DEVELOPMENT OF AUTOMOBILE GASKETS FROM LOCAL FIBRES

BY

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CERTIFICATION

I hereby certify that this project was carried out by MR. OLADELE ISIAKA OLUWOLE of the Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure and that this project has not been submitted elsewhere for the award of a degree.

05/09/06

DR.B.O.ADEWUYI
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DEDICATION

This project is dedicated to God and all that God use for me in order to achieve this goal.

ACKNOWLEDGEMENT

My first appreciation goes to Almighty God that made it possible for me to start and end this programme, the Alpha and Omega Himself.

My special thanks to my supervisors, Dr Adewuyi, B.O. and Dr. Borode J.O. for their invaluable assistance and advice that speed up the project. I also appreciate the effort of the lecturers of the Department for their brilliancy and support. God will help you all in Jesus name. Amen.

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I wish to express my sincere gratitude to my parents and my brothers and sisters for their moral and financial support. Brethren of the Redeemed Christian Church of God, Mercy of God Parish, Owo are not left out for their support, and finally, I thank God for favouring me with sister Josephine. God bless you all in Jesus Christ name. Amen.

TO GOD IS THE GLORY.

OLADELE, I. O.
AUGUST 2006

ABSTRACT

Bamboo (*Ozizentera arbonica*) coconut husk (*Cocus nucifera*), sponges (*Momodica bracteate*) and wood (cordial) were used as fibres for the development of low temperature tolerance automobile gaskets. The materials were sourced locally. The materials after collection were sun dried and then cut into smaller pieces for easy comminution. The materials were further prepared by pulverizing using laboratory ball mill followed by sieving to obtain uniform particle size. The particles of each material were mixed in different proportion which was later used for the production of different samples. Binder was then added to produce homogenous pastes. The pastes were then poured into prepared moulds to obtain the shape of the desired products. The casts were allowed to solidify and after which they were removed and sun dried. The dried samples were cut into shape for creep and hardness tests. The creep test was carried out at room temperature while the hardness tests were carried out at both room and at an elevated temperature of 200°C. The results of the analysis were used to select the materials that have close properties to the commercially sourced gasket materials. Suitability test was carried out on the materials using water, engine oil and petrol media. The materials maintained their respective structures in engine oil and petrol whereas it softens in water. The compatibility and suitability tests confirmed the possible applicability of the materials as gaskets in fuel pumps, carburetors and as well as engine oil sumps.

TABLE OF CONTENTS

CHAPTER TWO

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

1.0 INTRODUCTION

Material science and Engineering (MS & E) is by its very nature an interdisciplinary activity. Researchers from a wide variety of disciplines: metallurgy, ceramics, physics, chemistry, mechanics, electrical and electronic engineering etc. can participate in the MS & E activities. The need and desirability of such an interdisciplinary effort is understandable in as much as advanced or high-performance materials are critical for any of the modern industries. It is almost a given axiom that progress in any field (energy, building materials, transportation, consumer product etc.) depends on the availability of suitable materials having specific characteristics. In this regard, it is a truism that technological development depends on advances in the field of materials. Whatever the field may be, the final limitation on advancement depends on material.

It is pertinent to note the fundamental change that is occurring in the materials field. A fundamental reversal in the relationship between human beings and materials (has occurred). Its economic consequences are likely to be profound. Historically humans have adapted such natural materials as stone, wood, clay, vegetable fibre and animal tissue to economic uses. The smelting of metals and the production of glass represent a refinement in this relationship. Yet it only recently that advances in the theoretical understanding of the structure of physical and biological matter, in experimental technique and in processing technology have made it possible to start with a need and then develop a material to meet it. The classical model of materials application has been inverted. We

once sought applications for materials. We now design materials for what we need.

Designing materials for specific applications is, indeed, the underlying philosophy of composite materials. The materials marketplace is increasingly becoming a highly competitive arena where substitution of traditional materials by engineered materials is the norm; quality and value added to the material as well as the energy cost are critical in the final cost.(Chawla,1993)

1.1 Specific objectives of the Research

The specific objectives of the research are to:

(a) Utilize the local materials such as bamboo, coconut husk, wood and other agricultural by-products to produce gaskets;

(b) Evaluate the relevant mechanical properties such as creep rate and hardness;

(c) Evaluate the relevant mechanical properties such as creep rate and hardness; and

(d) Determine the suitability of the product as automobile gaskets.

1.2 Expected Contribution of the Research to Knowledge

Gasket produced from agricultural by-products can be used as substitutes for expensive imported ones. The study may open new vistas in the area of material selection for engineering application in automobiles.

CHAPTER TWO

2.0 COMPOSITE MATERIALS

In the continuing quest for improved performance, which may be specified by various criteria including less weight, more strength and low cost, currently used materials frequently reach the limit of their usefulness. Thus materials scientists, engineers and scientists are always striving to produce either improved traditional materials or completely new materials. Composites are an example of the latter category.

A composite is a material having two or more distinct constituents or phases and thus we can classify concrete made from mixture of stones, known as aggregate, held together by cement, as a composite.

In addition to synthetic composites there are naturally occurring composites of which the known examples are bone, wood and mollusk shells.

Composite materials can be studied from a number of different viewpoints each of which requires a different kind of expertise. Thus, the development of a composite material to resist corrosive environment is primarily within the field of materials science and chemistry. In contrast the design of a load bearing structure requires the expertise of an engineer. It is therefore essential for the full exploitation of currently available composites, and for the future development of composites, that experts in one field are able to understand the problems of those in another. The study of composites is truly interdisciplinary.(Mathews et al,1995)

2.1 DEFINITION OF TERMS

2.1.1 Composite

We have already stated that a composite is a mixture of two or more distinct constituents or phases. However this definition is not sufficient and three other criteria have to be satisfied before materials can be said to be a composite. First, both constituents have to be present in reasonable proportions, say greater than 5%. Secondly, it is only when the constituent phases have different properties and hence the composite properties are noticeably different from the properties of the constituents that we have come to recognize these materials as composites.

2.1.2 Matrix

We know that composites have two (or more) chemically distinct phases on a microscopic scale, separated by a distinct interface, and it is important to be able to specify these constituents. The constituent that is continuous and is often but not always present in the greater quantity in the composite is termed the matrix. The normal view is that it is the properties of the matrix that are improved on incorporating another constituent to produce a composite. A composite may have a ceramic, metallic or polymeric matrix. The mechanical properties of these three classes of material differ considerably. As a generalization, polymers have low strength and young's moduli, ceramics are strong, stiff and brittle and metals have intermediate strengths and moduli together with good ductility.

2.1.3 Reinforcement

The second constituent is referred to as the reinforcing phase, reinforcement as it enhances or reinforces the mechanical properties of the matrix.

In most cases the reinforcement is harder, stronger and stiffer than the matrix, although there are some exceptions. At least one of the dimensions of the reinforcement is small, say less than 500μm and sometimes only of the order of a micron. The geometry of the reinforcing phase is one of the major parameters in determining the effectiveness of the reinforcement; in other words, the mechanical properties of composites are a function of the shape and dimensions of the reinforcement. We usually describe the reinforcement as being either fibrous or particulate and this is commonly employed in classification scheme for composite materials.(Fig.2.1, Block A).

2.2 CLASSIFICATION OF COMPOSITES

Composites are classified base on the type of reinforcement, fibrous or particulate used and their orientation. Figure 2.1 represents a commonly employed classification scheme for composite materials which utilizes this designation for the reinforcement and their orientation.

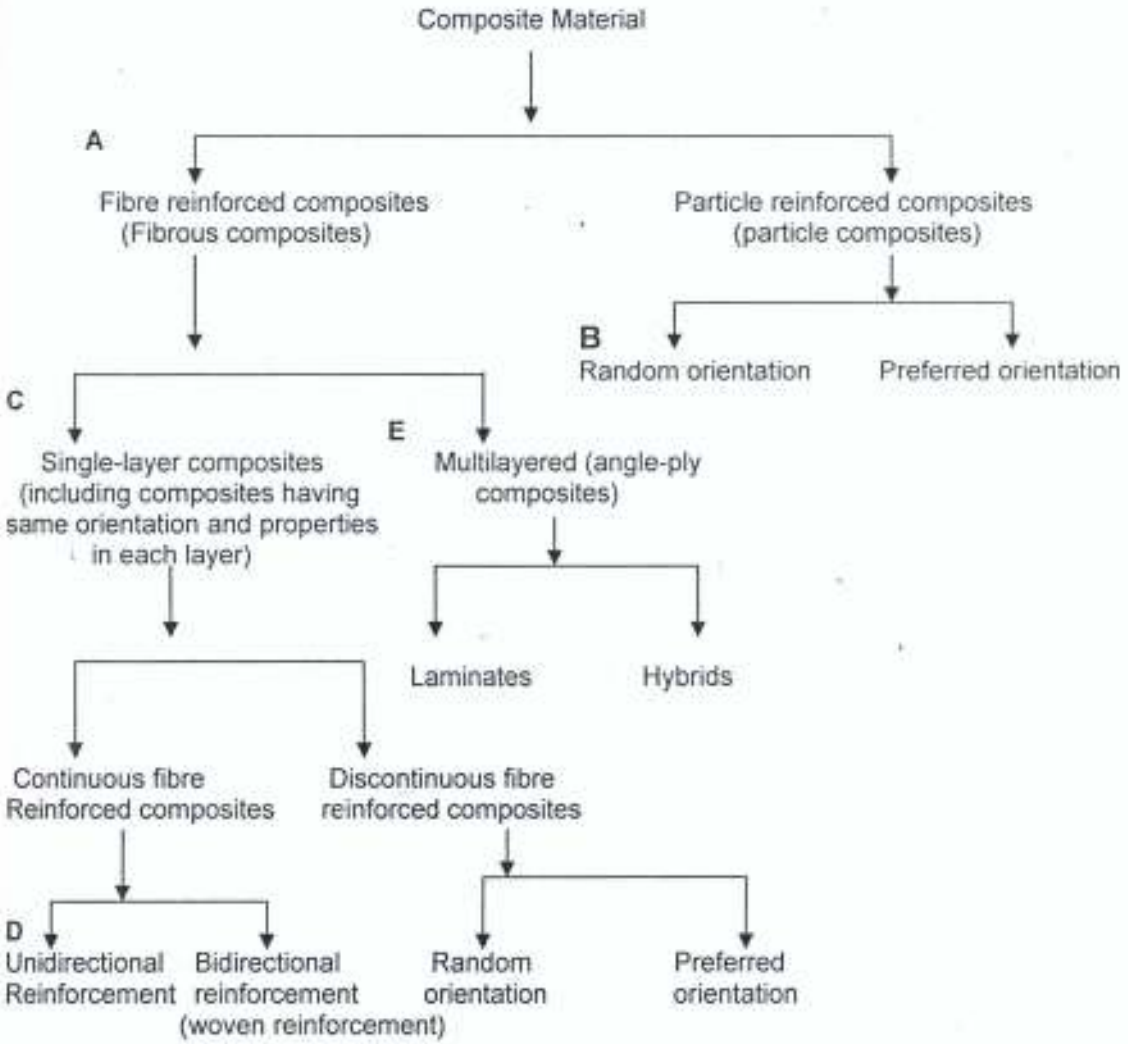
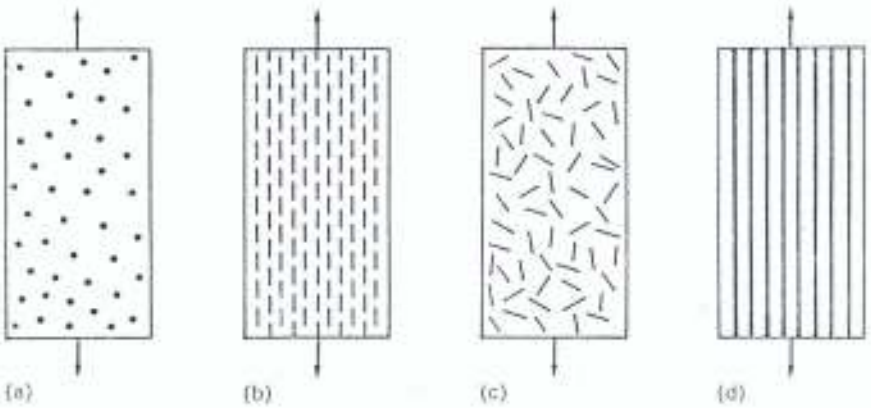


Fig. 2.1: Classification of composite materials

2.2.1 Particulate

Particulate reinforcements have dimensions that are approximately equal in all directions. The shape of the reinforcing particles may be spherical, cubic, platelet or any regular or irregular geometry. The arrangement of the particulate reinforcement may be random or with a preferred orientation (Block B). In the majority of particulate reinforced composites the orientation of the particles is considered for practical purposes to be random. [Fig.2.2(a)]



Examples of composites: (a) particulate, random; (b) discontinuous fibres, unidirectional; (c) discontinuous fibres, random; (d) continuous fibres, unidirectional.

Figure 2.2: Examples of composites

2.2.2 Fibrous

A fibrous reinforcement is characterized by its length being much greater than its cross-sectional dimension. However, the ratio of length to the cross-sectional dimension, known as the aspect ratio, can vary considerably. In single-layered composites long fibres with high aspect ratios give what are called continuous fibre reinforced composites, whereas discontinuous fibre composites are fabricated using short fibres of low aspect ratio (Block C). The orientation of the discontinuous fibres may be random or preferred [Fig.2.2(b) &(c)].

The frequently encountered preferred orientation in the case of a continuous fibre composite [Fig.2.2(d)] is termed unidirectional and the corresponding random situation can be approximated to by bi-directional woven reinforcement (Fig.1.1, Block D).

Multilayered composites are another category of fibre-reinforced composites. These are classified as either laminates or hybrids (Block E). Laminates are sheet constructions, which are made by stacking layers (also called plies or laminate and usually unidirectional) in a specified sequence. A typical laminate may have between 4 to 40 layers and the fibre orientation changes from layer to layer in a regular manner through the thickness of the laminate.

Hybrids are usually multilayers composites with mixed fibres and are becoming commonplace. The fibres may be mixed in a ply or layer by layer and these composites are designed to benefit from the different properties of the fibres employed. Some hybrids have a mixture of fibrous and particulate reinforcement (Mathews *et al.*, 1995).

2.3 Properties of the Matrix and Reinforcement

Although there are many examples of composites employed mainly for their physical properties, such as the super conducting composites consisting of continuous NB_3Sn fibres in a bronze matrix, most composites are designed tc exploit an improvement in mechanical properties. Even for composites produced essentially for their physical properties, the mechanical properties can play an important role during component manufacture and service. For these reasons, mechanical behaviour of matrix and reinforcement are considered.

2.3.1 Stiffness and Strength

Often we need to ensure that a component does not break, i.e. it has adequate strength, or that it does not suffer excessive deformation under load, that is, it has adequate stiffness. For these reasons, the behaviour of flat, plate-like

elements are considered as composite components are frequently fabricated in this way. Since most of the methods of calculating the stiffness and strength of composites are derived from the basic principles of mechanics and stress analysis, the latter are reviewed below.

2.3.1.1 Loads

We consider the loads acting on a structure or component to be of two basic types; forces and couples. Forces can be further subdivided into tensile, compressive and shear, and couples into bending moments and twisting moments (or torques). All of these can act in isolation or in combination, depending on the situation.

2.3.2 Structural entities

When carrying out a structural analysis it is convenient to represent the real structure by one or more, idealized elements. Each element will almost certainly be a simplification of the actual situation, in that we will make assumptions about the way the loads are distributed within it. These simplifications are often based on the dimensions of the part.

A straight member whose length is much greater than its cross sectional dimensions, and is subjected to a tension or compression along its length is referred to as a rod. A similar member, but subjected to a bending moment is known as a beam, and when loaded by a torque is called shaft.

When we have an element whose length and breadth are much greater than its thickness, and which is subjected to in-plane forces, we refer to it as a membrane. If we subject it to bending moments we call it a plate.

Cylindrical components can be treated as membranes provided the diameter is constant and much larger than the wall thickness. If the diameter of the cylinder varies along its length we would call it a shell, in this case its behaviour is similar to but more complicated than a plate.

