University of Southern Queensland

Faculty of Health, Engineering and Sciences

Theoretical study of the effect of fibre orientations and porosity on heat conductivity of reinforced polymer composites

Dissertation submitted by

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Abstract

In recent years, there has been an increasing demand for engineering materials which not only possess good mechanical and thermal properties but are also cheap and environmentally friendly. Composites are unique engineering materials which can be tailor made from a large variety of materials to suit specific applications. Composites primarily consist of a polymer resin matrix in which other material is incorporated in discrete units for reinforcing. The reinforcing materials can be in the form of fibres or flakes orientated in various ways to impart maximum performance.

Natural fibres such as sisal, kenaf, bagasse, hemp etc. have been studied as reinforcing material for conventional polymer resins. Such composites are often termed green composites and they have unique mechanical properties when compared to conventional composites. They are also available at a cheap price and weigh a lot less. In addition, they can also offer unique thermal and acoustic insulation properties. Due to these attractive features they are used in the automotive, aerospace, textile and construction industries. A particularly important feature which determines the properties of natural fibre composites and their porosity.

From an industrial and academic point of view, there is a need to study the heat conductivity of newly developed composites. This is influenced by the porosity of the composite. This project, investigated the effect of porosity and their orientation on the heat conductivity of polymer composites. Experimental and theoretical studies were conducted on mainly sisal-glass fibre polymer composites. Different volume of fibre fractions were tested in this study. It was expected that the presence of the fibres would dramatically improve the heat conductivity properties of the materials because the sisal fibres have internal porosity. The results of this work are expect to contribute to academic and industrial knowledge about the thermal performance of fibre composites. The data will be published in a professional journal. This knowledge will contribute to the manufacturing of newly developed materials for industrial applications.

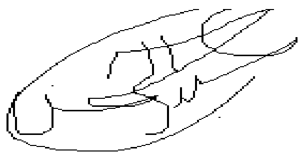
Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Abdalrahman R E S R Alajmi



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List of Contents

List of Figures

List of Tables

Abbreviations

ASTM	Australian Standard of Testing Material International
USQ	University of Southern Queensland
SiC	Silicon Carbide
VC	Composites porosity
VF	Fibre volume
VM	Matrix Volume
VP	Porosity
PEM	Proton Exchange Membrane
SAPF	Square Arrayed Pipe Filament
FEM	Finite Element Method
APDL	ANSYS Parametric Design Language

Chapter 1. Introduction

1.1. Introduction

In recent years, the use of sustainable polymer based products has gained a lot of interest. It is an active area in engineering research. Biocomposites, often called green composites have gained popularity in the last decade because of their attractive properties such as low cost of production, recyclability renewability and their mechanical properties when compared with synthetic fibre composites. In addition, governments have imposed stringent environmental regulations to decrease dependency on synthetic fibres or their composites. This is because of their adverse effects on the environment (Mallick, 2007).Because of this, academic and industrial research sectors are exploring the potential applications of natural fibres for use in conventional or biopolymer resins. This is in an approach to find environmentally friendly alternatives to conventional synthetic material.

An analysis of the available literature reveals that many studies are in progress on the influence of fibres on the mechanical (tensile, compressive and flexural) properties of composites. However, only a limited numbers of studies have addressed the heat conductive properties of natural fibre composites. Comprehensive investigators of the heat conducting properties of natural fibre composites is necessary to test their potential application in construction industry.

Experimental work has been conducted previously by USQ researcher, some research studies have considered the influence of fibre volume fraction on the heat conducting properties of natural fibre based composites. The volume fraction (often termed as porosity) is a key parameter in determining the thermal and chemical properties of natural fibre based composite. It has been observed that incorporation of natural fibres reduces the overall thermal conductivity of the final composite. Such behaviour might be related to the lower conductivity of the natural fibre or other factors. In addition, such phenomena have also been related to the high porosity of natural fibre composites. Further research is needed to and develop quantitative relationships between porosity and thermal conductivity.

1.2. Research question

Synthetic reinforcement materials are currently used in industry to replace expensive metal based materials. They have the added advantage of being light weight and cheaper. The materials face stringent environmental regulations because such materials may have a bad environmental impact. Synthetic reinforcement materials face issues such as non-reusability and non-degradability. Disposable products made from synthetic thermoset materials are usually not biodegradable and are becoming less favourable with each passing day.

Because of this, many scientists are attempting to resolve this issue by replacing the synthetic reinforcement materials with natural materials that are more environmental friendly. Even though, there are many limitations being faced in such attempts. From the literature (Devireddy and Biswas, 2016), it was found that the major concerns about using natural reinforcement materials are their thermal and low fire resistance proprieties. Also, not much works (Goda et al., 2014) has been done on the heat conductivity of these materials. A major question what is the impact of natural fibre reinforcement on the heat conductivity of these composite materials and how the porosity in the reinforcement affects heat conductivity?

1.3. Research Objectives

The aim of the current study is to investigate the influence of natural fibre porosity on the heat conductivity of materials used in the walls of, cars and airplane materials. The current research will focus on the numerical simulation of the heat conductivity of gypsum reinforced with both glass fibres and natural fibres, specifically sisal fibre reinforced polymer composites using ANSYS software. In this project the first objective is to fabricate polymer composites of different volume fractions using sisal fibres and to determine the level of porosity in each sample. The second objective was the measurement of heat conductivity of each sample and development of a mathematical model to correlate the porosity with heat conductivity.

1.4. Research Procedure

The steps undertaken to complete the research objectives are outlined as follows:

- To develop a numerical thermal conductivity model for fibre composite materials.
- To analysis the heat flux in the composites materials using the model.
- To study the effect of the porosity of the natural fibre composite the natural fibre porosity on the heat conductivity of the composites considering different volume fractions.
- To study the thermal behaviour of the composites under different operating conditions.

1.5. Expected Results

The expected results have a number of potential industrial applications as well as contributing to the general knowledge about these building materials. These includes:

- Fabrication of a novel composite that is competitive with existing commercial synthetic composites. This could be of interest to industries because they may be cheaper, and have better thermal and mechanical properties.
- Increase the confidence in using natural fibre composites, since, this work will compare the thermal conductivity properties of both products.

1.6. Project overview

The research project was under taken during 2016, finishing on the 13th of October, 2016. This section provides a brief outline of the work. Including the literature review, method of numerical analysis, results of the modelling investigation, and conclusion. This thesis is composed of the following five chapters.

1.6.1. Chapter 1| Introduction

The first chapter consists of a historical introduction to fibre reinforce polymer composites and the general outcomes that the other available articles have indicated. In addition, research question of the research project is an important concept that need to be focused on during the project. The introduction includes an initial theory in which the researcher discusses the expected outcomes of the research to be embedded in the results and discussion sections which is chapter 4. There are other sections which will not be included and they will be in the end of the thesis which they are references and appendix.

1.6.2. Chapter 2| Literature

The second chapter consists of a review of all the research found relevant to this project scope and it is objectives. Classification of composites and the base science of polymers and fibre based polymer composites. In addition, the experimental outcomes will be summarised as well as the effects of the porosity on the materials that has been chosen in the experimental and numerical study. Mechanical properties is a very important aspect and the most interesting properties are the heat conductivity values of the chosen materials which will be indicated in this chapter. Other composite material properties and behaviour.

1.6.3. Chapter 3| Numerical process methodology

This chapter provides a complete structure of methodology adopted during the numerical modelling. Initially, the basic method of software is described and a number of different steps involved in procedure of modelling have been outlined. A review of the numerical theory behind software modelling has also been given for providing an insight to the equations used by the software during processing. The major portion of this chapter is the explanation of model development in ANSYS software. The different steps ranging from preliminary development of shapes to the meshing of composite cylinders and development of final model, have been given along with the images of actual models. The properties of the materials used and the respective dimensions have also been screenshotted from the software for the complete of understanding for the reader.

1.6.4. Chapter 5| Discussion of Numerical Results

In this chapter focuses on the results which will be shown in an simple way to make the reader understand how the results and the models which has showed the comparison of both experimental and numerical results so that it would be more easier for the reader to understand the flow of the results and the reason behind why they are necessary. A screenshot will be taken directly of the simulation of the final model stages whether if it was the comparison of both methods and the different orientation models. There will be four different orientations Normal, Parallel, perpendicular and 45°orientations. The first orientation which actually identic ate the way that the experimental work has conducted and will examine it is results to be able to see if ANSYS composites does give a reasonable results and you will see that the reasonability has taken place and from there the more advanced of developing the models has taken place. Furthermore, the experimental results has been taken from a previous civil engineer student at USQ (Rashed A. 2015).

1.6.5. Chapter 5| Conclusion

In the last chapter, all the necessary finding will be explained in more details and recommendation will be summarised in this chapter. The most necessary findings whether it was the comparison between the experimental and the numerical results and their expected accuracy in developing the models. In addition, the final finding of the optimise resin, volume fraction and orientation and their effect on fibre composites materials. This chapter will be finalised with an obvious recap of what is concluded and what the future work can be for future researchers to make the model more accuracy, practical and valuable to make ANSYS as a great option for modelling composites materials.

Chapter 2. Literature Review

2.1. Introduction

This chapter reviews the basis science of heat conductivity in polymers, heat conductivity of fibre polymers composites and natural fibres. A broad classification of composites is given in Figure 2-1.

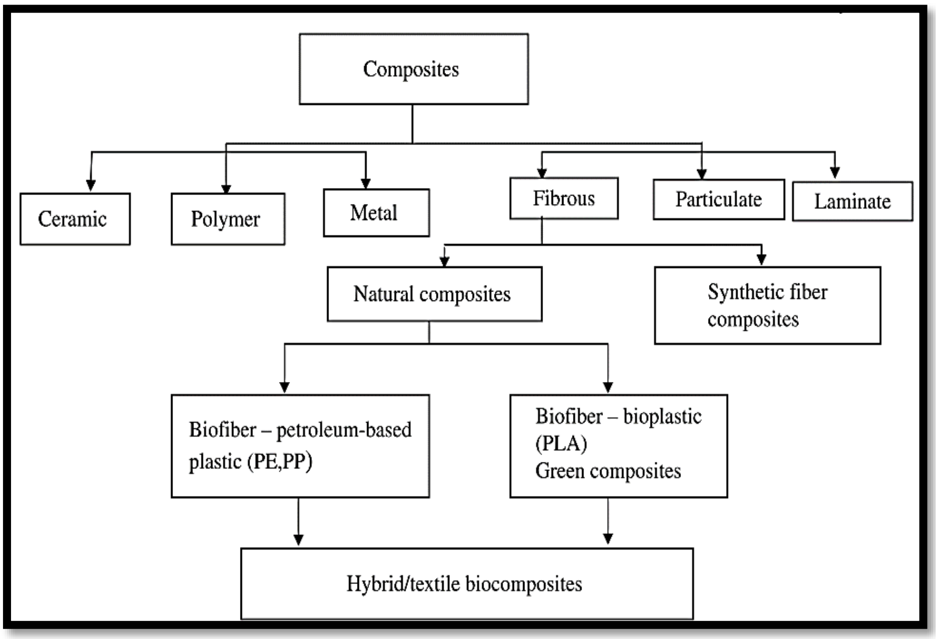


Figure 2-1.Classification of Composites (Malhotra et al., 2012)

Composites are manufactured by combining raw materials in two different phase such as resin and a reinforcing material. The resin material can be either ceramic, metal or polymer in which fibres are embedded to reinforce, in the case of polymers, the resins are normally thermosetting polymers. On the other hand, the reinforcing material can be fibrous or in any other form. It is normally synthesised material such as carbon, glass or aramid fibres. Natural fibres such as those based on wood or cellulose can also be incorporated into a biodegradable polymer matrix producing a new class of composites termed green composites. The reinforcing fibres provide structural integrity and improved mechanical properties to the composite. Combining the two different phases together produces a superior material often referred to as advanced fibre reinforced composite. An analogy of synthetic and natural fibres based composites is given in the Figure 2-2.

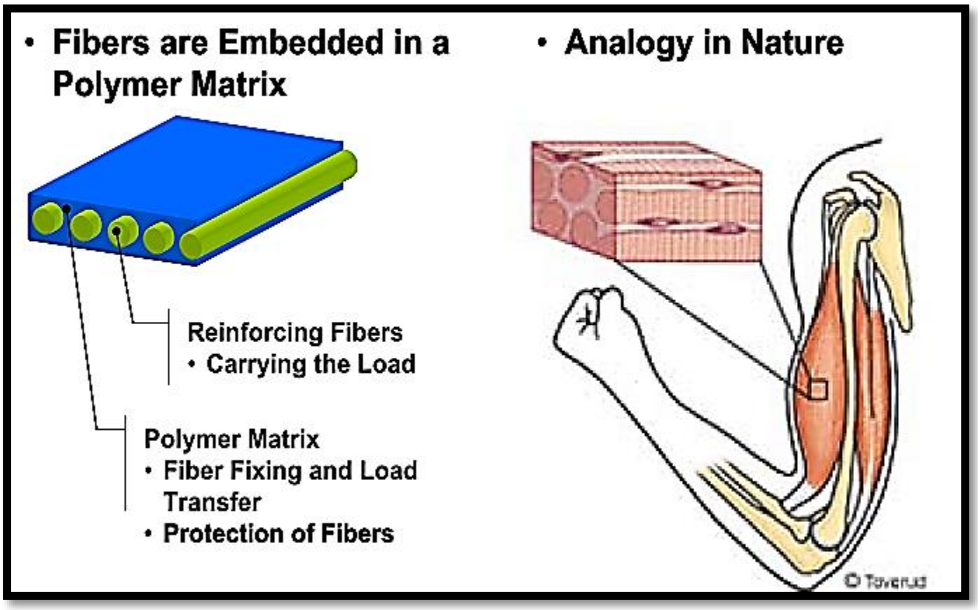


Figure 2-2. Synthetic & Natural fibre based composites (Selzer and Friedrich,1997)

Among the synthetic composites, fibreglass composites hold the maximum share of market because of their wide scale applications. Advanced natural fibre reinforced composites are also under investigation to make them competitive in terms of manufacturing cost, performance and long-term stability (Naskar, 2013). There is an increased interest in their use for a variety of applications such as in low cost housing and other civil structures, where materials having light weight yet good strength, and low environmental impact are required. There are many natural fibres such as sisal, banana, coir and jute. That have potential for reinforcing in polymer matrix composites (Chung Deborah, 2010, Friedrich and Almajid, 2013). Researchers have investigated the amount of natural fibre needed to reinforce polymer mortar composites to improve their fracture resistance. However, natural fibre composites are not exposed to tough mechanical impacts such as synthetic fibre composites, which are to a larger degree used in high tech engineering applications such as in the automotive and aerospace industries as what Chung Deborah have reported.

In the last decade, polymer composite materials have received a lot of interest and their production has moved from laboratory research to industrial application. The main attraction of natural fibres over synthetic fibres is that they are abundantly available in nature, are renewable, have a low cost, and are recyclable (Moeller and Matyjaszewski, 2012).

2.2. Fibrous Reinforcement in Polymers

The primary objective of incorporating fibrous material into a brittle polymeric matrix is to improve its mechanical properties. Generally, a fiber is defined as an elongated discrete piece or a bundle of thread composed of continuous filaments. Fibres which are thin and possess a longer surface to volume ratio, usually adhere better in the polymer matrix. The arrangement of fibres in a polymer matrix can be done in two orientations, quasi-isotropic or orthotropic: in the quasi-isotropic orientation, all fibres are oriented in either a single or in multiple directions. In the orthotropic orientation, the fibres are oriented in multiple directions (but always at right angles to each other). Mechanical properties of the fibre reinforced composite also depend on the orientation. The type and orientation of the fibres depends upon the intended application (Moeller and Matyjaszewski, 2012, Mallick, 2007). The reinforced material may be required to have such features such as excellent mechanical properties, lightweight, low-cost and convenient availability. They should also have long-term stability, and resistance to environmental variations. Compatibility with the polymer matrix an integral material and the compatibility with the fabrication process. These properties are the key characteristics which are desired by the fibres either synthetic, natural, mineral. The synthetic and natural fibres are further elaborated in the subsequent sections (Kohler and Nebel, 2006, Carlsson et al., 2014).

2.3. Synthetic Fibre

The synthetic fibres (also called man-made fibres) are made from a variety of organic or inorganic materials. Examples of organic fibres include fibres made from ultra-high density polyethylene and aramid (also commercially called Kevlar). Fibres made from carbon and glass are the most widely used inorganic fibres.

Their synthesis can be either through mechanical extrusion or by any chemical method. The incorporation of such fibres impart improved mechanical properties to the composite such as high strength and stiffness, but they also add must cost when compared to conventional engineering materials. They also pose environmental problems (Mallick, 2007). Properties of the most important synthetic fibres are givenin Table 2-1, SiC, boron and carbon fibre have high Young modulus above 200 GPa. Comparing to their different densities, high modulus carbon fibre has the highest specific modulus and tensile strength among all synthetic fibres. E glass fibre, which has a low and adequate modulus and tensile strength, are widely used in engineering applications due to their low cost.

Table 2-1. Typical properties of selected synthetic fibres (Mallick, 2007)

Property	Density, (g/cm^3)	Young Modulus (GPa)	Tensile Strength (MPa)
Material			
E glass	1.85	39.3	965
Kevlar 49	1.38	75.8	1378
SiC	3	250	2200
Boron	2.35	220	1109
Carbon (Hi modulus)	1.63	215	1240

2.4. Natural Fibre

Natural fibres, are those fibres that are found in nature and can be obtained from mineral, plant or animal sources. The building blocks plant fibres are cellulose dispersing as micro fibrils and amorphous medium lignin. The amount of cellulose depends on the type of fibre and is usually in the range of 60 to 80% by weight. The percentage of lignin is around 5 to 20% by weight and the moisture contents can range up to 20% by weight. Plant based fibres such as cotton, jute and flax, have cellulose as the primary building block and as a result their fibres are highly polar. This polarity is caused by the hydroxyl groups present on the surface and, when such fibres are embedded in a polymer to form a composite material, these hydroxyl groups form hydrogen bonding with the matrix. Animal fibres such as wool, silk, hair etc., on the other hand, consist of proteins. Mineral fibres are rarely used and investigated because of their carcinogenic nature (Wambua et al., 2003, Bismarck et al., 2005, Goda et al., 2014). Figure 2-3.Classification **of natural fibres (Bismarck et al., 2005)** shows the classification of natural fibres.

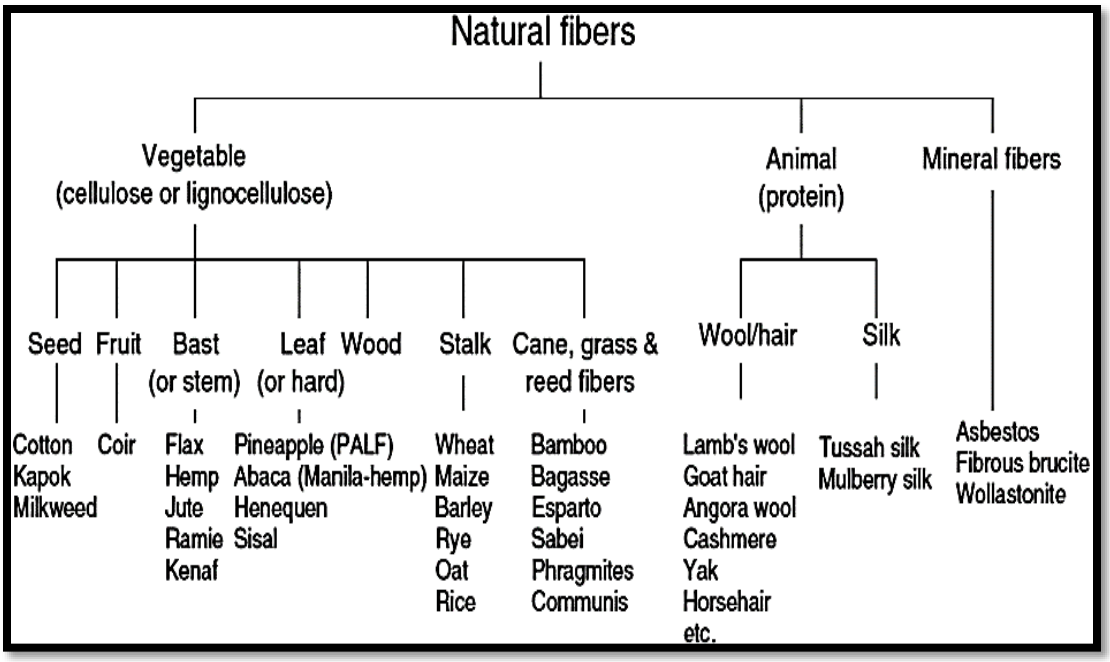


Figure 2-3.Classification of natural fibres (Bismarck et al., 2005)

2.4.1. Properties and composition of natural fibres

Some of the commonly properties of natural fibres are (Wambua et al., 2003, Kalia et al., 2011, Joshi et al., 2004),

- Density lies in a range of 1.2 – 1.6g/cm^3 and depends on material type and its microstructure
- Some of them are light because they are hollow structured
- Typical diameter lies in a range of 15-35µm

- They possess variable surface chemistry which is commonly dependent on the species
- They are affected by the processing temperature

An analysis of the literature provides the different chemical compositions, microfibrillar angles of fibre along with the respective moisture contents as shown in Table 2-2.

Table 2-2. Typical properties and composition of selected natural fibres (Bismarck et al., 2005) (Smole et al., 2013)

Fiber	Cellulose (wt%)	Hemicelluloses (wt%)	Lignin (wt%)	Pectin (wt%)	Moisture Content (wt%)	Waxes (wt%)	Microfibrillar Angle (deg)
Flax	71	18.6–20.6	2.2	2.3	8–12	1.7	5–10
Hemp	70–74	17.9–22.4	3.7–5.7	0.9	6.2–12	0.8	2–6.2
Jute	61–71.5	13.6–20.4	12–13	0.2	12.5–13.7	0.5	8
Kenaf	45–57	21.5	8–13	3–5			
Ramie	68.6–76.2	13.1–16.7	0.6–0.7	1.9	7.5–17	0.3	7.5
Nettle	86				11–17		
Sisal	66–78	10–14	10–14	10	10–22	2	10–22
Henequen	77.6	4–8	13.1				
PALF	70–82		5–12.7		11.8		14
Banana	63–64	10	5		10–12		
Abaca	56–63		12–13	1	5–10		
Oil palm EFB	65		19				42
Oil palm mesocarp	60		11				46
Cotton	85–90	5.7		0–1	7.85–8.5	0.6	—
Coir	32–43	0.15–0.25	40–45	3–4	8		30–49
Cereal straw	38–45	15–31	12–20	8			

2.4.2. Applications of natural fibres

Considerable research is in progress to develop composites with plant-based fibres that have properties similar to glass fibre composites or carbon reinforced composites used in the automotive industry (Joshi et al., 2004). Some of the common applications of plant-based plastic composites are (George et al., 2001, Kalia et al., 2011).

A number of automobile components such as door panels and spare tire covers, and hat racks. Which have been made from plant-based plastic composites by the renowned car manufacturers such as Ford, Daimler Chrysler, Opel, BMW, and Audi. Mercedes is using flax fibre reinforced plastics to manufacture door panels for their models.

In Canada, flax fibres reinforced polypropylene composites have been used for rear shelf panels of Chevrolet models, Opel has used similar composites for the back shelf of their Astra models. These applications of plant fibre-based composites are possible because of their attractive characteristics (George et al., 2001).

- Reduction in weight in the range of 10 to 30%
- Improved mechanical properties of the body parts
- Possibility of manufacturing complex structural parts in single fabrication step.
- High strength, stability and negligible splintering under crushing loads
- Safety to the environmental when recycling used cars
- Safe for workers involved in the fabrication and fixing of the moulded products as compared to glass fibre products
- Negligible emission of toxic components
- Economic benefit over conventional fibres

In addition to the above listed applications, biocomposites are also used in the following applications (De Rosa et al., 2009, Ku et al., 2011),

- Fibers such as sisal, wool, grass etc., are used in flooring materials
- Cotton and wool are used as reinforcement in textile applications
- Materials made from sisal based composites are used as roofing tiles, insulating material, and for fiberboard.
- Composites based on and jute are used in the aerospace space industry

2.4.3. Advantages of Natural Fibre Composites

A number of advantages (Goda et al., 2014, Moeller and Matyjaszewski, 2012, Kalia et al., 2011, Malkapuram et al., 2008, Begum and Islam, 2013, Saheb and Jog, 1999). Associated with natural fibre based composites are given as follows

- They offer low density and hence have low specific weight yet possess high stiffness and specific strength as compared to synthetic fibers such as glass.
- Handling of their raw materials is not hazardous to human health and their processing does not pose a human health risk
- They are generally an inexpensive option for agricultural countries
- They offer considerably less abrasion and wear
- Their acoustic and thermal insulating properties are very good
- They not only prevent dependency on petroleum based products but also helps in carbon dioxide sequestration
- They are biodegradable at the end of service life

2.4.4. Limitations of Natural Fibre

There are a number of limitations or challenges related to the application of natural fibre based composites. Some of the distinguishing ones are. (Thakur, 2013, Verhey et al., 2003, Niska and Sain, 2008, Cheung et al., 2009, Saheb and Jog, 1999),

- Because of their organic nature, biocomposites are prone to bacterial attack. The recommended solution is to add antifungal additives during the composite manufacturing
- They are not uniformity in dimension and in mechanical properties, even if they are from the same field. Such variation is not present in synthetic fibres.
- Natural fibres have a tendency to absorb moisture, which results in their swelling and deterioration. This problem leads to their dimensional instability and loss of mechanical properties.
- Their service temperature is limited to around 200°c. This limits their application in high temperature environments found in industrial practices.
- They have a poorly resistance to fire

- The cost of natural fibres generally depends on the agriculture market of a country.

2.4.5. Porosity in Natural Fibre Based Composites

Porosity is commonly referred to as these empty spaces or cavities which develop in a continuous material during processing or due to the air which becomes trapped during processing of the material. In composites, such cavities are developed during different processing steps such as mixing or consolidation of fibres and the polymer resin. In case of composites based on synthetic fibres, significant knowledge is present on how to control the porosity during the processing stage. In addition, the effect of this porosity on the mechanical and thermal properties is also well known (Madsen et al., 2007) (Hornsby et al., 1997, Firstov and Podrezov, 2000).

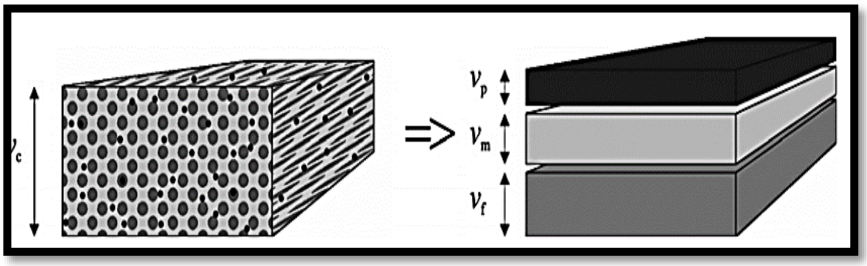


Figure 2-4.Schematic explanation of a composite porosity (vc) into three volume constituents, (vf) fiber volume, (vm) matrix volume and (vp) porosity (Madsen et al., 2007)

In the case of those composites which are made from natural fibres, the knowledge about the control of the porosity and its effect on the different properties (mechanical and thermal) of the final composite is very limited. Considering the fact that the porosity can contribute to around 30% (illustrated in

Figure 2-4) of the total volume fraction of the composite, it needs consideration for obtaining desired properties of natural fibres based composites (Madsen et al., 2007, Aziz and Ansell, 2004). Some of the researchers have proposed a method of porosity determination by using mathematical models. By using a number of empirical parameter is their model they predicted the porosity as a function of fibre weight fraction (Madsen et al., 2007). In addition, the model also enabled the calculation of matrix and natural fibre volume fractions. It has also been illustrated that the presence of cavities in the form of long capillaries also influence the composite properties. These capillaries strongly influence the permeability and heat transfer across the material. The development of a relationship between the porosity and thermal conductivity is usually not straightforward because it varies with the type of fibre and the polymer matrix (Stanković et al., 2008).

2.5. Heat conductivity of polymers

It is well known that the polymers have many applications in several industrial sectors. Many academic researchers have studied the electrical conductivity of polymers. Composites has a sensitive feature electrical conductivity in polymer - based composites, most of the applications in electronics and electrical requires electronically conductive polymer composites, numerous trading devices such as bipolar plates and gas flow layers in Proton Exchange Membrane (PEM) fuel cells, conductive pastes comprising the conductive stuffing and polymer resins. Therefore, according to the increase in the mechanical stronger polymers need to have higher electrical conductivity. The best way to study the electrical conductivity is to simulate and model the behaviour of the polymer, because of the effectiveness and the low-cost that these methods provide. Also, investigation of the properties of polymer matrix, it is reinforcement, and the interface between their naturals can be studied by this modelling. Several ways can be used for modelling the electrical conductivity in polymer- based composites. Investigators used numerical simulation (Liu and Schubert, 2016, Pal and Kumar, 2016, Taherian, 2016, Yuan et al., 2016), resistor-modelling, image processing, analytical and mathematical modelling (Taherian, 2016). There are several works have been recently done to instigate the electrical conductivity of such materials recently such as. Despite that, there is a lack of knowledge about the heat conductivity of these materials (Gojny et al. (2006)).

In the recent years, there is ongoing research conducting to investigate the heat conductivity of polymers and their composites due to their vast applications. Tanaka et al. (2015), reported that heat dissipation in composite polymers is essential for compact electrical devices but for different engineering applications.

Dos Santos, W. N. (2015) stated that mathematical modelling has become a reputable instrument for improving the control of procedures and creating superior polymer processing procedures. It has been investigated that simple and cheap disposition, a difference of the famous spilt column method is employed in the experimental investigation of the thermal conductivity of several chosen polymers, a (200 x 100 x 20) mm were prepared from taking a sample of a long commercial plates, part of that the results showed a solid uniformity when they are checked against results obtained by other techniques.

Thermal conductivity is the ability of a material to transfer heat. The method is according to the ASTM C518 procedures. According to research papers, natural fibres can decrease a composite's thermal conductivity and therefore allow it to be used as an insulator in a building. Mourad Chikhi etc. (Chikhi et al., 2013)developed a new biocomposite material as thermal insulation in buildings. The fibre is date palm fibres. From their experimental investigations, the thermal conductivity increases with the introduction of date palm fibre. The composite's compressive and flexural strength can be improved by adding adequate fibre content. This kind of new biocomposite is able to be used in buildings for thermal insulation.

According to Hanifi Binici's research paper (Binici et al., 2007), found that the fibre reinforced mud bricks, had better thermal insulation and mechanical properties according to both ASTM and Turkish standards. The testing results showed a higher compressive strength and heat conductivity than concrete brick. Azra Korjenic etc. (Korjenic et al., 2011) used jute, flax, and hemp to develop new insulting materials for buildings. Their thermal conductivity test results revealed that natural fibre composites are likely to become a suitable alternative to commonly used boards.

Satta Panyakaew, et al. (Panyakaew and Fotios, 2011) made a low density thermal insulation boards from coconut husk and bagasse. It is found that the bagasse insulation board has a low density of 350 Kg/m3 and a thermal conductivity values from 0.046 to 0.068 W/mK which is comparable to cellulose fibres and mineral wool.

2.5.1. Heat Conductivity of Natural Fibre Based Composites & Porosity

The composite polymers reinforced with natural fibres also offer good acoustic properties and thermal insulation. A number of research studies have determined the thermal conductivity of composites made by combining of resins such as polypropylene, polyesters, soya bean oil with natural fibres such as flax, cellulose, pulp, recycled paper, chicken feathers (Dweib et al., 2004, Kim et al., 2006, Belaadi et al., 2013). These studies focused on the effect of different natural fibres on the thermal and mechanical properties of conventional polymer resins. Some of them are further reviewed in this section Figure 2-5.

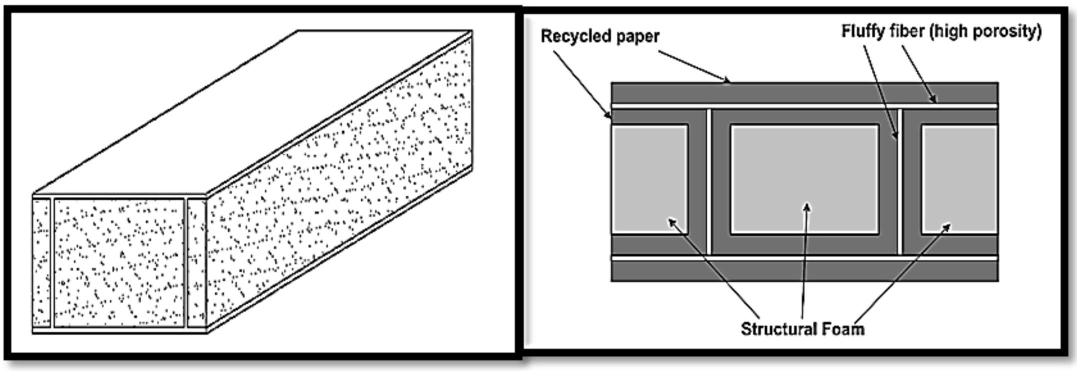


Figure 2-5.Proposed beam structure having foam wrapped in bio composite (Dweib et al., 2004)

In order to incorporate natural fibre based composites in structural applications, recently, date palm fibres were used for making biocomposites. The experimental investigations revealed that the thermal conductivity of the composite increases after the addition of date palm fibres. In addition, the compressive and flexural properties were also improved with the addition of adequate fibre contents (Alawar et al., 2009). Similarly, sandwich beams made of natural composites have been studied for structural applications. A number of natural fibres such as flax, recycled paper, cellulose, pulp, and chicken feathers added to a resin obtained from soya bean oil. It was found that the incorporation of natural fibres improved the mechanical properties of the sandwich beam but they also increase the thermal and acoustic resistance properties (Dweib et al., 2004).

Other studies have also reported thermally insulating materials such as boards made from coconut husk/bagasse and composites made from flax/ kenaf/ hemp/ sisal reinforced polypropylene. Both these materials showed good mechanical properties and an increase in thermal insulation which increased their suitability as structural materials (Kim et al., 2006, Vilay et al., 2008, Ramesh et al., 2013).

2.5.2. Heat Conductivity of Natural Fibre Based Composites

There are several methods that can be used theoretically and experimentally to assess the thermal conductivity of a material. The main purpose is to determine the coefficient of thermal conductivity which is expressed as W/mK. By Appling the following equation, the conductive heat transfer through any material can be calculated in the following $\boldsymbol{k} = \frac{\mathbf{Q\ L}}{\boldsymbol{A}\ \boldsymbol{\Delta}\mathbf{T}}$ Equation 2-1:

$$\boldsymbol{k} = \frac{\mathbf{Q\ L}}{\boldsymbol{A}\ \boldsymbol{\Delta}\mathbf{T}} \qquad \textbf{Equation 2-1}$$

Where,

k= is thermal conductivity in W/m K,

Q= is amount of heat transfer through the material in Joules/s or W,

A= is the area of the body in m^2 , ΔT = is difference in temperature in K°, L= Length of the body in m

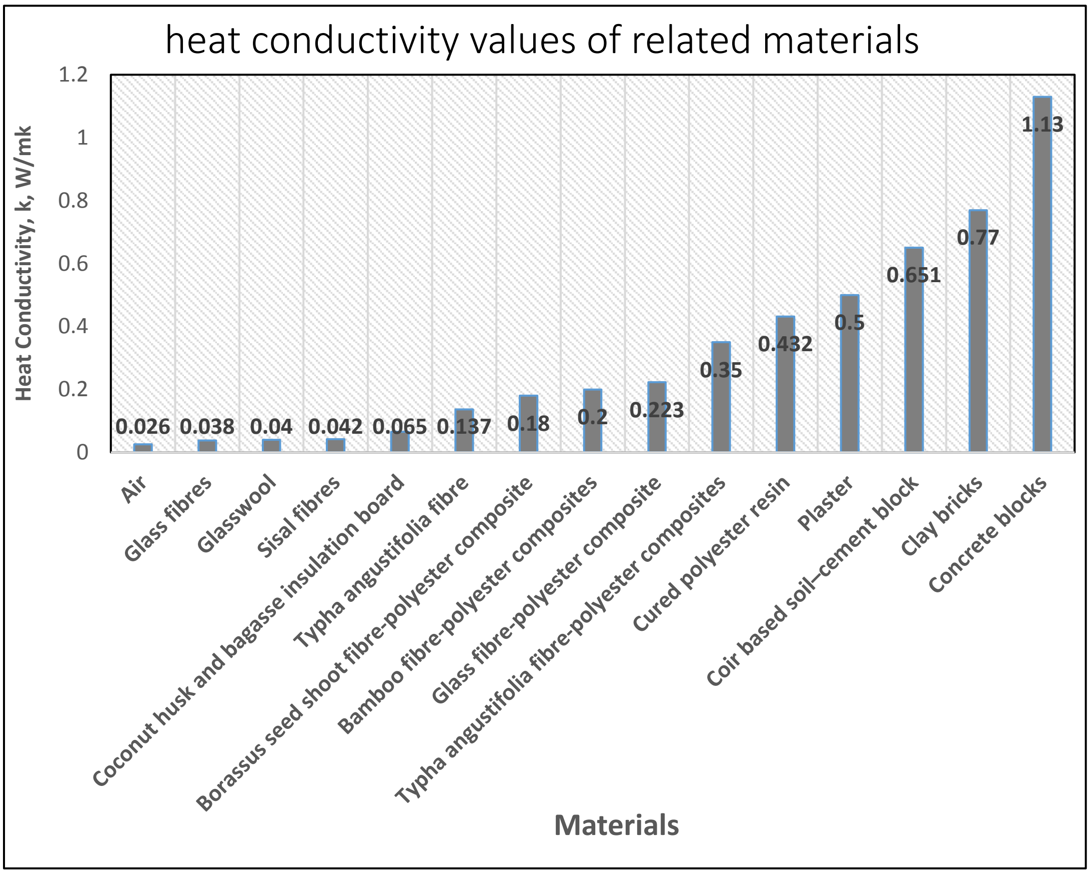


Figure 2-6.shows the heat conductivity values of some related materials (Liu et al., 2012a), (Neira and Marinho, 2009), (Neira and Marinho, 2009) (Ramanaiah et al., 2011) (Ramanaiah et al., 2011) (Mounika et al., 2012) (Mounika et al., 2012) (Mohapatra et al., 2015) (Panyakaew and Fotios, 2011) (Khedari et al., 2005)

Thermal conductivity defined as the quantum of heat transmitted through a unit thickness of material. It is used to assess and compare how simple is a materials transfer heat. Although, there is an inverse relationship between the thermal conductivity and heat insulation property. Many investigators have investigated tested the thermal conductivity of diversity materials so as to take out optimum thermal energy that would save the use of the appropriate materials to deliver their intended use.

Liu et al. (2012) studied the size of the lumen (the hollow part of fibre bundle) on the impact transverse thermal conductivity of unidirectional natural fibre composites. Through the computer modelling the unidirectional natural fibre composites was modelled in a two-dimensional SAPF. To evaluate the effective transverse thermal conductivity of this composite model thermal-electrical analogy technique need to be thoughtful.

It was observed that the geometrical ratio β is the most important parameter for the dimensionless effective transverse thermal conductivity K_t^+ of natural fibre composites. It is concluded that, the most effective on the transverse thermal conductivity of natural fibre composites more greatly as compared to conventional fibre composites are as follow:

The thermal conductivity ratio $\beta = K_f/K_m$ (where f and m represent Fibre and Matrix respectively)

- Fibre volume fraction
- The lumen size ratio α

Liu et al. (2012) have tested the transverse thermal conductivity of unidirectional epoxy composites reinforced with abaca and bamboo fibres using. Resign transfer modelling (RTM) technique. by using the based on the impact of the microstructure of natural fibre. It has been observed from the results that the transverse thermal conductivity has an interdependent relationship with bamboo as the thermal conductivity increases with increasing the bamboo fibre but decreased with increasing abaca fibres. In the other hand, it was found that the lumen structure plays a significant role instead of crystal structures and chemical component on the transverse on thermal conductivity of unidirectional composites based on both microstructure and theoretical analysis Liu et al. (2012). This information can be used to evaluate and design natural fibre reinforced composites with better thermal insulation properties.

