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**FACULTY OF PHYSICAL SCIENCES
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**Comparative Studies of the viscoelastic properties of polyethylene,
polyisoprene and polyvinyl chloride subjected to constant loads at different
constant temperatures**

By

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DECLARATION

I hereby declare that this thesis is my original work towards the Master of Science and that, to the best of my knowledge, has not been presented for a degree in any other University, except where due acknowledgment has been made in the text.

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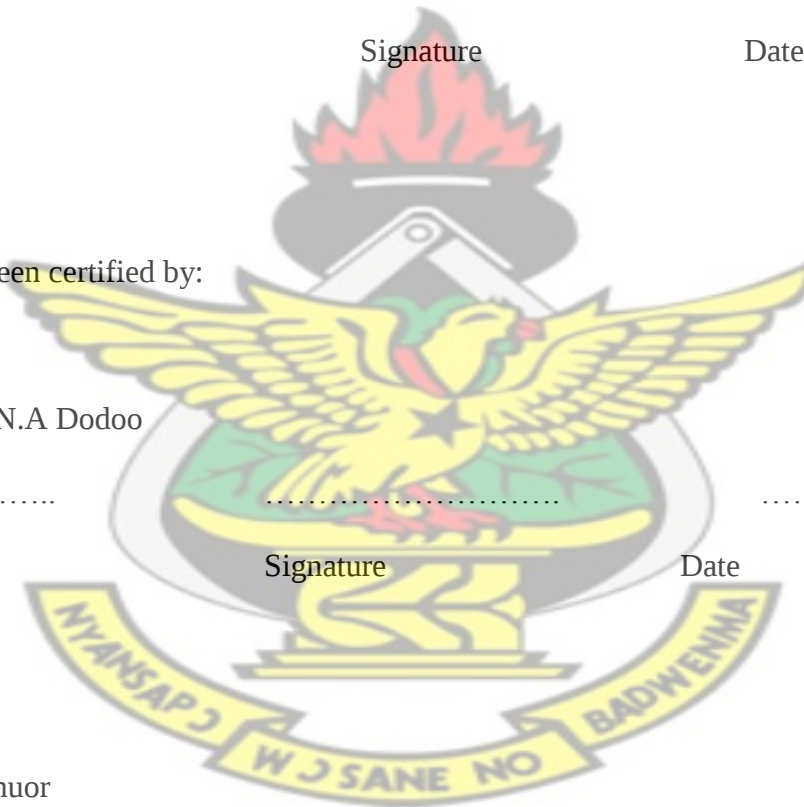
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ABSTRACT

Viscoelastic properties of selected polymers subjected to constant loads at different temperatures have been studied. The prepared samples were mounted in a furnace and subjected to a tension under constant loads at a specific temperature. Initial strain rates were determined. The change in elongation of the polymeric materials were measured and recorded. The loads were then increased for the same temperature and also at different temperatures. Graphs of strain against time were then plotted and the equations for the curves obtained were differentiated and the times substituted into the equations to obtain the strain rates. Generally, the initial strain rates were relatively higher due to chain uncoiling in the polymeric materials. Under a load of 0.5 kg, at temperatures of 50°C, 100°C and 150°C, polyethylene recorded minimum strain rates of 0.00346 min⁻¹, 0.01128 min⁻¹, 0.00346 min⁻¹ respectively with corresponding times of 28.06 mins, 18.16 mins and 6.52 mins. Polyisoprene, on the other hand, recorded comparatively low values of minimum strain rates as follows: under a load of 0.5 kg, at temperatures of 50°C, 100°C and 150°C respectively, the minimum strain rates were 0.0032989 min⁻¹, 0.003478 min⁻¹, 0.015146 min⁻¹ with corresponding times of 39.4 mins, 29.51 mins and 9.52 mins. PVC recorded the highest values of minimum strain rates under the same conditions with values 0.0131794 min⁻¹, 0.024498 min⁻¹ and 0.0301 min⁻¹ with corresponding time values of 24.21 mins, 14.24 mins, 12.26 mins. This can be attributed to PVC having the lowest heat distortion temperature compared to polyisoprene and polyethylene. Polyisoprene recorded the least strain rates under similar conditions of load or temperature due to the presence of crosslinks and double bonds in its molecular structure. Polyisoprene exhibited the highest stiffness and consequently the highest resistance to heat flow. The viscoelastic properties of the polymers used were characterized by temperature, loading, minimum strain rates and the time for the occurrence of

minimum strain rates. The minimum strain rates moved to shorter times as temperature increased. At low temperatures, the deformation of the polymer was slow. However, at high temperatures, the deformation was fast.

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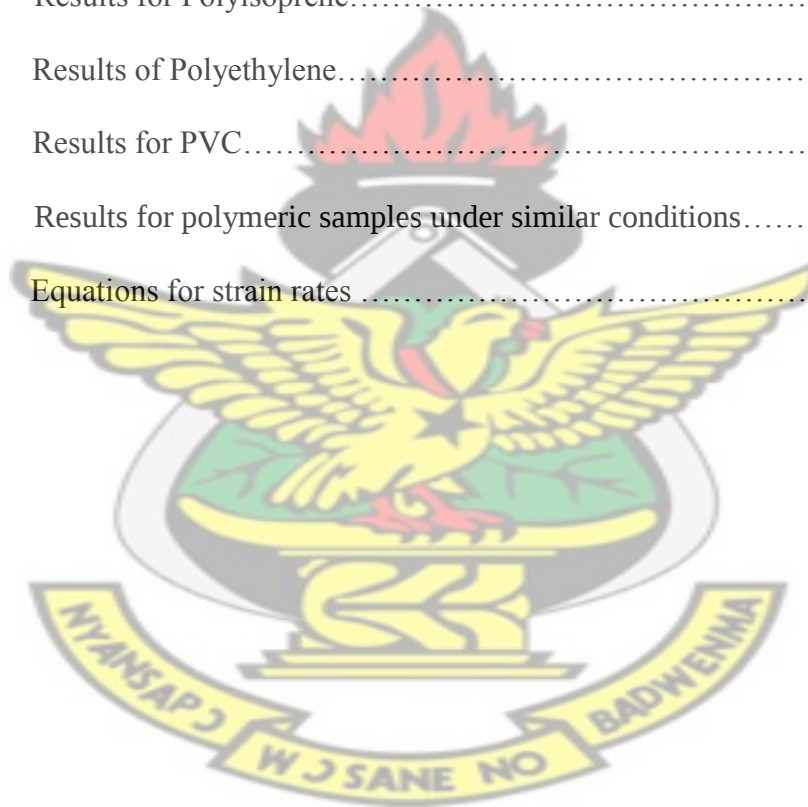
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CHAPTER 1

1.0 Introduction

Polymers have found widespread applications because of their mechanical behavior. One important mechanical property of polymers is viscoelasticity. Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both of these properties and as such exhibit a time dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material (Meyers and Chawla, 1999).

Unlike purely elastic substances, a viscoelastic substance has an elastic component and a viscous component. The viscosity of a viscoelastic substance gives the substance a strain rate dependent on time. Purely elastic materials do not dissipate energy when a load is applied, then removed. Hysteresis is observed in the stress-strain curve, with the area of the loop being equal to the energy lost during the loading cycle. Since viscosity is the resistance to thermally activated plastic deformation, a viscous material will lose energy through a loading cycle. Plastic deformation results in loss of energy which is uncharacteristic of a purely elastic material's reaction to a loading cycle (McCrum et al, 2003).

Specifically, viscoelasticity is a molecular rearrangement. When a stress is applied to a viscoelastic material such as a polymer, parts of the long polymer chain change positions. This movement or rearrangement is called creep. Polymers remain a solid material even when these parts of their chains are rearranging in order to accompany the stress and as this occurs, it creates a back stress in the material. When the back stress is the same magnitude as the applied stress, the material no longer creeps. When the original stress is taken away, the accumulated back stresses will cause the polymer chain to return to

its original form. The material creeps which gives the prefix “visco” and the material fully recovers, which gives the suffix –elasticity(McCrum, Buckley and Bucknell, 2003).

An anelastic material is a special case of a viscoelastic material; an anelastic material will fully recover to its original state on the removal of load.

The secondary bonds of a polymer constantly break and reform due to thermal motion. Application of a stress favours some conformations over others, so the molecules of the polymer will gradually flow into the favoured conformations over time. Because thermal motion is one factor contributing to the deformation of polymers, viscoelastic properties change with increasing or decreasing temperature. In most cases, the creep modulus, defined as the ratio of applied stress to time dependent strain, decreases with increasing temperature. Generally, an increase in temperature correlates to a logarithmic decrease in the time required to impart equal strain under a constant stress. In other words, it takes less work to stretch a viscoelastic material an equal distance at a higher temperature than it does at a lower temperature (Baeurle et al, 2002).

Viscoelastic calculations depend heavily on the viscosity variable η , the value of η can be derived as a function of temperature. Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as a linear response. When a material exhibits a linear response, it is categorized as a Newtonian material. In this case the stress is linearly proportional to the strain rate. If the material exhibits a non-linear response to strain rate, it is categorized as non-Newtonian fluid. There is also an interesting case where the viscosity decreases as the shear/strain rate remains constant. A material which exhibits this type of behavior is said to be thixotropic (Meyers and Chawla, 1999).

. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. When subjected to a step constant stress, viscoelastic materials experience a time dependent increase in strain. This phenomenon is called viscoelastic creep.

Many viscoelastic materials exhibit rubber like behavior explained by the thermodynamic theory of polymer elasticity. Some properties associated with viscoelastic materials are

- (i) If the stress is held constant, the strain increases with time (creep).
- (ii) If the strain is held constant, the stress decreases with time (stress relaxation)
- (iii) The effective thickness depends on the rate of application of the load.
- (iv) If cyclic loading is applied, hysteresis (a phase lag) occurs, leading to dissipation of mechanical energy. This is seen in the stress strain curve.
- (v) The rebound of an object following an impact is less than 100%.
- (vi) During rolling, frictional resistance occurs.

All materials exhibit some viscoelastic response. Synthetic polymers, wood as well as metals at high temperature display significant viscoelastic effects. An analysis or design involving such materials must incorporate their viscoelastic behavior. Knowledge of viscoelastic response of a material is based on measurement.

1.1 Significance of Research

The study of the viscoelastic behavior of polymeric materials is of interest to the materials scientist in several contexts. Materials used for structural applications of practical interest may exhibit viscoelastic behavior which has a profound influence on the performance of that material. In applications, one may deliberately make use of the viscoelasticity of certain materials in the design process to achieve a particular goal. Viscoelasticity is of interest in materials science, metallurgy and solid state physics since it is causally linked to a variety of microphysical processes and can be used as an experimental probe of those processes.

Mechanical and other properties of viscoelastic polymeric materials as functions of time and temperature are important to the materials scientist. The reason for this is the need to evaluate long-term performance and reliability of polymeric materials and components from short term tests and also the belief that the

properties in question are still far from sufficiently understood. Thus, we need the understanding not only for intellectual satisfaction but also for the development of predictive methods so as to be able to save dramatically the time required for the experiments.

Many soft materials, such as elastomeric polymers and biopolymer fibrils, undergo reversible phase or alignment transitions in response to pressure, shear and temperature, such microscopic structural changes often have significant effects on the mechanical properties of the product. Understanding the dynamic response of soft materials to deformations of pressure, temperature and shear is therefore important for the control of manufacturing processes.

1.2 Research Objectives

This study of viscoelastic properties of polymeric materials subjected to loads at different temperatures was to use the characterization of the polymer material to understand their behavior by

- (i) measuring the minimum strain rate of the polymeric material at different temperatures for the polymers; PVC, polyethylene, natural rubber.
- (ii) measuring the strain rates of the polymer material at different temperatures.
- (iii) determining the effect of temperature on the viscoelastic properties of polymers.
- (iv) establishing the effect of strain rate on the behavior of the polymeric materials.
- (v) establishing the effect of loading on the polymeric materials.

1.3 Previous work on the viscoelastic properties of polymers

Experimental studies of anelasticity, hysteresis and creep behavior have been conducted with the viscoelastic instrument (broadband viscoelastic spectroscopy or BVS) on solder, alloys, high loss elastomers, composites etc. Many reported experiments are at ambient temperature and cover a wide range of frequency. There is the use of Resonant Ultrasound Spectroscopy (RUS) in viscoelastic measurements to illustrate effects of internal friction, anelastic behavior or material damping.

In the nineteenth century, physicists such as Maxwell, Boltzmann and Kelvin researched and experimented with creep and recovery of glasses, metals and rubbers. Viscoelasticity was further examined in the late twentieth century when synthetic polymers were engineered and used in a variety of applications.

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CHAPTER 2

LITERATURE REVIEW

2.1 Molecular structure of polymers in general

Polymers (or macromolecules) are very large molecules made up of smaller units, called monomers or repeating units, covalently bonded together. This specific molecular structure (chainlike structure) of polymeric materials is responsible for their intriguing mechanical properties. The repeating structure is usually based on a carbon backbone. The carbon atom has four electrons in the outer shell. Each of these valence electrons can form a covalent bond to another carbon atom or to a foreign atom. The key to the polymer structure is that two carbon atoms can have up to three common bonds and still bond with other atoms. Polymer architecture can vary (Kahovek et al, 2002).

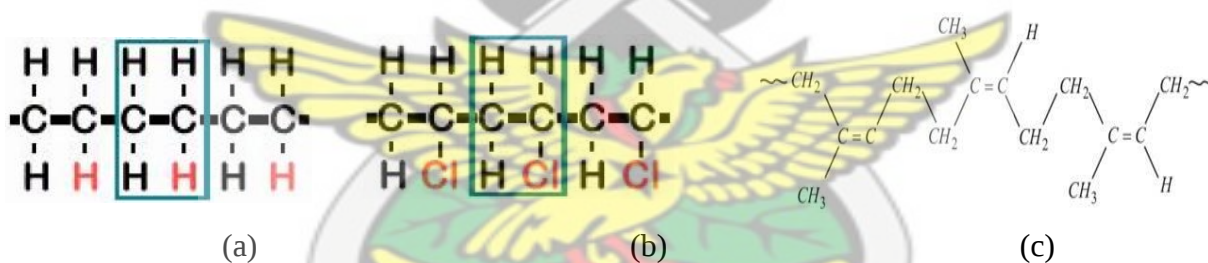


Fig. 2.1 Molecular structures of (a) polyethylene and (b) polyvinyl chloride (c) polyisoprene (<http://pvc.org/en/p/pvcs-physical-properties>), (<http://chemistrylearning.com/wpcontent/uploads/2009/04/image003.jpg&imgrefurl>)

A linear polymer consists of a long chain of monomers. A branched polymer has branches covalently attached to the main chain. Cross-linked polymers have monomers of one chain covalently bonded with monomers of another chain. Cross linking results in a three-dimensional network; the whole polymer is a giant macro-molecule. Elastomers are loosely cross-linked networks while thermosets are densely cross-linked networks (McGraw-Hill and Harper, 2002).



Figure 2.2: Types of molecular structures: (a) Linear chain (b) Branched molecule

(c) Cross-linked network (d) networked

(http://neon.mems.cmu.edu/cramb/27-100/lab/S00_lab2/Image2.gif&imgrefurl)

In each polymer molecule, the atoms are bound together by covalent bonds. However, the separate molecules, or segments of the same molecule, are attracted to each other by weak “intermolecular forces”, also termed “secondary” or “Van der Waals” forces. In general, covalent bonds govern the thermal and chemical stability of polymers. On the other hand, secondary forces determine most of the physical properties we associate with specific compounds. Melting, dissolving, vaporizing, adsorption, diffusion, deformation, and flow involve the making and breaking of intermolecular bonds so that molecules can move past one another or away from each other. Individual chains of polymers can also be chemically linked by covalent bonds (cross linked) during polymerization or by subsequent chemical or thermal treatment during fabrication. Once formed, these cross linked networks resist heat softening, creep, and solvent attack (Young and Lovell, 1991).

The polymer chains can be free to slide past one another (thermoplastic) or they can be connected to each other with cross links (thermoset). Thermoplastics (including thermoplastic elastomers) can be reformed and recycled, while thermosets (including cross linked elastomers) are not reworkable. Thermoplastics are polymers that flow when heated; thus, easily reshaped and recycled. This property is due to presence of long chains with limited or no cross links. In a

thermoplastic material the very long chain-like molecules are held together by relatively weak Van der Waals forces. When the material is heated the intermolecular forces are weakened so that it becomes soft and flexible and eventually, at high temperatures, it is a viscous melt (it flows). When the material is allowed to cool it solidifies again. Thermosets like vulcanized rubber decompose when heated; thus, cannot be reformed or recycled. Presence of extensive cross links between long chains induce decomposition upon heating and renders thermosetting polymers brittle (Treloar, 1975). A thermosetting polymer is produced by a chemical reaction which has two stages. The first stage results in the formation of long chain-like molecules similar to those present in thermoplastics, but still capable of further reaction. The second stage of the reaction (cross linking of chains) takes place during moulding, usually under the application of heat and pressure. During the second stage, the long molecular chains have been interlinked by strong covalent bonds so that the material cannot be softened again by the application of heat. If excess heat is applied to these materials they will degrade (Hallidin and Kame, 1977).



Fig. 2.3 Moulding and cross linking in polymers

2.2 Structure and properties of isoprene

Natural rubber is a polymer of isoprene (2-methyl-1,3-butadiene) i.e. $\text{CH}_2=\text{C}(\text{CH}_3)\text{CH}=\text{CH}_2$ in the form of folded polymeric chains which are joined in a network structure and have a high degree of flexibility. Isoprene (C_5H_8) is the monomer of natural rubber and also a common structure motif to an immense variety of other naturally occurring compounds, collectively

termed the isoprenoids. Molecular formula of isoprenoids are multiples of isoprene in the form of $(C_5H_8)_n$, and this is termed the isoprene rule (Ferry, 2008). Upon application of stress to a rubber material, the polymer chain which is randomly oriented undergoes bond rotations allowing the chain to be extended or elongated. The fact that the chains are joined in a network allows for elastomeric recoverability since the cross linked chains cannot irreversibly slide over one another. Elastomeric polymer chains can be cross linked, or connected by covalent bonds. Cross linking in elastomers is called vulcanization, and is achieved by irreversible chemical reaction, usually requiring high temperatures. Unvulcanized natural rubber (polyisoprene) is a thermoplastic and in hot weather becomes soft and sticky and in cold weather hard and brittle. It is poorly resistant to wear. Sulfur compounds are added to form chains that bond adjacent polymer backbone chains and cross links them. The vulcanized rubber is a thermosetting polymer (Smith, 1981). Cross linking makes elastomers reversibly stretchable for small deformations. When stretched, the polymer chains become elongated and ordered along the deformation direction. This is entropically unfavorable. When no longer stretched, the chains randomize again. The cross links guide the elastomer back to its original shape.

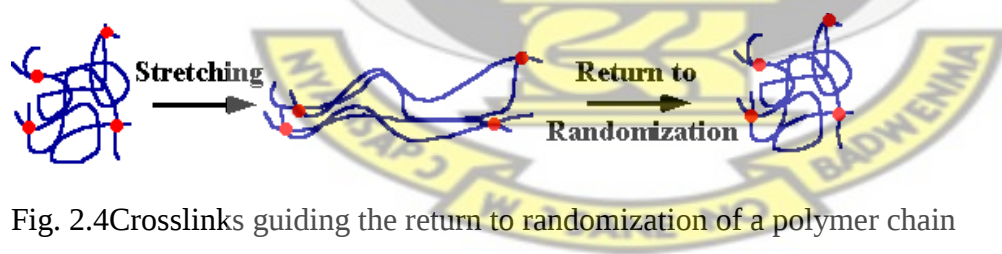


Fig. 2.4 Crosslinks guiding the return to randomization of a polymer chain

Isoprene is produced and emitted by many species of trees into the atmosphere (major producers are oaks, poplars, eucalyptus, and some legumes). The yearly production of isoprene emissions by vegetation is around 600 Tg, with half that coming from tropical broadleaf trees and the remainder coming from shrubs (Allen, 1999).

