EXPERIMENTAL INVESTIGATION AND MODELLING OF MOISTURE ABSORPTION EFFECT ON PALMYRA FIBRE

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CERTIFICATE

I hereby declare that the dissertation entitled "experimental investigation and modelling of moisture absorption effect on palmyra fibre" is an authentic record of my work carried out as requirements for the award of the degree of Master of Engineering in Production Engineering at Thapar Institute of Engineering and Technology, Patiala under the supervision of Dr. Deepak Jain (Assistant Professor, Mechanical Engineering Department) and Dr. Tarun Kumar Bera (Associate Professor, Mechanical Engineering Department). No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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ABSTRACT

Studies on the use of natural fibres as replacement to man-made fibre in fibre-reinforced composites have increased and opened up further industrial possibilities. Palmyra fibre is used as a fibre reinforcement material. Natural fibres have the advantages of low density, low cost, and biodegradability. However, the main disadvantages of natural fibres in composites are the poor compatibility between fibre and matrix and the relative high moisture sorption. Therefore, chemical treatments are considered in modifying the fibre surface properties. In this research, the different chemical modifications on Palmyra fibres for use in natural fibre-reinforced composites are considered. Chemical treatments including 5%alkali, 1% stearic acid and 4% stearic acid are performed. The chemical treatment of fibre aimed at improving the adhesion between the fibre surface and the polymer matrix may not only modify the fibre surface but also improves the hydrophobic properties. Water absorption of composites is reduced and modelling analysis has been done using Abaqus.

Keywords Natural Fibre; Palmyra Fibre; Moisture Absorption; Chemical modifications; Mass Gain Analysis.

NOMENCLATURE

ae	Length
ab	Width
D	Coefficient of diffusivity
M_t	moisture content at the time (t) of diffusion in percentage
M_∞	saturated moisture content in percentage
Vc	Volume of matrix
Vf	Volume of the composite
w1	mass of dry samples
w2	mass of wet samples

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CHAPTER 1

INTRODUCTION

Fibre reinforced composites contain fibres which are surrounded by the matrix with different boundaries with them. Continuous fibre reinforcement provides the maximum improvement in mechanical and physical properties. Toughness, strength and stiffness of matrix also are increased in polymers with reinforcement as compared to without reinforcement [1]. The different layers of fibre reinforced composite laminate are shown in Figure 1.1. The Coupling agents and coatings are used to get better wet ability whereas fillers are used to improve dimensional stability.

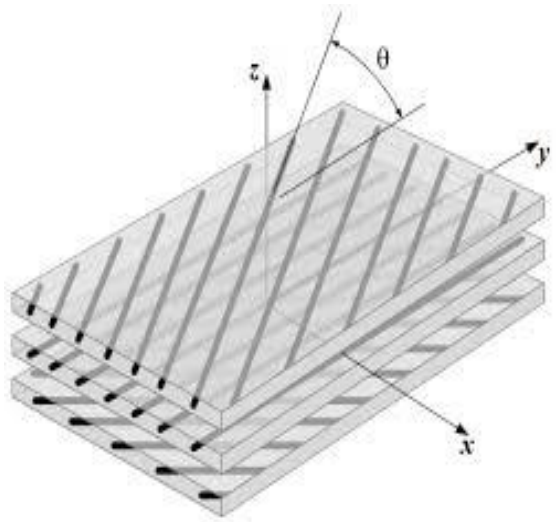


Figure 1.1 Different layers of fibre reinforced composite laminate [2]

1.1 INTRODUCTION TO NATURAL FIBRES

In recent years, the natural fibres have gained importance as strengthening in polymer composites. Natural fibres can be differentiating on the basis of their origin as they are produced from plants, animals and minerals, shown in Figure 1.2. The major drawback of these natural fibres is lack of availability in large quantities and with good moisture absorption and mechanical properties. Palmyra fibre is easily available in southern parts of India and having low cost. Palmyra fibre has also good moisture absorption properties. Moreover, these fibres are modified or prepared according to the required applications.

According to different climatic zones, there will be diversity in shapes and forms of natural fibres. Natural fibres can be used in the form of filaments and ropes. They can also be used as constituent of composites and also be used in the form of matted sheets to make other

products. Nowadays, natural fibres are used as raw material in textile, building, plastics and automotive industries [3].

(a) (b)

Figure 1.2 Natural fibres (a) Bamboo and (b) Agave Americana [4]

1.2 SOURCES OF NATURAL FIBRES

Natural fibres can be divided according to their sources.

1.2.1 Vegetables Fibres

The main component of vegetable fibre is cellulose base and lignin. For example- cotton, jute, flax, sisal and hemp. Vegetable fibres can be further divided into following types:-

- Leaf fibre: these are obtained from cells of the leaf, e.g. banana, pine needles
- Seed fibre: these are obtained from seeds of plants, e.g. cotton and kapok as shown in Figure 1.3
- Skin fibre: these are obtained from skin or the stem of the plant. They are having tensile strength higher than other vegetable fibres. Example- jute, kenaf and soybean fibre
- Fruit fibre: these fibres are obtained from the fruit of plant such as coir fibre
- Stalk fibre: these fibres are the trails of the plant, for example, From wheat and rice [5]

1.2.2 Animal Fibres

Animal fibres (Figure 1.4) are natural fibres are which obtained from animals. These fibres contain particular Proteins, for example:-silk, hair/fur and feathers. Some of these fibres are discussed further.

(a)

(b)

Figure 1.3 Vegetable Fibres (a) Kapok and (b) Cotton

- Wool: This is obtained from fur of animals, especially from sheep, shown in Figure 1.4(a) [6]
- Silk: Silk is a smooth and lustrous fibre. Silk fibre is obtained from the insects but mostly used commercial silk comes from the caterpillars, is shown in Figure 1.4(b)
- Avian fibre: Fibres obtained from birds, for example, feathers and feather fibre [6]

(a)

(b)

Figure1.2 (a) Wool Fibre from sheep and (b) Silk Fibre from caterpillar

1.3 TYPES OF FIBRE REINFORCED COMPOSITES

The most common fibres which are used as fibre reinforcement are carbon fibres, glass fibre, natural fibres etc. In addition to matrix, the fibre will be selected by the required application.

1.3.1 Carbon fibres

Carbon fibre composites are considered as high temperature materials as a mixture with carbon matrix. Carbon fibre reinforced composites (CFRPs) play an important role in

aerospace development as they are the light weight, high stiffness materials and replacement of conventional metals. As the modulus increases, the fibres tend to get more costly, harder to handle and more brittle. For the intermediate modulus, tensile strength of the carbon fibres is greatest.

1.3.2 Glass fibres

In glass fibres, glass has been spun into the fibres. Glass fibres having high strength, flexibility, stiffness and most importantly conflict to chemical harm. The intrinsic properties of different classes of glass fibres are discussed below in Table 1.1.

Table 1.1 Physical properties of glass fibres [7]

Classes of GFs	Physical properties
Glass A	High toughness and electrical resistivity
Glass R	High deterioration resistance
Glass AR	Low dielectric constant and corrosion resistance

1.3.3 Natural fibre reinforced composites (NFRC)

Natural fibre reinforced composites are a composite material in which matrix surrounded with natural fibres, for example palmyra, Agave Americana,pine needles etc. Mainly, polymers are divided into two categories, thermosets and thermoplastics. Thermoplastics matrix materials are made of one or two dimensional molecules, which have tendency to be softer on heating and get back to their properties on cooling. On the other hand, thermoset polymers are highly cross linked polymers. Thermoset set polymers have very high flexibility and modulus. Characteristics and performance of natural fibre reinforced composites are exaggerated with the factors, i.e. hydrophilic nature of natural fibres and fibre loading. To get good properties of NFRCs, high fibre loading is a must. The chemical constitution of natural fibres has an impact on the properties of NFRCs. The chemical composition of some natural fibres is shown in Table 1. 2.

1.3.4 General characteristics of Natural Fibre Reinforced Composites

The properties of NFRCs differ according to the fibres, sources and moisture conditions. The strength and performance of natural fibre reinforced composites depends on factors like the microfibrillar angle, structure, interface bonding between matrix and fibre, chemical properties and cell dimensions. Usually natural fibres show hydrophilic nature due to the

occurrence of hydroxyl group which is the drawback of natural fibres. There are some other factors which affect the performance of NFRCs.

(a) Orientation of Fibre

The orientation of natural fibres plays important role in controlling moisture diffusion and mechanical properties of composites. Generally, the fibres are oriented at 0°, 45° and 90°.

(b) Moisture Absorption

The natural fibres show hydrophilic nature in a humid environment. Swelling deformation and mechanical degradation are the damage variables in terms of moisture absorption. Unidirectional fibre reinforced composites show that if the matrix used is stiffer then it reduces the moisture diffusion in fibres [3].

(c) Volume Fraction

The volume fraction of fibres is describe as the ratio of fibre volume to the overall volume of composite.

$$Vf = \frac{Vf}{Vc} \tag{1.1}$$

Where *Vc* = the volume of the composite, *Vf* = the volume of fibre, *Vc* = the volume of matrix.

1.4 APPLICATIONS OF NATURAL FIBRE REINFORCED COMPOSITES

- NFRCs are used in furniture industry and textile industry.
- In construction industry such as roofing sheets, window frames, fencing, decking, shutting plate.
- These are also used in packing material, mobile cases and bags.
- In the automobile industry, NFRCs are used in making of floor mats, internal door paneling, rear storage and seat backs [3].

1.5 WHY NATURAL FIBRES??

The usage of natural fibres has increased gradually in the last few years. The main reason for using natural fibres compared to the synthetic fibres is an environmental concern, as natural fibres are biodegradable and come from renewable sources. If synthetic and natural fibres are compared on the basis of production then growing of jute fibres requires less than 10% of the energy used for the production of polypropylene. According to recent estimates, each year 35

million tons of natural fibres produced from plants, leaves, animals, birds, from the stalks of jute etc. Natural fibres are lighter in weight and lower in cost so they are economical and easy to handle, ship and transport. Natural fibres are superior to use in many ways as compared to synthetic fibres.

1.6 ADVANTAGES AND LIMITATIONS OF NFRCs

Table 1.2 Advantages and Limitations of natural fibre reinforced composites [3]

Advantages	Limitations
Production cost of natural fibres is lower than synthetic fibres.	Durability of natural fibres is less than synthetic fibres composites
High strength and stiffness	High moisture diffusion, which results in engorgement
Natural fibres are renewable resources, requires little energy for production	Lower strength
Less wear and tear to the machine while production of natural fibres	Larger inconsistency of properties
Low hazard during manufacturing process	Lower handing out temperatures

1.7 PALMYRA FIBRE

Palmyra palm is commonly known as *Borrassus Flabelliformis (*Figure 1.5*)* which is found in southern parts of India. Palmyra is a tough palm with age more than 100 years. Its height after full growth may go up to of 20 to 30 meters. The palmyra tree has a large trunk, ringed with leaf scars. There are 20 different types of species of palmyra fibre. But the commonly used species of fibres are Borrassus flabellifer (Palmyra palm).

The Palmyra fibre was established in mid of nineteenth century. The plant of palmyra palm fibre has a length of 65 foot. The palm tree produces a good volume of fibre if it is grown in hydromorphic soils. However, these trees also grew best in the environment which experiences high rainfall, high temperature and high moisture absorption. The surface structure of Raphia fibre is not symmetric.

Palmyra fibres leaves have size up to 25.11mm lengthy and 3mm wide. The palm trees can be divided into two categories, manocarpic and hepaxanthic. Manocarpic plants are those, which give flowers once and then die. Hepaxanthic plants are those whose being stems pass away after giving fruit but root system leftovers alive to generate new stalks.