2.3.3 Deformation

Each type of load referred to above produces a characteristic deformation of the body on which it acts. These are shown in figure 2.3. We also frequently refer to states of plane stress and plane strain. In plane stress, stresses normal to the plane in which the stresses act are considered to be zero e.g. a plate in simple bending. In plane strain, strains normal to the plane in which the stresses act are considered to be zero e.g. the cross-section of a bar held between rigid walls. (Mathews et al,1995)

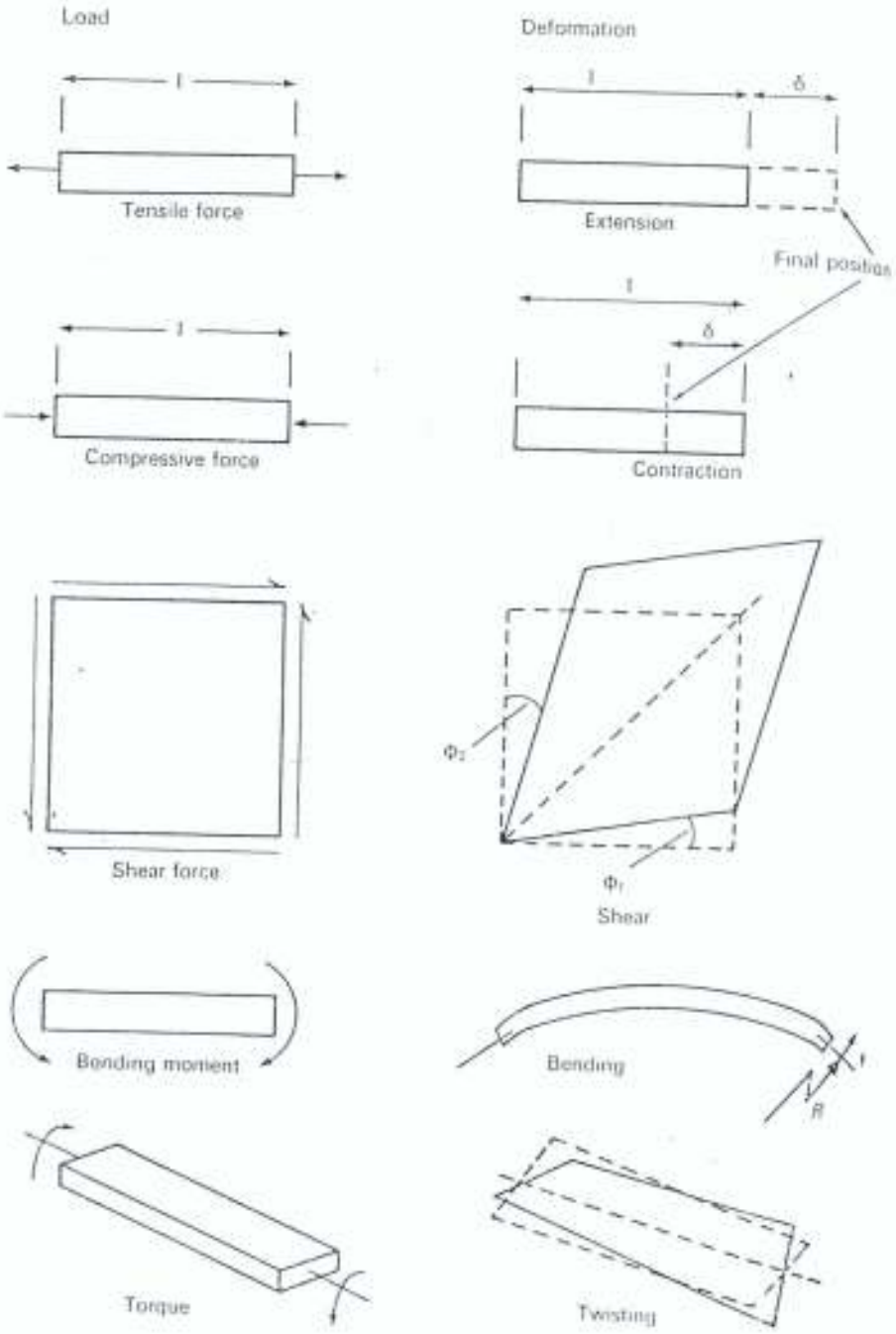


Figure 2.3: Loads and associated deformations

2.3.4 STRESS AND STRAIN

i. Stress

To allow us to deal with components of differing size we work with normalized loads. Thus tensile and compressive forces are divided by cross-sectional area to give the corresponding direct stress (σ) and shear force by a surface area to give a shear stress ((Fig. 2.4). Stress therefore has units of force/area (N/m^2 or pa). A bending moment alone will give rise to a direct stress which varies linearly through the depth of the component from tensile on one surface, to compressive on the other; a transverse force will cause shear stresses as well as direct stresses. (Fig. 2.4). A torque will give rise to shear stresses. Again, these will vary in linear fashion but can only be easily calculated for simple components. For plates it is usual to work with loads (forces and couples) per unit width.

ii. Strain

Strain is a non-dimensional measure of deformation; it can be elastic (instantaneous, reversible), anelastic (reversible, time dependent) or permanent. There are two types of strain, direct and shear, corresponding to the appropriate stress. Definitions (so-called 'engineering strain') are obtained from the quantities given in figure 2.2. So, direct strain $\varepsilon = \delta/l$ taken as positive for a tensile force and negative for compression; shear strain $\gamma = \emptyset_1 + \emptyset_2$ 2.1

δ = linear deformation

l = length

$\emptyset_1$ & $\emptyset_2$ = angular deformation

For bending, the radius of curvature is related to the direct strain by

$\varepsilon = y/R = ky$ 2.2

K being the curvature. The deflection can be related to the curvature using standard mathematical methods.

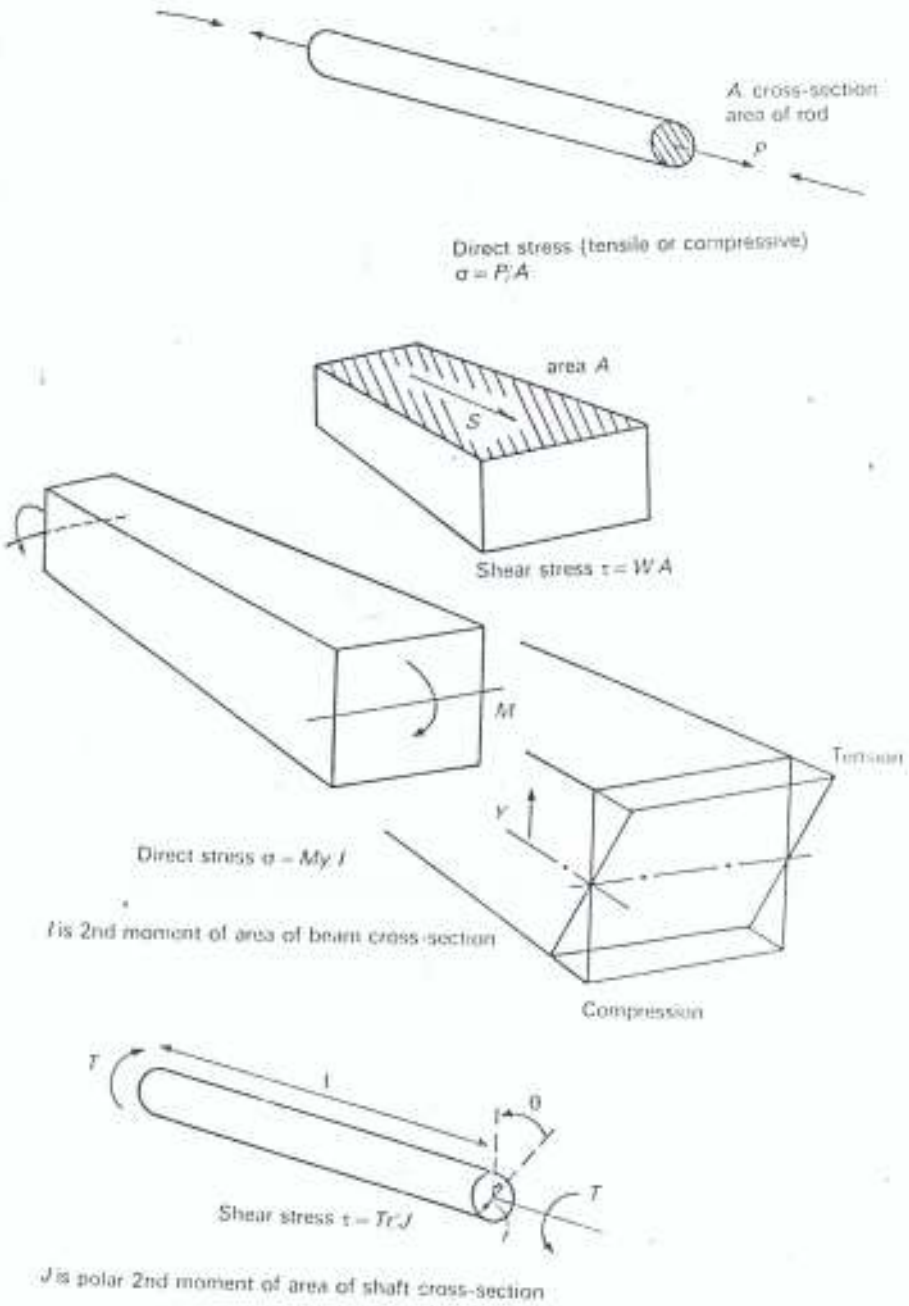


Figure 2.4: Load and associated stresses

2.4 FLEXIBILITY

There are of course many properties other than strength that we have to take into account when selecting reinforcement. In the case of fibres the flexibility is important as it determines whether the fibres may be easily woven or not and influences the choice of method for composite manufacture. The flexibility of a fibre depends mainly on the Young's modulus, E_f, and diameter D of the fibre:

$$\text{Flexibility} \quad \alpha \frac{1}{E_f D^4} \qquad (2.3)$$

Thus large diameter fibres with a high Young's modulus are not flexible. Finally, the fact that the reinforcement is bonded to the matrix means that any loads applied to a composite are carried by both constituents. As in most cases the reinforcement is the stiffer and stronger constituent, it is the principal load bearer. The matrix is said to have transferred the load to the reinforcement.

2.5 FACTORS WHICH DETERMINE PROPERTIES

2.5.1 Proportion

The fabrication and properties of composites are strongly influenced by the proportions and properties of the matrix and the reinforcement. The proportions can be expressed either via the weight fraction (w), which is relevant to fabrication, or via the volume fraction (v) which is commonly used in property calculations. The definitions of w and v are related simply to the ratio of weight (W) or volume (V) as shown below:

Volume fractions:

$$v_f = \frac{V_f}{Vc} \text{ and } v_m = \frac{V_m}{Vc} \qquad (2.4)$$

Weight fractions:

$$w_f = \frac{W_f}{Wc} \text{ and } w_m = \frac{W_m}{Wc} \qquad (2.5)$$

Where the subscripts m, f and c refer to the matrix, fibre (or in more general case, reinforcement) and composite respectively.

Where (v) = volume fraction
(w) = weight fraction
(V) = volume
(W) = weight

We note that

$$v_f + v_m = 1 \quad \text{and}$$

$$w_f + w_m = 1$$

We can relate weight to volume fractions by introducing the density, ρ, of the composite and its constituents. Now

$$W_c = W_f + W_m$$

Which as $W = \rho V$, becomes

$$\rho_c V_c = \rho_f V_f + \rho_m V_m \text{ or}$$

$$\rho_c = \rho_f \frac{V_f}{V_c} + \rho_m \frac{V_m}{V_c}$$

$$\rho_f v_f + \rho_m v_m \qquad \text{.....(2.6)}$$

It may also be shown that

$$1/\rho_c = w_f/\rho_f + w_m/\rho_m \text{ .....(2.7)}$$

Also we have : $w_f = \frac{W_f}{W_c} = \frac{\rho_f V_f}{\rho_c V_c} = \frac{\rho_f}{\rho_c} v_f$

and similarly:

$$w_m = \frac{W_m}{W_c} = \frac{\rho_m V_m}{\rho_c V_c} = \frac{\rho_m}{\rho_c} v_m \qquad \text{.....(2.8)}$$

It is possible from these to convert from weight fraction to volume fraction, and vice versa, provided the densities of the reinforcement (ρ_f) and the matric ρ_m) are known.

Equation 2.5 shows that the density of the composite is given by the volume fraction adjusted sum of the densities of the constituents. This equation is not only applicable to density but in certain circumstances may apply to other properties of composites. A generalized form of the equation is

$$X_c = X_m v_m + X_f v_f \quad \text{.....(2.9)}$$

Where X_c represents an appropriate property of the composite, and, as before V is the volume fraction and the subscripts m and f refer to the matrix and reinforcement respectively. This equation is known as the Law of Mixtures.

The amount of reinforcement that can be incorporated in a given matrix is limited by a number of factors. For example with particulate reinforced metals the reinforcement content is usually kept to less than 40 vol. % (0.4 volume fraction) because of processing difficulties and increasing brittleness at higher contents. On the other hand, the processing methods for fibre reinforced polymers are capable of producing composites with a high proportion of fibres, and the upper limit of about 70% (0.7 volume fraction) is set by the need to avoid fibre – fibre contact which results in fibre damage. (Mathews et al, 1995)

2.5.2 Interface

Most properties of a composite are a complex function of a number of parameters as the constituents usually interact in a synergistic way so as to provide properties in the composite that are not fully accounted for by the law of mixtures. The chemical and strength characteristics of the interface between the fibres and the matrix are particularly important in determining the properties of the composite. The interfacial bond strength has to be sufficient for load to be transferred from the matrix to the fibres if the composite is to be stronger than the un-reinforced matrix. On the other hand, if we are also concerned with the toughness of the composite, the interface must not be so strong that it does not fail and allow toughening mechanisms such as debonding and fibre pull-out to take place.

2.5.3 Other parameters

Other parameters which may significantly affect the properties of a composite are the shape, size, orientation and distribution of the reinforcement and various features of the matrix such as the grain size for polycrystalline matrices. These, together with volume fraction, constitute what is called the microstructure of the composite.

However it should be noted that even for properties which are microstructure dependent, and which do not obey the law of mixture, the volume fraction still plays a major role in determining properties. The volume fraction is generally regarded as the single most important parameter influencing

the composite's properties. Also, it is an easily controllable manufacturing variable by which the properties of a composite may be altered to suit the application.

2.5.4 Homogeneity

A problem encountered during manufacture is maintaining a uniform distribution of the reinforcement. Ideally, a composite should be homogeneous, or uniform, but this is difficult to achieve. Homogeneity is an important characteristic that determined the extent to which a representative volume of the material may differ in physical and mechanical properties from the average properties of the material. Non-uniformity of the system should be avoided as much as possible because it reduces those properties that are governed by the weakest part of the composite. For example, failure in a non-uniform material will initiate in an area of lowest strength, thus adversely affecting the overall strength of a component manufactured from that material.

2.5.5 Orientation

The orientation of the reinforcement within the matrix affects the isotropy of the system. When the reinforcement is in form of equiaxed particles, the composite behaves essentially as an isotropic material whose elastic properties are independent of direction. When the dimensions of the reinforcement are unequal, the composite can behave as if isotropic, provided the reinforcement is randomly oriented, as in a randomly oriented, short fibre-reinforced composite. In other cases the manufacturing process may induce orientation of the reinforcement and hence loss of isotropy; the composite is then said to be anisotropic or to exhibit anisotropy.

In components manufactured from continuous fibre reinforced composites, such as unidirectional or cross-ply laminates, anisotropy may be desirable as it can be arranged for the maximum service stress to be in the direction that has the highest strength. Indeed, a primary advantage of these composites is the ability to control the anisotropy of a component by design and fabrication.

It is clear from the preceding discussion that many factors may be important in determining the properties of composites; this should be borne in mind when studying theoretical models as all the factors are seldom accounted for in the development of the models (Agarwal *et al.*, 1990).

2.6 FAILURE CRITERIA

When determining the strength of an isotropic material, it is conventional to use principal stresses or strains in conjunction with a failure criterion. Principal values are the maximal at a point in a component and are found from the stresses, or strains, at that point, expressed in a convenient set of orthogonal axes. When the stresses vary throughout the component, as is usually the case, it is necessary to calculate the principal values at several points to find the absolute maximum.

Having determined the principal stress or stain, we would use these maximal in an appropriate failure criterion to predict whether, or not, the material will fail, failure being taken as yielding i.e. onset of permanent deformation or fracture.

For isotropic materials, there are a large number of criteria, the appropriate choice depending on the material (is it brittle or ductile?) and the local stress field

(one-, two-, or three-dimensional). There is no single criterion that is universally applicable.

A simple criterion is the maximum principal stress theory which states that failure will occur, in a material under a multi-axial stress field, when the maximum principal stress attains a value equal to the yield (σ_y) obtained from a uniaxial tensile, i.e.

$$\sigma_1 = \sigma_y \quad \text{.....} \quad (2.11)$$

A more complicated criterion, often known as the Von Mises Criterion is derived from considerations of shear strain energy. The equation defining failure for a three – dimensional stress stress state is

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_y^2 \text{.....} \quad (2.12)$$

where σ_1 ,σ_2 and σ_3 are the principal direct stresses.