2.3 Structure and properties of polyvinyl chloride (PVC)

Polyvinyl chloride (PVC), is the third-most widely produced plastic, after polyethylene and polypropylene. PVC is used in construction because it is cheaper and stronger than more traditional alternatives such as copper or ductile iron. It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is used in clothing and upholstery, electrical cable insulation, inflatable products and many applications in which it replaces rubber (Jones et al, 1980). Pure polyvinyl chloride without any plasticizer is a white, brittle solid. It is insoluble in alcohol, but slightly soluble in tetrahydrofuran. Polyvinyl chloride is produced by polymerization of the monomer vinyl chloride (VCM), as shown in Fig. 2.6.

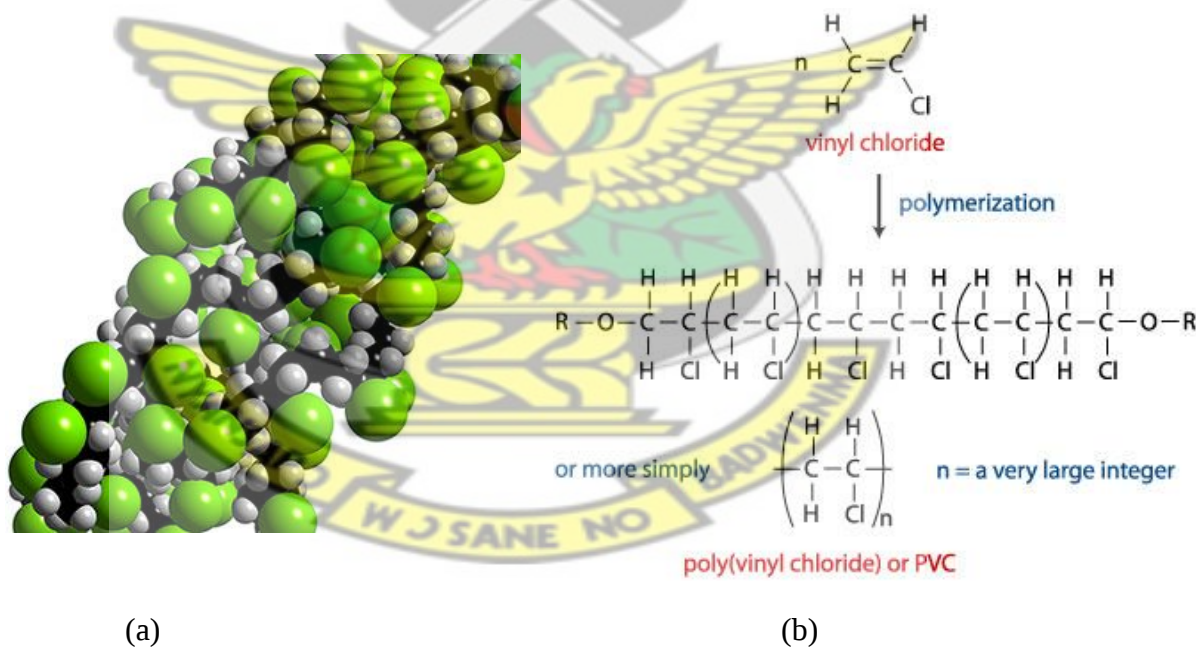


Fig. 2.5 (a) molecular structure of PVC (b) polymerization of vinyl chloride

(<http://www.3dchem.com/imagesofmolecules/pvc.jpg&l>)

PVC has mainly an atactic stereochemistry, which means that the relative stereochemistry of the chloride centres are random. Some degree of syndiotacticity of the chain gives a few percent crystallinity that is influential on the properties of the material. About 57% of the mass of PVC is chlorine. The presence of chloride groups gives the polymer very different properties from the structurally related material polyethylene(Hall, 1989).

The product of the polymerization process is unmodified PVC. Before PVC can be made into finished products, it always requires conversion into a compound by the incorporation of additives such as heat stabilizers, UV stabilizers, lubricants, plasticizers, processing aids, impact modifiers, thermal modifiers, fillers, flame retardants, biocides, blowing agents and smoke suppressors, and optionally, pigments.

2.4 Structure and properties of polyethylene

The primary use of polyethylene is within packaging (plastic bag, plastic films, geo-membranes, containers including bottles, etc.). Many kinds of polyethylene are known, but they almost always have the chemical formula $(C_2H_4)_n$. Thus PE is usually a mixture of similar organic compounds that differ in terms of the value of n .

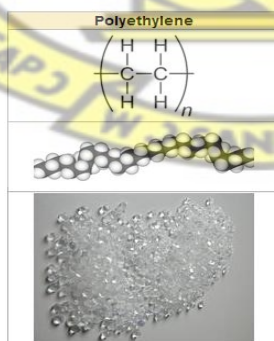


Fig. 2.7 Structure of polyethylene

(en.wikipedia.org/wiki/polyethylene)

Polyethylene is made from ethane gas, C_2H_6 . Ethane gas has two carbon atoms in the chain and each of the two carbon atoms shares two valence electrons with the other. If two molecules of ethane are brought together, one of the carbon bonds in each molecule can be broken and the two molecules can be joined with a carbon to carbon bond. After the two mers are joined, there are still two free valence electrons at each end of the chain for joining other mers or polymer chains. The process can continue linking more mers and polymers together until it is stopped by the addition of another chemical (a terminator), that fills the available bond at each end of the molecule. This is called a linear polymer and is building block for thermoplastic polymers (Crandal et al, 1999).

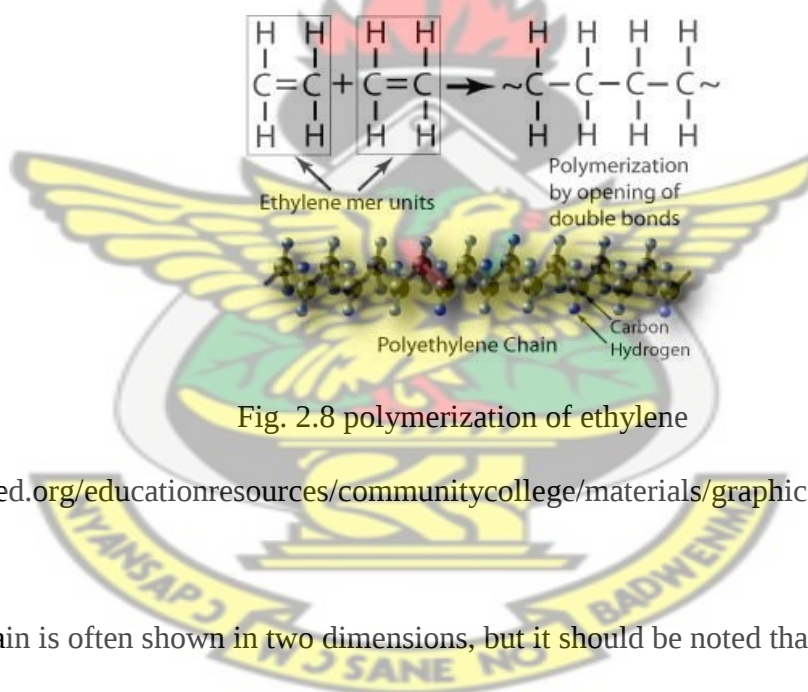


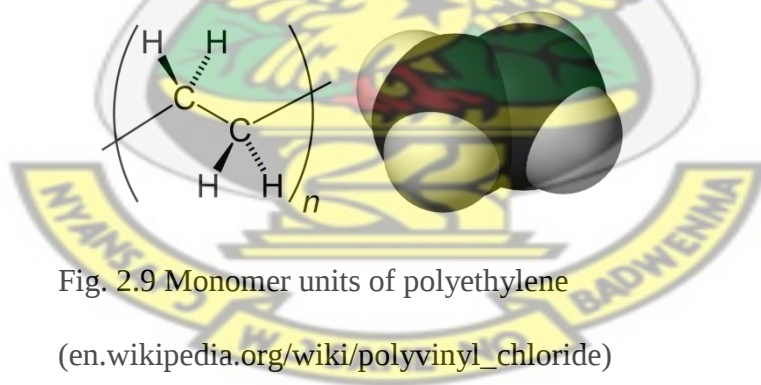
Fig. 2.8 polymerization of ethylene

(<http://www.ndted.org/educationresources/communitycollege/materials/graphics/polyethylenechain.jpg>)

The polymer chain is often shown in two dimensions, but it should be noted that they have a three dimensional structure. Each bond is at 109° to the next and, therefore, the carbon backbone extends through space. When stress is applied, these chains stretch and the elongation of polymers can be thousands of times greater than it is in crystalline structures. The length of the polymer chain is very important. As the number of carbon atoms in the chain is increased to beyond several hundred, the material will pass through the liquid state and become a waxy solid.

When the number of carbon atoms in the chain is over 1,000, the solid material polyethylene, with its characteristics of strength, flexibility and toughness, is obtained (Vliet and Krystyn, 2006). The change in state occurs because as the length of the molecules increases, the total binding forces between molecules also increases. The binding forces are the result of van der Waals forces between molecules and mechanical entanglement between the chains. When polyethylene like other thermoplastics are heated, there is more molecular movement and the bonds between molecules can be easily broken. This is why thermoplastic materials can be remelted.

Depending on the crystallinity and molecular weight, a melting point and glass transition may or may not be observable. The temperature at which these occur varies strongly with the type of polyethylene. The melting point for average, commercial, low-density polyethylene is typically 105 to 115 °C (Lakes, 1999). The monomer is ethylene (ethene). It has the formula C_2H_4 , consisting of a pair of CH_2 groups connected by a double bond, thus:



Ethylene is usually produced from petrochemical sources, but also is generated by dehydration of ethanol. Ethylene is a rather stable molecule that polymerizes only upon contact with catalysts. The conversion is highly exothermic, that is the process releases a lot of heat. Polyethylene is classified into several different categories based mostly on its density and branching. Its mechanical properties depend significantly on variables such as the extent and type of branching,

the crystal structure and the molecular weight (Dimitrienko, 2011). With regard to sold volumes, the most important polyethylene grades are HDPE, LLDPE and LDPE.

2.5 Viscoelastic models

Viscoelastic materials, such as amorphous polymers, semicrystalline polymers, and biopolymers, can be modeled in order to determine their stress or strain interactions as well as their temporal dependencies. These models, which include the Maxwell model, the Kelvin-Voigt model, and the Standard Linear Solid Model, are used to predict a material's response under different loading conditions. Viscoelastic behavior has elastic and viscous components modeled as linear combinations of springs and dashpots, respectively (Lakes, 1998). Each model differs in the arrangement of these elements, and all of these viscoelastic models can be equivalently modeled as electrical circuits. In an equivalent electrical circuit, stress is represented by voltage, and the derivative of strain (velocity) by current. The elastic modulus of a spring is analogous to a circuit's capacitance (it stores energy) and the viscosity of a dashpot to a circuit's resistance (it dissipates energy). The elastic components, as previously mentioned, can be modeled as springs of elastic constant E , given the formula: $\sigma = E\varepsilon$ where σ is the stress, E is the elastic modulus of the material, and ε is the strain that occurs under the given stress, similar to Hooke's Law. The viscous components can be modeled as dashpots such that the stress-strain rate relationship can be given as $\sigma = \eta \frac{d\varepsilon}{dt}$ where σ is the stress, η is the viscosity of the material, and $d\varepsilon/dt$ is the time derivative of strain. The relationship between stress and strain can be simplified for specific stress rates. For high stress states/short time periods, the time derivative components of the stress-strain relationship dominate. A dashpot resists changes in length, and in a high stress state it can be approximated as a rigid rod. Since a rigid rod cannot be stretched past its original

length, no strain is added to the system. Conversely, for low stress states/longer time periods, the time derivative components are negligible and the dashpot can be effectively removed from the system - an "open" circuit. As a result, only the spring connected in parallel to the dashpot will contribute to the total strain in the system(Turner, 2001).

2.5.1 Maxwell model

The Maxwell model can be represented by a purely viscous damper and a purely elastic spring connected in series. The model can be represented by the following equation:

$$\frac{dE_{Total}}{dt} = \frac{dE_D}{dt} + \frac{dE_S}{dt}$$

$$= \frac{\sigma}{n} + \frac{1}{E} \frac{d\sigma}{dt}$$

In this model, if the material is put under a constant strain, the stresses gradually relax, When a material is put under a constant stress, the strain has two components. First, an elastic component occurs instantaneously, corresponding to the spring, and relaxes immediately upon release of the stress. The second is a viscous component that grows with time as long as the stress is applied. The Maxwell model predicts that stress decays exponentially with time, which is accurate for most polymers. One limitation of this model is that it does not predict creep accurately. The Maxwell model for creep or constant-stress conditions postulates that strain will increase linearly with time. However, polymers for the most part show the strain rate to be decreasing with time(Callister, 2000)

2.5.2 Kelvin–Voigt model

The Kelvin–Voigt model consists of a Newtonian damper and Hookean elastic spring connected in parallel. It is used to explain the creep behaviour of polymers.

The constitutive relation is expressed as a linear first-order differential equation:

$$\sigma(t) = E\varepsilon(t) + \eta \frac{d\varepsilon}{dt}$$

The model represents a solid undergoing reversible, viscoelastic strain. Upon application of a constant stress, the material deforms at a decreasing rate, asymptotically approaching the steady-state strain. When the stress is released, the material gradually relaxes to its undeformed state. At constant stress (creep), the Model is quite realistic as it predicts strain to tend to σ/E as time continues to infinity. Similar to the Maxwell model, the Kelvin–Voigt model also has limitations. The model is extremely good with modelling creep in materials, but with regards to relaxation the model is much less accurate (Ward and sweeny, 2004).

2.5.3 Standard linear solid model

The Standard Linear Solid Model effectively combines the Maxwell Model and a Hookean spring in parallel. A viscous material is modeled as a spring and a dashpot in series with each other, both of which are in parallel with a lone spring. For this model, the governing constitutive relation is:

$$\frac{d\varepsilon}{dt} = \frac{E_2 \left(\frac{n}{E_2} \frac{d\sigma}{dt} + \sigma - E_1 \varepsilon \right)}{E_1 + E_2}$$

Under a constant stress, the modeled material will instantaneously deform to some strain, which is the elastic portion of the strain, and after that it will continue to deform and asymptotically

approach a steady-state strain. This last portion is the viscous part of the strain. Although the Standard Linear Solid Model is more accurate than the Maxwell and Kelvin-Voigt models in predicting material responses, mathematically it returns inaccurate results for strain under specific loading conditions and is rather difficult to calculate (David, 2001).

2.6 Effect of temperature on viscoelastic deformation

A characteristic feature of polymers is the way in which their response to an applied stress or strain depends on the temperature or time period of loading. The secondary bonds of a polymer constantly break and reform due to thermal motion. Application of a stress favors some conformations over others, so the molecules of the polymer will gradually "flow" into the favored conformations over time (Baeurle et al, 2006). Because thermal motion is one factor contributing to the deformation of polymers, viscoelastic properties change with increasing or decreasing temperature. In most cases, the creep modulus, defined as the ratio of applied stress to the time-dependent strain, decreases with increasing temperature. Generally speaking, an increase in temperature correlates to a logarithmic decrease in the time required to impart equal strain under a constant stress. In other words, it takes less work to stretch a viscoelastic material an equal distance at a higher temperature than it does at a lower temperature.

2.7 Creep of polymers

When subjected to a step constant stress, viscoelastic materials experience a time-dependent increase in strain. This phenomenon is known as viscoelastic creep.

At a time t_0 , a viscoelastic material is loaded with a constant stress that is maintained for a sufficiently long time period. The material responds to the stress with a strain that increases until

the material ultimately fails. When the stress is maintained for a shorter time period, the material undergoes an initial strain until a time t_1 at which the stress is relieved, at which time the strain immediately decreases (discontinuity) then continues decreasing gradually to a residual strain.

Viscoelastic creep data can be presented in one of two ways. Total strain can be plotted as a function of time for a given temperature or temperatures. Below a critical value of applied stress, a material may exhibit linear viscoelasticity. Above this critical stress, the creep rate grows disproportionately faster. The second way of graphically presenting viscoelastic creep in a material is by plotting the creep modulus (constant applied stress divided by total strain at a particular time) as a function of time (Jones et al, 1980).. Below its critical stress, the viscoelastic creep modulus is independent of stress applied. A family of curves describing strain versus time response to various applied stress may be represented by a single viscoelastic creep modulus versus time curve if the applied stresses are below the material's critical stress value.

Additionally, the molecular weight of the polymer of interest is known to affect its creep behavior. The effect of increasing molecular weight tends to promote secondary bonding between polymer chains and thus make the polymer more creep resistant. Similarly, aromatic polymers are even more creep resistant due to the added stiffness from the rings. Both molecular weight and aromatic rings add to polymers' thermal stability, increasing the creep resistance of a polymer (Lemaitre and Chadoche, 1994).

CHAPTER 3 -METHODOLOGY

3.1 Experimental set up

The setup for the experiment is as shown in the following diagrams.

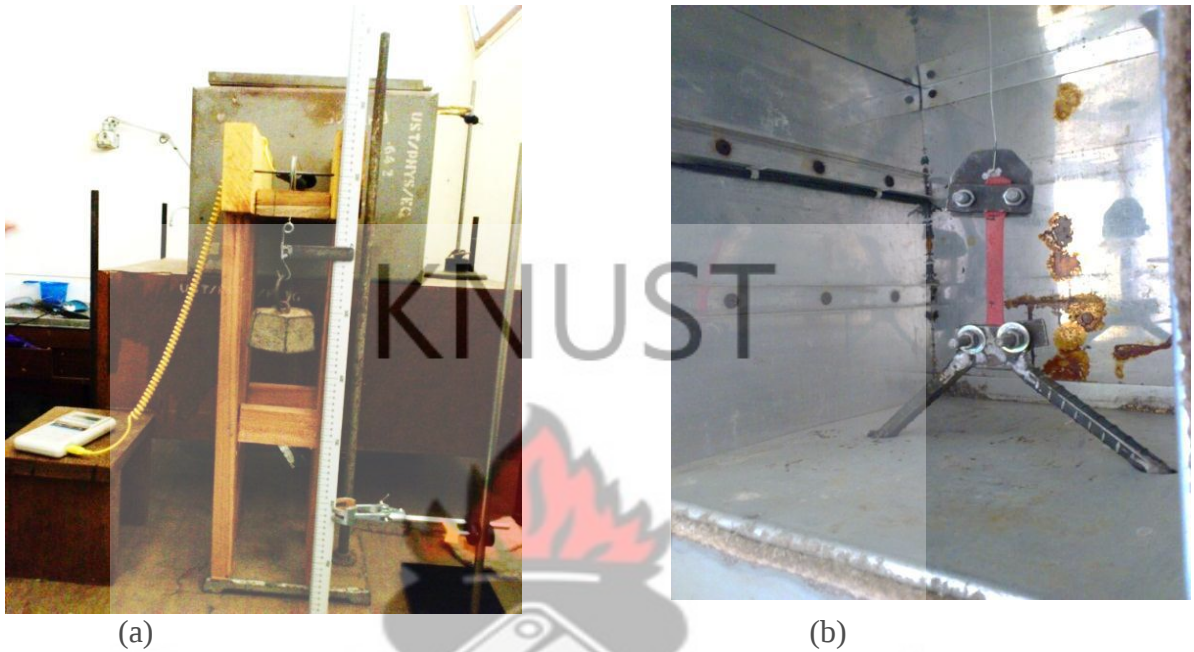


Fig. 3.1 Diagram of set up (a) and sample under tension in the oven (b)

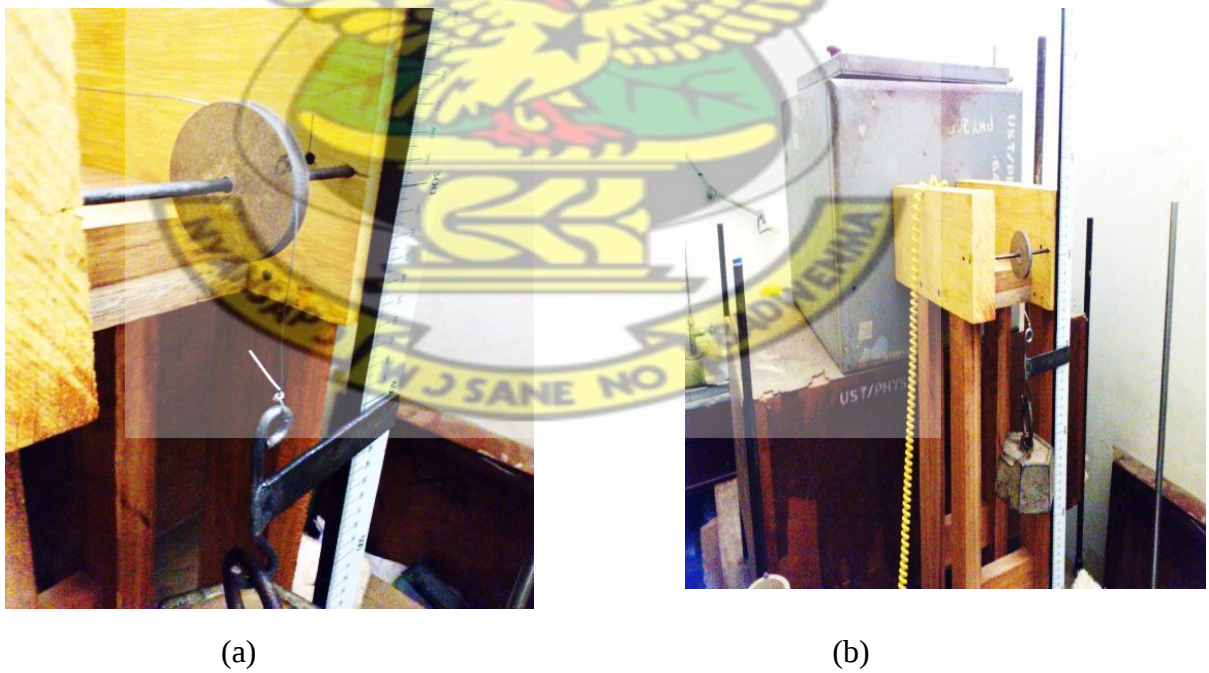


Fig. 3.2 Diagram of set up (a) measuring elongation and (b) showing how samples

were suspended (b)

3.2 Experimental procedure

Samples were obtained from the open market prepared and synthesized by the importing company (Duraplast). The regulator (a knob) on the furnace was adjusted to the required temperature. The oven was switched on for some time until the thermocouple read the required temperature (i.e 50°C). This temperature was read and recorded.