1.7.1 Cultivation of palmyra petiole fibres

The palm tree is cultivated specially for harvesting. The Palm leaf fibres were dry in the sunlight after extracting from the fronds of the palm tree. These fibres are used to produce roof coverings, ropes, supporting beams, sticks, shoes and hats. The trunk of the plant is used in making thatch houses, furniture, carpets and baskets etc. In the paper industry, leaf fibres are used in the manufacturing of paper [9].

1.7.2 Extraction of fibre

Palmyra fibres can be extracted from the stalk, leaf, stalk of plant and fruit of the palm fruit tree. Different sources from which fibres can be obtained are shown in Figure 1.5(a). In previous years, Borrassus fruit and palm fibrous waste were used to make fibre reinforced composites. In recent research, a new natural fibre introduced named Palmyra petiole fibre as shown in Figure 1.5(b). Fibrous waste produced during separation of fibre from plant used for making fibrous waste reinforced polyester composites. The length of palmyra fibre is up to 50mm [10].

(a) (b)

Figure 1.5 (a) Different resources of fibres in Palmyra Palm tree and (b) Extracted 'Palmyra Palm Petiole' fibre (Borrassus Flabelliformis) [10]

1.7.3 Specifications of Palmyra fibre

The specifications of Palmyra fibres are given in Table 1.2.

Table 1.3 Specifications of Palmyra fibre

Property	Value
Length of fibre	1 to1.5 mm

Diameter of fibre	0.5 mm to 1.5 mm
Density	0.4- 0.6 g/cc
Tensile strength	70 MPa to 250 MPa
Shear strength	4 MPa
Modulus of Elasticity	2.5 GPa to 10 GPa

1.7.4 Constituents of Palmyra fibre

The main structural component of Palmyra fibre is cellulose, which provides strength to the fibre. Due to the large cellulose content, these fibres are suitable for paper industry. The further important component of these fibres is hemi-cellulose which is useful to produce ethanol and other fermentation products. Table 1.5 shows the comparisons of densities and moisture contents in some raw materials of fibres.

Table 1.4 Comparisons of densities and wetness content in some parts of fibres [9]

Part of fibre	Density (g/cm^3)		Wetness Content (%)
	accurate	clear	
Date palm leaf	1.44	1.21	6.8
Jute stick	1.21	1.10	15.2
Baggasse	1.35	1.16	13.4
Hardwood	1.38	1.19	12.1

- Plant considered as a rich source of gums, glycosides, carbohydrates, albuminoids, fats, vitamins A, B and C.
- Roots are high in carbohydrates
- Yielded flabelliferrins, a bitter compound of steroidal saponins.
- Spirosterol is a leading aglycone in odiyal flour and palmyra inflorescence.
- Studies have suggested that plant is anti- inflammatory, antibacterial, antioxidant, cytotoxic and anticancer properties [11].

1.8 SCOPE AND CONTRIBUTION OF THE THESIS

Scope of the current research mainly lies within the experimental and modelling validation of results with Abaqus tool. Though mass gain in Palmyra fibre reinforced composite have been measured using experimental set up i.e. Water Bath, Cryostat Bath and Environment

Chamber. Experiments have been done with NaOH and Stearic acid treated Palmyra fibres. The main contributions of the present work are pointed below:

- From chemical treatments of Palmyra fibres, hydrophobic properties of Palmyra fibres will be improved
- Modelling validation has been done to verify the experimental work
- Chemical treatments and their effect on mass gain in Palmyra Fibres are discussed in detail

1.9 ORGANIZATION OF THE THESIS

Outline of the thesis is described as follows:

Chapter 1 contains the introduction of fibre reinforced composites, natural fibres and types of natural fibres. Palmyra fibre is discussed in detail. Properties, limitations and constituent of Palmyra fibre are discussed in detail.

Chapter 2 contains the literature study. Literature study on numerous research papers was carried out focusing mainly in two areas: (1) Natural fibers and (2) Diffusion and moisture absorption in natural fibers (Palmyra fibers). Literature gap and objectives of current research are also discussed in this chapter.

Chapter 3 deals with the chemical treatments of Palmyra fibre. Further SEM analysis is also explained in this chapter.

Chapter 4 explains the fabrication procedure of specimens for untreated, alkali treated, 1% stearic acid treated and 4% stearic acid treatment. Graphical comparison of the results is also shown in this chapter.

Chapter 5 deals with the experimental and modelling validation of mass gain in different Specimens of Palmyra fibre with the help of Abaqus tool. Finite element analysis is also discussed in this chapter.

Chapter 6 deals with the conclusions of the Thesis.

CHAPTER 2

LITERATURE REVIEW

Literature study on numerous research papers was carried out focusing mainly in three areas: (1) Natural fibers and (2) Diffusion and moisture absorption in natural fibers (Palmyra fibers). Natural fibers easily available, recyclable and have low prices. Natural Fibre reinforced polymer composites developing an environment sociable material and replacing glass and carbon fibers. They are easily available, recyclable and have low prices.

2.1 LITERATURE REVIEW ON NATURAL FIBRES

An investigation has done to analyze the interfacial performances of natural fibers reinforced composites due to reduced interphase bonding between hydrophobic natural fibre reinforced composites and hydrophilic natural fiber reinforced composites. Chemical bonding and oxidation are types of fiber surface treatments to improve the interfacial bonding properties of these composites. Further research conducted to study polymer composite with 30% fiber loading shows improvement mechanical properties [12]. Study on the diameter, length and weight distribution of Borrassus Fibres (Palmyra) has been conducted. Alkali treatments with 5%, 10% and 15% solutions of NaOH have been done to investigate these properties. If the proportion of alkali treatment increases, the fibre diameter reduces. So, the diameter of fibre changes with respect to the percentage of NaOH solution. Table 2.1 and Table 2.2 show the effects of alkali treatment on the density and diameter of the fibres.

Table 2.1 Consequence of NaOH treatment on density of sisal fibre

Sl. No.	Fibre Type	Density (g/cc)
1	Raw fibre	1.2578
2	5% treated fibre	1.2610
3	10 % treated fibre	1.3012

An alkali treatment of the Borrassus fibres improves the density of fibres. Fourier-transform infrared spectroscopy (FTIR) analysis has been done to study the chemical composition of raw and alkali treated fibres. It confirmed that the alkali treatment removes impurities like hemi cellulose, lignin and other such impurities [13].

The study has been done on cellulosic pine needles fibers which are used as alternate synthetic fibers. Pine needles showed effective improvement in mechanical properties of composites. These are decreased if fiber loading is beyond 30%. The polymer matrix used in this study was Urea-Formaldehyde resin. It seems that coupling agent do not have any positive effect on all the fibers and polymer resins. Electrospun nano-cellulose loading gives better results if applied on the surface of nano-composites [14]. A research was conducted on the effect of non-uniform orientation of different natural fibers i.e. kenaf, banana and hybrid kenaf/banana composites. Result obtained from this research is that uniformly woven hybrid composites have high mechanical strength than non-uniformly woven hybrid composites. They also have studied energy absorption in failure mechanisms but damage sequence is still not verified. The investigation has also been done on the void content of natural fiber and matrix interface, if steady manufacturing processes are used, the space between the interface and bulk composites can be minimized. Subsistence of voids decreases the mechanical and physical properties of composites [15].The study has been done on Pine Apple Leaf fibres (PALF) and Kenaf fibres (KF) to investigate the improvement of their compatibility with polymer matrices. PALF and KF are treated with combination of 2% silane and 6% NaOH. SEM analysis was performed to compare the surface morphology of PALF and KF. SEM result shows that silane treated fibres have less impurities than other chemical treated fibres [16]. An investigation has been done to study the synthetic and natural fibre reinforced composites. Hand layup method is used to fabricate the composites of S- glass and E glass. Wet layup, vaccum sacking methods are used to make the composites of silk and epoxy. Results showed the filler material enhances the elasticity. The study confirmed that 33% by volume of silk fibres give more flexural quality [17].

Study the effect of fibre treatments on flexural strength and modulus of natural fibres has been conducted. Cellulose fibres are used as the main constituent of natural fire composites due to their low production cost, a large quantity of availability, low density, (20% by weight) after reinforced into nylon matrix. Table 2.4 shows the chemical treatments of plant fibres. Silane and alkali treatments have been done on the fibres. Silane treated fibres have greater flexural strength and high specific strength than alkali. The Reason behind this was that aspect ratio of silane treated fibres are higher than alkali treated fibres.

Alkali treatments were done with 5%, 6% and 10% strength. Combination of silane and alkali solution treatment gives better results than a single treatment. Physical treatments like enzymes and electron beam radiation is also done on fibres to study the effect on flexural

strength. Electron beam radiation treatment breaks down the properties of fibres due to over extraction of extractives of fibres [18].

2.2 LITERATURE REVIEW ON MOISTURE DIFFUSION IN FIBRES

Fick's law is normally insufficient for recitation water absorption in composites. So at high temperature and humidity conditions, Non- Fickian law is valid the coupled model methodology to examine the strain assisted diffusion from the basic principles of thermodynamics plays significant role towards modelling of bond degradation mechanism at the interface between Fibre reinforced composite and substrate [19]. The investigation has been done to evaluate the effect of coating fibres with acrylonitrile butadiene styrene to reduce the moisture absorption. Natural fibres deteriorate earlier as compare to synthetic fibres. To reduce the degradation, fibres are coated with acrylonitrile butadiene styrene. SEM analysis has been done to study the surface of fibres and their cross sections of coated and uncoated fibres. FTIR study has been done to compare the chemical bonding between coated and uncoated fibres. Results of both FTIR and SEM show that coating of fibres protects the surface of fibres. ABS (Acrylonitrile Butadiene Styrene) coated fibres show less moisture absorption due to coated layer [20].

Mechanical and moisture absorption properties, weight percentage and fibre length were studied using banana fibre composite. Table 2.5 shows the moisture diffusion and permeability coefficient of hybrid composite. From the interpretation of table 3, 50/50 hybrid composite shows lower water absorption. The hybridization of natural fibre with glass and carbon fibre gave better performance than hybridize with natural fibres. Morphological study of surfaces of fibres was carried out by SEM [21]. Observation has been done on moisture adsorption with Fickian equation in natural fibers (caroa and macambira) reinforced with unsaturated polyester composites, with the help of theoretical and experimental techniques. A mathematical model is anticipated and numerical finite method was used to solve the mathematical equations. Experimentation has been done by dipping the samples in water bath at different temperature conditions.

Mass gain is calculated by using the relation given as

$$\% \text{ of moisture absorption} = \frac{w2-w1}{w1} \quad (2.1)$$

Where w1= the mass of dry samples

w2 = the mass of wet samples.

Moisture diffusion influenced with different temperature conditions and fiber loading also effects the moisture diffusion in fiber reinforced composite. Further research has been done on cured Carbon Fiber composites to study the water absorption effect on mechanical properties of reinforced fiber composites. With the help of this indenter drop in stiffness of CFRP plates are also measured [22]. Study has been done to reduce the moisture absorption in jute- epoxy composites. Jute fibers are treated with alkali solution, then fabricated and coated with acrylic paint to reduce the absorption of water on the surface of the composite. After fabrication of alkali treated fibers, samples are immersed in distilled water bath for 28 days. Variation of pH value of NaOH solution also influenced the water diffusion in jute-epoxy composites. Samples are also immersed in pH 4, 7 and value of NaOH solution. Results show that acrylic paint acts as good moisture resistant [23].

Study has done to find the consequence of different surface treatments performed on the surface of natural fibres. Natural fibres have high moisture property, which is their major drawback. Bonding strength is also improved, so that dimensional stability of fibre reinforced composites increases and reduces the moisture absorption. Alkali, silane, acrylation and Isocyanate are some chemical treatments used to improve the properties of fibres.