Under plane stress conditions, such as found in a thin sheet subjected to biaxial loading, equation 2.8 reduces to

$$\sigma_1^2 + \sigma_2 - \sigma_1\sigma_2 = \sigma_y^2 \quad \text{(Mathews } et\ al.\text{, 1995)} \text{.....} \quad (2.13)$$

2.7 GASKETS AND SEALS

2.7.1 GASKETS

A gasket is a specific form of mechanical seal used to fill space in order to keep liquids, gases and other contaminants from getting where they are not wanted. Most commonly used in industries where mechanical parts are fitted together, such as the automotive industry, gaskets can come in all shapes and sizes and have a variety of materials to choose from; each designed to perform sealing functions for specific purposes. Fig. 2.5

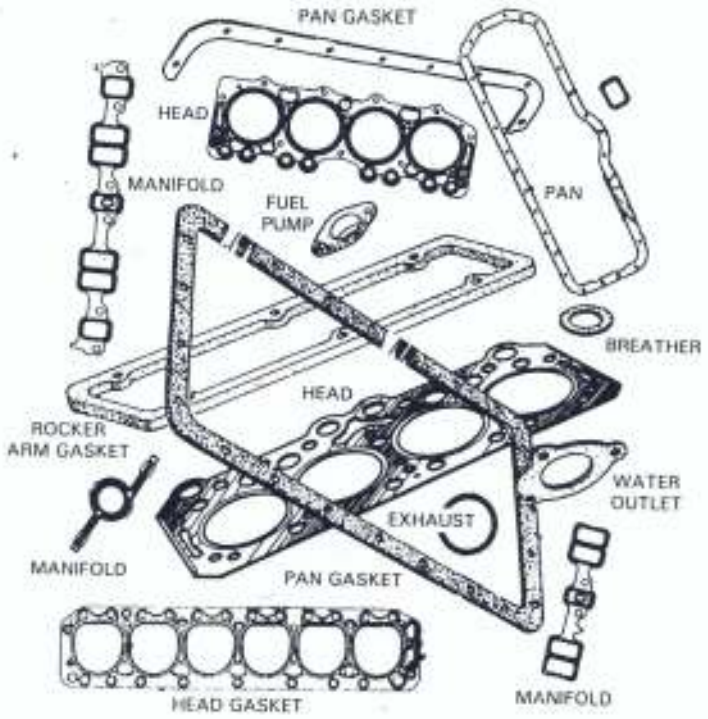


Fig 2.5: Few of the typical gaskets used in an engine.

In an engine where machined parts fit together, gaskets are used to make the joints tight and to prevent leakage of oil, water and /or gasoline.

The cylinder heads must seal in the water of the cooling system and must also contain the pressure of the exploding fuel. Thin steel, copper, and asbestos gaskets are used between the head and the engine block.

It is very difficult to machine metal parts to the degree of accuracy necessary for leak proof joints. As the engine expands and contracts during warm up and

cooling periods, there are minute shifts in the fastened parts. This, coupled with vibration, will loosen many parts to the point of leakage.

Gasket material is somewhat resilient (soft and springy) and will adapt itself to expansion and contraction. It will also conform to irregularities in the surfaces of the mating parts. Fig. 2.6 (Martin et al, 1985)

2.7.1.1 HOW GASKETS ARE MADE

Because of the variety of material a gasket can be made from the creation process varies, but primarily consists of simply cutting out the proper shape from the materials in question. Materials commonly used in gasket making are paper, silicon, rubber, metal fiberglass, plastic polymer and even felt. Some gaskets may even contain asbestos, if their specific application calls for it.

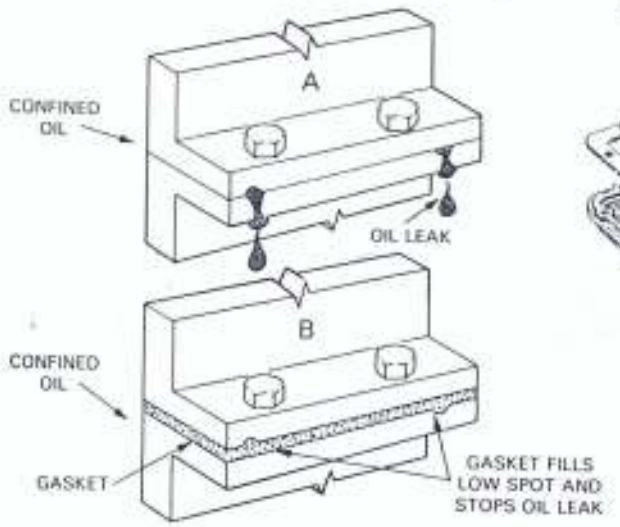
2.7.1.1 HOW GASKETS WORK

Designed primarily to fit between mated machine parts, the gasket is compressed between two objects, filling the microscopic spaces between them, and thereby creating a seal that will keep liquid and gases and dirt from entering the space between the components. By keeping the enclosure contamination-free, the gasket allows the machinery to last longer, work more efficiently, and provide a certain amount of predictable performance.

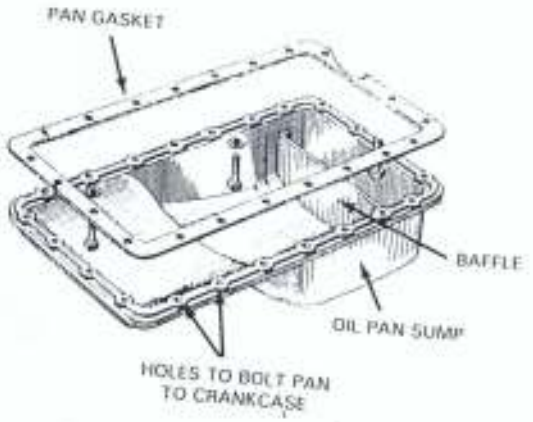
It is said that the stronger the compression, the better the gasket works. If there is not enough pressure on the seal, it will slide around or open up and allows contaminants through. A hot compression test is used to determine if a particular gasket passes muster. This test applies with constant temperature and pressure

on the gasket measuring the "compression set" of the seal. This will determine the stress/creep relaxation resistance and reserve, letting manufacturers know if the gasket is going to open up under pressure.

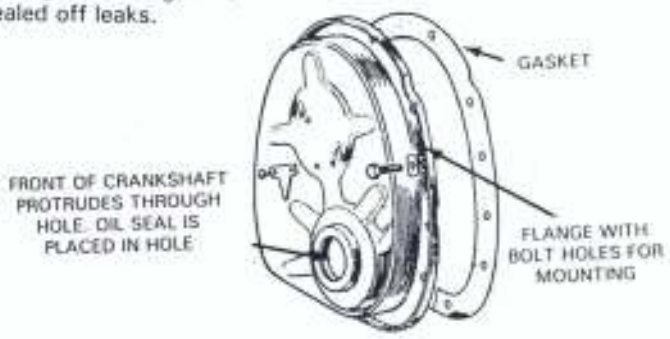
Many industrial applications of gaskets include compression pressures of up to 2000 psi or even higher. It is thought that the more compressive load that is applied to a gasket, the longer it will last. When shopping for a gasket, consider the application. Fig 2.6 (Chris, 2006).



Gaskets are designed to compress and seal irregular surfaces. Note in A how oil is leaking out through two areas while in B a gasket has sealed off leaks.



Engine oil pan size and shape will vary widely. (Nissan)

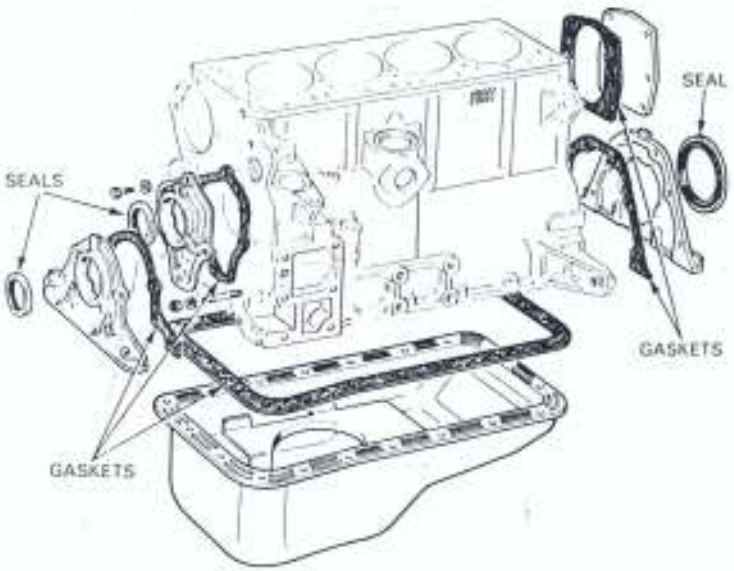


One type of stamped steel timing gear cover. (British-Leyland)

FIG 2.6: Application of gaskets

2.7.2 SEALS

Seals prevents leakage between a stationary part (housing and cover) and a moving part. They can be formed in engines ,transmissions, rear ends , power steering units, and almost any parts containing fluid and moving parts. A seal allows the shaft to spin or slide inside the non moving part without fluid leakagr. Seals are normally made of synthetic rubber moulded unto a metal body. Fig 2.7 (James,1998)



Gasket prevents leakage between stationary parts.
Seal prevents leakage between moving part and stationary part.
(Fiat)

Fig 2.7 Seal mounted in stationary part.

2.7.2.1 OIL SEALS

Cars and light trucks may have up to 15 oil seals or shaft seals. The seal closes or seals the space between stationary and moving parts. It protects the bearings, retains the lubricant and seal out contaminants. The oil seal may act as a separator that prevents two different substances from mixing.

Most oil seals are radial lip seals. A metal case holds the flexible sealing lip against the rotating shaft. Some seals have a garter spring that helps hold the lip in contact with the sealing surface. Seals of this type include the front and rear crankshaft seals and the crankshaft seal on overhead – crankshaft engines. Front-wheel grease seals are similar to oil seals. Lip seals are also used on the steering – gear input shaft and the power – steering – pump shaft.

The automobile and engine use a variety of seals. They include O-ring seals and packing seals. These often serve as gaskets to seal between two no-moving parts.

2.7.3 SEALANTS/ SEALERS

A sealer is commonly coated on a gasket to help prevent leakage, and to hold the gasket during assembly. There are numerous kinds of sealers. They have different properties and are designed for different uses.

Hardening sealers are used on permanent assemblies such as fittings and threads, and for filling of uneven surfaces. They are usually resistant to heat and most chemicals .

Nonhardening sealers are for semi permanent assemblies: cover plates, flanges, threads, hose connections, and numerous other applications. They are also resistant to most chemicals and moderate heat. Shellac is a nonhardening sealer. It is a gummy, sticky substance that remains pliable. It is frequently used on fiber gasket as a sealer and to hold the gasket in place during assembly.(James,1998)

2.7.3.1 FORMED IN-PLACE GASKETS

Instead of being preformed, some gaskets are formed in place by squeezing a bead of plastic gasket material or sealant from a tube onto one of the mating surfaces. Typical surfaces include valve covers, thermostat housings, water pumps and differential covers.

There are two common types of form-in-place gasket materials: aerobic and anaerobic.

Aerobic material hardens in the presence of air. It is used to form a rubber-like gasket on thin, flexible flanges.

Anaerobic material hardens in absence of air to form a plastic-like substance. It is used between two smooth, true surfaces, not on thin, flexible flanges. These materials are not the same and cannot be used interchangeably (William *et al.*, 1993).

2.8 MECHANICAL PROPERTIES OF MATERIALS

2.8.3 HARDNESS

The hardness of a material is a poorly defined term which has many meanings depending upon the experience of the person involved. In general, hardness usually implies a resistance to deformation, and for metals the property is a measure of their resistance to permanent or plastic deformation. To a person concerned with the mechanics of materials testing, hardness is most likely to mean the resistance to indentation, and to the design engineer it often means an easily measured and specified quantity which indicates something about the strength and heat treatment of the metal. There are three general types of

hardness measurements depending on the manner in which the test is conducted. These are: indentation hardness, scratch hardness and rebound or dynamic hardness. Only indentation hardness is of major engineering interest for metals.

2.8.1.1 BRINELL HARDNESS TEST

The Brinell hardness test consists in indenting the metal surface with a 10mm diameter steel ball at a load of 3000kg. For soft metals, the load is reduced to 500kg to avoid too deep an impression and for very hard metals a tungsten carbide ball is used to minimize distortion of the indenter. The load is applied for a standard time, usually 30s and the diameter of the indentation is measured with a low-power microscope after removal of the load. The average of two readings of the diameter of the impression at right angles should be made. The surface on which the indentation is made should be relatively smooth and free from dirt or scale. The Brinell hardness number (BHN) is expressed as the load P divided by the surface area of the indentation. This is express by the formula:

$$BHN = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)} = \frac{P}{\pi D t} \quad \text{.....} \quad (2.14)$$

Where P = applied load, kg

D = diameter of ball, mm

d = diameter of indentation, mm

t = depth of the impression, mm

The units of the BHN are kilograms per square millimeter (Kg/mm^2) $1kgf/mm^2 = 9.8Mpa$).

2.8.1.2 MEYER HARDNESS TEST

Meyer suggested that a more rational definition of hardness than that proposed by Brinell would be one based on the projected area of the impression rather than the surface area. The mean pressure between the surface of the indenter and the indentation is equal to the load divided by the projected are of the indentation.

$$p_m = \frac{p}{\Pi r^2} \text{.....} \quad \text{....(2.15)}$$

Meyer proposed that this mean pressure should be taken as the measure of hardness. It is referred to as the Meyer hardness.

$$\text{Meyer hardness} = \frac{4p}{\pi d^2} \text{.....} \quad (2.16)$$

Like the Brinell hardness, Meyer hardness has units of kg/mm^2. The Meyer hardness is less sensitive to the applied load than the Brinell hardness. For a cold worked material the Meyer hardness is essentially constant and independent of load, while the Brinell hardness decreases as the load increases. For an annealed metal the Meyer hardness increases continuously with the load because of strain hardening produced by the indentation. The Brinell hardness, however, first increases with load and then decreases for still higher loads. The Meyer hardness yet it is rarely used for practical hardness measurements.

2.8.1.3 ROCKWELL HARDNESS TEST

This test utilizes the depth of indentation under constant load as a measure of harness. A minor load of 10kg is first applied to seat the specimen. This minimizes the amount of surface preparation needed and reduces the tendency for

ridging or sinking in by the indenter. The major load is then applied, and the depth of indentation is automatically recorded on a dial gage in terms of arbitrary hardness members. The dial contains 100 divisions, each division representing a penetration of 0.002mm. The dial is reversed so that a high hardness which corresponds to a small penetration results in a high hardness number. This is in agreement with the other hardness numbers described previously but unlike the Brinell and Vickers hardness designations, which have units of per square millimeter (kgf/mm^2), the Rockwell hardness numbers are purely arbitrary.

2.8.1.4 VICKERS HARDNESS TEST

The Vickers hardness test uses a square-base diamond pyramid as the indenter. The included angle between opposite faces of the pyramid is 136^0. This angle was chosen because it approximates the most desirable ratio of indentation diameter to ball diameter in the Brinell hardness test. Because of the shape of the indenter, this is frequently called the diamond – pyramid hardness test. The diamond-pyramid hardness number (DPH) or Vickers hardness number (VHN or VPH) is defined as the load divided by the surface area of the indentation. In practice, this area is calculated from microscopic measurements of the lengths of the diagonals of the impression. The DPH may be determined from the following equation:

$$DPH = \frac{2p\sin\left(\frac{\theta}{2}\right)}{L^2} = \frac{1.854p}{L^2} \quad \text{.....} \qquad (2.17)$$

where P = applied load, kg

L = average length of diagonals, mm

θ = angle between opposite faces of diamond = 136^0

The Vickers hardness test has received fairly wide acceptance for research work because it provides a continuous scale of hardness, for a given load, from very soft metals with a DPH of 5 to extremely hard materials with a DPH of 1,500. The loads ordinarily used with this test range from 1 to 120kg, depending on the hardness of the metal to be tested. A perfect indentation made with a perfect diamond-pyramid indenter would be a square.

2.8.1.5 . MICROHARDNESS TESTS

Many metallurgical problems require the determination of hardness over very small areas. The measurement of the hardness gradient at a carburized surface, the determination of the hardness of individual constituents of a microstructure, or the checking of the hardness of a delicate watch gear might be typical problems. The development of the knoop indenter by the National Bureau of Standards and the introduction of the Tukon tester for the controlled application of loads down to 25g have made micro hardness testing a routine laboratory procedure.

The knoop indenter is a diamond ground to a pyramidal form that produces a diamond-shaped indentation with the long and short diagonals in the approximate ratio of 7:1 resulting in a state of plane strain in the deformed region. The knoop hardness number (KHN) is the applied load divided by the unrecovered projected area of the indentation.

$$KHN = \frac{P}{A_p} = \frac{P}{L^2C} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.18)$$

where p = applied load, kg

A_p = unrecovered projected are of indentation, mm^2

L = length of long diagonal, mm

C = a constant for each indenter supplied by manufacture

The surface of the specimen must be carefully prepared. Metallographic polishing is usually required. Work hardening of the surface during polishing can influence the results. The long diagonal of the knoop impression is essentially unaffected by elastic recovery for loads greater than about 300g. However, for lighter loads the small amount of elastic recovery becomes appreciable. Further, with the very small indentation produced at light loads the error in locating the actual ends of the indentation becomes greater. Both these factors have the effect of giving a high hardness reading, so that it is usually observed that the knoop hardness number increases as the load is decreased below about 300g.

2.8.1.6 HARDNESS AT ELEVATED TEMPERATURE

Interest in measuring the hardness of metals at elevated temperatures had been accelerated by the great effort which has gone into developing alloys with improved high temperature strength. Hot hardness gives a good indication of the potential usefulness of an alloy for high temperature strength applications. Some degree of success has been obtained in correlating hot hardness with high temperature strength properties. Hot hardness testers using a Vickers indenter made of sapphire and with provisions for testing in either vacuum or an inert atmosphere ere have been developed, and a high temperature micro hardness test has been described.