According to Ramanaiah et al. (2011) have discovered that thermal conductivity of *Typha angustifolia* fibre reinforced polyester composites decreases with increase in fibre content. It was observed that the number of thermal conductivity gained from empirical tentative models were optimum with the agreement that have been experimentally measured values. In part of that, the composites under the investigation had good insulating properties that would be suitable for real life applications. For example, electronic packages, insulation boards, automobile parts and for building construction.

An evaluation have been done by Binici et al. (2016) evaluated the impact of stalk sample size with epoxy/corn stalk particle ratio on the thermal conductivity of the composites and it's mechanical properties. Mechanical properties have been compared with the commercially available bio-based insulation materials. The investigation has defined that it is possible to use bio-composite materials with minimum heat transfer coefficients. The developed composites have thermal conductivity coefficients lower than 0.1 W/mk, meeting the requirement set by TS 805 EN 601 in order to qualify a material as a thermal insulator. The researcher was satisfactory on the effectiveness of the sustainable filler from organic origin.

Wang and Qin (2015), reported that the overall thermal property of the composites increased with increase of interface thickness for carbon and glass fibres. However, it decreased for composites model thermal property of hemp fibre decreases. It is concluded that the rising of interface thickness will increase the volume fraction of the fibre and interface region. While the volume friction of the special element manufacture lower thermal conductivity of the composite because the thermal conductivity of both interface and fibre materials have a lower thermal conductivity than the matrix. This is an example of why a higher fibre volume fraction can uncertainly results in either lower or higher effective thermal conductivity of the composites.

Chapter 3. Numerical Process Methodology

3.1. Introduction

Finite Element Method (FEM), was introduced in 1956 it is considered a powerful computational tool estimation of solutions to problems faced in real-life engineering. Physical phenomena occur in a continuum of matter ranging from solid to gas subject to field variables. These field variables usually vary between points and they possess a finite number of solutions within that domain. By using this tool, the problems are simplified by converting the whole domain into a finite number of pieces or elements. An approximate function could be associated with the unknown field variables. Modelling of thermal can be carried out by using FEM programs such as ANSYS (Dewangan and Satapathy, 2012). In this research, ANSYS was used to analyze conductive heat transfer through fibre composite bodies.

A number of practical heat transfer problems require the use of numerical methods, which allow problems to be solved quickly. The effect of changes in parameters can often be seen when a problem is modelled numerically. A numerical formulation can also be performed by using partial differential equations. These equations are replaced by discrete approximations, Such as temperature fields that are approximated by the values at discrete points. As a result, a computational mesh is formed (in Cartesian or cylindrical coordinates) and the field is considered at consecutive time-steps with a time increment Δt (Bloomberg, 1996). This type of modelling of a cylindrical composite is explained in this chapter. In Figure 3-1 the flow of the Numerical programme of a cylindrical model is summarised.

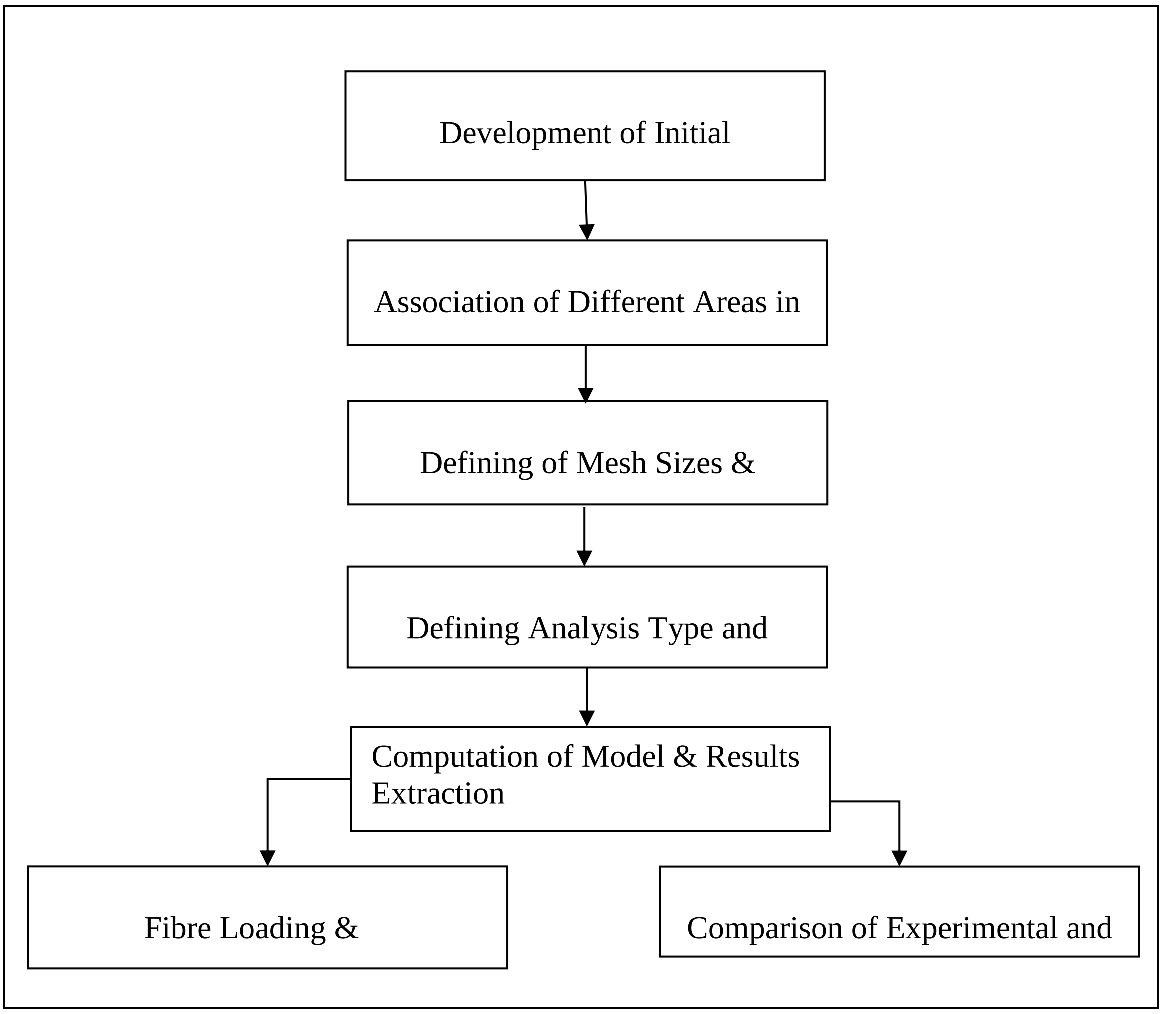


Figure 3-1: Flowchart of the development of a cylindrical model

3.2. Numerical Modelling of Cylindrical Coordinates

Consider heat transfer across a cylinder whose radius is r and the heat transfer is taking place in vertical and radial directions in a rotational symmetry around the z-axis. Here, the temperature along r in the z-direction at a specific time t is given by,

$$T = T\,(r, z, t)$$

A radial and a vertical thermal process which is rotationally symmetric around the z-axis is considered for this modelling. Here, the interval along *'r'* is divide into a mesh having cell widths (as shown in Figure 3-2) as follows,

$\Delta r_i, i = 1$, N

The inner boundary is at $r = r_I$, outer boundary at $r = r_o$, and the midpoint is at $r = r_i$. Here r_I, may be at the z axis and hence zero.

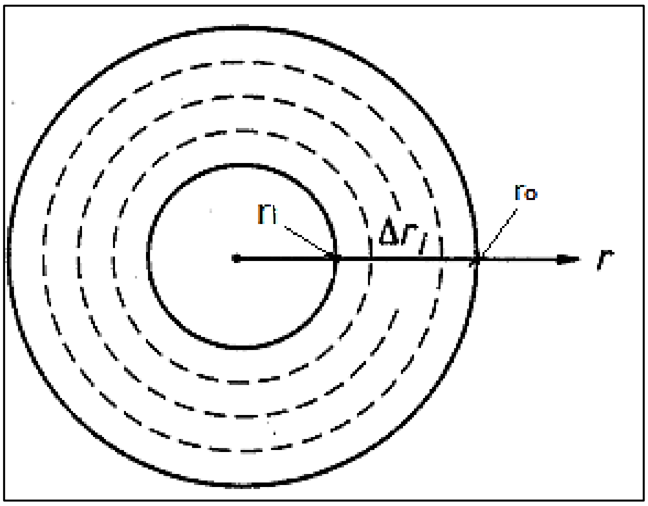


Figure 3-2.Proposed cylinder for heat transfer study

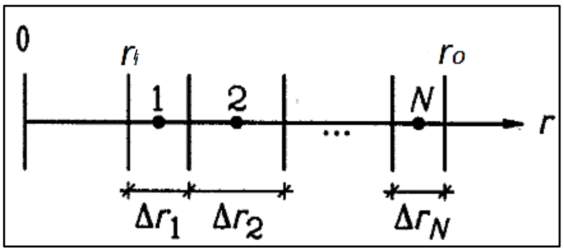


Figure 3-3.Details of the meshes in the radial direction

Here we have,

$$r_1 = r_I + {}^{\Delta r_1}/_2$$

$$r_i = r_{i-1} + {}^{\Delta r_{i-1}}/_2 + {}^{\Delta r_i}/_2$$

In the above equation, 'i' ranges from 2 to N. If the widths of the individual cells are summed up, we get the total annulus width as follows,

$\sum_{i=1}^{N} \Delta r_i = r_0 - r_I$

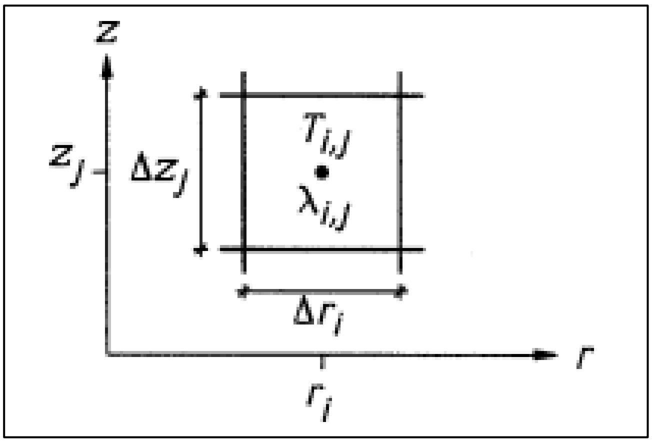


Figure 3-4.A mesh element in the cylindrical coordinates

The dimensions in the z-direction are shown in the above Figure 3-4 and the cell widths in the z-direction are given as Δz_j. At the middle point of $Cell\ (i,j)$ the temperature at a time step of ‘n’ is given by the following relation,

$$T_{i,j} = T(r_i, z_j, n\Delta t)$$

Here, the $Cell\ (i,j)$ shown in the figure is an annular section of cylindrical shape and its dimensions are given as,

$$r_i - {}^{\Delta r_i}/_2 \leq \boldsymbol{r} \leq r_i + {}^{\Delta r_i}/_2,$$

$$z_j - {}^{\Delta z_j}/_2 \leq \boldsymbol{z} \leq z_j + {}^{\Delta z_j}/_2$$

The volume of the cell can be given by using the dimensions of cell by the following relationship,

$$\Delta r_i \Delta z_j\ 2\pi r_i = [\pi\ (r_i + {}^{\Delta r_i}/_2)^2 - \pi\ \left(r_i - {}^{\Delta r_i}/_2)^2\right] \Delta z_j$$

The conductance (K) between two successive cells, i.e. $Cell\ (i, j)$ and $l\ (i - 1, j)$, could be given as,

$$K_{i-0.5j} =$$

$$\frac{\Delta z_j}{\ln\left({r_{i-0.5}}/{r_{i-1}} \right)\left({1}/{2\pi\lambda_{i-1,j}} \right) + \ln\left({r_i}/{r_{i-0.5}} \right)\left({1}/{2\pi\lambda_{i,j}} \right) + \left({R_{i-0.5,j}}/{2\pi r_{i-0.5}} \right)}$$

The conductance in the above equation is in watts per kelvin (W.k). The thermal conductivity is given by the term for cells respectively. In addition, $R_{i-0.5,j}$ represents an optional thermal resistance present at the interface of two cells. The first term in the denominator gives the value of the thermal resistance per unit height of the $r_{i-1} \leq \boldsymbol{r} \leq r_{i-0.5}$ annulus.

The heat conductance in the direction of the z-axis can be given as a product of area of cell perpendicular to z-axis ($2\pi r_i \Delta r_i$) and unidimensional conductance. The equation is given as follows,

$$K_{i,j-0.5} =$$

$$\frac{2\pi r_i \Delta r_i}{\left({0.5\ \Delta z_{j-1}}/{\lambda_{i,j-1}} \right) + \left({0.5\ \Delta z_j}/{\lambda_{i,j}} \right) + R_{i-0.5,j}}$$

The heat flows are shown in the Figure 3-4. They are given by the product of temperature difference and the conductance. These flows are used for all 'i' and 'j' and are as follows,

$$Q_{i-0.5,j} = K_{i-0.5,j}\ (T_{i-1,j} - T_{i,j})$$

$$Q_{i,j-0.5} = K_{i,j-0.5}\ (T_{i,j-1} - T_{i,j})$$

In a time-step of Δt, an increase or decrease in the temperature takes place and as a result $\boldsymbol{T}_{i,j}$ is used for next time-step. Hence, the heat balance equation takes the form as follows,

$$\Delta r_i \Delta z_j \, 2\pi r_i \, C_{i,j}(\boldsymbol{T}_{i,j} - T_{i,j}) =$$

$$\left[Q_{i-0.5,j} - Q_{i+0.5,j} + Q_{i,j-0.5} - Q_{i,j+0.5} \right] \Delta t$$

The choice of a stable time-step for the $Cell\ (i,j)$ is made by using the stability criteria given as,

$$\Delta t < \left(\Delta r_i \Delta z_j \, 2\pi r_i \, C_{i,j} \big/ \sum K \right)$$

Here, $\sum K = K_{i-0.5,j} + K_{i+0.5,j} + K_{i,j-0.5} + K_{i,j+0.5}$

The above criteria for numerical stability must be satisfied for the $Cell\ (i,j)$ and the smallest time-step obtained is used to guarantee stability for all cells.

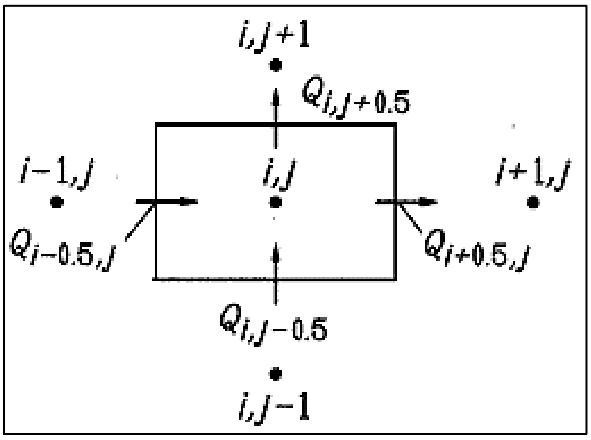


Figure 3-5.Illustration of heat flows (W) to and from the cell (i.j)

3.3. Introduction to ANSYS Software

In this project, ANSYS software was used to simulate thermal conductivity patterns in porous natural fibre based composites. The objectives was to determine the relationship between the heat flow across a composite sample and the void fractions or porosity present within that sample. The amount of heat energy was varied to obtain different temperature profiles. In addition, the porosity of the composite was also varied and to develop a relationship between these two parameters. Some of the generalised steps which are involved in this simulation are as follows (Soleimaninia, 2012),

- The ANSYS (mechanical APDL) interface was opened and at the very first stage, the job name and the type of analysis was created
- Information about the elements involved and the related material was incorporated in the next steps
- Even though the ANSYS software has the ability to generate meshes in the beginning it is recommended that a few notes are used and the coordinates or domains for the geometry are manually entered (example of a meshed geometry as follows (Zlaugh, 2012))
- In the next step, the different areas in a geometry are then associated with the materials mentioned previously and their attributes are further elaborated
- The mesh size is defined and meshing is conducted. After the meshing is complete the final step in the instructional steps is to define the analysis type and then proceed to the solving of the model.
- The next step is solving the model and once the solution of the simultaneous equations is obtained the software alerts the user
- Once the model is computed, the post processing tools can be applied. These involve visualisation of the computed displacements through analysis of temperature plots.

3.3 Numerical Theory behind ANSYS Modelling

The first law of thermodynamics states that thermal energy is conserved. Specializing this to a differential control volume the equation of the following form can be given as (SAS, 2012),

$$Q = \nabla.\{q\} + \left(\frac{\partial T}{\partial t} + \{v\}^T \, \nabla T\right)\rho c$$

In the above equation,

Q = Heat generation rate/unit volume

{q} = Heat flux vector

ρ = Density

c = Specific heat

T = Temperature

t = Time

The vector functions are further explained as,

$$\text{Vector operator} = \nabla = \begin{cases} \partial/_{\partial x} \\ \partial/_{\partial y} \\ \partial/_{\partial z} \end{cases}$$

$$\text{Velocity vector for mass transport of heat} = \{\text{v}\} = \begin{cases} V_x \\ V_y \\ V_z \end{cases}$$

In the next step, the heat flux vector is related to the thermal gradients by using the Fourier's law of heat conduction as follows,

$$\{q\} = -[D] \, \nabla T$$

Here, [D] is the conductivity matrix which is given as follows,

$$[D] = \begin{bmatrix} K_{xx} & 0 & 0 \\ 0 & K_{yy} & 0 \\ 0 & 0 & K_{zz} \end{bmatrix}$$

In above matrix, the K_{xx}, K_{yy}, and K_{zz} are the conductivity elements in the x, y, and z dimensions respectively. The equations could be combined to form a compound equation as follows,

$$Q = (-[D]\,\nabla T) + \left(\frac{\partial T}{\partial t} + \{v\}^T\,\nabla T\right)\rho c$$

$$Q + \nabla.([D]\,\nabla T) = \left(\frac{\partial T}{\partial t} + \{v\}^T\,\nabla T\right)\rho c$$

The above equation can be expanded to more familiar form as follows,

$$\left(\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + v\frac{\partial T}{\partial z}\right)\rho c = Q + \frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)$$

Here it has been assumed that all of the effects are in the global Cartesian system. There are three boundary conditions considered for this system and it has been presumed that these conditions cover the entire element. These are given as follows,

- Specified temperatures acting over the surface S_1,

T = T*

The T* in above is the specified temperature.

- Specified heat flows acting over the surface S_2 is given as,

$-Q^* = \{n\}\{q\}^T$

Here,

{n} = Unit outward normal vector

Q* = Specified heat flow

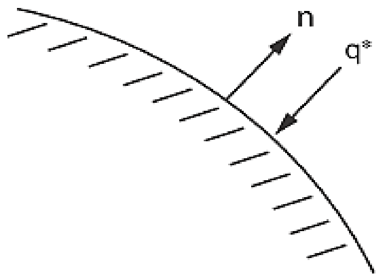


Figure 3-6. Specified heat flows

- According to Newton's law of cooling, the specific convection surfaces over the surface (S_3) is given as,

$$\{q\}^T\{n\} = h_f(T_S - T_B)$$

Here,

h_f = film coefficient with generic value of $(T_B + T_S)/2$, unless specified for the element

T_b = Adjacent fluid's bulk temperature

T_s = Temperature at the model surface

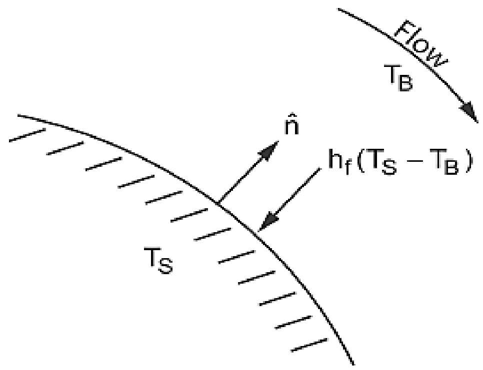


Figure 3-7. Specified Convection Surfaces

3.4 Development of ANSYS models

There were different stages in the development of ANSYS model. These included the following,

- Formation of preliminary model shape
- Generation of mesh
- Final model shape

These steps are written in detail as follows,

3.4.1 Formation of preliminary model shape

The preliminary shapes of models and fibres were made by providing information about the elements and related material. The geometries created are shown in the figures 9 to 11. The thermal properties of the three materials of composite cylinders are also given in the Table 3-1.

Table 3-1. Thermal properties of composite materials

Material	Thermal Conductivity (W/mk)	Specific heat (kcal/kg^{o}C)
Gypsum	0.17	0.26
Sisal fibre	0.07	-
Glass Fibre	0.04	0.16

All composites materials have been inserted in the Engineering data of ANSYS and all their mechanical properties will be in shown from Figure 3-9 to Figure 3-14 properties that are most important and need to make sure that they have entered correctly is the thermal properties such as heat conductivity and specific heat.

Outline of Schematic A2, B2, C2, D2, E2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	GLASS FIBRE			E	
4	GYPSUM			E	
5	Resin Epoxy			C	
6	Resin Poly Ester			C	
7	Resin Vinyl Ester			C	
8	SISAL FIBRE			E	

Figure 3-8 All resins and composites involved in the model

Properties of Outline Row 4: GYPSUM

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2312	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's Modu...			
5	Young's Modulus	4.57E+10	Pa		
6	Poisson's Ratio	0.33			
7	Bulk Modulus	4.4804E+10	Pa		
8	Shear Modulus	1.718E+10	Pa		
9	Tensile Yield Strength	6.5E+11	Pa		
10	Isotropic Thermal Conductivity	0.75	W m^-1 C^-1		
11	Specific Heat	26	J kg^-1 C^-1		

Figure 3-9 Mechanical properties of Gypsum

Properties of Outline Row 8: SISAL FIBRE

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1330	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's Modu...			
5	Young's Modulus	2E+10	Pa		
6	Poisson's Ratio	0.33			
7	Bulk Modulus	1.9608E+10	Pa		
8	Shear Modulus	7.5188E+09	Pa		
9	Tensile Yield Strength	6.5E+11	Pa		
10	Isotropic Thermal Conductivity	0.07	W m^-1 C^-1		
11	Specific Heat	15	J kg^-1 C^-1		

Figure 3-10 Mechanical properties of Sisal fibre

Properties of Outline Row 3: GLASS FIBRE

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2550	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's Modu...			
8	Young's Modulus	7.2E+10	Pa		
9	Poisson's Ratio	0.33			
10	Bulk Modulus	7.0588E+10	Pa		
11	Shear Modulus	2.7068E+10	Pa		
12	Tensile Yield Strength	2.05E+09	Pa		
13	Isotropic Thermal Conductivity	1.6	W m^-1 C^-1		
14	Specific Heat	0.15	J kg^-1 C^-1		
15	Isotropic Seebeck Coefficient	0.17	V C^-1		

Figure 3-11 Mechanical properties of glass fibre

Properties of Outline Row 6: Resin Poly Ester

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.2E-09	mm^-3 t		
3	Isotropic Elasticity				
4	Derive from	Young's Modu...			
5	Young's Modulus	3000	MPa		
6	Poisson's Ratio	0.316			
7	Bulk Modulus	2.7174E+09	Pa		
8	Shear Modulus	1139.8	MPa		
9	Isotropic Thermal Conductivity	0.05	W m^-1 K^-1		
10	Specific Heat	1.3	J g^-1 K^-1		
11	Ply Type				

Figure 3-12 Mechanical properties of Resin polyester

Properties of Outline Row 5: Resin Epoxy

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.16E-09	mm^-3 t		
3	Isotropic Elasticity				
4	Derive from	Young's Modu...			
5	Young's Modulus	3780	MPa		
6	Poisson's Ratio	0.35			
7	Bulk Modulus	4.2E+09	Pa		
8	Shear Modulus	1400	MPa		
9	Tensile Yield Strength	54.6	Pa		
10	Isotropic Thermal Conductivity	0.35	W m^-1 C^-1		
11	Specific Heat	0.24	J kg^-1 C^-1		
12	Ply Type				

Figure 3-13 Mechanical properties of Resin epoxy

Properties of Outline Row 7: Resin Vinyl Ester

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.2E-09	mm^-3 t		
3	Isotropic Elasticity				
4	Derive from	Young's Modu...			
5	Young's Modulus	3000	MPa		
6	Poisson's Ratio	0.316			
7	Bulk Modulus	2.7174E+09	Pa		
8	Shear Modulus	1139.8	MPa		
9	Isotropic Thermal Conductivity	0.15	W m^-1 C^-1		
10	Specific Heat	0.24	J kg^-1 C^-1		
11	Ply Type				

Figure 3-14 Mechanical properties of Resin vinylester

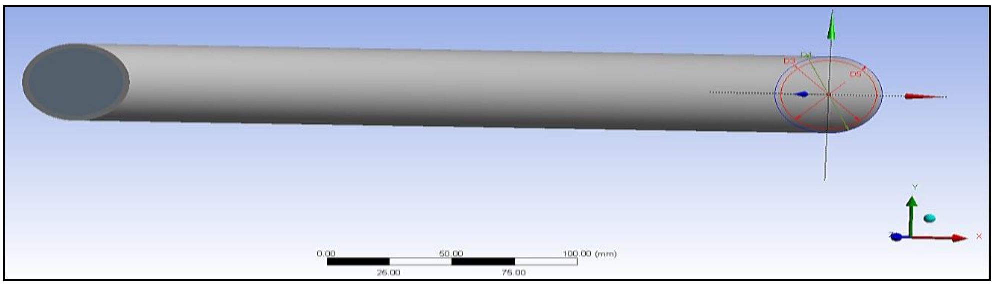


Figure 3-15.Initial model of gypsum cylinder without sisal fibres

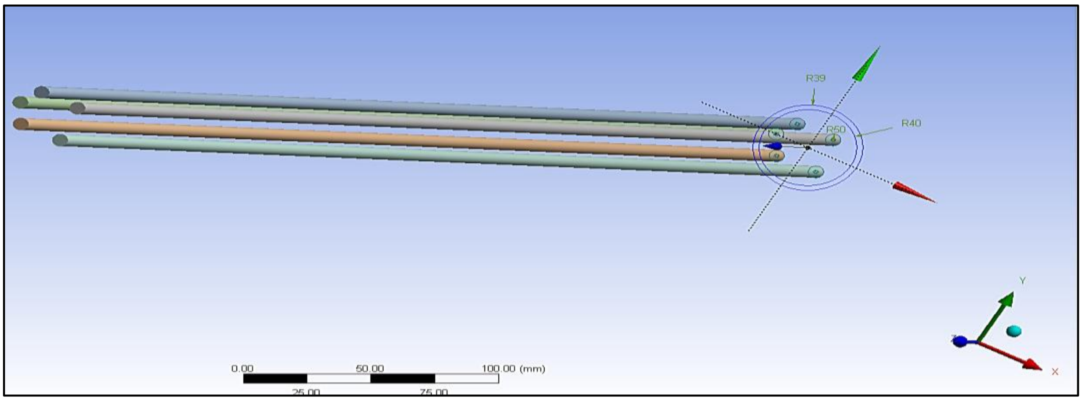


Figure 3-16.Modelling of the extruded sisal-glass fibres

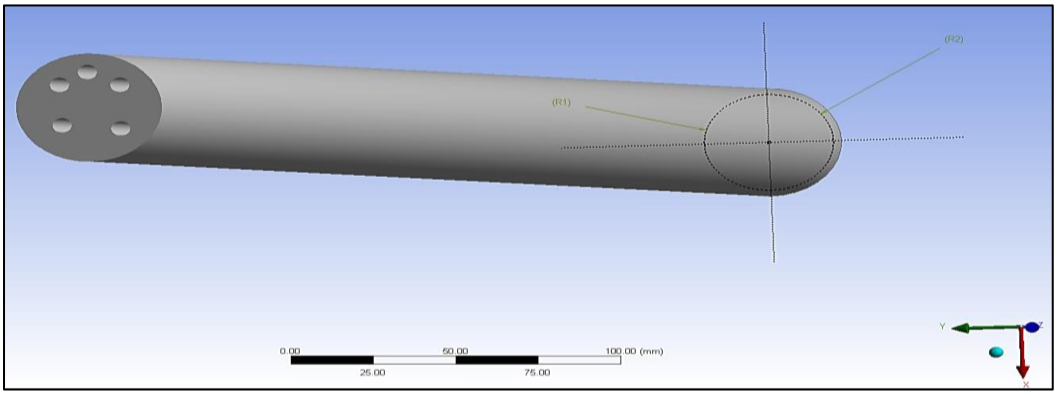


Figure 3-17.Simple model of composite cylinder with surface points of fibres places

3.4.2 Generating the mesh

Meshing is the most important tool in the computer simulation as it can make the results more accurate, irrespective of the simulation being structural, static or thermal analysis. In addition, meshing is a very useful tool for generating a specific area in the model which needs a focused analysis. This makes the users more comfortable in using it in some specific cases. For example, in the project model, temperature has been applied on one area of which a finest mesh is required as compared with the rest surfaces where a coarser mesh is sufficient. The different meshes created for each composite cylinder are shown in the Figure 3-18 and Figure 3-19.

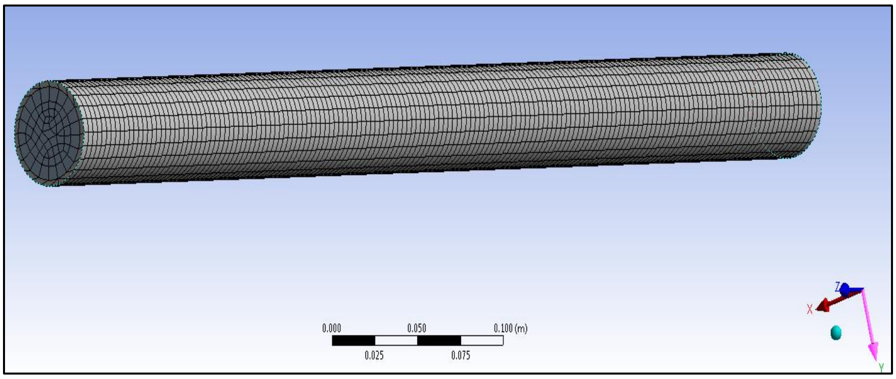
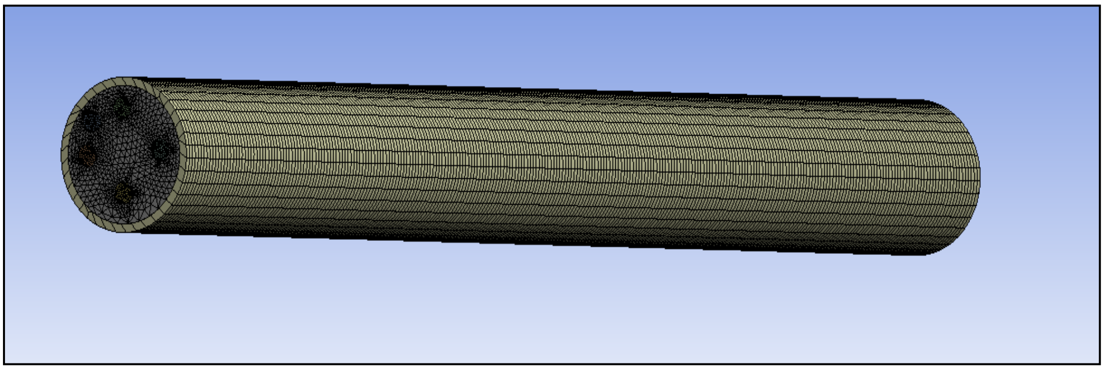


Figure 3-18.Meshed of the primarily model of a gypsum cylinder without sisal fibres



Details of "Mesh"

Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Sizing	
Inflation	
Advanced	
Statistics	
Nodes	259712
Elements	116189
Mesh Metric	None

Figure 3-19.Meshed model of composite cylinder incorporated with 20% sisal fibres with it is nodes and elements

The meshed models were divided in to five sections for analysing the heat flow across the composite cylinders. The total length of the cylinder was taken as 10cm and each section length into 2cm. The temperature of the beginning of the cylinder was taken as 120^{o}C and this model is shown in figure 17 as follows. The orientation of the five parts in coordinate system is also given along with in figure

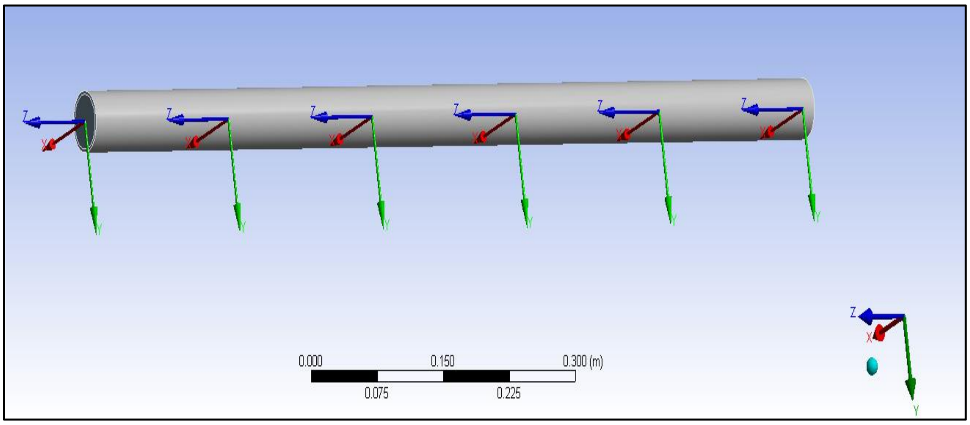


Figure 3-20. Orientation of the five parts of composite cylinder in coordinate system

3.4.3 Boundary condition

The boundary conditions are given in Figure 3-21, it can be seen that 120 C° has been applied in one side and the end of the other side a convection of 20 C°have also applied the covered insulated material which is shown in blue colour of Zero heat flow and has a convection of 20 C°.

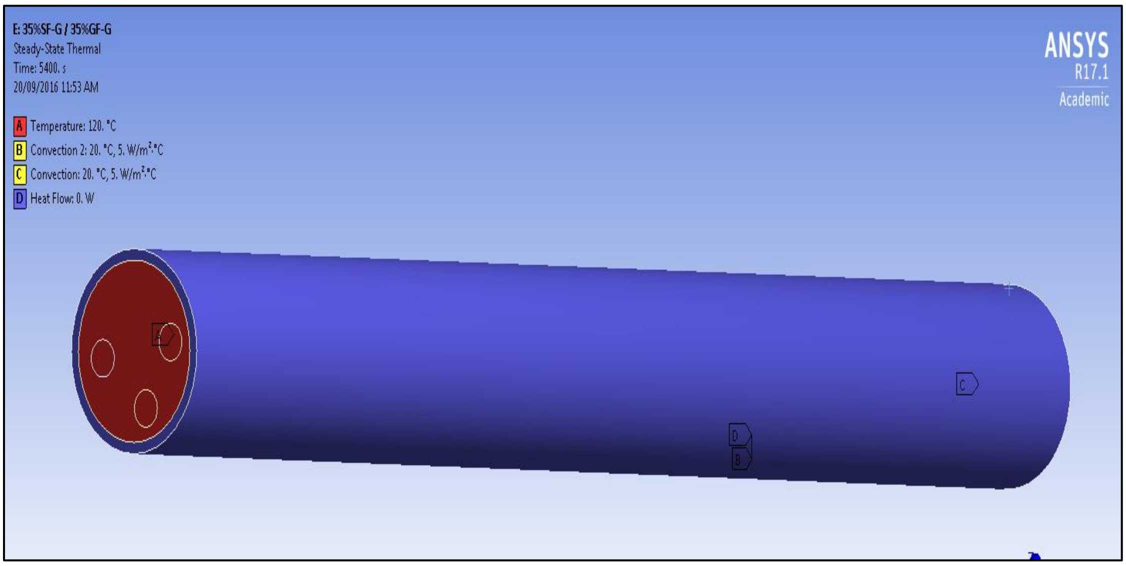
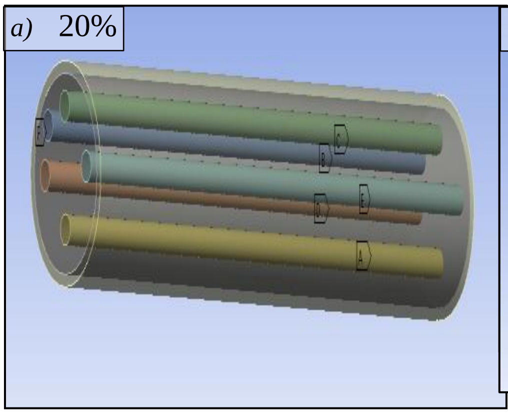


Figure 3-21. Boundary conditions of composite cylinder

3.4.4 Fibre/Polymer modelling in ANSYS

The model was then solved and solution of the simultaneous equations was obtained by the software to give images of the models from figure 20 to 23. The dimensions of the model cylinders are also given in the table 4.



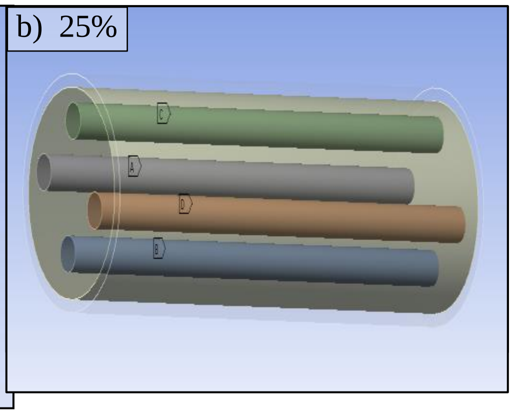
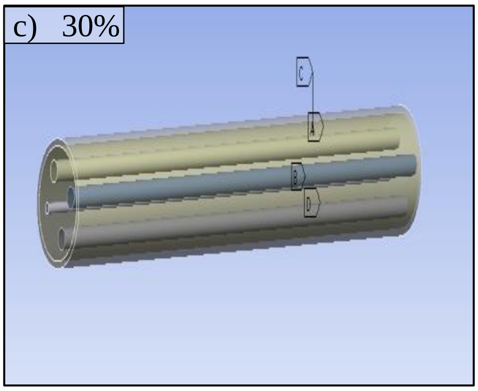


Figure 3-22.Model of composite cylinder incorporated with 20% sisal fibres

Figure 3-24.Model of composite cylinder incorporated with 25% sisal fibres



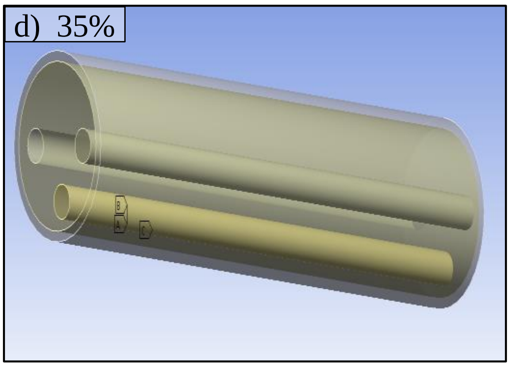


Figure 3-23.Model of composite cylinder incorporated with 30% sisal fibres

Figure 3-25.Model of composite cylinder incorporated with 35% sisal fibre

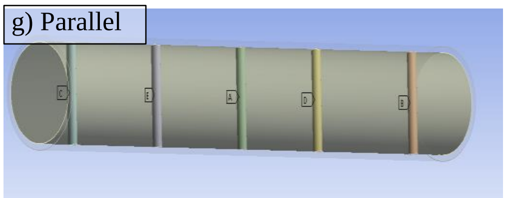


Figure 3-26.Model of composite cylinder incorporated with Parallel Orientation with 20% sisal-glass fibres

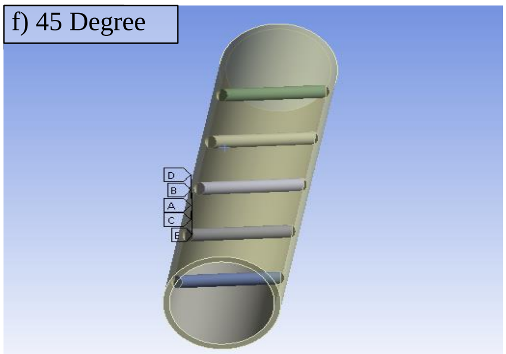


Figure 3-27 Model of composite cylinder incorporated with 45 degree Orientation of 20% sisal-glass fibres

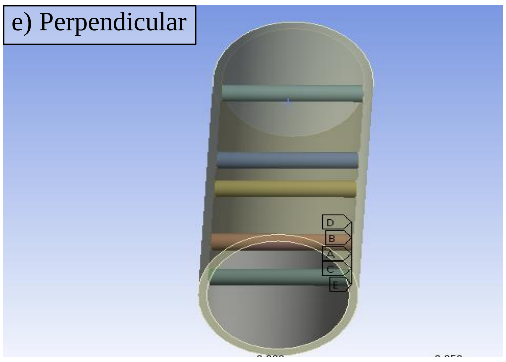


Figure 3-28 Model of composite cylinder incorporated with Perpendicular Orientation of 20% sisal-glass fibres

Table 3-2. Dimensions of the cylinder models and fibres involved

Volume fraction %	Dimensional Parameters	Number of fibres	Radius (cm)
Non	**R39**	**-**	**2.0**
20%	**R40**	**5**	**0.3111**
25%	**R51**	**4**	**0.3478**
30%	**R52**	**4**	**0.381**
35%	**R53**	**3**	**0.4115**

Chapter 4. Results and Discussion

4.1 Introduction

The numerical results of the thermal characteristics of different fibre/matrix composites, are presented in this chapter. However, due to the large amount of data was obtained in this project, the raw data was introduced in appendix E and the main findings are given in this section. Numerical test was evaluated on mainly sisal fibre and glass fibre which they combined with Gypsum. On other hand, it was combined also with different Resins in Table 4-1 all the samples of the used materials will be listed. Prolonged heat exposure was conducted on the beginning of the cylinder with a duration of 90 minutes and the measurements was taken at these points T1, T2, T3, T4, T5 and T6 from 6 coordinates systems that has been discussed and shown in the previous chapter in Figure 3-20 and in Figure 4-1 showed the methodology of the experimental. Volume fractions of the thermal conductivity of the composite has taken place. The comparison of the experimental and the numerical results is also evaluated.