Fiber orientation plays an important role in moisture diffusion. Simulation has been done by arranging the fibers were arranged in different orientations using finite element method. Microstructures of fibers with different orientations have also been studied and then analysis of saturation time has been done. A single filament of fibers and clusters of fibers used to check moisture diffusion. The results show that moisture absorption can be controlled with the layout of fibers in the matrix. Bulk and minority of fibers do not influence the moisture diffusion .If fibers are oriented at 0° C and 90°C then showed greater resistant to moisture rather than randomly oriented fibers [25].

Table 2.2 Moisture content in different natural fibres

Name of the fibre	Jute	Flax	Hemp	Ramie	Sisal	Palm	Cotton
Moisture content	12.6	10.0	10.8	8.0	11.0	11.8	33-34

Determine the fiber volume fractions of glass fibers reinforced with ortho-phtalic polyester resin. Fiber volume fraction was varied from 40% to 70% and neat resin specimens also observed. Comparison of moisture absorption parameters were done by using solution

provided by Crank [26]. Hygrothermal degrading test was performed to investigate the consequence of water and temperature on Polylactic and sisal composites. Amount of sisal fibre in a composite was also studied. Observations revealed that swelling between fibre and matrix due to water sorption weakened the surface of the composite. Adding of sisal fibre decreases the water diffusivity in composite due to their greater ability to resist water diffusion. The following equation was used to examine the diffusivity of composite:-

$$\frac{Mt}{Ms} = \frac{4}{l}\left(\frac{Dt}{\pi}\right)^{1/2} \tag{2.2}$$

Where D is the diffusion coefficient, Mt/Ms represents the ratios of square root of time.

$$\text{Usually,} \quad \frac{Mt}{Ms} \leq 0.5 \tag{2 .3}$$

Results show that composition of composite and hygrothermal ageing temperature shows small difference on the addition of coupling agents. The difference was higher above the glass transition temperature [27].The moisture absorption of unidirectional fibres was studied. A three dimensional model was developed. 3D modelling analyzes the stress along the fibre length. It was observed that the variation of boundary conditions has a remarkable effect. Stresses are calculated through well known Finite Element Analysis. The comparison of the stresses along fibres calculated through Finite element analysis and CCA model. Results confirmed that CCA model show good concurrence than Finite Element Analysis [28].

Investigation has been carried on studied the hygro-thermal ageing effect on fatigue bending and quasi- static behaviors of the composite. The composite was made replace the use of Nylon in the manufacturing of spur gears. On the completion of hygrothermal ageing, aged and un- aged specimens were compared. Results showed that hygro-thermal ageing have no considerable effect on flexural properties of High density Polyethylene and Short Birch Fibres composite. The reason behind the poor durability was analyzed by performing FTIR, Thermogravimetric analysis and SEM analysis [29]. To formulate the non- linear constitutive model for natural fibre composites under humidity conditions, the theoretical model describes the inelastic deformation and moisture diffusion in fibres. Theoretical and experimental results were compared to check their temperature dependency, durability during the entire hygrothermal ageing process. In addition to the comparison of theoretical and experimental data, this model also identifies the evolution of elastic modulli, volumetric swelling and diffusion of water molecules [30].

2.3 OBSERVATIONS FROM LITERATURE

After the detailed study of different research papers and books related to natural fibres and natural fibre reinforced composites, it is observed so as there are many different ways to improve the hydrophobic properties of fibres. Most of the research has been done on the chemical treatments of fibres. In chemical treatments, they were focused on alkali treatment but very few attempts have been made on treatment of Palmyra fibres with stearic acid.

2.4 OBJECTIVES OF PRESENT RESEARCH

After studying literature on Natural Fibres it is also observed that very few attempts have been made on modelling and validation of results with experimental results. Therefore, the objectives of the current thesis work are:

- To analyze the moisture absorption behavior of Palmyra Fibre Reinforced Composites
- To analyze the behavior under temperature conditions and atmospheric conditions (0°C, 25°C, 50°C, 75°C, 25°C/70%RH, 50°C/70%RH and 75°C/70%RH)
- To compare the results of untreated, Alkali treated, 1% stearic acid treated and 4% stearic acid treated specimens of Palmyra Fibre Reinforced Composites
- To validate the experimental results and modelling results with the help of Abaqus Software

CHAPTER 3

FIBRE TREATMENT OF PALMYRA FIBRES

Natural fibres are known to have high moisture absorption characteristics. It is the major disadvantage of natural fibers which restricted the use of these fibers in commercial applications. In addition, they also have low dimensional stability. In order to improve their dimensional stability and to reduce moisture absorption capacity, the chemical treatment of natural fibers is necessary. These treatments are expected to improve the durability with reduced moisture ingress. Historically, several methods of fibre treatments are proposed. In this work, Palmyra fibres were considered and were subjected to three different fibre treatment methods. All these methods are explained in subsequent sections.

3.1 Alkali Treatment

The Palmyra fibres (50% w/v) were soaked in 5% NaOH solution. Fibres were immersed in 5% NaOH solution for one hour at room temperature. After one hour, fibres were carried out from the solution and were cleaned with distilled water to get rid of the leftover traces of NaOH if these traces were still stick to the surface of fibres. Finally, fibres were dried for 24-48 hours at room temperature (Figure 3.1). Before the alkali treatment, fibres were straight and smooth but after the treatment, they formed rough surface [13].

(a) (b)

Figure 3.1 (a) Fibres before alkali treatment and (b) Fibres after alkali treatment

3.2 ONE PERCENT STEARIC ACID TREATMENT

Stearic acid treatment provides fatty acid layer on the fibre surface. The presence of this layer reduces the water retention inside the fibres. This treatment provides non-toxic and

long lasting solution to improve the moisture barrier properties. Stearic acid treatment is expected to improve the stability of Palmyra fibres.

Towards this treatment, Palmyra fibres were immersed in 1% concentration solution (w/v) of Stearic acid in ethanol. The solution consists of 1 g of stearic acid and 100 ml of ethanol. The fibres were kept in stearic acid solution for 0.5 hr at room temperature, then taken away the fibres from solution and dried in furnace for 0.5 hr at 100°C. After drying, the fibres were kept in sealed packets in dark area until they were fabricated. The texture of fibres after drying is shown in Figure 3.2.

Figure 3.2 Fibers after 1% stearic acid treatment

3.3 FOUR PERCENT STEARIC ACID TREATMENT

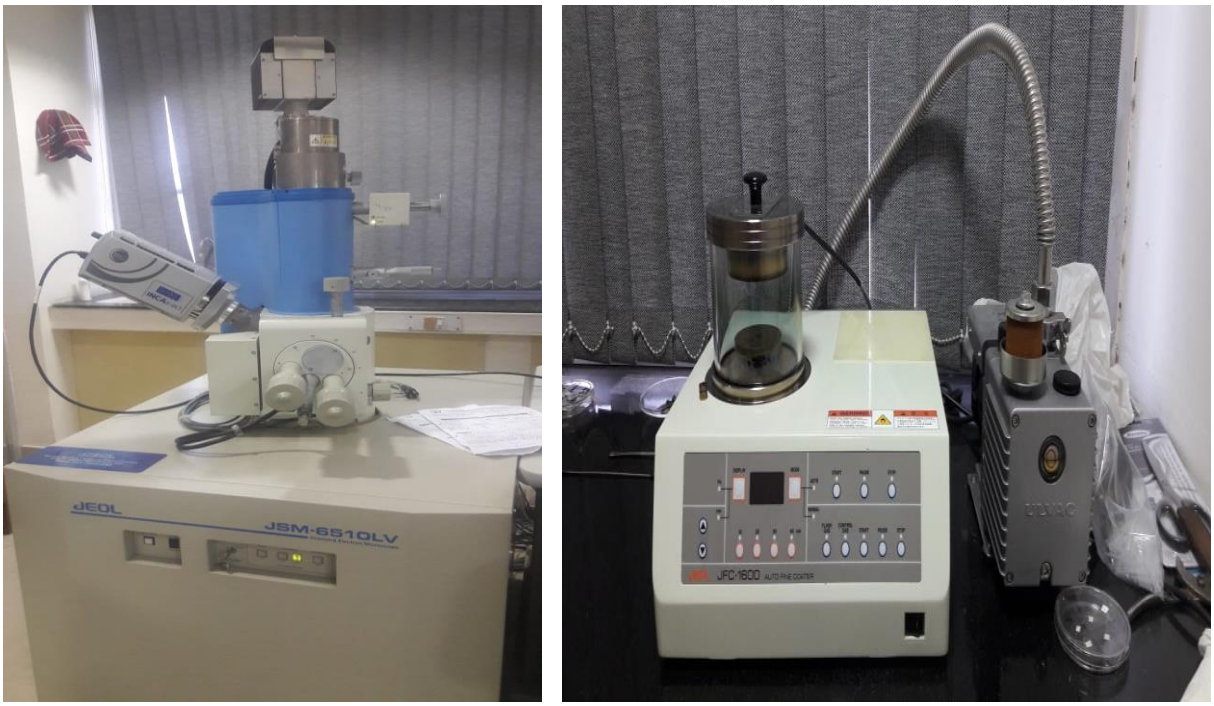
Fibres were treated with 4% concentration solution of stearic acid in ethanol. The solution consists of 4 g of stearic acid and 400ml of ethanol. Fibres were soaked in solution for about half an hour and then taken out. Finally, fibers were dried in furnace for 1 hour at 100°C. The fibres after taken away from the furnace are shown in Figure 3.3.

Figure 3.3 Fibres after 4% stearic acid treatment

As discussed above, stearic acid provides the fatty layer on surface of fibre which reduces the moisture absorption in fibres. The effect of increased concentration of Stearic acid on the moisture ingress inside the fibre matrix composite fabricated using these fibres was observed [24].

3.4 SCANNING ELECTRON MICROGRAPHICAL STUDY (SEM)

The cross section of the Palmyra fibres are analyzed with the help of JSL6510LV Scanning Electron Microscope (made in Japan). The instruments for analysis and coating are shown in Figure 3.4(a). The untreated and treated fibres are cut into the size of holder and dried at room temperature for 24 hrs. The pieces of fibre are build up on metal studs for 1 hr using a JFC 1600 Auto Fine Coater which is shown in Figure 3.4(b). This coater is used for preparing the specimens for SEM observation.



(a) (b)

Figure 3.4 (a) SEM testing machine and (b) Coater used for preparing the specimens

The ability to efficiently and accurately characterize the cross sectional area of fibres is critical. From the SEM images, it is assumed that fibre cross section is uniformly circular. Figure 3.5 and 3.6 shows the SEM images of treated and untreated Palmyra fibres.