In an extensive review of hardness data at different temperatures, Westbrook showed that the temperature dependence of hardness could be expressed by:

$$H = Ae^{-BT} \quad - \qquad (2.19)$$

Where H = hardness, kgf/mm^2

T = test temperature

A,B = constant

Hardness measurements as a function of temperature will show an abrchange at the temperature at which an allotropic transformation occurs (Hardness Testing, 1985).

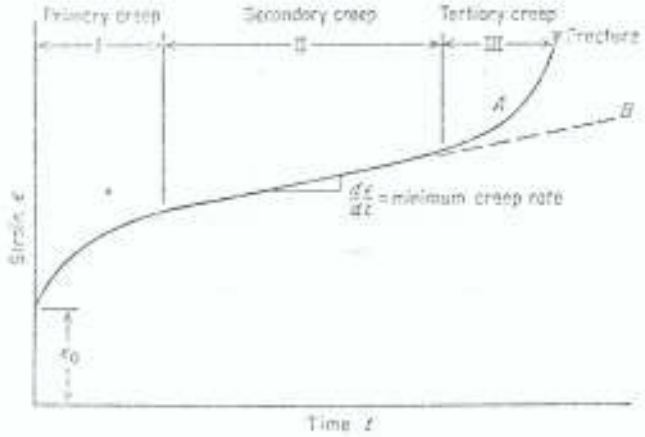
2.8.2 CREEP

The progressive deformation of a material at constant stress is called creep. To determine the engineering creep curve for a metal, a constant load is applied to a tensile specimen maintained at a constant temperature and the strain (extension) of the specimen is determined as a function of time. Although the measurement of creep resistance is quite simple in principle, in practice it requires considerable laboratory equipment. The lapsed time of such tests may extend to several months, while some tests have been run for more than 10 years.

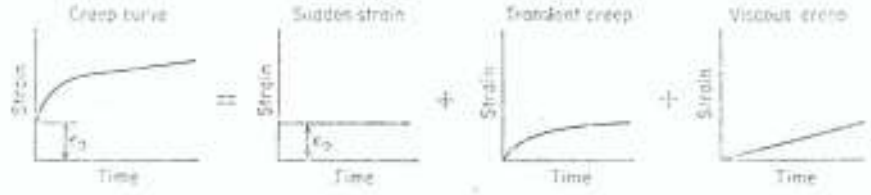
2.8.2.1 CREEP CURVE

The curve in the figure below illustrates the idealized shape of a creep curve. The slope of this curve ($d\varepsilon/dt$ or $\dot{\varepsilon}$) is referred to as the creep rate. Following an initial rapid elongation of the specimen, ε_o, the creep rate decreases with time, then reaches essentially a steady state in which the creep rate changes

little with time and finally the creep increases rapidly with time until fracture occurs. Thus, it is natural to discuss the creep curve in terms of its three stages. It should be noted, however, that the degree to which these three stages are readily distinguishable depends strongly on the applied stress and temperature.



Typical creep curve showing the three steps of creep. Curve *A*, constant-load test; curve *B*, constant-stress test.



Andrade's analysis of the competing processes which determine the creep curve.

Fig. 2.8: Typical extension-time curve

2.8.2.2 CREEP TEST

In making an engineering creep test, it is usual practice to maintain the load constant throughout the test. Thus, as the specimen elongates and decreases in cross sectional area, the axial stress increases. The initial stress which was applied to the specimen is usually the reported value of stress. Methods of compensating for the change in dimensions of the specimen so as to carry out the creep test under constant-stress conditions have been developed. When constant stress tests are made it is found that the onset of stage III is greatly delayed. The dashed line (curve B) shows the shape of a constant-stress creep curve. In engineering situations, it is usually the load not the stress that is maintained constant, so a constant-load creep test is more important. However, fundamental studies of the mechanism of creep should be carried out under constant-stress conditions.

2.8.2.3 STAGES OF CREEP

From the figure above, the strain represented by ε_o occurs practically instantaneously on the application of the load. Even though the applied stress is below the yield stress, not all the instantaneous strain is elastic. Most of this strain is instantly recoverable upon the release of the load (elastic), while part is recoverable with time (anelastic) and the rest is nonrecoverable (plastic). Although the instantaneous strain is not really creep, it is important because it may constitute a considerable fraction of the allowable total strain in machine parts. Sometimes the instantaneous strain is subtracted from the total strain in the creep

specimen to give the strain due only to creep. This type of creep curve starts at the origin of coordinates.

The first stage of creep, known as primary creep represents a region of decreasing creep rate. Primary creep is a period of predominantly transient creep in which the creep resistance of the material increase by virtue of its own deformation. For low temperatures and stresses, as in the creep of lead at room temperature, primary creep is the predominant creep process.

Creep in this period is solely due to dislocation movement in crystalline materials. Work-hardening occurs more rapidly than any concomitant recovery processes so the creep rate decelerates with time.

Two alternative equations are used to describe primary creep. The first is

$$\varepsilon = \alpha \log t \quad \text{.....2.20}$$

Where α is a constant and t is time. This equation usually only applies at very low temperatures, but it does hold for a variety of materials, e.g. aluminium, rubber and glass. A more widely obeyed equation, which is applicable at higher temperature and stress is

$$\varepsilon = \beta t^m \quad \text{.....2.21}$$

Where β is a constant and m ranges from 0.03 to 1.0 depending on the material, stress and temperature.

The second stage of creep, also known as secondary creep, is a period of nearly constant creep rate which results from a balance between the competing processes of strain hardening and recovery. For this reason, secondary creep is usually referred to as steady-state creep. The average value of the creep rate

during secondary creep is called the minimum creep rate. This is the most important design parameter derived from the creep curve.

During this phase the rate of recovery is sufficiently fact to balance the rate of work-hardening, so that the material creeps at a steady rate. Structural observations show that polygonization is an important recovery process during secondary creep. Grain boundary sliding is also a feature of polycrystalline materials deforming by steady-state creep. However, the contribution to the total strain from grain boundary sliding is generally small, less than straight line, viz.

$$\varepsilon = Kt \quad \text{.....2.22}$$

Where K is constant, which is temperature and stress-dependent. This is because recovery processes are temperature and stress-dependent; the temperature dependence, for example, arises from the change in the rate of diffusion with temperature (discussed in Chapter 7). In fact the creep rate, which is equal to the constant K, can be represented by an expression of the form

$$d\varepsilon/dt = A\sigma^n \exp\left(-Q/RT\right) \quad \text{.....2.23}$$

Where A and n are constants; n is usually in the range 3 to 7 for metals and 1 to 2 for polymers. Q is called the activation energy for creep and is approximately equal to the activation energy for diffusion (Anderson, *et al.*, 1994).

The third stage or tertiary creep mainly occurs in constant load creep tests at high stresses at high temperatures. Tertiary creep occurs when there is an effective reduction in cross-sectional area either because of necking or internal void formation. Third stage creep is often associated with metallurgical changes such as coarsening of precipitate particles, recrystallization, or diffusional changes

in the phases that are present. Creep curve with three well-defined stages will be found for only certain combinations of stress and temperature.

2.8.2.4 CREEP IN PLASTICS

Creep in steel is important only at elevated temperatures. In general, creep becomes significant at temperatures above about 0.4Tm where Tm is the absolute melting temperatures. However, materials having low melting temperatures will exhibit creep at ambient temperatures. Good examples are lead and various types of plastic. Lead has a melting temperature of 326^{0}C (599k), and at 20^{0}C (293k or about 0.5Tm), it exhibits similar creep characteristics to those of iron at 650^{0}C.

Plastics also creep at ambient temperatures but, compared to lead, they are able to sustain much greater extensions before failure. The creep curves are similar in shape to those for metals, but the mechanism of deformation is quite different because of the difference in structure of the material. Finally, it should be noted that with polymer materials, the primary creep stage, where the creep is decreasing, is largely recovered when the creep load is removed. This behaviour is unlike that observed in most metallic systems.

The complex Fig.2.6 processes taking place during creep make it difficult to quote an equation that describes the creep behaviour of all polymers. Many empirical equations have been proposed and one which applies to some of the common engineering plastics has the form:

$$\Sigma = \Sigma_0 + B\sigma^m t^k \quad \text{.....-} \qquad (2.24)$$

where Σ = tensile creep strain after a time t.

Σ_0 = initial strain produced on loading

σ = applied creep stress

B,M,K are constant for a given polymer

In many polymers, the initial strain is very small and can be ignored, so that in these cases:

$$\Sigma = B\sigma^m t^k \qquad (2.25)$$

The equipment for testing creep in plastics in the laboratory is shown below.

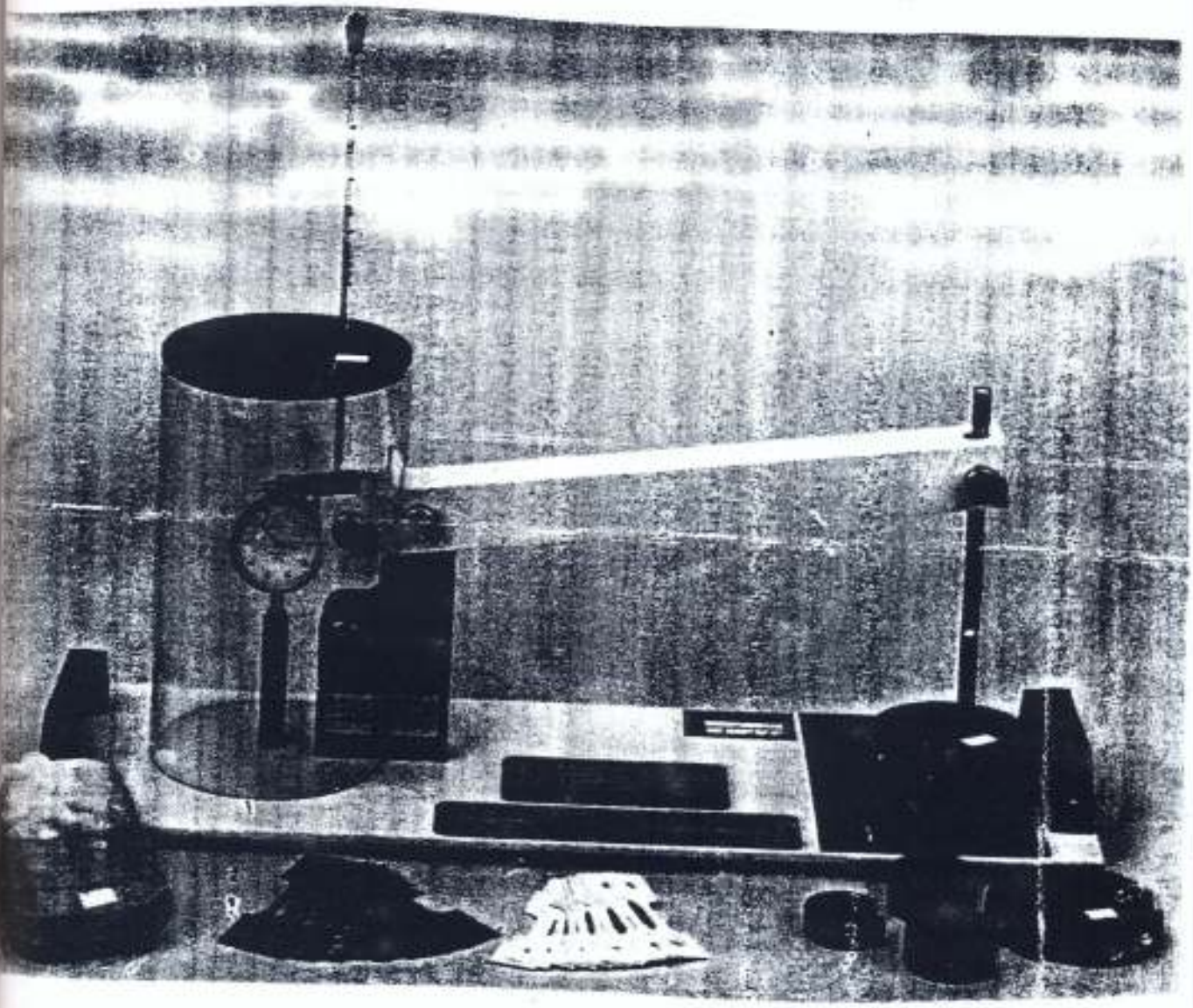


Fig 2.9: Creep testing machine

2.8.2.5 PREDICTION OF LONG-TIME PROPERTIES

Frequently high-temperature strength data are needed for conditions for which there is no experimental information. This is particularly true of long-time creep and stress-rupture data. Obviously, in such situations extrapolation of the data to long times is required. Reliable extrapolation of creep and stress-rupture curves to longer times can be made only when it is certain that no structural changes occur in the region of extrapolation which would produce a change in the slope of the curve. A logical method of extrapolating stress-rupture curves which takes into consideration the changes in slope due to structural changes has been proposed by Grant and Bucklin.

As an aid in extrapolation of stress-rupture data several time-temperature parameters have been proposed for trading off temperature for time. The basic idea of these parameters is that they permit the prediction of long-time rupture behaviour from the results of shorter time tests at higher temperatures at the same stress. When properly developed, these time-temperature parameters can be used to represent creep-rupture data in a compact form, allowing for analytical representation and interpolation of data. They can also be used to provide a simple means of comparing the behaviour of materials and rating them on a relative basis. Finally, these parameters are useful to extrapolate experimental data to ranges ordinarily difficult to evaluate directly because of test limitations.

The Sherby-Dorn temperature-compensated time parameter provides a rational basis for the development of these parameters.

$$\theta = t.esp\left(\frac{-\theta}{RT}\right) \quad \ldots\ldots \qquad (2.26)$$

Taking the natural logarithm of both sides

$$\ln\theta = \ln t - \frac{\theta}{RT} \quad \text{.....} \quad (2.27)$$

$$\ln t = \ln\theta + \frac{\theta}{RT} \quad \text{.....} \quad (2.28)$$

If θ and θ/R are functions of stress only, equation (2.24) is linear in lnt and I/T.

Where t can be the time to rupture or time to reach a given creep rate.

From equation (2.24), Larson-Miller parameter can be formulated as:

$T(\ln t + c) = f(\sigma) = p$ or

$P = T(\ln t + c)$ ..... .(2.29)

Where T = test temperature in k

t = time to rupture in h

c = Larson-Miller Constant often taken to be 46. The value varies from about 35-60 depending on materials.

The Larson-Miller parameter expressed in terms of minimum creep rate instead of time to rupture is:

$P = T(c - \ln \dot{\varepsilon})$ (Dieter 1988)..... (2.30)

CHAPTER THREE

3.0 MATERIALS AND EXPERIMENTAL TECHNIQUES

3.1 PROCUREMENT OF MATERIALS

As stated by (Mathews et.al., 1995), composite material consits of two or more distinct constituents, the matrix and the reinforcement. The matrix used in this project work is Top Bond white glue while the reinforcements are: Bamboo (*Ozizentera arbonica*), coconut husk (*Cocus nucifera*), sponges (*Mornodica bracteate*), and wood (Cordial).

These plant products are essentially micro-composites consisting of cellulose fibres in an amorphous matrix of lignin and hemicellulose and often have a high length to diameter ratio, called the 'aspect ratio' greater than 1000. The strength and stiffness of these fibres are low compared with the synthetic fibres currently available.

Other materials used are: Nylon for moulding, plywood for moulding box, measuring cylinder, mixer and fastener.

3.2 PREPARATION OF MATERIALS

Some of the materials mentioned above need to be prepared before they can be used. The following operations were therefore carried out on them.

3.2.1 PREPARATION OF BAMBOO, COCONUT HUSK, SPONGES AND WOOD

The above mentioned fibres were sun dried and pulverized. Bamboo and wood were sawn and the pulverized dust were collected in the furniture workshop while the coconut husk and sponges were pulverized with the ball mill at the Mineral processing Laboratory of the Department of Metallurgical and Materials

Engineering, FUTA. This was followed by sieving, using aperture size of 850μm at the same laboratory.

3.2.2 PREPARATION OF BONDING MATERIAL

The bonding material used as the matrix, Top Bond white glue was stirred properly for homogeneity of the liquid.

3.2.3 MOULD PREPARATION

The plywood was used for the production of mould for casting of the material. The mould was produced to have the expected shape and size of the final finished composites. The mould cavities have the same size as the control sample.