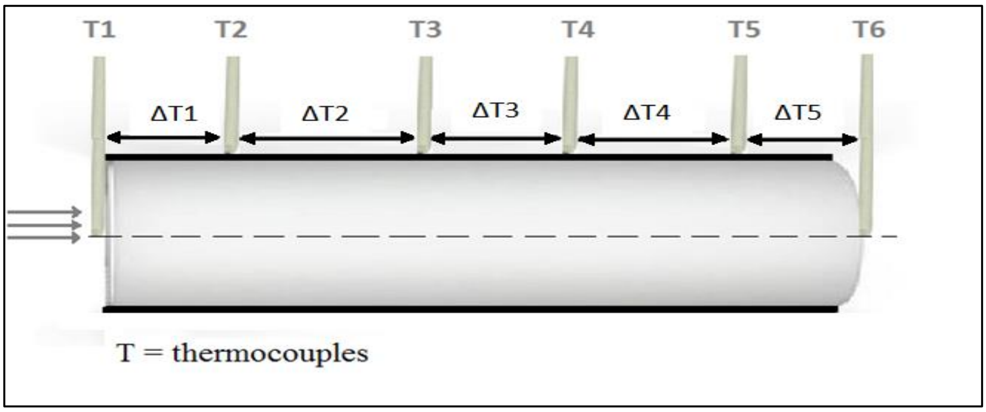


Figure 4-1 Temperatures reading along the cylinder (Rashed F Alajmi 2015)

Table 4-1 List of composite samples involved in the model

Type of fibre	Samples	Fibre volume fraction %
–	Pure gypsum	0%
Sisal	SF-Gypsum	20%-35%
Glass	GF-Gypsum	20%-35%
Sisal	SF-Polyester	20%-35%
Glass	GF-Polyester	20%-35%
Sisal	SF-Epoxy	20%-35%
Glass	GF-Epoxy	20%-35%
Sisal	SF-Vinylester	20%-35%
Glass	GF-Vinylester	20%-35%

4.2 Sample of ANSYS Results

4.2.1 Gypsum with 20% of Glass-fibre

The results for gypsum with 20% glass-fibre the results Figure 4-2 and Figure 4-3 are taken from the ANSYS. The images are taken of gypsum composite reinforced with 20% Glass fibres as all the other volume fractions are presented in Appendix G., Figure 4-3 shows the temperatures at different points across the cross-sectional area of the composite cylinder. As shown previously in Figure 3-20, the cylinder was divided into multiple sections for assessing the temperature distribution along the cylinder length. The temperature decreases from the heated end towards the unheated end. Figure 4-2 for example shows that the temperature varies from 56.5°C to 21°C for one observation. The graph in Figure 4-3 provides similar information about the changes in temperatures along with timeframe

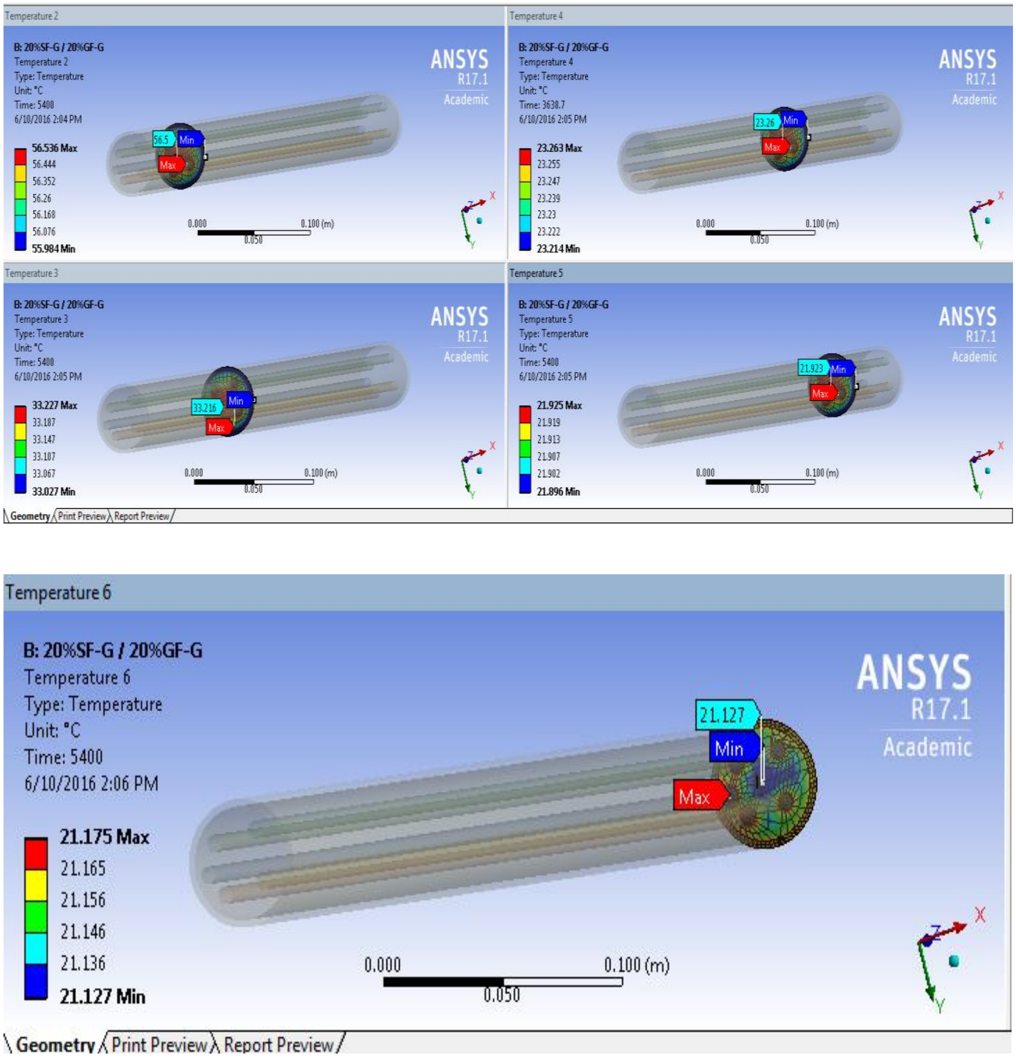


Figure 4-2 simulation of temperatures from T2-T6

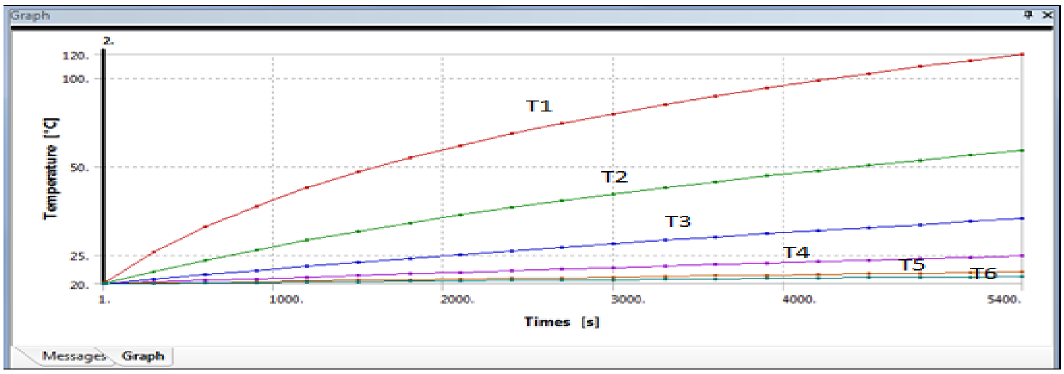


Figure 4-3.Variation of temperatures along the composite cylinder lengths with time

Figure 4-3 shows the different temperatures along with the glass fibre-gypsum cylinder which has taken from ANSYS graph and it can be seen that the first curve shows the highest temperature of around 120°C and that refer to T1 the second curve of the following curve is showing T2 which is about 56.536°C till the last curve which T6 which is about 21.127°C. All the temperatures differences of the simulated model was tabled in the following

Table 4-2 Temperatutes differences across Glass fibre-gypsum composites of both experimental and numerical results

	Experimental Results					Numerical Results				
Materials	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5
Pure gypsum	62.7	15.5	12.4	4.0	0.3	63.0	12.5	6.5	2.0	0.5
GF20%G	63.5	17.2	9.8	4.6	1.4	70.1	14.3	15.5	1.6	0.3
GF25%G	65.6	16.4	8.1	3.3	1.2	70.5	14	9.8	5.5	0.5
GF30%G	67.2	16.8	7.1	3.0	0.4	64.2	18.7	4.7	3.4	0.6
GF35%G	68.2	19.7	7.8	4.7	1.2	69.6	23.3	9.76	2.44	0.56

The error was calculated using $\%\boldsymbol{ERROR} = \frac{|\boldsymbol{EXP-NUM}|}{\boldsymbol{EXP}} * \mathbf{100}$

Equation 4-1

$$\%\boldsymbol{ERROR} = \frac{|\boldsymbol{EXP-NUM}|}{\boldsymbol{EXP}} * \mathbf{100}$$ **Equation 4-1**

	Experimental Results					Numerical Results				
Materials	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5
Pure gypsum	62.7	15.5	12.4	4.0	0.3	63.0	12.5	6.5	2.0	0.5
GF20%G	63.5	17.2	9.8	4.6	1.4	70.1	14.3	15.5	1.6	0.3
GF25%G	65.6	16.4	8.1	3.3	1.2	70.5	14	9.8	5.5	0.5
GF30%G	67.2	16.8	7.1	3.0	0.4	64.2	18.7	4.7	3.4	0.6
GF35%G	68.2	19.7	7.8	4.7	1.2	69.6	23.3	9.76	2.44	0.56

Table 4-2 shows the all data from the experimental and numerical results in the numerical side it can be seen that with the increment of volume fraction of glass fibre at ΔT1 is slightly increasing until is end to 25% it was dropping down. Glass fibre shows decreasing of heat transfer with compared to pure gypsum. The decrement of the insulation performance of pure gypsum is -7.1, -7.5, -1.2, and -6.6% for all volume fractions of 20, 25, 30 and 35% respectively. Which shows that the highest gap between T1 and T2 is the glass fibre with volume fraction of 25%. In addition, this results in making glass fibre more conductive to heat than pure gypsum which means that glass fibre is better insulation performance with compared to pure gypsum. However, that does not show an agreement with the experimental results as it showed that the highest gap in temperatures between T1 and T2 is the glass fibre with 35% and that is obviously because of the mistake that might be involved while making the model of both 30% and 35% volume fraction. However, it did show agreement with both 20% and 25% of glass fibre. Same studies had conducted by Cao et al. (2015) thermal insulation features of glass fibre used for board building. It was defined that it is hard to be able to suddenly explain the porous of that is inside a structure due to the complexity of the composites it is well known that the heat conductivity drop with raising porosity of the near-linear rate.

In the following Table 4-3 all the error percentage between the experimental and numerical results has been calculated using equation 4-1 .

Table 4-3 Errors between the experimental and numerical results of Glass fibre-gypsum

% Errors between Experimental and Numerical Results					
Materials	%Error (ΔT1)	%Error (ΔT2)	%Error (ΔT3)	%Error (ΔT4)	%Error (ΔT5)
PG	3.66	32.3	47.6	50	66
GF20%G	1.1	16.86	58.16	65.2	78.57
GF25%G	6.09	14.63	20.99	66.67	58.33
GF30%G	4.32	11.31	33.8	13.33	50
GF35%G	6.89	18.27	25.13	48.09	53.33

4.2.2 Gypsum with 20% of Sisal-fibre

Similarly, the ANSYS results for sisal fibre reinforced gypsum composite were exported from the software and are shown in the Figure 4-4 and Figure 4-5. These images are of 20% sisal fibre volume fraction of the composite. The images ranging from Temperature 2 to Temperature 6 show the temperatures at different measurements positions across the cross-section of the composite cylinder. As compared to the glass fibres, we have a considerable difference of temperature for the sisal fibres at the first observation point. The thermal conductivity of sisal fibre composite was much less than glass fibre a temperature difference of 5°C. Similarly, at the last observation point, the temperature forces in this sisal fibre composite is lower as compared to the glass fibres composite. The temperature varied from 51°C to 20.5°C across the length of the composite cylinder.

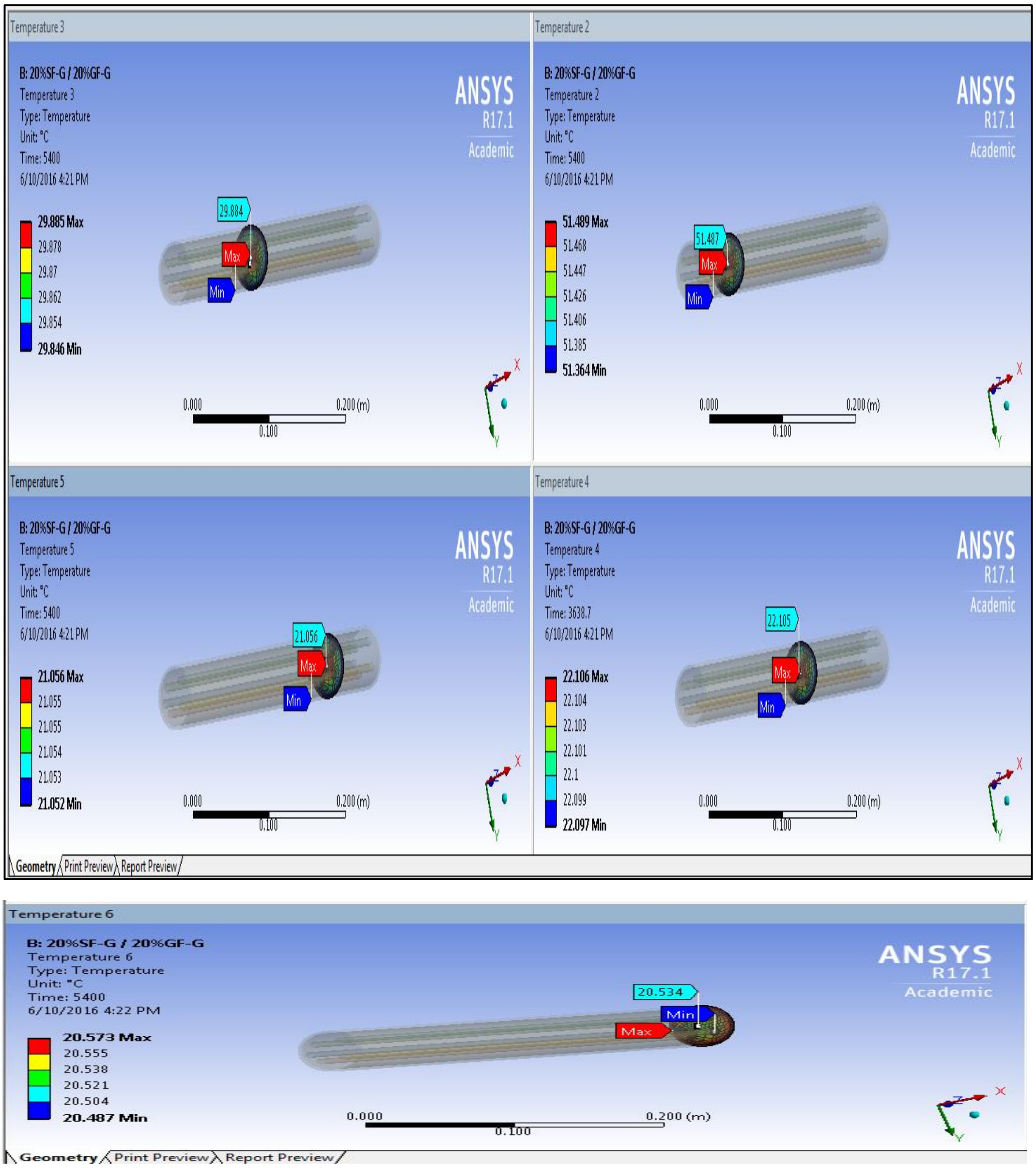


Figure 4-4 Images from the ANSYS software showing temperatures at different sections along the cylinder

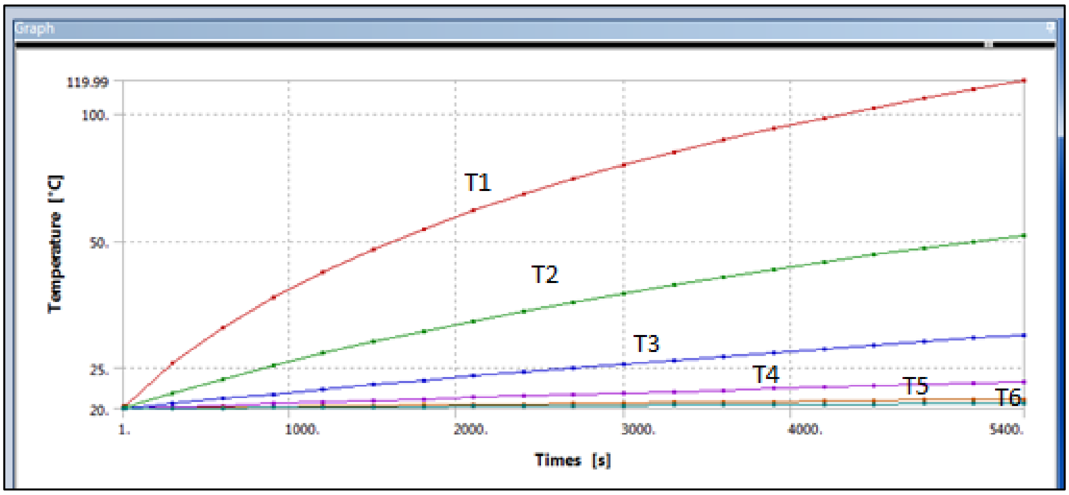


Figure 4-5 Variation of temperature along the composite cylinder lengths with time

Figure 4-5 shows the different temperatures with respect to the total length of the cylinder with the sisal fibre-gypsum cylinder which has taken from ANSYS graph and it can be seen that the first curve showed the highest temperature of around 120°C and that refer to T1. Secondly, the next curve is showing T2 which is about 51.487°C till the last curve which is T6 shows about 20.534°C. All the temperatures differences of the simulated model was tabled in the followingTable 4-4.

Table 4-4 Temperatutes differences across Sisal fibre-gypsum composites of both experimental and numerical

	Experimental Results					Numerical Results				
Materials	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5
Pure gypsum	62.7	15.5	12.4	4.0	0.3	65.0	20.5	6.5	2.0	0.5
SF20%G	67.4	17.5	7.1	3.3	2.3	68.4	17.4	6.9	3.0	3.2
SF25%G	68.5	15.7	6.8	3.3	0.6	69.2	16.6	4.82	3.4	4.54
SF30%G	71.0	8.8	8.9	4.6	0.6	70.3	14.7	9.7	2.5	1.8
SF35%G	73.0	15.8	7.8	3.9	2.2	72.8	17.7	6.48	4.70	1.63

From Table 4-4 Temperatutes differences across Sisal fibre-gypsum composites of both experimental and numerical, which obtained both experimental and numerical results by discussing the numerical results it can be observed again that ΔT1 shows slightly similar reading. The first temperature differences shows increasing with respect of adding sisal fibre, from the vol.% of 35% shows the highest temperature differences from ΔT1 and ΔT2 indicates that the heat transfer between these two points is in its highest gap in temperature. This illustrate that with the addition of sisal fibre the thermal transfer decreases, which make sisal fibre as a better heat insulator performer. The increment in heat insulation feature is 3, 3.4, 4.2, 5.3 and 7% for all volume fraction of 20, 25, 30 and 35% respectively.

Table 4-5 Errors between the experimental and numerical results of Sisal fibre-gypsum

% Errors between Experimental and Numerical Results					
Materials	%Error (ΔT1)	%Error (ΔT2)	%Error (ΔT3)	%Error (ΔT4)	%Error (ΔT5)
Pure gypsum	3.66	32.3	47.6	50	66
SF20%G	1.48	0.57	2.82	9.09	39.1
SF25%G	2.19	6.24	29.12	45.65	65.6
SF30%G	5.2	21.8	8.99	45.65	50
SF35%G	5.75	12.1	16.9	20.5	25.91

4.3 Experimental and Numerical Results of Sisal\gypsum Composites

Figure 4-6 to Figure 4-9 show a comparison between the experimental and numerical results obtained for heat conduction by using different percentages of sisal fibre in gypsum. The figures show good agreement between both the numerical and experimental results. This provides some reassurance that the ANSYS model is working correctly and is suitable for simulating the heat behavior of composites. The figures show that there is a slight difference exists between experimental and numerical studies assessment of heat transfer along composite length. However, it has also been observed that for some composite samples at particular lengths, the difference between the two studies was almost negligible. The 25% composite showed similarity between the two studies at lengths of 0.08 and 0.1 m and similar results were seen for the 25% composite at these two lengths.

However, the experimental study showed slightly higher heat conduction than theoretical values at different lengths for all composite samples. Even though, both studies showed a uniform decrease in the temperature values along the composite lengths, but at some point the experimental temperature was higher. One exception was the point at a length of 0.02 m for the 25% composite at which the numerical temperature was nearly 3°C higher than the experimental temperature. When such a case is compared with other samples of sisal mixed with gypsum, the experimental temperature might involve any inaccuracy because of the affection of any operating conditions.

The composites experienced a major temperature drop at length of 0.02 m and further a limited temperature variation existed. An approximate average decrease of 67°C in the temperature was obtained from 0 to 0.02 m. The temperature values along the length of the composites are in consistent with the results obtained in previous studies (Ashour et al., 2010). At the place of sisal fibres, the wheat straw fibres were used to make composites with natural plastic materials. A wide variety of fibre percentages ranging from 0 to 75% were used and the composites were studied at different temperatures ranging from 10°C to 40°C. The composites were found to have similar heat insulation capabilities along their respective lengths Ashour et al., (2010).

Another similar study was conducted by (Chikhi et al., 2013). in which date palm fibres were used to form composites with gypsum. It was mentioned that the fibres were less conductive as compared to the gypsum alone and a considerable drop in temperature was observed with increasing percentage of fibres in the composites.

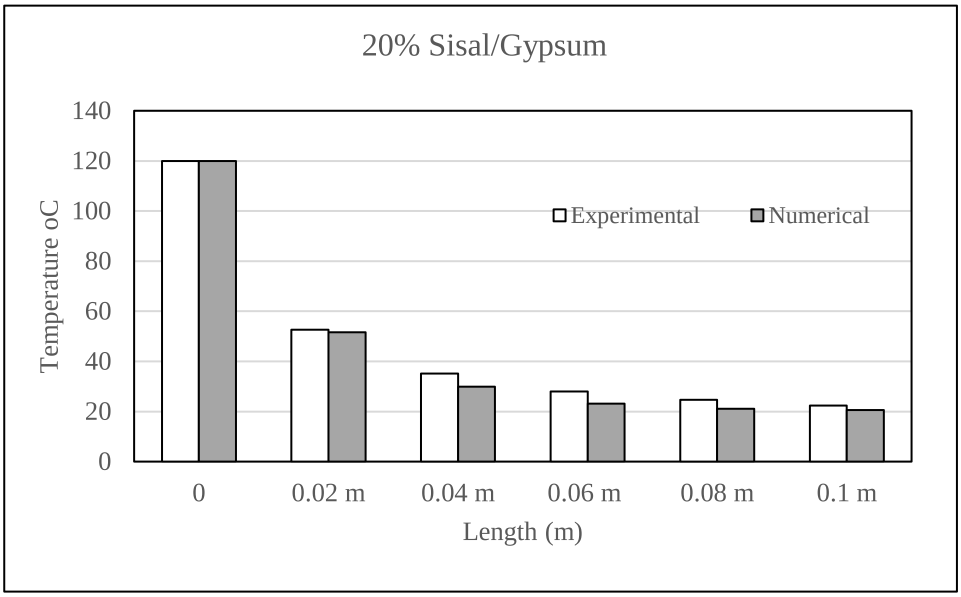


Figure 4-6.comparison between experimental and numerical results of 20% sisal\gypsum

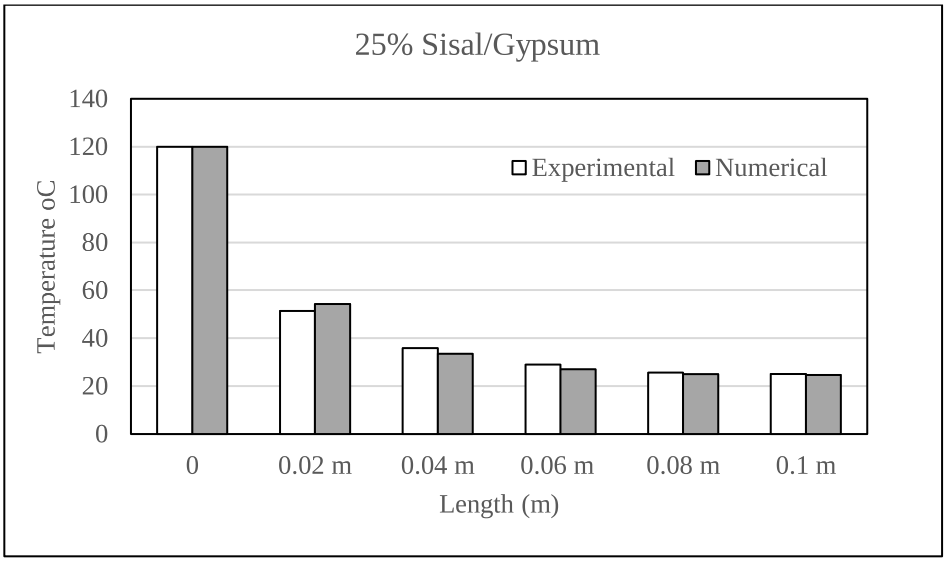


Figure 4-7.comparison between experimental and numerical results of 25% sisal\gypsum

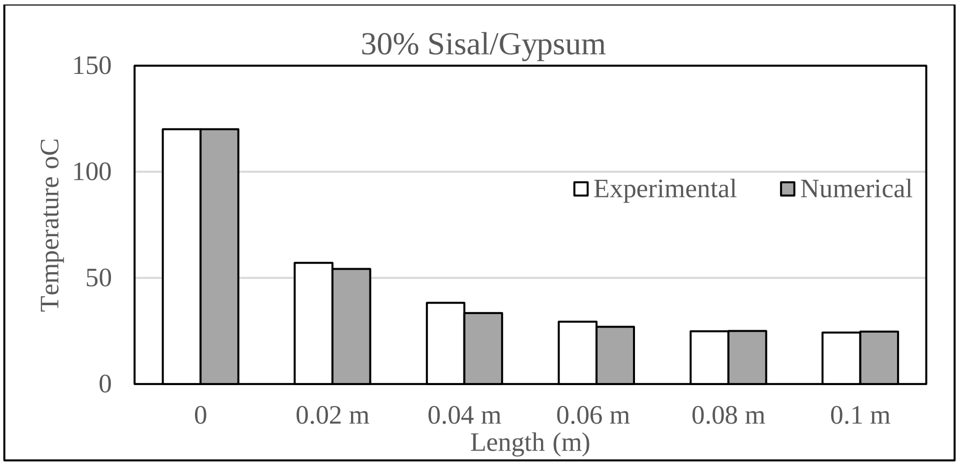


Figure 4-8.comparison between experimental and numerical results of 30% sisal\gypsum

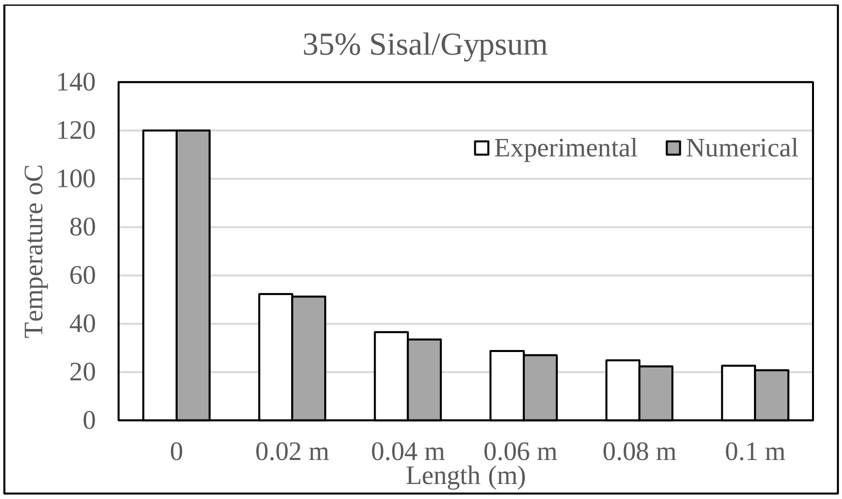


Figure 4-9.comparison between experimental and numerical results of 35% sisal\gypsum

4.4 Experimental and Numerical Results of Glass\gypsum Composites

Similar to the sisal fibre composites, the difference in the experimental and numerical values was found for the different glass fibre composite samples. The results for the glass fibre composites are shown in the figure is a ranging from

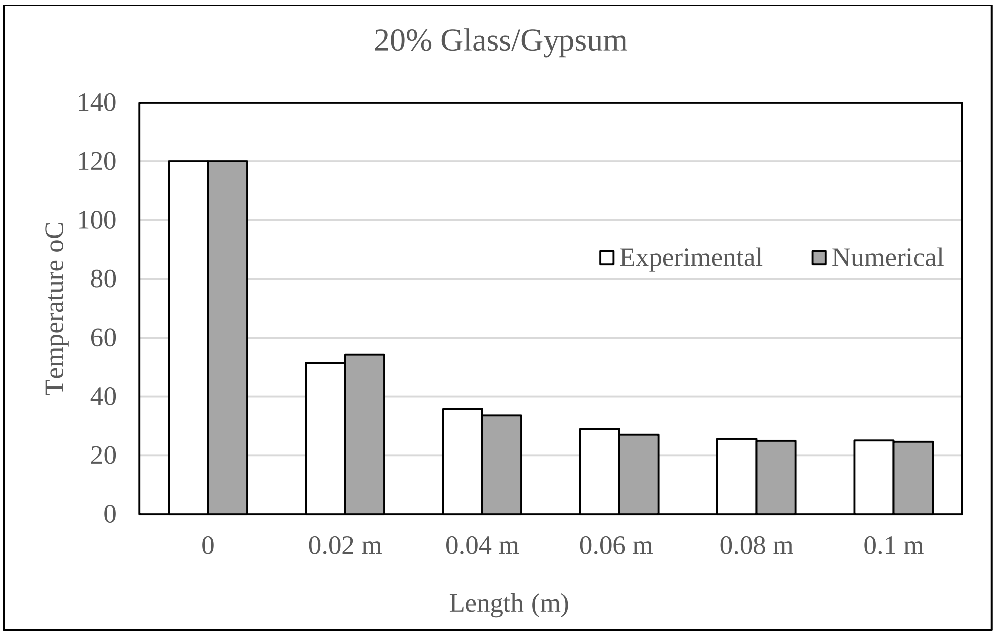


Figure 4-10 to Figure 4-13. In addition, similarity results was also found between both experimental and numerical studies, but in this case two of the samples showed similarity in the results of both studies at particular lengths. However, in contrast to the sisal fibre composites, a number of numerical temperature values where a higher as compared to the experimental temperatures. For example, the 20%, 30%, and 35% glass fibre composites showed such trends.

As an overall, a uniform decrease in the results was also obtained along the length of the composite samples. As before, these composites also experienced the major temperature drop at length of 0.02 m. Further along the length, the temperature variation was very much limited and a smooth decrease in temperature was observed. The approximate average decrease in temperature from 0 to 0.02 m length was around 68°C and further along the length this decrease ranged from 2°C to 9°C.

Recently, a study developed a mathematical model and analysed the thermal conductivity patterns of Glass fibre boards. The fibre board samples had different percentages of glass fibres and it was found that increasing percentage of fibres provide better insulation. However, it was suggested that the percentage should be in a limiting range for getting the maximum insulation properties (Cao et al., 2015). In our case, however, the lowest temperature was 20°C and maximum length and it was achieved for 20% and 35% glass fibre composites. Rest of the two samples were able to achieve 24°C as the lowest temperature at full length.

Here, the high percentage of error can be found at the middle section of the sample. This can be due to the fact that thought sections are far from the boundaries. The long-time of running and/or find meshing can be used to reduce that amount of error. This point has been given in the recommendations section.

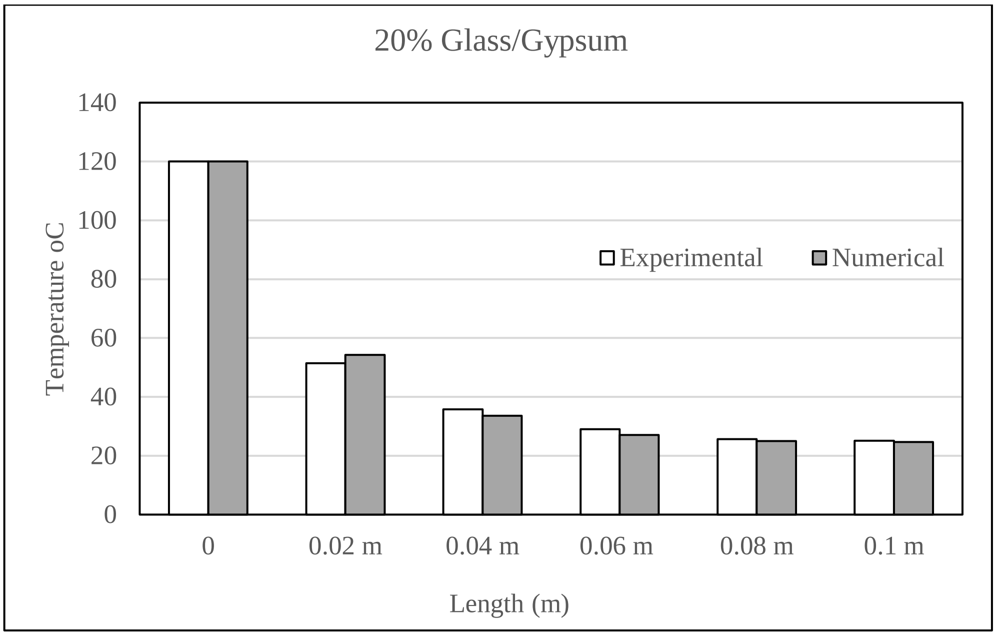


Figure 4-10 comparison between experimental & numerical results of 20% glass\gypsum

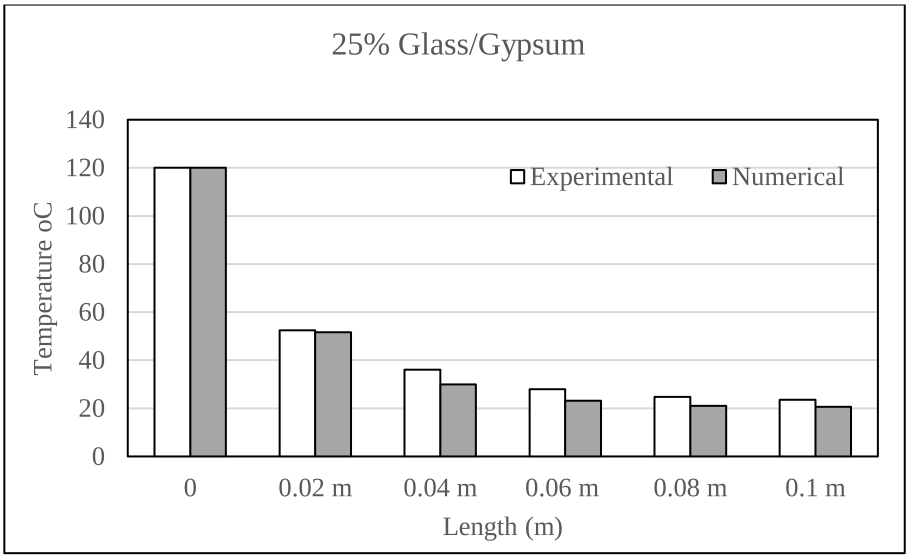


Figure 4-11 comparison between experimental and numerical results of 25% glass\gypsum

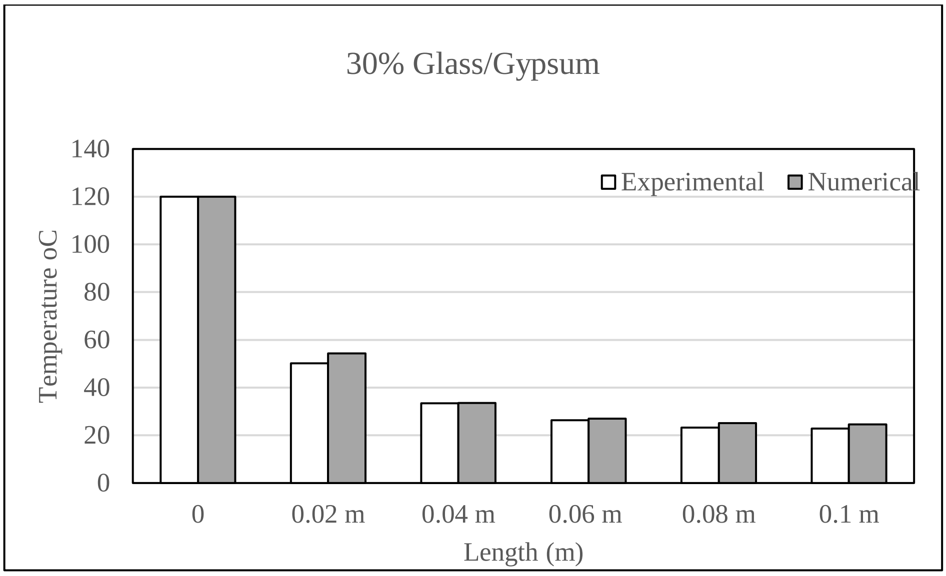


Figure 4-12 comparison between experimental and numerical results of 30% glass\gypsum

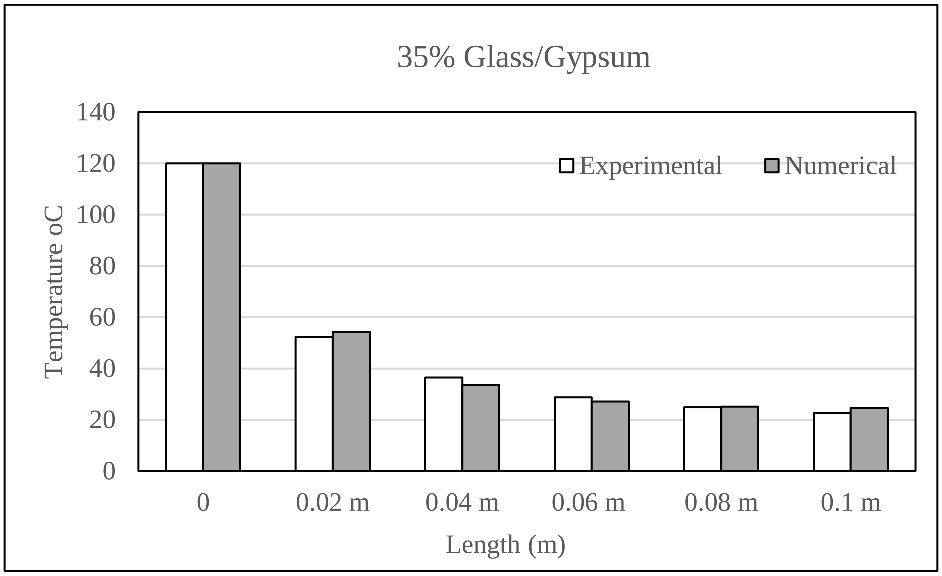


Figure 4-13 comparison between experimental and numerical results of 35% glass\gypsum

4.5 Influence of Volume Fraction of fibres

A comparison of both sisal and glass fibres in terms of their insulation capabilities in gypsum is shown in the figure 4.9. A no uniform trend is obtained with increasing fibre volume contents in the gypsum and a wide difference in the values is obtained for each fibre. The 25% glass fibre composite exhibited the maximum insulation percentage of 59% and the lowest was 53.6% for 30% Glass fibre loading. All glass fibre composites showed higher insulation capability as compared with the sisal fibres composites.