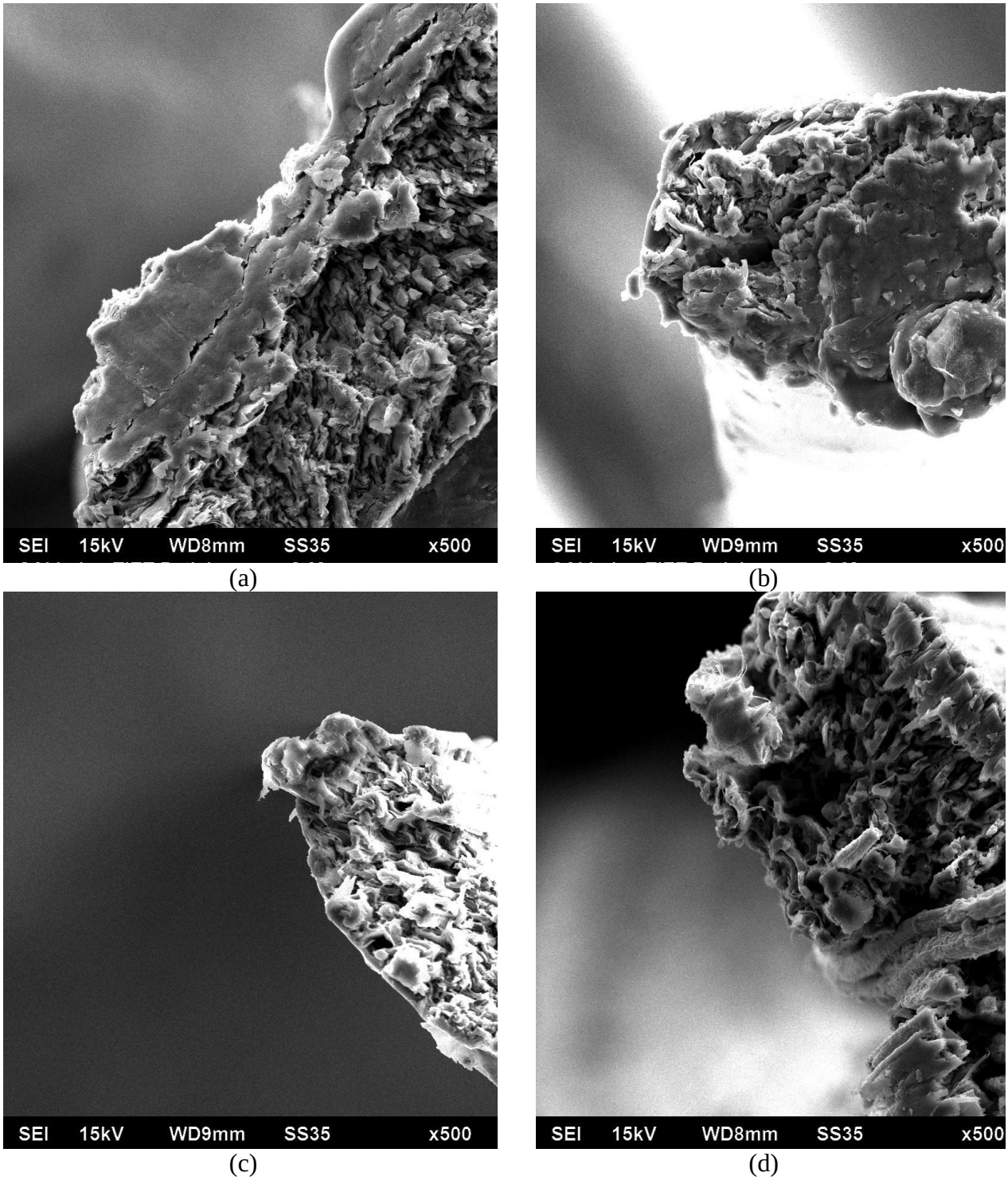


Figure 3.5 Cross section of treated and untreated Palmyra fibres: SEM image of (a) untreated fibres, (b) 5% Alkali treated fibres, (c) 1% stearic acid treated fibres and (d) 4% stearic acid treated fibres. (Line Scale 50µm)

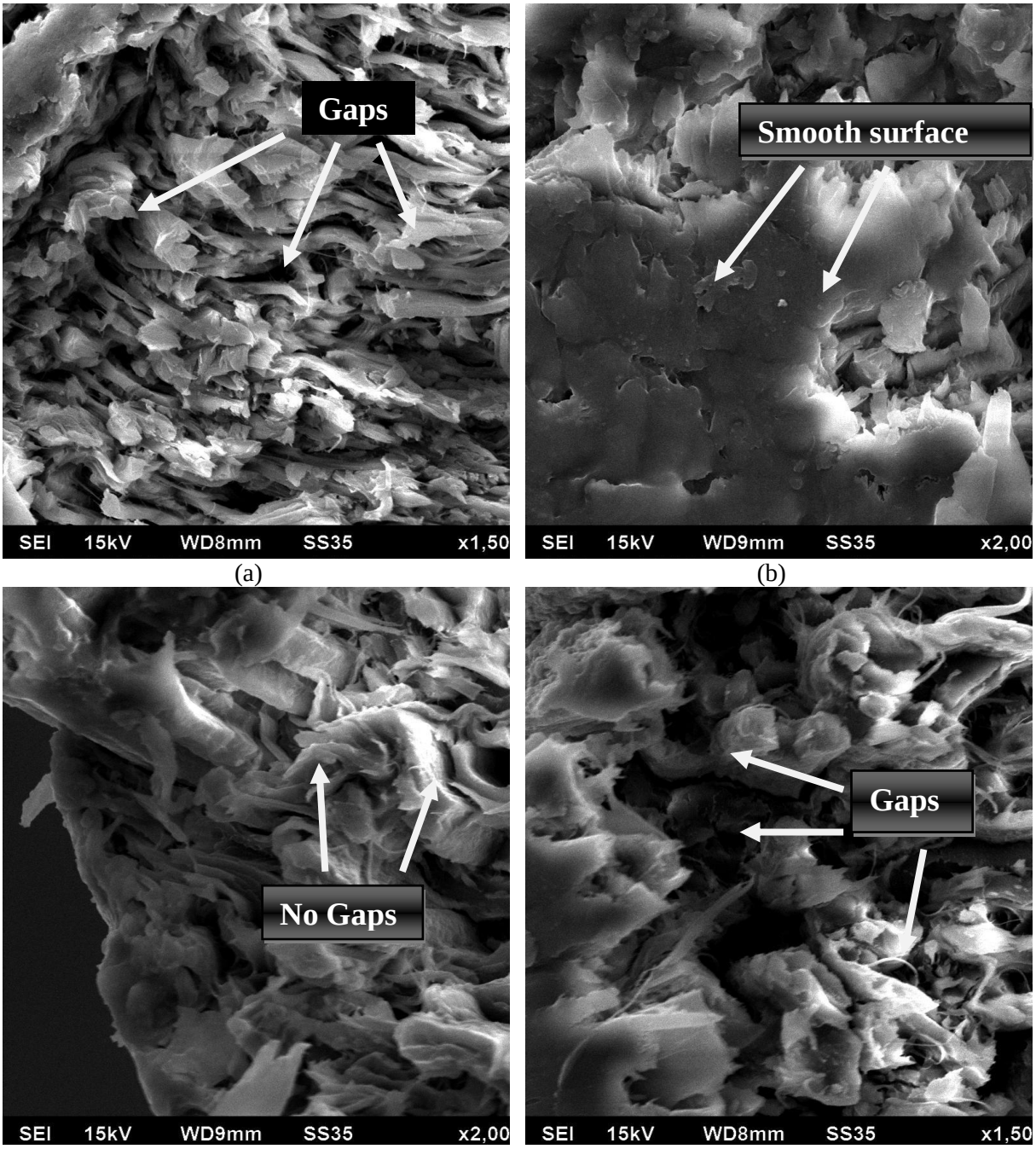


Figure 3.6 Magnifying images of Palmyra fibres: (a) Untreated fibres, (b) 5% Alkali treated fibres, (c) 1% stearic acid treated fibres and (d) 4% stearic acid treated fibres (Line scale 10µm)

CHAPTER 4

FABRICATION OF COMPOSITE USING NATURAL FIBRE

4.1 HAND LAY UP PROCESS

Hand lay -up technique is the simplest, common and least expensive molding technique. It requires minimal infrastructure and equipment. This method is suitable for making wide variety of products from. The steps for the hand layup process are quite simple. First step is applying release gel on the mould surface to make it free from sticking of composite sheet. Instead of mould surface, Teflon sheets can be used because these are non adhesive and does not require any release gel. Then mix the epoxy and hardener liquid in an appropriate proportion and poured on the Teflon sheet or on the mould surface. The epoxy resin is uniformly spread over the sheet using brush. Then place second layer of woven mat of fibre and then again apply the layer of epoxy. This process will go on until required thickness will be achieved. After applying final layer of epoxy, pressure is applied. Then cure the sheet at room temperature or at some other specific condition or temperature. After curing, the developed composite part is taken out and further cut into required sizes. Schematic detail of hand layup is shown in. Curing time depends upon the type of composite. For epoxy resin based curing time is generally lies between 24 to 48 hours. Epoxy resin is used for the thermosetting polymers. A hand layup method has applications in the areas like boat hulls, automobile parts, aircraft components *etc* [31].

4.2 MATRIX MATERIAL

The matrix system consists of a high viscosity, transparent texture epoxy resin LY 556 and a room temperature curing hardener HY- 951 (Figure 4.1). The epoxy and hardener has been purchased from the Excellence Resins, Meerut.

4.2.1 Properties of epoxy

Epoxy content (ISO 3000)	5 kg
Viscosity at 25° C (ISO 12058- 1)	12000 (MPa s)
Density at 25° C (ISO 1675)	1.15-1.20 (g/cm^3)

- Transparent in color
- Anhydride and have low viscosity
- Good fibre impregnation properties [32].

Figure 4.1 Epoxy Resin LY 556 and Hardener HY 951

4.2.2 Properties of Hardener

- Low viscosity
- Good mechanical strength
- Excellent resistance to the chemical and atmospheric degradation

4.3 PREPARATION OF SPECIMENS

The specimen required for experimentation is made-up by hand layup process. Palmyra fibres are used to prepare the specimen. The composite specimen consists of total 3 layers. At first, the epoxy resin is mixed with hardener in the proportion of 10:1 by weight and mixed for 5 minutes so that the mixture thoroughly blended as shown in Figure 4.2(c). Then the Teflon sheet is cleaned properly to make it free from moisture and other foreign particles as shown in Figure 4.2 (d). After that, epoxy resin spread on the Teflon sheet with the help of brush. The quantity of the epoxy used is 233g in accordance to maintain the ratio 3:7 between fibre and epoxy (ASTM standards). After that, 50g Palmyra fibres are taken and distributed unidirectional on the epoxy layer with the help of blush and roller as shown in (Figure 4.2a). After putting top layer of resin, laminated sheet is placed under uniformly distributed load at a room temperature for curing, shown in Figure 4.2 (a).

Laminated sheets were cured for 48 hours under room temperature. Cured sheets are shown in Figure 4.3 (b). Below mentioned steps are used for the fabrication of untreated fibres and same can be used for alkali treated fibres, 1% stearic acid treated and 4% stearic acid are fabricated following the same steps [33].

(a)

(b)

(c)

(d)

(e)

(f)

Figure 4.2 Detailed sequence of fabrication of specimens (a) 50 grams bundles of fibres used in one layer, (b) Epoxy and hardener used, (c) Mixture of epoxy and hardener, (d) Applying first layer of epoxy on teflon sheet, (e) Layer of fibres on epoxy resin and (f) Roller to spread the epoxy uniformly

(a)

(b)

Figure 4.3 (a) Uniform load applied on sheet to be cured and (b) Cured sheet after 48 hours

4.4 FABRICATION DETAILS

Table 4.1 Summarized fabrication details of fibre composite

Palmyra fibre	30 g
Palmyra fibre ratio	50% by weight
Epoxy with hardener	10:1
Fibre to epoxy	3:7
Temperature	Room temperature

4.5 SIZE OF LAMINATE

Initially we take untreated Palmyra fibre, which is fabricated into the form of sheet. The Palmyra fibre reinforced composite material is cut into the dimensions as mentioned below.

Width = 25mm, Length = 75mm, Thickness = 5mm

The dimensions of the specimen are taken according to ASTM D3039. The final specimens of untreated fibres are shown in Figure 4.5.

Figure 4.4 Untreated specimens

Similarly, composite sheets of alkali treated fibres, 1% stearic acid treated fibres and 4% stearic acid treated fibres are made. After that sheets are cut in same dimensions as shown in Figure 4.6 (a-d).