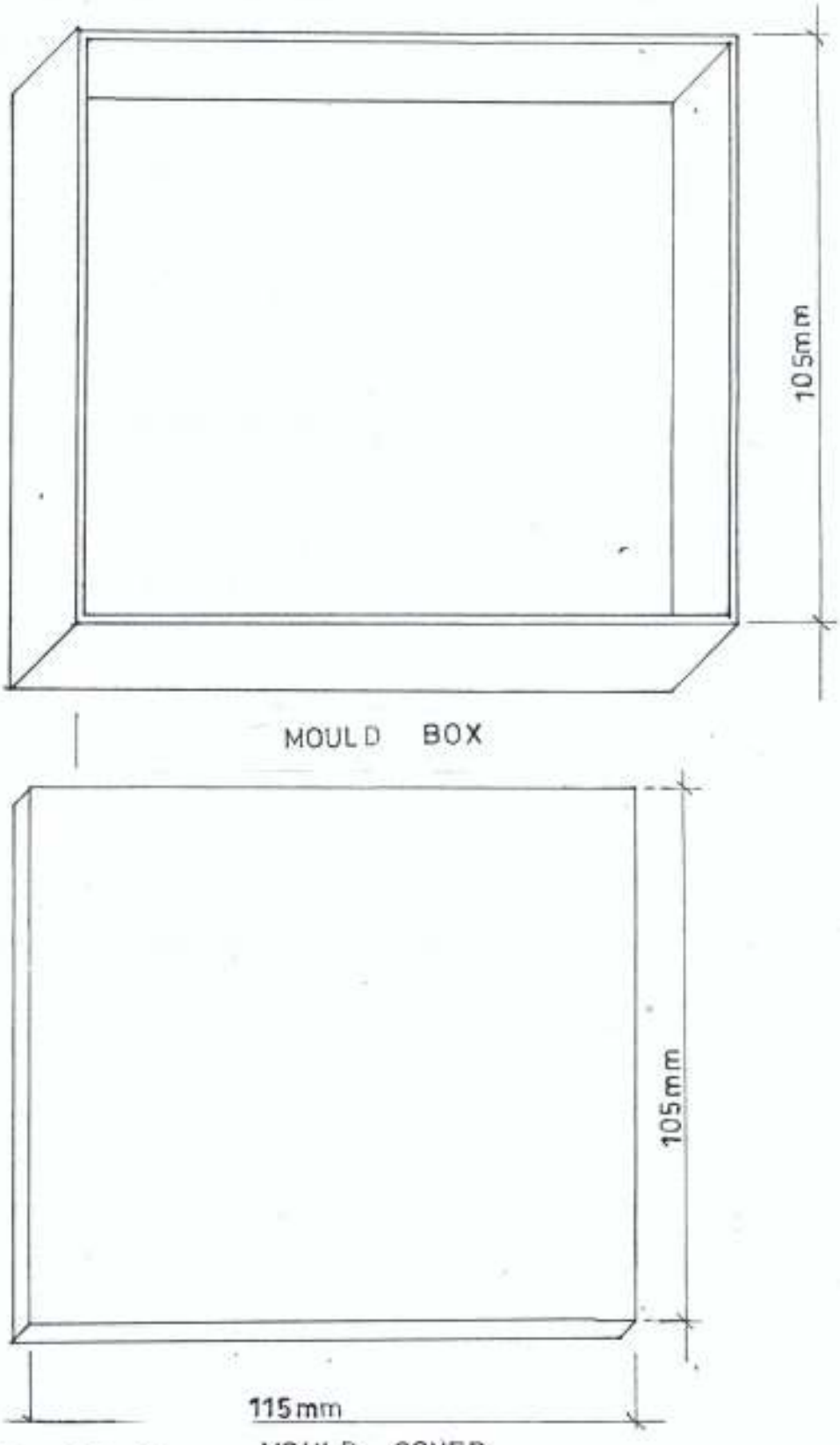


FIG. 3.1: Wood Mould

3.3 MOULDING AND CASTING OF PRODUCTS

Casting is the process of pouring liquid materials into a predetermined mould cavity for solidification.

3.3.1 MIXING PROPORTION

Volumetric measuring cylinder was used to measure the materials in order to obtain the expected mixture composition. It was calibrated in milliliter (ml). This was used to measure the fibres and the matrix in the proportion 40:60 respectively. Fifteen samples were produced in the following given proportions:

S/N	MATERIALS	FIBRE COMPOSITION(S)(40%)
1	Ba	Bamboo
2	Ch	Coconut husk
3	Sp	Sponges
4	Wd	Wood
5	Ba + ch	Bamboo and coconut husk
6	Ba + Sp	Bamboo and sponges
7	Ba + Wd	Bamboo and wood
8	Ch + Sp	Coconut husk and sponges
9	Ch + Wd	Coconut husk and wood
10	Wd + Sp	Wood and Sponges
11	Ba + Ch + Sp	Bamboo, Coconut husk and Sponges
12	Ba + Ch + Wd	Bamboo, Coconut husk and wood
13	Ba + Sp + Wd	Bamboo, Sponges and Wood
14	Ch + Sp + Wd	Coconut husk, Sponges and Wood

15 Ba + Ch + Sp + Wd Bamboo, Coconut husk, Sponges and Wood

Each of these was properly mixed with the binder (60%) to produce each homogeneous paste.

To cast, nylon was spread on the mould cavities and the homogeneous pastes were poured inside. After proper spreading, nylon was used to cover them before they were finally covered with the mould cover.

3.3.2 PRESSING AND DRYING

The pastes were compressed by placing a load of 20kg on them each for five minutes in other to obtain the shape of the desired products. The casts were allowed to solidify and after which they were removed and sun dried.

3.4 MEASUREMENT OF MECHANICAL PROPERTIES OF THE MATERIALS

Two major tests were carried out on the products. These were creep test and hardness test. A model was adapted to predict the rupture time for the gaskets at elevated temperatures of (150^0C, 200^0C and 250^0C).

3.4.1 CREEP TEST

The test was carried out at the Mineral Processing Laboratory of the Department of Metallurgical and Materials Engineering, FUTA. Laboratory SM106 Creep Measurement Apparatus was used together with watch for recording the time interval for the extension produced by the applied load on the specimens.

3.4.1.1 PREPARATION OF MATERIAL FOR CREEP TEST

From the materials, the shape below was produced and used to carry out the test.

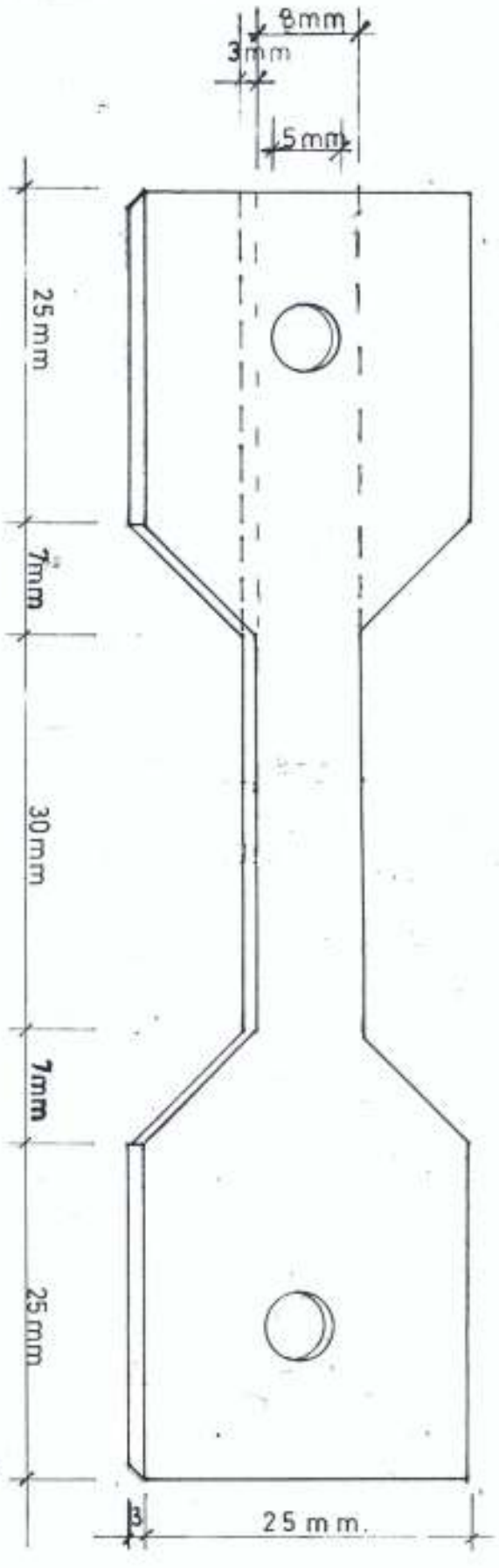


FIG. 3.2: Creep Specimen

3.4.1.2 TEST PROCEDURE

The specimen was positioned on the machine and a constant, predetermined load of 0.2kg was added. The load hanger was raised to the loading position and fixed at that point. After proper arrangement, the DTI was zero and the stop watch reset. The load was gently released and the stop watch started. Extension readings from the DTI were taken after every 1-minute for 60 minutes.

3.4.2 HARDNESS TEST

The hardness test was carried out at the Nigerian Foundry Limited, Ilupeju, Lagos. Two tests was carried out, one at room temperature and the other at elevated temperature (200^{0}C) by Equip tip hardness mobile tester.

3.4.2.1 TEST PROCEDURE FOR ROOM TEMPERATURE HARDNESS (25^{0}C)

The materials were placed horizontally on the platforms and were pressed five times for indentation. The hardness value was displaced on the screen corresponding to the Brinell hardness number.

3.4.2.2 TEST PROCEDURE FOR ELEVATED TEMPERATURE HARDNESS (200^{0}C)

The material was charged into the furnace and maintained at 200^{0}C for 30 minutes. This was followed by testing. Each material was brought out and placed horizontally on the platform and pressed five times for indentation. The hardness value was displaced on the screen corresponding to the Brinell hardness number.

CHAPTER FOUR

4.0 EXPERIMENTAL RESULTS AND DISCUSSION

In this chapter, the results are shown and discussed as follows:

4.1 RESULTS

4.1.1 CREEP TEST RESULTS

Data from the creep test experiment was given in table 4.1 below. This was followed by the corresponding figures (Fig. 4.1-4.4). From the curves, the creep rate for each was determined:

TABLE 4.1: DATA FOR THE CREEP TEST EXPERIMENT SHOWING EXTENSION (mm) AGAINST TIME (Min) FOR THE GASKET MATERIALS AT ROOM TEMPERATURE (25°C)

MATERIALS / TIME	Ba	Ch	Sp	Wd	Ba+ Ch	Ba+ Sp	Ba+ Wd	Ch+ Sp	Ch+ Wd	Sp+ Wd	Ba+ Ch+ Sp	Ba+ Ch+ Wd	Ba+ Sp+ Wd	Ch+ Sp+ Wd	Ba+ Ch+ Sp+ Wd	Control Material
1	9.70	5.51	5.52	639	7.50	6.77	6.24	3.30	5.34	5.90	6.87	5.83	5.30	5.12	3.40	4.85
2	9.99	5.93	6.17	7.15	8.60	7.31	7.13	3.59	5.90	6.35	7.55	6.41	5.95	5.47	3.78	4.88
3	10.75	6.22	6.62	7.61	9.34	7.61	7.71	3.78	6.25	6.66	7.95	6.78	6.39	5.69	3.99	4.90
4	10.97	6.43	6.99	7.98	9.89	7.95	8.20	3.92	6.51	6.89	8.29	7.05	6.74	5.69	3.99	4.90
5		6.61	7.30	8.31	10.36	8.21	8.59	4.03	6.71	7.08	8.56	7.25	7.00	5.97	4.33	4.92
6		6.76	7.57	8.59	10.80	8.43	8.94	4.12	6.91	7.22	8.79	7.42	7.25	6.11	4.45	4.93
7		6.88	7.77	8.82	11.15	8.61	9.26	4.21	7.06	7.36	9.02	7.61	7.46	6.22	4.57	4.94
8		7.00	7.94	9.04	11.47	8.87	9.53	4.28	7.22	7.49	9.21	7.71	7.63	6.32	4.68	4.95
9		7.10	8.09	9.25	11.80	8.97	9.79	4.35	7.32	7.61	9.40	7.81	7.76	6.40	4.78	4.96
10		7.20	8.25	9.42		9.06	10.03	4.41	7.41	7.71	9.57	7.89	7.93	6.48	4.86	4.97
11		7.30	8.41	9.58		9.19	10.25	4.47	7.51	7.82	9.74	7.97	8.10	6.56	4.94	4.97
12		7.38	8.57	9.76		9.32	10.43	4.53	7.60	7.92	9.89	8.05	8.25	6.63	5.02	4.98
13		7.46	8.72	9.92		9.42	10.61	4.58	7.70	8.02	10.04	8.13	8.39	6.69	5.09	4.99
14		7.54	8.87	10.8		9.51	10.79	4.63	7.77	8.11	10.19	8.23	8.53	6.75	5.16	5.00
15		7.62	9.13	10.23		9.61	10.96	4.65	7.83	8.20	10.31	8.30	8.67	6.80	5.22	5.00
16		7.70	9.31	10.36		9.72	11.16	4.73	7.91	8.28	10.42	8.36	8.79	6.85	5.27	5.01
17		7.76	9.49	10.48		9.82	11.32	4.76	7.98	8.38	10.56	8.42	8.91	6.90	5.32	5.02
18		7.82	9.66	10.60		9.90	11.48	4.80	8.05	8.45	10.68	8.48	9.04	6.94	5.38	5.02
19		7.88	9.82	10.74		9.99	11.60	4.84	8.10	8.52	10.78	8.56	9.16	6.99	5.43	5.02
20		7.94	9.97	10.85		10.08	11.80	4.88	8.17	8.59	10.87	8.62	9.28	7.03	5.48	5.03
21		8.00	10.12	10.95		10.16	11.90	4.92	8.24	8.66	10.96	8.67	9.38	7.07	5.53	5.03
22		8.06	10.29	11.06		10.24		4.95	8.28	8.72	11.06	8.77	9.49	7.10	5.58	5.04
23		8.12	10.44	11.17		10.32		4.99	8.32	8.78	11.17	8.86	9.60	7.15	5.63	5.04
24		8.18	10.55	11.29		10.40		5.03	8.35	8.83	11.26	8.94	9.17	7.18	5.68	5.05
25		8.24	10.70	11.39		10.47		5.07	8.42	8.87	11.34	9.04	9.82	7.23	5.73	5.05
26		8.30	10.85	11.48		10.55		5.10	8.48	8.93	11.34	9.16	9.90	7.26	5.77	5.06
27		8.36	11.00	11.56		10.36		5.14	8.54	8.98	11.52	9.26	10.07	7.30	5.82	5.06
28		8.40	11.13	11.67		10.72		5.17	8.59	9.03	11.60	9.36	10.12	7.34	5.86	5.06
29		8.44	11.27	11.77		10.80		5.20	8.64	9.08	11.64	9.48	10.23	7.37	5.91	5.06
30		8.48	11.35	11.84		10.87		5.24	8.68	9.13	11.70	9.60	10.32	7.45	5.96	5.07
31		8.52	11.50	11.29		10.95		5.27	8.74	9.17	11.80	9.72	10.41	7.48	6.00	5.07
32		8.57	11.59	11.99		11.01		5.30	8.78	9.22	11.89	9.77	10.50	7.51	6.04	5.08
33		8.62	11.77			11.07		5.33	8.81	9.26	11.97	9.82	10.59	7.55	6.08	5.08
34		8.66	11.89			11.13		5.36	8.86	9.31		9.86	10.68	7.57	6.12	5.08
35		8.77	12.02			11.20		5.39	8.91	9.37		9.91	10.77	7.61	6.16	5.08

MATERIALS TIME	Ba	Ch	Sp	Wd	Ba+ Ch	Ba+ Sp	Ba+ Wd	Ch+ Sp	Ch+ Wd	Sp+ Wd	Ba+ Ch+ Sp	Ba+ Ch+ Wd	Ba+ Sp+ Wd	Ch+ Sp+ Wd	Ba+ Ch+ Sp+ Wd	Control Material
36		8.73	12.15			11.27		5.42	8.94	9.41		9.96	10.85	7.64	6.20	5.09
37		8.78	12.20			11.34		5.44	8.97	9.46		10.01	10.93	7.67	6.23	5.09
38		8.82	12.22			11.39		5.47	9.01	9.50		10.04	11.01	7.81	6.27	5.09
39		8.86				11.45		5.50	9.03	9.55		10.07	11.09	7.84	6.30	5.10
40		8.89				11.52		5.53	9.07	9.60		10.10	11.17	7.86	6.33	5.10
41		8.93				11.58		5.55	9.09	9.63		10.14	11.25	7.89	6.36	5.10
42		8.96				11.63		5.58	9.15	9.68		10.17	11.33	7.91	6.40	5.10
43		8.99				11.68		5.60	9.18	9.73		10.25	11.40	7.95	6.43	5.11
44		9.02				11.72		5.63	9.23	9.78		10.28	11.47	7.97	6.46	5.11
45		9.06				11.76		5.65	9.28	9.82		10.32	11.54	7.99	6.50	5.11
46		9.09				11.81		5.68	9.30	9.85		10.36	11.62	8.01	6.54	5.11
47		9.12				11.88		5.70	9.32	9.88		10.39	11.69	8.03	6.58	5.12
48		9.15				11.94		5.72	9.40	9.92		10.44	11.77	8.05	6.62	5.12
49		9.19				12.00		5.75	9.44	9.96		10.48	11.84	8.06	6.65	5.12
50		9.23				12.06		5.77	9.48	9.99		10.52	11.90	8.07	6.68	5.12
51		9.26				12.12		5.79	9.51	10.05		10.55	11.94	8.08	6.71	5.12
52		9.30						5.81	9.53	10.09		10.58		8.14	6.74	5.12
53		9.33						5.84	9.56	10.13		10.61		8.17	6.77	5.13
54		9.36						5.87	9.58	10.16		10.63		8.19	6.81	5.13
55		9.38						5.89	9.63	10.20		1067		8.20	6.84	5.13
56		9.41						5.91	9.66	10.25		10.69		8.21	6.87	5.13
57		9.44						5.93	9.68	10.31		10.73		8.22	6.90	5.13
58		9.47						5.95	9.70	10.35		10.77		8.23	6.92	5.13
59		9.49						5.97	9.74	10.39		10.79		8.24	6.95	5.14
60		9.52						5.99	9.76	10.42		10.83		8.25	6.97	5.14