Such trend was also observed in another study by Patnaik et al. He modelled and experimentally studied the thermal characteristics of glass fibre reinforced epoxy composites having different percentages of glass fibres. He found an increase in the insulation capability of composites with increasing glass fibre contents. However, he found that the insulation capability of the composite was dependent on the glass fibre contents. The insulation capability was increased with the increase in fibre loading starting from 15% and, on the other hand, it was decreased slightly beyond 45 % loading (Patnaik et al., 2012). Almost similar behaviour is also evident in the figure and we get the maximum insulation percentage at 25% volume fraction.

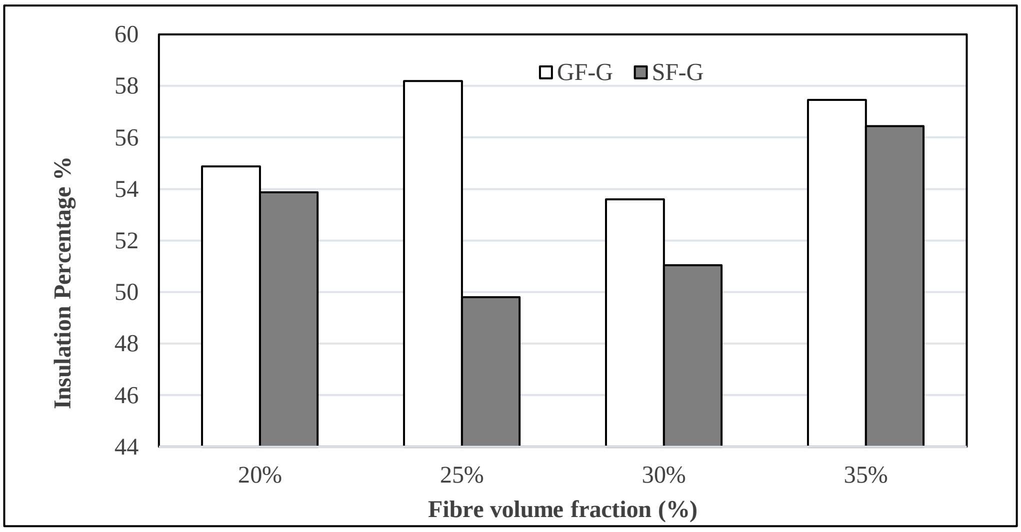


Figure 4-14. Comparison on the insulation of sisal and glass fibre-gypsum composites with different volume fraction

4.6 Influence of Orientation in Sisal Fibre/Epoxy

Figure 4-15 shows the impact of fibre orientation at different loadings on the insulation properties of the composite. For all types of fibre orientations, an increase in the insulation capability of composites was obtained at all loadings. With the passage of time, a smooth curve was formed for each loading and a uniform increase in the insulation percentage was obtained. The fibre orientations at parallel, perpendicular, and 45° gave values with close proximity at all time intervals. As an overall these three orientations had higher values at each time interval as compared to the normal orientation.

The impact of fibre orientation on the thermal characteristics of a composite was also studied by Devireddy and Biswas. They performed steady-state heat transfer simulations by using ANSYS software for determination of thermal conductivity. This study was conducted for natural fibres reinforced epoxy composites with fibre loadings ranging from 10% to 30%. The fibres were oriented in the composites in normal and transverse direction to the heat flow. They also experienced a reduction in thermal conductivity after incorporation of fibres in the epoxy resin and obtained similar results with the composites having fibres oriented in normal direction (35%) as compared to the transverse direction (44%). The lower insulation capability with the normal orientation is mainly due to the alignment of fibres parallel to the heat flux direction (Devireddy and Biswas, 2016).

When the fibre loading is increased from 20 to 25%, a slight increase in the insulation capability of composite is observed. For example, after the expiry of 90 minutes, an increment of nearly 0.1% was observed in the insulation percentage of 30% fibre loading as compared to the 20%. Such slight variations (increase or decrease in insulation percentages) are also observed at other time intervals. However, any appreciable change is not observed as compared to the earlier studies. According to Kalaprasad et al., with increasing fibre content, the void contents of a composite increases and hence insulation capability of the composite increases (Kalaprasad et al., 2000).

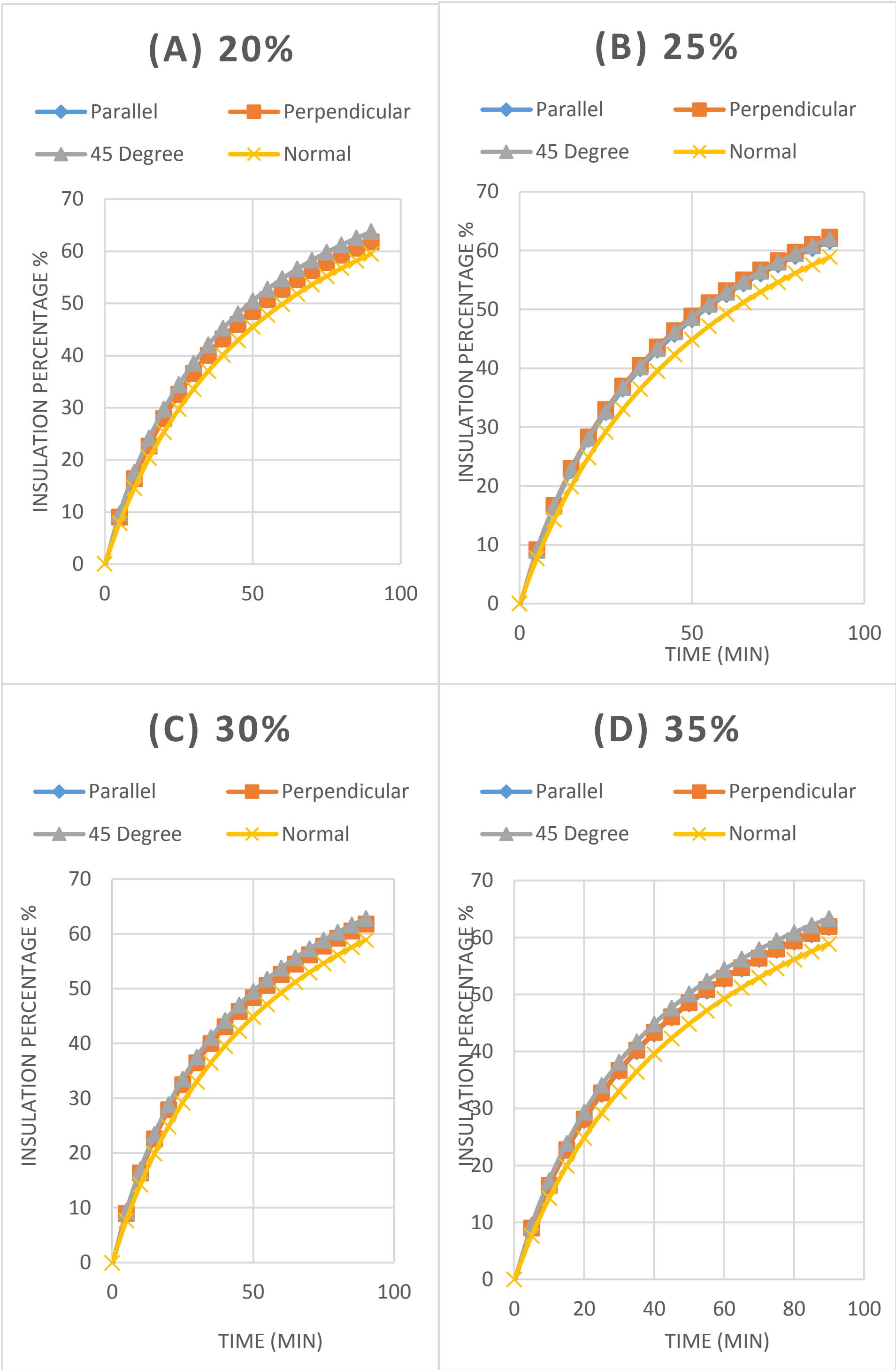


Figure 4-15 Influence of orientation in sisal fibre/epoxy composites (A) 20%, (B) 25%, (C) 30%, (D) 35%

4.7 Influence of Orientation in Glass Fibre/Epoxy

Figure 4-16 shows the impact of fibre orientation at different loadings on the insulation properties of the composite.

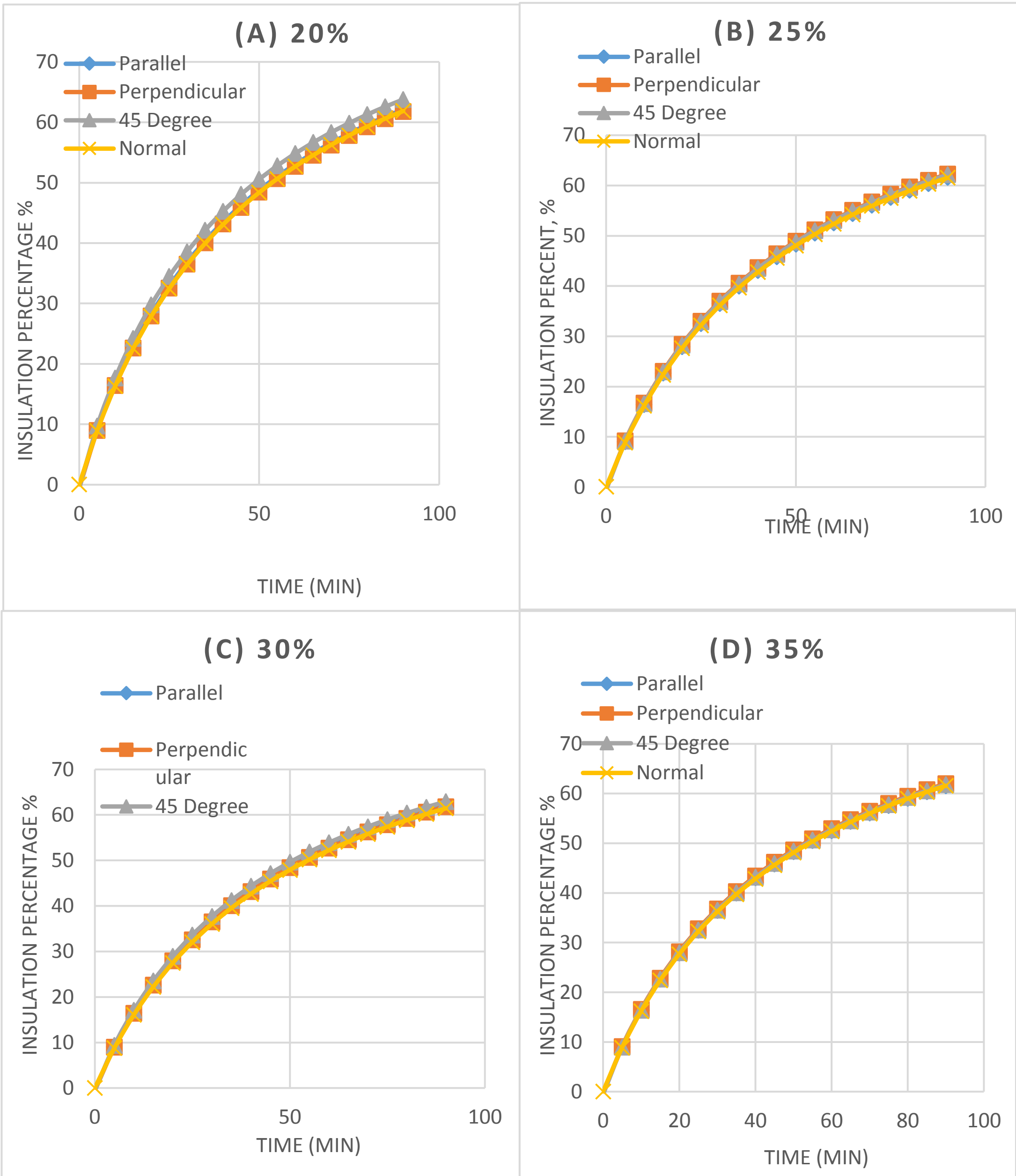


Figure 4-16.Influence of orientation in glass fibre/epoxy composites (A) 20%, (B) 25%, (C) 30%, (D) 35%

4.8 Influence of Orientation in Sisal Fibre/Polyester

Figure 4-17 shows the impact of sisal fibres orientation at different loadings on the insulation properties of the polyester based composite. As evident, at all loadings the glass fibre composites gave similar insulation trends. Over the time, each orientation in all of the composites gave similar insulation tendency. The effect of fibre loading and its orientation on the heat conduction capability of the composites was marginal. Such behaviour can be explained by the relatively good thermal conductivity (>1 W/mK) and isotropic nature of the glass fibres as compared to the natural or sisal fibres (0.07 W/mK) (Kalaprasad et al., 2000). Such characteristics of the glass fibres nullify the effects of fibre orientation and we get pretty much the same values of thermal insulation at all orientations along the timeframe.

Glass fibres usually contain iron ions (Fe^{2+}) which supply electron for thermal conduction. Similar as before, at a specific time interval (for example 90-minute), a slight variation was present in the insulation percentage is of the four composites. This behaviour shows that; with increasing glass fibres contents, we get a slight decrease in thermal conductance at a specific temperature. Such behaviour has also been reported by Cao et al., in his study in which he modelled and experimentally studied the thermal conductivity of glass fibre reinforced boards (Cao et al., 2015). If temperature is varied, an increase in the thermal conductance has been reported with increasing glass fibre contents (Kalaprasad et al., 2000).

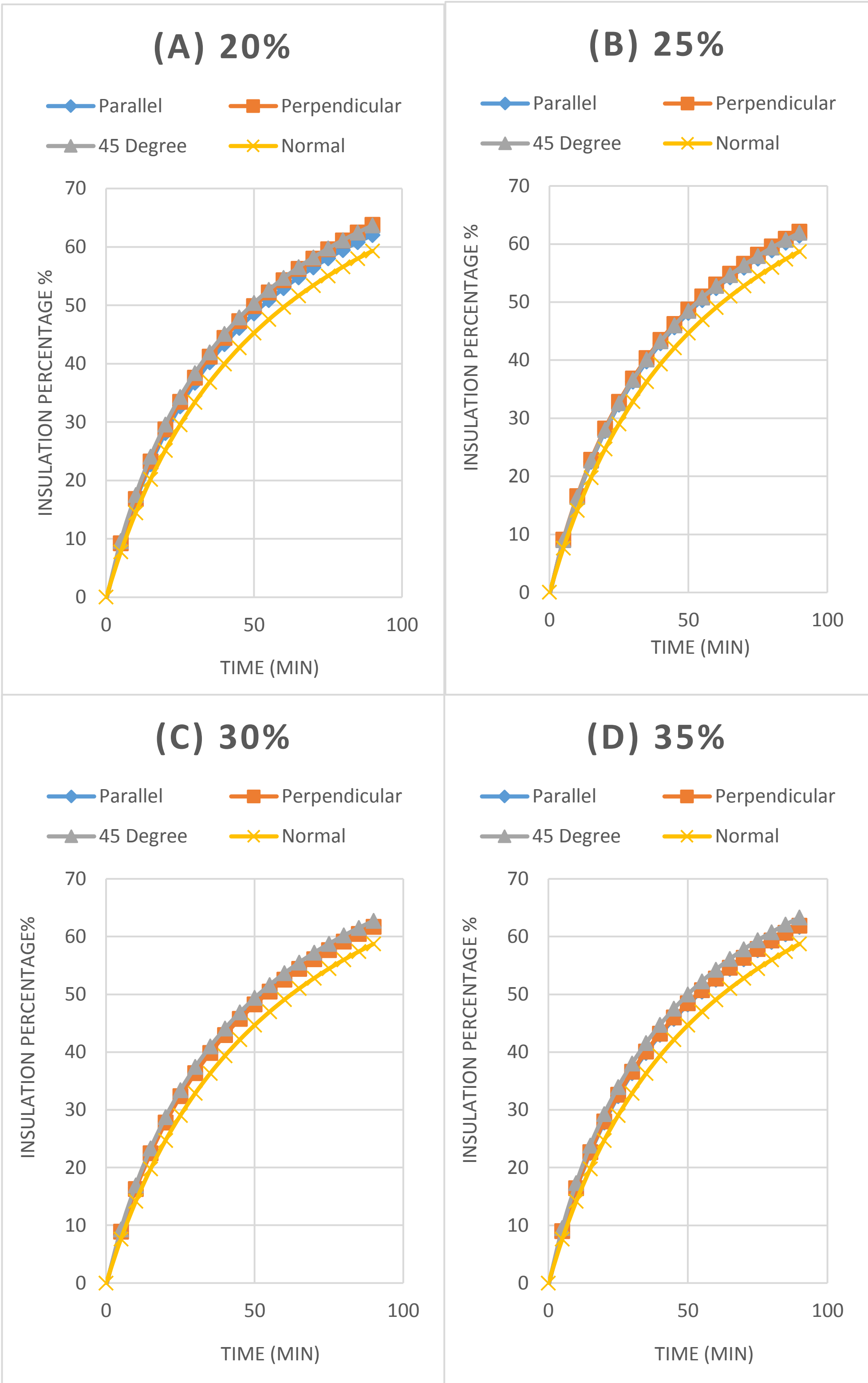


Figure 4-17.Influence of orientation in sisal fibre/polyester composites (A) 20%, (B) 25%, (C) 30%, (D) 35%

The thermal insulation results with sisal fibre reinforced polyester resin are very much similar to the epoxy resin composites. As evident from the figure, we again get low insulation values for the composites having different loadings in the normal orientation. Rest of the three orientations gave almost similar results at all time intervals.

The impact of bamboo fiber orientations on thermal conductivity of polyester-based composites was also studied by Mounika et al. (2012). The thermal conductivity measurements were taken at different angles (0°, 45°, and 90°) to the direction of heat flow. He found a decrease in the thermal insulation properties with increasing fibre orientation angle (Mounika et al., 2012). However, such behaviour was not observed with the sisal-polyester composed in this study.

4.9 Influence of Orientation in Glass Fibre/Polyester

From Figure 4-18 it can be observed that the impact of glass fibres orientation at different loadings on the insulation properties of the polyester based composite.

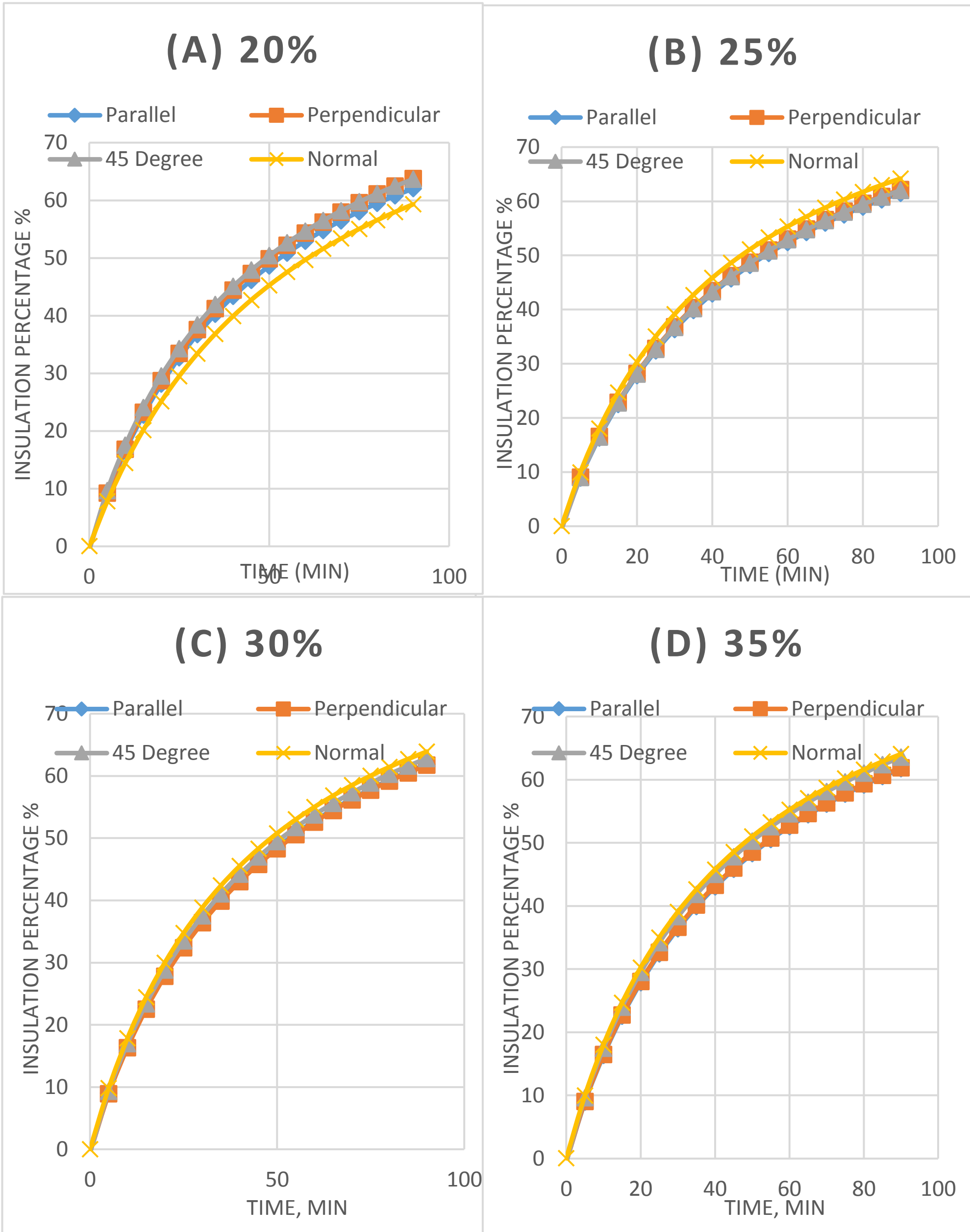


Figure 4-18.Influence of orientation in glass fibre/polyester composites (A) 20%, (B) 25%, (C) 30%, (D) 35%

As evident from Figure 4-18, the normal orientation of glass fibres give the higher insulation percentages at all time intervals for b to d cases. However, opposing results were obtained with the case a. Such difference in trend for the case could be attributed to the amount of fibre loading as compared to the other cases. Other researchers, studying the thermal characteristics of glass fibre based composites with ANSYS modelling, have also observed that thermal conductance varies by varying the fibre contents. They found that insulation magnitude decreased slightly beyond 45 wt.% loading and it increased in case of 25 wt.% loading (Patnaik et al., 2012). Such observation was also made in the current study.

In a recent study, polyester resins were reinforced by using natural fibres such as sisal and glass fibres. The thermal characteristics (thermal conductivity, diffusivity, and specific heat) were studied under different fibre loadings (20 to 40% fibre loading). As an overall, a reduction of 16% to 22% in the thermal conductance of natural fibre reinforced composites was observed as compared to the pure polyester resin. The incorporation of glass fibres into the polyester resin resulted in a decrease in the overall thermal insulation of polyester resin. The better thermal transport properties of the glass fibre were responsible for such behaviour. As a contradiction, in our study it was observed that we get low percentage of insulation at the max time (90min) for sisal fibres as compared to the glass fibre reinforced composites.

The researchers also used normal and perpendicular models for predicting the heat flow characteristics of composites fabricated with fibres oriented in the normal and perpendicular direction. A sharp decrease in the thermal insulation of the composites was predicted by the normal first order model with increasing glass fibre content. On the other hand, the perpendicular first order model indicated a slight but uniform decrease in the composite insulation characteristics (Idicula et al., 2006). Such observations have also been made for the two orientations of both sisal and glass fibres.

4.10 Influence of Orientation in Sisal Fibre/Vinyl Ester

Figure 4-19 shows that the impact of sisal fibres orientation at different loadings on the insulation properties of the vinyl ester based composite. The insulation percentages with sisal fibre reinforced vinyl ester resin are similar to the epoxy and polyester-based composites. As before, the incorporation of sisal fibres decrease the overall thermal conductance of vinyl ester resin. With the normal orientation, we get low insulation values for the composites having different sisal loadings. The insulation percentages obtained with the rest of the three orientations were in close proximity and they followed similar trend.

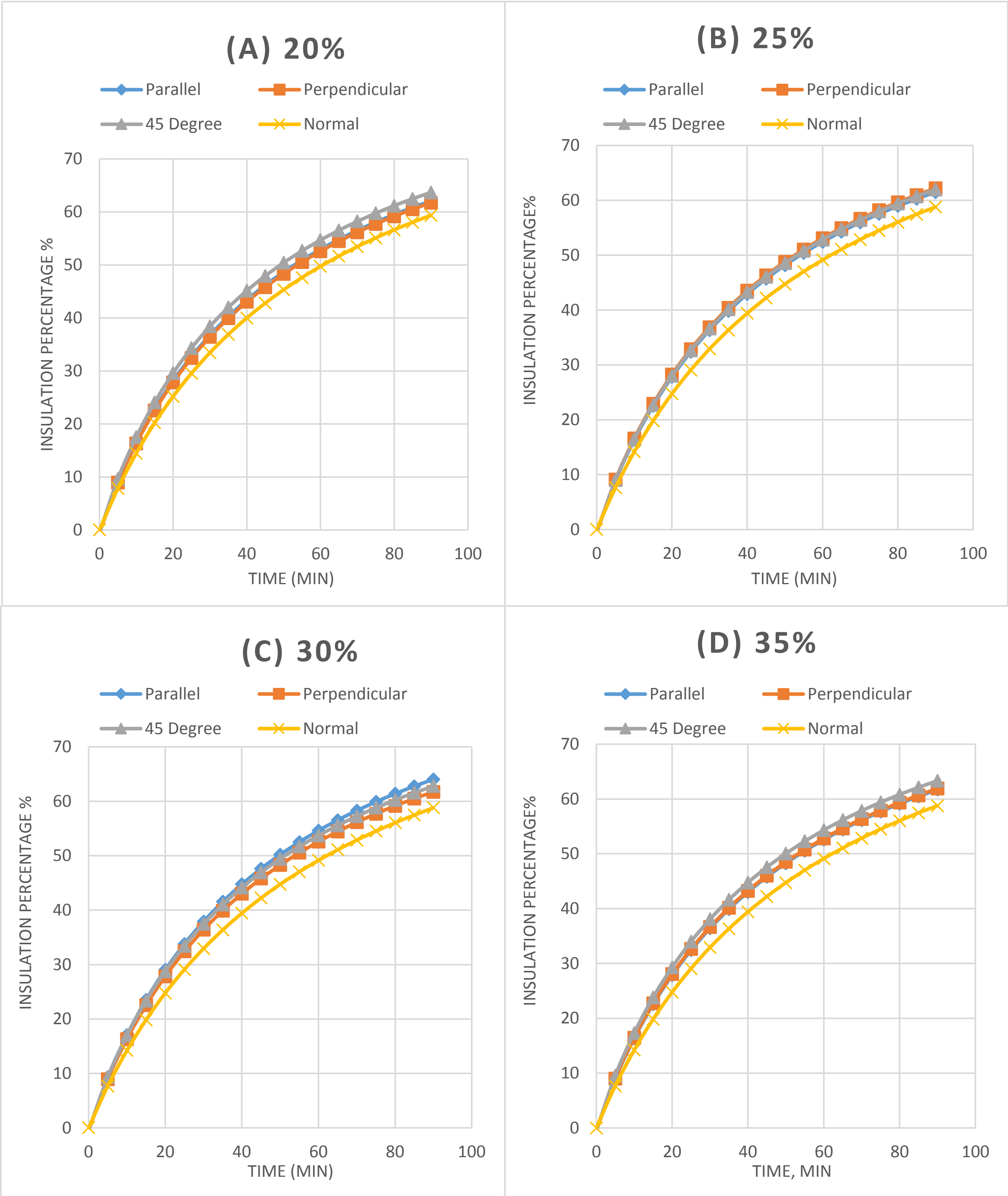


Figure 4-19.Influence of orientation in sisal fibre/vinyl ester composites (a) 20%, (b) 25%, (c) 30%, (d) 35%

4.11 Influence of Orientation in Glass Fibre/Vinyl Ester

Figure 4-20 shows the impact of glass fibres orientation at different loadings on the insulation properties of the vinyl ester based composite. As evident, at all loadings the glass fibre-vinyl ester composites gave insulation trends similar to the glass fibre-epoxy composites. We also get similar insulation tendency for all glass fibre orientations. Almost negligible effect was seen of fibre loading and its orientation on the heat insulation percentages. Such behaviour of the glass fibres in vinyl ester can again be attributed to their better conductance as the different composites had no effects of fibre orientation.

A recent research study utilised glass fibres and natural (basalt, vetiver) fibres for making vinyl ester-based hybrid composites. This composites were studied for thermal loadings during machining process by using ANSYS Workbench. Similar results were obtained with the both types of fibres and the thermal conductivity of the vinyl ester resin was considerably decreased. The vinyl ester resin possesses the properties of unsaturated polyester and epoxy. Modelling results indicated a less heat flux in the natural fibre based hybrid composites during machining operation as compared to the glass fibre based hybrid composites (Rathinavel et al., 2015).

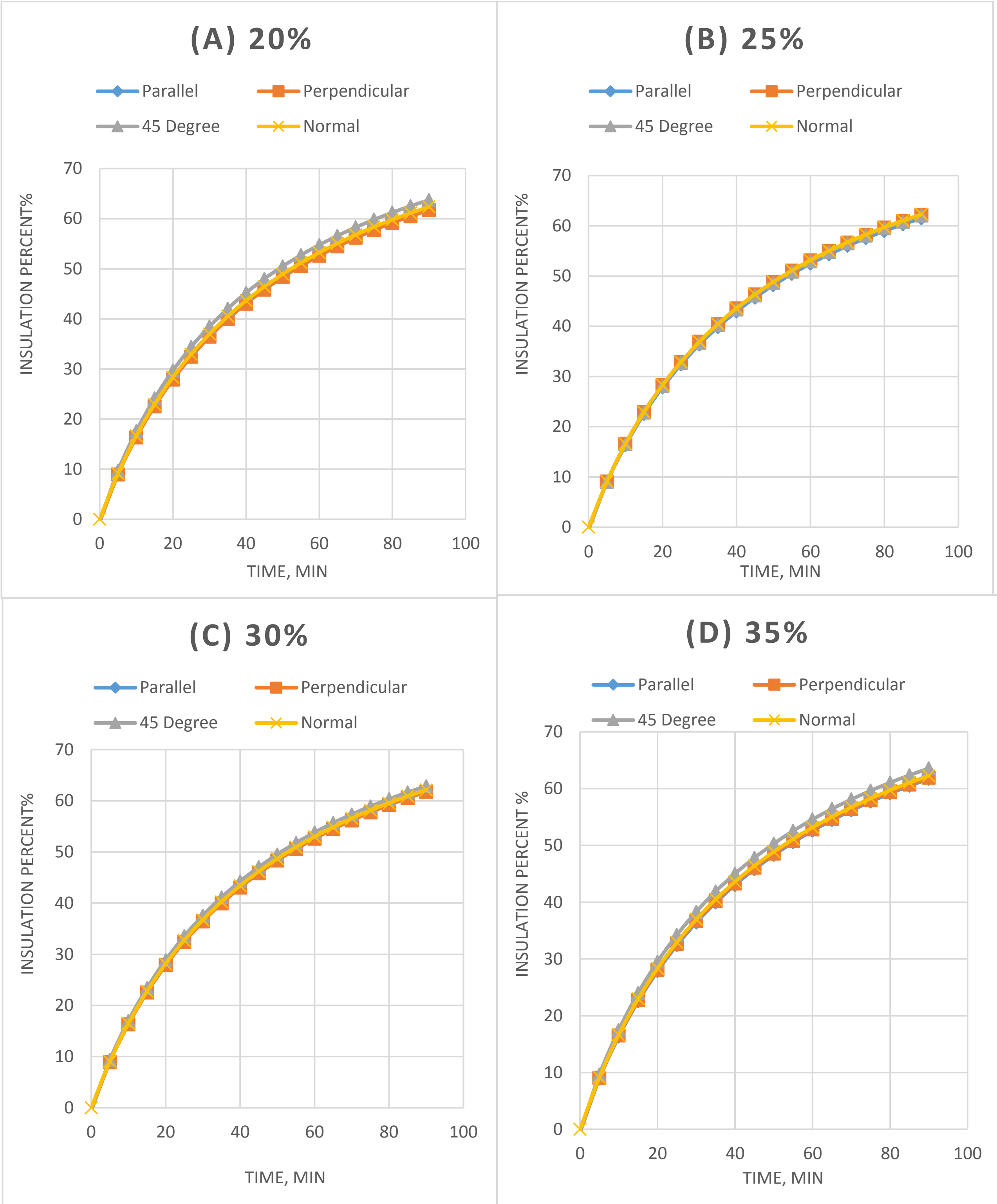


Figure 4-20.Influence of orientation in glass fibre-vinyl ester composites (A) 20%, (B) 25%, (C) 30%, (D) 35%

4.12 Influence of Fibre Orientation

The influence of the orientation of each fibre (45°) on insulation properties of resins with 35% fibre loading is shown in the Figure 4-21 and Figure 4-22, respectively. The mentioned figures demonstrate the impact of glass and sisal fibre orientation on the different resin based composites. As evident from the figures, the incorporation of glass fibres show a slight variation in the impact on insulation properties of the three resin. With the epoxy resin, we get slightly lower values of insulation percentage along the whole-time spectrum as compared to the other two resins which show similar values. On the other hand, sisal fibres do impart insulation properties to the three resins. But all the three types of composites (sisal with the three resins) show almost same insulation properties throughout the time spectrum. However, with sisal fibre it can be seen from the plot that have been made and zoomed in that the sisal fibre combined with both (45°) orientation, 35% volume fraction and epoxy resin gives the highest insulation performance which is more than polyester resin and vinylester by 0.07758 and 0.04958. Whereas, in glass fibre case it observed that with same conditions of orientation and volume fraction with respect to vinylester resin showed the maximum insulation percentage which is higher than the other resin by 0.0278 and 1.7768 of both polyester and vinylester respectively.

