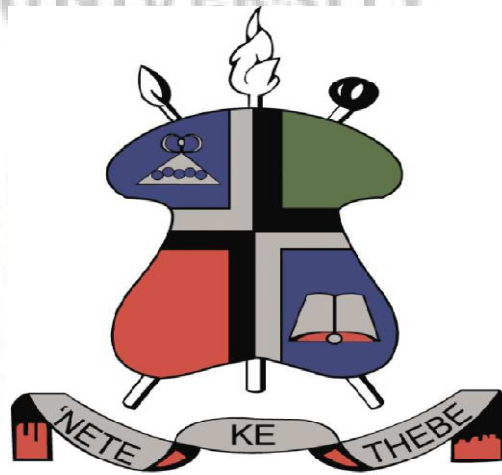


# Moisture Absorption, Dimensional Stability Properties and Applications of Composites made from Thermosetting Resins, Reinforced with Sandstone, Diorite, and Corn Stalk.

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May, 2011

Moisture absorption, Dimensional Stability Properties and applications of composites made from thermosetting resins, reinforced with sandstone, diorite, and cornstark.

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**A research project submitted in partial fulfillment of the requirements for the award of degree**

**BACHELOR of Science in CHEMICAL TECHNOLOGY**

**(BSc. Chem. Tech.)**

**In the Department of Chemistry and Chemical Technology**

**Faculty of Science and Technology**

**THE NATIONAL UNIVERSITY OF LESOTHO**

**Supervisor: Dr. T. Thamae**

**May 2011**

**Roma (NUL)**

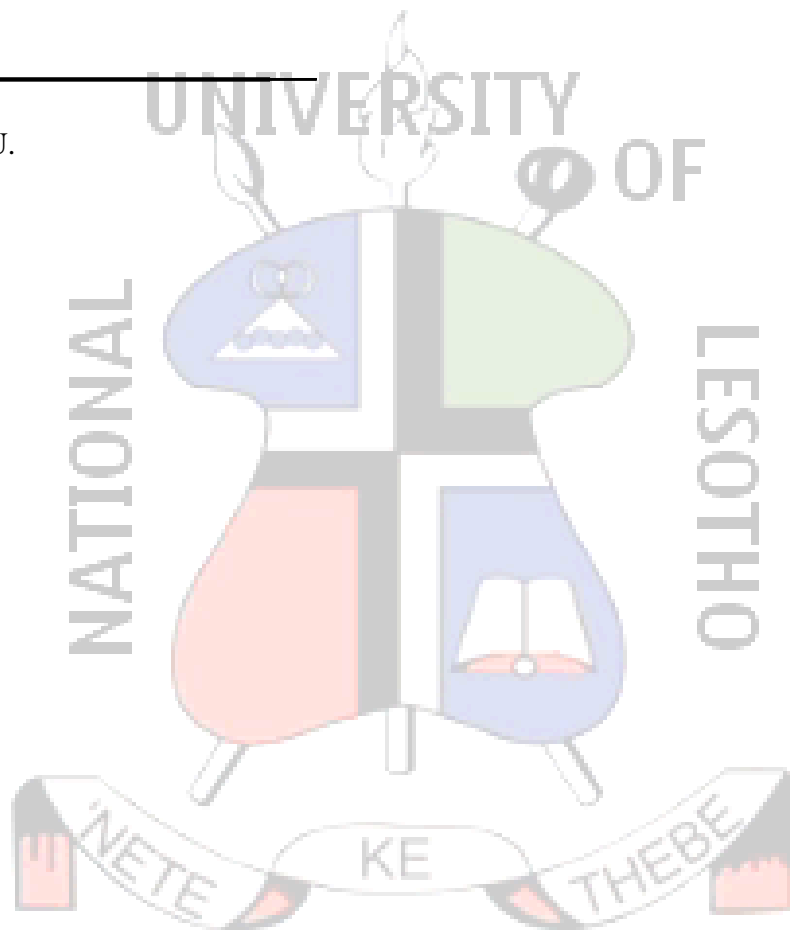
## DECLARATION

I do hereby verify that this written report is my own individual work and contains my own original ideas, concepts and designs. No portion of this report has been copied in whole or in part from another source, with the possible exception of properly referenced material.

Signature: \_\_\_\_\_

OSIKI IZIJESU.

May, 2011



## DEDICATION

This project is dedicated to my family and friends and to all those involved in 21<sup>st</sup> century development of engineering and technology.

OSIKI I.O

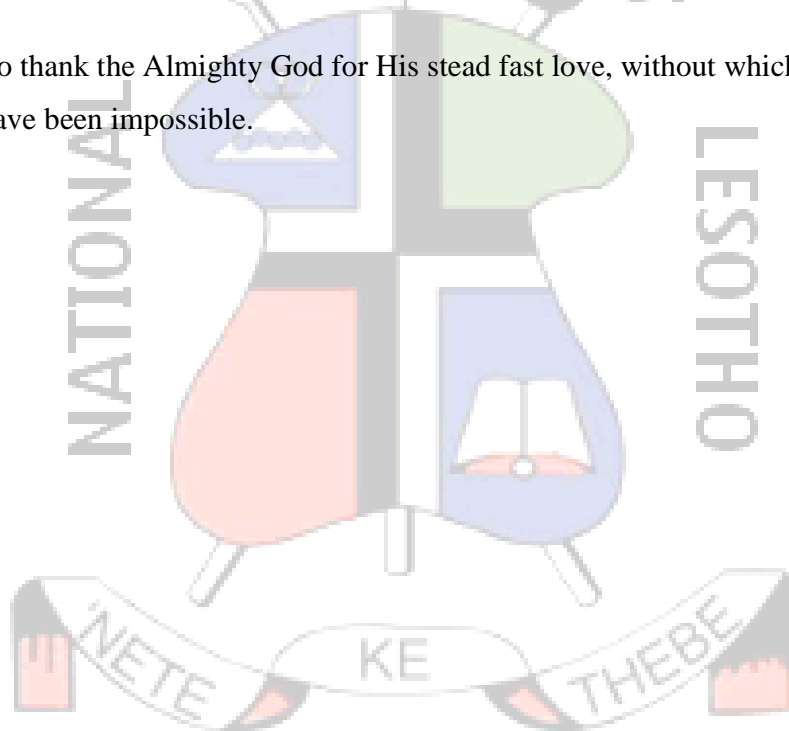


## **ACKNOWLEDGEMENT**

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Secondly, my heart goes out to my family who encouraged me to complete the project work even when it seemed like a daunting task, their support is much appreciated. Again I want to sincerely thank my colleagues for seeing potential in my research work even at the earliest stages of my work.

Finally, I want to thank the Almighty God for His steadfast love, without which completing the project would have been impossible.



## ABSTRACT

Moisture absorption and dimensional stability of materials is one major concern in any engineering design, as well as in any environment. This is because moisture absorption and poor dimensional stabilities in any material is capable of leading to the degradation and ultimate failure of such a material. The purpose of this research however, was to study the moisture absorption as well as dimensional stability properties of composites made from thermosetting polymers, reinforced with diorite, sandstone, and cornstalk. Other objectives of the research were to determine possible applications of the different composite materials as well as determine which of the thermosetting polymer resins would be most applicable as matrix material. Moisture absorption was carried out using the long term immersion procedure based on the ASTM D 570 - 98 standard. From the results of moisture absorption, the corn stalk-polyester composite was found to absorb more moisture than the other synthesized composite. The diorite-polyester composite absorbed the least moisture and results indicate that moisture decreases with increasing amount of the diorite filler added. The dimensional stability tests indicate that the sandstone-polyester composite is the most dimensionally stable of all the composite materials made in this research, and comparison of this composite with the water based acrylic resin-sandstone composite indicates that the polyester composite is the preferable choice of polymer resin as matrix material for the production of composites. This conclusion was based on facts obtained from dimensional stability tests that indicate that the polyester resin is more stable dimensionally when filled with sandstone. Finally, designs were made from the various composites and this include table tops made from polyester-diorite composites, wall tiles made from polyester-sandstone composite, artifacts made from polyester-cornstalk composite, and wall tiles were also made using the water-based acrylic resin. A cost analysis was also carried out and although cornstalk was estimated as possible material for production of cost effective composites but its undesirable properties such as high moisture intake , made the sandstone a preferable choice of filler material for production of cost effective materials.

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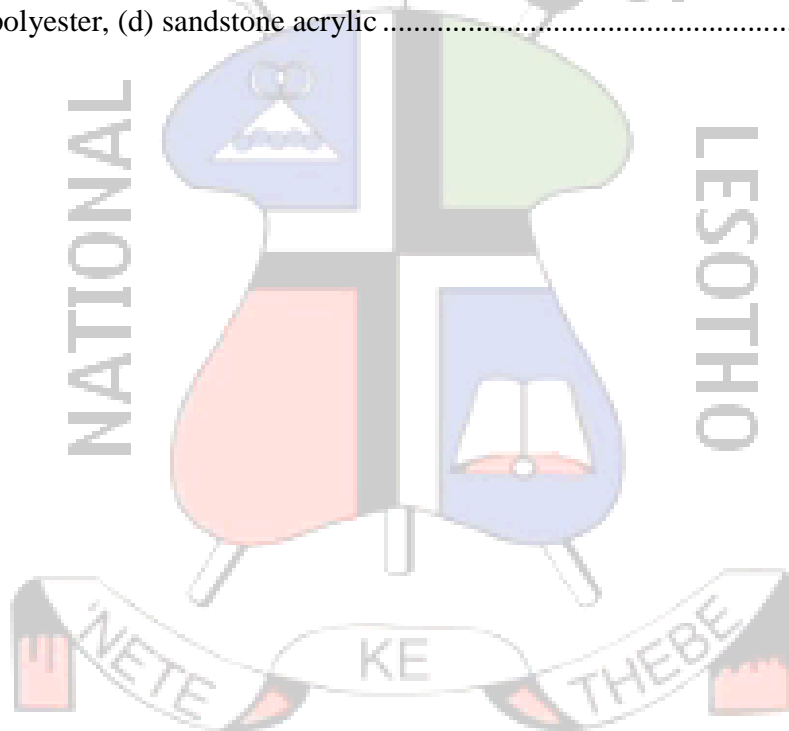
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# CHAPTER ONE: INTRODUCTION

## 1.0 Introduction

Ever since the 1970's composite materials have found profound use in many industrial sectors around the globe (Boukhoulda B.F et al, 2006), this is mainly due to researches that have focused on improving composites over the last decade. As the millennium approached, composite materials began to find applications in engineering and most importantly, in civil infrastructure. This wide spread applications of composite has thus increased the need for more pristine engineering approaches to the design of structures made of composite materials (Barbero E.J, 1999).

Today, modern technologies require combinations of properties that usually cannot be met by using other materials such as, metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for applications in the aero-space industry, under water, and in transportation industries. For instance, aircraft designers have in recent times been searching for materials that have low densities, are stiff, are strong, are abrasion and impact resistant, and are not easily corroded (Callister W.D, 2007). This is of course an odd combination of characteristics, and has called for the need for materials engineers to come up with designs that have most or all of these characteristics or properties. Often, strong materials are relatively dense, and increasing the strengths as well as stiffness usually results in decreased impact strength. Material property combinations are being extended by the continued development of composite materials. Generally, a composite is considered to be any multi-phased material that exhibits significant proportions of the properties of both constituent phases such that a better combination of properties is realized (Hull, D. and T.W. Clyne, 1996).

In designing composite materials, designers have worked on combining various kinds of materials which includes metals, ceramics, polymers, and most recently, fibres to produce high performance materials. Most composites have been designed to improve combinations of mechanical properties such as stiffness, toughness, and ambient as well as high temperature strength. Usually, composite materials are composed of two phases, of which one is termed the matrix and surrounds the other phase usually called reinforcement (Callister W.D, 2007). As mentioned composites can be made from a combination of different materials, this research

however, focuses on composite materials that use a combination of polymer matrix with milled cornstalk, sand stone, and diorite. The proceeding paragraphs introduce what these materials are.

### **1.0.1 Polymers**

For thousands of years, natural polymers have been used for various applications. Some of this includes their use in biological systems, where these polymers not only perform mechanical functions, but also contain and regulate chemical reactions (Michael F.A, and Jones D.R.H). Recently, man has begun to find ways to make his own polymer, known today as synthetic polymers. Most or all of the polymers in use today have been synthesized by man in one way or the other.

Naturally occurring polymers mentioned earlier, are those derived from plants and animals. They include, wood, rubber, wool, cotton, leather, and silk. Other natural polymers such as proteins, enzymes, starches, and cellulose are examples of polymers that are important in biological and physiological processes in plants and animals. Recent research has made possible the determination of the molecular structures of this group of materials, and the development of numerous polymers, which are synthesized from small organic molecules. Today many of our polymeric materials such as plastics, rubber, and fibre materials are all synthetic polymers (Rosen, S.L., 1993)

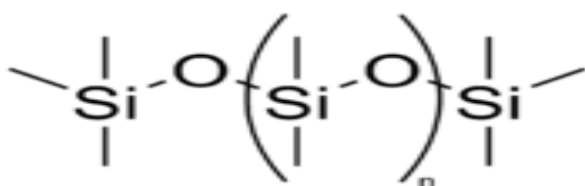
The response of a polymer to mechanical forces at elevated temperatures is related to its dominant molecular structure. In fact, one classification scheme for these materials is according to behavior with rising temperature. Thermoplastic and thermosets are the two subdivisions. Thermoplastic polymers are polymers that can be reprocessed after being formed. These kinds of polymers soften when heated and harden when cooled. Molecularly, as temperature is increased during processing, secondary bonding forces become less pronounced, such that the relative amounts of adjacent chains become facilitated only when a stress is applied. It is important to note also that, irreversible degradation of this kind of polymer is possible and occurs when a molten thermoplastic polymer is raised to extremely high temperatures. Thermoplastic polymers are known for their branched chain structure with flexible chains, which is one reason they are relatively soft polymers. Common thermoplastics include polyethylene, polystyrene, and so on.