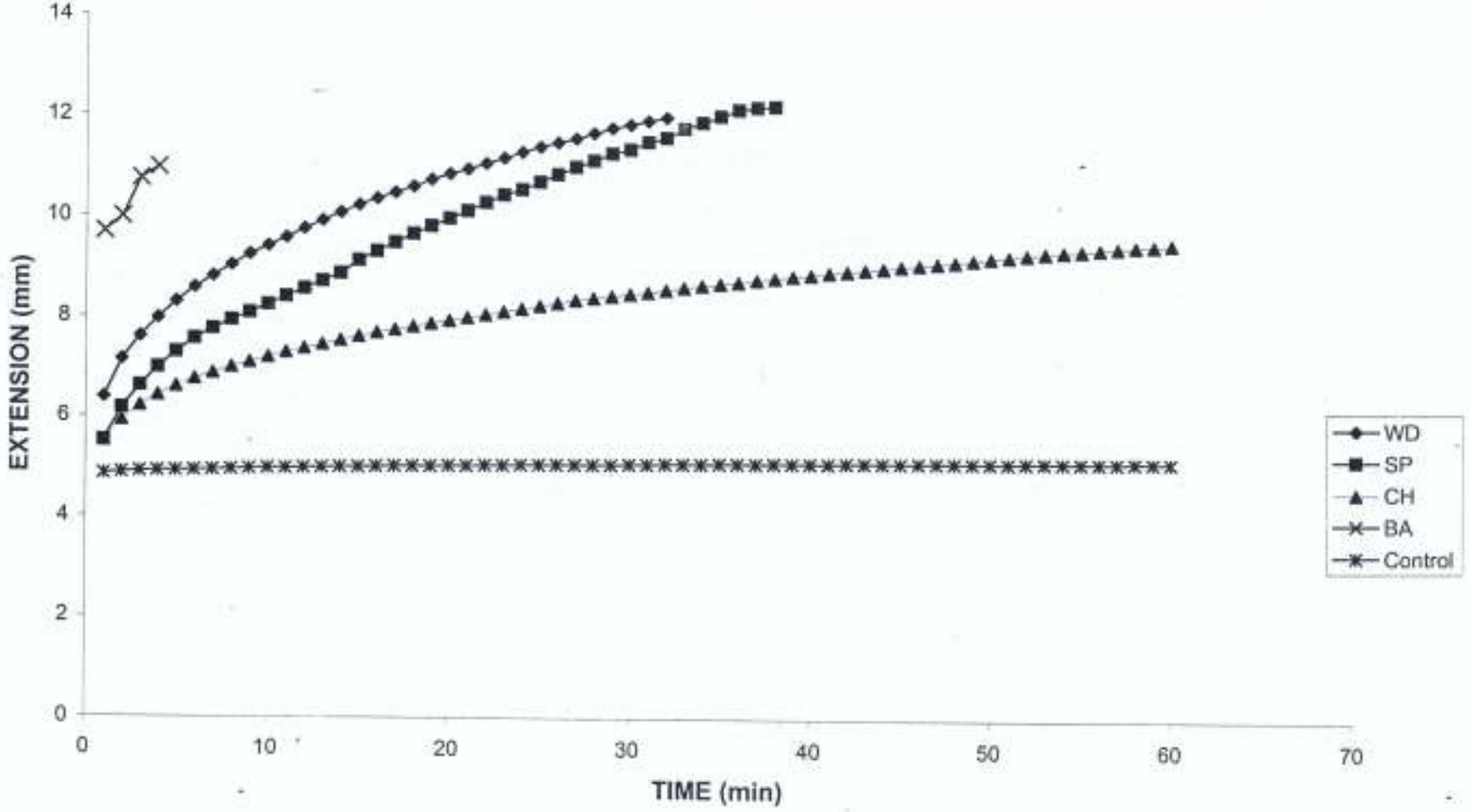


FIG 4.1 EXTENSION-TIME CREEP CURVES FOR GASKET MADE FROM ONE FIBRE COMPONENT AND THE CONTROL MATERIAL

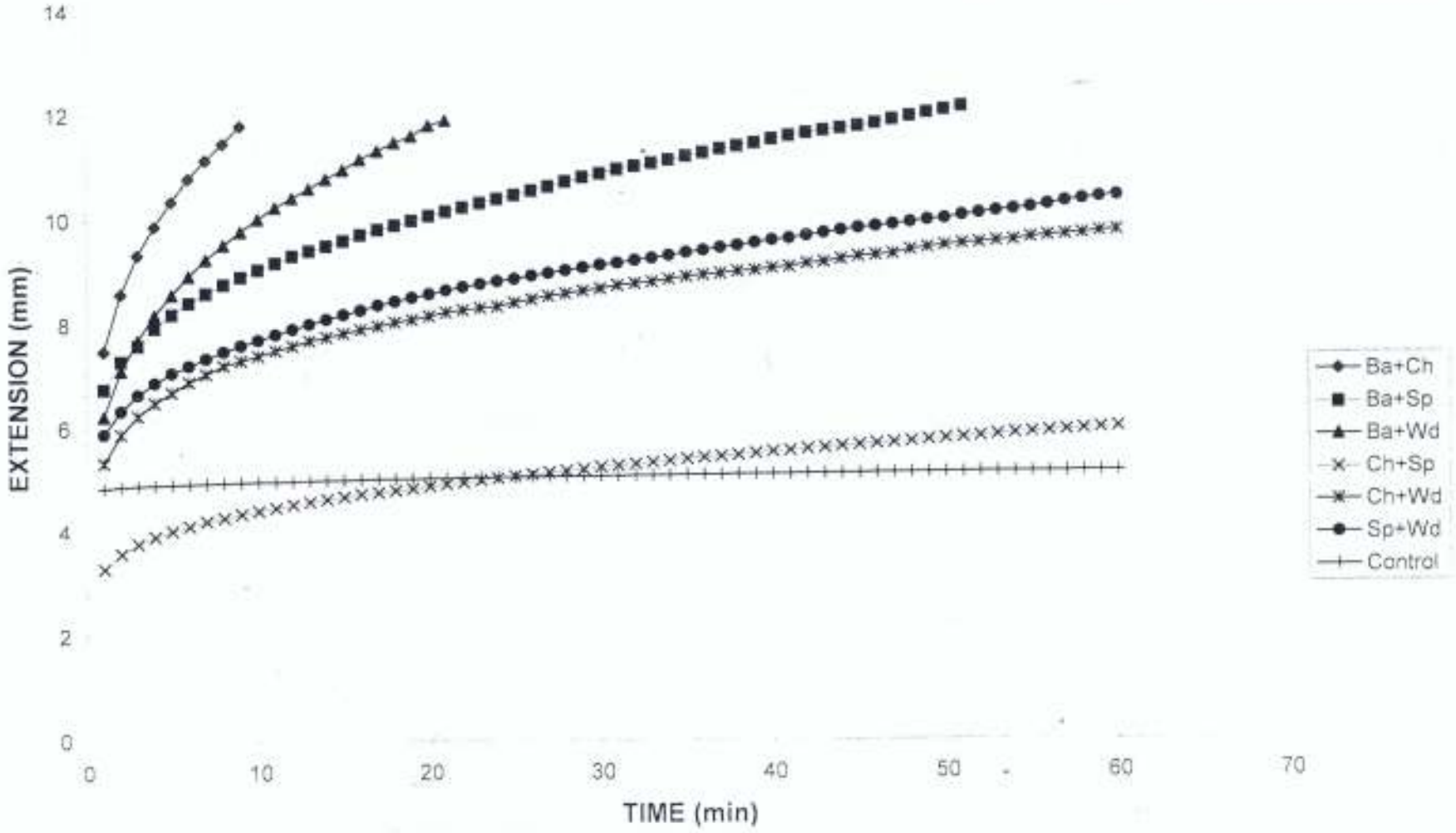


FIG 4.2 EXTENSION-TIME CREEP CURVES FOR GASKET MADE FROM TWO-FIBRE COMPONENTS AND THE CONTROL MATERIAL

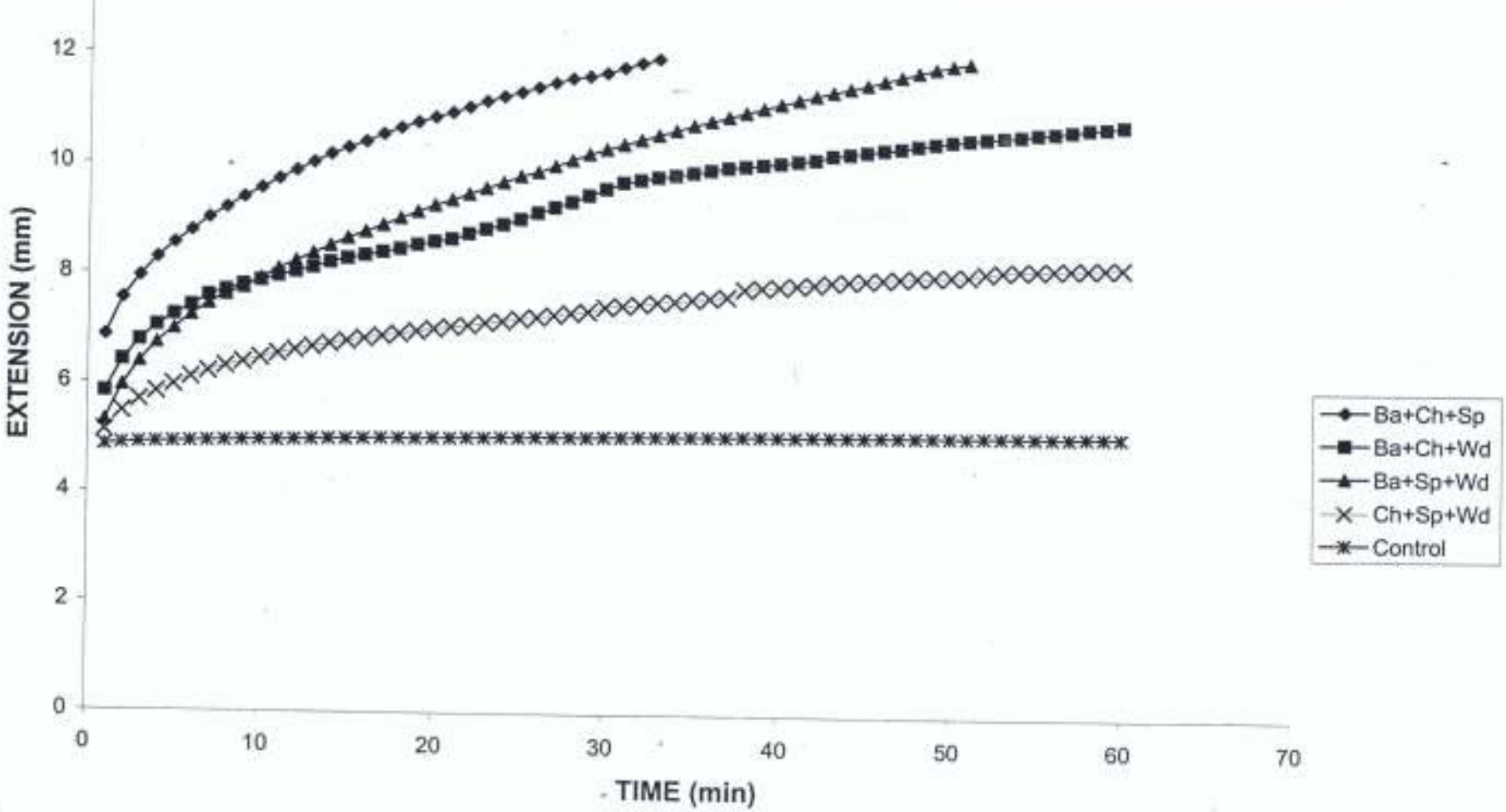


FIG 4.3 EXTENSION-TIME CREEP CURVES FOR GASKETS MADE FROM THREE-FIBRE COMPONENTS AND THE CONTROL MATERIAL

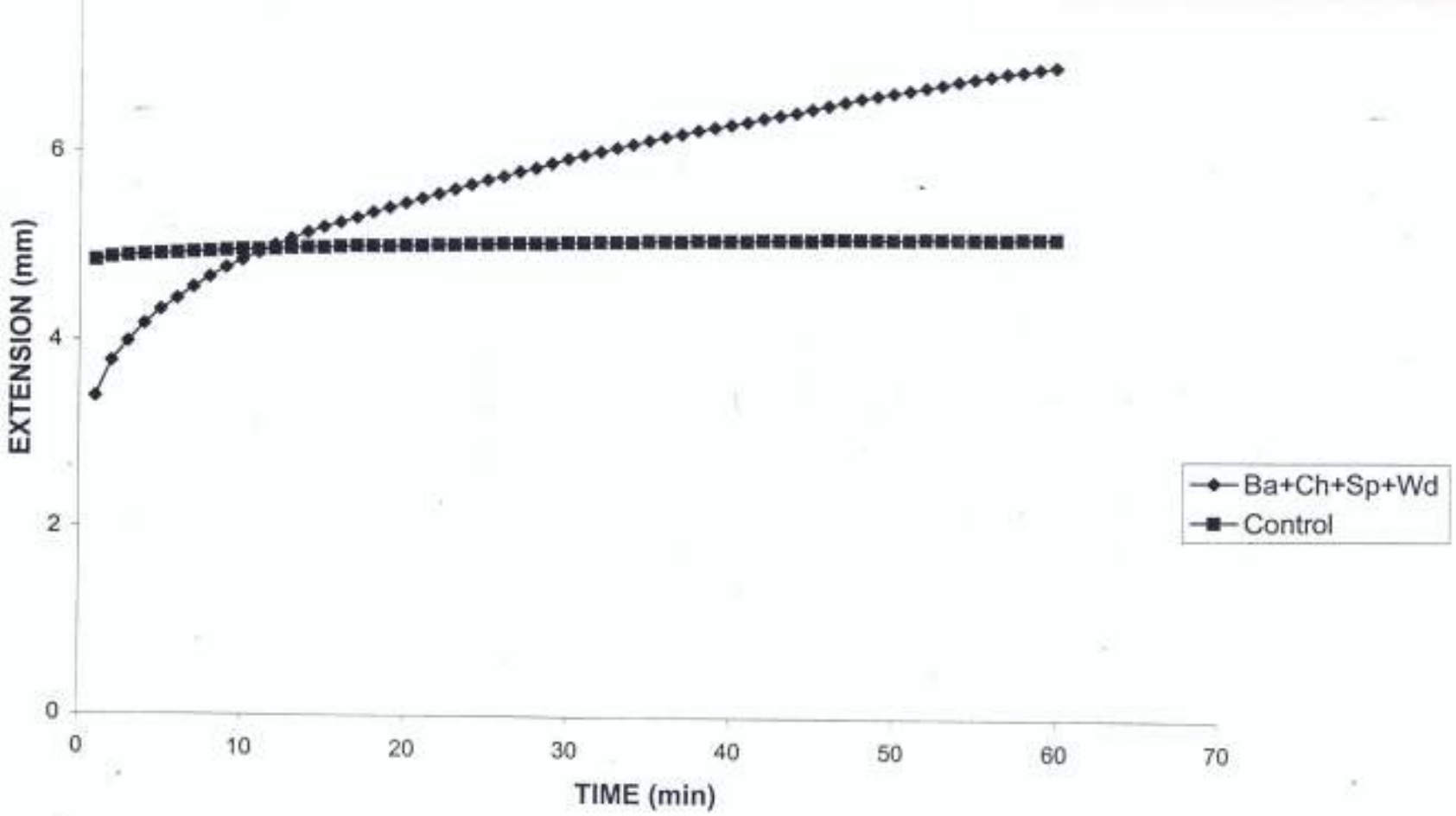


FIG 4.4 EXTENSION-TIME CREEP CURVES FOR GASKETMADE FROM FOUR-FIBRE COMPONENTS AND THE CONTROL MATERIAL

4.1.1.1 CREEP RATE

Creep rate (ε) = $\frac{d\varepsilon}{dt}$ (4.1) (Dieter, 1988)

The values for these are given in appendix 1

4.1.1.2 RUPTURE TIME

Rupture time for each of the materials at different elevated temperatures was determined as follows from the creep rate for each material:

$P = T(\ln t + C)$ ..... (4.2)

Where P = Larson – Miller parameter

T = the test temperature in k

t = time to rupture in h

c = Larson-Miller constant often taken to be 46

The Larson-Miller parameter expressed in terms of minimum creep rate instead of time to rupture is

$P = T(c - \ln \varepsilon)$..... (4.3)

Where ε = minimum creep rate, and all other parameters are as defined above. (Dieter, 1988).