(a)

(b)

(c)

(d)

(a)

(b)

(c)

(d)

Figure 4.5 (a) Untreated samples, (b) 1% stearic acid treated samples, (c) 5% NaOH treated samples and (d) 4% stearic acid treated samples

4.6 EXPERIMENTAL SET UP

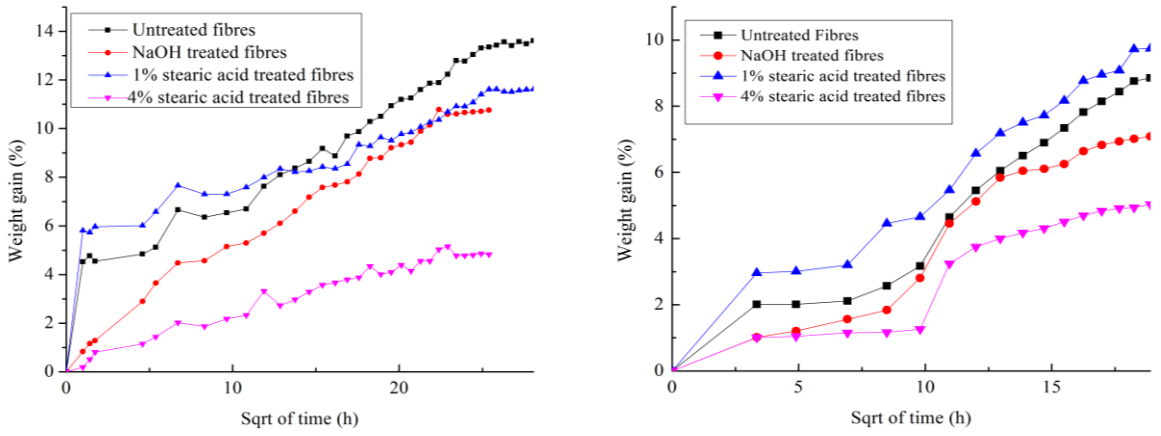
4.6.1 Water Bath

Water bath is a device that maintains water at a constant temperature (Figure 4.7(a)). It is fabricated of insulated material and thermostat to maintain the temperature.

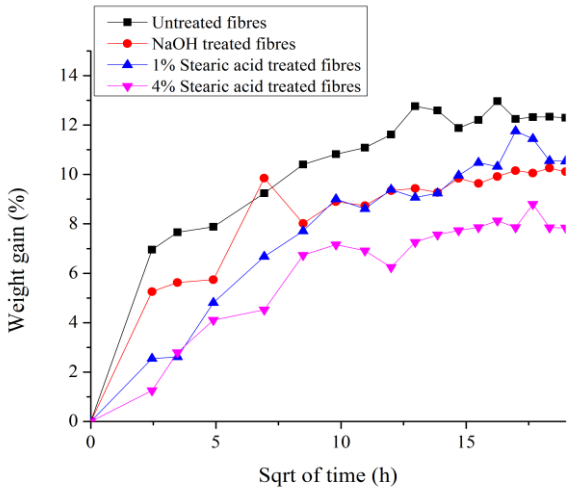
(a) (b)

Figure 4.6 (a) Water bath chamber and (b) Specimens in water bath chamber

For carrying out experimental work, the working conditions for the fibre reinforced composites are 25°C, 50°C and 75°C. The specimens are kept in water bath under these temperatures as shown in Figure 4.7b. At 25°C, the specimens have taken 25 days to be saturate. At 50°C, the specimens have taken 15 days and at 75°C the specimens have taken 7 days to be saturated. Mass gain was measured for all the specimens. In starting, it is measured with the difference of 2 hours. After attaining the trend of curve, mass gain of the specimens was measured after 24 hours. Comparison of experimental results of water bath specimens is shown in Figure 4.8. The graphs interpret that mass gain is lowest in 4% stearic acid and highest in untreated fibres.



(a) (b)



(c)

Figure 4.7 Experimental results of mass gain of water bath chamber: (a) Mass gain at 25°C, (b) Mass gain at 50°C, and (c) Mass gain at 75°C

4.6.2 Cryostat Bath

Cryostat bath is a device used to maintain low cryogenic temperatures i.e. 0°C or below 0°C is shown in Figure 4.9. Mass gain of specimens is observed under 0°C and these specimens have taken 30 days to get saturated. Mass gain curve for 0°C is shown in Figure 4.10.

Figure 4.8 Cryostat Bath

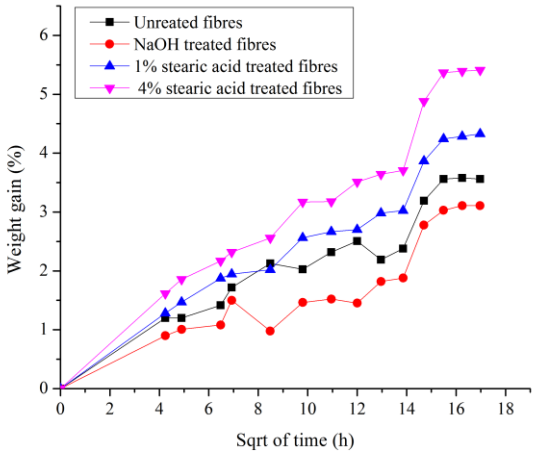


Figure 4.9 Mass gain curve at 0°C

4.6.3 Environment Chamber

An environment chamber is a climatic chamber used to test the effects of specific environment conditions and humidity conditions (Figure 4.11a). Specimens were kept under the temperature conditions at 25°**C,** 50°C and 75°C with 75% fixed relative humidity as shown in Figure 4.9b.

(a) (b)

Figure 4.10 (a) Environment Chamber and (b) Specimens in Environment Chamber

The experimental results of environment chamber are shown in Figure 4.12. Graphical data represents that stearic acid treated specimens with 4% concentration shows lowest mass gain as compare to other specimens.

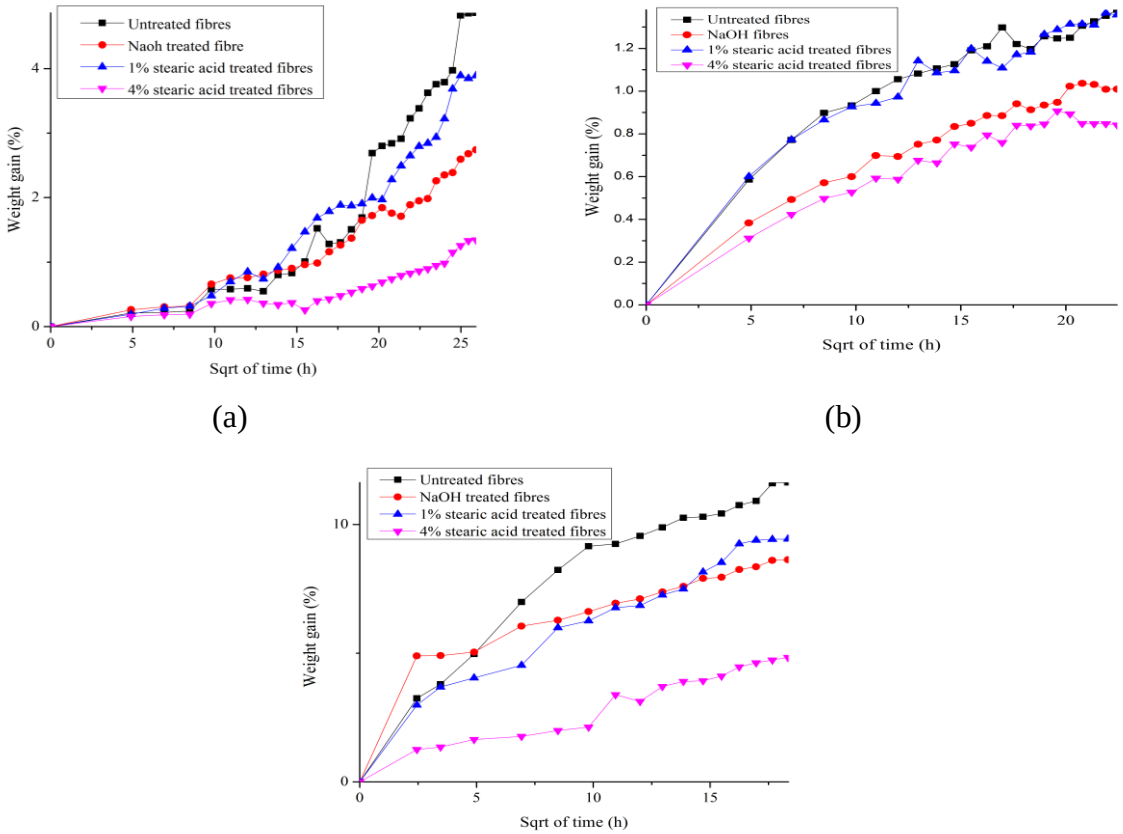


Figure 4.11 Experimental results of mass gain curve of Environment Chamber (a) Mass gain at 25°C, (b) Mass gain curve at 50°C and (c) Mass gain curve at 75°C

CHAPTER 5

FINITE ELEMENT ANALYSIS FOR MOISTURE DIFFUSION

5.1 INTRODUCTION

Finite Element Analysis (FEA) makes possible, dividing the system into small sections and analyzing each section. The system as a whole made up of tiny sections. The degrees of freedom, where at one point the various independent movements are possible which are represented by nodes. The corners of the elements are called nodes. Type of element is depends upon the characteristic of original structure. For one- dimensional structure, line elements will be used. The summarized steps for Finite element model are shown in Figure 5.1. For two-dimensional structures, triangular or quadrilateral elements will be used.

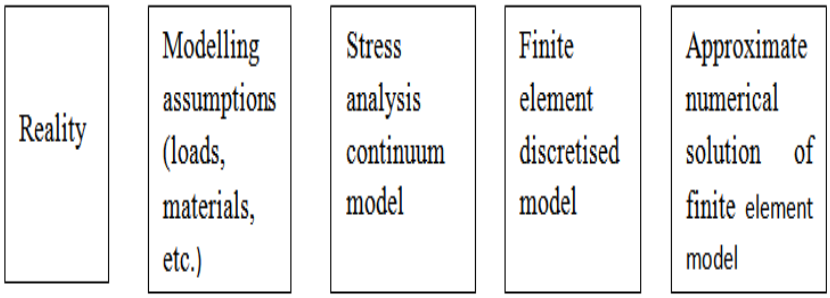


Figure 5.1 Summarized steps of FEM model

Then corresponding equations are formulated according to the corresponding loads. Firstly equations are solved for primary unknowns and then for secondary unknowns (like diffusivity and solubility). These results are generated for each node. Nodes are shown in Figure 5.2. Preprocessing, analysis and post processing are three main steps involved in Finite Element Analysis. Geometry is created at first step and then results are generated at second step and in last step interpret results in graphical form.

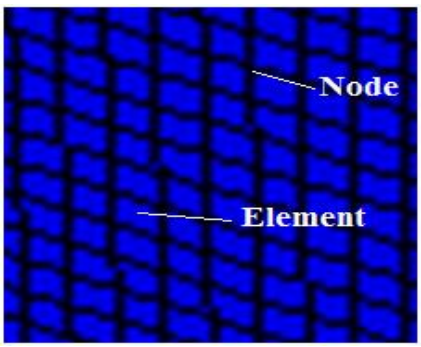


Figure 5.2 Magnifying view of meshed model showing elements and nodes

5.2 FICK'S SECOND LAW

Fick's second law of diffusion describes the diffusion kinetics, where the concentration changes with time. In three dimensional space, it can be written as:

$$\frac{\partial c}{\partial t} = D.\frac{\mathrm{d}^2\mathrm{c}}{\mathrm{dx}^2} \tag{5.1}$$

Where, $\frac{\partial c}{\partial t}$ = Change in concentration

D = Coefficient of diffusivity

5.3 DIFFUSIVITY CALCULATIONS

Moisture absorption behavior of fibre reinforced composite is generally calculated by the Fick's law of diffusion. The solution of Equation (5.1) gives the mass uptake M_t of a fibre reinforced composite in humid condition. This is given by

$$\frac{M_t}{M_\infty} = 1 - \sum_0^\infty \frac{8}{(2n+1)^2\pi^2} \exp[-\frac{(2n+1)^2\pi^2 t}{(2l)^2}] \tag{5.2}$$

Where M_t = moisture content at the time (t) of diffusion in percentage,

M_∞ = saturated moisture content in percentage,

l = half of the composite laminate thickness.