The polyisoprene sample was then mounted in the furnace as shown in Fig. 1 (b) and subjected to tension under a constant load of 500 g. The initial extension was measured and recorded. The initial strain was then determined. The changes in length with their corresponding times were read and recorded, the strains then determined. The procedure was repeated for 1000 g and 1500 g at the same temperature. The procedure was also repeated for PVC and polyethylene samples. The regulator was adjusted to the next required temperature and the above steps are repeated for the two other constant temperatures. (i.e. 100°C and 150°C).

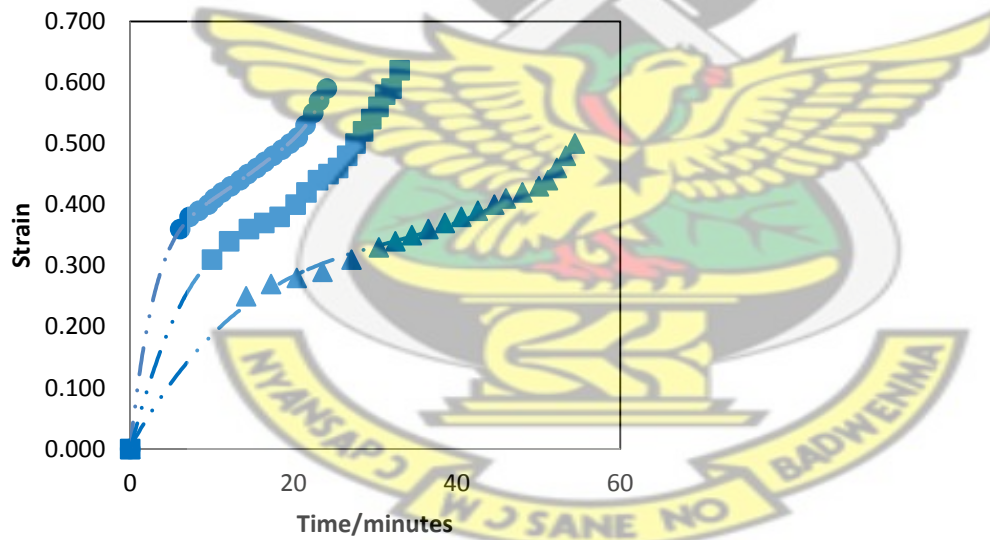
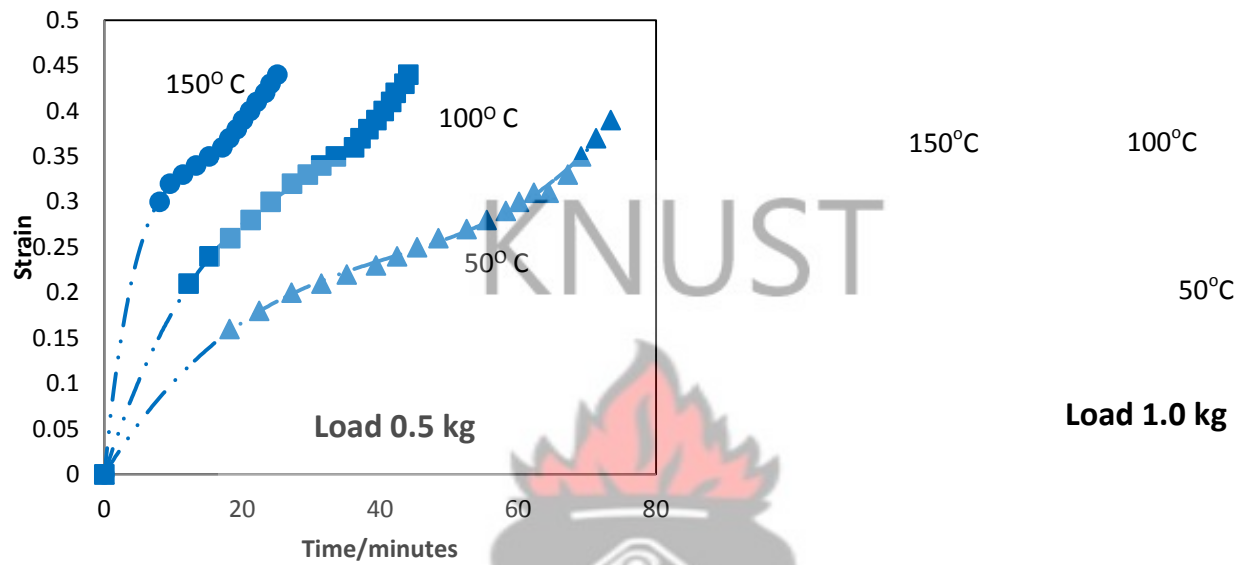
Graphs of strain against time are plotted for each polymeric sample at the various different constant temperatures. The temperatures were carefully selected for below glass transition temperature, above glass transition temperature and near the glass transition temperature for each polymeric sample. The strain rates were determined from the derivatives of the equations of the curves obtained from the plots of strain against time and substituting the time values into the equation. These equations are shown in Appendix E.

Graphs of strain rate against time were also plotted and the minimum strain rate and the corresponding times to attain them were determined from the graphs.

CHAPTER FOUR

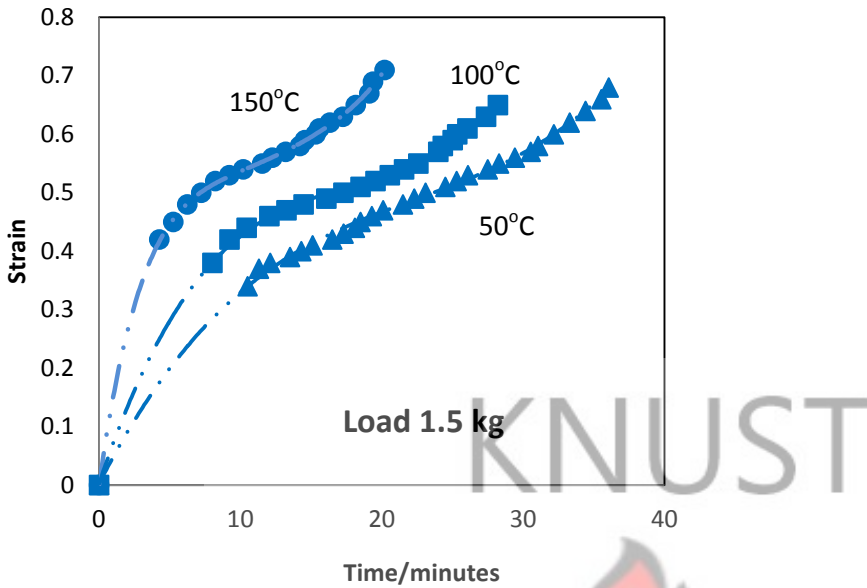
RESULTS AND DISCUSSION

4.1 Effect of temperature on the viscoelastic properties of polyisoprene



(a)

(b)



(c)

Fig. 4.1 Graphs of strain against time for poly isoprene at three different temperatures of 50°C, 100°C and 150°C under a loads of (a) 0.5 kg, (b) 1.0 kg and (c) 1.5 kg.

Not enough data was obtained between $t = 0$ and $t = 10$ mins because deformation in this region (primary region) were too fast as the molecules of the polymer uncoiled and measurements of strain were extremely difficult to determine. The value of the glass transition temperature is an important descriptor of polymer thermo chemical response and is a fundamental measure of the materials propensity for mobility. At temperatures much above the glass transition temperature of -70°C for polyisoprene, the strain rates were much higher and the polymer acted in a rubbery manner in which it exhibited large instantaneous and fully reversible strain in response to the applied stress. Table 4.1(a) and 4.1(b) below give the minimum strain rates for poly isoprene under the stated conditions.

Table 4.1 (a) Minimum strain rates for polyisoprene subjected to different loads at different constant temperatures.

	50°C	100°C	150°C

Load/kg	Strain rates/min ⁻¹	Strain rates/min ⁻¹	Strain rates/min ⁻¹
0.5	0.0032989	0.003478	0.015146
1.0	0.0040134	0.0040299	0.0083624
1.5	0.0152025	0.014371	0.072017405

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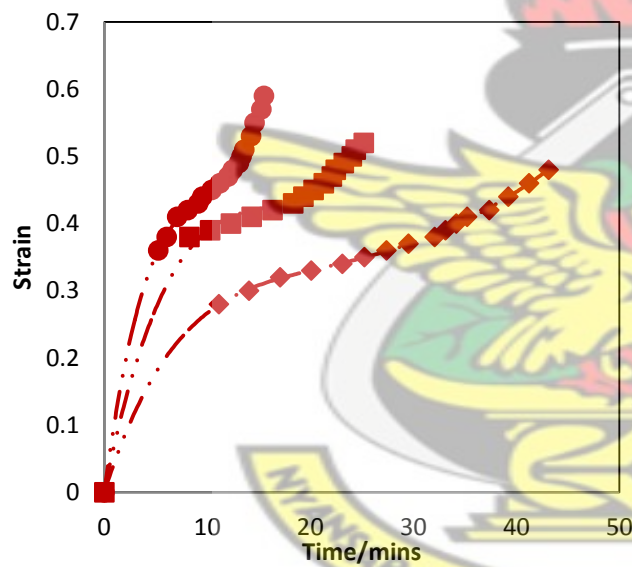
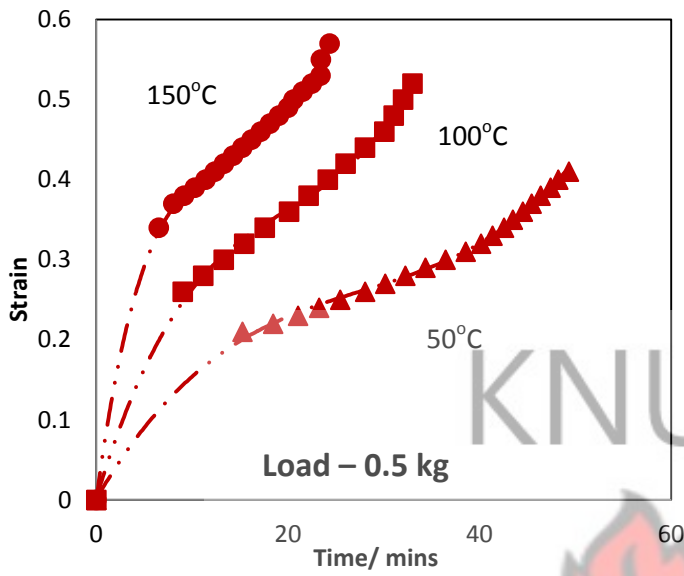
Table 4.1 (b) Times for minimum strain rates for polyisoprene subjected to different loads at different constant temperatures.

	50°C	100°C	150°C
Load	Time/mins	Time/mins	Time/mins
0.5 kg	39.4	29.51	9.52
1.0 kg	32.47	14.54	8.42
1.5 kg	18.50	10.29	7.23

From the graphs, it is observed that the strain rates are low at temperatures below the glass transition temperature but the initial strain rates are always high. The initial strain rates are high due to the chain uncoiling process which is essentially frozen out at temperatures above the glass transition temperature.

As the chain uncoiling process freezes out, the polymer is able to respond only by bond stretching with comparatively lower strains. In the range near the glass transition temperature of the polymeric samples, the polymer's response is a combination of viscous fluidity and elastic solidity and this region is termed viscoelastic. As the temperature was increased, the stiffness of polyisoprene which makes it resistant to heat flow dropped rapidly because the secondary bonds (Vander Waals forces) between its molecules were broken and atoms easily moved to new positions sliding past each other. The glass transition temperature represents a reversible transition from a hard and relatively brittle state into a molten or [rubber](#)-like state. It is an inherent property of the material and depends on the internal energy of the polymer material. At still higher temperatures, the entanglements slip and the material becomes a viscous liquid. This is observed also with increased load as from the graphs of Fig. 4.4.

4.2 Effect of temperature on the viscoelastic properties of polyethylene



(a)

(b)

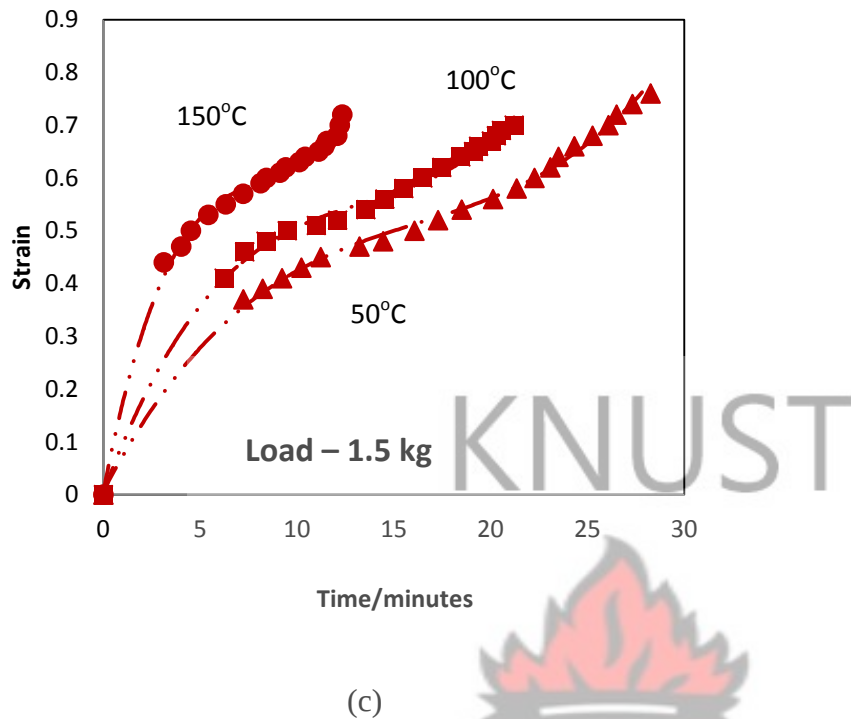


Fig. 4.2 Graphs of strain against time for polyethylene at three different temperatures of 50°C, 100°C and 150°C under a loads of (a) 0.5 kg, (b) 1.0 kg and (c) 1.5 kg.

As previously, the value of the glass transition temperature was an important descriptor of polymer thermochemical response and was a fundamental measure of the materials propensity for mobility. At temperatures much above the glass transition temperature of polyethylene (-125°C) (https://en.wikipedia.org/wiki/Glass_transition), the strain rates were so high due to covalent bond rupture as a result of thermal agitation. The initial strain rates were very high because due to chain uncoiling as the material was stretched. This initial strain rate reduced until it attained a minimum value and then started to increase at a steady rate. The results for polyethylene under the different loading conditions at different constant temperatures are shown in the table below.

Table 4.2 (a) Minimum strain rates for polyethylene subjected to different loads at different constant temperatures.

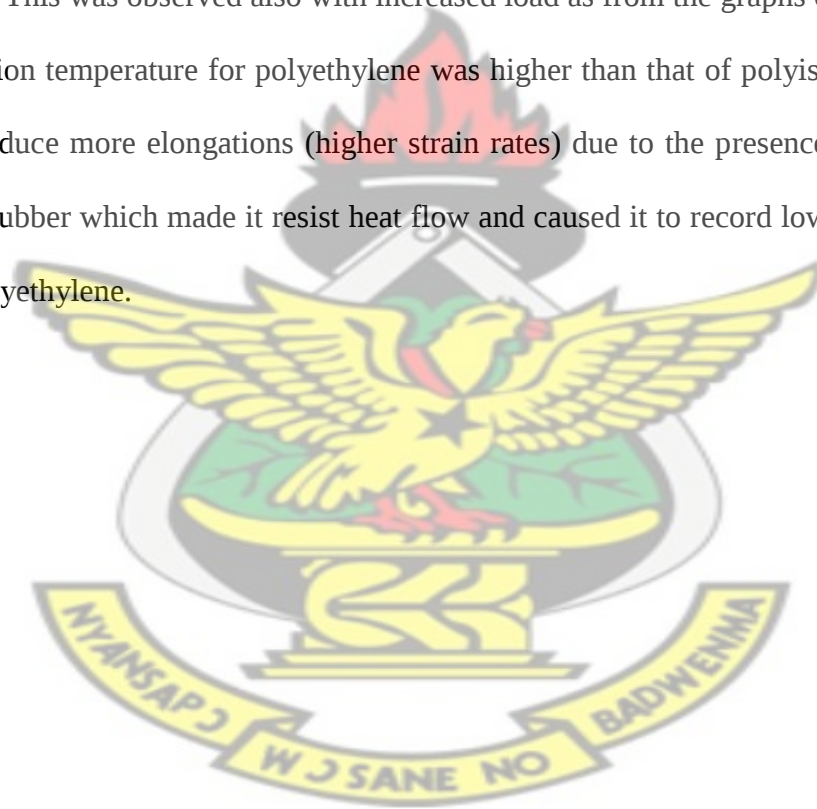
	50°C	100°C	150°C
Load/kg	Strain rate/min ⁻¹	Strain rate/min ⁻¹	Strain rate/min ⁻¹
0.5	0.00346	0.01128	0.03640
1.0	0.015891	0.027950	0.069313
1.5	0.020448	0.059692	0.120234

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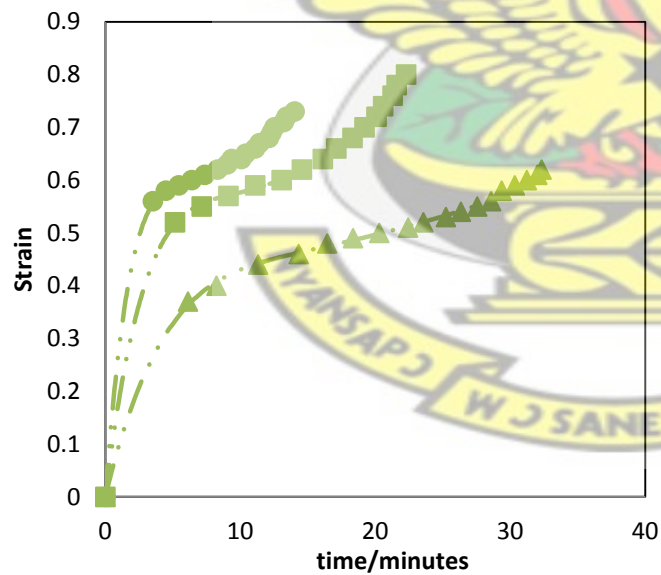
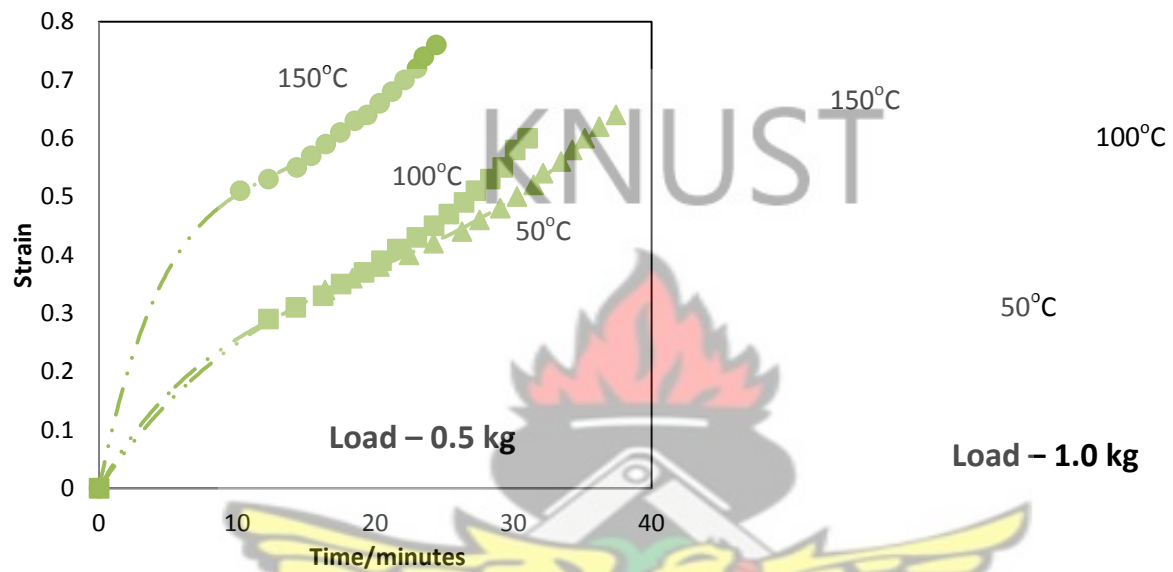
loads Table 4.2 (b) Times for minimum strain rates for polyethylene subjected to different at different constant temperatures.