Thermosetting polymers on the other hand are networked polymers, which become permanently hard during their formation, and would usually not soften upon heating. Thermosets have covalent cross-links between adjacent molecular chains. During heat treatments, these bonds hold the chains firmly together to resist the chain motions that would usually occur at high temperatures, this is the reason why they would not soften when heated. These polymers may also be subject to degradation, although this would usually only occur at extremely elevated temperatures. In comparison however, thermosets are no doubt harder and stronger than thermoplastics. The dimensional stability of thermosets has made them more desirable in numerous applications. Examples of common thermosets include vulcanized rubbers, epoxies, phenolics, and some polyester resins (Callister W.D, 2007).

### **1.0.2 Silicone rubber**

Silicone rubber is a rubber-like material composed of silicone which is itself a polymer containing silicon together with carbon, hydrogen, and oxygen as shown in Figure 1. silicone rubbers are widely used in industry and there are of course multiple formulations. There are three main industrial classifications of silicone rubbers: High temperature vulcanizing, sometimes called heat curable, are usually in a semi-solid gum form in the uncured state. Another type is the liquid silicone rubber, sometimes called heat curable liquid material. These are processed on specially designed injection molding and extrusion production equipment. The last type is the room temperature vulcanizing, which usually comes as a flow-able liquid and are used for sealants, mold making, encapsulation and potting. This research however, focuses entirely on the room temperature vulcanizing silicone rubber. In the room temperature vulcanizing silicone rubber, single part systems consists of polydialkyl siloxane with terminal hydroxyl groups, which are reacted with organosilicon cross-linking agents. This reaction is carried out in a moisture free environment and results in the formation of a tetra functional structure. Curing on the other hand takes place when materials are exposed to moisture. It is important to note however that atmospheric moisture is sufficient to activate the reaction, and as such thickness should be limited if only a particular side is exposed to the source of moisture. Furthermore curing is also relatively slow and relies on moisture ingress into the polymer. This type of silicone rubbers have properties such as: relatively good thermal stability. The thermal stability of silicones stems from the thermal stability of Si-O and Si-CH<sub>3</sub> bonds which are themselves thermally stable.

However, the partially ionic structure of these bonds means that the bond is highly polarized and the bonds are susceptible to attack from concentrated acids and alkalis at ambient temperatures. Also, this type of silicone rubbers is generally flexible at low temperatures due mainly to their low glass transition temperature ( $T_g$ ). However, they also tend to stiffen up at higher temperatures. Again, the siloxane backbone unit, Si-O has a bond length of 1.63 Armstrong and a bond angle of 130 degrees. This bond length and bond angle means the siloxanes can move further and change their conformation easily, making for a flexible material.



**Figure 1: repeating unit of silicone rubber**

### 1.0.3 Diorite

Diorite is a grey to dark grey intermediate intrusive igneous rock composed principally of plagioclase feldspar. It may contain small amounts of quartz, microcline and olivine (Blatt, H. and R.J. Tracy, pg 53). It can also be black or bluish grey, and frequently has a greenish cast. Diorite may also be associated with either granite or gabbro intrusions, into which they may subtly merge. Diorites result from partial melting of a mafic rock produced in volcanic arcs, and in cordilleran mountain building such as in the Andes Mountains as batholiths. Diorite is a relatively rare igneous rock which is only found in certain regions around the world such as in Leicestershire (midland quarry products). One property of the diorite which makes it so applicable is its hardness. Diorites are extremely hard rocks, this property however, allows it to be polished and worked firmly, which results in durably finished work (Blatt. H and R.J. Tracy).

### 1.0.4 Sandstone

Sand stone is a very common sedimentary rock and perhaps the best known sedimentary rock. Sandstone formation usually takes place in many environments, these environments include

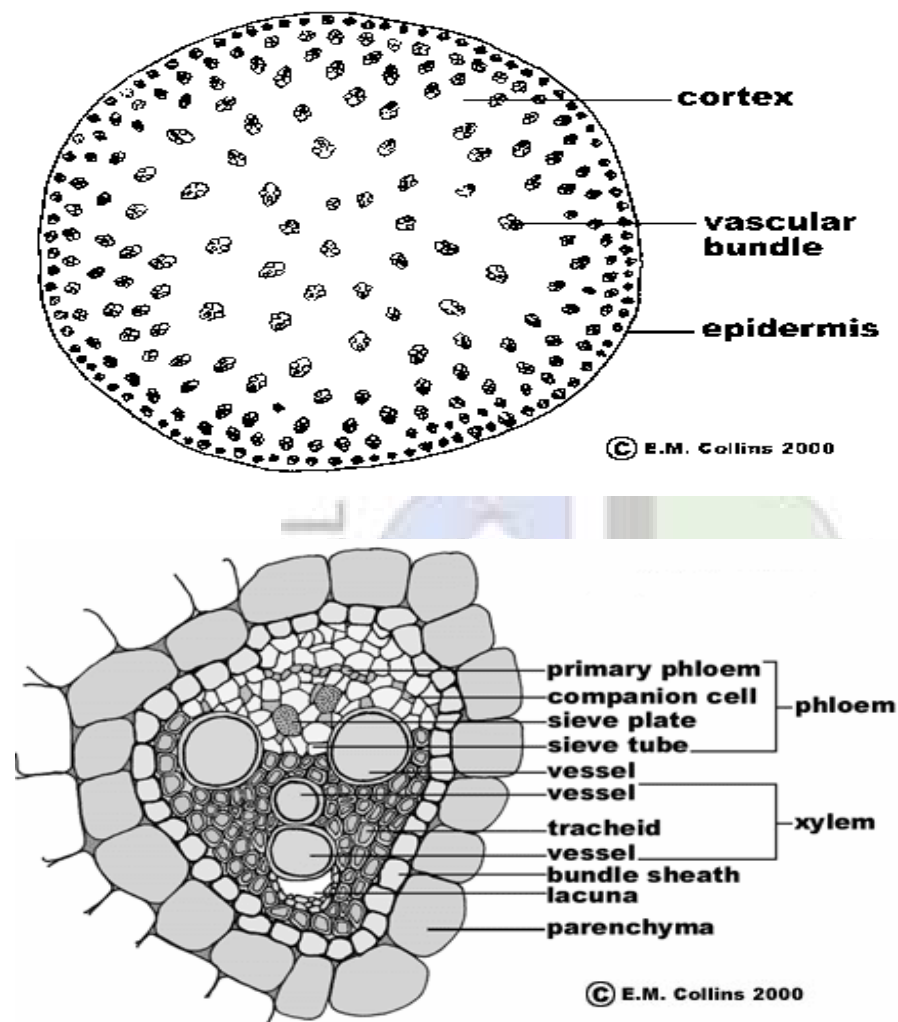
majorly those with water such as rivers, oceans, to mention but a few (Amethyst Galleries Inc, 2010). Sandstone as already mentioned, is a sedimentary rock composed mainly of sand sized minerals or rock grains. Most sand stones are composed of quartz and/or field spar which are amongst the most common minerals in the earth's crust. Sand stones have properties differing from the earlier mentioned diorite in that, they are easy to work but then are still resistant. This combination of properties has made them useful as building and pavement materials (Edensor. T, and Drew. I). sandstones are cemented by certain minerals which can influence the durability, color, porosity, and usefulness of the sandstone. Cementing agents include calcite, quartz, clays, and gypsum. Generally sandstones are very porous rocks due to the pore spaces present in their structure (Amethyst Galleries Inc, 2010).

### **1.0.5 Natural fibre**

The oxford dictionary describes natural fibre as fibre that exists freely in nature. In other words, these fibres do not need further synthesis as they are used in the forms in which they exist in nature. Natural fibers are today being recognized due to their high strength, and light weight when they are used as reinforcement composites (Mohammad. N.A.B). Natural fibres are renewable sources of fibre and are fast emerging as potential alternatives to the already known synthetic fibers such as glass fiber, this is because they are inexpensive, as well as more environmentally friendly when compared to synthetic fibres (Peijs. T). The advantages associated with the use of natural fibre have made them applicable for use as reinforcement in engineering composites (Jacob. M et al; Gassan. J and V.S.Cutowski).

In this research the natural fibre employed is the corn stalk fibre. Corn which is generally referred to scientifically as *zea mays* falls under the monocot classification of plants. Monocot stems have scattered vascular bundles near the outside edge of the stem, and these bundles are surrounded by large parenchyma in the cortex region. Monocot stems, such as those of corn, do not have a vascular cambium and do not exhibit secondary growth by the production of concentric annual rings. Their scattered vascular bundle is composed of xylem and phloem tissues, and each bundle is surrounded by a ring of cells called a bundle sheath. The structural strengths of woody monocots are due to clusters of heavily lignified tracheid and fibers

associated with the vascular bundles. Figure one, gives a pictorial description of scattered vascular bundles in the stem cross section of corn (zea mays).



**Figure 2: cross section of the stem of corn (Zea mays) showing parenchyma tissue and scattered vascular bundles.**

Ahmed., A and J.Y., Zhu, 2006, suggest that corn stalk amongst many other agricultural products, is the most promising source of fiber, although their use is limited because they contain large amounts of cellulose. The composition of corn stalk as determined by Han and Rowell, 1997, is as follows: cellulose (35-50%), lignin (5-34%), pentosan (about 20-41%). Usta et al., 1990, the morphological properties as determined by Usta et al., 1990 are: fiber length



(1.32mm), fiber width (2.34um), lumen width (24.3um), and cell wall thickness (6.8um). These properties thus indicate how the overall property of the corn stalk is affected and how their application is likely to be limited.

Mehmet et al, 2010, found in their research that prepared sample panels containing high amounts of corn stalk were found to have higher fiber aspect ratio. This panels contained soft parenchyma cells in their core structure, and attracted more water due to presence of attractive OH groups. They also observed poor dimensional stability as higher amounts of corns stalk were added.

Lignocellulosic fibres such as those of corn stalk have structure and composition which is unlike most fibres. Corn stalks which are Lignocellulosic are composed of cells that contain about 0.5-3.0mm cellulose in length, which is so small compared to those of other fibres. Further more, Lignocellulosic fibres such as those of corn stalk contain large amounts of lignin, typically about 20%. Narendra and yigi, 2005, suggest that high amounts of lignin affects the structure and properties of the fibres, this thus suggests that the structure and properties of corn stalk fibres are affected because of their high lignin content. From figure 1, it is clear that corn stalks posses large amount of lignin, this is seen clearly in the relative amount of tracheid containing lignin shown in figure 1. The lignin which is prominent in the corn stalk structure as stated earlier, affects the properties of the corn stalk as well as their subsequent applications.

Addition of cornstalk fiber decreases the hygroscopic and mechanical properties of materials that employ their use, such as in the making of composites. For instance, Mehmet et al, 2010 concluded in their research that even though physical and mechanical properties declined with increased addition of the corn stalk fiber, broad mechanical properties still aligned with standard requirements, this means that despite the limitations in properties of corn stalk, they still find very wide applications in many industries today.

#### Crystal structure of corn stalk fibers

Corn stalk amongst many fibers in use today has low crystallinity values. Narendra and yigi, 2005, noted in their research that crystallinity affects the chemical absorption of a fiber. They concluded that, low crystallinity corresponds to high amorphous regions, which are more accessible to chemicals and water. They also stated that crystallinity is related to the strength of any fibre, and that high crystallinity corresponds to highly strong fibre, this explains again why



corn stalk is not as strong as other fibres because its crystallinity is small compared to those of other fibres such as flax fibres. Again, the high amounts of single cells in corn stalk results in greater number of binding spots which then degenerates further to weak links that degrade and break very easily leading to mechanical failure.

### 1.1 Objectives

The composites industry is advancing all the time. New varieties of fillers (reinforcements) and matrix materials are being introduced, manufacturing processes are being developed, and existing processes are being upgraded to mean the recent demands of composite materials. To develop a composite material, it is momentous to choose concepts that are both technically and commercially feasible. Recently, greater emphasis is being placed on production of more viable composites which have better and improved qualities or properties. If a holistic approach is adopted in this regard, composite materials are bond to take an even more important role in the near future. In this research two thermosetting polymer resins were considered, this was because one aim was to determine how this different thermosets vary and based on this determine which is likely to have more potential in the near future. Researchers today are constantly looking to coming up with the best polymers as matrix for use in composite production, whose properties when matched with those of the intending fillers (reinforcement) give an overall excellent material of very high quality in terms of their overall properties. This research however, focuses on the following areas:

- Investigation of the moisture absorption and dimensional stability properties of composites made from thermosetting polymers and reinforced with sand stone, diorite, and natural fiber.
- To investigate appropriate applications of the various composites synthesized in view of this study.
- To determine which thermosetting polymer has the greatest potential use as matrix materials for the production of composite materials.