A plot of $\frac{M_t/\%}{M_\infty/\%}$ versus $\frac{\sqrt{t/s}}{2}$ is linear at the starting stage and the diffusivity can be calculated from its slope, but it is below $\frac{M_t/\%}{M_\infty/\%} \leq 0.5$.

For $\frac{M_t/\%}{M_\infty/\%} \leq 0.5$, Equation (5.2) can be rewritten as

$$\frac{M_t}{M_\infty} = 4[\frac{Dt}{\pi(2l)^2}]^{1/2} \tag{5.3}$$

The diffusion coefficient, D, is calculated from the plot $\frac{M_t/\%}{M_\infty/\%}$ versus $\frac{\sqrt{t/s}}{2}$ using equation (5.4).

$$\mathrm{D} = \frac{\pi}{16}[\frac{M_t/\%}{M_\infty/\%} . \frac{2}{\sqrt{t/s}}]^2 \tag{5.4}$$

5.4 MODELLING PROCEDURE

To validate the experimental approach a model was developed (refer Figure 5.3). In its simplest initial version, model represents a 3D geometry of specimen and is applicable to the simulation of diffusivity of fibre reinforced composite.

The procedure is explained below:

1) Creating Model: The model is based upon the Fickian law of diffusion. The 3 D model was created according to the Fickian Law of Diffusion. Using sketcher module of Abaqus, created the geometry of model which is shown in Figure 5.3. The rectangle is selected to draw a model then extrude it to attain 3 D model of fibre reinforced composite. The dimensions of the below model are ae= bf= cg= dh =75mm, fh= eg= ac= bd= 25mm and ab= cd= gh= ef= 5mm.

2) Creating Material: The composite considered at this time is Palmyra fibre reinforced composite which is made up of Palmyra fibre and epoxy matrix. So the mass diffusion properties are defined for Untreated, alkali treated, 1% stearic acid treated and 4% stearic acid treated composites at various temperature conditions i.e. 25°C, 50°C, 75°C (water bath chamber and environment chamber) and 0°C (Cryostat bath). In environment chamber, Relative humidity is 70%RH for the temperatures (25°C, 50°C and 75°C).

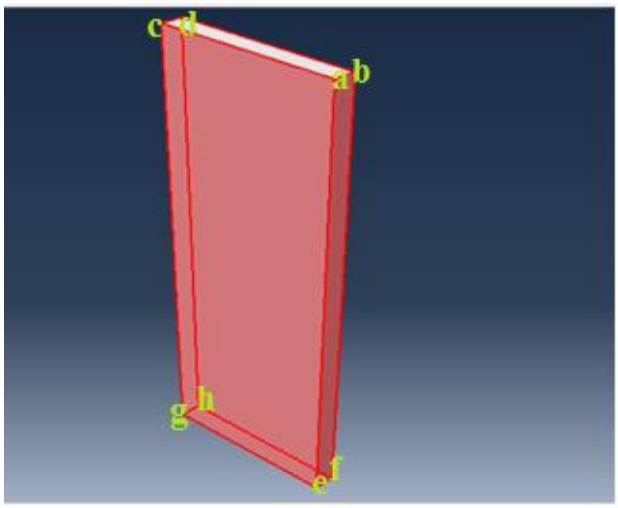


Figure 5.3 3D Model of Palmyra fibre reinforced composite

3) Creating and Assigning Sections: Sections are defined in order to assign properties to the particular model. After sections were created, they were assigned along with material properties to the composite (Untreated, alkali treated, 1% stearic acid treated and 4% stearic acid treated).

Table 5.1 Diffusivities of specimens at different conditions

Type of specimen	Diffusivity						
	Cryostat Bath		Water Bath		Environment Chamber (70%RH)		
	0°C	25°C	50°C	75°C	25°C	50°C	75°C
Untreated	1.004×10^{-12}	5.411×10^{-13}	1.802×10^{-12}	8.352×10^{-12}	3.262×10^{-13}	1.533×10^{-13}	2.720×10^{-12}
5% alkali treated	4.810×10^{-13}	5.248×10^{-13}	1.326×10^{-12}	6.592×10^{-12}	1.999×10^{-10}	2.653×10^{-14}	3.127×10^{-12}
1% Stearic acid treated	8.343×10^{-13}	1.528×10^{-8}	1.920×10^{-12}	4.247×10^{-12}	6.686×10^{-13}	2.853×10^{-14}	2.092×10^{-12}
4% stearic acid treated	4.071×10^{-13}	5.282×10^{-13}	1.597×10^{-12}	5.593×10^{-12}	4.229×10^{-13}	1.436×10^{-14}	2.09×10^{-12}

4) Meshing: After assigning sections we need to mesh the model so as to analyze it. Now seeding is required before meshing in order to decide the size of meshing. Meshing of model is shown in Figure 5.4.

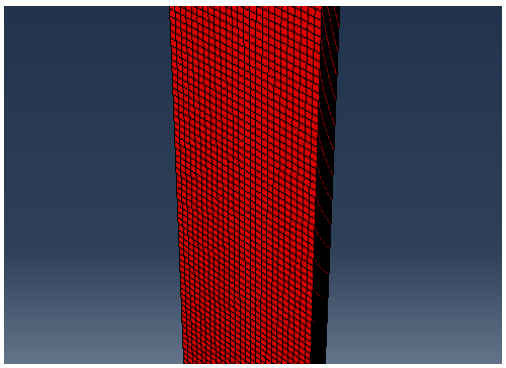


Figure 5.4 Meshed Model

5) Creating Steps and Boundary Conditions: Steps are created in order to apply diffusion boundary conditions.

Step1 – *Mass diffusion analysis:* The analysis for the moisture and diffusion is done in this step. As per the experiment details, it is known that material is exposed to the water from all sides. This step will include the both effect of temperature and moisture effect on composite material. The diffusivities of the specimens are shown in table1.

Boundary Conditions: The moisture intake condition is applied as boundary condition as shown in fig 5.5.

Initial condition:

$$c = 0 \qquad (0 \le x \le L, 0 \le y \le W, 0 \le z \le h, \forall t = 0) \tag{5.5}$$

Boundary condition:

$$c = c_{amb} \qquad [(x = 0, L), (y = 0, w), (z = 0, h) \forall t > 0) \tag{5.6}$$

The final weight gain , $M(\Omega_m, t)$, by the FRPC sheet due to moisture ingression at time is calculated through the volume integral of the moisture concentration at that time. That is $M(\Omega_m, t) = \int_{\Omega_m} c(x, y, z, t)\, dV$

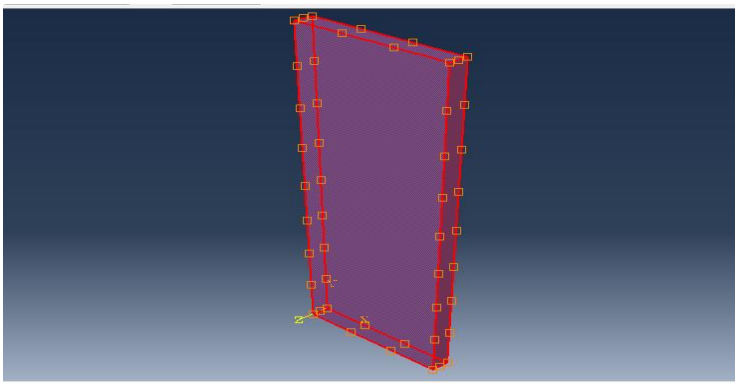


Figure 5.5 Model showing the boundary conditions

6) Creating Analysis Job: After the completion of all these steps and input parameters are defined, the job is submitted for analysis. It will do the analysis stepwise as defined in above steps. The solution was viewed in results section.

5.5 GRAPHICAL COMPARISON OF MODELLING RESULTS WITH EXPERIMENTAL RESULTS (CRYOSTAT BATH)

Figure 5.6 illustrated the comparison of experimental and modelling results of mass gain in untreated specimens at 0°C. The laminate sheet is exposed to the water from all the sides. As shown in graphs mass gain is higher in untreated laminate of composite, moderate in alkali and 1% stearic acid treated and lowest in 4% stearic acid treated laminate.

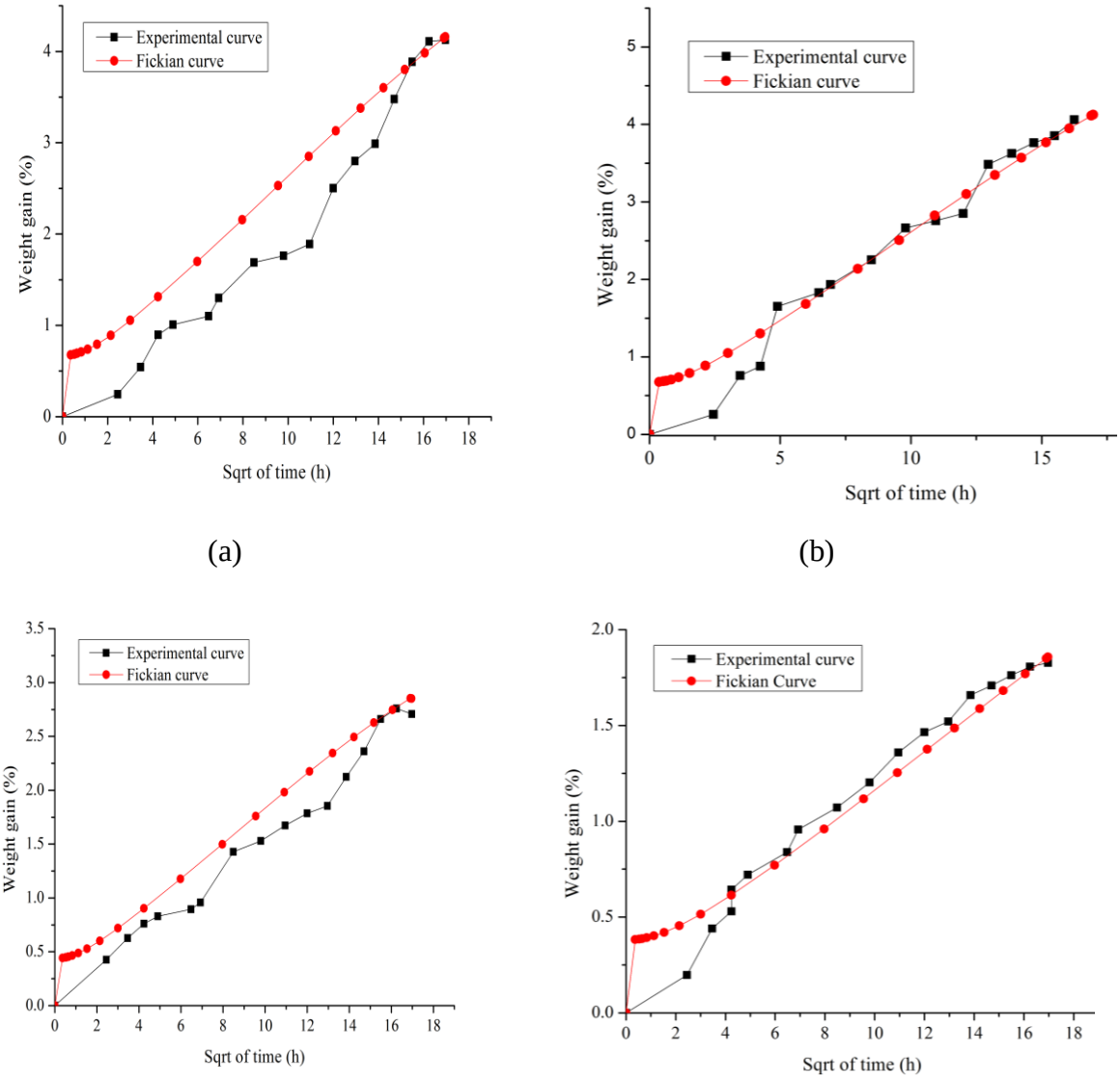
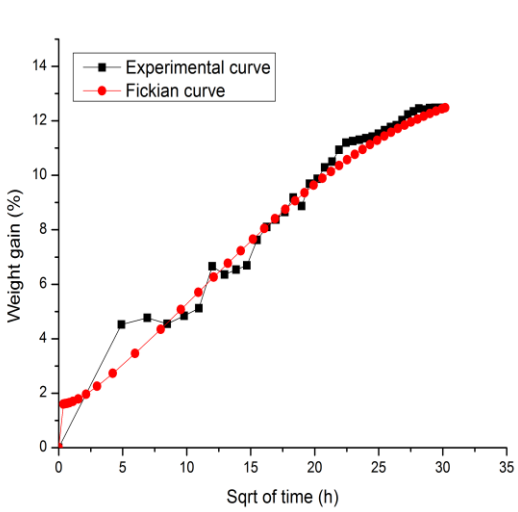