	50°C	100°C	150°C
Load/kg	Time/mins	Time/mins	Time/mins
0.5 kg	28.06	18.16	6.52
1.0 kg	20.04	16.32	5.23
1.5 kg	17.29	12.10	4.42

At 100°C the polymer's response was a combination of viscous fluidity and elastic solidity and this region was termed viscoelastic. As the temperature is increased through the glass transition temperature its stiffness dropped rapidly because the Vander Waals forces between the molecules of the polyethylene were broken and atoms easily move to new positions sliding past each other. At still higher temperatures, the entanglements slipped and the material became a viscous liquid. This was observed also with increased load as from the graphs of Fig. 4. Though the glass transition temperature for polyethylene was higher than that of polyisoprene, the latter was seen to produce more elongations (higher strain rates) due to the presence of crosslinks in the vulcanized rubber which made it resist heat flow and caused it to record lower strain rates as compared to polyethylene.



4.3 Effect of temperature on the viscoelastic properties of PVC



(a)

(b)

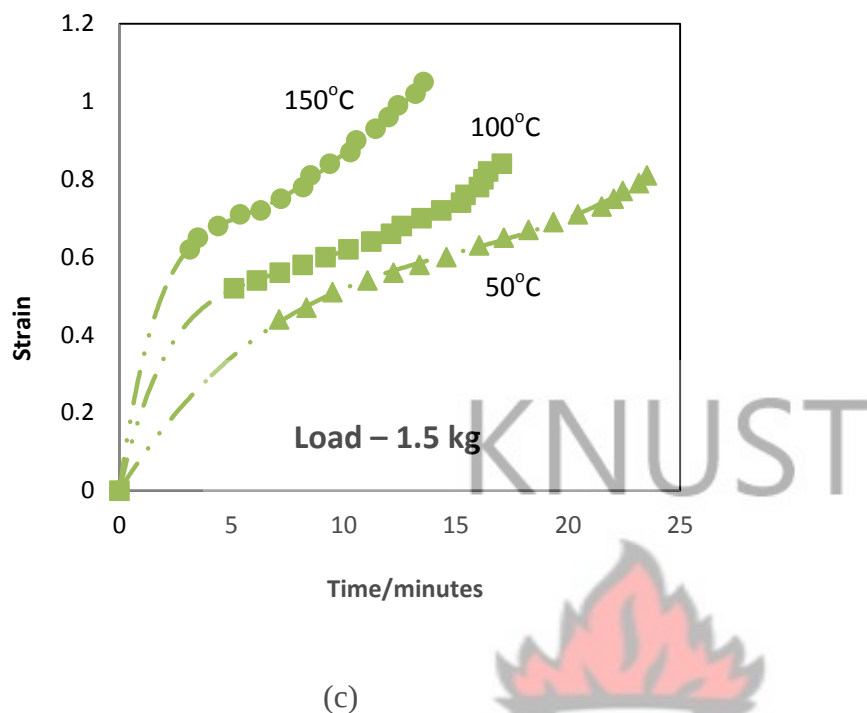


Fig. 4.3 Graphs of strain against time for PVC at three different temperatures of 50°C, 100°C and 150°C under loads of (a) 0.5 kg, (b) 1.0 kg and (c) 1.5 kg.

From the graphs in Fig. 4.3, PVC was seen to record the highest strain rates under the same conditions as compared to polyethylene, polyisoprene as indicated in Table 4.3(a). Initial strain rates were very high usually due to chain uncoiling, a characteristic exhibited by polyethylene and polyisoprene as well. The strain rates were then seen to reduce with time after which it increased at a steady rate. After chain uncoiling, PVC deformed by bond stretching. Beyond 100°C, i.e. above the glass transition temperature of 80°C (https://en.wikipedia.org/wiki/Glass_transition), the rates were so high, with PVC recording the highest strain rates under the same conditions with minimum strain rates occurring at faster times as compared to polyethylene and PVC. The table below gives the strain rates for PVC under the stated conditions.

Table 4.3 (a) Minimum strain rates for PVC subjected to different loads at different constant temperatures.

	50°C	100°C	150°C
Load/kg	Strain rate/min ⁻¹	Strain rate/min ⁻¹	Strain rate/min ⁻¹
0.5	0.0131794	0.024498	0.030100
1.0	0.0147090	0.026850	0.035446
1.5	0.0474290	0.053945	0.061090

Table 4.3 (b) Times for minimum strain rates for polyisoprene subjected to different loads at different constant temperatures.

	50°C	100°C	150°C
Load/kg	Time/min	Time/min	Time/mins
0.5	24.21	14.24	12.26
1.0	11.32	7.14	3.52
1.5	10.24	5.11	3.4

As the temperature was increased PVC's stiffness dropped rapidly because the Vander Waals forces between its molecules broke down and the atoms easily moved to new positions sliding past each other. At still higher temperatures, the entanglements slip and the material became a viscous liquid. This was observed also with increased load as seen from the graphs of Fig. 4.5.

Plastic deformation of polymers involved chain uncoiling which resulted in high initial strain rates and chain sliding with atoms of the polymer moving to new positions. Increasing temperature increased the relative space between chains and made uncoiling easier.

Viscoelastic properties changed with temperature. An increase in temperature correlated to a logarithm decrease in time required to impart equal strain under a constant stress as temperature broke the secondary bonds allowing the material to flow with ease. It took less work to stretch the viscoelastic materials at an equal distance at a higher temperature than a lower temperature since the spacing between adjacent chains were increased making the uncoiling easier and subsequently chain sliding. Molecular rearrangements were enhanced.

4.4 Stages of creep in the polymeric materials that relates their viscoelastic behavior

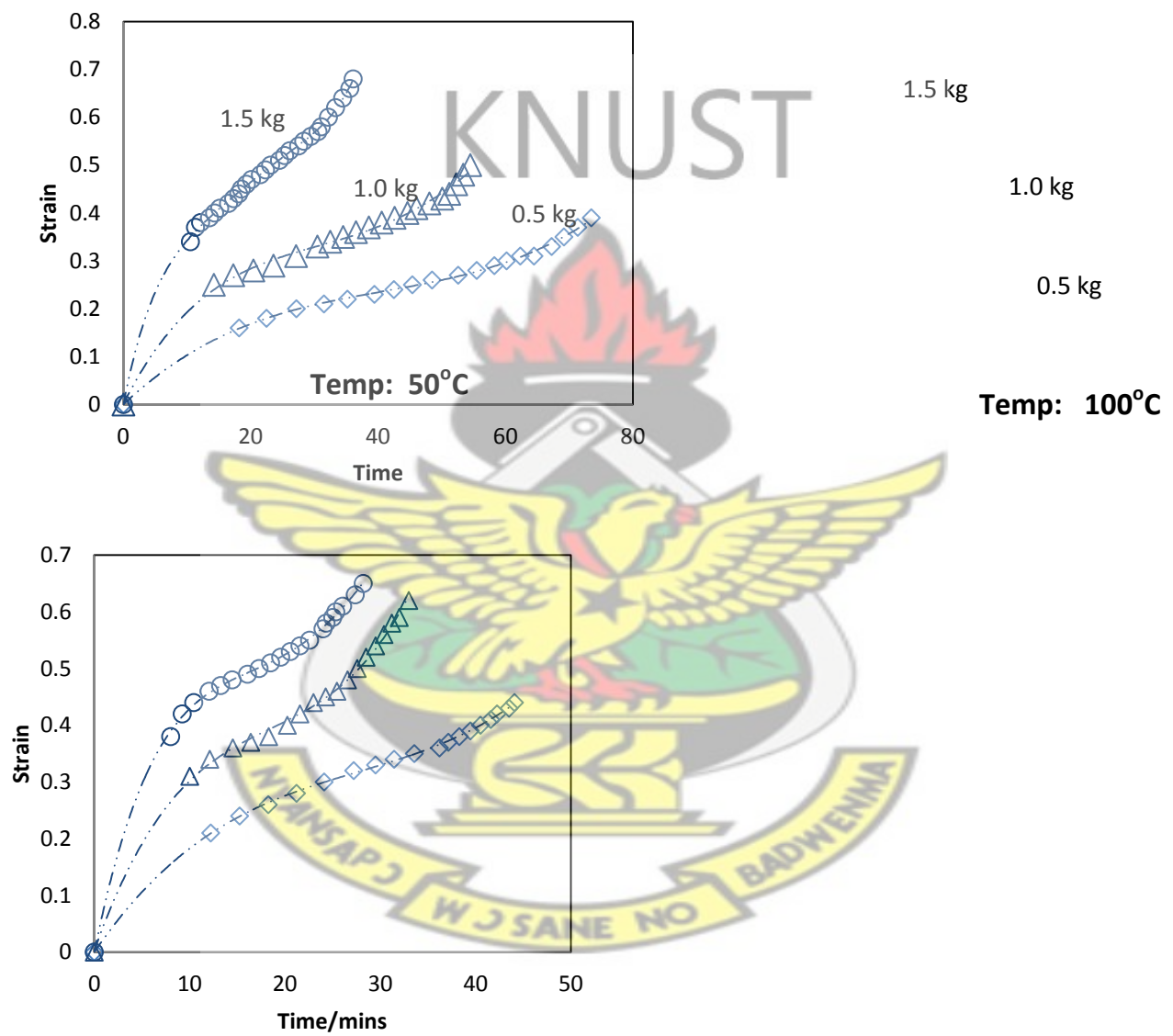
From the graphs in Figures 4.1, 4.2 and 4.3, it was observed that the creep strains plotted against time were characterized by three stages; the primary, secondary and tertiary stages for all three constant temperatures. This way of deformation is a characteristic of viscoelastic materials. The primary region was the early stage of the loading where the strain rate was relatively high but slowed down with increasing time. The strain rate in this region was high because there was uncoiling of the polymer chains as the load was applied. Unfortunately, not enough information was gathered in this region since the polymeric materials strained at a faster rate. The secondary stage was the stage where the strain rate reached a minimum and beame

nearly constant. The strain rate was steady due to balance between work hardening and thermal softening of the polymeric materials. The last stage of creep is where the strain rates increased exponentially with stress due to necking. This was the tertiary stage. This trend was observed with the polymeric materials with increasing temperature and load as shown in Figures 4.4, 4.5 and 4.6.

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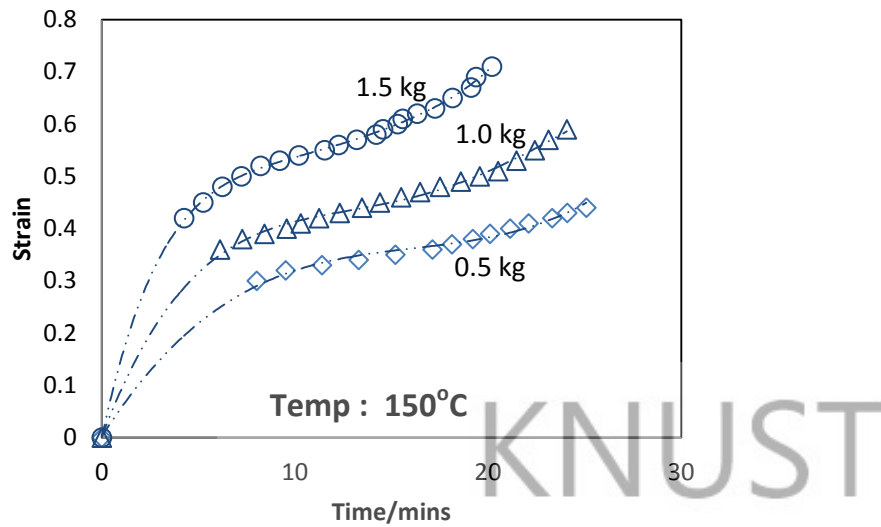


4.5 Effect of loading on the deformation of polyisoprene



(a)

(b)



(c)

Fig. 4.4 Graphs of strain against time for polyisoprene at three different loads of 0.5 kg, 1.0 kg and 1.5 kg at (a) 50°C (b) 100°C and (c) 150°C.

Table 4.4 Minimum strain rates for polyisoprene subjected to loads of 0.5 kg, 1.0 kg and 1.5 kg at (a) 50°C, (b) 100°C and (c) 150°C.

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
0.5	0.0032989	39.4
1.0	0.0040134	32.47
1.5	0.0152025	18.50

(a)

Load	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
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kg		
0.5	0.003478	29.51
1.0	0.0040299	14.54
1.5	0.014371	10.29

(b)

Load kg	Minimum strain rate mm/min ⁻¹	Time for occurrence of minimum strain rate/min
0.5	0.015146	9.52
1.0	0.0083624	8.42
1.5	0.0720174	7.23

(c)

It was observed that minimum strain rates for polyisoprene increased with increased loads and the corresponding times of occurrence for the minimum strain rates also decreased with increased loading.

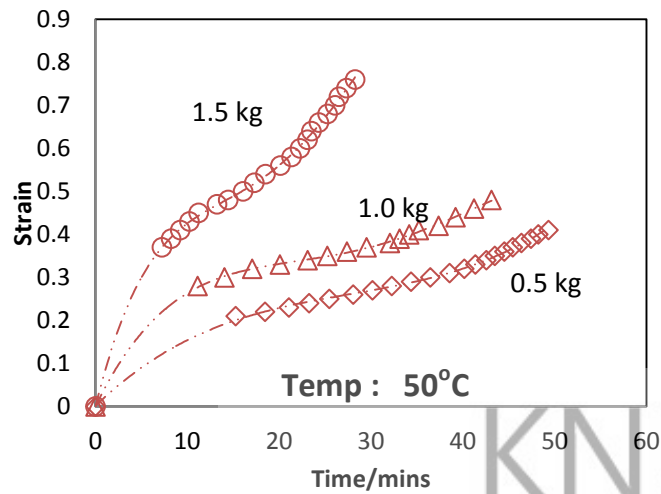
This implied that it took a lesser time to obtain an equal strain for the polyisoprene at higher loads under the same conditions of temperature. The effect of increased loading was found to be the same as increased temperature. Loading introduced stresses in the polymeric material which the material responded to as an increase in elongation. The greater the magnitude of the load, the greater the stresses introduced. From Table 4.1, strain rates for the same loading conditions were

lower for polyisoprene as compared to polyethylene and PVC because of the presence of crosslinks which increases its stiffness. The stiffer a material is, the greater its resistance to loading. Stiffness in the polyisoprene sample was also increased by the presence of double bonds in its structure.

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4.6 Effect of loading on the deformation of polyethylene

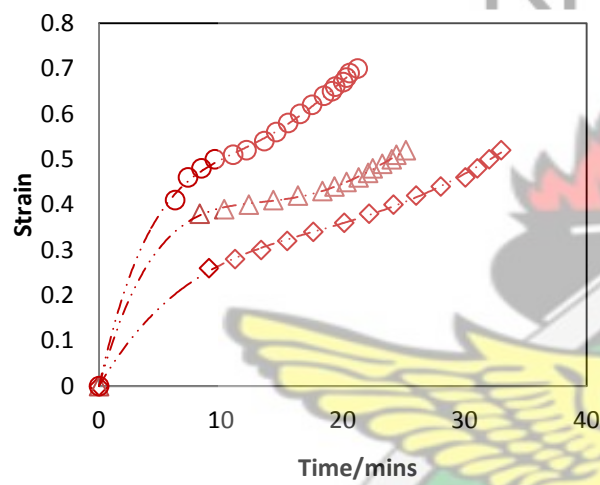


1.5 kg

1.0 kg

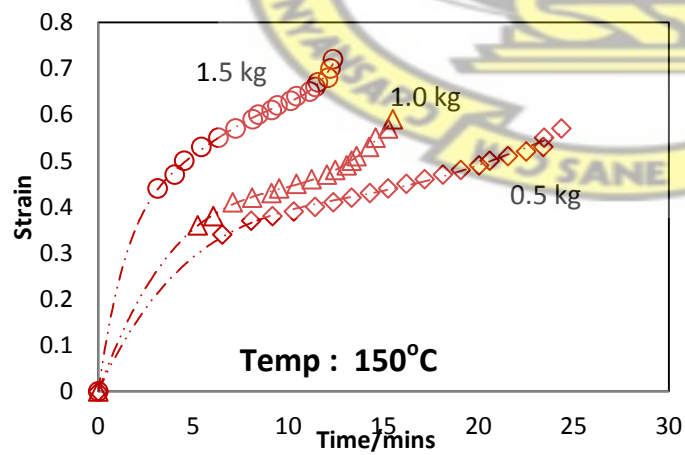
0.5 kg

Temp : 100°C



(a)

(b)



(c)

Fig. 4.5 Graphs of strain against time for polyethylene at three different loads of 0.5 kg, 1.0 kg and

1.5 kg at (a) 50°C, (b) 100°C and (c) 150°C.

Table 4.5 Minimum strain rates for polyethylene subjected to loads of 0.5 kg, 1.0 kg and 1.5 kg at (a) 50°C, (b) 100°C and (c) 150°C.