## **Chapter two: LITERATURE REVIEW**

### **2.0 Composite materials**

Composite materials fall under two groups, those that exist freely in nature, and those that are synthesized by man. Natural composite materials have always been used because, many natural materials have structures of two or more distinct features which evidently suit the definition of a composite. An example of such composite material is wood, which is made of a matrix of lignin, and a reinforcement of cellulose. Synthetic composite on the other hand are those made by man primarily to improve materials properties. An example of such is the popularly known concrete which is made of a cement matrix and stone reinforcements (Mohammad N.A.B). Today, many materials man uses are composite materials.

### **2.1 Definition of a composite**

The superiority in property and numerous applications of composite has made them widely known across the globe. This new trend has ensured that the impact of composites is in no small way felt by the materials industry, making the composite industry a fast growing industry world wide. Although today, there appears to be no universal definition for a composite, many definitions has in any case being coined by a few authors.

The oxford dictionary for example defined a composite has anything made of different parts or materials. It also defined it has something made by putting together distinct parts or materials (Hornby A.S, pg 230).

Yu, M. et al, defined a composite in engineering as, any group of materials that can be physically assembled to form one single mass without physically merging imperceptibly to form a uniform material in every respect. This means the resulting material would still posses components or properties identifiable as the constituents of the different materials.

Also united composite described a composite as a combination of two or more materials (reinforcing elements, fillers, and composite matrix binder) differing in form or composition on a macro scale. The composite is such that the components or materials do not loose character and

identity by mixing together, although their combination improves the composite material's properties (Frank .K.Ko, 2002).

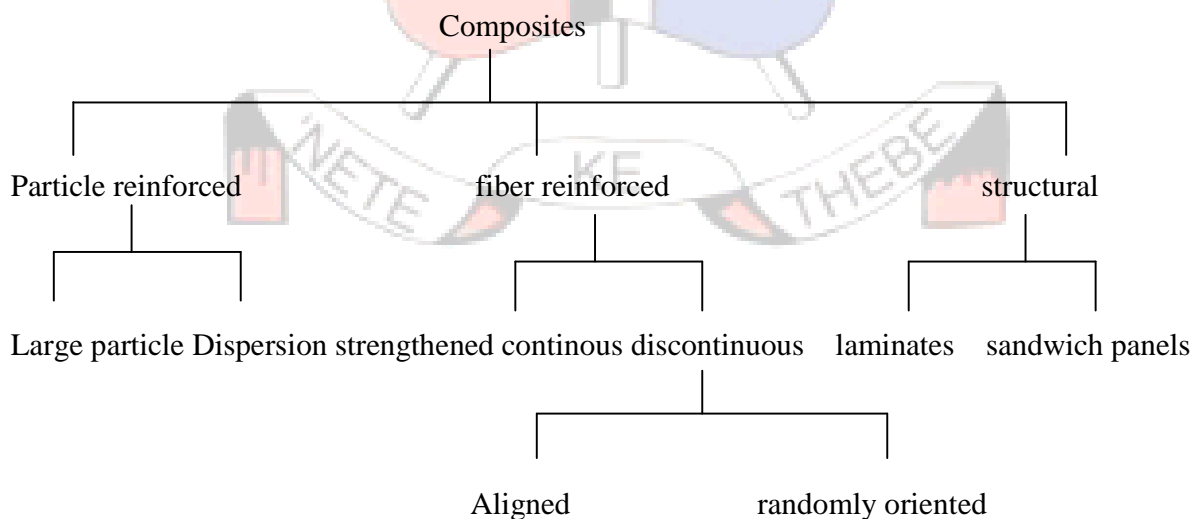
Another author describes a modern day composite as one that is multi-phased, in which the constituent phase must be chemically different and separated by a distinct interface (Peter, S.T, 1993).

David.H, and N. Shiraishi, described a composite as either a naturally occurring or synthesized material, made of two or more separate parts, which have unique physical and chemical properties, which remain separate and distinct within the composite structure.

## 2.2 Classification of composite materials

Based on the different definitions of a composite material, composites were produced by combinations of different materials which were either, metallic, organic, or inorganic. Each of the materials were expected to have appropriate characteristics, and function appropriately to improve the composite's property (Mohammad N.A.B). Based on this a number of classifications exist. One simple scheme for the classification of composite is as shown in figure 1, and it consists of three main divisions, two of which are the main focus of this research (particle reinforced and fiber reinforced) and the last one being the structural composites.

Figure 3 shows the various sub divisions of the various categories of composites.



**Figure 3: classification scheme for the various types of composites (Callister W.D, 2007)**

### **2.2.1 Structural composites**

A structural composite is normally composed of both homogenous and composite materials. The properties of this kind of composite are dependent on both the properties of the constituent materials, and on the geometrical design of the various structural elements. Structural composites are divided into two categories as indicated in figure 1, laminates and sandwiched panels.

### **2.2.2 Particle reinforced composites**

Figure one shows that a particle reinforced composite can be further subdivided into large particle or dispersion strengthened composite. The term large is used to indicate that particle-matrix interactions cannot be treated on the atomic or molecular level, rather continuum mechanics is used. The level of improvement of composite property is dependent on the matrix and the particle interface bonding. For dispersion strengthened composites, the particles are usually much smaller than the large particle composite, and strengthening of the particle and matrix interface bonding is usually on a molecular level. Many polymeric materials are known to employ the use of large particles as fillers in making of composites. These fillers are used mainly to improve the mechanical properties of the composites as well as replace the more costly polymeric materials, and examples include sand stone and granite, which is one focus of this research. It is important that particles be distributed evenly to ensure effective reinforcement and improvement in properties (Callister W.D, 2007).

### **2.2.3 Fiber reinforced composites**

These types of composites have become very important in the composites industry, chiefly because of their ever improving properties being discovered through researches. The specific goals in these designs are usually that of achieving high strength in finished composites as well as stiffness on a weight basis. Today many fiber reinforced composites are being produced that make use of low density fiber and matrix materials, which in many regards have improved properties (Callister W.D, 2007). Fiber reinforced composites like all other types as indicated in figure 1 are also divided into two categories. These are those that have short fibers, and those that have long fibers usually referred to as continuous fiber reinforced materials (waterman and J.Pamela, 2007).

### **2.3 Composite composition**

Composites are made up of separate distinct parts known as constituent materials. These constituent materials are in two categories: the matrix and the reinforcement. The matrix serves as a support to the reinforcement, and helps usually to maintain the relative positions of the reinforcement. The reinforcement on the other hand, is usually a high strength material used to improve the overall property of the composite material. A combination of both phases however, produces properties which cannot be gotten from individual properties of the different materials (David.H, and N. Shiraishi).

### **2.4 Composite matrix**

Most commercially produced composites use a polymer matrix material often called a resin solution. There are several categories of polymers, the most common one include, polyester, vinyl ester, epoxy, polyamide, to mention but a few (Matzkanin et al). Thermosetting resins have become increasingly important in industry in recent times, and are now being used as matrix materials in polymer composites, such as fiber reinforced composites (Mohammad N.A.B). In this research focus was on acrylic resins and polyester resin.

#### **2.4.1 Acrylics**

This kind of resins have outstanding light transmission and resistance to weathering, and their applications include their use as lenses, as transparent air craft enclosures, and as drafting equipment (Harper, C.A, 1975). Acrylic is a useful, clear plastic that resembles glass, but has properties that make it superior to glass in many ways. Common brands of high-grade acrylic include Polycast, Lucite and Plexiglass.

#### **2.4.2 Polyester resins**

These kinds of resins tend to have a yellowish tint. They also have excellent electrical properties and low cost, and can be formulated for room or high temperature use. They find applications in the making of helmets, boats, auto body components, chairs, surf boards, to mention but a few. One major problem associated with this resins is that they tend to degrade over time (Callister W.D, 2007). Polyester resins usually would require an hardener for it to cure, one of which is MEKP. MEKP is composed of an organic peroxide (a catalyst), and mixing this with the

polyester resin results in a chemical reaction which causes building up of heat and subsequent curing or hardening of the resin.

## **2.5 Natural fiber composites**

Natural fiber composites are renewable sources for the production of high performance composites. Joseph .K et al, Writes that researchers across the world are looking to producing composites from more renewable sources. He writes that this is because of the ecological benefits derived from using renewable materials. One of such benefits is that, they save valuable resources, are more environmentally friendly as opposed to those that were initially produced, and do not cause health problems. Today natural fibers are being used as fillers for use in automobile parts. Natural fibers such as sisal, jute, coir, oil palm fiber, to mention but a few have all been found to be good reinforcements in both thermoset and thermoplastic matrices (Varma I.K et al, and V.G Geethamma et al). Bledzki A.K and J.Gassan (1999) write that, the last decade has seen natural fiber composite being applicable in many industries, due mainly to the desirable properties natural fibers possess.

Today natural fiber composite is used as construction material, such as decking and railing products (Morton .J et al and C.Clemons, 2002). Although natural fiber has found wide application, an undesirable property, hygroscopicity has in one way or the other limited their function. Moisture absorption of composites containing natural fiber has severe long term effects on natural fiber composites. This is because an increase in moisture absorption decreases the mechanical properties of such composites as well as decreasing its dimensional stability (Stark .N and Marcovich N.E et al). Although efforts have been made by researchers to address this issue, such as the use of coupling agents and compatibilizers, moisture absorption still remains a major concern of natural fiber composites (D.N Saheb and J.P. Jog, Lu J.Z et al, and H.Z. Rozman).

In engineering practice, moisture absorption test is generally used for quality control purposes and to measure the quality of the composite material with time (Lemana .Z et al, 2008). Moisture absorption increases with increasing fiber loading, and research done by Thomas et al confirms this. They investigated the relationship between the moisture absorption of pineapple leaf fiber

reinforced low density polyethylene composites, and found that moisture absorption increases linearly with increasing fiber loading. Also Stark .N in her work on wood floor-polypropylene composites concluded that although moisture absorption is smaller for low fiber loading, due to encapsulation of the wood flour by the polypropylene matrix, it is however greater for increased fiber loading, because matrix encapsulation becomes minimal with increasing fiber content.

Effects of exposure to moisture cannot be over emphasized, as Rui-Hua et al found in their study that pores, micro cracks, delamination, and complete structure relaxation, are the defects that occur during long term exposures. They also found that the strength of this composites decrease with time when exposed to hygro-environments.

Diffusion theory is one theory that explains the mechanism of moisture absorption and provides means for quantifying the mass transfer. Momentously natural fibers and polymers exhibit different properties in terms of moisture absorption, as a result the distribution of the fibre within the polymer matrix goes a long way in indicating how moisture would be absorbed within the composite material (Berkowitz .B and R.P. Ewing).

It is important to note that most polymeric matrices are relatively moisture resistant. W. Wang et al found in their research on the study of moisture absorption in natural fiber plastic composites, that the polymer matrix prevented moisture absorption in the composite only at low fiber loading, but as fiber loading increased, the moisture absorption rate also increased. Precautions are thus needed to prevent moisture absorption when high fiber loading is applied.

Furthermore, many other mechanical properties of composites are dependent on the fiber loading. L.A.Pothan et al (2003) in their work on dynamic mechanical analysis of banana fiber reinforced polyester composites found that, improvement in composite properties is possible at high fiber content. They also report that, at the maximum fiber loading modulus peaks (from plots) get broadened, emphasizing the improved fiber-matrix adhesion at high fiber content. Thus banana fibre reinforced polyester composites are greatly dependent on the volume fraction of the fiber. N.M white and M.P Ansell (1983) also found that as fiber volume fraction increased from zero, initial stiffness and strength decreased, but properties steadily improved maximally in strength and in young's modulus. They also found that carefully aligned fibers possessed greater strength than those aligned randomly, and that reduced composite density with increasing fiber

content had a beneficial effect on the composite's specific stiffness. Also, flexural results found for the composite was much greater than that of the pure resin, indicating improvements of the composite properties. They thus concluded that, useful composite materials can be manufactured from straw fiber and polyester resin, since results showed that, the straw fibers considerably improved the stiffness, strength, and toughness of the resin, and ultimately the composite material.

Again, natural fibers added to polymers as fillers reduce the product cost of composites by replacing the more expensive polymer with the cheap and readily available natural fiber. A further advantage is however gained if these fibers improve the overall properties of the composite material (White N.M and M.P. Ansell).

It is important to note here that natural fibers are much cheaper than man made fibers, hence why they are quickly becoming substitutes for the man made fibers. In fact for instance, corn stalk which is a natural fiber comes at almost no cost at all in their use as fillers in making fiber composites. Again, the low specific gravity of natural fibres (about  $1.25-1.50\text{g/cm}^3$ ) when compared to their synthetic fiber counterparts (about  $2.6\text{g/cm}^3$ ), has made them applicable in producing high strength to weight ratio in composite materials. The use of natural fiber has also provided a healthier working condition than the synthetic fibers. For example glass fiber which is a synthetic fiber causes skin irritation and respiratory diseases, arising from glass fiber dust (Mohammad N.A.B, 2007).

Indeed degradation in natural fiber composite properties over a long period of time subject to environmental conditions is a direct consequence of the development of specific damages such as resin cracking, fiber fracture, and destroyed bond between the fiber-resin interface (Scida.D et al).