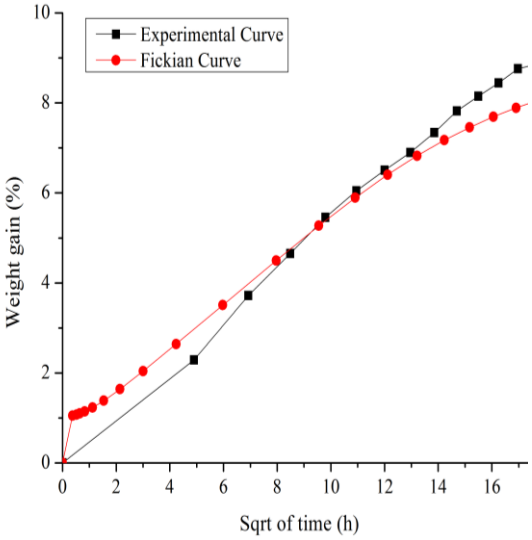
Figure 5.6 Comparison of mass gain curve at 0°C (a) Untreated, (b) Alkali treated, (c) 1% stearic acid treated and (d) 4% stearic acid treated

5.6 GRAPHICAL COMPARISON OF MODELLING RESULTS WITH EXPERIMENTAL RESULTS OF WATER CHAMBER

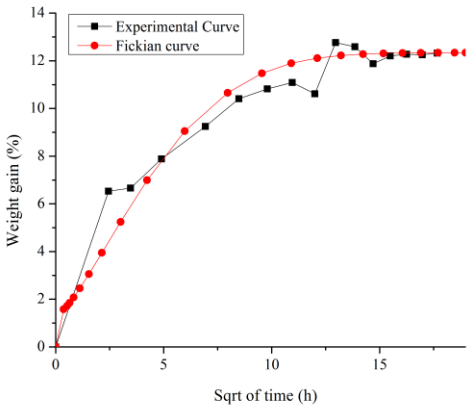
Figure 5.7, Figure 5.8 and Figure 5.9 shows the comparison of untreated specimens at 25°C, 50°C, and 75°C (water chamber). The laminate sheet is exposed to the water from all the sides. As shown in graphs mass gain is higher in untreated laminate of composite, moderate in alkali and 1% stearic acid treated and lowest in 4% stearic acid treated laminate.



(a)

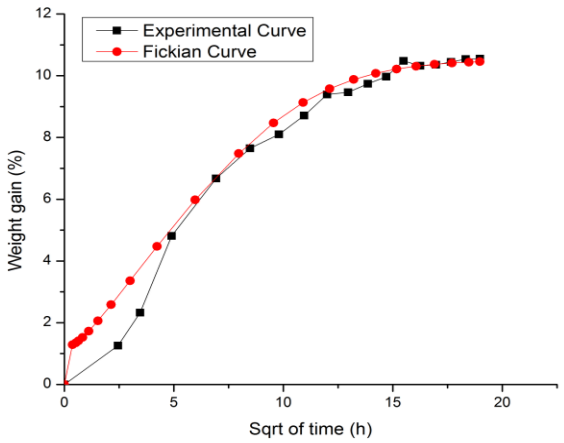


(b)

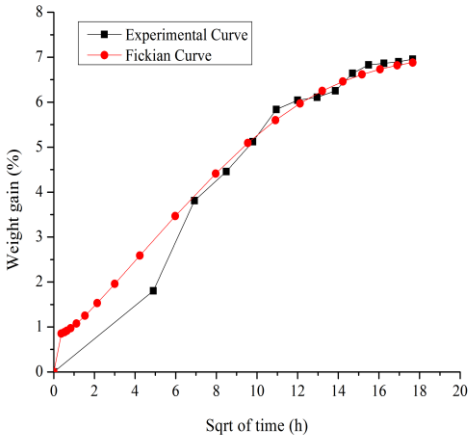


(c)

Figure 5.7 Comparison of mass gain curves of untreated specimens in water bath chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C



(a)



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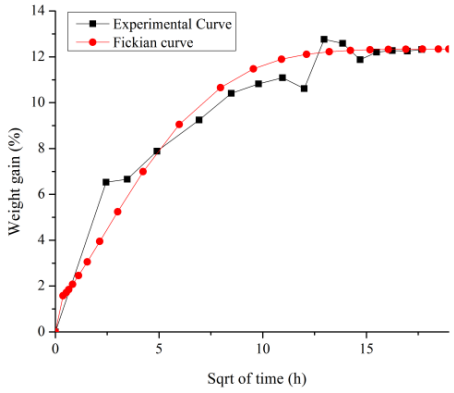
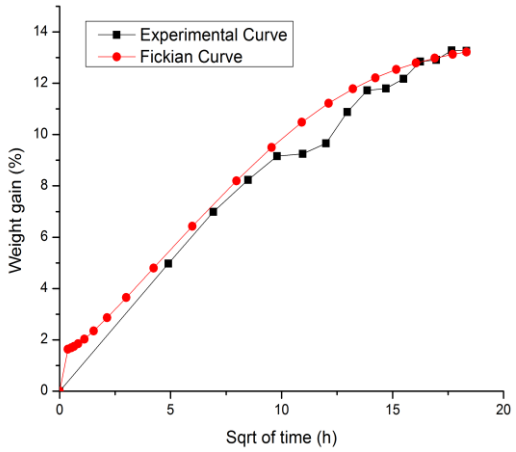
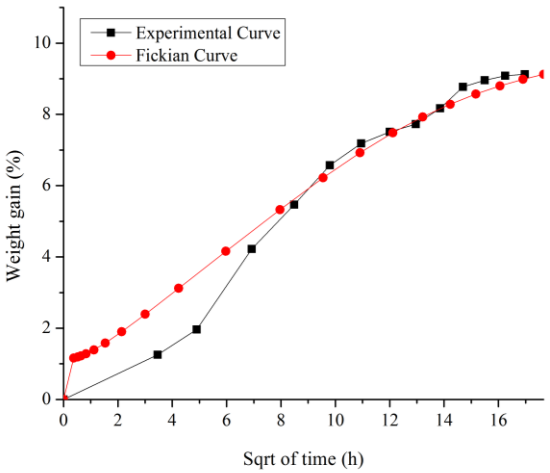


(c)

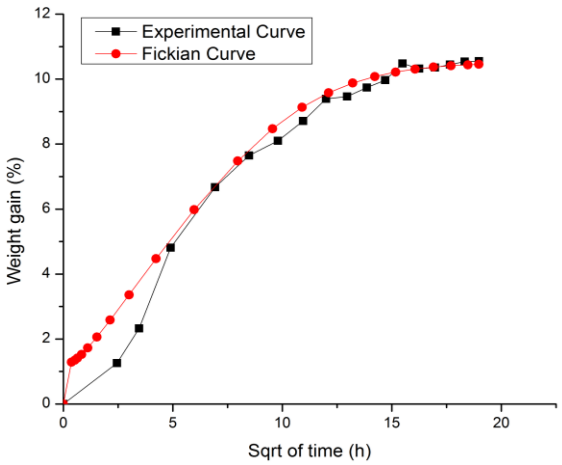
Figure 5.8 Comparison of mass gain curves of 5% alkali treated specimens in water bath chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C



(a)

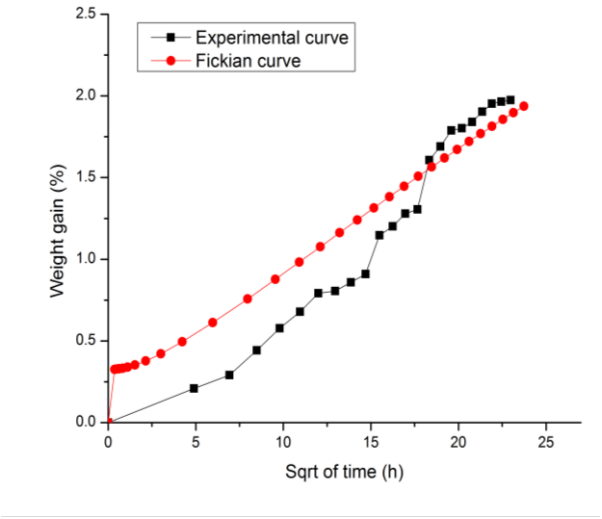


(b)

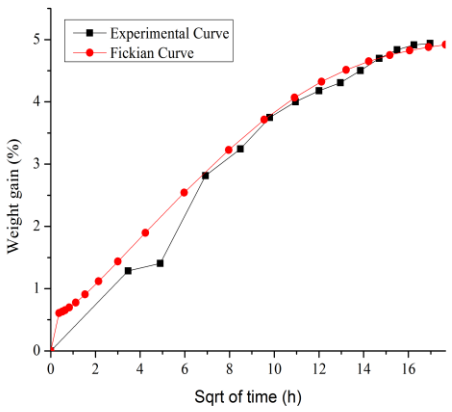


(c)

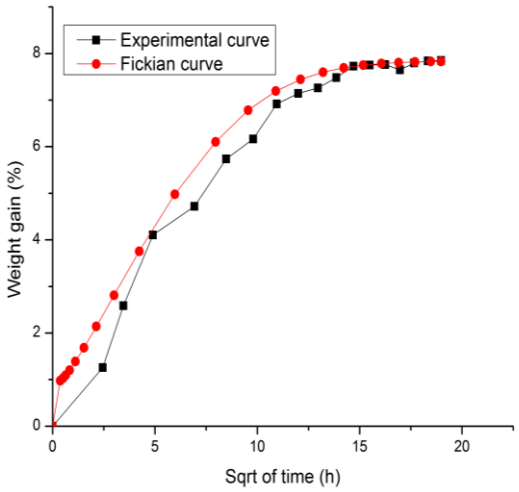
Figure 5.9 Comparison of mass gain curves of 1% stearic acid treated specimens in water bath chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C



(a)



(b)

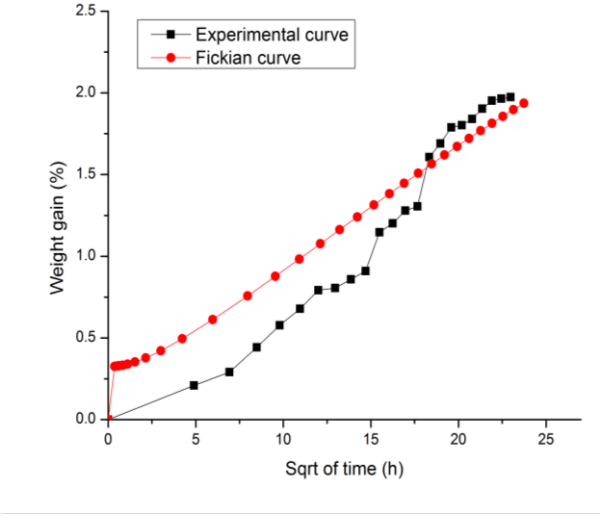


(c)

Figure 5.10 Comparison of mass gain curves of 4% stearic acid treated specimens in water bath chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C

5.7 GRAPHICAL COMPARISON OF MODELLING RESULTS WITH EXPERIMENTAL RESULTS OF ENVIRONMENT CHAMBER

Figure 5.11, Figure 5.12 and Figure 5.13 shows the comparison of untreated specimens at 25°C, 50°C, and 75°C (water chamber) with 70% relative humidity. The laminate sheet is exposed to the water from all the sides. As shown in graphs mass gain is higher in untreated laminate of composite, moderate in alkali and 1% stearic acid treated and lowest in 4% stearic acid treated laminate.