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
0.5 kg	0.00346	28.06
1.0 kg	0.015891	20.04
1.5 kg	0.020448	17.29

(a)

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
0.5	0.01128	18.16
1.0	0.02795	14.32
1.5	0.059692	12.10

(b)

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
0.5	0.0364	6.52

1.0	0.069313	5.23
1.5	0.120234	4.42

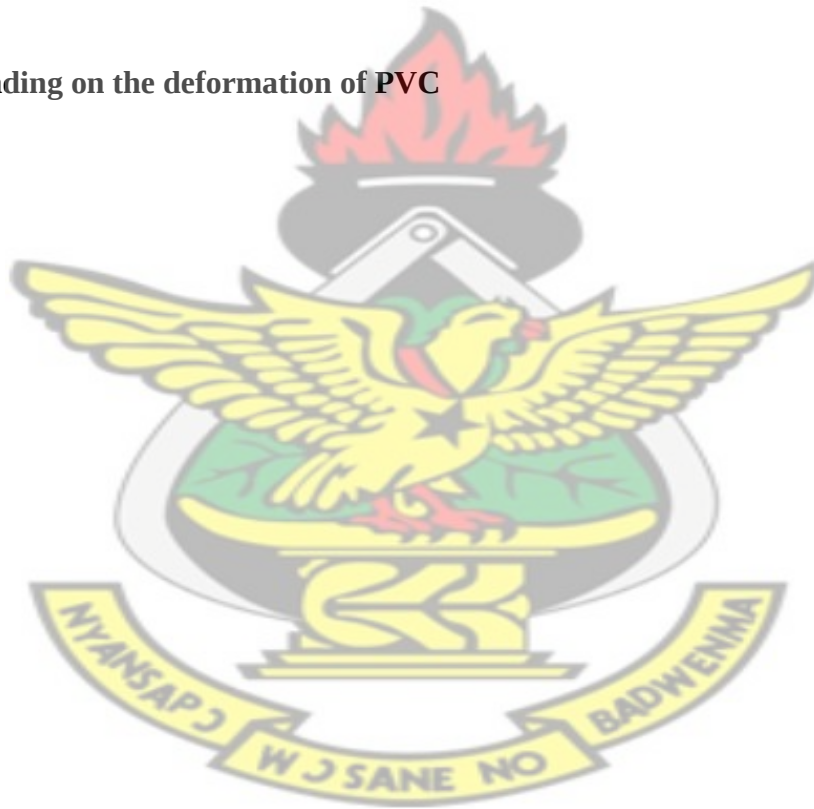
(c)

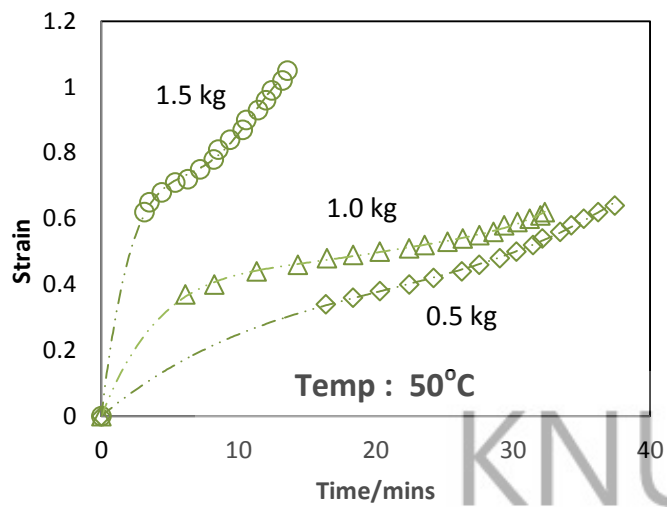
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Minimum strain rates for polyethylene increased with increased loads and the corresponding times of occurrence for the minimum strain rates also decreased with increased loading. The decreasing time suggested that it took lesser times for polyethylene to undergo the same extent of elongation as the stresses introduced were increased by increased loading. Polyethylene responded to the stresses introduced by bond stretching and chain sliding. The degree of bond stretching depended directly on the magnitude of the applied load. The decreasing times for the occurrence of the minimum strain rates as temperature and loading was related to how viscous the material was under those conditions. The ease to flow was increased on increasing loads and temperature.

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4.7 Effect of loading on the deformation of PVC



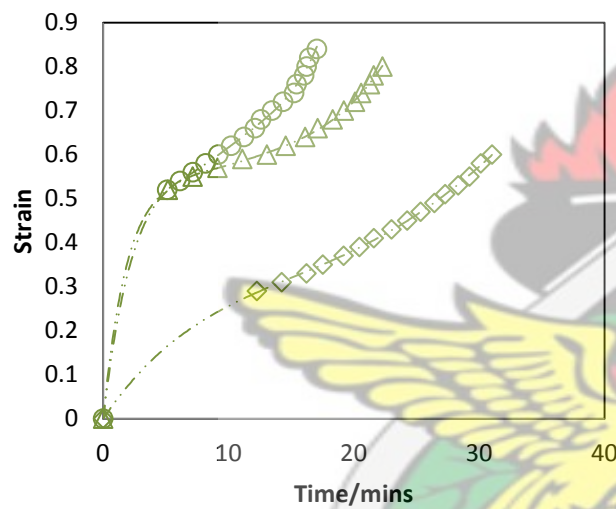


1.5 kg

1.0 kg

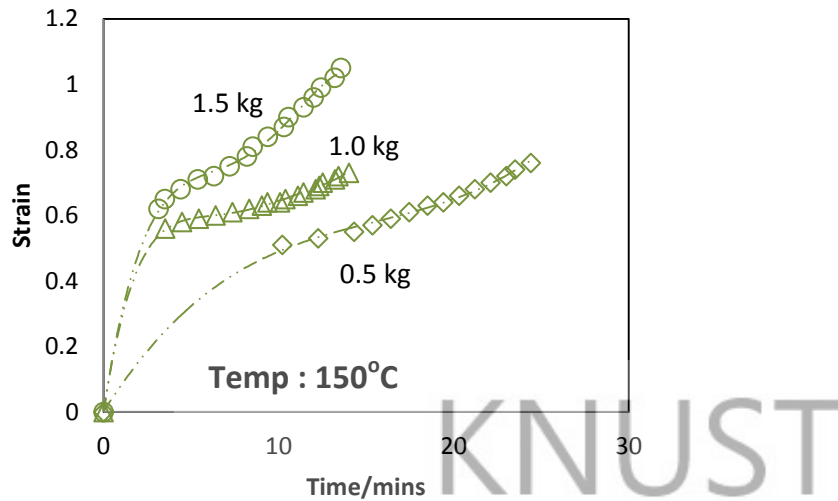
0.5 kg

Temp : 100°C



(a)

(b)



(c)

Fig. 4.6 Graphs of strain against time for PVC at three different loads of 0.5 kg, 1.0 kg and 1.5 kg

at (a), 50°C (b) 100°C and (c) 150°C

Table 4.6 Minimum strain rates for PVC subjected to loads of 0.5 kg, 1.0 kg and 1.5 kg at (a) 50°C, (b) 100°C and (c) 150°C.

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
0.5	0.0131794	24.21
1.0	0.014709	11.32
1.5	0.047429	10.24

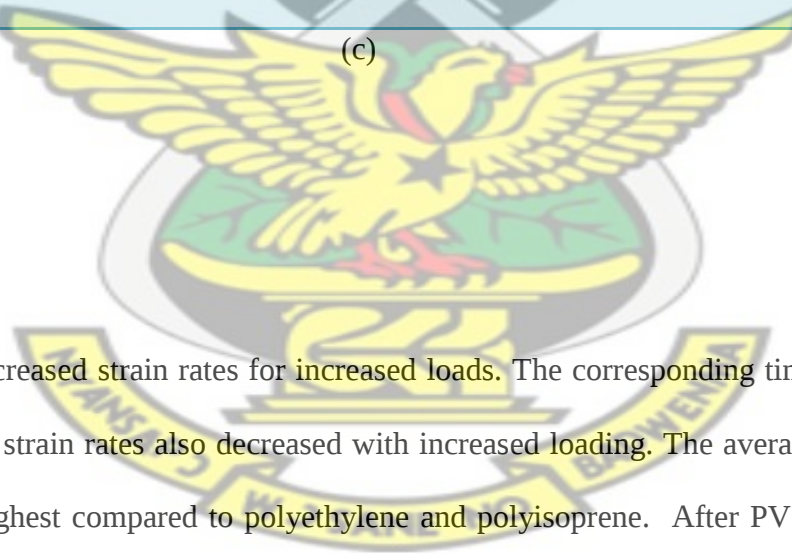
(a)

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
------------	--	--

0.5	0.024498	14.24
1.0	0.02685	7.14
1.5	0.053945	5.11

(b)

Load kg	Minimum strain rate min^{-1}	Time for occurrence of minimum strain rate/min
0.5	0.0301	12.26
1.0	0.035446	3.52
1.5	0.06109	3.4

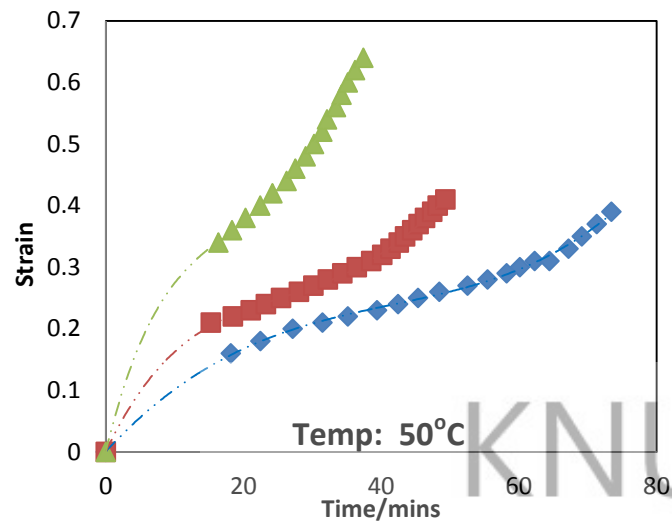


PVC recorded increased strain rates for increased loads. The corresponding times of occurrence for the minimum strain rates also decreased with increased loading. The average strain rates for PVC were the highest compared to polyethylene and polyisoprene. After PVC had reached its heat distortion temperature, the loads increased its stretching ability considerably increasing the elongations as a result of bond stretching and displacement of atoms within its molecular structure. The degree of bond stretching depended directly on the magnitude of the applied load. The times for minimum strain rates to occur also decreased with increasing load which implied that the materials resistance to deformation was reduced as loads and temperature increased.

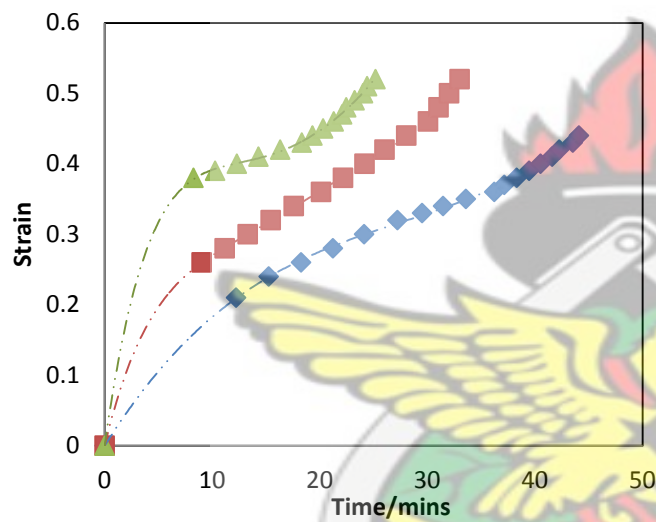
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4.8 Deformation Behaviour of the materials at constant temperatures and under different loads

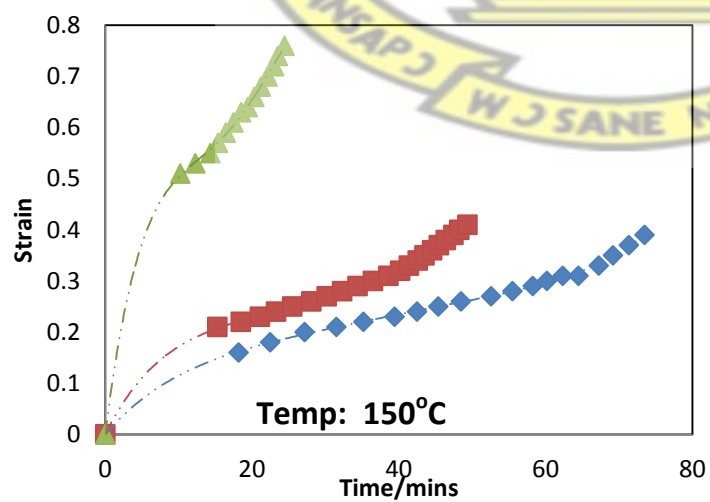


Temp : 100°C



(a)

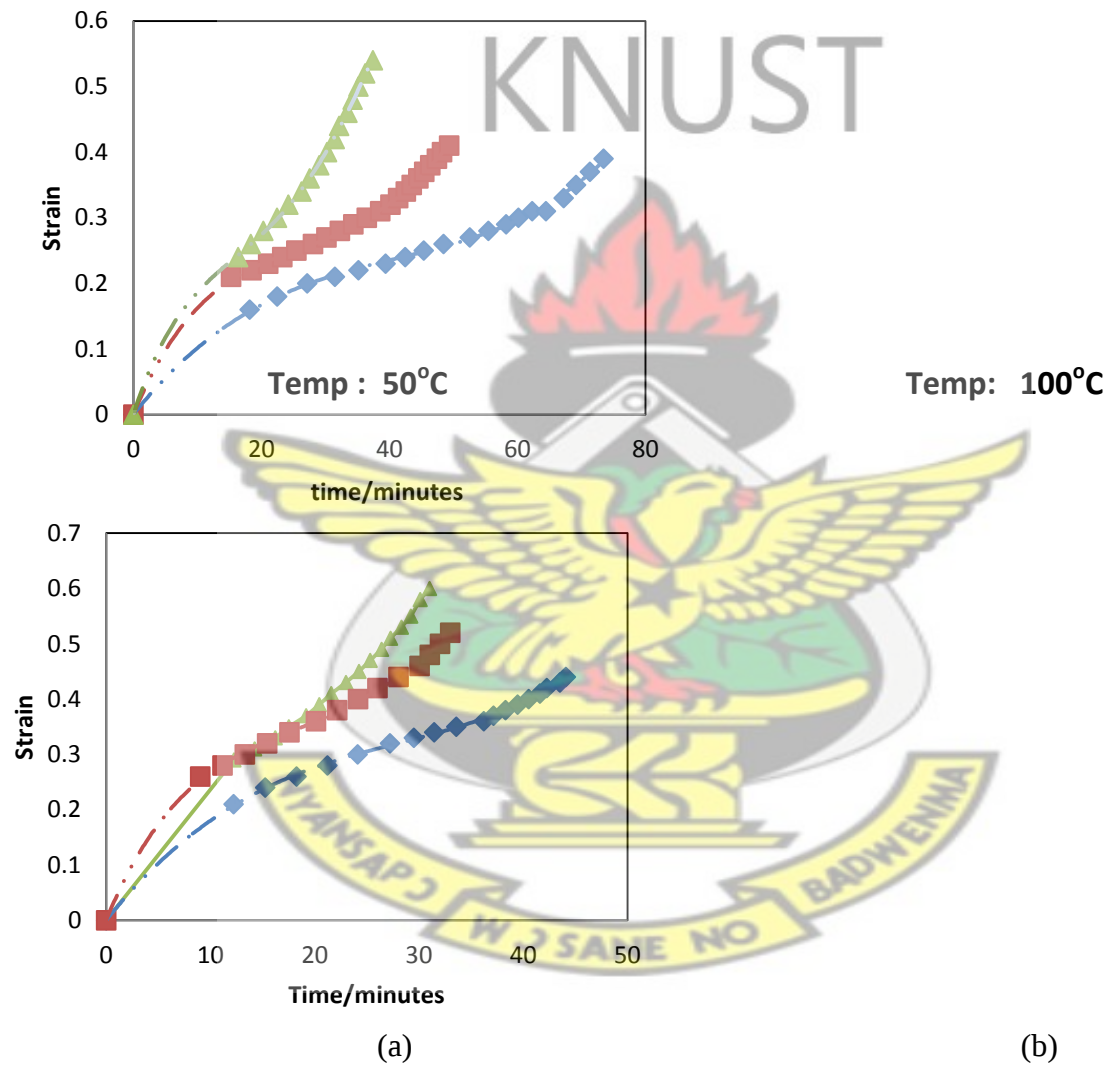
(b)

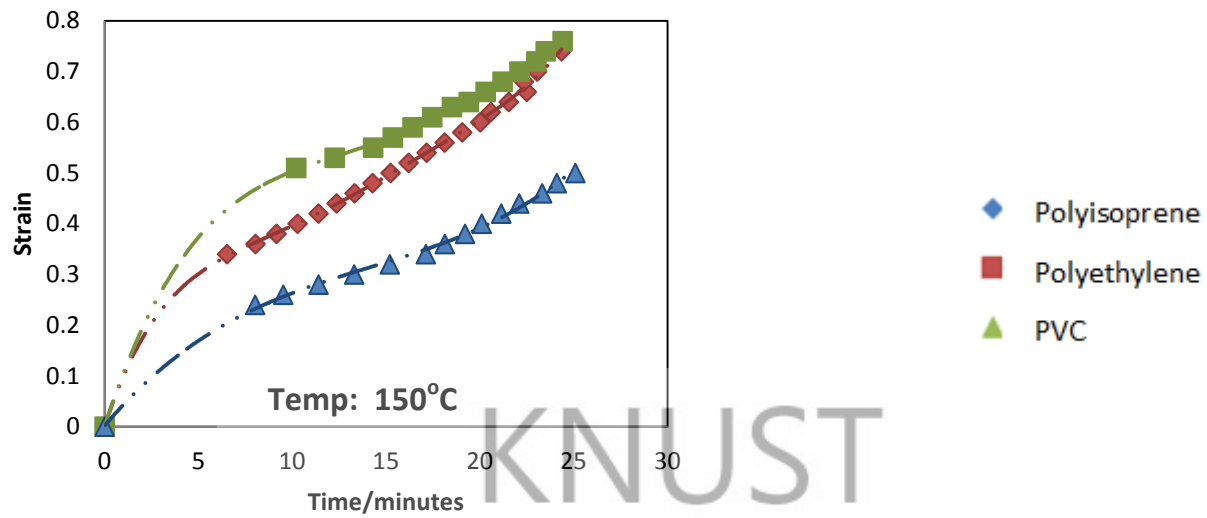


- ◆ Polyisoprene
- Polyethylene
- ▲ PVC

(c)

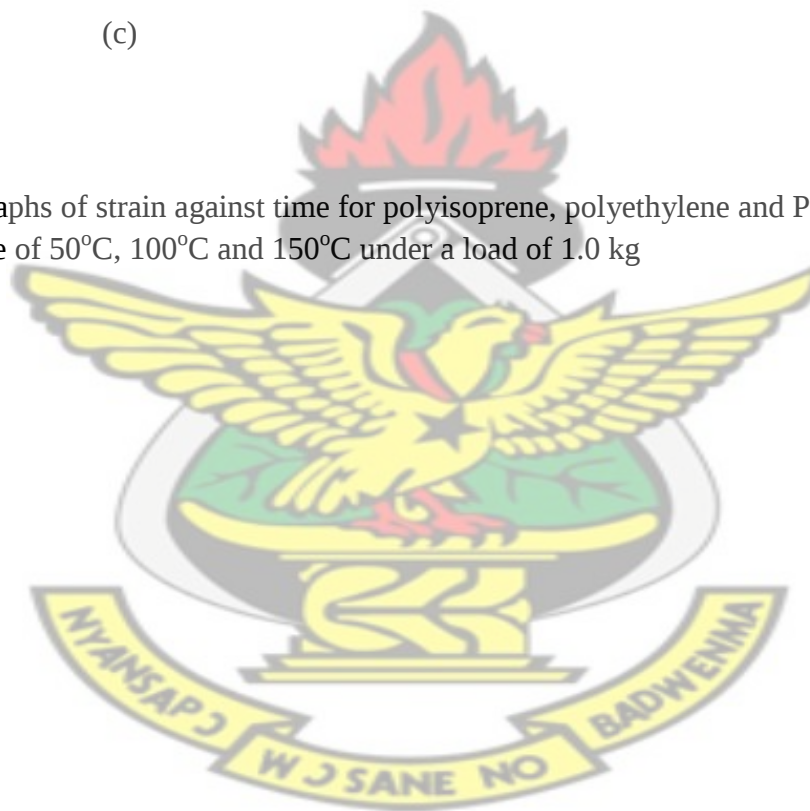
Fig. 4.7 Graphs of strain against time for polyisoprene, polyethylene and PVC at constant temperature of (a) 50°C, (b) 100°C and (c) 150°C under a load of 0.5 kg