## **2.6 Diorite plastic composite**

Properties of this type of composite are strongly dependent on those of the diorite reinforcement. Although the polymer resin contributes in no small way to the overall composite properties, improvement in properties is still attributed to the use of diorites as reinforcements. Diorite is an extremely hard rock (Blatt. H, and R.J. Tracy), as such their use as reinforcements in composites would serve to improve the hardness or toughness property of such composites. Indeed, hardness



is one desirable property of composites, since their application in many environments is strongly dependent on how well they are able to withstand harsh environmental conditions. Diorites are also desired because they are only slightly porous. I.H.Gul and A.Maqsood (2006) in their work on properties of diorite, found the porosity of diorites to be about 0.162 to 0.490 weight percent. The low porosity of diorites is one reason why they would serve as good reinforcements even in hygro environments.

### **2.7 Sand stone plastic composite**

Not many sand stone plastic composites are known, but researches done on sandstone have indicated based on their properties that, they could also be potential fillers for composite synthesis in the near future. David .C et al (1993) suggested that, these properties are usually controlled by the porous network characteristics of the stones. Also permeability, capillarity, and electrical conductivity are some properties that are affected by the sand stone porosity. Porosity is one major concern to the use of sand stone as reinforcements. Generally sand stones are very porous rocks (Amethyst Galleries Inc, 2010), which is one draw back that would ultimately be encountered in their outdoor applications. The presence of pores in sand stones allows them to absorb moisture from the environment, but in their use as fillers this is reduced by the polymer matrix, known to be highly moisture and solvent resistant. In any case, the properties of the composite are a function of the respective properties of the matrix and filler, which is combined to give the composite a unique and improved property.

Importantly, some sand stones have porous network characteristics that allow them to absorb only negligible amounts of moisture. Another property of sand stone is that they are resistant to corrosion and weathering (Edensor.T and I. Drew), making them good reinforcements in the making of high performance composites.

### **2.8 General properties of composites**

Generally composites do not have the same physical properties in all directions, but have properties which are different depending on the direction of applied force. Evidently the stiffness or toughness of a composite is dependent on the relative position of the applied force. Composite stiffness however, is also dependent on the composite design, such as the orientation of

reinforcements within polymeric matrices, the nature of the different materials, and the adhesion of the composite interface (waterman and J.Pamela, 2007).

Composite materials, based on a polymer matrix and reinforced by fibers or particles, have a high potential to develop materials with extremely favorable properties. The true understanding of the mechanical properties of a wide combination of materials is today becoming more prominent than in the last few decades, although much work is still required to improve these properties. Recent researches are however focusing on, understanding of interactions between phases, understanding the development of stresses in composites, and understanding the behavior of the individual phases themselves (E. Nes, 1997).

Moisture absorption of materials is one property of the material that can never be underemphasized or overlooked, this is because the moisture absorption property of materials goes a long way to define exactly how the material functions and which ultimately dictates how that material would be used. Polymeric materials are permeable to moisture absorption in one way or the other and would thus absorb moisture when placed in humid environments. From this it is clear that moisture absorption composites are dependent largely on the nature of the polymeric matrix and the filler (reinforcement) as is the case in this present research.

## **2.9 Applications of composites**

The past two decades, has shown the gradual development of advanced materials, and today the use of composite materials in various structures is becoming increasingly resourceful, with major impacts being felt in the aerospace and automobile industries, where design considerations are focused mainly on better and improved properties of materials. The use of composites in the aerospace industry has improved fuel efficiency commercially (Mohammad N.A.B, 2007).

Composite materials have gained recognition in the manufacturing of high performance products that need to be light weight, yet strong enough to support heavy components such as aircraft components, boat and scull hulls, bicycle frames, and racing car bodies (CRG Industries, 2009).

Other uses include fishing rods, storage tanks, and base ball bats. The new Boeing 787 structure including the wings and fuselage is composed largely of composites. Polymeric composites were mainly developed for aerospace applications where the reduction of the weight was the leading objective. Research in this regard thus focused on optimization of the structural performances of these materials (Giordano, M, et al, year).

Composite materials are also being applied in orthopedic surgery (Mathews, F.L. and R.D, Rawlings, 1999). Biomedicine is another field where composites are being applied. Materials able to imitate the complex properties of the natural tissues, which are composites in nature, have been developed, although this is not yet widely known today (Goldberg, T, 2000). This observation is probably due to lack of awareness and delayed technological transfer between these areas.

In 2007, an all composite military high mobility multi-purpose wheeled vehicle was introduced by TPI composites and Armor Holdings Inc, the first all composite military vehicle. The use of composites helped to reduce the weight of the vehicle as well as increase higher payloads (Vantage associates Inc, 2003). Other visible applications of composites can be seen in pavements along road ways in the form of aggregate reinforced Portland cement or asphalt concrete. Other personal composites include: shower stalls, bathtubs, sinks, artifacts, and countertops, to mention but a few (Mathews, F.L. and R.D, Rawlings, 1999).

### **2.10 Why composites?**

Composites offer quite long term benefits. A comparism of composites with many material indicate today that, the benefits that can be derived from the use of composite far out weighs those derived from the use of other known types of materials.

One major benefit derived from the use of composite materials is that of weight savings. Many composites produced today are lighter than most other known materials. Lemana Z. et al (2008), reports that, composites offer good long term behaviors in aggressive environments and high strength stiffness to weight ratios. This means that the fact that many composites produced today are light weighted does not mean compromise in their properties. Composites are amazingly light weight, especially in comparism to materials like concrete, metal, and steel. A composite structure would often weigh about a quarter of a steel structure with the same length. The means

for instance that, a car made from composites would weigh about a quarter that of a car made from steel. This ultimately leads to fuel and energy savings.

One leading advantage of composite materials is the ability to combine physical properties of the different components to obtain new structural or functional properties. Composite materials have for a long time been known to man, for instance the structural properties of straw were combined with a clay matrix to produce the early construction materials. Today the development of polymeric materials and high modulus reinforcements, has introduced a new generation of composites (Giordano, M, et al, year)

More importantly, composite materials can be constructed to exhibit the best qualities from their constituents that neither constituent possesses distinctly (Jones R.M, 1975). Better quality materials are only arrived at by taking advantage of the good qualities of each material that makes up the composite structure and coming up with one that has exceptionally better qualities and properties to serve purposes, each separate material could not.

Concern for the environment is an issue of increasing importance in today's society. To gain a concise understanding of environmental impacts attributed to a particular product or material, it is necessary to survey and assess its entire life cycle, from the production of its raw materials, till it is no longer in use. The advantage of composite materials is that, environmental impacts from both their manufacture and use is normally low, which from an environmental point of view, makes them very good substitutes to replace other materials being used today. Natural fiber composites for instance are produced from the readily available and renewable fiber. Which means their production saves valuable resources (since they are obtained from renewable sources), is environmentally sound, and does not cause health problems (Sreekala, M.S, et al, 1997).

## **CHAPTER 3: METHODOLOGY**

### **3.1 Materials**

Preparation of the composite material samples involved quite a lot and use of several materials. The different materials used include: sandstone, corn stalk, diorite, polyester matrix and water-based acrylic resin matrix.

#### **3.1.1 Sandstone**

The sandstone was obtained from the Roma Mountains, a walking distance from the National University of Lesotho, Lesotho, southern Africa. Care was taken in selection of sand stones with similar physical properties, properties such as physical texture as well as color were the main criteria used in selection of sand stones. This was necessary because properties of sandstones used as reinforcements in composites could vary depending on the physical property of the sand stone in use. After careful selection, the sandstones were transported to the chemical technology research laboratory of the University for Careful Preliminary Operations.

#### **3.1.2 Diorite**

Another material, the diorite was obtained from the Lesotho funeral services. The diorites were prior to laboratory analysis used as grave site building materials, of which the waste was disposed off. This disposed off waste formed the bulk of diorite materials collected. An agreement reached between the department of chemical technology, and the Lesotho funeral services ensured that there was adequate supply of the diorite material for use in composite synthesis.

#### **3.1.3 Corn stalk**

The corn stalk was supplied by local farmers who harvested the corn stalk on agreement with the department. The corn stalk used was harvested in bulk, which was thereafter delivered to the department of chemical technology for further analysis. Again care was taken in the harvesting of the stalks, to ensure that those with desired corn stalk fibre were harvested

### **3.1.4 Mould**

A silicone rubber mould was used for the casting of all composite materials, this was made possible owing to the nature of the silicone mould such as its flexibility that allows for easy extrusion of cast moulds. Generally there are three classifications of silicone rubber; high temperature vulcanizing sometimes called heat curable, liquid silicone rubbers sometimes called heat curable liquid materials, and room temperature vulcanizing. The room temperature vulcanizing type of silicone rubber usually comes as a flow-able liquid and is used for sealants, mould making and potting. The room temperature vulcanizing type of silicone rubber was however chosen for purposes of this research majorly because it cures at room temperature, and it has high flexibility that allows for easy removal of cast materials. The making of the silicone rubber mould in this research followed appropriate mixing of silicone rubber with silicone catalyst in the ratio of a hundred parts to ten parts respectively, this was then allowed to set at room temperature. The silicone rubber used was supplied by A.M.T. Composites, Gauteng, South Africa.

### **3.1.5 Matrix (Resin)**

The matrix materials used, polyester resins (UPE 1685LV) and water-based acrylic resin matrixes were supplied by Cray Valley Resins, South Africa and A.M.T. Composites, Gauteng, South Africa respectively. The two resins were selected mainly to compare the differences between both resins and determine based on analysis which would be more applicable in commercial production of composites. Tables 1 and 2 show vividly properties of resins used. Silicone rubber was supplied as well by A.M.T composites used for preparation of moulds for casting of required composite materials.

Description of UPE 1685LV: this is a pre-accelerated, unwaxed, non-thixotropic, rigid, medium-low reactivity DCPD- orthophthalic unsaturated polyester resin. It has superior filler wetting properties and is capable of high filler loadings, producing polymer concrete with good mechanical performance of the matrix.

Material one is a two-part material consisting of a mineral crystal base and water- based acrylic resin. These cross-link to form high strength reacted crystals within an acrylic envelope. The

products designed using the water-based acrylic resin has been proposed to have the characteristics which were provided by the suppliers as:

- Low toxicity
- Low exotherm
- Excellent surface finishes
- Good physical and mechanical properties
- Resistance to water and ultraviolet
- Excellent characteristic under freeze
- Improved working environment

The polyester resin also has characteristics such as:

- Low exotherm, which means it is suitable for bulk casting
- Pre-accelerated, which means it requires only addition of catalyst
- DCPD based, which means it has low styrene emission, superior filler and pigment wet-out, and high filler loading.

In this research however, both material one and UPE 1685LV will be referred to as water-based acrylic resin and polyester resin respectively. Table 1 and 3 show the properties of the different resins used. Properties of a tested 3mm unfilled material provided by the suppliers of the resin is shown in table 2

**Table 1: Liquid Properties of Polyester resin**

Property	Specification
Viscosity @ 25°C (Brook field cps)	140-160
Gel time @ 25°C (1% m/m Luperox K1, minutes)	18-22
Cure time (minutes)	39-43
Peak exotherm (°C)	110-120
Specific gravity (g/cm <sup>3</sup> )	1.10-1.12
Non-volatile content (%)	60-64
Acid value (mgKOH/g)	35-40
Liquid appearance	Greenish brown
Stability in the dark @ 25°C (months)	6

**Table 2: properties of a 3mm unfilled casting of a polyester matrix, post cured for 3 hours @ 80oC**

Property	Specification
Deflection temperature under load (264 psi, °C)	70
Tensile strength (MPa)	70
Tensile modulus (MPa)	3900
Flexural strength (MPa)	95
Flexural modulus (MPa)	4000
Volumetric shrinkage (%)	7.0
Elongation at break (%)	1.8
Impact strength (KS/m <sup>2</sup> )	7.8