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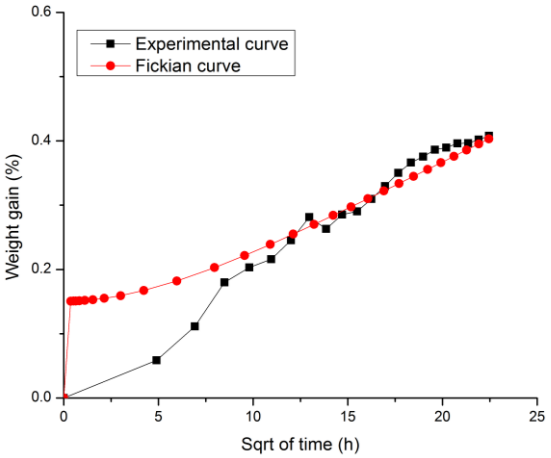

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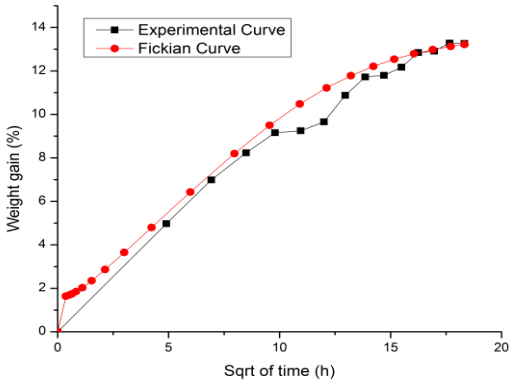
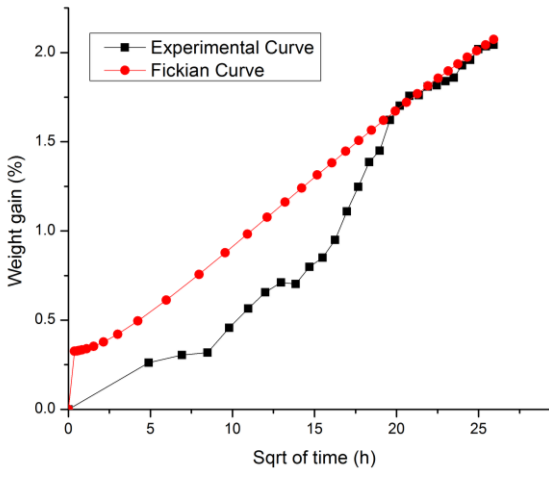


(c)

Figure 5.11Comparison of mass gain curves of untreated specimens in Environment bath chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C



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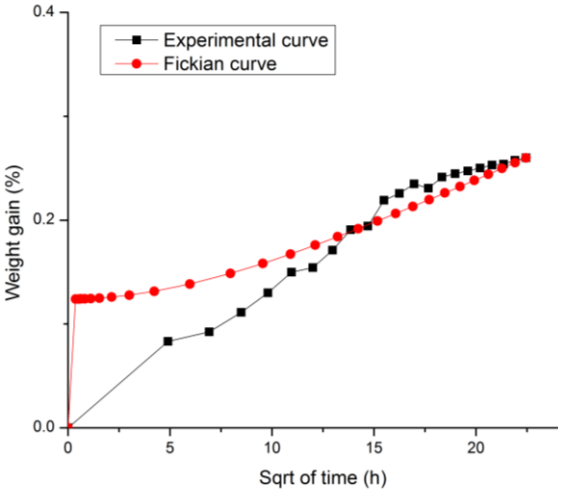

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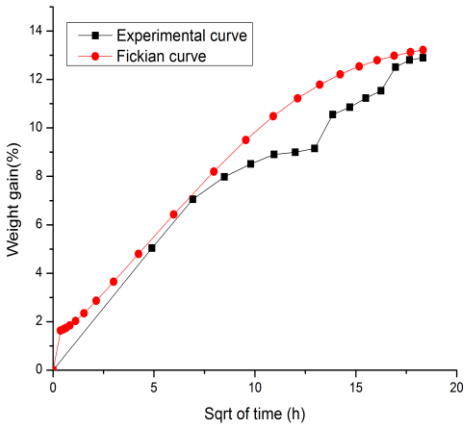
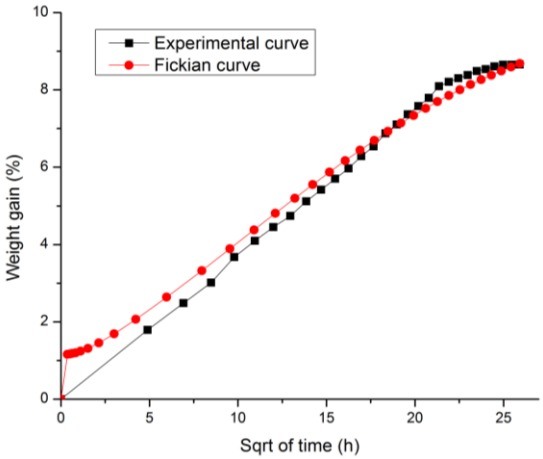
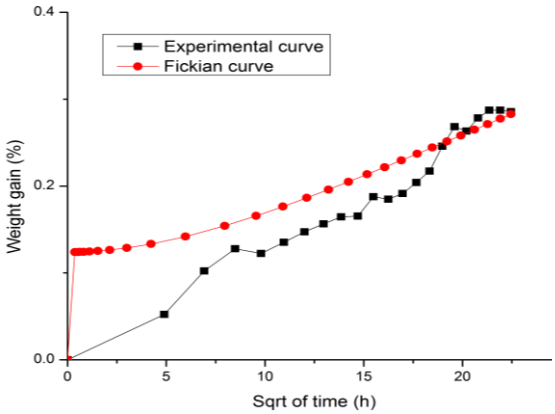


(c)

Figure 5.12 Comparison of mass gain curves of Alkali treated specimens in Environment chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C



(a)



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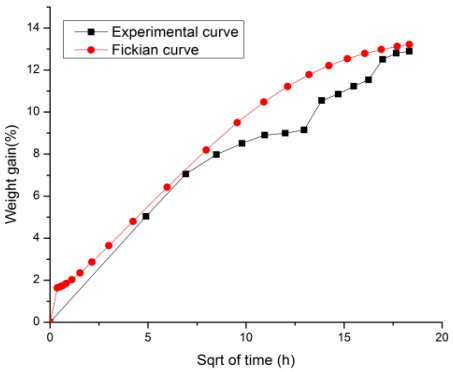
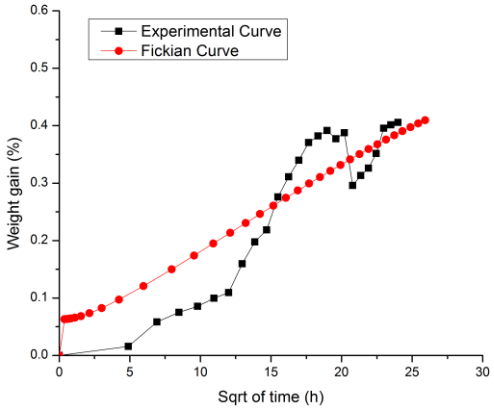


(c)

Figure 5.13 Comparison of mass gain curves of 1% stearic acid treated specimens in Environment chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C



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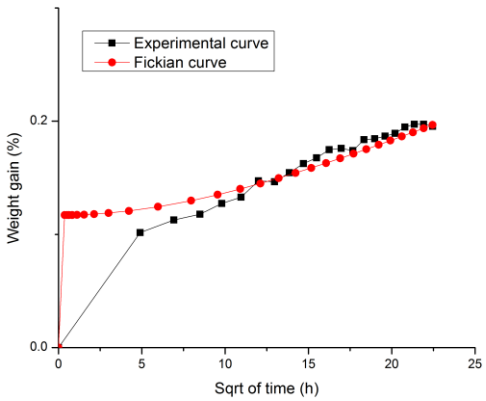

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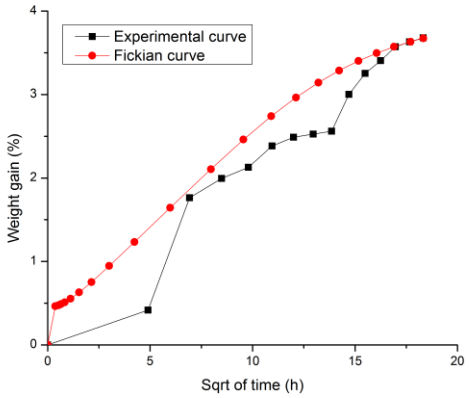

(c)

Figure 5.14 Comparison of mass gain curves of 4% stearic acid treated specimens in Environment chamber (a) mass gain curve at 25° C, (b) mass gain curve at 50° C and (c) mass gain curve at 75° C

CHAPTER 6

CONCLUSIONS

6.1 CONCLUSIONS

The following conclusions have been obtained:

1) Various chemical treatments have been done on Palmyra fibre to improve their hydrophobic properties but the treatment of fibres with 4% stearic acid gives best results.

2) Experimental work has been done to calculate the mass gain of untreated, alkali treated, 1% stearic acid treated and 4% stearic acid treated Palmyra fibres under temperature conditions (0°C, 25°C, 50°C and 75°C) with the help of cryostat and water bath chamber. It has been observed that under these temperature conditions, mass gain reduces as the temperature increases. But in addition to this, mass gain is lowest in 4% stearic acid at these temperature conditions.

3) Further experimental work has been done on the fibre reinforced composite under atmospheric conditions (70% RH along with 25°C, 50°C and 75°C) with the help of environment chamber. Under these conditions, mass gain is very slow as compared to temperature conditions.

4) Analytical results are validated with modelling results (Abaqus tool). This comparison in the form of graphical representation shows that 4% stearic acid treatment is best to improve the hydrophobic properties of Palmyra fibre.

5) SEM analysis has been done to analyze the cross section of fibres before and after chemical treatments. This analysis revealed that stearic acid treatments fill the gaps present in internal structure of the fibre and this reduces moisture diffusion within the fibres.

6.2 SCOPE OF FUTURE WORK

1) Mass gain analysis can be done on hybrid composites in collaboration with Palmyra fibre.

2) Tensile testing can be done on treated and untreated specimens of Palmyra fibre reinforced composites. Then comparison can be done on untreated and treated composites.

3) Other chemical treatments can be done on these composites with different concentrations of stearic acid.

4) Mass gain analysis can be done using different environment and temperature conditions.

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