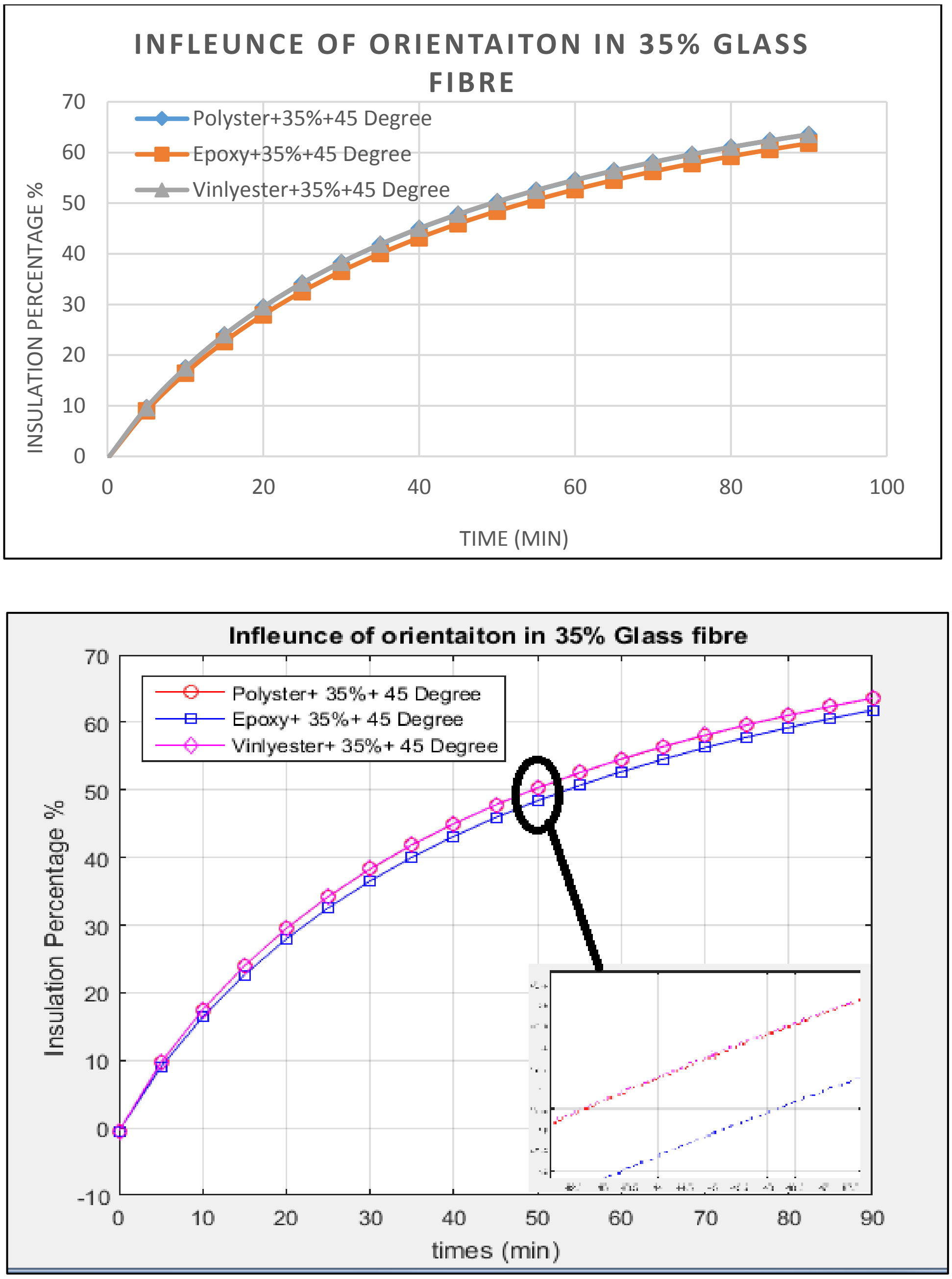
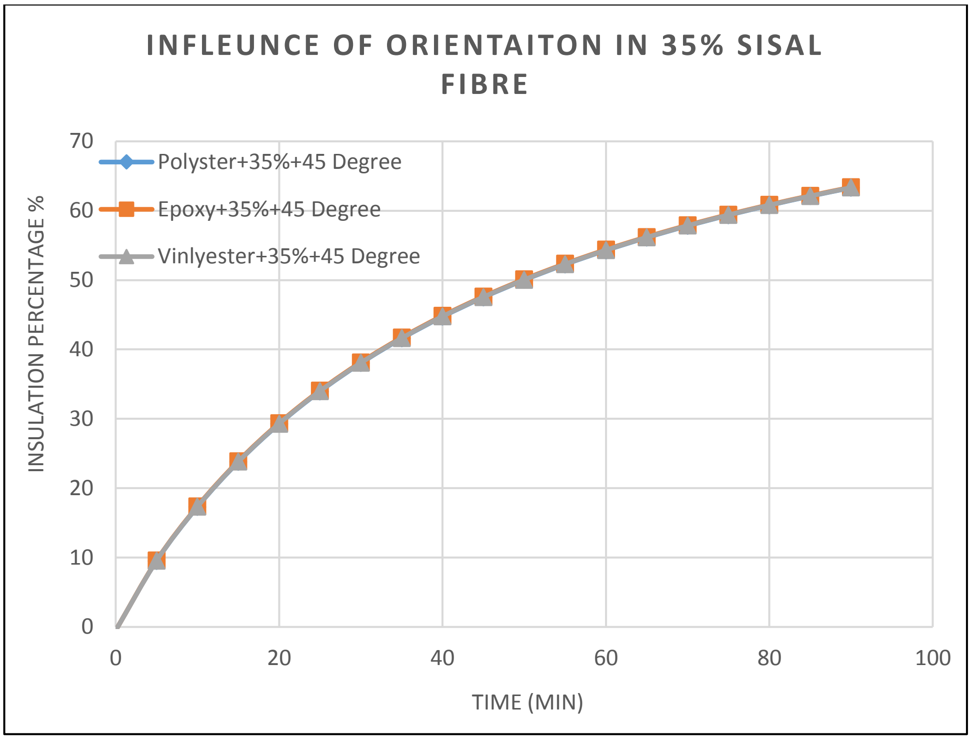


Figure 4-21. Influence of glass fibre (35% loading) orientation on the resin insulation properties by plotting the graph again in matlab to show the differences


INFLEUNCE OF ORIENTAITON IN 35% SISAL FIBRE
Polyster+35%+45 Degree
Epoxy+35%+45 Degree
Vinlyester+35%+45 Degree
INSULATION PERCENTAGE %
TIME (MIN)
0
10
20
30
40
50
60
70
0
20
40
60
80
100

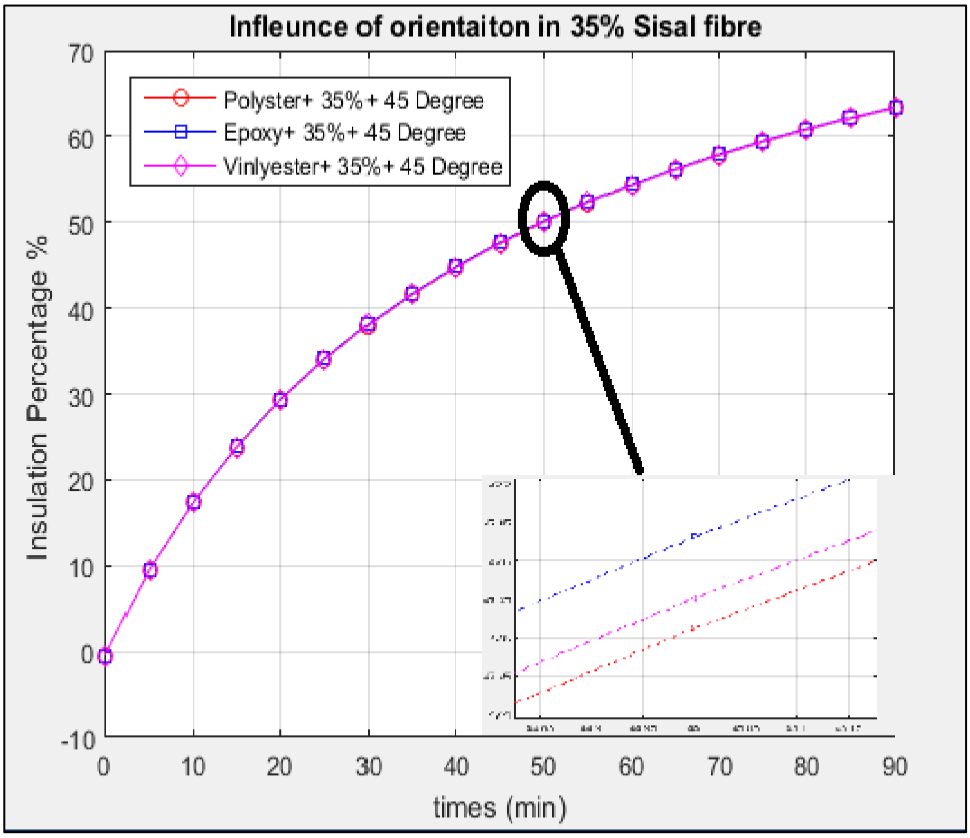

Infleunce of orientaiton in 35% Sisal fibre
Polyster+ 35%+ 45 Degree
Epoxy+ 35%+ 45 Degree
Vinlyester+ 35%+ 45 Degree
Insulation Percentage %
times (min)
-10
0
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
90

Figure 4-22.Influence of sisal fibre (35% loading) orientation on the resin insulation properties by plotting the graph again in matlab to show the differences

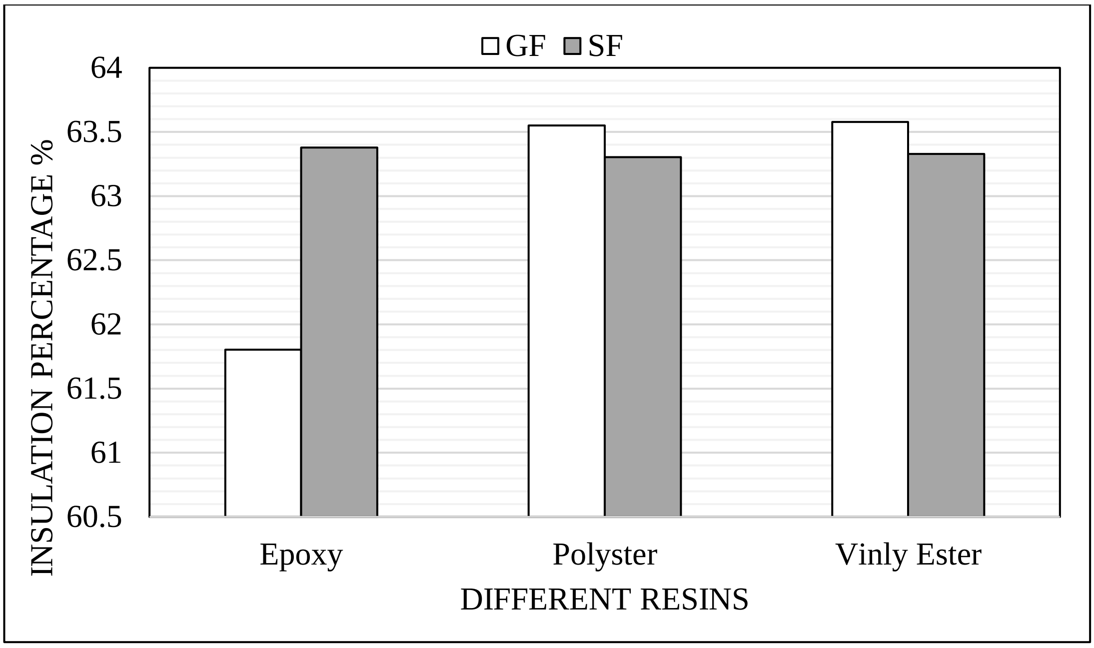


Figure 4-23. Influence of glass and sisal fibre (35% loading) orientation on the insulation properties of three resins

Figure 4-23 shows the impact of fibre orientation on the insulation percentage of the three resins. Except epoxy, glass fibre reinforced polyester and vinyl ester composites showed maximum insulation percentage of nearly 63.5 % (slightly higher than the sisal fibre). On the other hand, with sisal fibres, these composites showed maximum insulation percentage of nearly 63%. Hence the difference of insulation capability between these two sets of composites was marginal. However, for the epoxy resin which got a considerable difference between the insulation capabilities of sisal and glass fibre based composites. Similar results are also found in other studies (Sahu, 2014, Devireddy and Biswas, 2016).

Earlier studies working with glass or natural fibre reinforced polyester and vinyl ester resins have found that the polyester composites incorporated with natural fibres (such as sisal, banana, bamboo…etc.) show higher thermal insulation as compared to the glass fibres or pure polymer resin (Idicula et al., 2006, Mounika et al., 2012, Rathinavel et al., 2015). However, the insulation characteristics for polyester and vinyl ester resins obtained in our study could be explained on the basis of fibre-resin interaction. A number of studies has reported that the adhesion between polymer resin and natural fibres (such as sisal) is usually weak as compared to the glass fibre (Watt et al., 1998, Li et al., 2000, Njuguna et al., 2011). This weak interaction between the two phases could result in low insulation capability of sisal-polyester/vinyl ester composites. However, future studies could be done for further exploration of such characteristics of natural fibres.

Chapter 5. Conclusion and Recommendations

5.1. Conclusion

These results have shown that it was possible to construct a theoretical models in ANSYS that produced results which reflected the experimental findings. This analysed used to evaluate the thermal performance of a range of synthetic and natural fibres comparison. This evaluation conclude the effect of volume fraction of fibre and the orientation of fibres and thermal conductivity of the composites as mentioned before in section 2.1 objective of the research was to be able to fabricate polymer composites of different volume fractions using sisal fibres and to determine the level of porosity in each sample of composites. The second objective was the measurement of heat conductivity of each sample and development of a mathematical model to correlate the porosity with heat conductivity.

Higher volume fraction of natural fibres produced composites with higher insulation performance. Whereas, higher volume fraction of synthetic fibre produced composites with a lower insulation performance. Orientation of both synthetic and natural fibres at forty five degrees to each other produced composites with a higher insulation performance than at any other orientations. Epoxy based polymer produced composites with higher insulation performance than polyester and vinylester based composites and gypsum. The best insulation performance for synthetic fibre composites was fibre glass companied with vinylester. The results suggest that the improved performance of natural fibre based composites was due at least in part to the internal porosity of the fibres.

This investigation have shown the wide range of thermal performance of synthetic and natural fibres composites. They are affected by many parameters is their manufacture. These results highlight the advanced biocomposites and provide a foundation for further research on the molecular basis of resistance heat transfer within the composites. That can be driving to the recommendation which will summarized in the following dot points.

5.2. Further research recommendation

There were few limitation on doing the simulation of thermal conductivity of the models mainly was the limited timeframe of the project of the timeframe of the project and the student licence that provided by USQ. In terms of these limitation the following recommendations can be follow for further researcher.

- Conducting both experimental and theoretical with different fibre composites materials to confirm the use of ANSYS as a good simulation tool for examine the thermal conductivity.
- Using different orientations parameters with the same materials involved to further investigation where other orientation can give better insulation performance or not.
- Developing the model with more refinement of the meshing in critical areas to increase the accuracy of the results.
- Using different temperatures and decrease the length of the cylinder and see where if it improve the insulation performance or not.

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APPENDIX A: Project Specification

For	**Abdalrahman Alajmi**
Title	Numerical Study on the Influence of porosity on heat conductivity of fibre reinforced polymer composites
Major	Mechanical engineering
Supervisor	Dr Belal Yousif
Enrolment	ENG 4111-ONC S1, 2016 ENG 4112-ONC S2, 2016
Project Aim	1. The main aim of the work will be focusing on the influence of the porosity of the natural fibres on the heat conductivity of the materials. 2. To develop a numerical model for fibre composite materials using ANSYS software.
Sponsorship	Nil

Programme

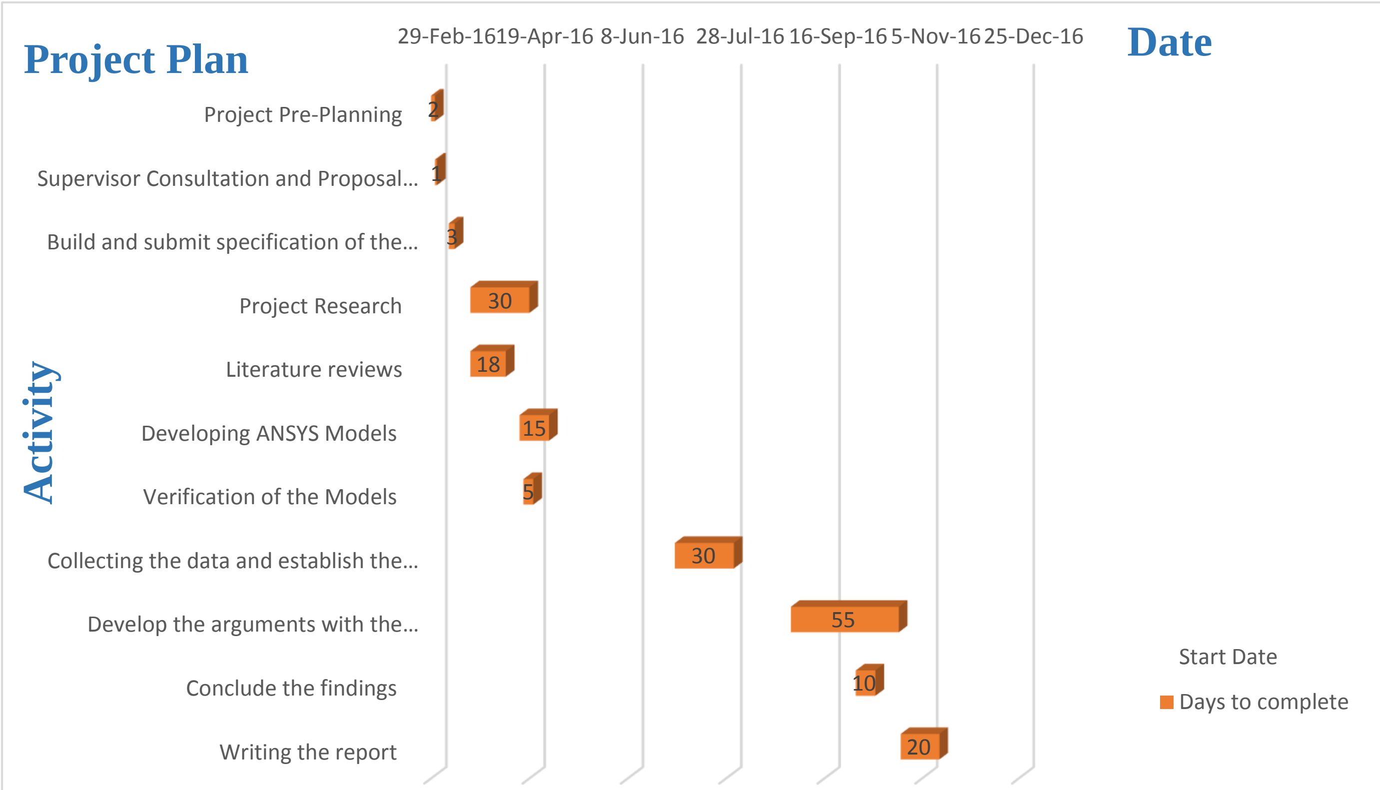
1. Study the literature.
2. Understand ANSYS software and how to develop the models.
3. Develop the models of the composites in ANSYS.
4. Consider different parameters in the prepared models.
5. Compare the numerical results with the experimental.
6. Analyse the results and conclude the findings.

Agreed

__Abdalrahman Alajmi U1054487__ (Student) ____, BFY___ __(Supervisor

APPENDIX B: Project Research Timeline

No	Activity	Start Date	Days to complete
1	**Project Pre-Planning**	29-Feb-16	2
2	Supervisor Consultation and Proposal Submission	2-Mar-16	1
3	Build and submit specification of the project & Approval	9-Mar-16	3
4	**Project Research**	20-Mar-16	30
5	**Literature reviews**	20-Mar-16	18
6	**Developing ANSYS Models**	14-Apr-16	15
7	Verification of the Models	16-Apr-16	5
8	Collecting the data and establish the comparison with the Experiments	2-Jul-16	30
9	Develop the arguments with the Literature in the Results and Discussion	30-Aug-16	55
10	Conclude the findings	2-Oct-16	10
11	**Writing the report**	25-Oct-16	20



	Writing the report	Conclude the findings	Develop the arguments with the Literature in the Results and Discussion	Collecting the data and establish the comparison with the Experiments	Verification of the Models	Developing ANSYS Models	Literature reviews	Project Research	Build and submit specification of the project & Approval	Supervisor Consultation and Proposal Submission	Project Pre-Planning
Start Date	25-Oct-1	2-Oct-16	30-Aug-1	2-Jul-16	16-Apr-1	14-Apr-1	20-Mar-1	10-Mar-1	9-Mar-1	1-Mar-16	29-Feb-1
Days to complete	20	10	55	30	5	15	18	30	3	1	2

APPENDIX C: Resource Requirement Plan

Basically the project will be more numerically testing as I will be using two important resources to finalise the results of other works and my thoughts they are as below:

ANSYS Software

ANSYS is an Analysis System used for all general purpose software, it used to compute and simulate relations of all expertise of physics, structural, vibration, fluid dynamics, electromagnetic and heat transfer for engineers as well as for real life applications.

Consequently ANSYS, which allows to simulate tests and examine under working conditions, permits to examine in hypothetical environment before industrial model of products. In addition, defining and improving the centres weak, computing life and intuition prospective problems are possible by 3D simulations in virtual environment.

ANSYS software with its modular structure as showed in the figure below can provides only the necessary features or tools. Also, ANSYS can work integrated with any other engineering software on desktop by making an additional CAD and FEA connection modules.

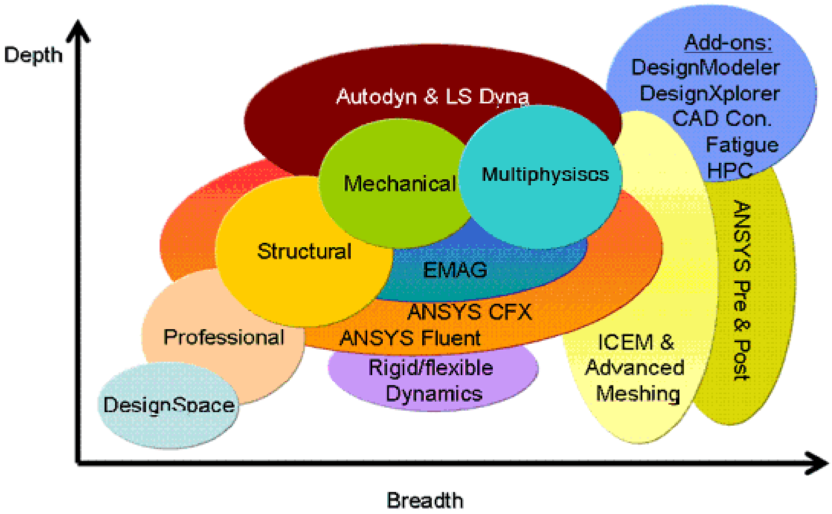


Figure C-5-1: Shows ANSYS software with its modular structure

The importation of ANSYS can apply CAD data and also allows to build a geometry with its "pre-processing" abilities. For instance, in the same pre-processor, finite element model (a.k.a. mesh) which is desired for calculation is generated. After significant loadings and holding out analyses, consequences can be viewed as numerical and graphical.

Advanced engineering analysis can be carried by ANSYS in a quick, safe and virtually way by it is diversity of contact algorithms; time based loading features and nonlinear material models.

ANSYS Workbench, which is written for high level agreement with especially PC, is more than an interface and anybody who has an ANSYS license can work with ANSYS Workbench. As same as ANSYS interface, ability of ANSYS Workbench is limited due to taken license. However, USQ have provided a student license for all on campus student in Z block, Z307/8/10/11 (Figes Engineering 2003).

Science Direct

Will be using science direct to find as much articles as they are available to finials and build my literate review.

APPENDIX D Implementation RiskAssessment

A summary of the various risk factors involved and their probable available solutions are given in following table.

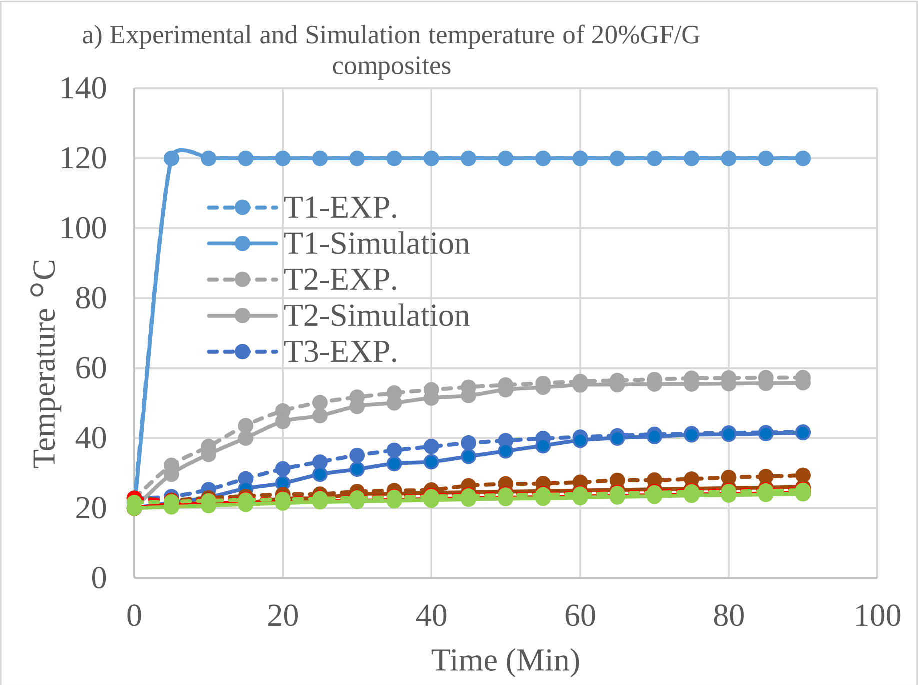
No	Risk Definition			Inherent Risk		
	Hazard Event	Key Causes	Effects	L'hood	Cons.	Overall
Health & Safety						
	Spending too much time facing the computer and doing the project	Spending too much time researching and typing	losing sight and fatigue	Definitely	Major	HIGH
	Driving to Brisbane to take a private lessons for ANSYS	I need to take private tutorials for ANSYS	Death or injury	Possible	Major	HIGH
Quality						
	Unavailability of data and parameters.	the industrial people not in-cooperate with us	Not complete the project	Possible	Major	HIGH
			Delay in submitting the assignment	Possible	Major	HIGH
Cost						
	Project budget insufficient to take private tutorials for ANSYS.	Not enough finical support from my sponsor neither the university	No take the take private tutorials for ANSYS.	Likely	Moderate	HIGH
Time						
	Late submission of project documentation.	Poor time management. External reviews overdue.	Failure or lower grade	Possible	Major	HIGH

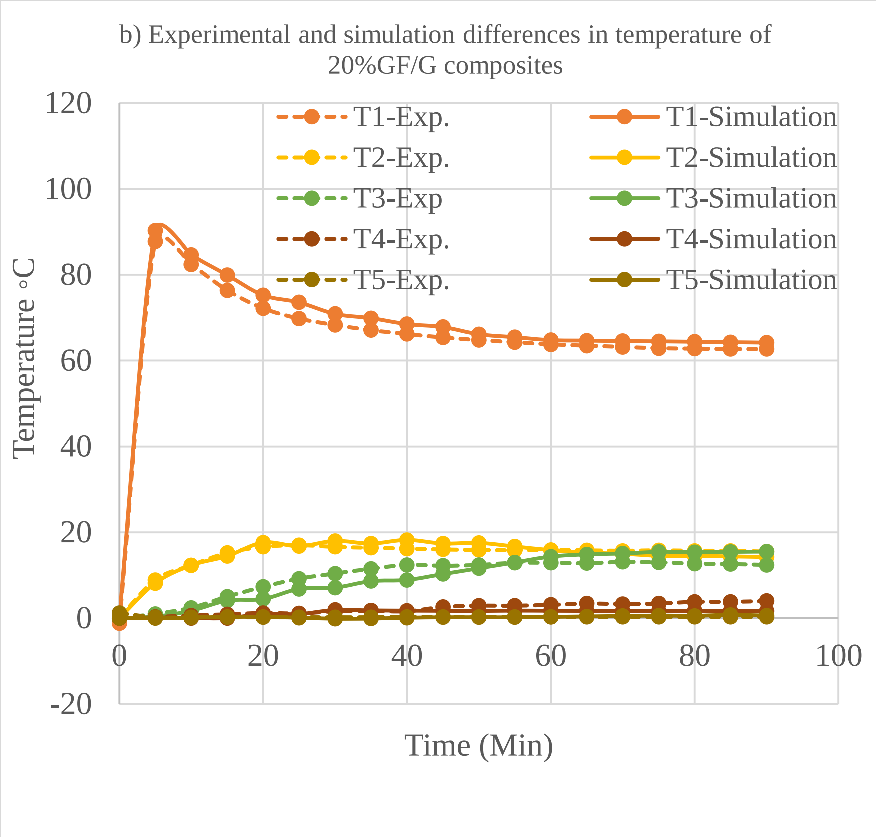
Step 6 – Approval		
Drafter's Comments:		
Drafter Details:		
Name: Abdalrahman Alajmi	Signature: Abdalrahman	Date: 24/05/2016
Assessment Approval: (Extreme or High = VC, Moderate = Cat 4 delegate or above, Low = Manager/Supervisor) *I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.*		
Name: Belal Yousif	Signature: BFY	Date: 24/05/2016
Position Title: Project Supervisor		

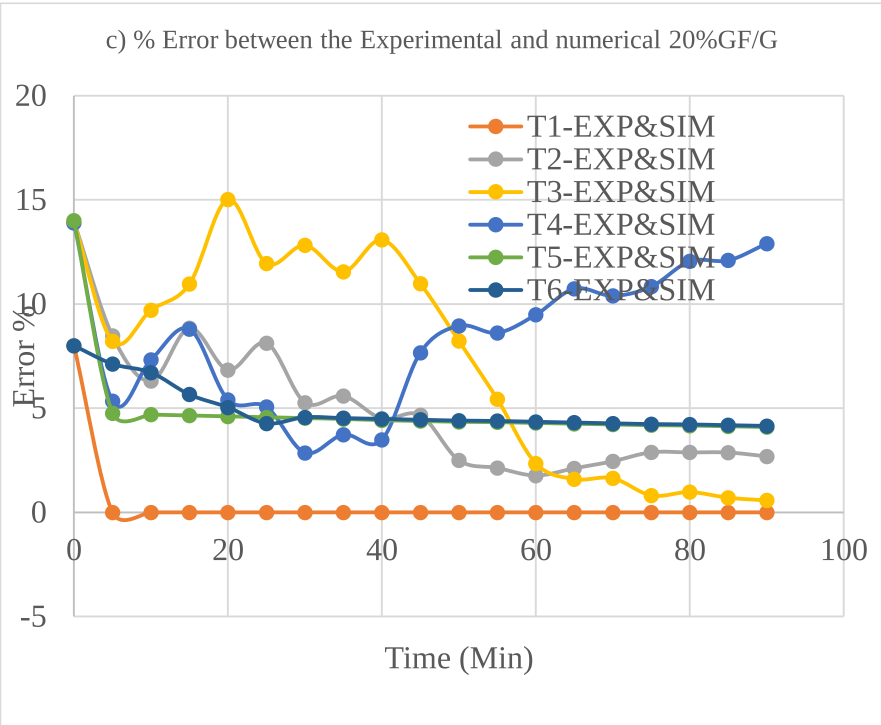
APPENDIX E: Differences, Errors and the real comparison of the Experimental and Numerical results

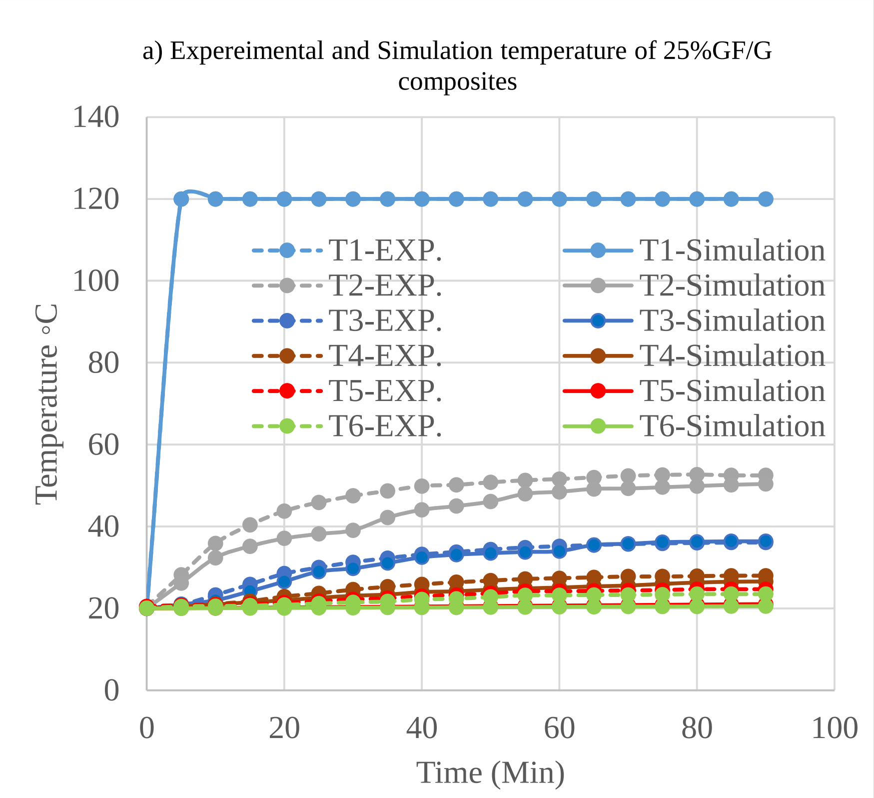
Appendix E1: Influence of the glass fibre on the heat conducting of fibre composites considering different volume fracture

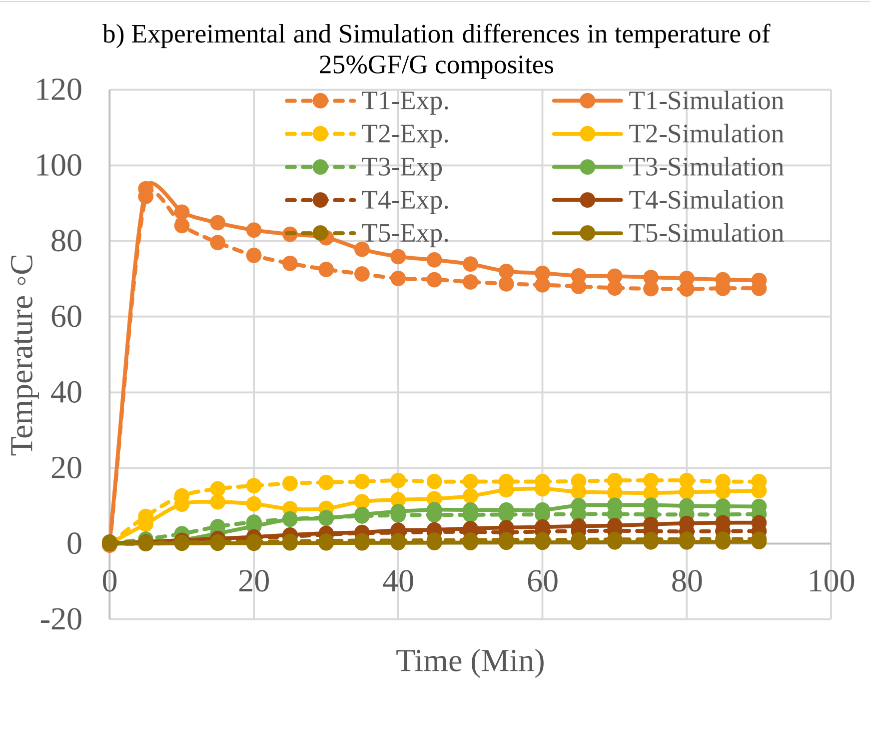
Appendix E1.1: Glass fibre 20% with gypsum

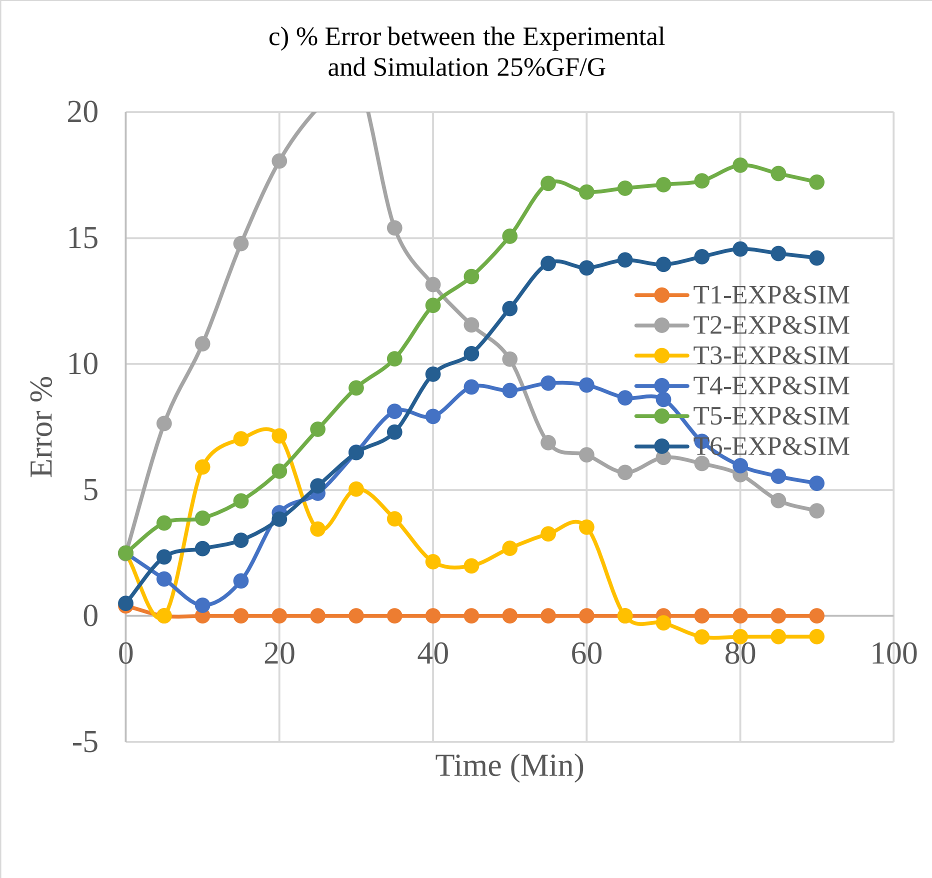



b) Experimental and simulation differences in temperature of 20%GF/G composites
Temperature °C
Time (Min)
T1-Exp.
T2-Exp.
T3-Exp
T4-Exp.
T5-Exp.
T1-Simulation
T2-Simulation
T3-Simulation
T4-Simulation
T5-Simulation
120
100
80
60
40
20
0
-20
0
20
40
60
80
100

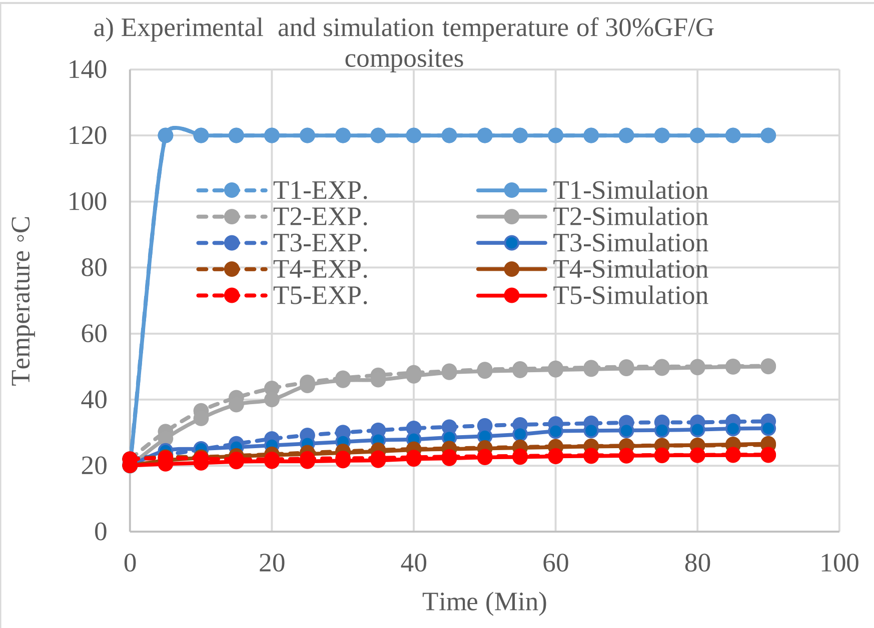

c) % Error between the Experimental and numerical 20%GF/G
Error %
Time (Min)
T1-EXP&SIM
T2-EXP&SIM
T3-EXP&SIM
T4-EXP&SIM
T5-EXP&SIM
T6-EXP&SIM
20
15
10
5
0
-5
0
20
40
60
80
100

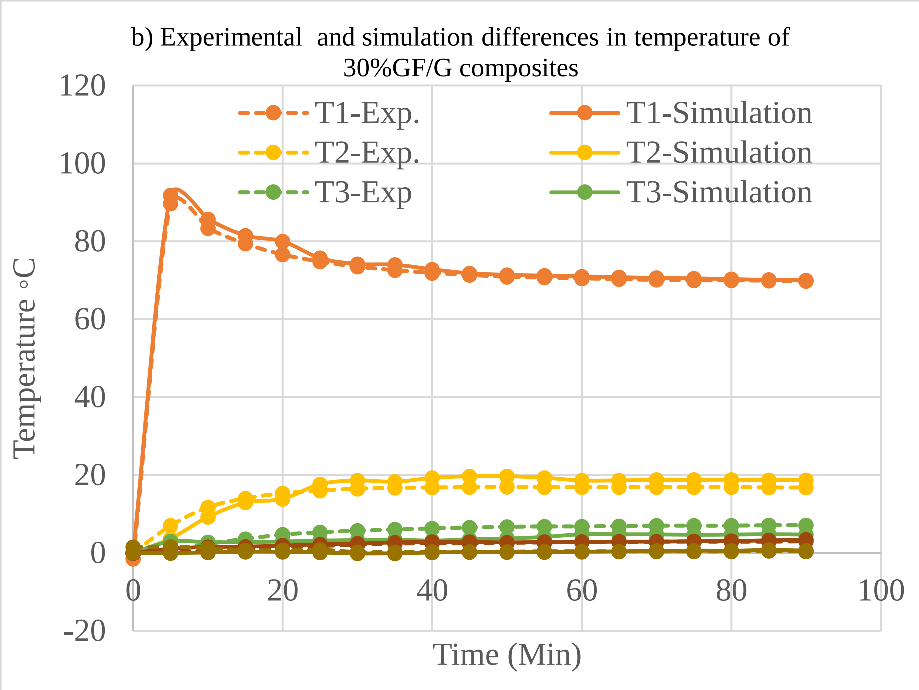

a) Expereimental and Simulation temperature of 25%GF/G composites
Temperature °C
Time (Min)
T1-EXP.
T2-EXP.
T3-EXP.
T4-EXP.
T5-EXP.
T6-EXP.
T1-Simulation
T2-Simulation
T3-Simulation
T4-Simulation
T5-Simulation
T6-Simulation
0
20
40
60
80
100
120
140
0
20
40
60
80
100