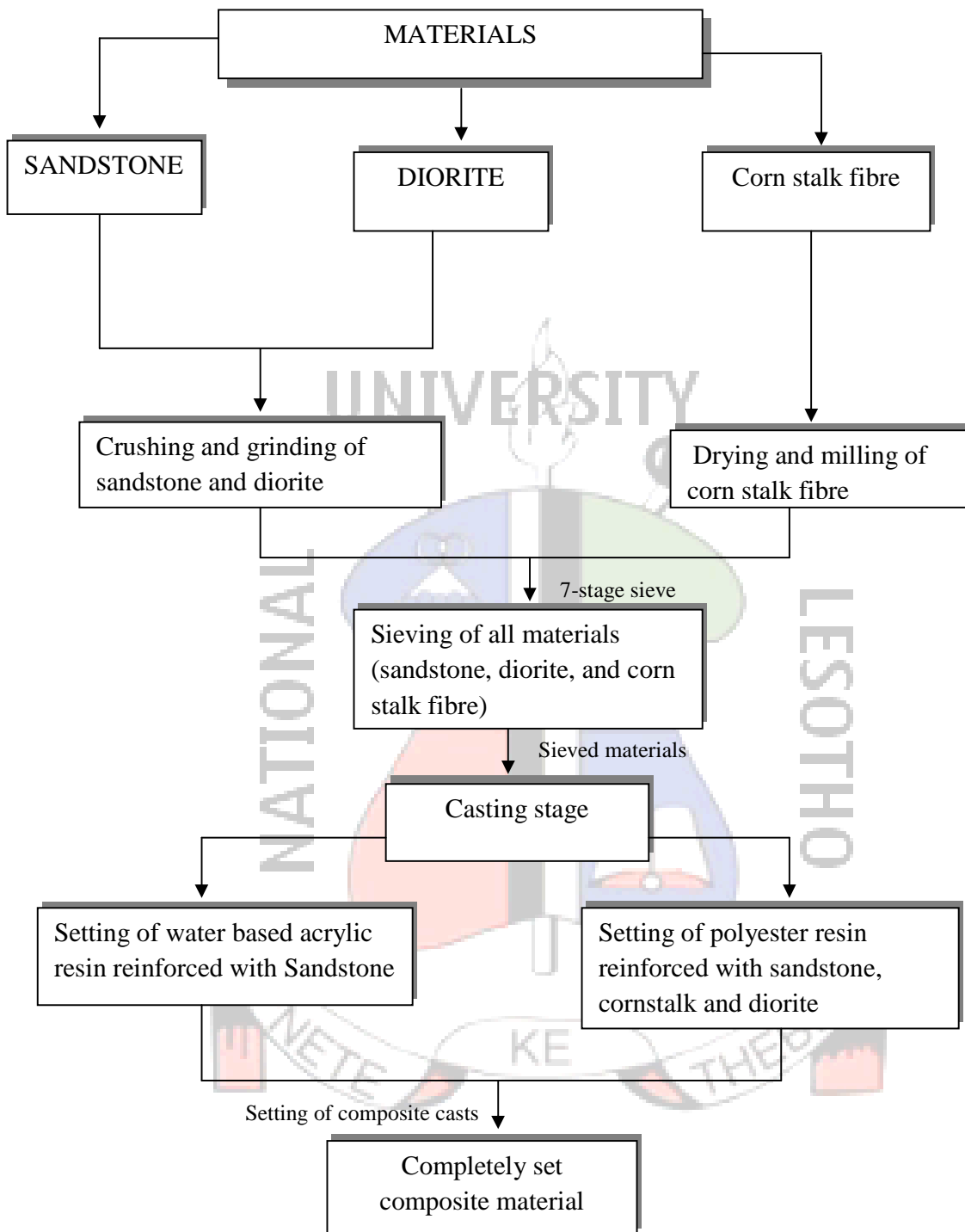


**Table 3: properties of water-based acrylic resin**

Technical Data	
Property	Specification
Density (wet)	1.75 Kg/m <sup>3</sup>
Density (dry)	1.66 Kg/m <sup>3</sup>
Pot life	17 minutes
Final set	1 hour
Mechanical Properties	
Property	Specification
Compressive strength	30 MPa
LOP	20 MPa
MOR	60 MPa
Shore D	85

### **3.2 Composite Fabrication and Material Fabrication**

Firstly all materials (sandstone, diorite, and corn stalk) had to be prepared for use as composite materials. This preparation included crushing, grinding, and sieving. Crushing and grinding of the sand stone and granite was done manually. Crushing and grinding of the sandstone and diorite samples was done with the aid of a sledge hammer, this was done to reduce the particle size of the sandstone and diorite samples to aid further processing. Sieving of all materials was done with the aid of a 7 stage filter, although the corn stalk sample had to be grinded using Russell Hobb's grinder before the filtration was done. Silicone rubber moulds were also prepare for use as cast moulds prior to composite fabrication. Composite fabrication was only made possible using the silicone rubber mould for casting of the composite mix. The silicone rubber mould had dimensions of 3.7mm×8.7mm×1.2mm. Figure 2 shows vividly the complete preparation steps followed, from initial stage to the final stage of the finished composite material.



**Figure 4: flow chart showing stepwise preparation of composite**

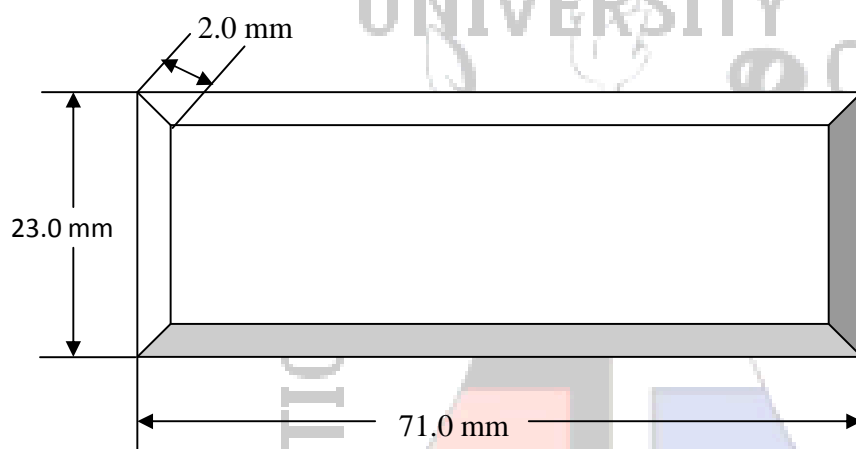
### 3.3 Material testing

#### 3.3.1 Moisture absorption

##### 3.3.1.0 Conditioning of materials

For conditioning of the materials, five samples each of the already produced composite materials were weighed. This was done by selecting five samples of the polyester resin composite as well as the acrylic resin composite for use in the moisture absorption test of the materials.

This is as shown in the figure 2 below:



**Figure 5: diagram showing dimensions of the materials**

The materials were then placed in an oven at about 70°C for twenty four hours, after which the initial weight was measured to the nearest 0.001g.

##### 3.3.1.1 Moisture absorption test procedure

The long term immersion procedure based on the ASTM D 570-98 standard was used in the moisture absorption test.

- Twenty-four hour immersion; the already conditioned samples of each kind of material was placed in a container filled with distilled water. Care was taken to ensure that all material samples were completely immersed in the distilled water. At the end of the

twenty-four hour duration each of the samples of the different kinds of materials, were removed from the water, wiped dry, and immediately weighed to the nearest 0.001g.

- Long-term immersion; in determining the total amount of water absorbed when substantially saturated, the conditioned samples of the different kinds of materials were tested as previously described, except that at the end of a one-week period, the samples were removed from the water, wiped dry, weighed to the nearest 0.001g, and then placed back into the distilled water.

This procedure was then repeated for an interval of two weeks for a total period of thirteen weeks and two days, until an observable saturation point was reached. The saturation point was observed from the results obtained after each two-week interval, which showed from the measured masses, a point where the materials could no longer absorb water.

### 3.3.1.2 Calculation

The moisture absorption was reported as percentage change in weight of the materials during immersion, and was calculated to the nearest 0.01% as in equation 1.

$$\text{Moisture content (\%)} = \frac{\text{weight moist} - \text{weight oven-dry}}{\text{weight oven-dry}} * 100 \dots\dots\dots (1)$$

### 3.3.2 Dimensional stability

The dimensional stability was carried out to determine the extent of change in dimensions of the composite materials with in-take of water. This was carried out by measuring the dimensions of the conditioned composite samples using a vernier calliper to measure the length, width as well as thickness of all the materials. The dimensions were then recorded successively with each moisture absorption reading taken. This was because one of the research aims was to determine how the extent or rate of absorption of the different materials affects their stabilities with regard to the material's dimensions. The dimensional stability was reported in terms of changes in length of the different composite samples and was calculated using equation 2.

$$\% \text{ Increase in length} = (\text{original length} - \text{new length})/(\text{original length}) * 100 \dots\dots\dots (2)$$

## **CHAPTER FOUR: RESULTS AND DISCUSSION**

### **4.0 Properties of composites**

#### **4.0.1 Moisture absorption**

In this research, the moisture absorption property of the different composite material was determined by placing the composites in water baths for a period of thirteen weeks and two days and observing the change in weights of the composites, measured in-between two week intervals.

From Figure 6, the moisture absorption decreases with increased addition of the diorite filler (0-70%) to the polyester resin. However, an exception was observed in the case of 80% diorite filler added. One possible explanation for this was in the preparation of this particular composite filled with 80% diorite. In the preparation, most of the particles were exposed and were not be completely covered by the polyester matrix, as such penetration of moisture into the composite structure was made easier, owing majorly to the exposed particles. The fact that most of the particles at 80% loading were not completely covered suggests that moisture absorption would be evidently higher in that composite and this was accurately confirmed as indicated in Figure 6. Again, the decrease in the moisture absorption with increasing filler content could be due to the chemical nature of the constituents of the diorite filler, even though adequate information on their nature was not available at the time of this report, to verify this assumption. The general moisture absorption trend here could be due to strong inter-molecular filler- matrix bonding that decreased the rate of moisture absorption with increasing filler (diorite) added. Thus the higher the amount of filler added the stronger the filler matrix bond and the smaller the rate of moisture absorption of the composite material. Another explanation for the observed decrease of moisture absorption with increasing filler content could be due to the fact that particles of the diorite are encapsulated at higher filler content hence inhibiting the free movement of moisture into the composite structure.

In Figure 7, moisture absorption increases with increasing amount of cornstalk fibre filler added. This is as expected and has been confirmed by many other authors (Thamae.T, et al, 2010). The enhanced moisture uptake in cornstalk fibre reinforced polymer composites can be attributed to the hydrophilic nature of the fibre due to the presence of hydroxyl groups which attract water molecules and bind with them through hydrogen bonding. This means that at higher fibre

content, there are more hydroxyl sites to attract water molecules which invariably lead to increases in moisture absorption. Again cellulose containing fibres increase the interfacial area of the fibre matrix and allow water to be absorbed along the fibre matrix interfaces. This is also confirmed by the research done by H. Alamin, et al, 2009. This means that moisture absorption is higher at higher fibre loading because of increased cellulose content.

