect of impact modification on the mechanical properties of wood-fiber thermoplastic composites with high impact polypropylene (HIPP). Journal of Thermoplastic Composite Materials 1996; 9:342-63.

[41] Hornsby PR, Hinrichsen E, Tarverdi K. Preparation and properties of polypropylene composites reinforced with wheat and flax straw fibers. Part II. Analysis of composite microstructure and mechanical properties. Journal of Materials Science 1997; 32: 1009-1015.

[42] Yang GC, Zeng HM, Li JJ. The study of technology and properties of composites for sisal fiber reinforced PVC. Fiber Reinforced Plastics/Composites 1995; 6:22-6.

[43] Manikandan KC, Nair SMD, Thomas S. Tensile properties of short sisal fiber reinforced polystyrene composites. Journal of Applied Polymer Science 1996; 60:1483-97.

[44] Kalaprasad G, Joseph K, Thomas S. Theoretical modelling of tensile properties of short sisal fiber-reinforced low-density polyethylene composites. Journal of Materials Science 1997; 32:4261-7.

[45] Broutman LJ, Krock RH. Modern composite materials. Reading (MA): Addison Wesley, 1967.

46] Hirsch TJ. Modulus of elasticity of concrete affected by elastic moduli of cement paste matrix and aggregate. In Proceedings of the American Concrete Institute 1962; 59(12):427-51.

[47] Rosen BW. Fiber composite materials. Metals Park (OH): American Society for Metals, 1965. p. 58

[48] Nielson LE. Mechanical properties of polymers and composites, vol. 2. New York: Marcel Dekker, 1974.

[49] Cox HL. The elasticity and strength of paper and other fibrous materials. British Journal of Applied Physics 1952; 3:72-9.

[50] Bowyer WH, Bader MG. On the re-enforcement of thermo- plastics by imperfectly aligned discontinuous fibers. Journal of Materials Science 1972; 7:1315-21.

[51] Paul A, Thomas S, Pavithran C. Electrical properties of natural- fiber reinforced low density polyethylene composites: a comparison with carbon black and glass-fiber filled

low density polyethylene composites. Journal of Applied Polymer Science 1997; 63:247-66.

[52] Joseph K, Thomas S, Pavithran C. Effect of ageing on the physical and mechanical properties of sisal-fiber-reinforced polyethylene composites. Composites Science and Technology 1995; 53:99-110.

[53] Prasantha RP, Kumar ML, Amma G, Thomas S. Short sisal fiber reinforced styrene-butadiene rubber composites. Journal of Applied Polymer Science 1995; 58:597-612.

[54] Varghese S, Kuriakose B, Thomas S. Stress relaxation in short sisal-fiber-reinforced natural rubber composites. Journal of Applied Polymer Science 1994; 53:1051-60.

[55] Kumar RP, Thomas S. Short fiber elastomer composites: effect of fiber length, orientation, loading and bonding agent. Bulletin of Materials Science 1995; 18:1021-9.

[56] Kumar PR, Thomas S. Tear and processing behaviour of short sisal fiber reinforced styrene butadiene rubber composites. Polymer International 1995; 38:173-82.

[57] Varghese S, Kuriakose B, Thomas S. Short sisal fiber reinforced natural rubber composites: high-energy radiation, thermal and ozone degradation. Polymer Degradation & Stability 1994; 44:55±-61.

[58] Varghese S, Kuriakose B, Thomas S, Koshy AT. Mechanical and viscoelastic properties of short fiber reinforced natural rubber composites: effects of interfacial adhesion, fiber loading, and orientation. Journal of Adhesion Science & Technology 1994; 8:235±48.

[59] Varghese S, Kuriakose B, Thomas S, Premalatha CK. Rheological behaviour of short sisal fiber reinforced natural rubber composites. Plastics Rubber & Composites Processing & Applications 1993; 20:93-9.

[60] Singh M, Garg M. Gypsum-based fiber-reinforced composites an alternative to timber. Construction & Building Materials 1994; 8:155-60.

[61] Hernandez OF, Oteiza IDe, Villanueva L. Fire behaviour of sisal short fibers reinforced gypsum. In Miraveter A, editor. Proceedings of the Ninth International Conference on Composite Materials (ICCM/9), vol. 5, composites behaviour, Madrid, 12±16 July 1993, p. 951-7

[62] Coutts RSP, Warden PG. Sisal pulp reinforced cement mortar. Cement & Concrete Composites 1992; 14:17-21.

[63] Mwafongo FG. Sisal-reinforced cement. Batiment International/ Building Research & Practice 1987; 20:241-2.

[64] Hernandez OF, Oteiza IDe, Villanueva L. Experimental analysis of toughness and modulus of rupture increase of sisal short fiber reinforced hemi hydrated gypsum. Composite Structures 1992; 22:123-37.

[65] Bissell TJ, Mutuli SM. The interfacial bond strength of sisal cement composites using a tensile test. Journal of Materials Science Letters 1982; 1:244-6.

[66] Swift DG. Sisal-cement composites and their potential for rural Africa. In: Marshall IH, editor. Composite structures 3, Elsevier Applied Science Publisher. London/New York: p. 774-87.

[67] Kalapradad G, Joseph K, Thomas S. Influence of short glass fiber addition on the mechanical properties of sisal reinforced low-density polyethylene composites. Journal of Composite Materials 1997; 31:509-26. 2054 Y. Li et al. / Composites Science and Technology 60 (2000) 2037-2055

[68] Kalaprasad G, Thomas S, Pavithran C, Neelakantan NR, Balakrishnan S. Hybrid effect in the mechanical properties of short sisal/glass hybrid fiber reinforced low-density polyethylene composites. Journal of Reinforced Plastics and Composites 1996; 15:48-73.

[69] Yang GC, Zeng HM, Jian NB, Li JJ. Properties of sisal fiber/ glass fiber reinforced PVC hybrid composites. Plastics Industry 1996; 1:79-81.

[70] Kim JK, Mai Y-W. Engineered interfaces in fiber reinforced composites. Oxford: Elsevier, 1998.