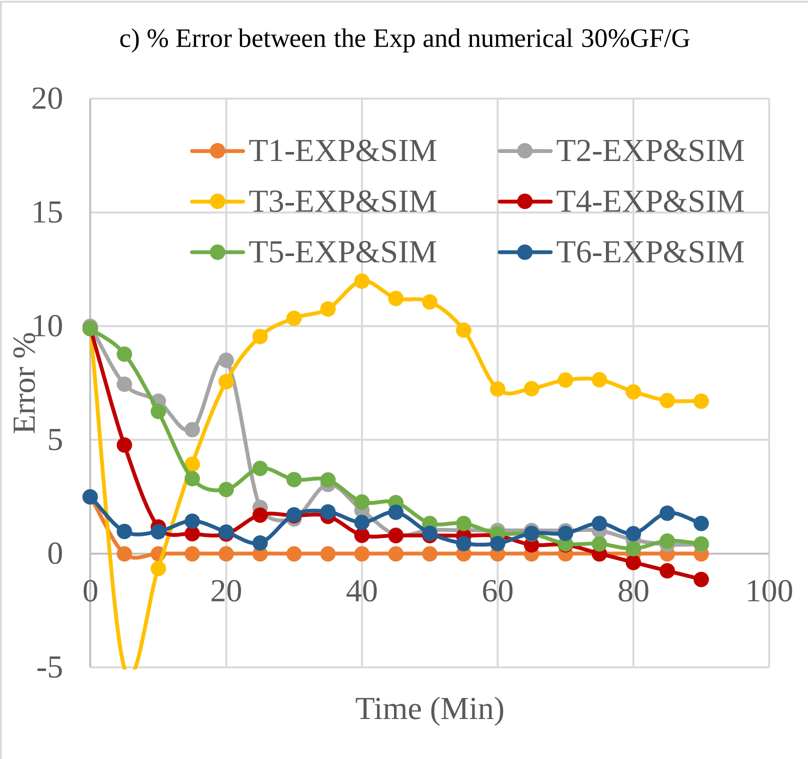

b) Expereimental and Simulation differences in temperature of 25%GF/G composites
Temperature °C
Time (Min)
T1-Exp.
T2-Exp.
T3-Exp
T4-Exp.
T5-Exp.
T1-Simulation
T2-Simulation
T3-Simulation
T4-Simulation
T5-Simulation
-20
0
20
40
60
80
100
120
0
20
40
60
80
100



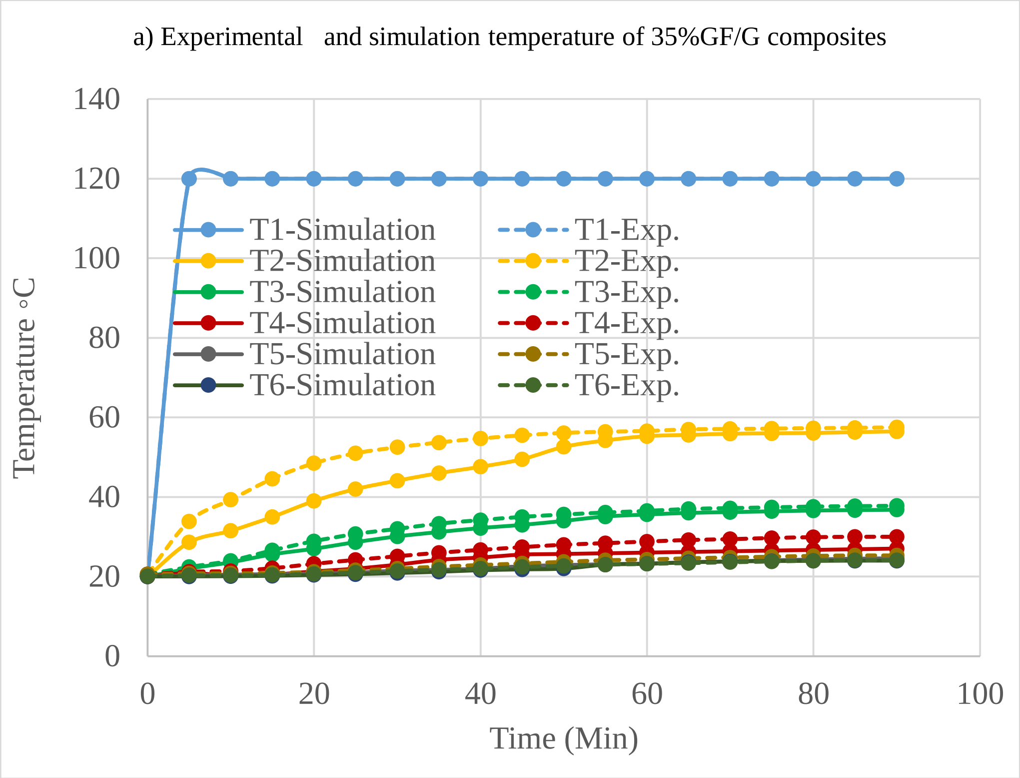
Appendix E1.2: Glass fibre 30% with Gypsum

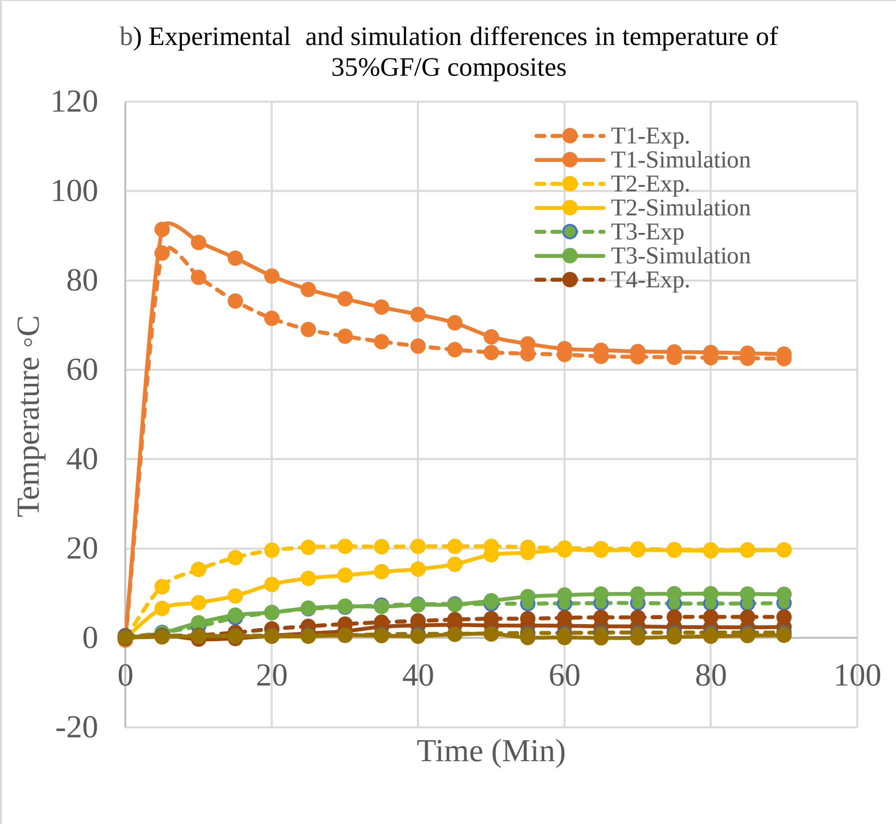


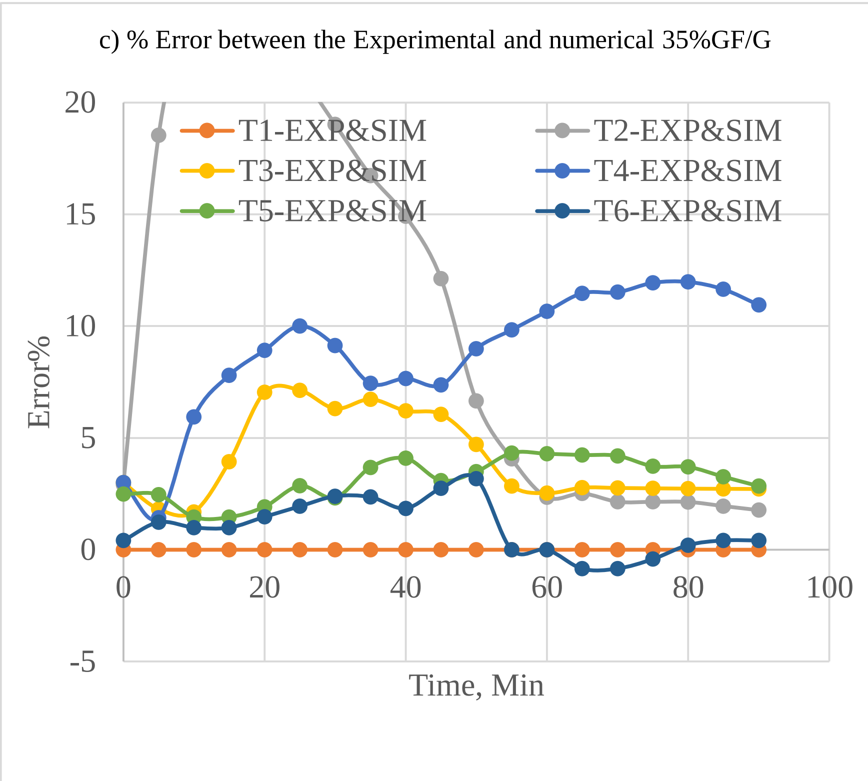

b) Experimental and simulation differences in temperature of 30%GF/G composites
T1-Exp.
T1-Simulation
T2-Exp.
T2-Simulation
T3-Exp
T3-Simulation
Temperature °C
Time (Min)
120
100
80
60
40
20
0
-20
0
20
40
60
80
100


c) % Error between the Exp and numerical 30%GF/G
T1-EXP&SIM
T2-EXP&SIM
T3-EXP&SIM
T4-EXP&SIM
T5-EXP&SIM
T6-EXP&SIM
Error %
Time (Min)
20
15
10
5
0
-5
0
20
40
60
80
100

Appendix E1.3: Glass fibre 35% with Gypsum

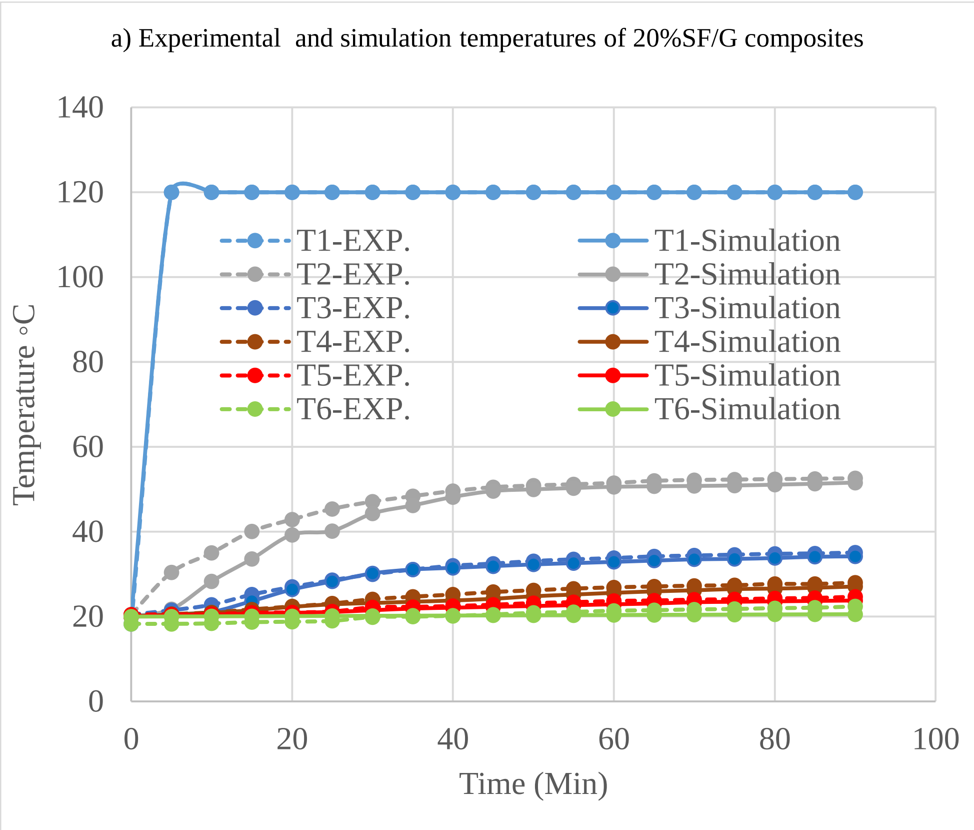


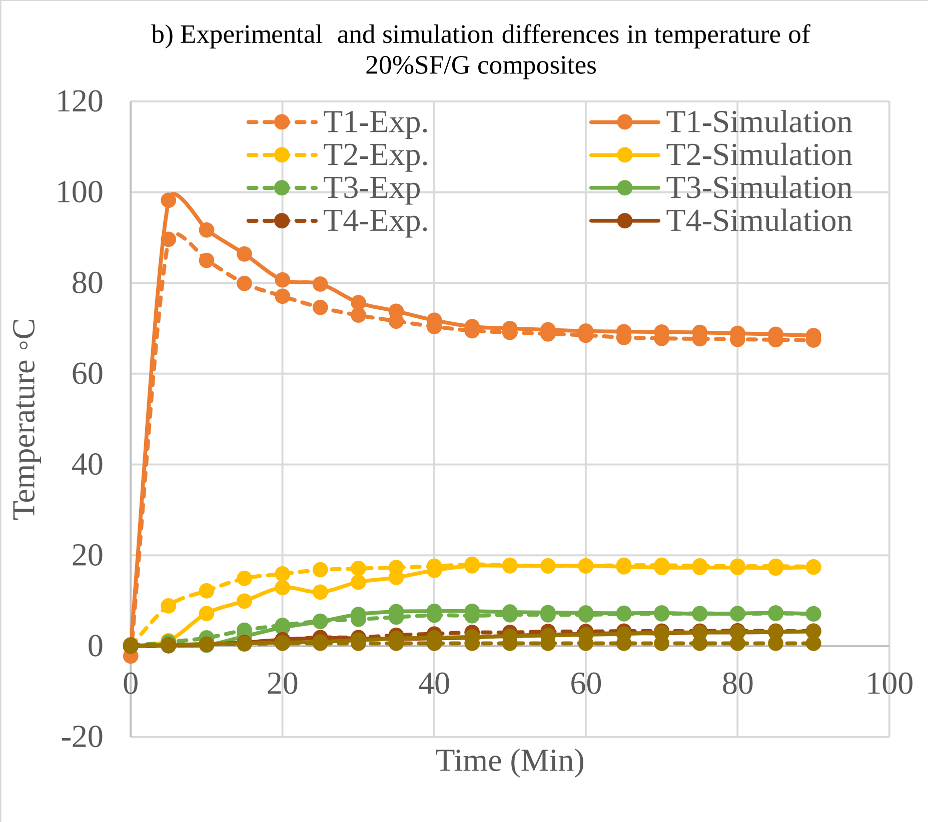

b) Experimental and simulation differences in temperature of 35%GF/G composites
T1-Exp.
T1-Simulation
T2-Exp.
T2-Simulation
T3-Exp
T3-Simulation
T4-Exp.
Temperature °C
Time (Min)
120
100
80
60
40
20
0
-20
0
20
40
60
80
100

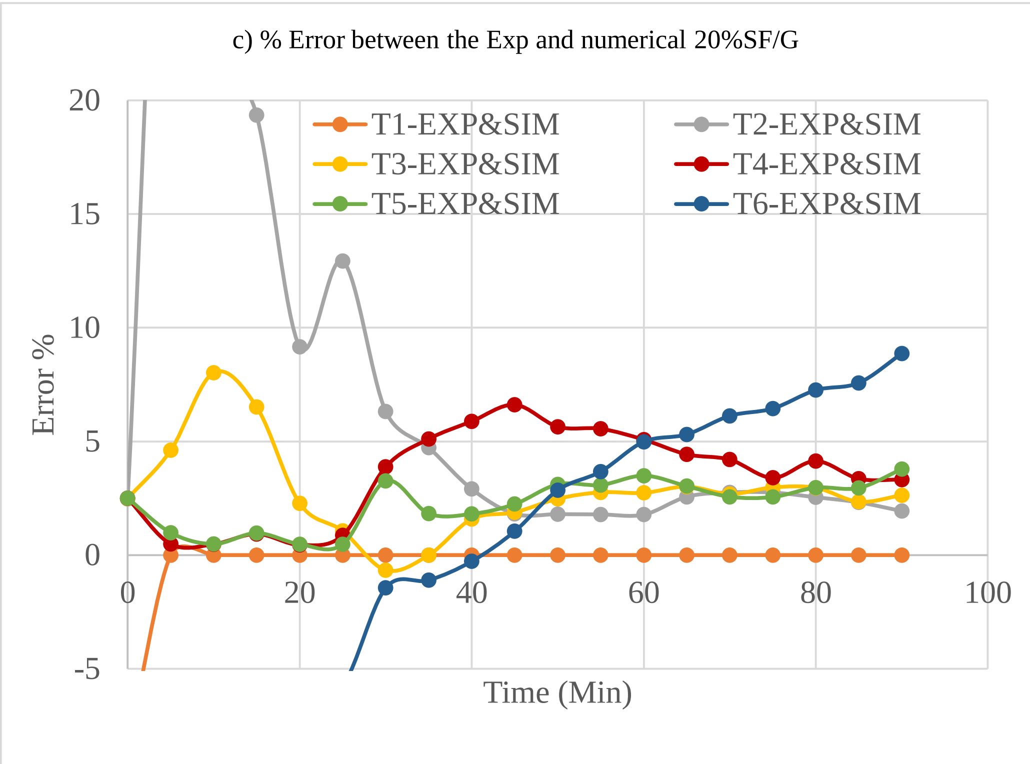

c) % Error between the Experimental and numerical 35%GF/G
T1-EXP&SIM
T2-EXP&SIM
T3-EXP&SIM
T4-EXP&SIM
T5-EXP&SIM
T6-EXP&SIM
Error%
Time, Min
20
15
10
5
0
-5
0
20
40
60
80
100

Appendix E2: Influence of the sisal fibre on the heat conducting of fibre composites considering different volume fracture

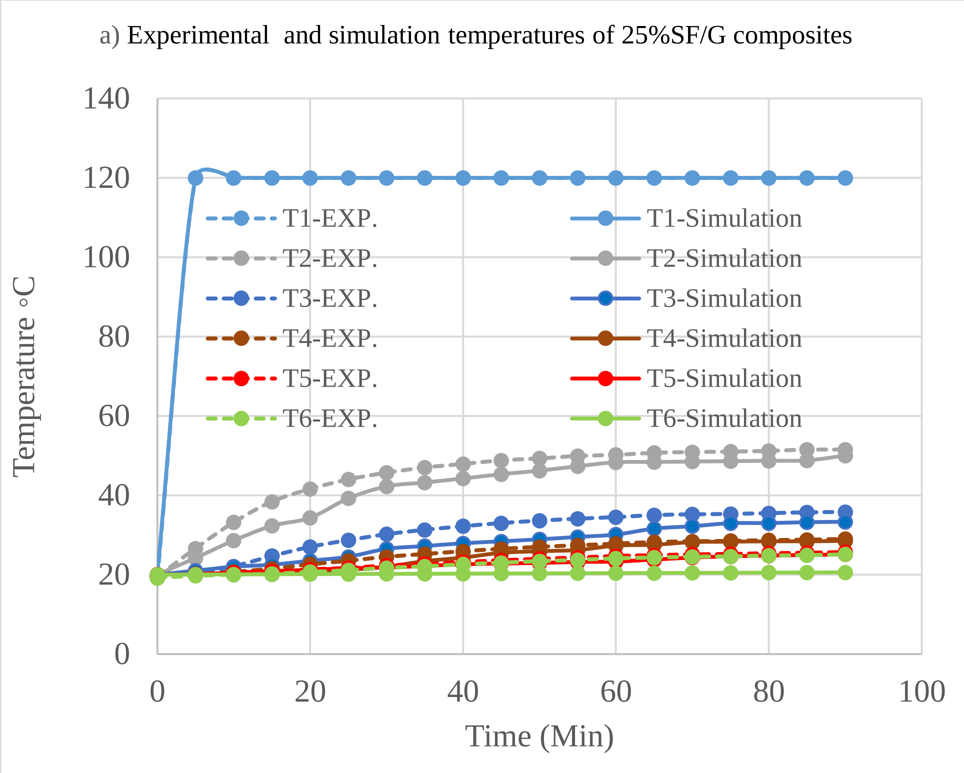
Appendix E2.1: Sisal fibre 20% with Gypsum

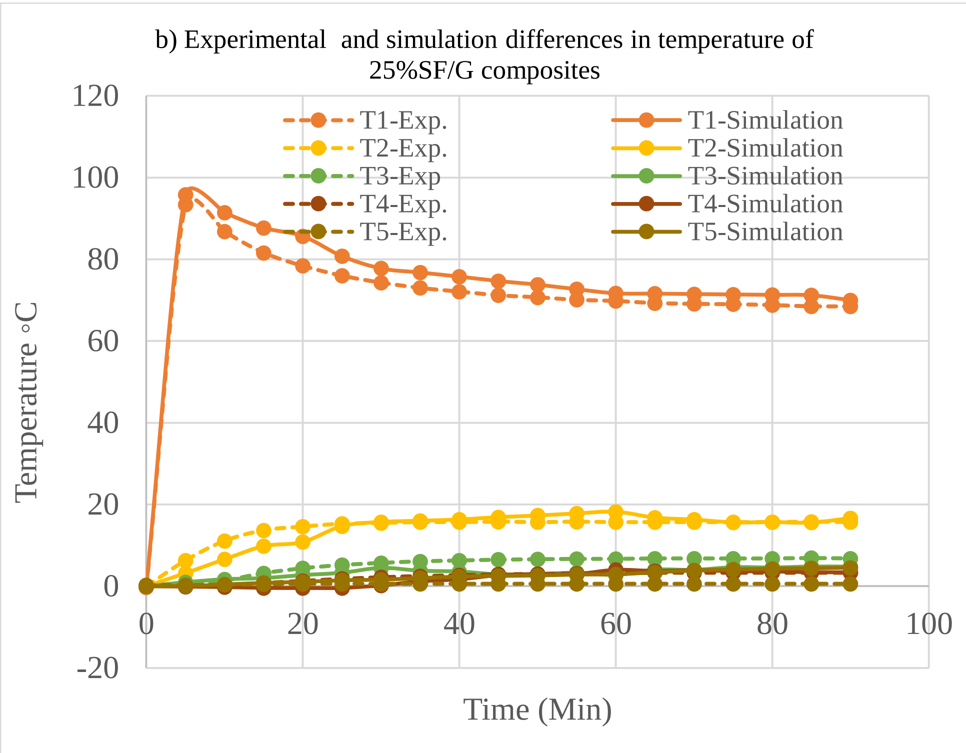


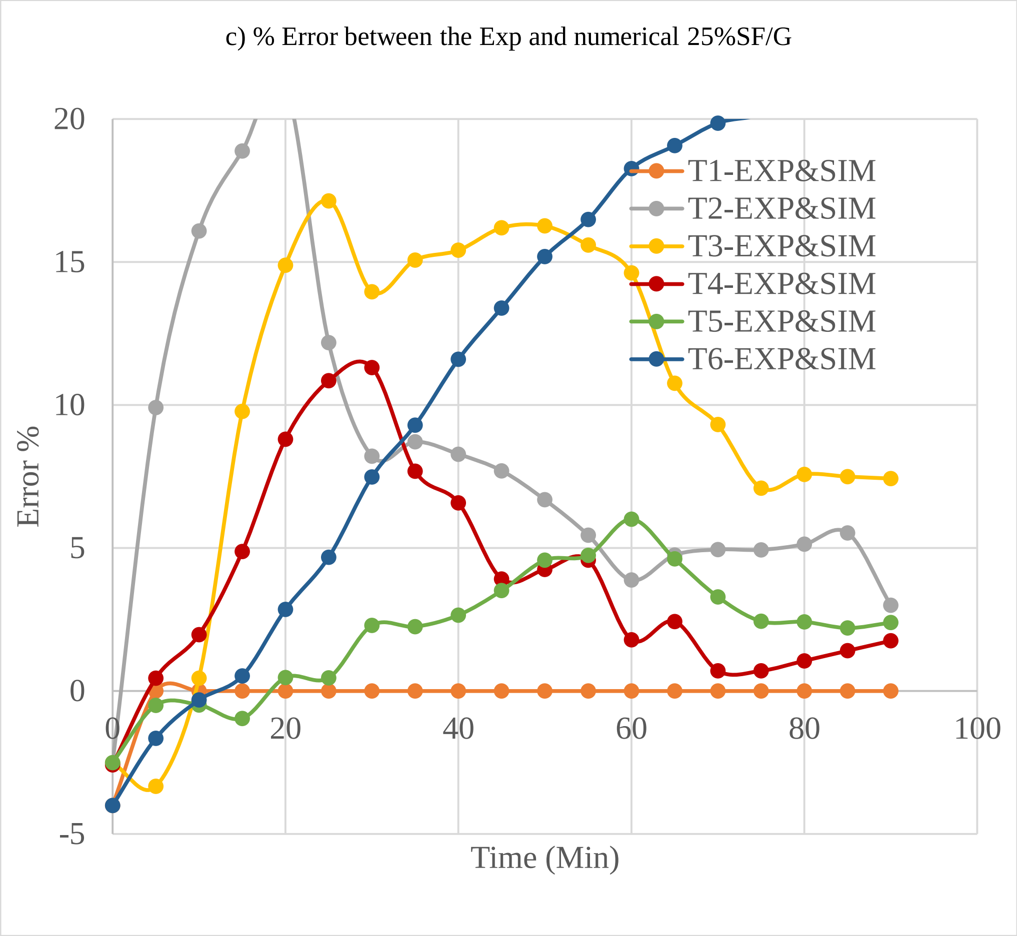

b) Experimental and simulation differences in temperature of 20%SF/G composites
T1-Exp.
T2-Exp.
T3-Exp
T4-Exp.
T1-Simulation
T2-Simulation
T3-Simulation
T4-Simulation
Temperature °C
Time (Min)
120
100
80
60
40
20
0
-20
0
20
40
60
80
100


c) % Error between the Exp and numerical 20%SF/G
T1-EXP&SIM
T2-EXP&SIM
T3-EXP&SIM
T4-EXP&SIM
T5-EXP&SIM
T6-EXP&SIM
Error %
Time (Min)
20
15
10
5
0
-5
0
20
40
60
80
100

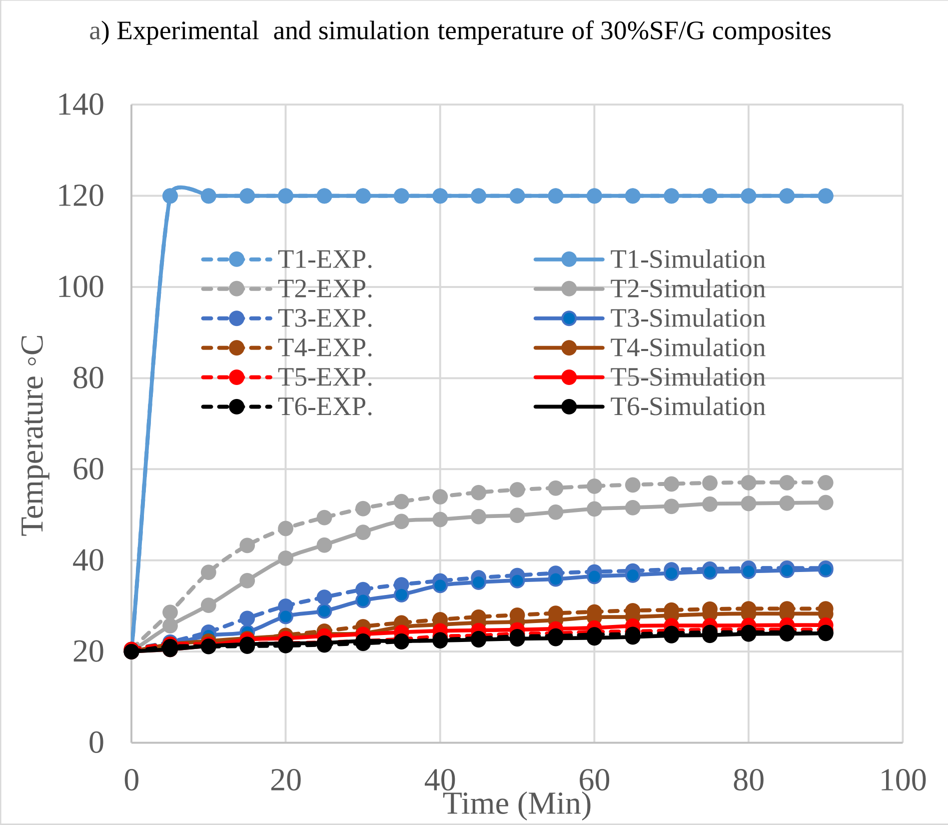
Appendix E2.2: Sisal fibre 25% with Gypsum

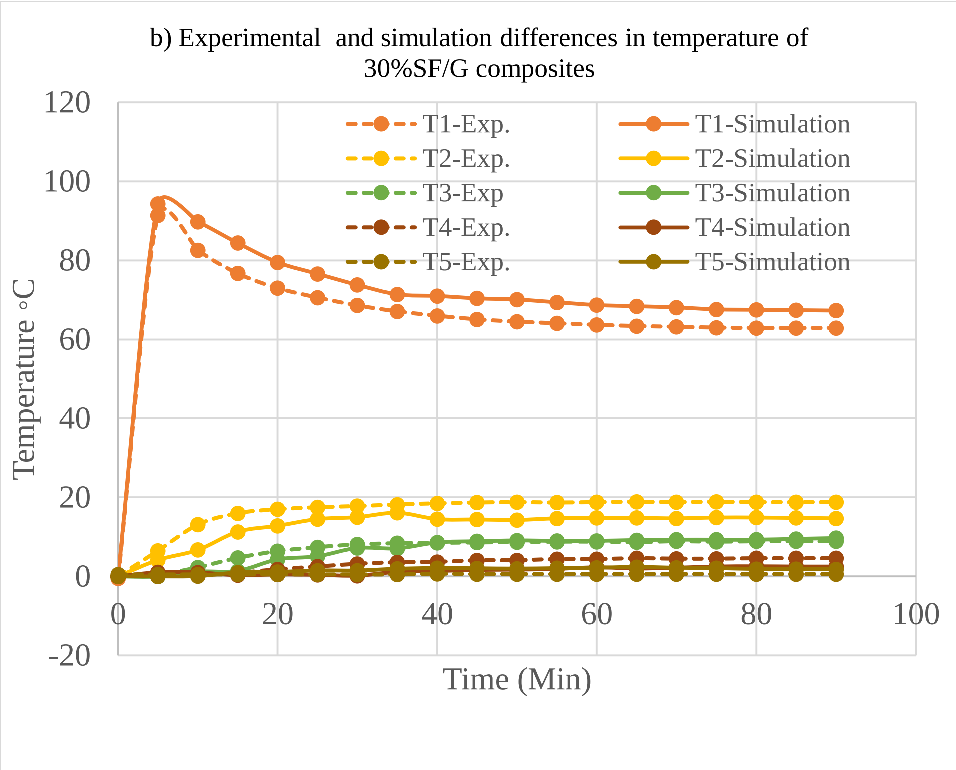


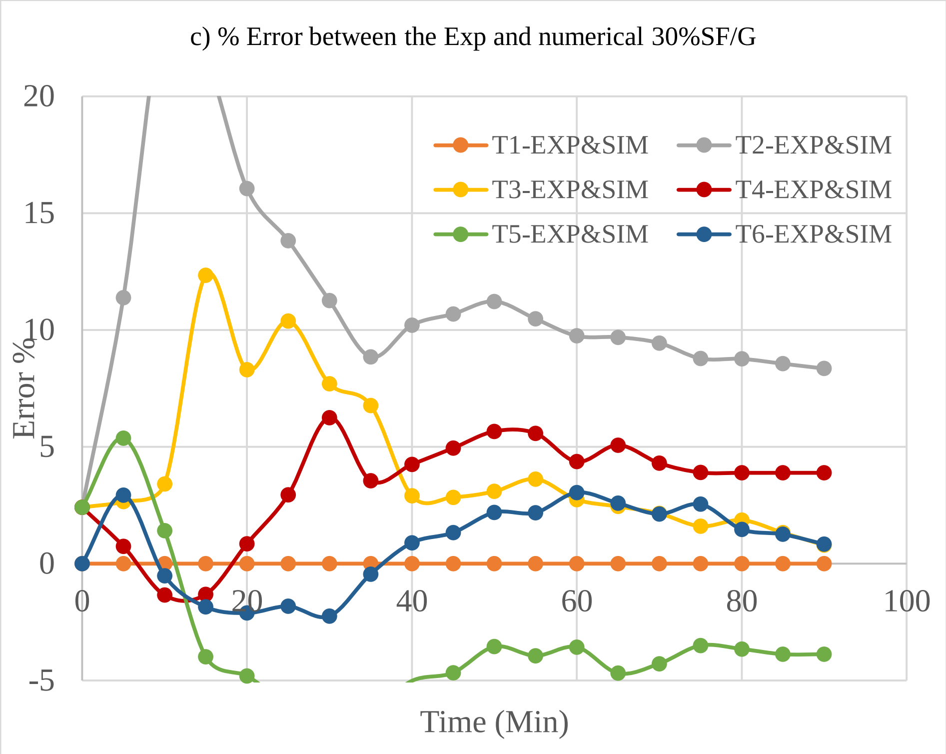



c) % Error between the Exp and numerical 25%SF/G
20
15
10
5
0
-5
Error %
0
20
40
60
80
100
Time (Min)
T1-EXP&SIM
T2-EXP&SIM
T3-EXP&SIM
T4-EXP&SIM
T5-EXP&SIM
T6-EXP&SIM

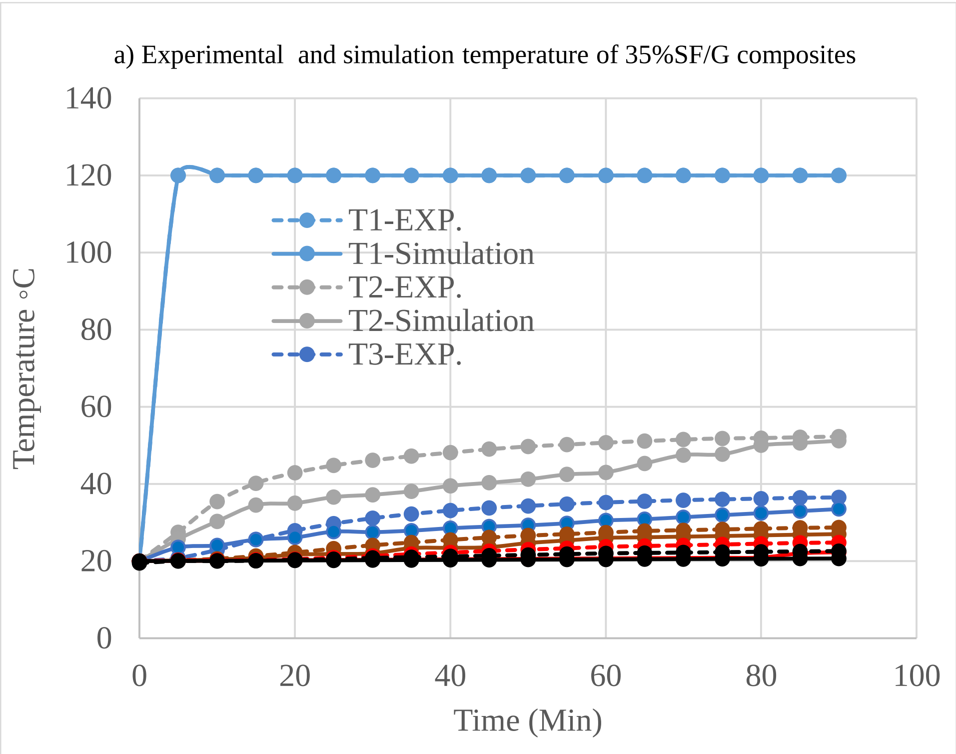
Appendix E2.3: Sisal fibre 30% with Gypsum

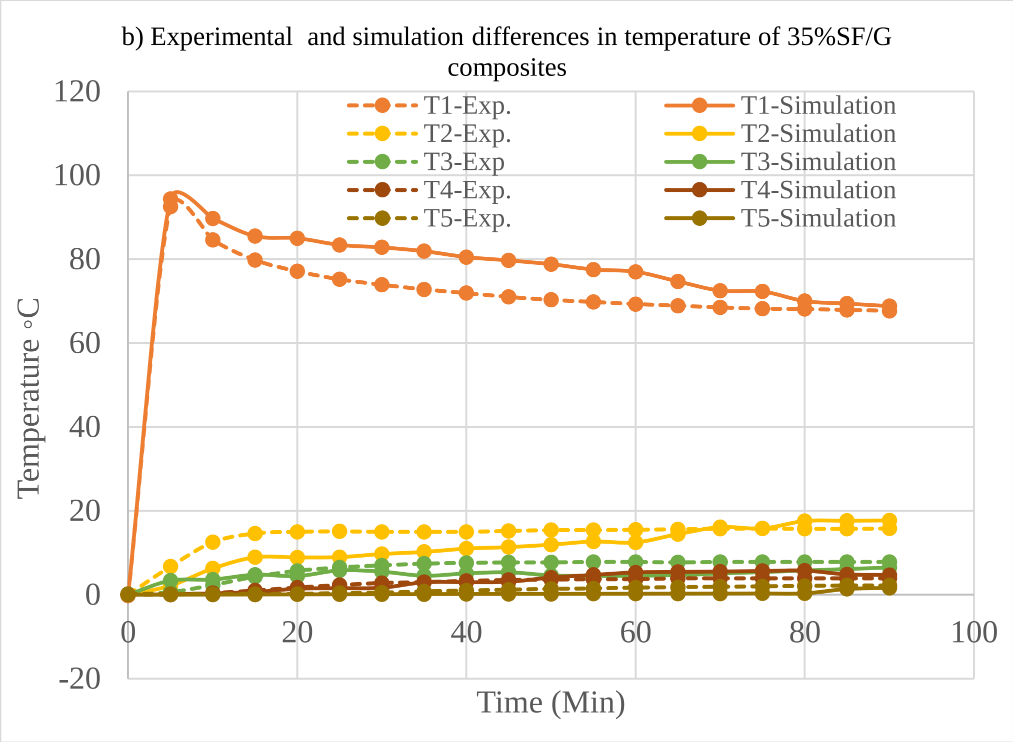


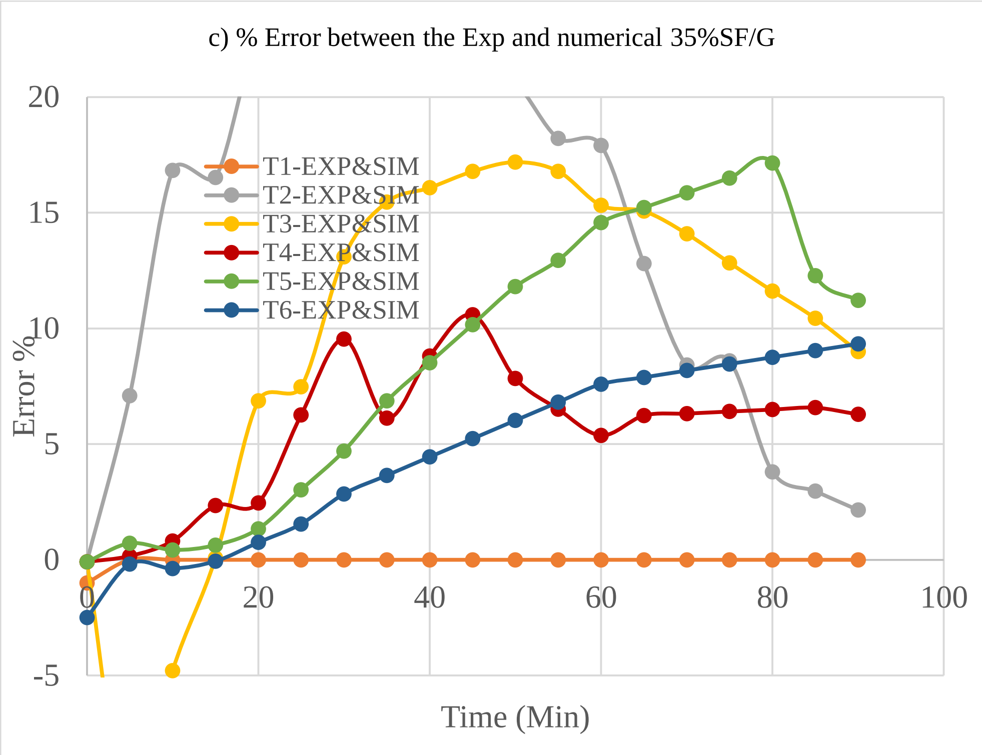




Appendix E2.4: Sisal fibre: 35% with Gypsum




b) Experimental and simulation differences in temperature of 35%SF/G composites
T1-Exp.
T2-Exp.
T3-Exp
T4-Exp.
T5-Exp.
T1-Simulation
T2-Simulation
T3-Simulation
T4-Simulation
T5-Simulation
Temperature °C
Time (Min)


c) % Error between the Exp and numerical 35%SF/G
T1-EXP&SIM
T2-EXP&SIM
T3-EXP&SIM
T4-EXP&SIM
T5-EXP&SIM
T6-EXP&SIM
Error %
Time (Min)