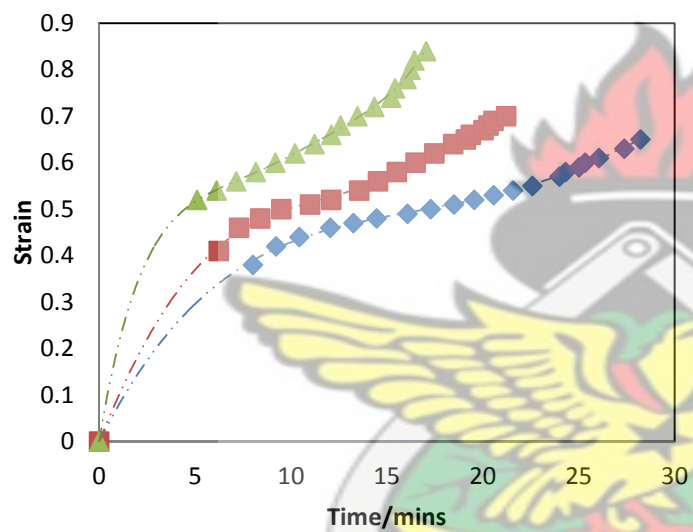
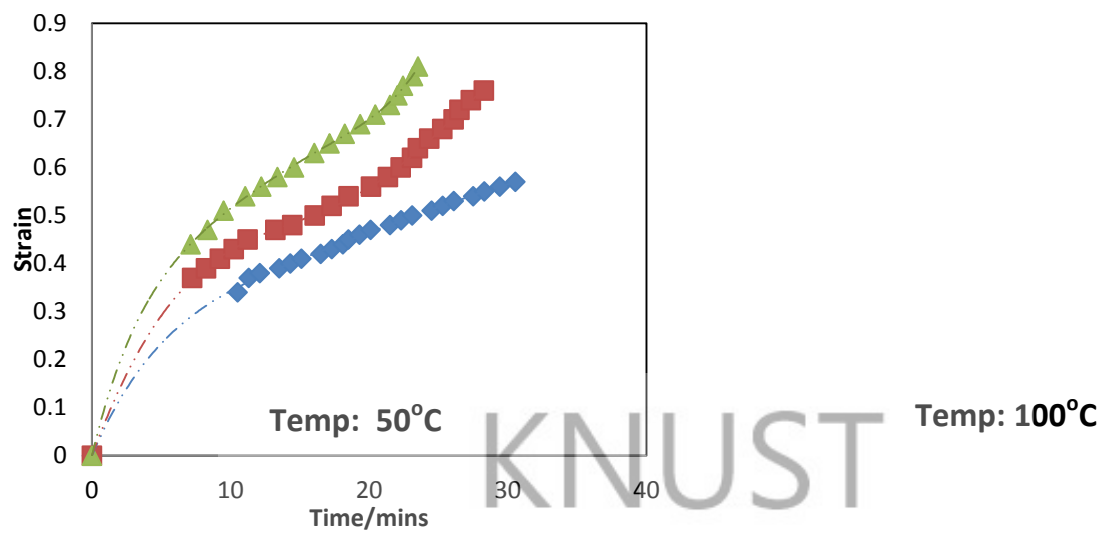




(c)

Fig. 4.8 Graphs of strain against time for polyisoprene, polyethylene and PVC at constant temperature of 50°C, 100°C and 150°C under a load of 1.0 kg





(a)

(b)

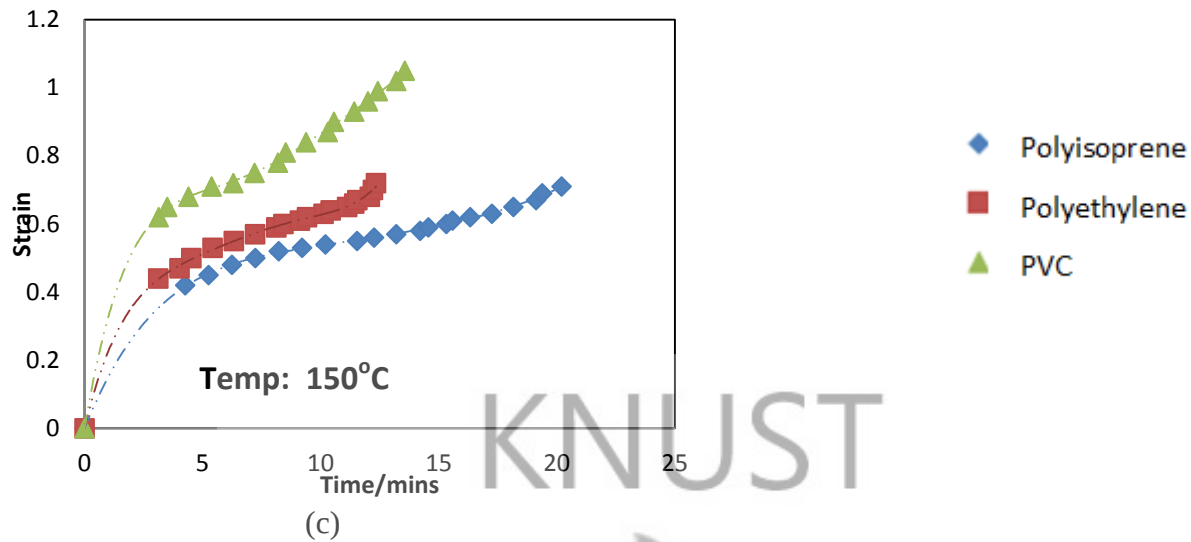


Fig. 4.9 Graphs of strain against time for polyisoprene, polyethylene and PVC at the same constant temperature of (a) 50°C, (b) 100°C and (c) 150°C under a load of 1.5 kg.

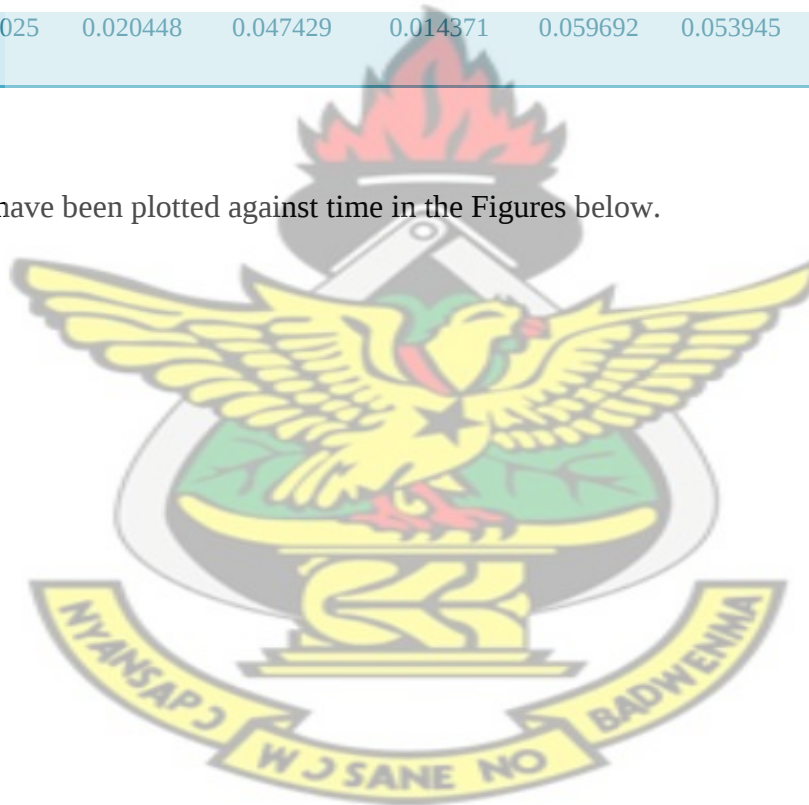
Under the same loading conditions at a particular constant temperature, PVC was observed to register the highest strain rates followed by polyethylene, with polyisoprene recording the lowest strain rates at these conditions. PVC recorded higher strain rates due to the addition of additives and plasticizers into its structure to soften it during manufacture. Secondly, the continuous carbon-carbon single bonds in its main chain were highly flexible and presented it with a low softening temperature. Once softened, the material extended more easily. Polyisoprene, on the other hand, had increased stiffness due to the presence of crosslinks in its structure making it to resist softening to a higher extent and therefore recording higher strains. Polyethylene was between the two as it had no crosslinks or additives but a normal thermoplastic responding to heat softening.

Table 4.7 Minimum strain rates for all three samples subjected to loads of 0.5 kg, 1.0 kg and 1.5 kg at

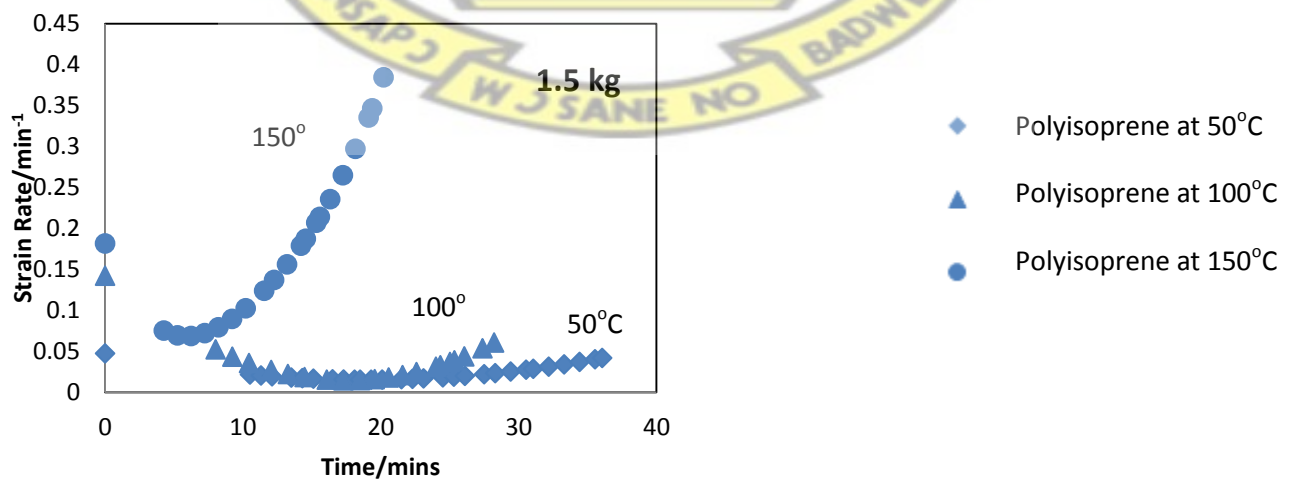
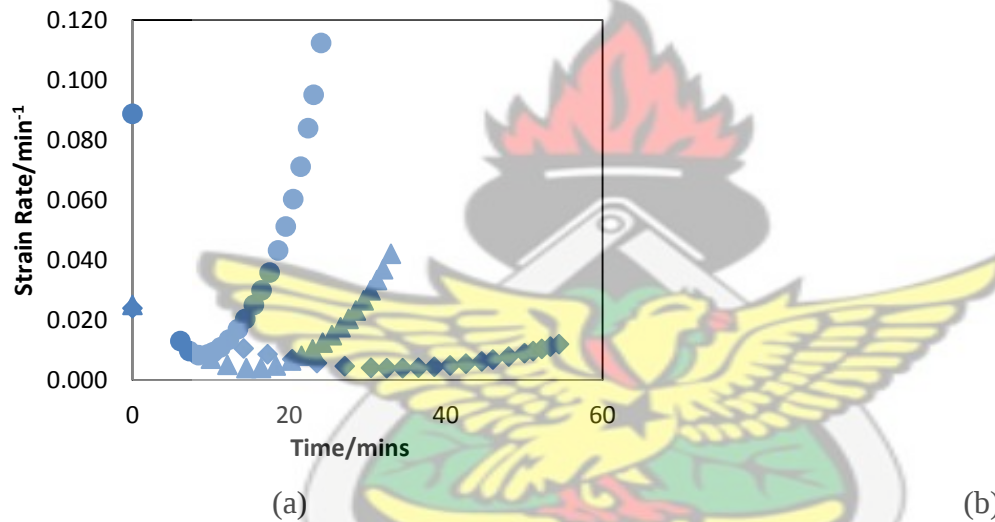
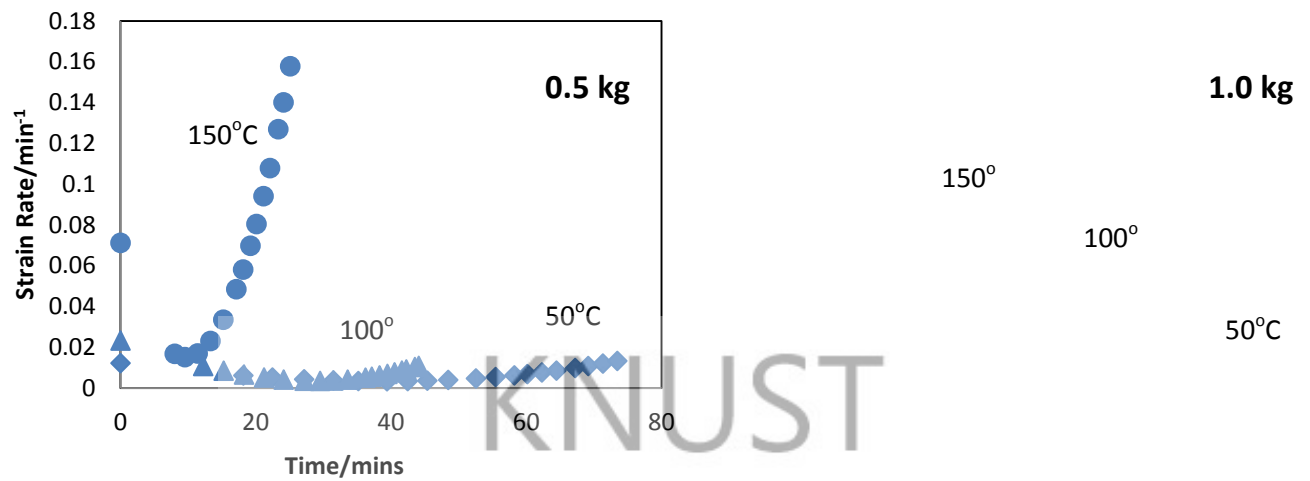
(a) 50°C, (b) 100°C and (c) 150°C.

Temp	50°C			100°C			150°C		
Load/kg	Strain rates/min ⁻¹			Strain rates/min ⁻¹			Strain rates/min ⁻¹		
	ISO	PE	PVC	ISO	PE	PVC	ISO	PE	PVC
0.5 Kg	0.0032989	0.00346	0.0131794	0.003478	0.01128	0.024498	0.015146	0.03640	0.0301
1.0 Kg	0.0040134	0.015891	0.014709	0.0040299	0.02795	0.02685	0.0083624	0.069313	0.0354
1.5 Kg	0.0152025	0.020448	0.047429	0.014371	0.059692	0.053945	0.0720174	0.120234	0.0611

The strain rates have been plotted against time in the Figures below.



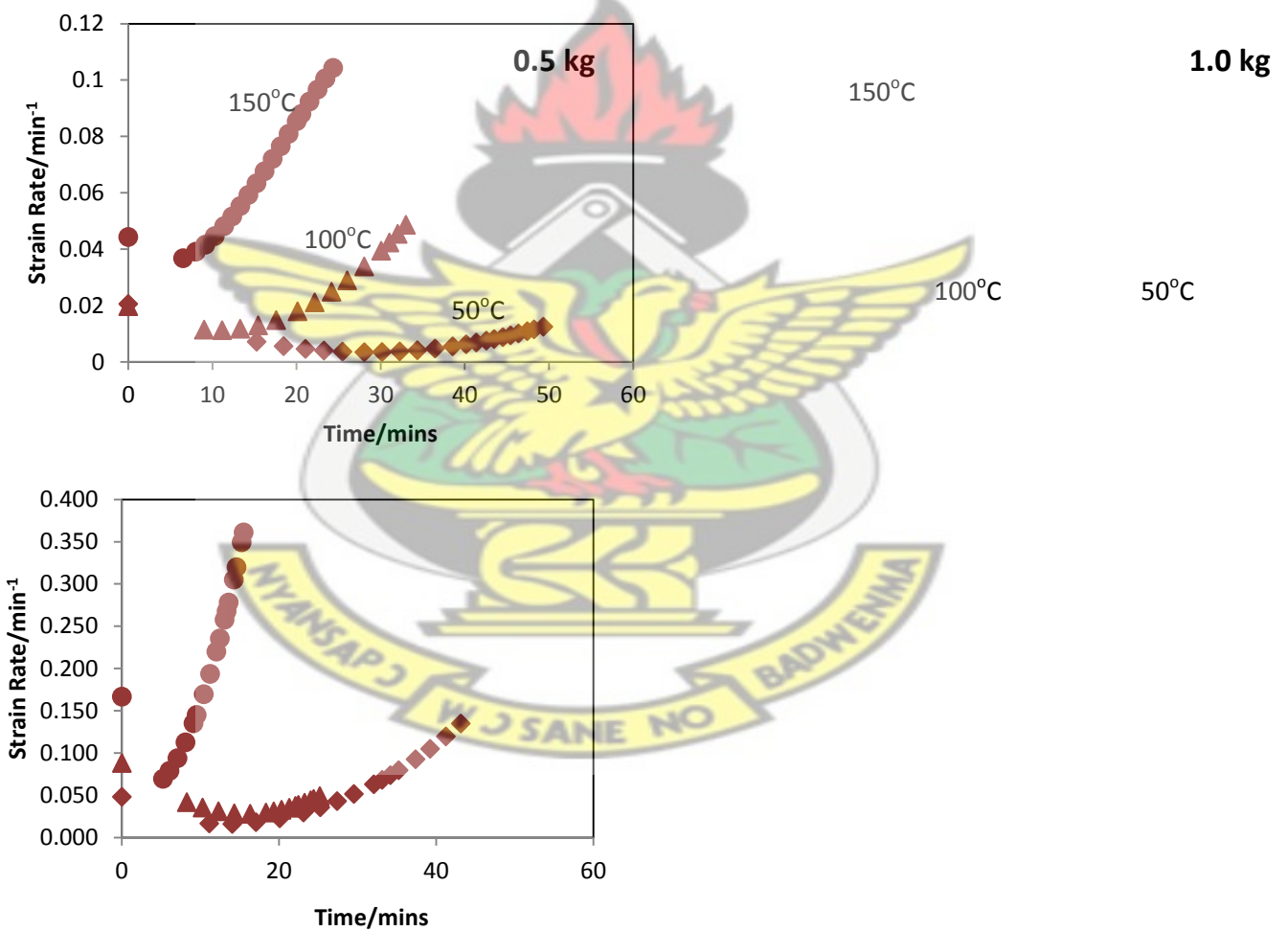
4.9 Effect of temperature and loads on strain rates of polyisoprene



(c)

Fig. 4.10 Graphs of strain rate against time for isoprene at three different temperatures of 50°C, 100°C and 150°C under loads of (a) 0.5 kg, (b) 1.0 kg and (c) 1.5 kg.