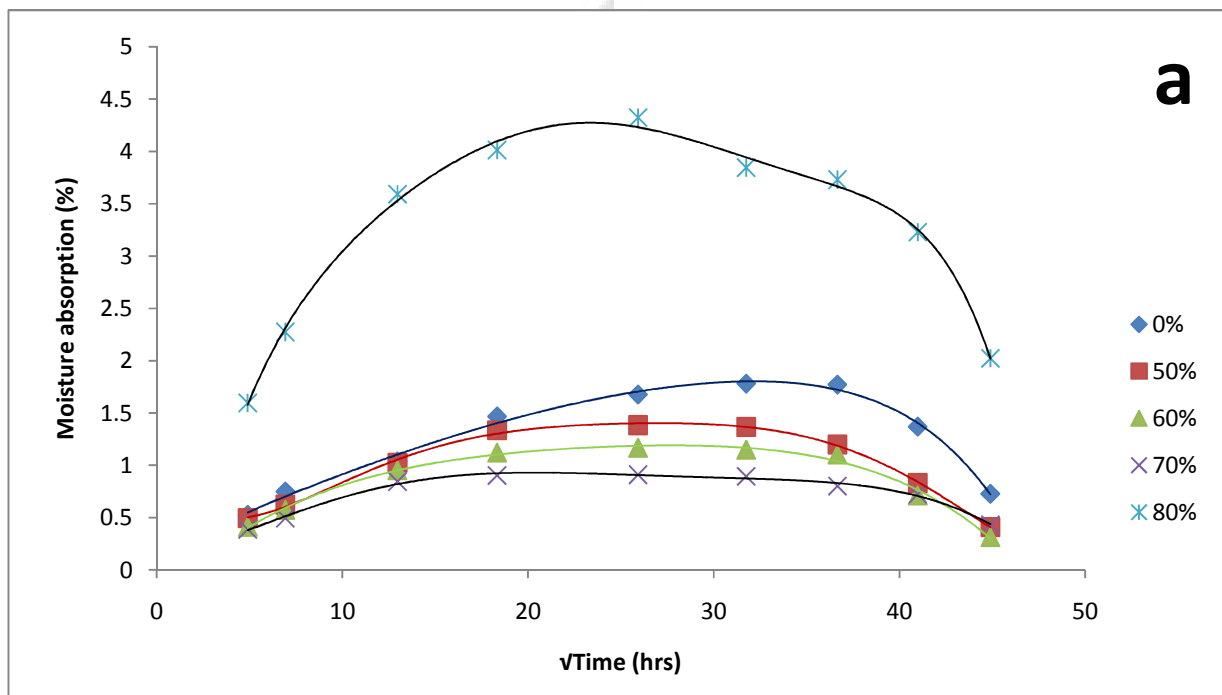


Figure 6: moisture absorption property of diorite-polyester composite

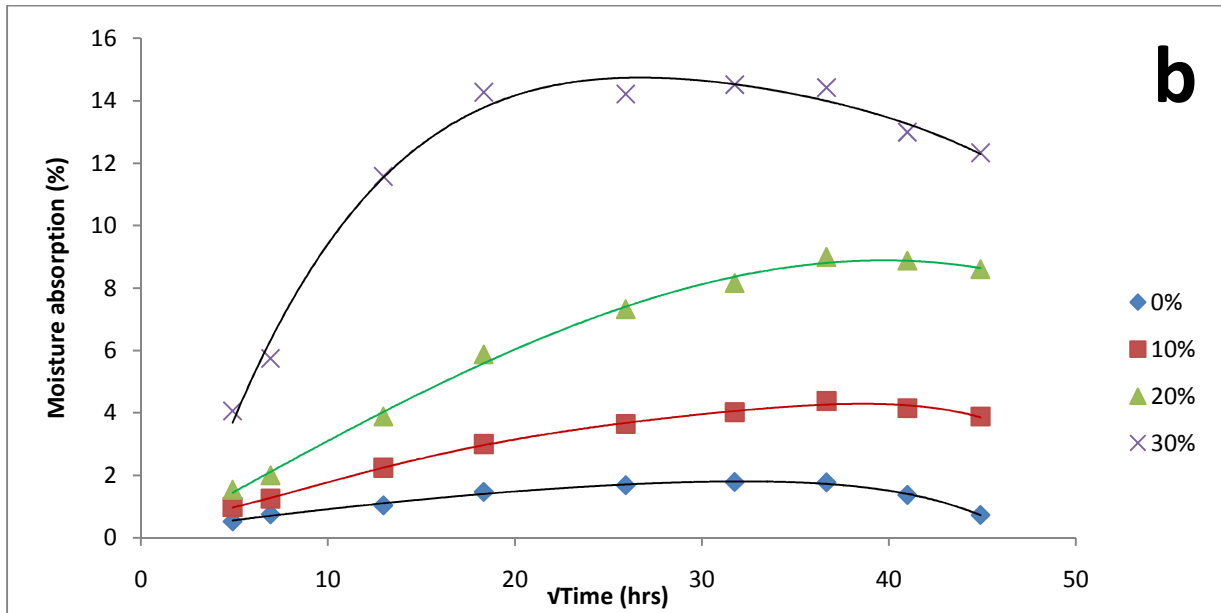


Figure 7: moisture absorption property of cornstalk fibre-polyester composite

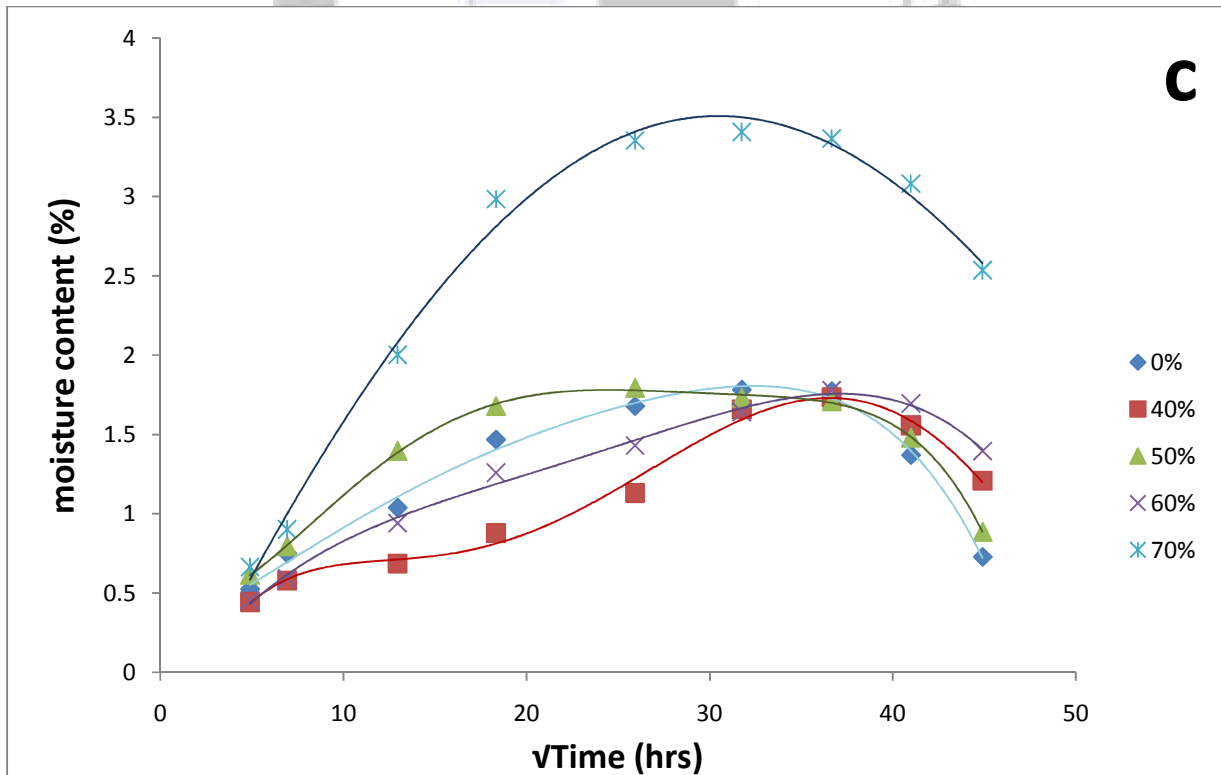
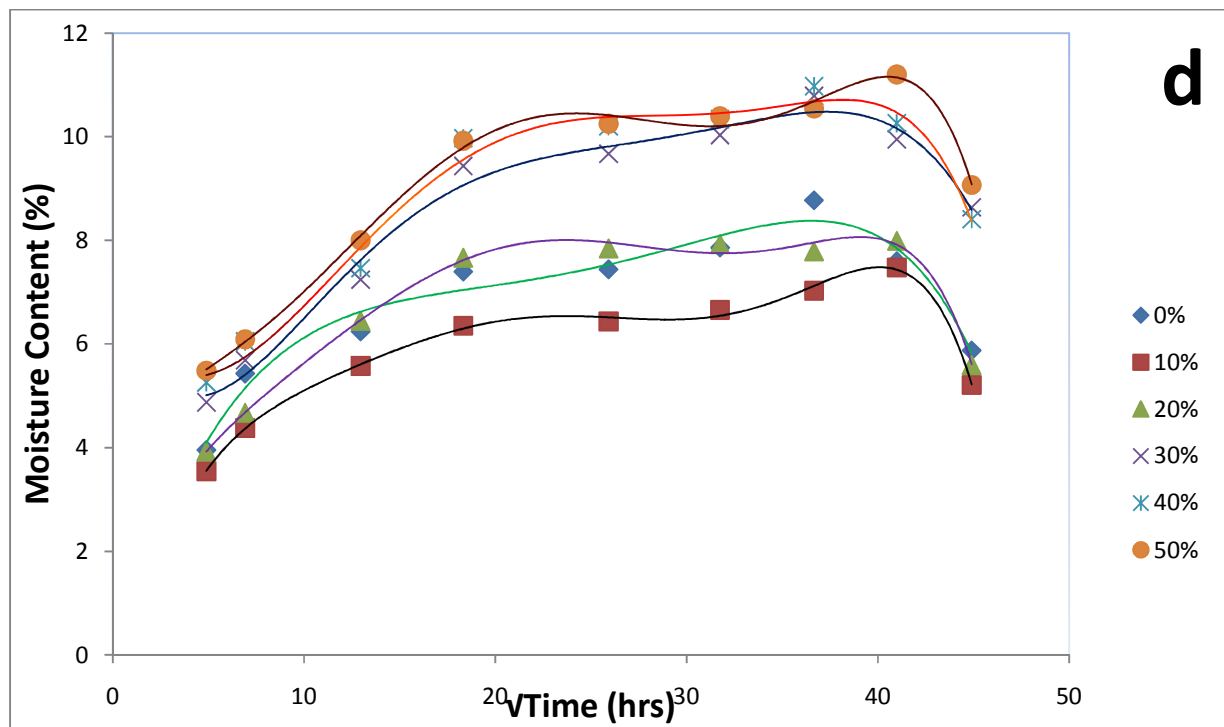


Figure 8: moisture absorption property of sandstone-polyester composite



**Figure 9: moisture absorption property of sandstone-acrylic resin composite**

Furthermore, milled cornstalks contain a parenchyma tissue called pith, this is as shown in figure 2. Important to note again is that cornstalk particles contain some components of the pith and is believed to add to the water retention abilities of the composites. (Thamae.T et al, 2010). This means that higher cornstalk filling would ultimately give rise to composites which have high retention abilities and which would retain the absorbed water for a period of time, this is clearly observed in the moisture absorption plot shown in figure 7.

Another interesting observation made by (Thamae.T. et al, 2010) is that at low cornstalk fiber content there is a great percentage of cornstalk fibers fully encapsulated by the polymer matrix. This is however with exception of particles exposed at the composite surface. Encapsulation of particles means that there are only very few particles that come in contact with water, which means the encapsulated particles are not involved in the movement of water through the composite material and hence moisture absorption is reduced, since again as already stated, there are no hydroxyl sites to attract water molecules and facilitate their movement through the entire



composite structure. This is thus a vivid phenomenon to explain the general trend observed in Figure 7.

Also, there is a notable transition of interest indicated in Figure 7, where there is a rapid change in the moisture absorption at 30% cornstalk filler added. This can be explained based on the observation put forward by Thamae.T, et al, 2010, which is that, increasing the cornstalk content increases the chances of particles rubbing against each other and forming agglomerates which are enclosed by the polymer matrix. Agglomeration occurs when the stickiest particles collide due to turbulence and adhere to each other forming agglomerates. Again, since lingo-cellulosic materials such as cornstalk fibres have strong intermolecular hydrogen bonding forces between their particles, there is a 'critical cornstalk fibre content' at which agglomerates formed results in clusters that serve as passages for water movement in the particles. (Wang et al, 2005). It is at this point that the composite water uptake increases rapidly to levels higher than those observed for all other samples. This observation again could be due to increased difficulty in mixing at higher fibre loading. This is as shown in Figure 7 where moisture absorption suddenly increases between the 20% fibre loading and the 30% fibre loading.

The plot in Figure 8 for the sandstone-polyester composite shows moisture absorption increasing with time for the sandstone- polyester composites. However, for this composite no general trend in the moisture absorption could be observed.

Although, the plot in Figure 8 shows that at 70% of the filler loading, there is high moisture absorption, but at other percentages of the filler loading, it is unclear what the general trend of this composite should be. Unavailability of data on the nature of the filler at the time this report was written made it difficult to quantify the possible factors that could markedly explain these deviations. The only possible explanation that can be put forward here is that moisture absorption properties of this particular composite is believed to be strongly dependent on the nature of the sandstone filler.

The plot in the Figure 9 shows the determination of moisture absorbed for a composite now made from sandstone reinforced acrylic resin. The general moisture absorption trend for this composite as shown in Figure 9 is that moisture absorption increases with increasing sandstone filler loading. Moisture absorption was expected to increase from 0% to 50% of the sandstone

filler loading, however results obtained indicated otherwise. This derivation is however believed to be attributed to the nature of the sandstone. Again an interesting observation was made for all the filler loadings at times between 30-45 hours<sup>0.5</sup>, as shown in figure 9. In this region there is an increase in moisture absorption for all the samples, after the expected saturation point. This increase shows that for this kind of composite material, absorption of water is still possible even after the saturation point. This phenomenon can only be due to the nature of the sandstone filler, even though concrete evidence to this effect has not been looked into as yet. It is believed that, generally sandstones have porous network structures that allow them to absorb moisture from humid environments such as, the conditions the composites were subjected to in this research. Thus at higher sandstone filler loading, moisture absorption is higher since the structure of the sandstones allows them to absorb moisture. Again the fact that the acrylic resin is water based explains why moisture absorption is high even at low percentage amounts of the sandstone filler.

Generally comparing all the composites and their resistances to moisture absorption, it is clear from Figures 6,7,8,9 that the cornstalk fibre composite is the least resistant to absorption of moisture, this is due to the structure of the cornstalk, as explained previously. It is difficult to exactly compare the resistance to moisture absorption of the composites since the percentage loading of the filler used varies from filler type to matrix type used, and since doing this does not give a true explanation of how the resistances to moisture absorption for the different materials differ from one another. However, Figures 8 and 9 can be compared to determine which composite is most resistant. Considering 50% sandstone loading in both composites, one observes that the maximum moisture absorption of the acrylic resin-sandstone composite is (about 11%) much higher than that of the sandstone-polyester composite (about 1.6%). This means that the polyester-sandstone composite is evidently more resistant to moisture absorption than the acrylic resin-sandstone composite, this is due mainly to the fact that the acrylic resin is water based and therefore has the highest tendency to absorb moisture. Of all the composite materials, the diorite-polyester had the least average moisture absorption, since its moisture intake decreased with increasing diorite content.

#### 4.0.2 Diffusion Coefficients

Diffusion in the composites industry is one important phenomenon that describes the movement of water within composite structure. Absorption of water into a solid composite material is strictly governed by the gradient of water concentration between the surroundings and inside the material, and as such the degree of water saturation as a function of time can be described by the simplified Fickian diffusion equation developed by Shen and Springer (1976), as shown in equation (3).

$$D = \pi \left( \frac{h}{4M_\infty} \right)^2 \left( \frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}} \right)^2 \dots\dots\dots(3)$$

The diffusion coefficient is typically the only unknown parameter in the above equation, and can be adjusted to fit experimental data. Thus equation (3) can be rearranged to give:

$$\frac{Mt}{M_\infty} = 4/h \sqrt{D/\pi} * \sqrt{t} \dots\dots\dots(4)$$

And a plot of  $m_t$  as a function of  $\sqrt{t}$  gives the diffusion coefficients in the initial linear region. The diffusion coefficients determined experimentally have been recorded in Table (4). The results obtained however do not give a general trend and makes it difficult to describe exactly the rate of water movement within the composite structure. This observation can be explained based on the assumptions of the Fickian diffusion equation. The equation assumes that water diffusion occurs only in a single direction. Thus, it is typically applied to predict the water absorption behavior of plane material sheets with a low ratio between the thickness dimension and length and width dimensions. Moisture absorption is then governed by diffusion in the thickness direction. It is evident from table (4), that the experimental data deviates from the Fickian diffusion equation and the calculated constants might therefore not reflect the through process of water absorption in the composites and may not accurately describe the rate movement of water into composite structure. Furthermore, it is believed that water diffusion in polar systems such as that observed in the cell wall of plant fibres is delayed by the hydrogen bonding of the water molecules (Macrovich et al, 1999) and this might explain the low diffusion as seen in table 4.