APPENDIX F: Matlab Code

```
% This program performs a series of steps according to the paper called:
%   "Theoretical study of the effect of fibre orientations and porosity on heat conductivity of reinforced polymer composites"
%                         Author/code Writer: Abdalrahman Alajmi
%-----------------------------------------------------------------------------------------------------------------------------------------
% 29/09/2016
clc; % clear the command window.
clear; %% clear the workspace.
close all %%% close all figure windows.
format long; %%%% to set the valuse into short format
% Load valuse from Excel file
%% Sisal-Polyester with 35% Volume fracture with 45 degree of Orientation
y1=[-0.5
9.518240295
17.29959531
23.78062486
29.26087257
33.9570562
38.02449909
41.58338012
44.72154708
47.51141382
50.00590807
52.25160508
54.2819274
56.1284662
57.81307937
59.35816876
60.77840011
62.09027358
63.30380441
];
%% Sisal-Epoxy with 35% Volume fracture with 45 degree of Orientation
y2=[-0.5
9.573033708
17.38846484
23.8887435
29.37788813
34.08218126
38.15153143
41.70699639
44.84564571
47.63087932
```

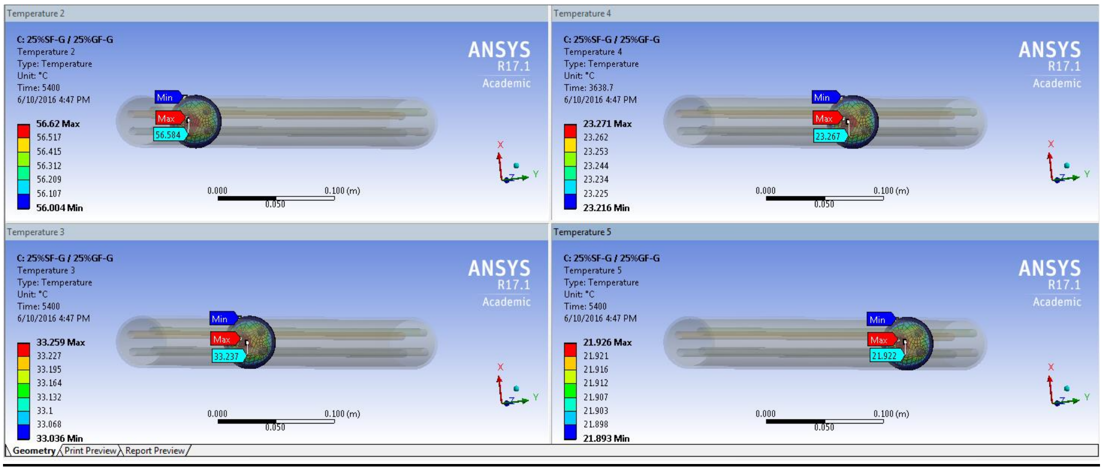
```
47.63087932
50.1200113
52.36222232
54.38663688
56.22702812
57.90853481
59.4466359
60.86187806
62.16949385
63.37758088
];
%% Sisal-Vinlyester with 35% Volume fracture with 45 degree of Orientation
y3=[-0.5
9.537728213
17.3278856
23.81611949
29.30224525
34.00025651
38.06731488
41.62577461
44.7639904
47.55094923
50.0448367
52.28744985
54.31901133
56.16329524
57.84592604
59.38876858
60.80715399
62.11685246
63.32868804
];
%% The duration of the sumilation which is (90 minutes )
t=0:5:90;
%% Plotting the Graph and zoom in to show the differences betweern the lines
plot(t,y1,'ro-',t,y2,'bs-',t,y3,'md-');grid on %% to plot the graph
xlabel('times (min)') %% to write in the X-axsis
ylabel('Insulation Percentage % ')%% to write in the Y-axsis
legend('Polyster+ 35%+ 45 Degree','Epoxy+ 35%+ 45 Degree','Vinlyester+ 35%+ 45 Degree','Location','northwest')
title(['Infleunce of orientaiton in 35% Sisal fibre '])%% to write in the Title
```

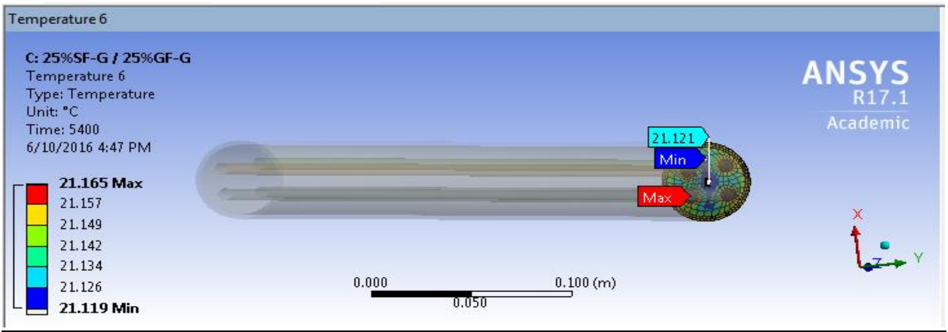
```
% Glass-Polyester with 35% Volume fracture with 45 degree of Orientation
y1=[-0.5
9.611323298
17.45746808
23.97818127
29.48797464
34.20085047
38.28169266
41.84642897
44.99001157
47.78034194
50.27611327
52.51952689
54.54893129
56.39180065
58.07352257
59.61509883
61.03375114
62.34166909
63.55160236];
%% Glass-Epoxy with 35% Volume fracture with 45 degree of Orientation
y2=[-0.5
8.98149405
16.40360301
22.64000304
27.95380932
32.53564989
36.532033
40.03976029
43.14705643
45.91878694
48.40652508
50.65179068
52.68838608
54.54410957
56.24203177
57.80145974
59.2386743
60.56750063
61.80214459
];
```

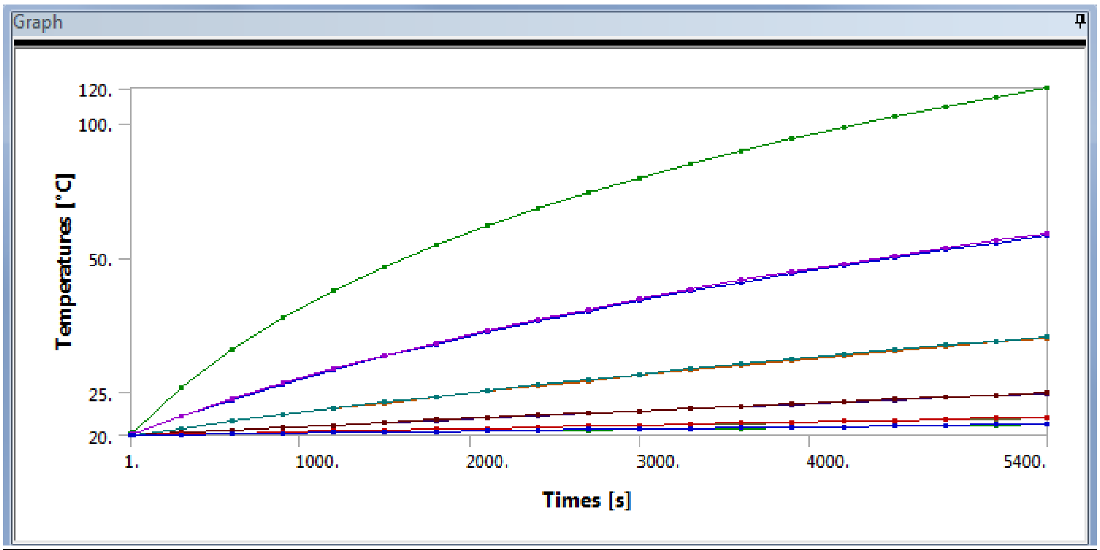
```
%% Glass-Vinlyester with 35% Volume fracture with 45 degree of Orientation
y3=[-0.5
9.635252897
17.48899038
24.01717379
29.53144903
34.24574404
38.32772333
41.8943432
45.03333858
47.82436317
50.31911399
52.56016043
54.58730192
56.42977147
58.1109068
59.64915534
61.06533307
62.37125749
63.57886415
];
%% The duration of the sumilation which is (90 minutes )
t=0:5:90;
%% Plotting the Graph and zoom in to show the differences betweern the lines
plot(t,y1,'ro-',t,y2,'bs-',t,y3,'md-');grid on %% to plot the graph
xlabel('times (min)') %% to write in the X-axsis
ylabel('Insulation Percentage % ')%% to write in the Y-axsis
legend('Polyster+ 35%+ 45 Degree','Epoxy+ 35%+ 45 Degree','Vinlyester+ 35%+ 45 Degree','Location','northwest')
title(['Infleunce of orientaiton in 35% Glass fibre '])%% to write in the Title
```

APPINDIX G: ANSYS RESULTS

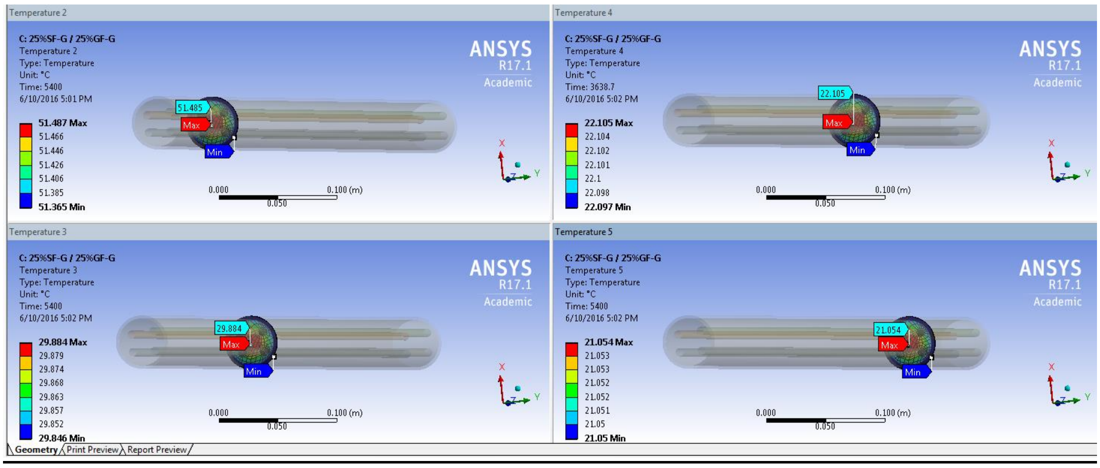
Appendix G1:- Glass Fibre 25% with Gypsum

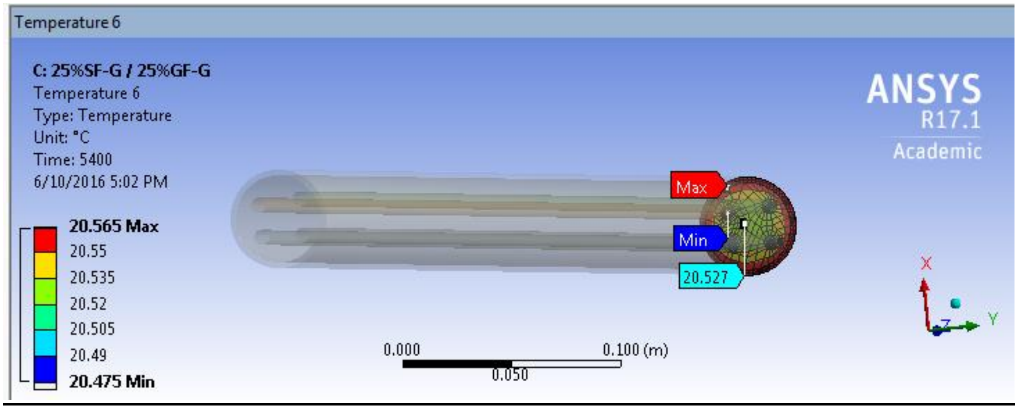


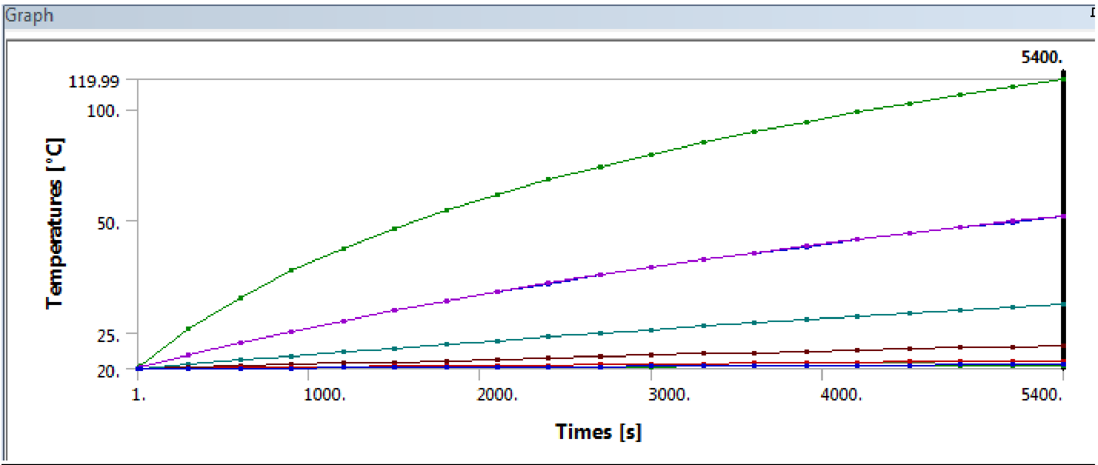




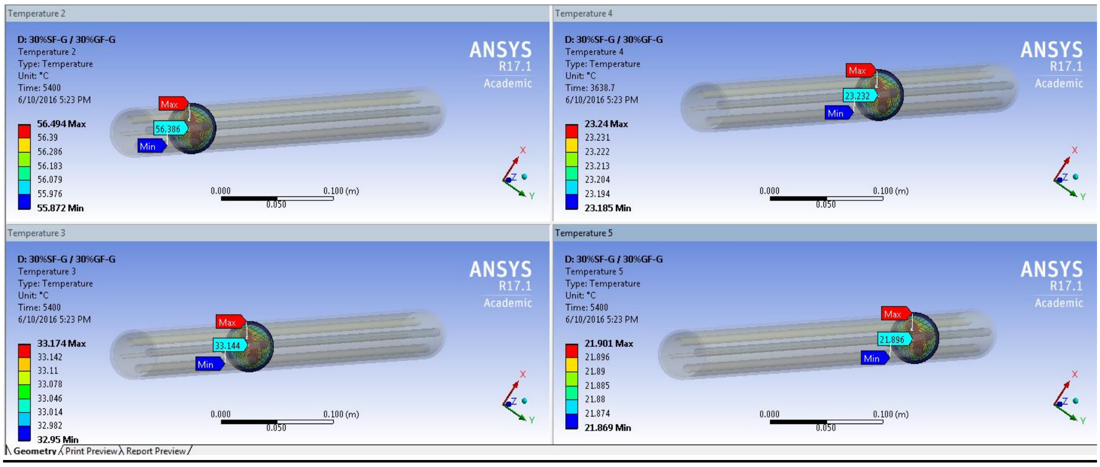
Appendix G2:- Sisal fibre 25% with Gypsum

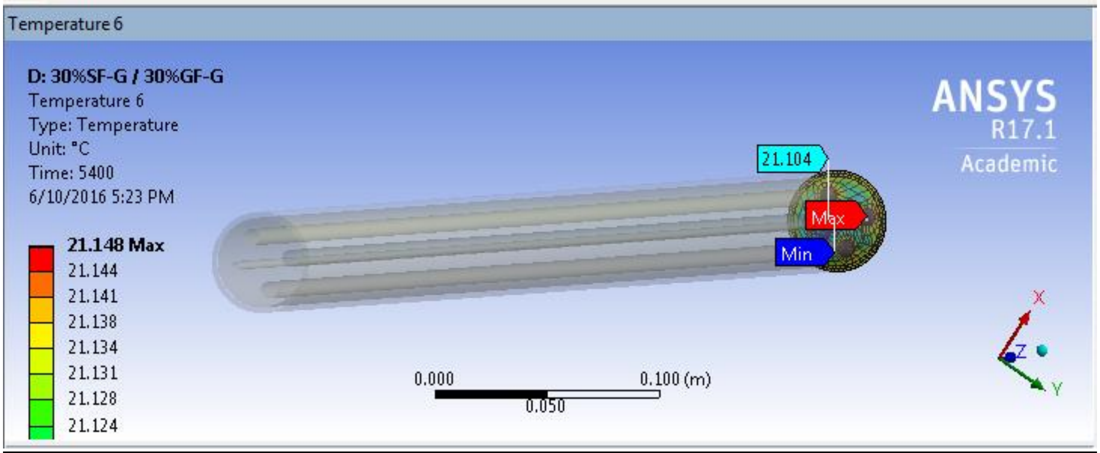


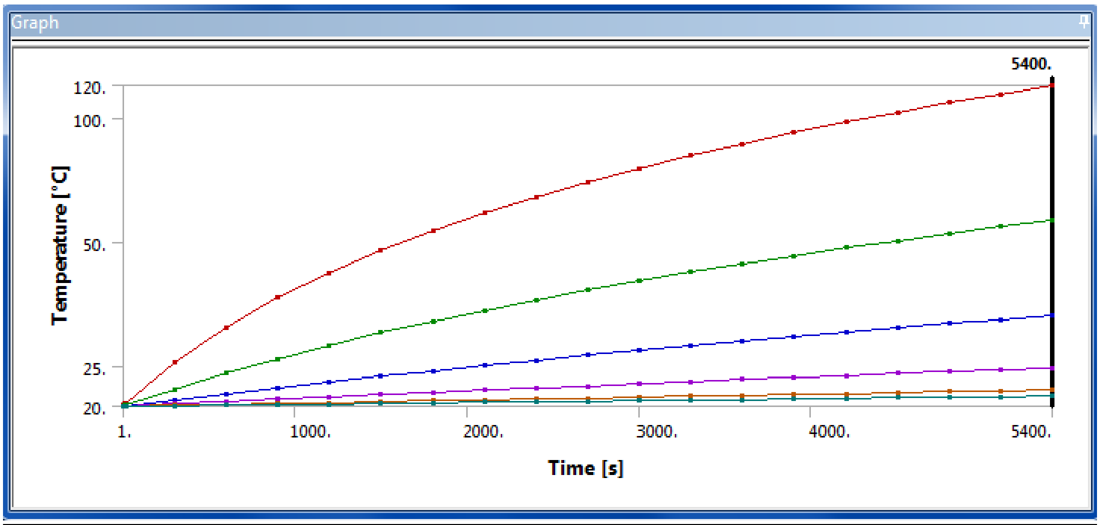




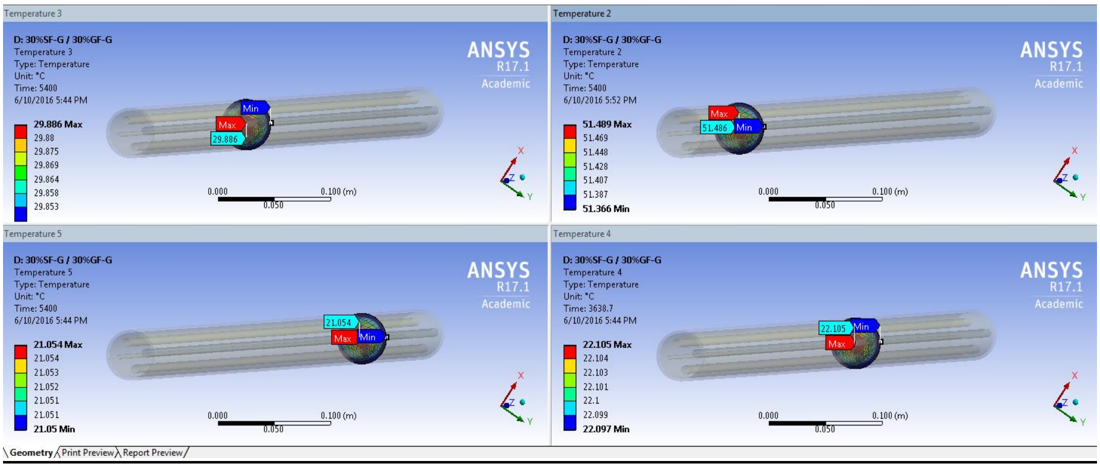
Appendix G3:- Glass Fibre 30% with Gypsum

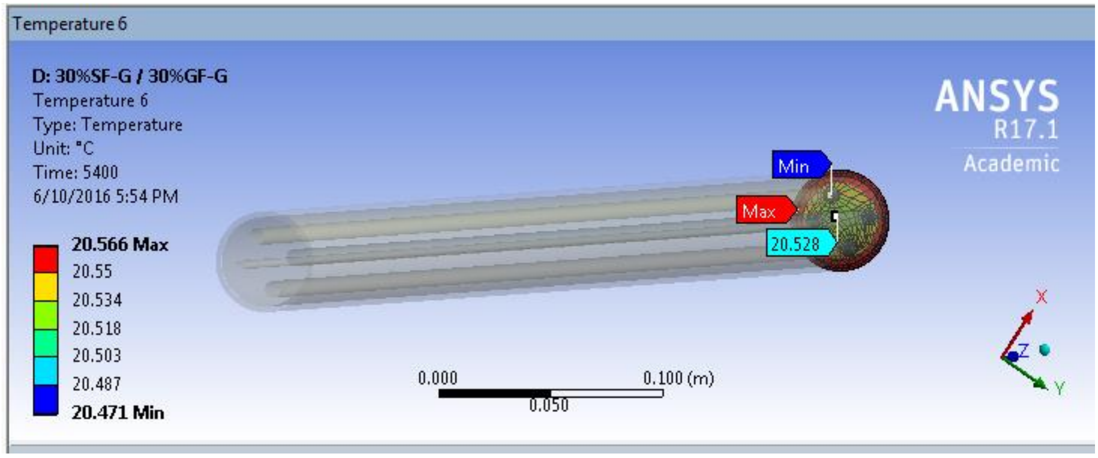




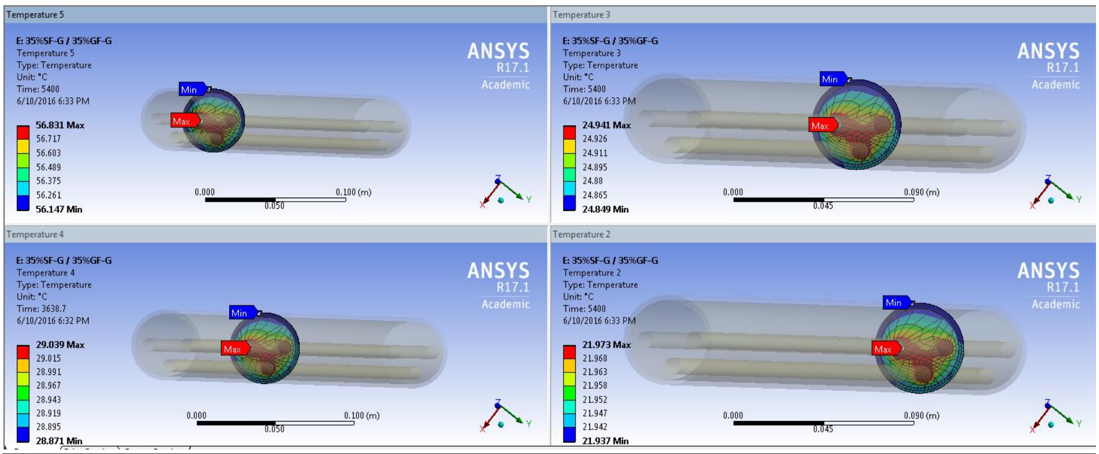


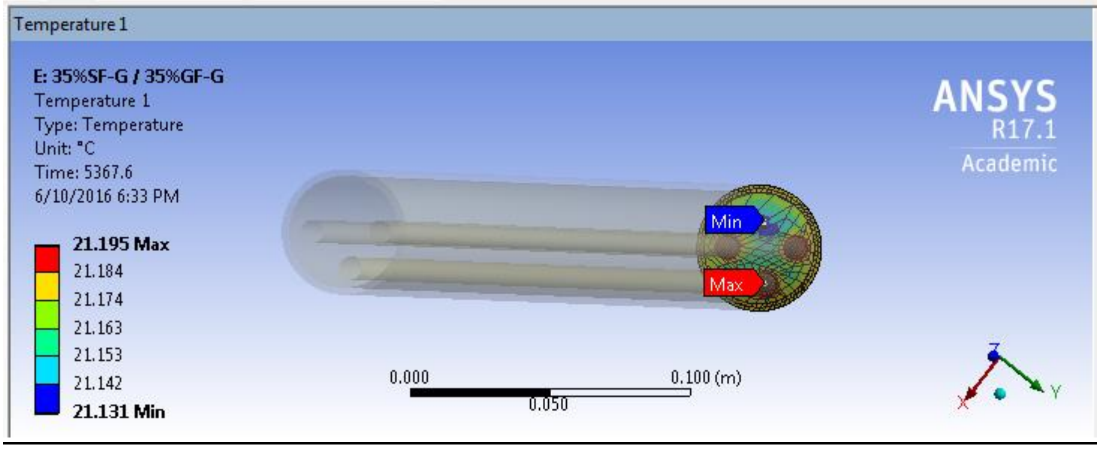
Appendix G4:- Sisal Fibre 30% with Gypsum



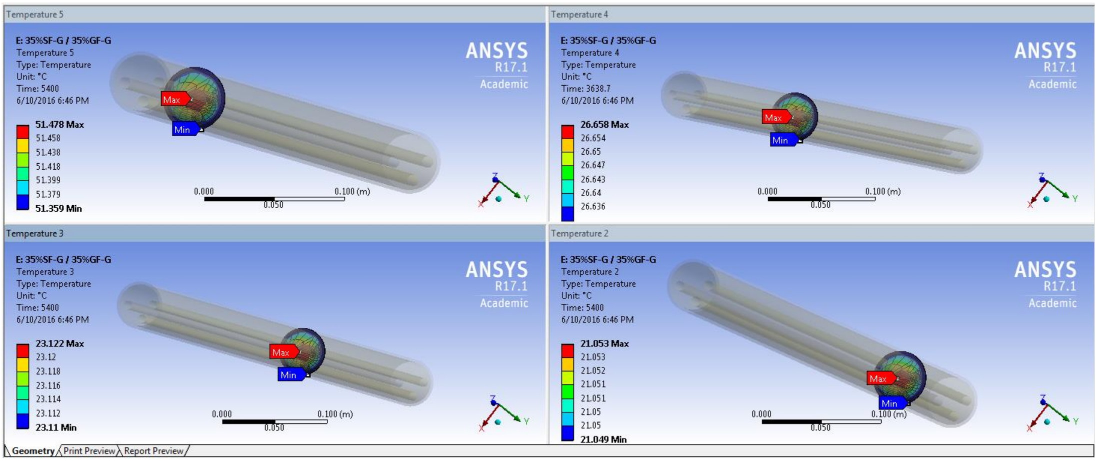


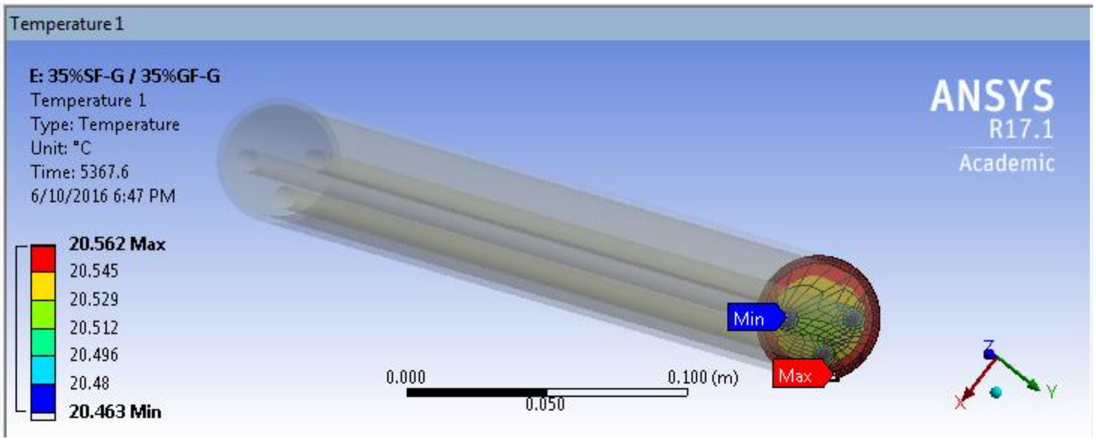
Appendix G5:- Glass Fibre 35% with Gypsum



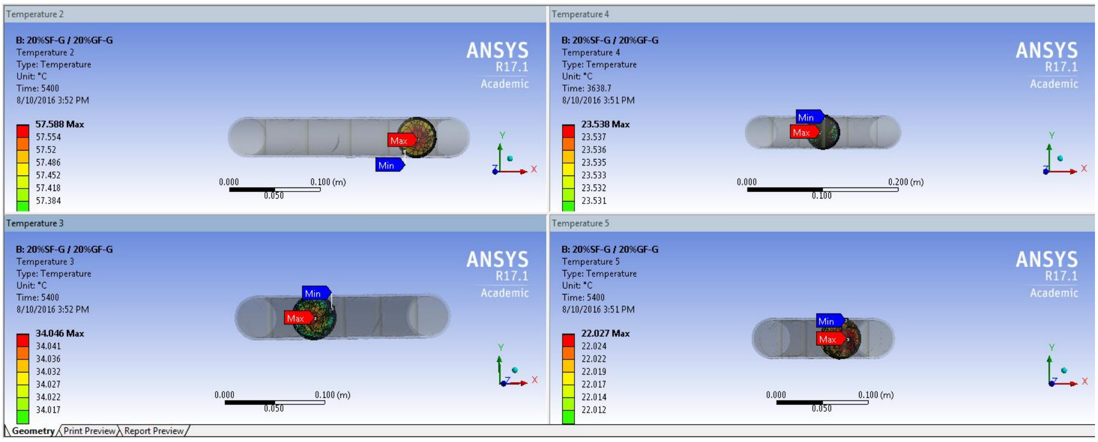


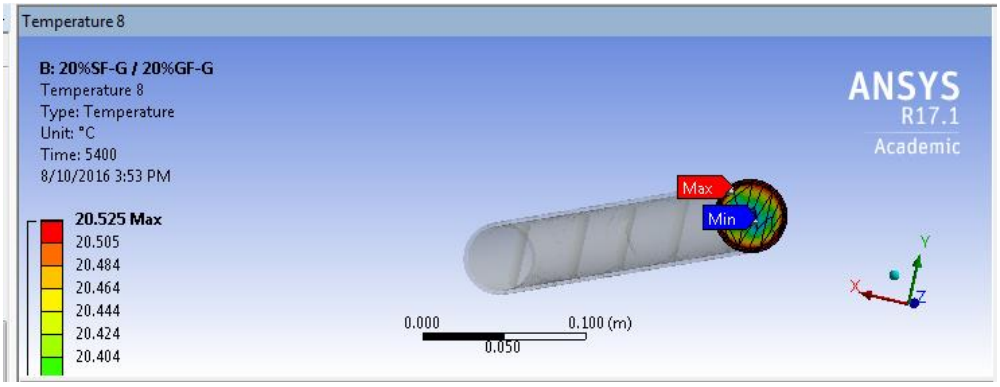
Appendix G6:- Sisal Fibre 35% with Gypsum



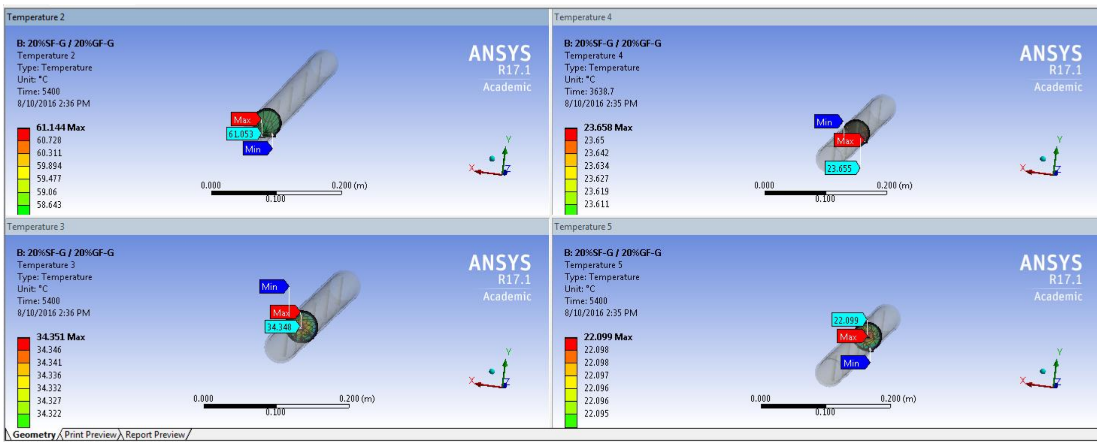


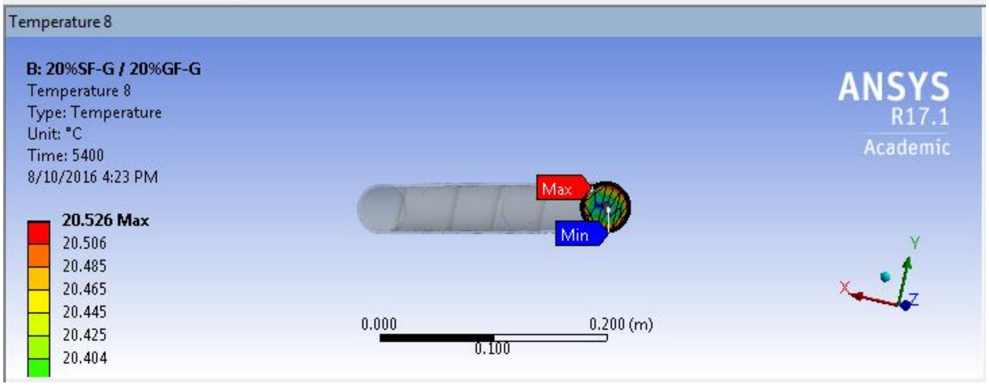
Appendix G7:- Sisal Fibre 20% with Polyester/Parallel Orientation



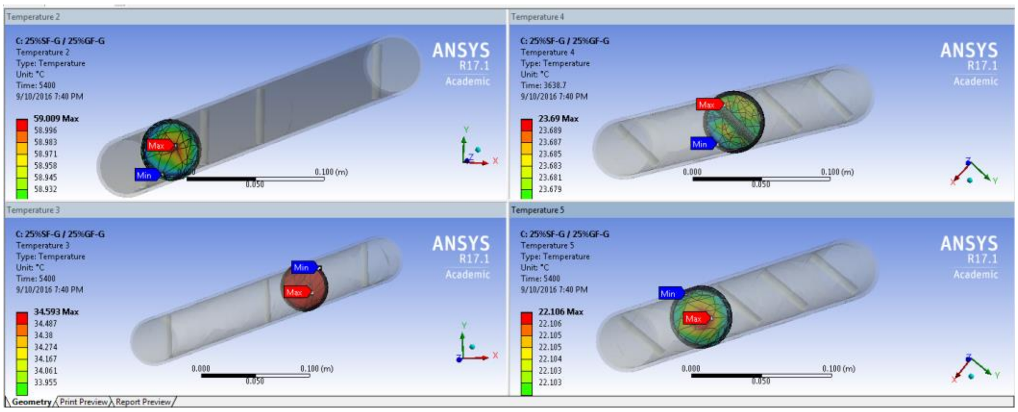


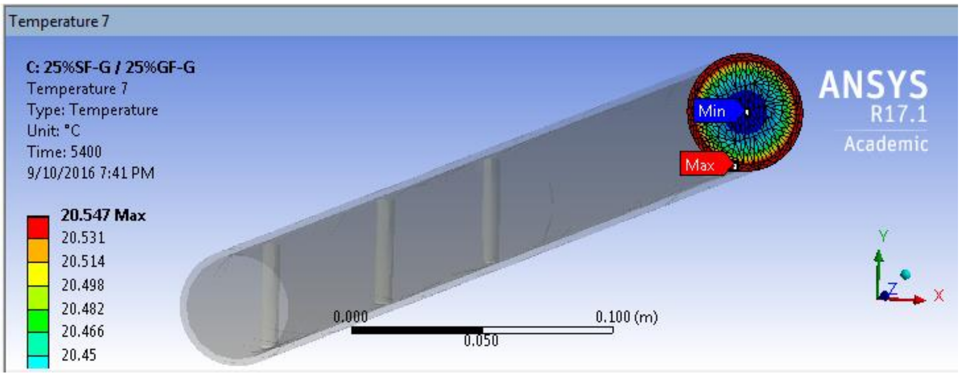
Appendix G8:- Glass Fibre 20% with Polytester/Parallel Orientation