The values for these are given in appendix 2

4.1.1.3 APPLIED LOAD

To determine the applied load, the load on the specimen can be found by taking moment about the pivot bearing as follows:

Moment = Force x distance - (4.4)

Anticlockwise moment = Clockwise moment – (4.5)

Therefore, if F_1, F_2, and F_3 are the forces that act on the specimen with distance S_1, S_2 and S_3 respectively.

$$F_1S_1 = F_2S_2 + F_3S_3$$

Where F_1 = load on the specimen

F_2 = weight hanger + support pin + load(m) applied.

F3 = Tensile pull on specimen

And F = mass x acceleration due to gravity

The values for these are given in appendix 3

4.1.2 HARDNESS TEST RESULTS

Data from the harness tests was given in table 4.3 and 4.4 for room and elevated temperatures respectively. This was followed by their corresponding figures (Fig. 4.5 – 4.8).

Table 4.3: Room Temperature Test Values (25^0C)

Ba	Ch	Sp	Wd	Ba + Ch	Ba + Sp	Ba + Wd	Ch + Sp	Ch + Wd	Sp + Wd	Ba+Ch +Sp	Ba+Ch +Wd	Ba+Sp +Wd	Ch+Sp +Wd	Ba+Ch +Sp+Wd	Contn Materi
86	161	159	133	153	148	161	176	164	157	162	120	163	101	194	203

Table 4.4: Elevated Temperature Test Values (200^0C)

Ba	Ch	Sp	Wd	Ba + Ch	Ba + Sp	Ba + Wd	Ch + Sp	Ch + Wd	Sp + Wd	Ba+Ch +Sp	Ba+Ch +Wd	Ba+Sp +Wd	Ch+Sp +Wd	Ba+Ch+ Sp+Wd	Control material
91	178	148	160	182	101	126	164	108	103	155	153	145	109	155	210

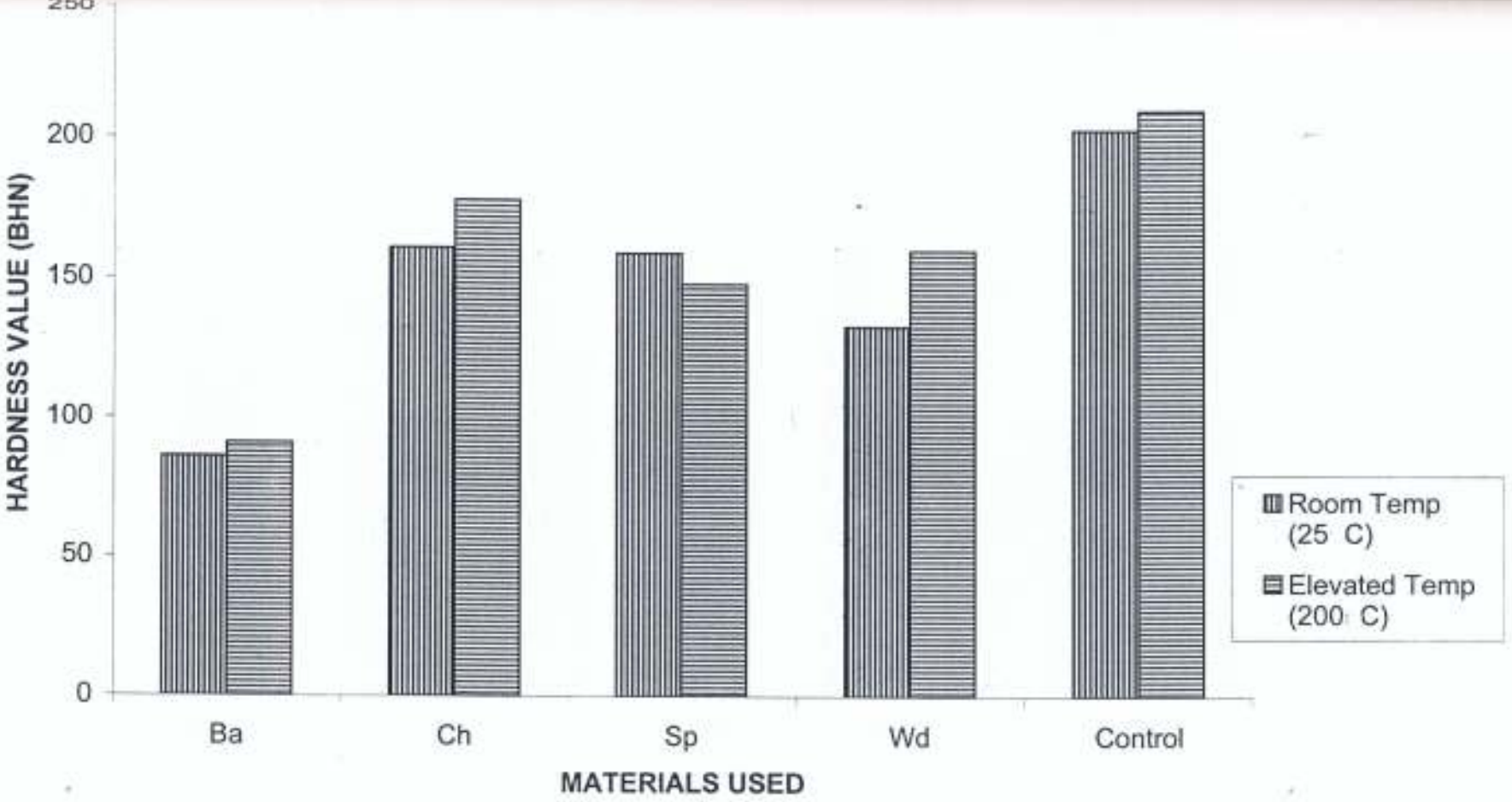


FIG 4.5 BAR CHART OF HARDNESS VALUES FOR GASKET MADE FROM ONE FIBRE COMPONENT AND THE CONTROL AT ROOM AND ELEVATED TEMPERATURES

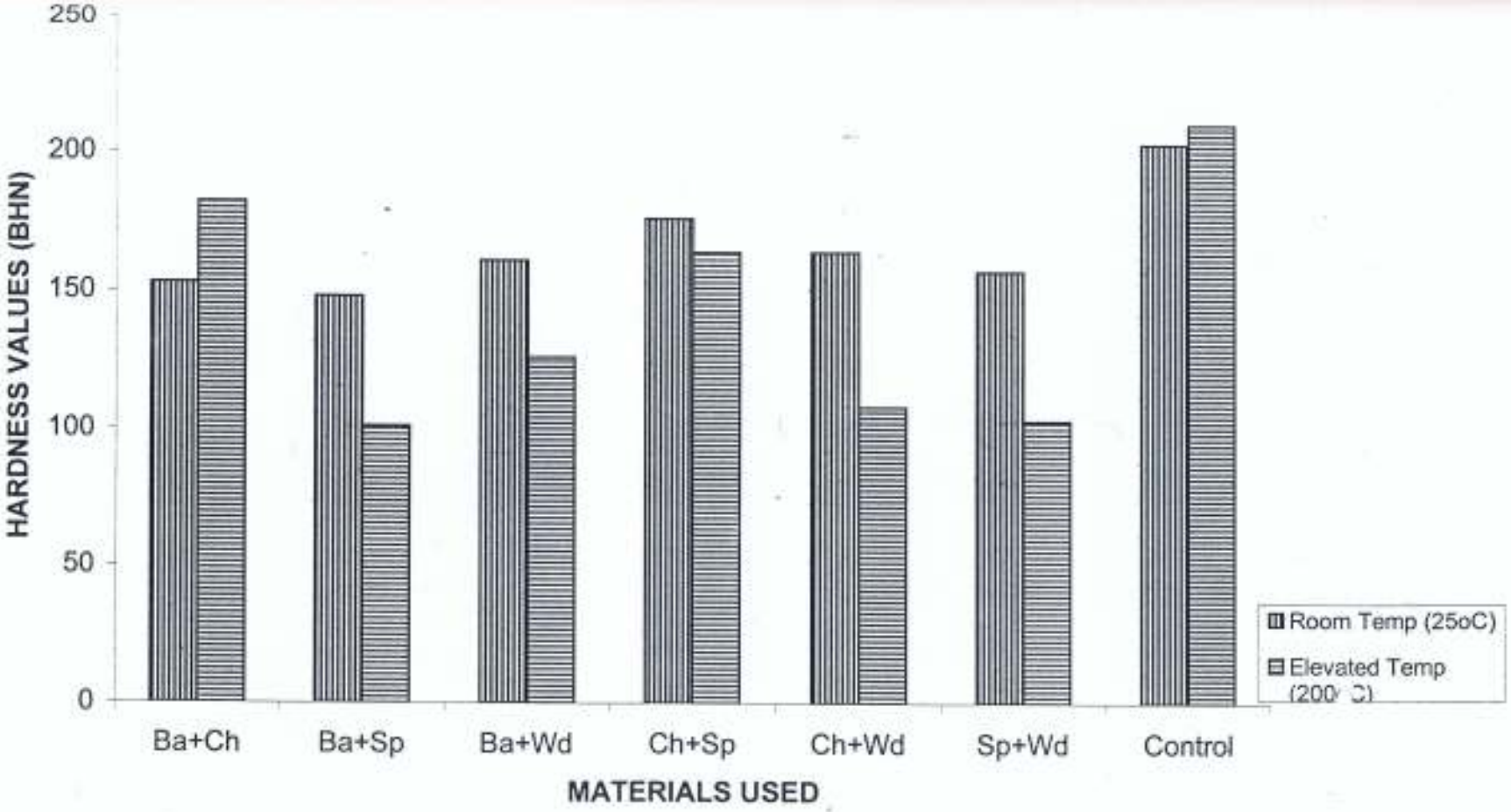


FIG 4.6 BAR CHART OF HARDNESS VALUES FOR GASKET MADE FROM TWO FIBRE COMPONENTS AND THE CONTROL AT ROOM AND ELEVATED TEMPERATURES

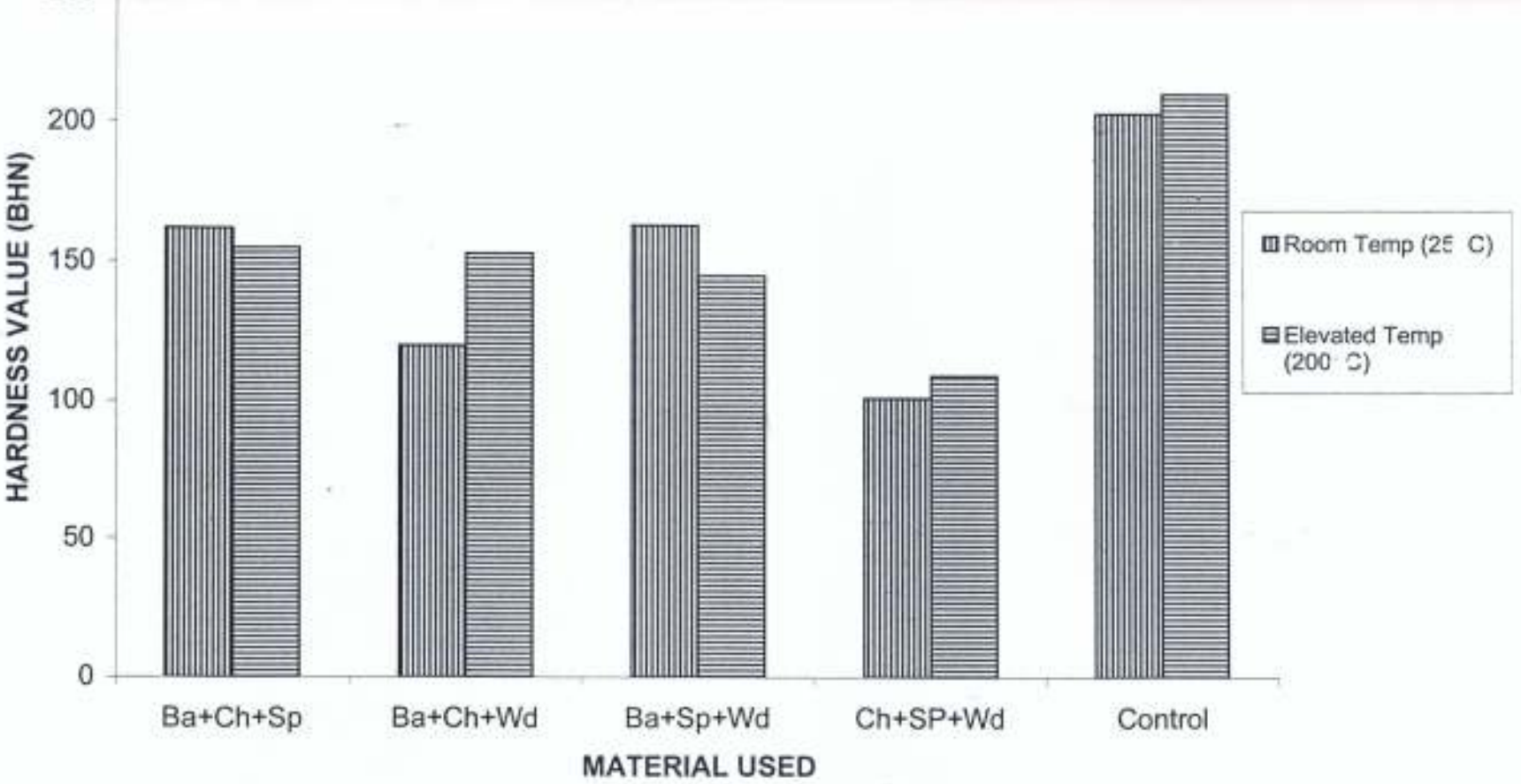


FIG 4.7 BAR CHART OF HARDNESS VALUES FOR GASKET MADE FROM THREE FIBRE COMPONENTS AND THE CONTROL AT ROOM AND ELEVATED TEMPERATURES

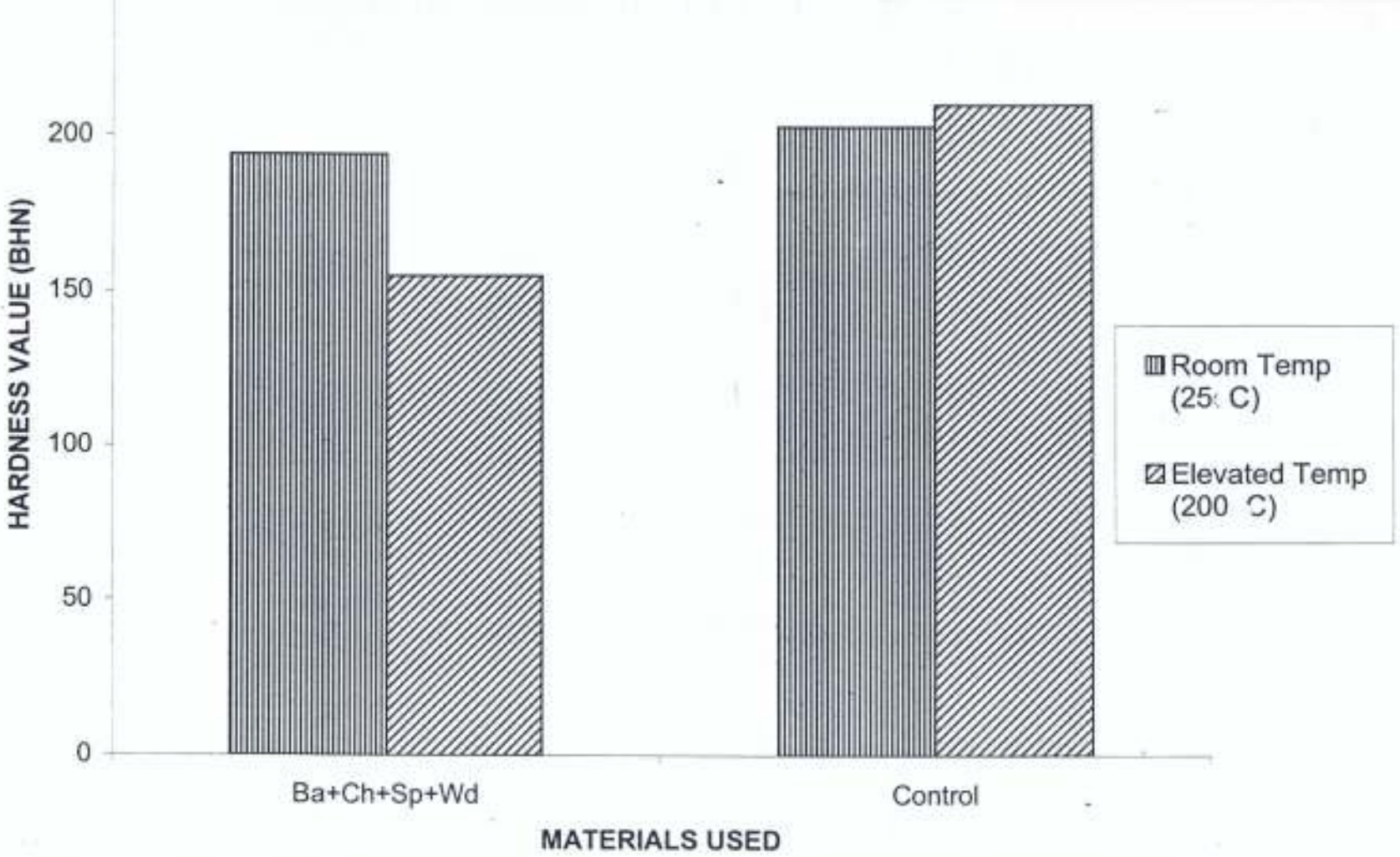


FIG 4.8 BAR CHART OF HARDNESS VALUES FOR GASKET MADE FROM FOUR FIBRE COMPONENTS AND THE CONTROL AT ROOM AND ELEVATED TEMPERATURES