4.10 Effect of temperature and loads on strain rates of polyethylene



(a)

(b)

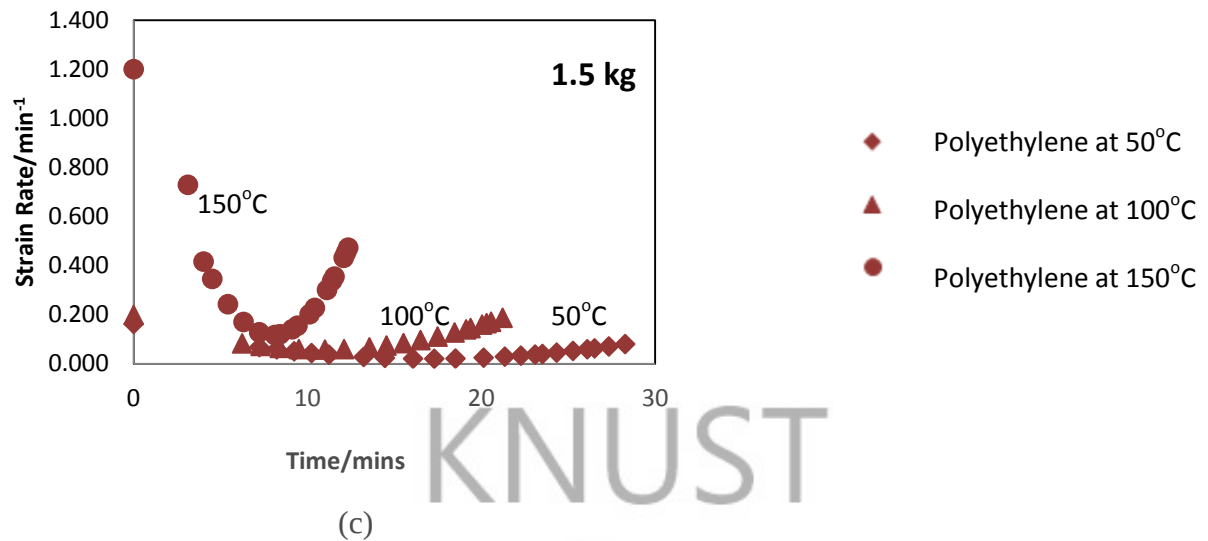
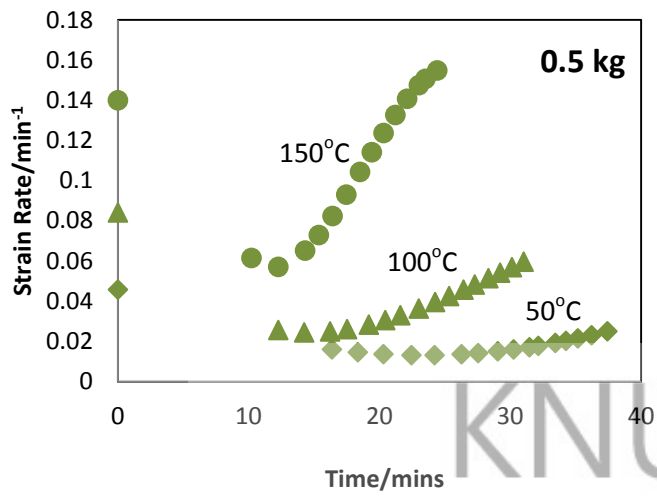


Fig. 4.11 Graphs of strain rate against time for polyethylene at three different temperatures of 50°C, 100°C and 150°C under loads of (a) 0.5 kg, (b) 1.0 kg and (c) 1.5 kg

4.11 Effect of temperature and loads on strain rates of PVC

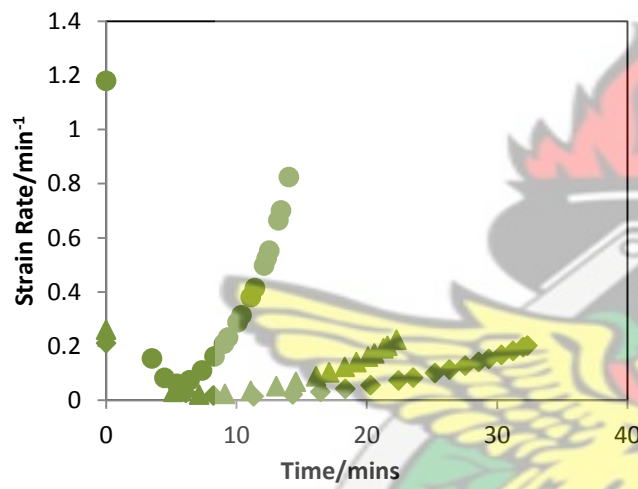


1.0 kg

50°C

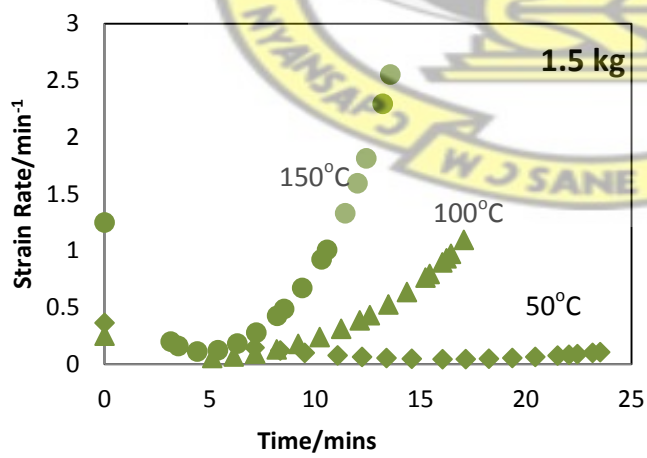
100°C

50°C



(a)

(b)



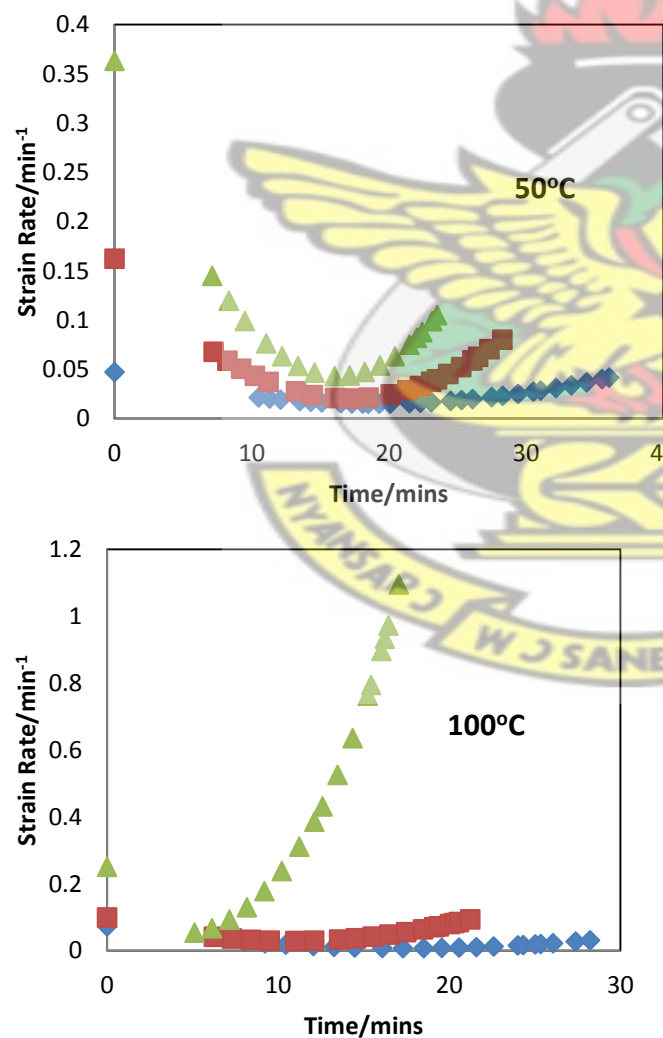
(c)

- ◆ PVC at 50°C
- ▲ PVC at 100°C
- PVC at 150°C

Fig. 4.12 Graphs of strain rate against time for PVC at three different temperatures of 50°C, 100°C and 150°C under loads of (a) 0.5 kg, (b) 1.0 kg and (c) 1.5 kg

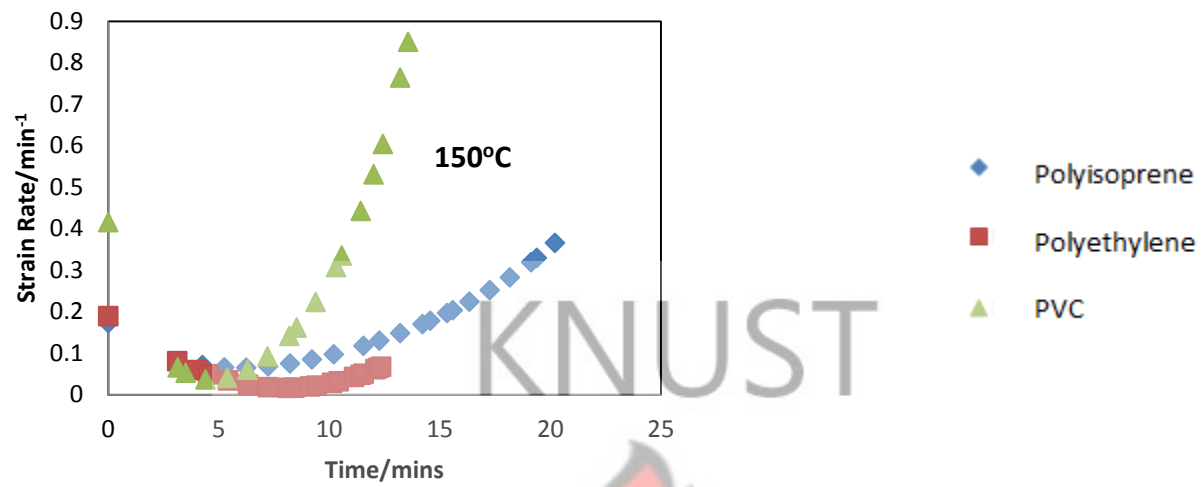
4.12 Deformation Behaviour of the polymeric materials at the same conditions of temperature

and loading



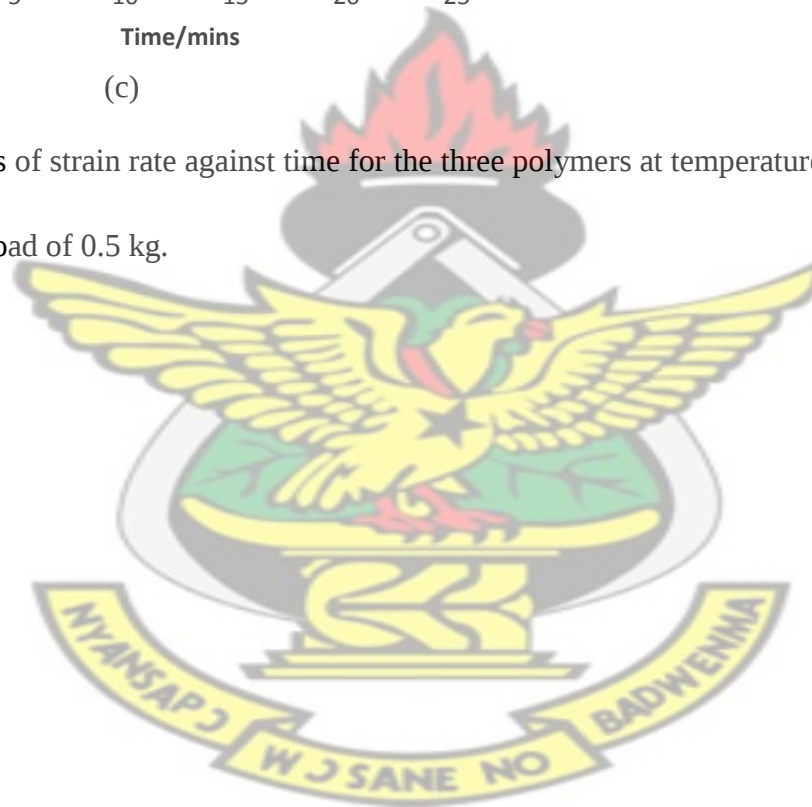
(a)

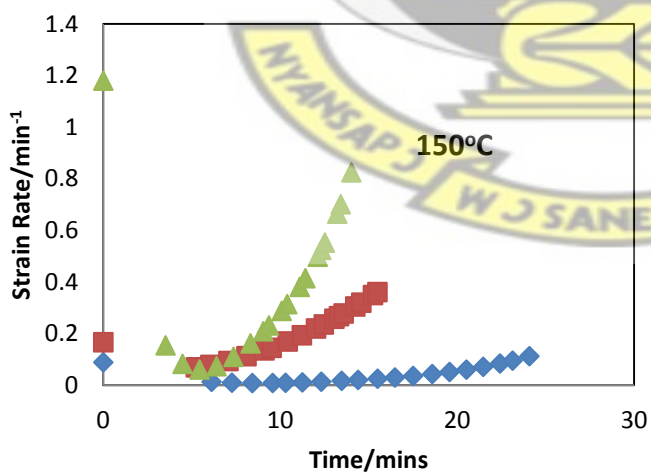
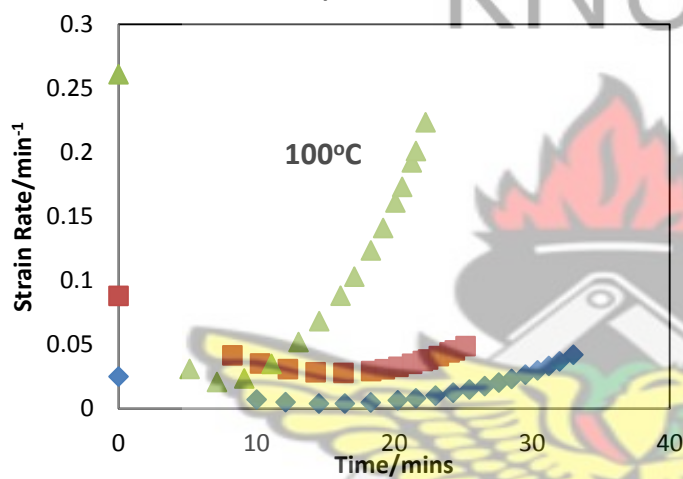
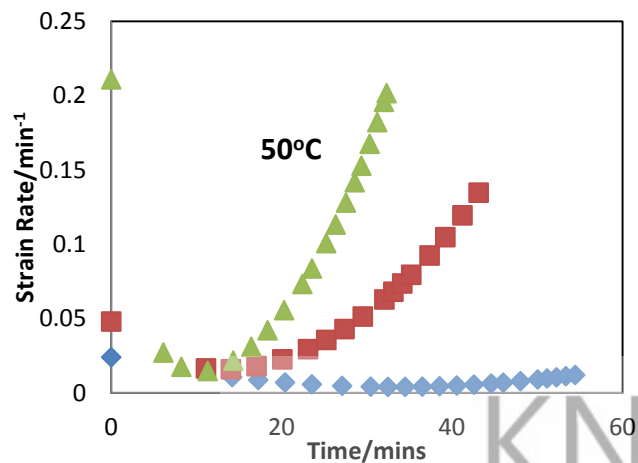
(b)



(c)

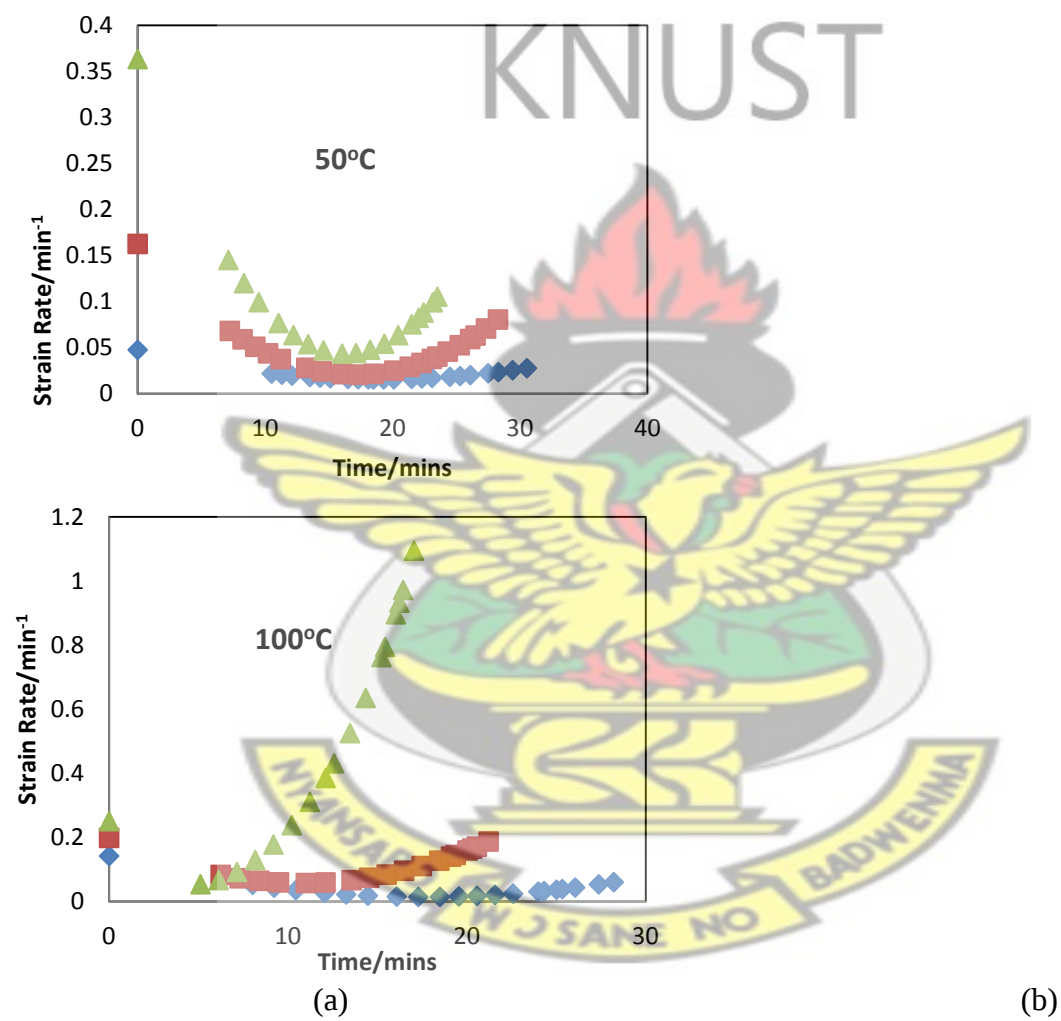
Fig. 4.13 Graphs of strain rate against time for the three polymers at temperatures of 50°C, 100°C and 150°C under a load of 0.5 kg.





- ◆ Polyisoprene
- Polyethylene
- ▲ PVC

Fig. 4.14 Graphs of strain rate against time for the three polymers at temperatures of (a) 50°C, (b) 100°C and (c) 150°C under a load of 1.0 kg.



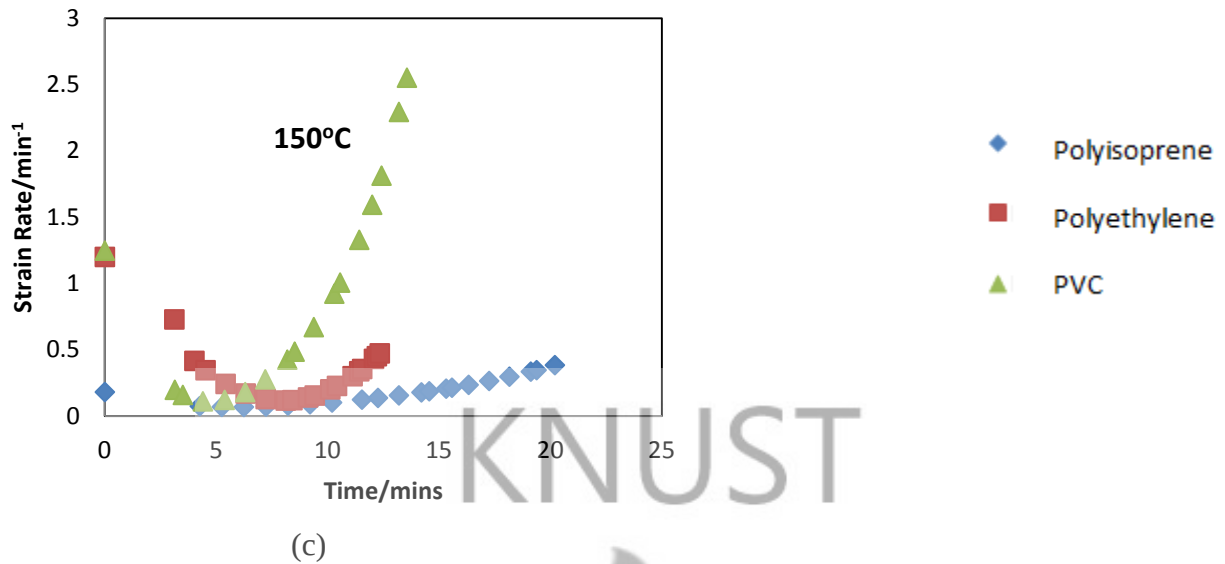


Fig. 4.15 Graphs of strain rate against time for the three polymers at temperatures of (a) 50°C , (b) 100°C and (c) 150°C under a load of 1.5 kg.