Again, the relative small length and width dimensions of the samples means that water diffusion in these two directions cannot be neglected, and the one dimensional Fickian equation as already used can therefore not be applied to estimate the diffusion coefficients as well measure the ability of the water molecules to penetrate the composite structure.

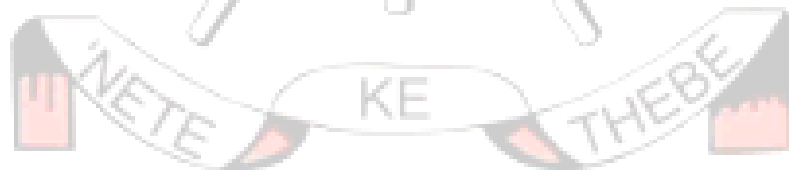
**Table 4: Diffusion coefficients of composite samples (m<sup>2</sup>/hr)**

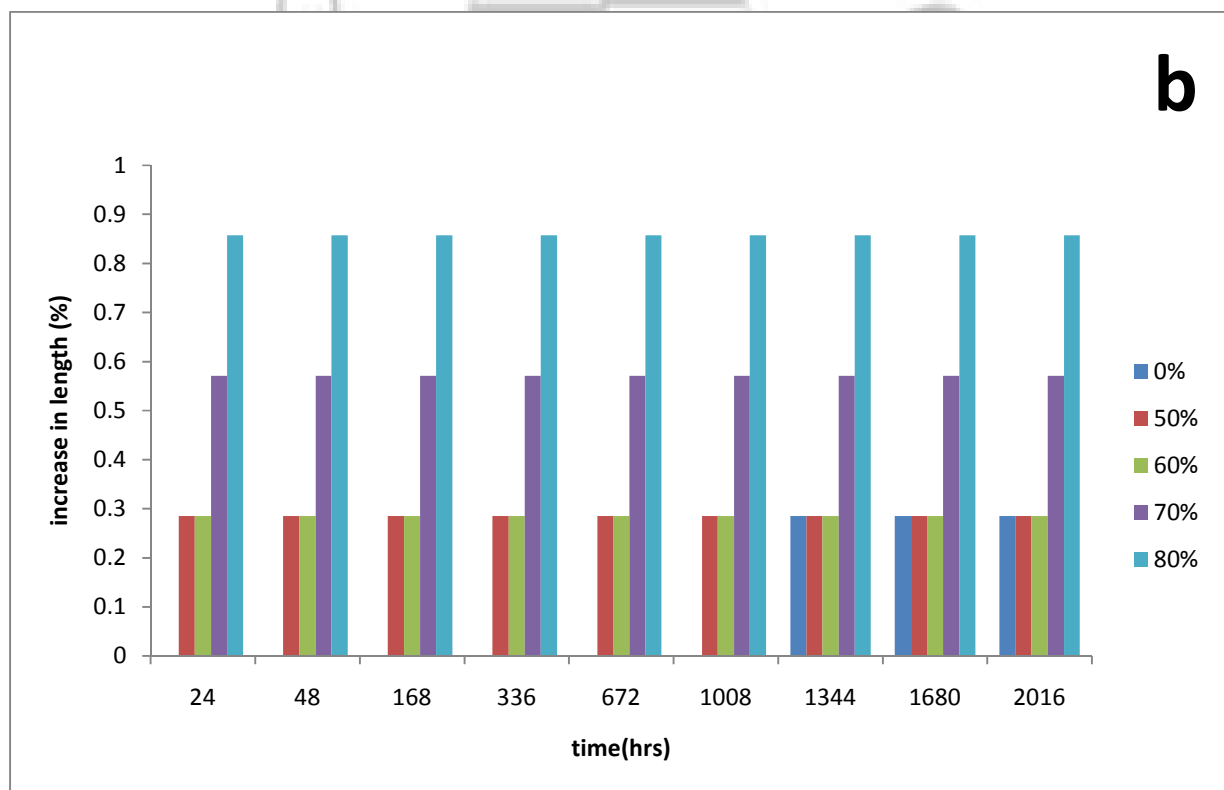
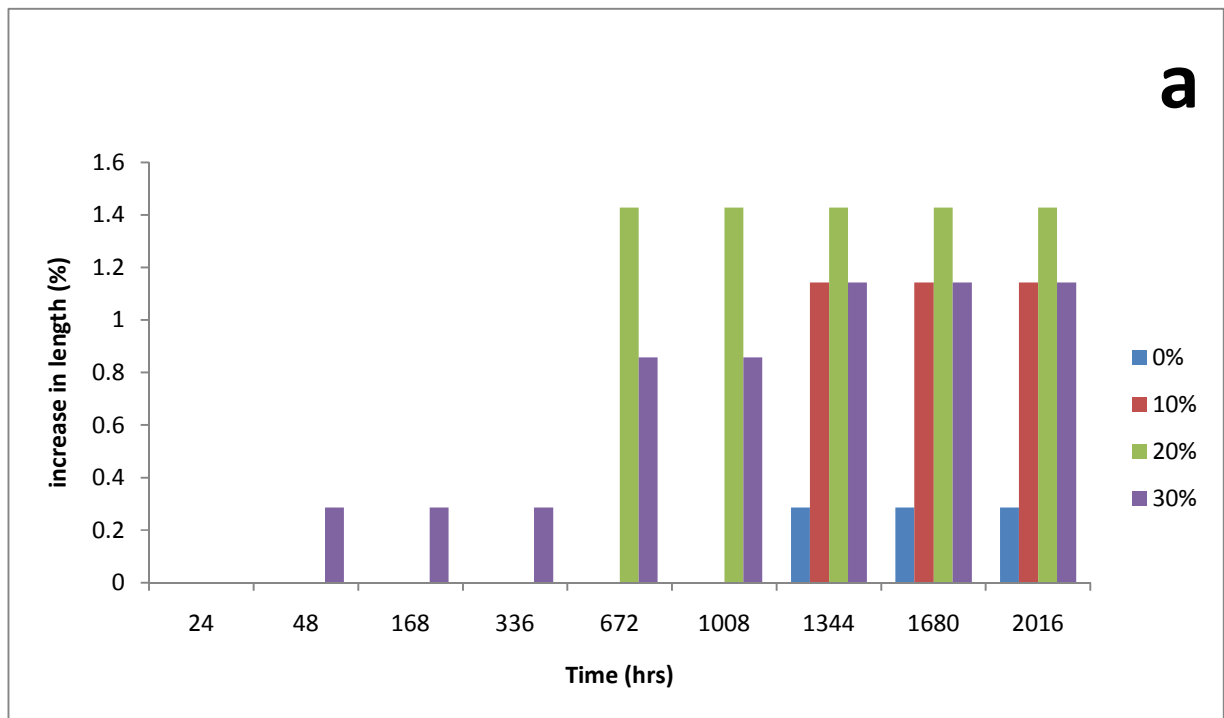
Specimen	Percentage of filler added (%)								
	0	10	20	30	40	50	60	70	80
Sandstone and polyester	8.309 × 10 <sup>-9</sup>	-	-	-	2.337 × 10 <sup>-9</sup>	1.188 × 10 <sup>-9</sup>	8.727 × 10 <sup>-9</sup>	2.201 × 10 <sup>-9</sup>	-
Acrylic and sandstone	2.636 × 10 <sup>-9</sup>	1.392 × 10 <sup>-9</sup>	5.779 × 10 <sup>-9</sup>	1.162 × 10 <sup>-9</sup>	1.185 × 10 <sup>-9</sup>	6.140 × 10 <sup>-9</sup>	-	-	-
Natural fibre and polyester	8.309 × 10 <sup>-9</sup>	4.452 × 10 <sup>-9</sup>	9.128 × 10 <sup>-9</sup>	1.528 × 10 <sup>-9</sup>	-	-	-	-	-
Diorite and polyester	8.309 × 10 <sup>-9</sup>	-	-	-	-	2.201 × 10 <sup>-9</sup>	2.138 × 10 <sup>-9</sup>	2.176 × 10 <sup>-9</sup>	5.770 × 10 <sup>-9</sup>

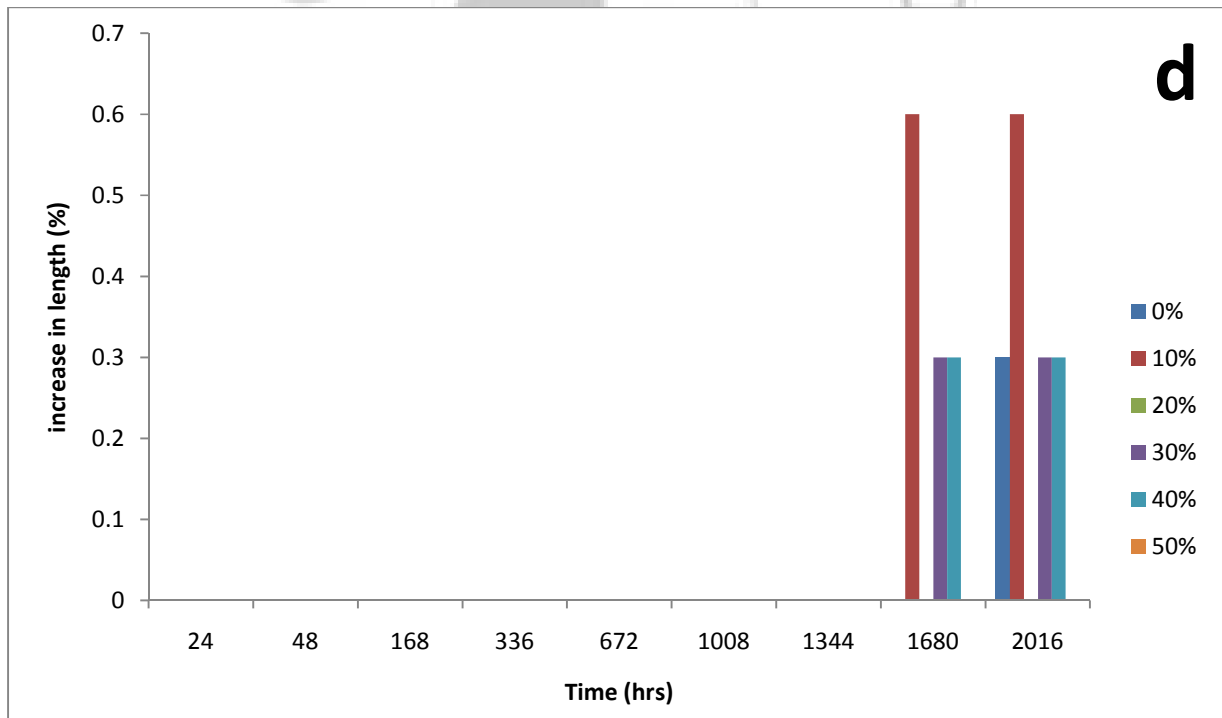
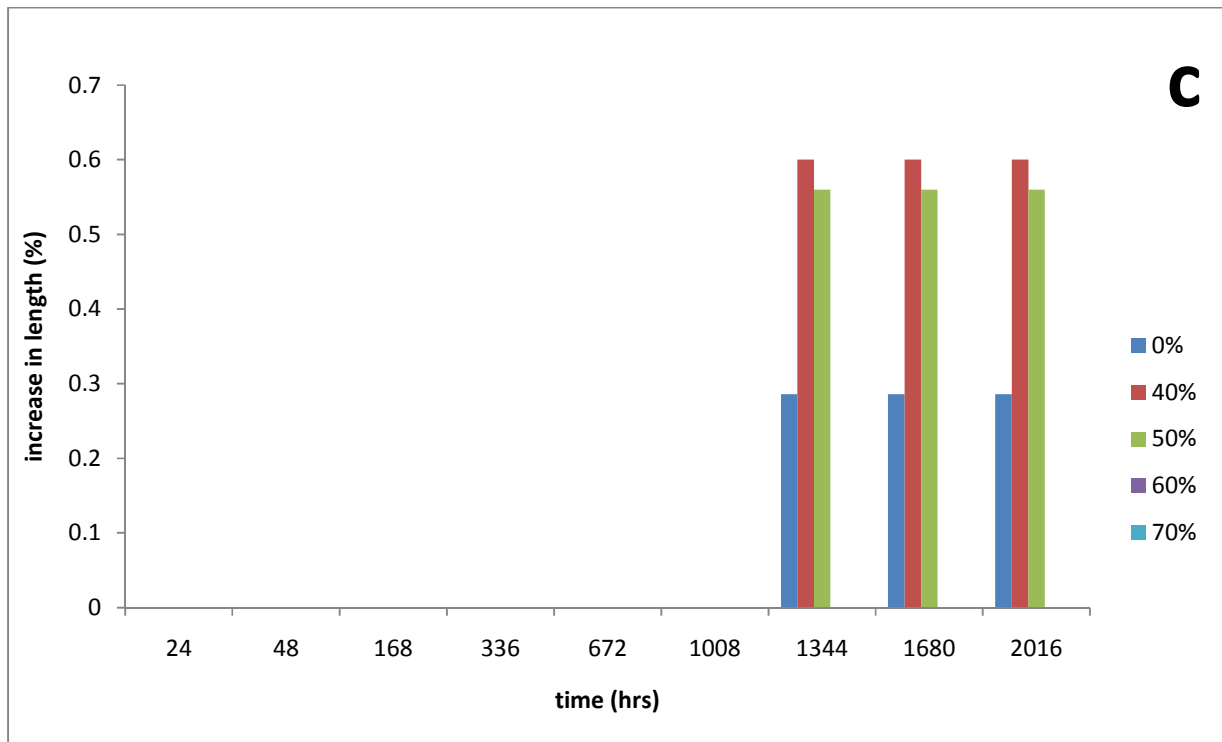
#### 4.0.3 Dimensional stability