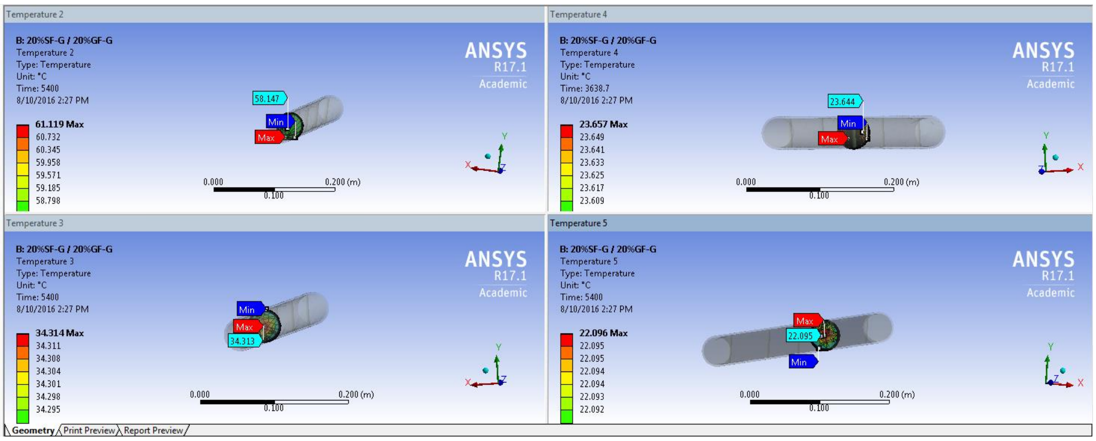


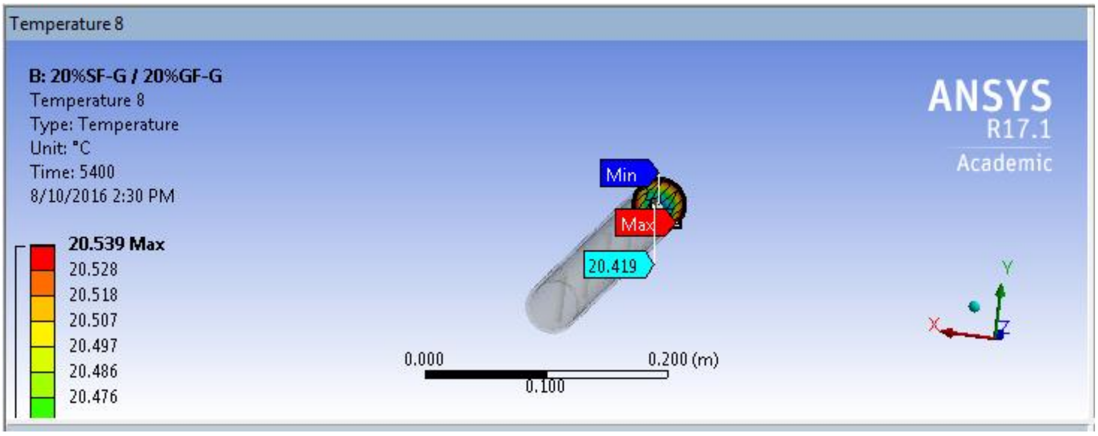
Appendix G9:- Glass Fibre 20% with Vinylester/Parallel Orientation



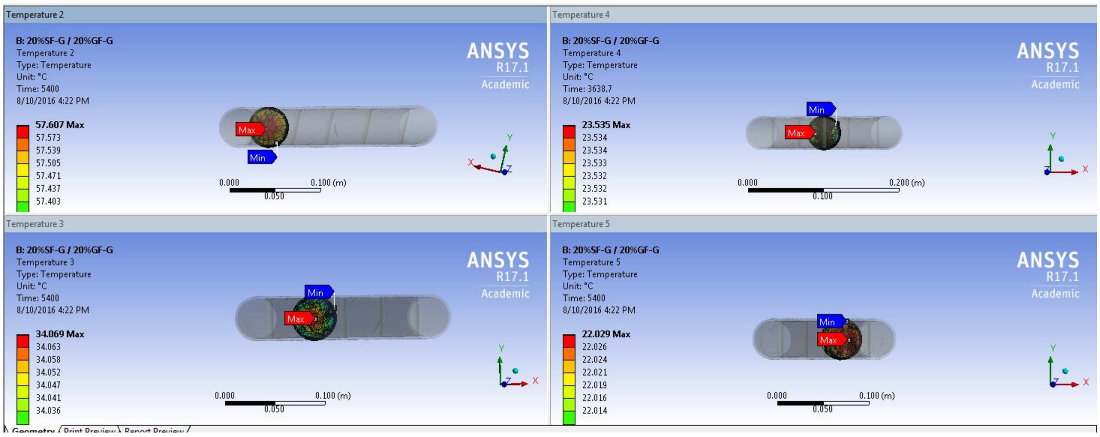


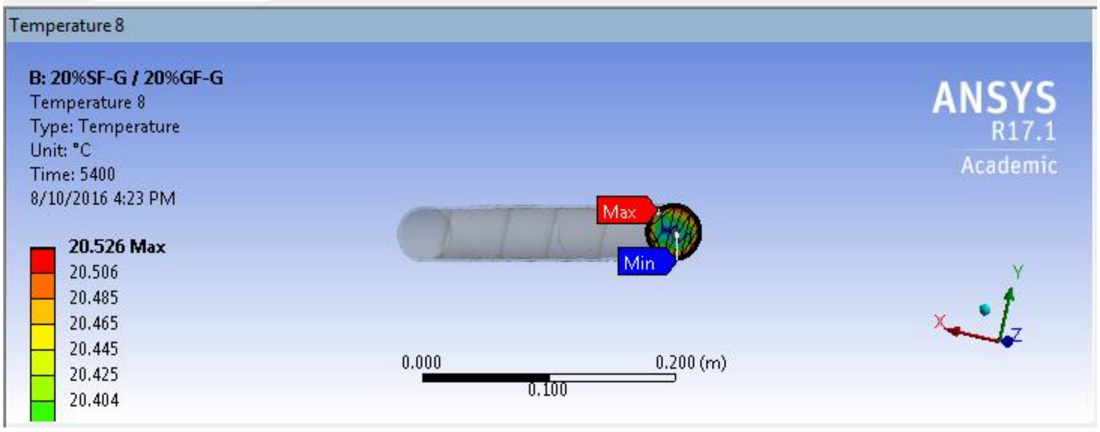
Appendix G10:- Sisal Fibre 20% with Vinylester/Parallel Orientation



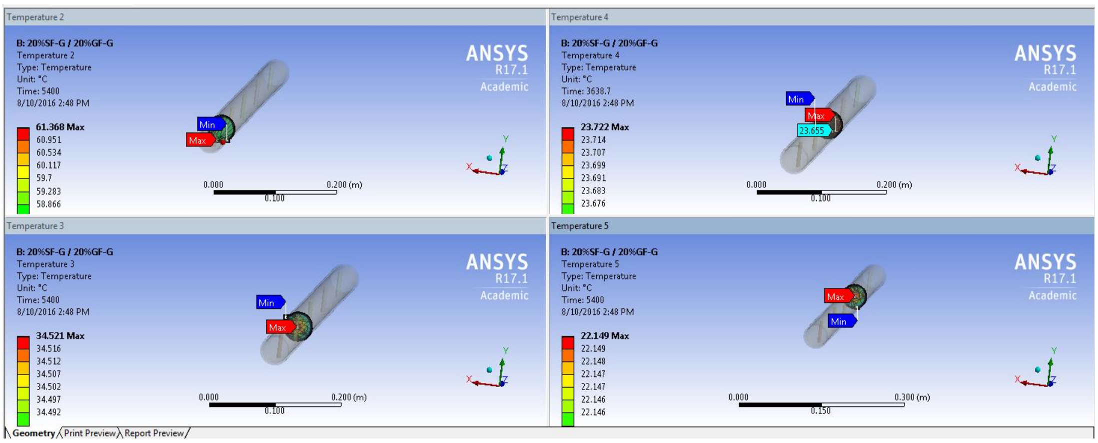


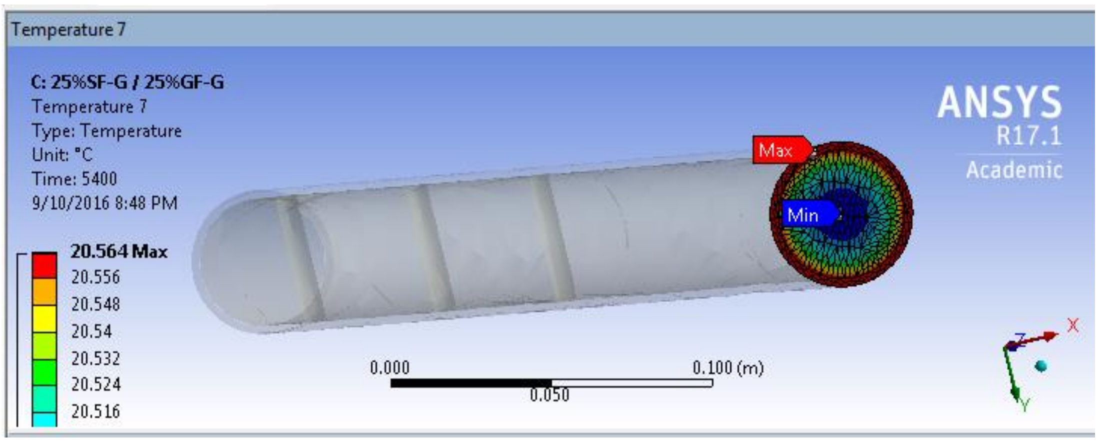
Appendix G11:- Glass Fibre 20% with Polyester/Parallel Orientation



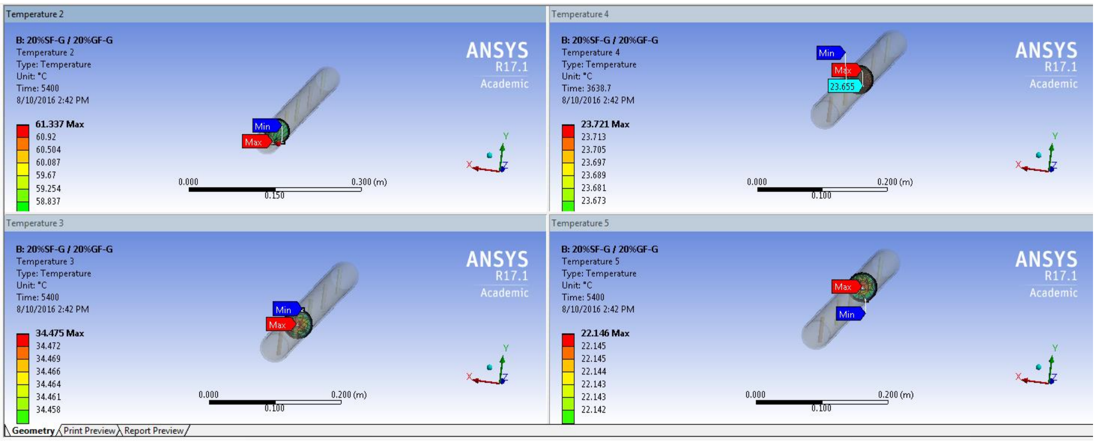


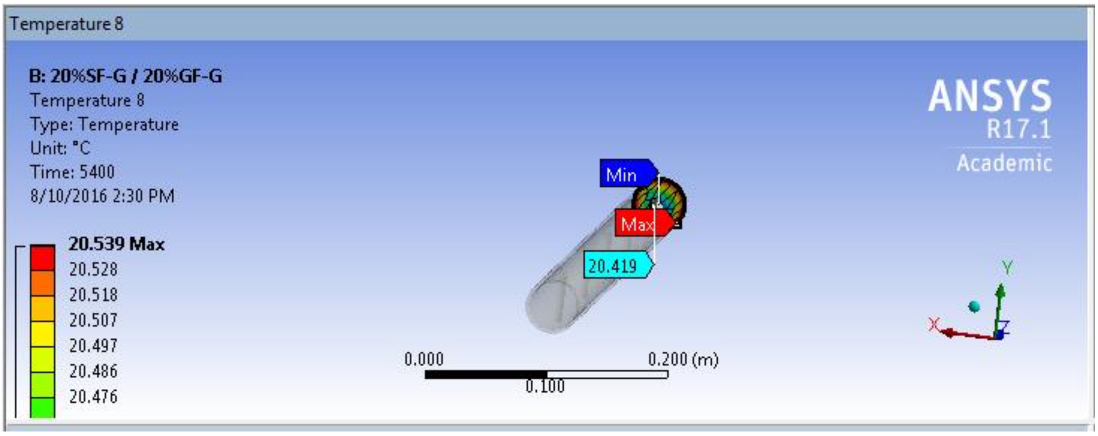
Appendix G12:- Glass Fibre 20% with Epoxy /Parallel Orientation



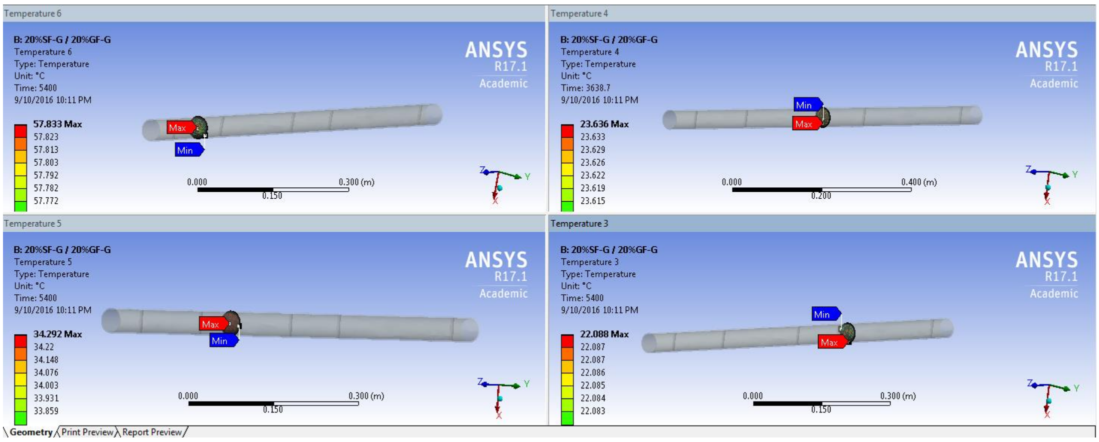


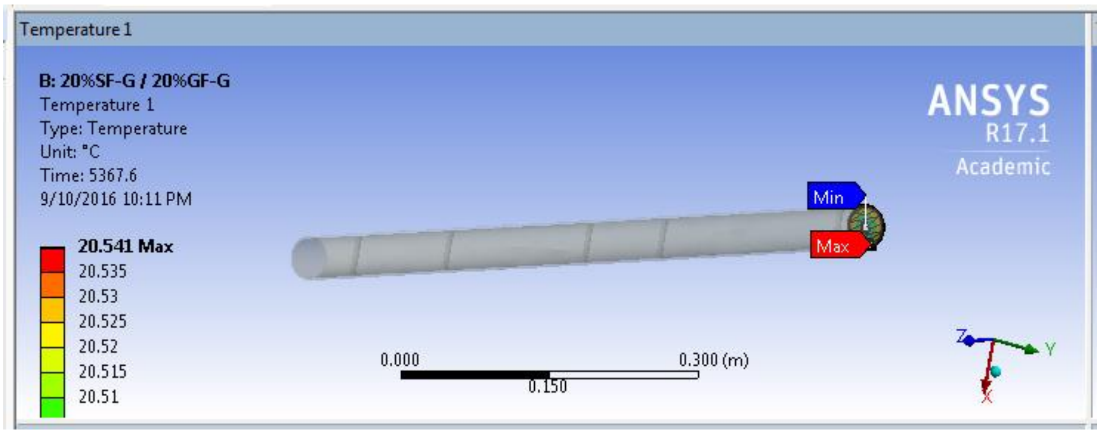
Appendix G13:- Sisal Fibre 20% with Epoxy /Parallel Orientation



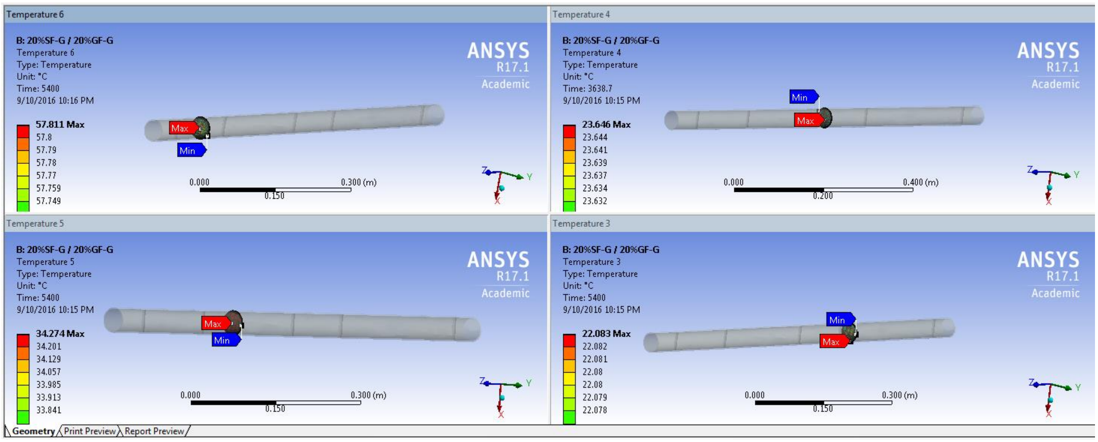


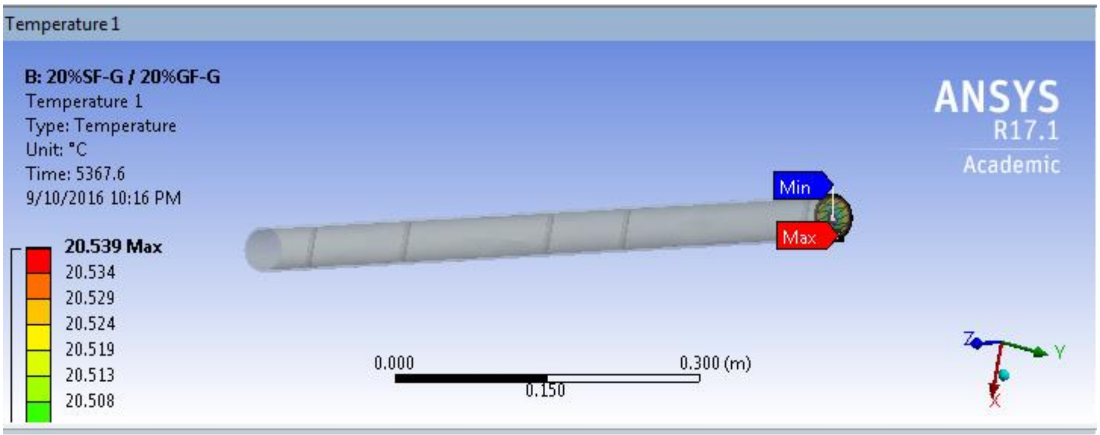
Appendix G14:- Glass Fibre 20% with Epoxy /Perpendicular Orientation



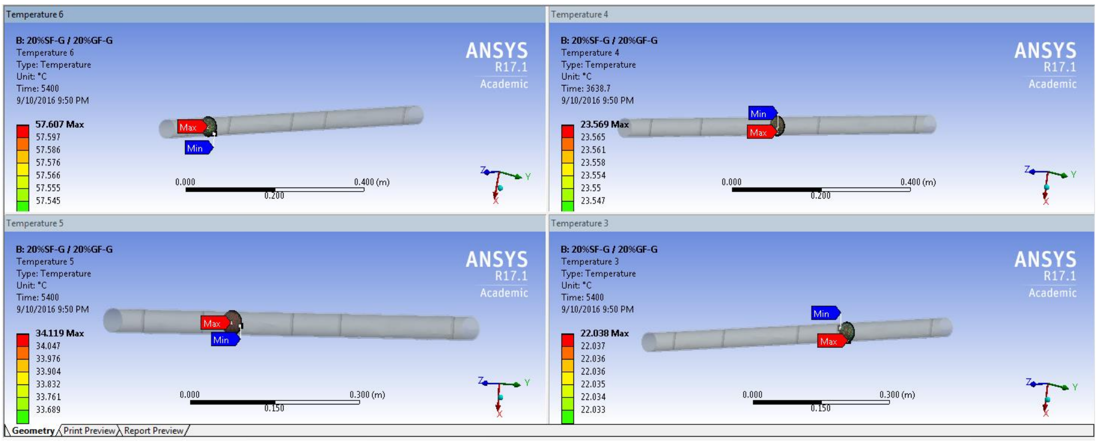


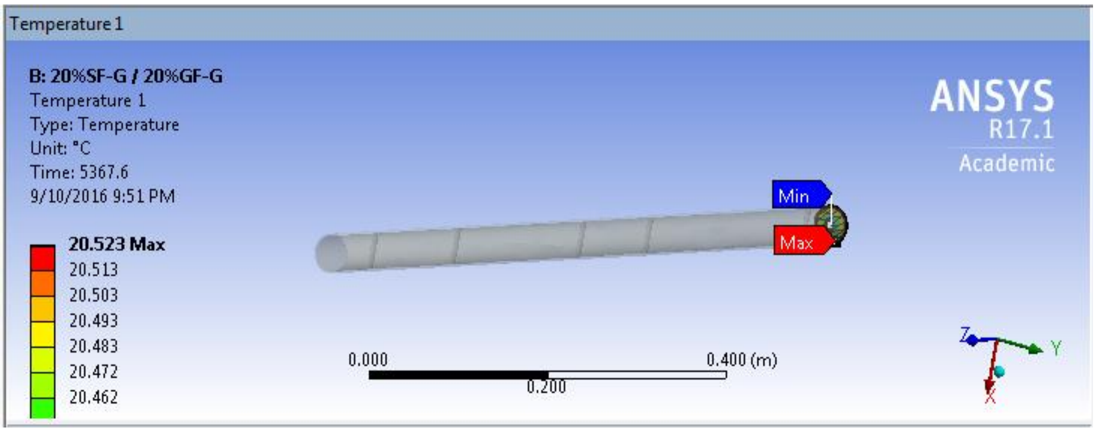
Appendix G15:- Sisal Fibre 20% with Epoxy /Perpendicular Orientation



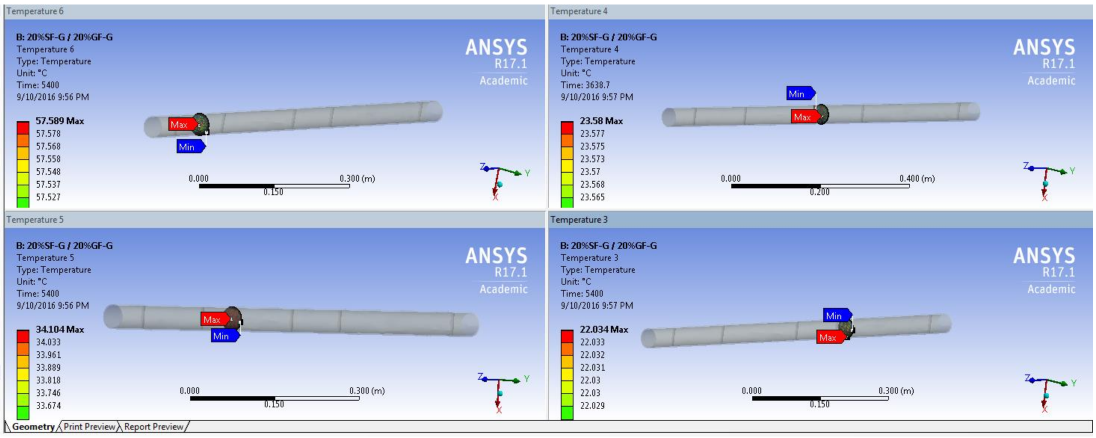


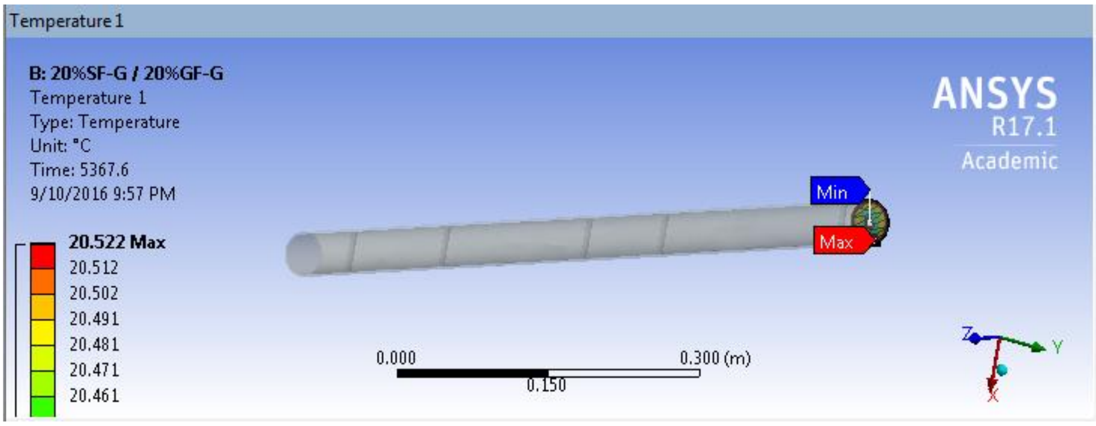
Appendix G16:- Glass Fibre 20% with Vinylester /Perpendicular Orientation



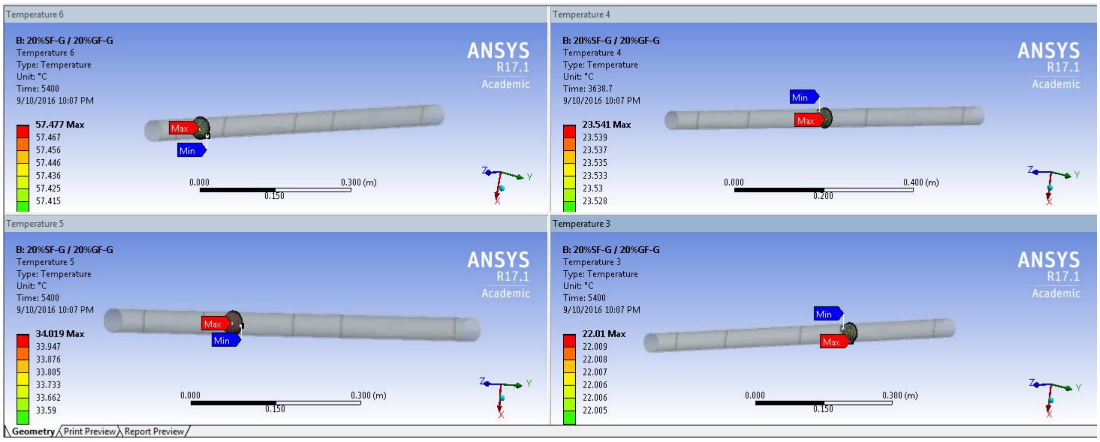


Appendix G17:- Sisal Fibre 20% with Vinylester /Perpendicular Orientation

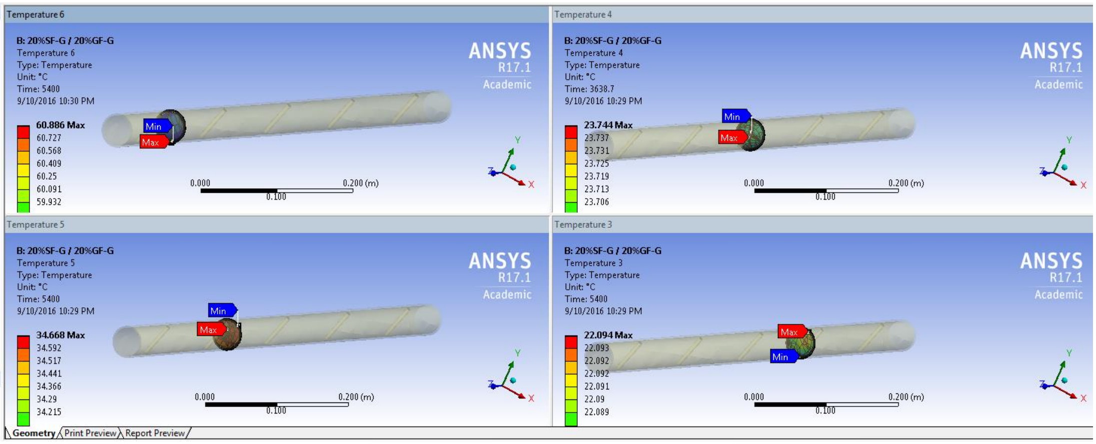


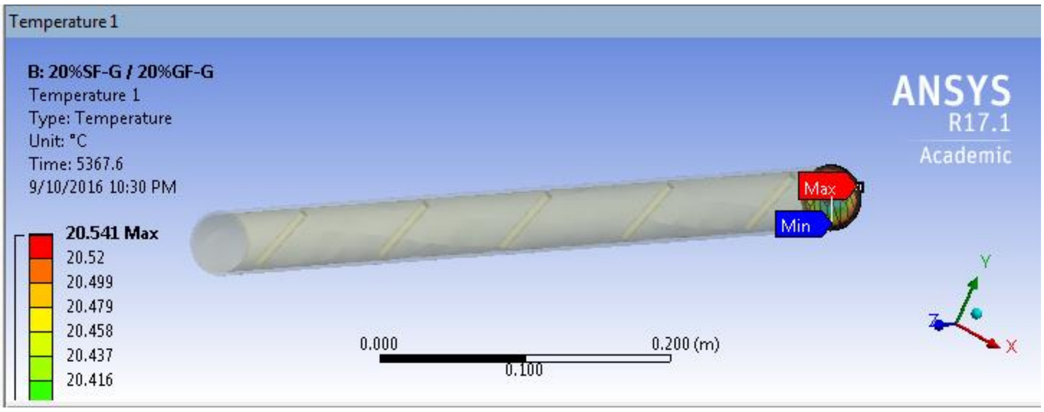


Appendix G18:- Glass Fibre 20% with Polyester /Perpendicular Orientation

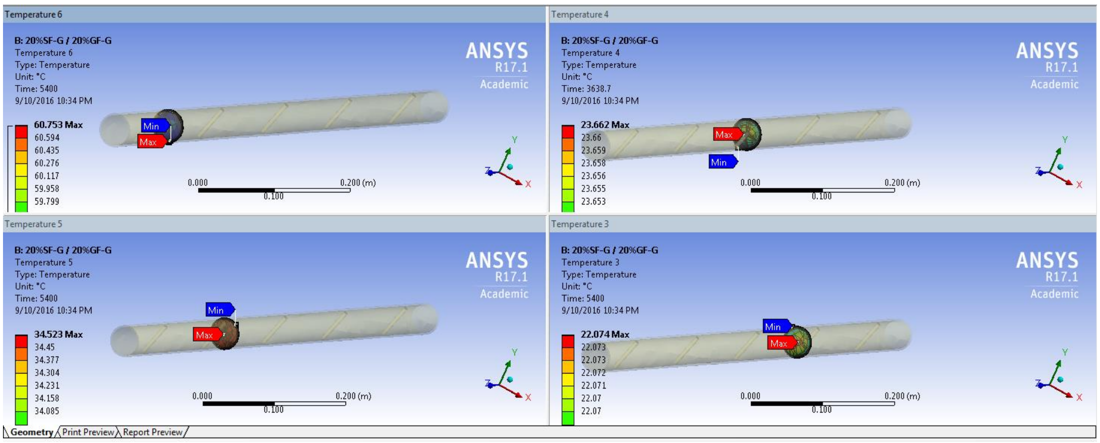


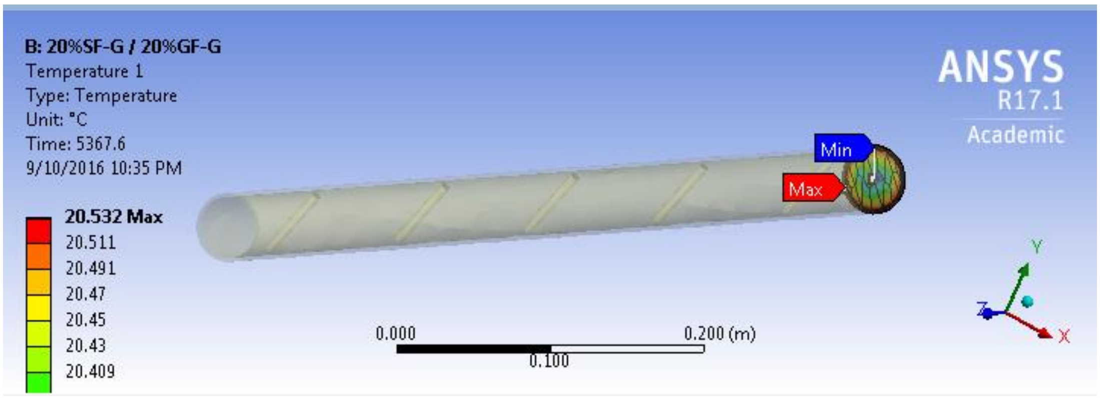
Appendix G19:- Glass Fibre 20% with Polyester /45 Degree Orientation



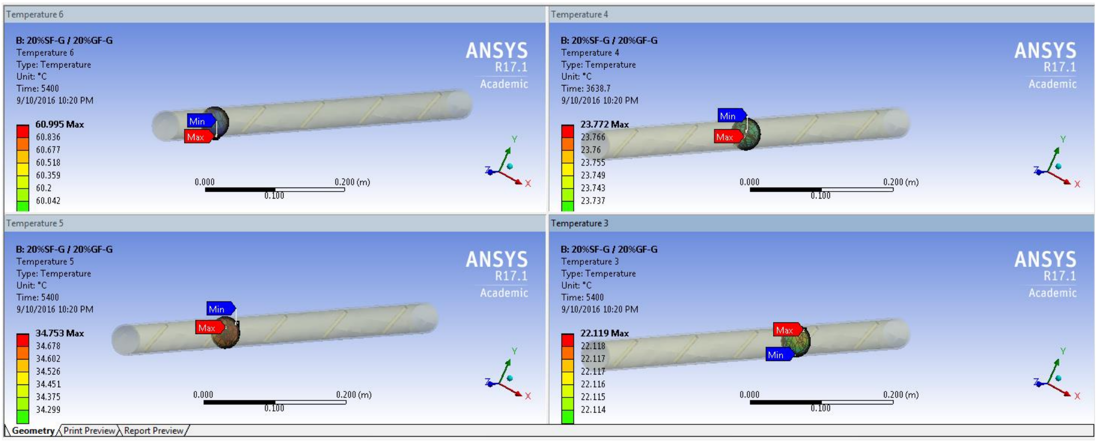


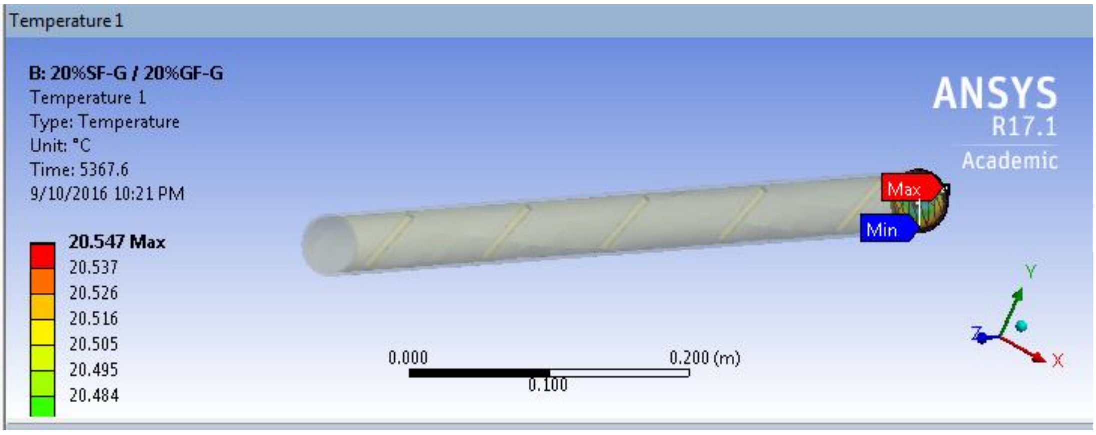
Appendix G20:- Sisal Fibre 20% with Polyester /45 Degree Orientation



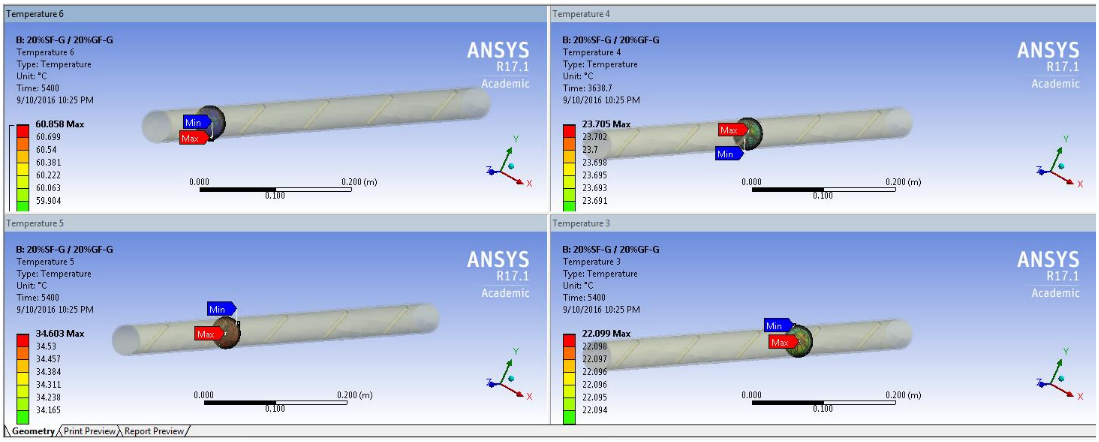


Appendix G21:- Glass Fibre 20% with Vinylester/45 Degree Orientation

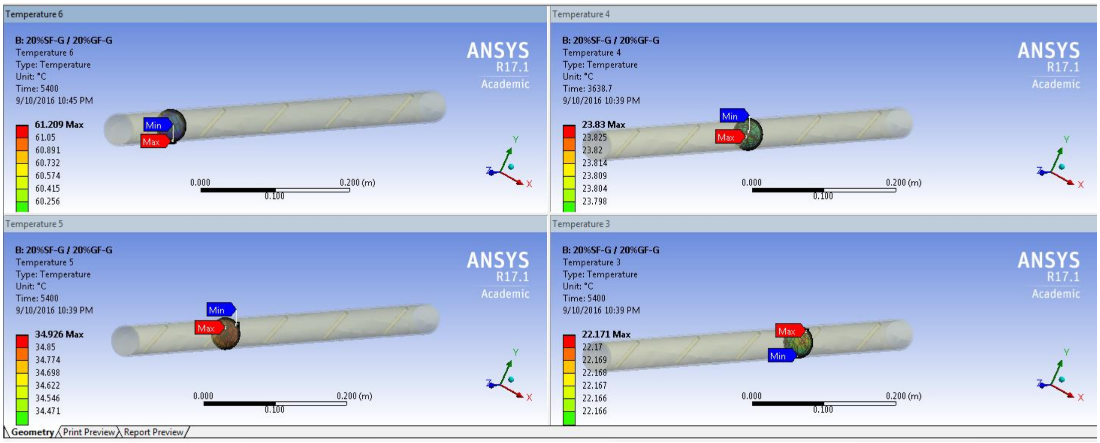


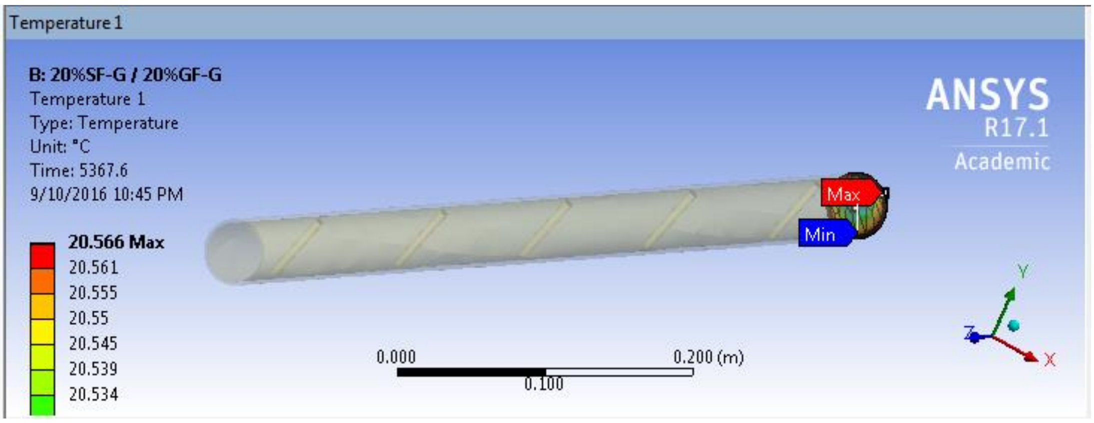


Appendix G22:- Sisal Fibre 20% with Vinylester/45 Degree Orientation



Appendix G23:- Glass Fibre 20% with Epoxy/45 Degree Orientation





Appendix G24:- Sisal Fibre 20% with Epoxy/45 Degree Orientation