4.1.3 DENSITY OF THE MATERIALS

The materials densities were calculated as follows:

Density = $\frac{\text{Mass in g}}{\text{Volume in ml}}$ ...(Mathews et al., 1995) ..... (4.6)

The values for these are given in appendix 4

4.2 DISCUSSION

4.2.1 Summary of the results were tabulated as follows:

Table 4.5

Summary of results

Materials	Density g/ml	Creep Rate	Hardness Rm. Temp	Hardness Elev. Temp.	Rupture time at elevated temperatures in hour			
					150°C	200°C	250°C	Remark
		mm/min	(BHN)	(BHN)				
Ba	0.773	0.20000	86	91	2.17×10^{-7}	8.49×10^{-9}	6.17×10^{-10}	Nil
Ch	0.882	0.02857	161	178	8.57×10^{-7}	2.89×10^{-8}	1.87×10^{-9}	Good
Sp	1.074	0.15000	159	148	2.66×10^{-7}	1.02×10^{-8}	7.27×10^{-10}	Good Density
Wd	0.884	0.10000	133	160	3.53×10^{-7}	1.31×10^{-8}	9.16×10^{-10}	Good Hardness
Ba + ch	0.921	0.33330	153	182	1.51×10^{-7}	6.15×10^{-9}	4.61×10^{-10}	Good density & hardness
Ba + Sp	0.959	0.05000	148	101	5.76×10^{-7}	2.03×10^{-8}	1.36×10^{-9}	Good density
Ba + Wd	0.876	0.17500	161	126	2.38×10^{-7}	9.23×10^{-9}	6.66×10^{-10}	Nil
Ch + Sp	0.921	0.02222	176	164	1.02×10^{-6}	3.39×10^{-8}	2.16×10^{-9}	Good
Ch + Wd	0.780	0.03000	164	108	8.25×10^{-7}	2.80×10^{-8}	1.82×10^{-9}	Good creep rate
Sp + Wd	1.121	0.04000	157	103	6.74×10^{-7}	2.34×10^{-8}	1.54×10^{-9}	Good density
Ba+Ch+Sp	0.925	0.05000	162	155	5.76×10^{-7}	2.03×18^{-8}	1.36×10^{-9}	Moderate
Ba+Ch+Wd	0.887	0.04990	120	153	5.76×10^{-7}	2.03×18^{-8}	1.36×10^{-9}	Moderate
Ba+Sp+Wd	1.000	0.05714	163	145	5.24×10^{-7}	1.87×10^{-8}	1.26×10^{-9}	Moderate
Ch+Sp+Wd	1.052	0.03125	101	109	8.02×10^{-7}	2.73×10^{-8}	1.78×10^{-9}	Good
Ba+Ch+Sp+Wd	0.938	0.03333	194	155	7.66×10^{-7}	2.62×10^{-8}	1.71×10^{-9}	Good
Control Material	1.744	0.00625	203	210	2.49×10^{-6}	7.54×10^{-8}	4.45×10^{-9}	Good

4.2.2 DENSITY OF THE MATERIALS

Density is a measure of how densely packed or well compacted a material is within a given space.

From the results, the mixture of sponges and wood followed by sponges and finally the mixture of coconut husk, sponges and wood have the best densities close to the imported material that serves as the control.

Control material >(sp+wd) > (sp) > (ch+sp+wd)

1.744 > 1.121 > 1.074 > 1.052

4.2.3 CREEP RATE

Creep rate is a design parameter that gives the rate at which the material is deformed. Hence, high rate means early deformation and consequent failure while low rate means prolonged deformation and failure (Dieter, 1988).

From the results, the mixture of coconut husk and sponges followed by coconut and finally the mixture of coconut husk and woods have the best creep rate close to the imported material that serves as the control.

Control material > (ch+sp) > (ch) > (ch+wd)

0.00625 > 0.02222 > 0.02857 > 0.03000

4.2.4 RUPTURE TIME

Rupture time is the period at which a materials experience a major change in its microstructure or reach a given creep rate (Dieter, 1988). It depends on many factors such as creep rate, temperature and stress (applied load). Increase in any of these factors decreases the rupture time and vice versa.

4.2.5 HARDNESS

Hardness usually implies a resistance to deformation. Hardness measurements as a function of temperature will slow an abrupt change at the temperature at which an allotropic transformation occurs (Dieter, 1988).

From the results at room temperature measurements, the mixture of the four fibres followed by the mixture of coconut husk and sponges and finally the mixture of coconut husk and wood have the best hardness value close to the imported material that serves as the control.

Control material > (Ba+ch+sp+wd) > (ch+sp) > (ch+wd)

203 > 194 > 176 >164

At elevated temperature measurements, the mixture of bamboo and coconut husk followed by coconut husk and finally the mixture of coconut husk and sponges have the best hardness value close to the imported material that serves as the control.

Control material > (Ba+ch) > (ch) > (ch+sp)

210 182 178 164

The results of the analysis were used to select the material that have close properties to the commercially sourced gasket material as follows:

	Density	Creep rate	Hardness at Room temp.	Hardness at Elevated temp.
1	Sp+wd	Ch+sp	Ba+ch+sp+wd	Ba+ch
2	Sp	Ch	Ch+sp	Ch
3	Ch+sp+wd	Ch+wd	Ch+wd	Ch+sp

4.2.5 SUITABILITY TEST

Suitability test was carried out on the selected materials using water, engine oil and petrol media. The materials maintained their respective structures in engine oil and petrol whereas it softens in water. The compatibility and suitability test confirmed the possible applicability of the materials as gaskets in fuel pumps, carburetors and as well as engine oil sumps.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From this research, the following conclusions can be deduced:

(i) The mixtures of sponges and wood have the best density (1.121g/ml) close to the control material (1.744g/ml). This was followed by sponges product (1.074g/ml) and finally, the mixture of coconut husk, sponges and wood (1.052g/ml). Therefore, when seeking for highly densed products, these can be considered.

(ii) The response of the produced gaskets to creep deformation show that the mixture of coconut husk and sponges have the best creep resistance (0.02222) close to the control material (0.00625). This was followed by coconut husk product (0.02857) and finally, the mixture of coconut husk and wood (0.03000). It therefore implied that, these are the best materials for creep resistance and can be considered when seeking for such property.

(iii) The response of the materials to hardness at room temperature show that the mixture of the four fibres, bamboo, coconut husk, sponges and wood, have the best hardness (194 BHN) close to the control material (203BHN). This was followed by the mixture of coconut husk and sponges (176 BHN) and finally, the mixture of coconut and wood (164 BHN). They are therefore good for room temperature applications.

(iv) The response of the materials at an elevated temperature of 200^{0}C show that, the mixture of bamboo and coconut husk have the best hardness (182 BHN) close to the control material (210 BHN). This was followed by coconut husk product (178 BHN) and finally, the mixture of coconut husk and sponges (164 BHN). It follows therefore that for high temperature applications, those materials will perform well as best substitute.

The research confirmed the excellent performance of the imported gasket material that was used as the control basically due to its external coating but the locally produced (selected materials) can be used as substitute in the following order: Coconut husk and sponges (Ch+Sp), Coconut husk (Ch) and Coconut husk and Wood (Ch+Wd).

5.2 RECOMMENDATION

The results of the research show that:

- better results can be obtained with smooth surface coatings;
- for low temperature tolerance gaskets, the materials must be soft and ductile;
- for high temperature tolerance gaskets, the materials must be hard and strong;
- optimum mixture was obtained with two fibre components, coconut husk fibre based being the best;
- Coconut husk fibre is the best single fibre used.

Therefore, the following recommendations were made for further research:

i. The effect of variation in the percentage of the matrix to reinforcements (fibres) on the materials.

ii. The effect of variation in the compaction of the materials during production.

iii. The effect of suitable sealant as a coating on the materials.

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APPENDIX

1.0: CREEP RATE

Ba: $\frac{d\varepsilon}{dt} = \frac{10.8 - 10.6}{6 - 1} = \frac{0.2}{1} = 0.02\text{mm/min}$

Ch: $\frac{d\varepsilon}{dt} = \frac{9.4 - 9.2}{57 - 50} = \frac{0.2}{7} = 0.02857\text{mm/min}$

Sp: $\frac{d\varepsilon}{dt} = \frac{10.6 - 10.3}{24 - 23}$ or $\frac{9.9 - 9.6}{21 - 19} = \frac{0.3}{2} = 0.15\text{mm/min}$

Wd: $\frac{d\varepsilon}{dt} = \frac{12.5 - 12.3}{37 - 35} = \frac{0.2}{2} = 0.1\text{mm/min}$

Ba + ch: $\frac{d\varepsilon}{dt} = \frac{11.8 - 10.8}{9 - 6} = \frac{1}{3} = 0.33333\text{mm/min}$

Ba + sp: $\frac{d\varepsilon}{dt} = \frac{10.7 - 10.5}{30 - 26}$ or $\frac{12.1 - 11.9}{52\text{-}48} = \frac{0.2}{4} = 0.05\text{mm/min}$

Ba + Wd: $\frac{d\varepsilon}{dt} = \frac{12\text{-}6 - 11.9}{25\text{-}21} = \frac{0.7}{4} = 0.175\text{mm/min}$

Ch + sp: $\frac{d\varepsilon}{dt} = \frac{5.8 - 5.6}{52\text{-}43} = \frac{0.2}{9} = 0.02222\text{mm/min}$

Ch + Wd: $\frac{d\varepsilon}{dt} = \frac{9.7 - 9.4}{58\text{-}48}$ or $\frac{9.3 - 9.0}{48\text{-}38} = \frac{0.3}{10} = 0.03\text{mm/min}$

Wd + sp: $\frac{d\varepsilon}{dt} = \frac{10.2 - 10.0}{57\text{-}52} = \frac{0.2}{5} = 0.04\text{mm/min}$

Ba + Sp + Ch: $\frac{d\varepsilon}{dt} = \frac{12.5 - 12.3}{46 - 42} = \frac{0.2}{4} = 0.05\text{mm/min}$

Ba + Ch + Wd: $\frac{d\varepsilon}{dt} = \frac{9.5 - 9.3}{34\text{-}31} = \frac{0.2}{3} = 0.03333$ or

$\frac{d\acute{\varepsilon}}{dt} = \frac{10.7 - 10.6}{58 - 55} = \frac{0.1}{3} = 0.06666$

$= \frac{0.03333 + 0.06666}{2} = \frac{0.09999}{2} - 0.04999\text{mm/min}$

Ba + Sp + Wd: $\frac{d\varepsilon}{dt} = \frac{12.2 - 11.8}{57 - 50} = \frac{0.4}{7} =$ 0.05714mm/min

Ch + Sp + Wd: $\frac{d\varepsilon}{dt} = \frac{7.8 - 7.5}{41 - 33} = \frac{0.3}{8} =$ 0.025 or

$\frac{d\varepsilon}{dt} = \frac{7.9 - 7.8}{46 - 42} = \frac{0.1}{4} =$ 0.0375

$= \frac{0.025 + 0.375}{2} = \frac{0.0625}{2} =$ 0.03125mm/min

Ba + Ch + Sp + Wd: $\frac{d\varepsilon}{dt} = \frac{6.5 - 6.2}{45 - 36} = \frac{0.3}{9} =$ 0.03333mm/min

Control material: $\frac{d\varepsilon}{dt} = \frac{5.1 - 5.0}{39 - 23} = \frac{0.1}{16} =$ 0.00625mm/min

1.2: **RUPTURE TIME**

Since the rupture time was given in hour, the creep rate was converted to hour before substitution into the formula. Thus:

$\varepsilon = \frac{d\varepsilon}{dt} \times 60$, $T = 25^0C = 298k$, $C = 46$

i. (Ba):$P = 298 (46 - \ln 12)$

$= 12967.50$

At 150^0C

$12967.50 = 423 (\ln t + 46)$

$\ln t = -15.34$

$T = 2.17 \times 10^{-7}h$

At 200^0C

$12967.50 = 473(\ln t + 46)$

$\ln t = -18.58$

$t = 8.49 \times 10^{-9}h$

At 250^0C

12967.50 = 523 (Int + 46)
Int = -21-21
t = 6.17×10^{-10}h

ii. (Ch): P = 298(46-ln 1.7142)
= 13547.39

At 150^{0}C

13547.39 = 423(Int + 46)
Int = -13.97
t = 8.57×10^{-7}h

At 200^{0}C

13547.39 = 473 (Int + 46)
Int = -17.36
t = 2.89×10^{-8}h

At 250^{0}C

13547.39 = 523(Int + 46)
Int = -20.10
t = 1.87×10^{-9}h

iii. (Sp):p = 298(46 – Int + 46)
= 13053.23

At 150^{0}C

13053.23 = 423(Int + 46)
Int = -15.14
t = 2.66×10^{-7}h

At 200^{0}C

13053.23 = 473(Int + 46)
Int = -18.40
t = 1.02×10^{-8}h

At 250^{0}C

13053.23 = 523(Int + 46)

Int = -21.04

$t = 7.27 \times 10^{-10}h$

The rupture time for other materials with two more fibre components as well as the control were also determined and tabulated as follows:

Table 4.2 Rupture time at elevated temperatures in hour

150°C	200°C	250°C
$2.17x10^{-7}$	$8.49x10^{-9}$	$6.17x10^{-10}$
$8.57x10^{-7}$	$2.89x10^{-8}$	$1.87x10^{-9}$
$2.66x10^{-7}$	$1.02x10^{-8}$	$7.27x10^{-10}$
$3.53x10^{-7}$	$1.31x10^{-8}$	$9.16x10^{-10}$
$1.51x10^{-7}$	$6.15x10^{-9}$	$4.61x10^{-10}$
$5.76x10^{-7}$	$2.03x10^{-8}$	$1.36x10^{-9}$
$2.38x10^{-7}$	$9.23x10^{-9}$	$6.66x10^{-10}$
$1.02x10^{-6}$	$3.39x10^{-8}$	$2.16x10^{-9}$
$8.25x10^{-7}$	$2.80x10^{-8}$	$1.82x10^{-9}$
$6.74x10^{-7}$	$2.34x10^{-8}$	$1.54x10^{-9}$
$5.76x10^{-7}$	$2.03x18^{-8}$	$1.36x10^{-9}$
$5.76x10^{-7}$	$2.03x18^{-8}$	$1.36x10^{-9}$
$5.24x10^{-7}$	$1.87x10^{-8}$	$1.26x10^{-9}$
$8.02x10^{-7}$	$2.73x10^{-8}$	$1.78x10^{-9}$
$7.66x10^{-7}$	$2.62x10^{-8}$	$1.71x10^{-9}$
$2.49x10^{-6}$	$7.54x10^{-8}$	$4.45x10^{-9}$

1.3 APPLIED LOAD

$F_1 \times 42 = 0.4 \times 9.81 \times 336 + 4.44 \times 9.81 \times 394$

$42F_1 = 3.924 \times 336 + 43.5564 \times 394$

$= 1318.464 + 17161.222$

$= 18479.686$

$F_1 = \frac{18679.686}{42} = 439.993 = 440N$

1.4 DENSITY OF THE MATERIALS

Ba: $\frac{6.960}{9} = 0.773g/ml$

Ch: $\frac{7.938}{9} = 0.882g/ml$

Sp: $\frac{8.590}{8}$ = 1.074g/ml

Wd: $\frac{7.075}{8}$ = 0.884g/ml

Ba + Ch: $\frac{6.449}{7}$ = 0.921g/ml

Ba + Sp: $\frac{6.711}{7}$ = 0.959g/ml

Ba + Wd: $\frac{7.009}{8}$ = 0.876g/ml

Ba + Sp: $\frac{9.205}{10}$ = 0.921g/ml

Ch + Wd: $\frac{7.795}{10}$ = 0.780g/ml

Wd + Sp: $\frac{8.971}{8}$ = Wd: $\frac{8.003}{1.121}$g/ml

Ba+Sp+Ch: $\frac{7.403}{8}$ = 0.925g/ml

Ba+Ch+Wd: $\frac{8.871}{10}$ = 0.887g/ml

Ba+Sp+ 8 = 1.000g/ml

Ch+Sp+Wd: $\frac{9.467}{9}$ = 1.052g/ml

Ba+Ch+Sp+Wd: $\frac{8.446}{9}$ = 0.938g/ml

Control material: $\frac{8.718}{5}$ = 1.744g/ml

Appendix 5
Scanned Photograph of the samples


E


F


G


H


I


J


K


L


M


N


O


P