Dimensional stability again is one important property of a composite material that is critical for the application of the composite material. Poor dimensional stability will cause warping and other changes in the shape of the material. In this research, the dimensional stability of the

different composite materials was determined by calculation of the percentage increase in length of the composite material samples. Although changes in dimension of the composite material should include all dimensions of the composite material, but results showed that changes in other dimension was either following the same trend as those observed for changes in length or they remained completely unchanged at the time this report was written. The changes in length thus helped to give an overview of how the dimension of the different composite materials changed with absorption of moisture. Figure 10(a) shows the increase in length with time of the cornstalk fibre-polyester composite. The Figure indicates that most of the composites did not initially increase in length as their dimensions remained unchanged. As time progressed, the 30% fiber loading began to increase in length, this was followed by the 20% fiber loading and thereafter an increase was observed for both the 0% and 10% fiber loading. It is thus believed that from this, the presence of the corn stalk fiber will cause deterioration of the dimensional stability of the polyester matrix. This is likely to have been caused by composite effects such as interface debonding, and matrix fracture, which has a significant influence on the elasto-plastic behavior of the composites. Figure 10(b) shows increase in length with time of the diorite polyester composite. Generally, the increase in length is higher at higher filler loading and is smaller at lower filler loading. The Figure also shows that after an initial increase in length, the dimensions of the composite materials remained unchanged through out the entire duration of the research.







**Figure 10: dimensional stability bar chart, (a) cornstalk-polyester, (b) diorite-polyester, (c) sandstone-polyester, (d) sandstone acrylic**

Again Figure 10(c) shows increases in length for the sandstone-polyester composite. The trend observed here is generally that, the length changes only slightly as filler loading increased. No observable changes in length was noted at higher filler loadings and this is believed to be due the nature of the sandstone fillers which most likely forms a strong matrix-filler bond that allows them to have relatively stable dimensions even at higher sandstone filler loading. Also Figure 10(d) shows how the dimensions of the sandstone acrylic resin composite changes with increasing amount of the filler as a function of time. For this composite, 50%, 40%, and 20% filler loading showed no changes in dimension, while those filled with 0%, 10%, and 30% sandstone showed changes in dimension. The 10% sandstone-acrylic resin composite proved to be the least stable having the highest change in its dimension, while both 30% and 0% showed relatively the same changes in their dimensions through out the entire research duration. From this one can conclude that averagely, there is higher dimensional stability at higher filler loading and poorer dimensional stability at lower filler loadings.

Generally speaking, the cornstalk-polyester composites gives the highest average increase in length as indicated in Figure 10(a), this is immediately followed by the diorite-polyester composite. That of the sandstone in both types of polymer resins indicates approximately the same average increase in length. This brings one to conclude that, the corn stalk-polyester composite has the poorest dimensional stability while the sandstone composites have the best overall dimensional stability. The poor dimensional stability of the cornstalk fiber composite is basically due to the nature of the cornstalk fibre and is cause by defects discussed previously such as weak interfacial bonding between the fibre and the polyester matrix. The good dimensional stability observed in the sandstone composite is yet to be understood and a thorough look into the nature of this filler would be required to explain accurately this observation.

#### **4.1 Application**

Composite materials today have gained popularity and this is greatly due to the peculiar properties exhibited by composite materials. Composite materials are important because they



combine the properties of the different individual materials that make up the composite structure to give a material with excellent properties. To this end, composite materials find wide use in many areas of society today. This research however focused on a number of different applications of the already fabricated composite materials. Important to note here is that the applicability of the composite material is dependent on the properties of the composite itself. For instance, the poor dimensional stability of the cornstalk polyester composite means that, their application would be limited to low humid areas. Thus the designs made during this research included their use as artifacts and their use for table top designs. They have also been proposed to be used for the interior components of automobiles.

A look at the properties of the sandstone composites indicates that they may not be limited only to low humid areas, this is because their good dimensional stability observed when they were subjected to moisture conditions indicates that they would also be applicable in humid areas. Thus this research based on the properties of the different composite materials, looked into making designs such as wall tiles of different textures, building materials such as lining of outer walls, as well as their use in making artifacts.

The diorite-polyester composite is believed to have excellent hardness and toughness properties, even though time did not permit the testing of the impact strength of this composite to confirm this belief. The major design however considered here was, designing of table tops, this is because of its observed hardness property since its application as a table top means it would need to withstand varying load pressures. Another important advantage of their use as table tops is that they give excellent surface finishes when polished and are believed to be resistant to solvents.

#### **4.1.1 Cost analysis**

One other major desire any design of a composite strives to achieve is cost effectiveness both in terms of production and purchase. Apart from the attributed properties of composite materials, the cost of the composite material is one important factor that has to be considered during the production of composite materials. Today, many researches are focused on producing less expensive composite materials without compromising their intended properties. In this research

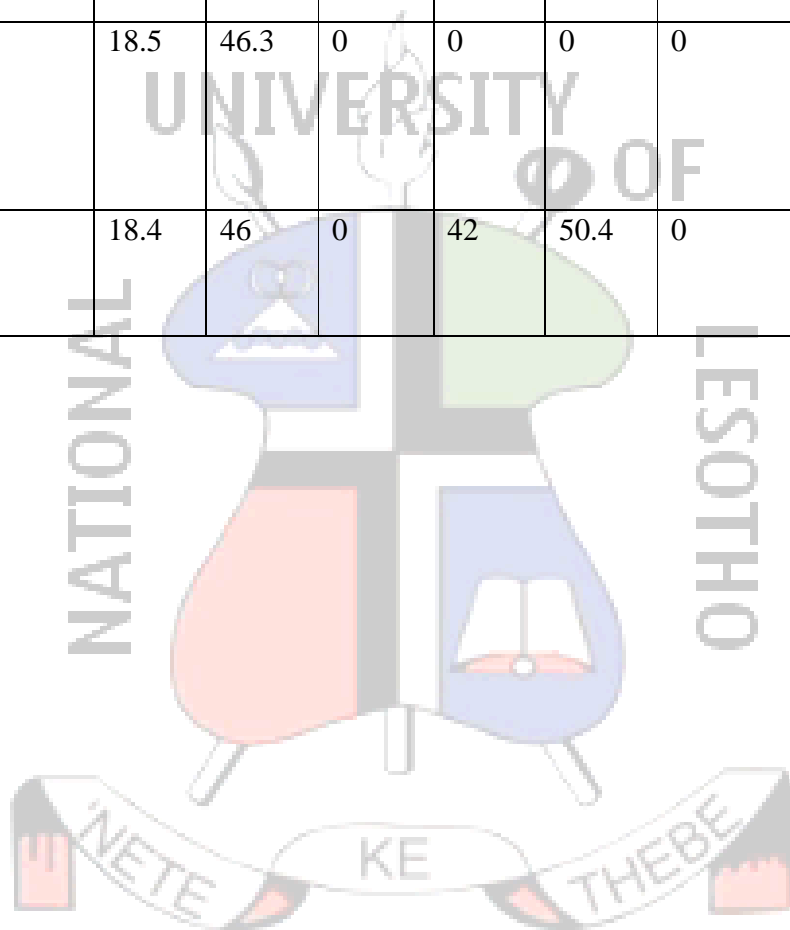
the cost analysis on production of composites was estimated to determine which of the composite materials is likely to be more cost effective.

For instance, the polyester resin was filled with sandstone, diorite and cornstalk fibre. The cost of obtaining 1kg of polyester resin is about R25, while the cost of the sandstone is estimated at R2/kg. The cost of the sandstone here includes the labour costs incurred in crushing the sandstone. This comes at very low costs because the sandstone is one natural resource that is relatively available and major costs are only incurred in terms of labour costs. If say about 60% of sandstone is used to replace the polymer matrix then the costs of obtaining a kg of composite would be about R11.2. Comparing the amount of the more expensive polyester resin to that of the composite made from a mixture of the resin and sandstone we can reliably say that the sandstone reduces the price of the polyester resin by about 55.2%, which is one aim the composite strives to achieve. Again the cost of obtaining a kg of diorite is estimated at R4 while that of the cornstalk fibre is estimated at R1. The cost of obtaining the corn stalk is so low because corn is a staple food here in the southern region of Africa and obtaining the cornstalk comes at almost no cost. Table 5 shows the percentage cost saved in using the relatively cheap fillers.

The water based-acrylic resin on the other hand comes at a price quite higher than those of the polyester resin. The cost of obtaining 15kg of the acrylic resin is about R400, which means a kg costs about R27. Although the use of the sand stone filler reduces the cost of the acrylic resin by about 53.7% for a 50% loading of the sandstone, the relatively cheaper cost of the sandstone-polyester composite leads one to opt for a more cost effective composite materials whose properties is not compromised. This means that the sandstone-polyester composite would be the best choice in terms of cost effectiveness. Further estimates are given in table 5.

**Table 5: percentage cost saved in the use of different fillers at various amounts of the filler**

Resin type	Filler type (percentage added)								
	Sandstone			Diorite			Cornstalk fibre		
	0	20	50	0	50	60	0	20	30
Water-based acrylic	0	18.5	46.3	0	0	0	0	0	0
polyester	0	18.4	46	0	42	50.4	0	19.2	28.8



## CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

### 5.0 Conclusion

This research has led to the following conclusions: the cornstalk-polyester composite of all the composites studied, has the highest moisture content and moisture content increases with increase in the cornstalk fibre added. Also the diorite-polyester composite was found to have the lowest average moisture content. This means the polyester-diorite composite is the preferable choice in terms of the moisture absorption property of the composite materials, since results obtained showed it had the least average moisture content of all the different composite materials.

Again the cornstalk-polyester composite was found to have the poorest dimensional stability since its dimensions changed much more than those of the other composite materials. The sandstone-polyester and sandstone-water based acrylic composites were found to have the best average dimensional stability, as dimensions of the composites changed only slightly. However the sandstone-polyester composite was found to be more dimensionally stable. This means the polyester resin is a preferable choice of matrix material, for the production of the composites.

Finally, application of the composite materials was based mainly on the obtained properties of each of the composite materials. Designs made in this research include, wall tiles made using the sandstone-polyester composite (this was based on its good dimensional stability and low average moisture content), artifacts made using the cornstalk fibre, and table tops were designed using the diorite as fillers. The cost of obtaining the different fillers used varies depending on their availability. The cost of obtaining the cornstalk fiber is quite lower than the cost of obtaining the other filler materials, however the properties of the cornstalk fibre as filler material as mentioned earlier limits its application. The cost of obtaining the sandstone on the other hand was found to be lower than that of the diorite filler this is because the diorite is not as abundant as the sandstone.

Thus based on the entire study, the sandstone has the greatest potential as filler material and the polyester is the preferred choice of matrix material

## 5.1 Recommendation

In this research time was a limiting factor that inhibited the understanding of a number of observations. One area that could be looked into is the mechanical properties of the different composite materials as such, future studies should focus on determining the mechanical properties of the composite materials to determine where the different composites would be most applicable and under what conditions.

Another area that could be looked into is the aspect of the surface morphology of the different composite materials and how it affects their overall properties. Surface morphology should be done to determine the difference between the surface morphology of the moisture absorbed composite specimens to that of the dry composite specimen, particularly in terms of voids, porosity, swelling, absorption in micro-cracking, and disbanding around filler. Therefore, studies of the composite surface topography would provide vital information, on the level of interfacial adhesion that exists between the filler and the matrix.

Furthermore, suggestion is that the water used for the moisture absorption test be analyzed for the ion content and their role in the rate of diffusion of moisture in the different composite materials should also be evaluated.

Interestingly today, there is no limit to the type of natural fiber available to man, and natural fibers have been proposed as potential replacement to the overly used synthetic fibers. This is because researchers are coming up with results that point to the fact that many natural fibers possess properties that supersede those of synthetic fibers. Hence researches should focus on developing methods that improve the quality of natural fibers and how they can be applicable in developing composites with exceptional properties, while ensuring that these developments are cost effective.

Finally a look into the thermal stability is proposed for future studies to determine how the composite materials would expand or contract under high or low temperature conditions.

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