PVC recorded a rise in minimum strain rate at 50°C as follows; 0.01318 min^{-1} , $0.014709 \text{ min}^{-1}$, 0.04317 min^{-1} for loads of 0.5kg, 1.0 kg and 1.5 kg respectively. The time for the minimum strain rates to occur was found to decrease with increasing loading and increasing temperature. At 50°C , the times for the minimum strain rates to occur were found to be 24.21 mins, 11.32 mins and 8.50 mins at 0.5 kg, 1.0 kg and 1.5 kg respectively.

At 100°C , isoprene recorded minimum strain rates as follows 0.02499 min^{-1} , 0.02085 min^{-1} , 0.05395 min^{-1} for loads of 0.5kg, 1.0 kg and 1.5 kg respectively. The times for the minimum

strain rates to occur being 16.22 mins, 7.14 mins and 5.11 mins for loads of 0.5kg, 1.0 kg and 1.5 kg respectively.

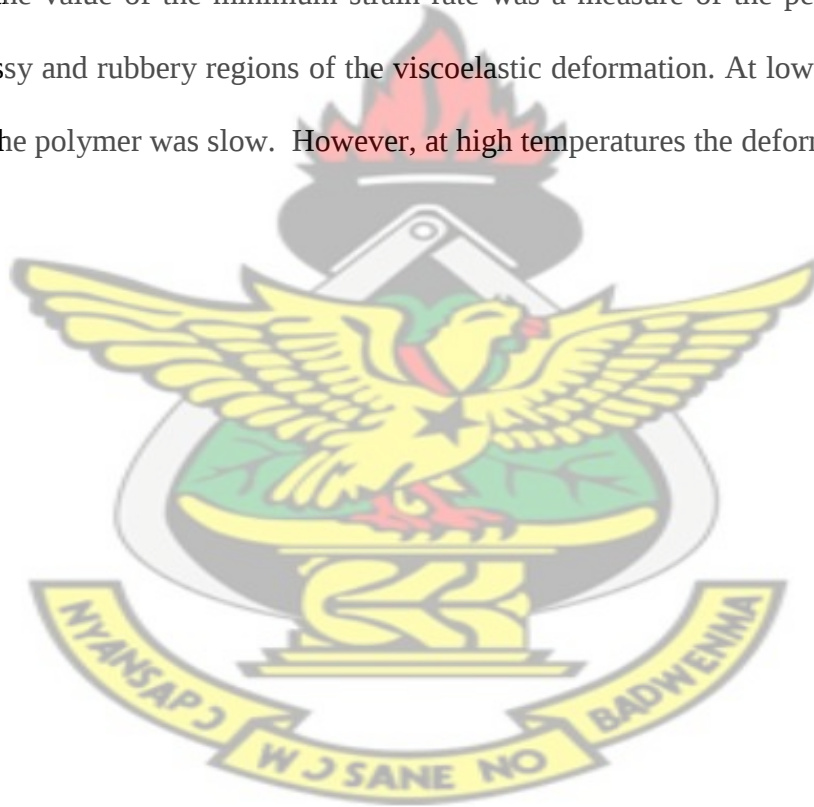
A similar observation was made at 150°C with minimum strain rates of 0.0571 min⁻¹, 0.10158 min⁻¹,

0.1109 min⁻¹ for loads of 0.5kg, 1.0 kg and 1.5 kg respectively. The times for the minimum strain rates to occur being 12.26 mins, 5.44 mins and 64.4 mins for loads of 0.5kg, 1.0 kg and 1.5 kg respectively.

At the same load the materials were found to respond differently to a rise in temperature even though there was a general trend of strain rate increasing with temperature. Upon application of stress to a rubbery material, the polymer chain which was randomly oriented underwent bond rotations allowing the chain to be extended or elongated. The graphs of Fig. 13, 14 and 15 depicted the behaviour of the materials on changing the load. It was observed that as the load increased the strain rates also increased appreciably with PVC having the highest strain rate and as the temperature was increased. This was because the molecular structure of PVC was made of continuous carbon-carbon single bonds in the main chain. Since this main chain was highly flexible, PVC products had the disadvantage of having low heat distortion temperature (softening temperature) compared with PE and polyisoprene. Polyisoprene recorded the least strain rates under the same conditions because it has a greater chain stiffness compared to PE and PVC.

Chain stiffness was increased by bulky side groups and double bonds or aromatic chain groups. The presence of double bonds in the structure of polyisoprene gave it an increased stiffness. Melting temperature and glass transition temperature both increased with increasing chain stiffness. Secondly, there were crosslinks present in the polyisoprene sample due to

vulcanization. Crosslinking was achieved by irreversible chemical reaction, usually requiring high temperatures. Sulfur compounds were added to form chains that bonded adjacent polymer backbone chains and cross-linked them. The vulcanized rubber was a thermosetting polymer. Crosslinking made elastomers reversibly stretchable for small deformations. When stretched, the polymer chains became elongated and ordered along the deformation direction. Crosslink networks resisted heat softening, creep and solvent attack. In effect, these cross links resisted heat softening making polyisoprene less stretched as compared to PE and PVC. The physical significance of the value of the minimum strain rate was a measure of the period of transition between the glassy and rubbery regions of the viscoelastic deformation. At low temperatures the deformation of the polymer was slow. However, at high temperatures the deformation was fast.



CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following are the conclusions of the study of the viscoelastic properties of the selected polymers subjected to constant loads at different constant temperatures.

1. At higher temperatures, the strain rates generally were much higher than at room temperature and the material acted in a rubbery manner. Polyisoprene recorded minimum strain rates of $0.0032989 \text{ min}^{-1}$, $0.003478 \text{ min}^{-1}$ and $0.015146 \text{ min}^{-1}$ at temperatures of 50°C , 100°C and 150°C respectively under a load of 0.5 kg. PVC recorded the highest values of minimum strain rates with the same load of 0.5 kg as $0.0131794 \text{ min}^{-1}$, $0.024498 \text{ min}^{-1}$, 0.0371 min^{-1} at 50°C , 100°C and 150°C respectively. Polyethylene however, recorded values of minimum strain rates between PVC and polyisoprene with values of 0.00346 min^{-1} , 0.01128 min^{-1} , 0.0364 min^{-1} .
2. All three polymeric materials recorded comparatively higher initial strain rates due to chain uncoiling on the application of the loads at the different temperatures.
3. The effect of loading was similar to that of temperature with the polymeric materials recording increasing strain rates as the magnitudes of the applied loads were increased. The combined effect of loading and temperature produced the highest strain rates for PVC.
4. PVC recorded the highest strain rates because of the introduction of additives and plasticizers into its structure which reduced its heat distortion temperature and consequently reduced its resistance to heat flow. The presence of cross links and

- double bonds in polyisoprene increased the chain stiffness which in turn increased its resistance to heat flow.
5. Increasing temperature resulted in a decrease in time for the occurrence of minimum strain rate. This was observed in all the polymeric samples. The observation indicated that the materials response to heat in terms of molecular rearrangements hastened with temperature making it more viscous at higher temperature.
 6. The time for the occurrence of the minimum strain rates was related to the viscosity of the polymeric material. The higher the temperature, the smaller the time for the occurrence for the minimum strain rates and the more viscous the material was. In effect, the viscosity of the material increased with temperature.
 7. The viscoelastic properties of the polymers used were characterized by temperature, loading, minimum strain rates and the time for the occurrence of minimum strain rates.
 8. Minimum strain rates moved to shorter times as temperature increased.
 9. At low temperature, the deformation of the polymer was slow. However, at high temperatures, the deformation was fast.
 10. The physical significance of the minimum strain rate was a measure of the period of the transition between glassy and rubbery regions of the deformation of the polymers.

5.2 Recommendations

Knowledge of the viscoelastic properties is very important if a polymeric material is to be used at varying temperatures. Materials used for structural applications may exhibit viscoelastic behaviour and as such must be subjected to such tests as in this research. There is the need to

evaluate the long term performance and the reliability of polymeric materials from these short term tests. It is of paramount importance to understand the dynamic response of polymeric materials(soft materials) to deformation of pressure, temperature and shear to control their manufacturing processes.

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APPENDIX A

Results for Polyisoprene

Table 5.1 Results for polyisoprene at 0.5 kg for 50°C

Length/mm	Time/mins	new length/mm	Strain/mm	Strain rate/min ⁻¹
505.0	0.00	0.0	0.14	0.012200
510.0	18.16	55.0	0.16	0.006141
511.0	22.46	56.0	0.18	0.005137
511.5	27.15	56.5	0.2	0.004272
512.5	31.48	57.5	0.21	0.003704
513.0	35.16	58.0	0.22	0.003409
514.0	39.40	59.0	0.23	0.003299
515.0	42.46	60.0	0.24	0.00338
516.0	45.36	61.0	0.25	0.003588
517.0	48.45	62.0	0.26	0.003957
518.0	52.55	63.0	0.27	0.004689
519.0	55.46	64.0	0.28	0.005384
520.0	58.23	65.0	0.29	0.006188
521.0	60.15	66.0	0.3	0.006829
522.0	62.30	67.0	0.31	0.007629
523.0	64.45	68.0	0.31	0.008519
524.0	67.22	69.0	0.33	0.009802
525.0	69.15	70.0	0.35	0.010789
526.0	71.32	71.0	0.37	0.011991

527.0	73.45	72.0	0.39	0.01327
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Table 5.2 Results for polyisoprene at 0.5 kg for 100°C

Length/mm	Time/s	new length/mm	Strain/mm	Strain rate/min ⁻¹
510.0	0.00	0.0	0.00	0.023300
518.0	12.22	58.0	0.21	0.0107929
519.0	15.25	59.0	0.24	0.0085001
520.0	18.26	60.0	0.26	0.0066068
520.5	21.22	60.5	0.28	0.0051505
521.5	24.12	61.5	0.30	0.0041438
522.0	27.22	62.0	0.32	0.0035608
523.0	29.51	63.0	0.33	0.0034778
524.0	31.46	64.0	0.34	0.0036522
525.0	33.58	65.0	0.35	0.0041085
526.0	36.22	66.0	0.36	0.005082
526.5	37.15	66.5	0.37	0.0055358
527.5	38.3	67.5	0.38	0.0061791
528.0	39.46	68.0	0.39	0.0069217
529.0	40.52	69.0	0.40	0.0076842
529.5	41.60	69.5	0.41	0.008545
530.0	42.26	70.0	0.42	0.0091134
531.0	43.52	71.0	0.43	0.0102892
532.0	44.09	72.0	0.44	0.0108607

Table 5.3 Results for polyisoprene at 0.5 kg for 150°C

Length/mm	Time/s	new length/mm	Strain/mm	Strain rate/min ⁻¹
513	0.00	0	0.00	0.07120000
525	8.02	62	0.30	0.01676024
526	9.52	63	0.32	0.01514624
527	11.40	64	0.33	0.01693600
528	13.30	65	0.34	0.02305400
529	15.20	66	0.35	0.03350400
530	17.12	67	0.36	0.04846464
531	18.13	68	0.37	0.05811014
532	19.21	69	0.38	0.06977846
533	20.10	70	0.39	0.08044600
534	21.14	71	0.40	0.09411576
535	22.10	72	0.41	0.10788600
536	23.32	73	0.42	0.12698144
537	24.10	74	0.43	0.14012600
538	25.09	75	0.44	0.15786086

Table 5.4 Results for polyisoprene at 1.0 kg for 50°C

Length/mm	Time/mins	new length/mm	Strain/mm	Strain rate/min ⁻¹
535.00	0.00	0.00	0.00	0.024000
545.00	14.20	60.00	0.25	0.010590
546.00	17.25	61.00	0.27	0.008656
547.00	20.40	62.00	0.28	0.007011
547.50	23.55	62.50	0.29	0.005723
548.00	27.10	63.00	0.31	0.004699
548.50	30.45	63.50	0.33	0.004150
549.00	32.47	64.00	0.34	0.004013
550.00	34.49	65.00	0.35	0.004024
551.00	36.51	66.00	0.36	0.004182
552.00	38.53	67.00	0.37	0.004486
553.00	40.55	68.00	0.38	0.004937
554.00	42.57	69.00	0.39	0.005536
555.00	44.59	70.00	0.40	0.006281
556.00	46.01	71.00	0.41	0.006893
557.00	48.03	72.00	0.42	0.007888
558.00	50.05	73.00	0.43	0.009030
559.00	51.15	74.00	0.44	0.009714
560.00	52.25	75.00	0.46	0.010441
561.00	53.35	76.00	0.48	0.011212
562.00	54.45	77.00	0.50	0.012026

Table 5.5 Results for polyisoprene at 1.0 kg for 100°C

Length/mm	Time/mins	new length/mm	Strain/mm	Strain rate/min ⁻¹
530.00	0.00	0.00	0.00	0.025100
545.00	10.02	65.00	0.31	0.007180
546.00	12.12	66.00	0.34	0.005140
547.00	14.54	67.00	0.36	0.004030
547.50	16.42	67.50	0.37	0.004080
548.00	18.30	68.00	0.38	0.004900
549.00	20.26	69.00	0.40	0.006570
550.00	21.58	70.00	0.42	0.008140
551.00	23.00	71.00	0.44	0.010250
551.50	24.28	71.50	0.45	0.012550
552.00	25.46	72.00	0.46	0.015010
553.00	26.57	73.00	0.48	0.017660
554.00	27.59	74.00	0.50	0.020420
555.00	28.52	75.00	0.52	0.023240
556.00	29.52	76.00	0.54	0.026630
557.00	30.40	77.00	0.56	0.029960
558.00	31.22	78.00	0.58	0.033390
558.50	32.00	78.50	0.59	0.036990
560.00	33.00	80.00	0.62	0.042130

Table 5.6 Results for polyisoprene at 1.0 kg for 150°C

Length/mm	Time/mins	New length/mm	Strain/mm	Strain rate/min ⁻¹
536.00	0.00	0.00	0.00	0.088760
555.00	6.12	69.00	0.36	0.013049
556.00	7.27	70.00	0.38	0.009719
556.50	8.42	70.50	0.39	0.008362
557.00	9.57	71.00	0.40	0.008558
557.50	10.30	71.50	0.41	0.009333
557.50	11.25	71.50	0.42	0.010967
558.00	12.32	72.00	0.43	0.013530
559.00	13.47	73.00	0.44	0.017038
560.00	14.40	74.00	0.45	0.020421
561.00	15.50	75.00	0.46	0.025088
561.50	16.48	75.50	0.47	0.029938
562.00	17.51	76.00	0.48	0.035880
563.00	18.59	77.00	0.49	0.043258
564.00	19.57	78.00	0.50	0.051217
565.00	20.52	79.00	0.51	0.060346
566.00	21.47	80.00	0.53	0.071157
567.00	22.42	81.00	0.55	0.083984
568.00	23.13	82.00	0.57	0.095106
569.00	24.08	83.00	0.59	0.112370

Table 5.7 Results for polyisoprene at 1.5 kg for 50°C

Length/mm	Time/mins	New		Strain rate/min ⁻¹
		length/mm	Strain/mm	
544.00	0.00	0.00	0.00	0.047300
558.00	10.51	64.00	0.34	0.021507
559.00	11.31	65.00	0.37	0.020358
559.50	12.11	65.50	0.38	0.019325
560.00	13.51	66.00	0.39	0.017793
560.50	14.31	66.50	0.40	0.017076
560.50	15.11	66.50	0.41	0.016474
561.00	16.50	67.00	0.42	0.015703
561.50	17.30	67.50	0.43	0.015416
562.00	18.10	68.00	0.44	0.015245
562.50	18.50	68.50	0.45	0.015203
563.00	19.30	69.00	0.46	0.015204
564.00	20.10	70.00	0.47	0.015321
564.50	21.50	70.50	0.48	0.015803
564.00	22.30	70.00	0.49	0.016236
565.00	23.10	71.00	0.50	0.016785
566.00	24.50	72.00	0.51	0.018023
567.00	25.30	73.00	0.52	0.018888
567.50	26.10	73.50	0.53	0.019869
568.00	27.50	74.00	0.54	0.021863

569.00	28.30	75.00	0.55	0.023160
570.00	29.42	76.00	0.56	0.025170
571.00	30.54	77.00	0.57	0.027406
572.00	31.06	78.00	0.58	0.028521
573.00	32.18	79.00	0.60	0.031088
574.00	33.30	80.00	0.62	0.033880
575.00	34.42	81.00	0.64	0.036898
576.00	35.54	82.00	0.66	0.040142

Table 5.8 Results for polyisoprene at 1.5 kg for 100°C

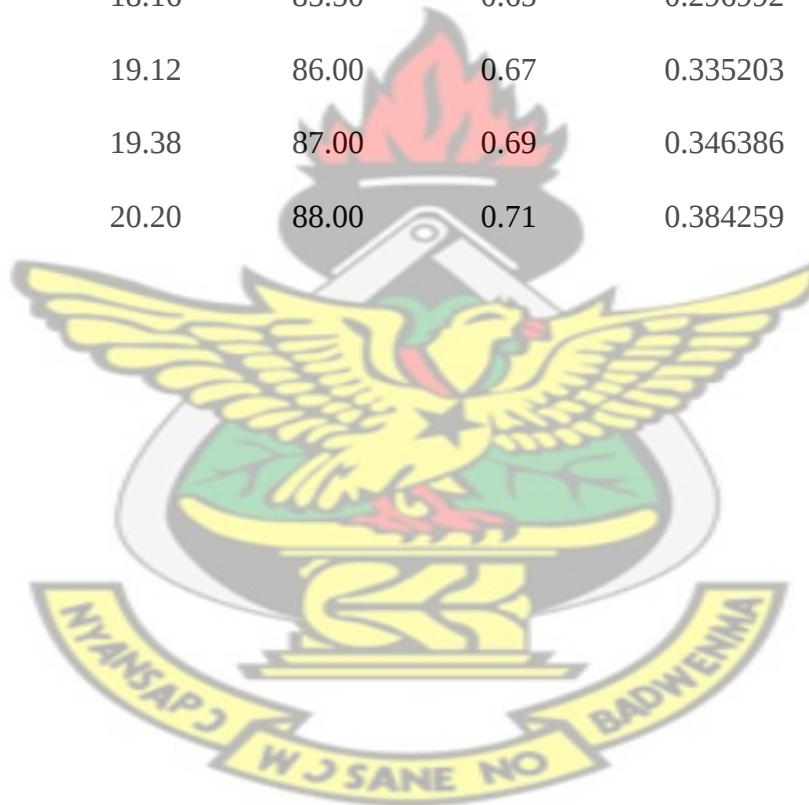
Length/mm	Time/mins	new length/mm	Strain/mm	Strain rate/min ⁻¹
545.00	0.00	0.00	0.00	0.142100
564.00	8.02	69.00	0.38	0.052252
565.00	9.23	70.00	0.42	0.043293
566.00	10.44	71.00	0.44	0.035540
567.00	12.05	72.00	0.46	0.027092
567.50	13.26	72.50	0.47	0.022148
568.00	14.47	73.00	0.48	0.018408
568.50	16.08	73.50	0.49	0.015302
569.00	17.29	74.00	0.50	0.014371
570.00	18.50	75.00	0.51	0.014646
571.00	19.56	76.00	0.52	0.015877
572.00	20.57	77.00	0.53	0.017911

573.00	21.58	78.00	0.54	0.020784
574.00	22.59	79.00	0.55	0.024497
575.50	24.00	80.50	0.57	0.031086
576.00	24.32	81.00	0.58	0.032809
577.00	25.02	82.00	0.59	0.036872
577.50	25.34	82.50	0.60	0.038863
578.00	26.06	83.00	0.61	0.043653
579.00	27.38	84.00	0.63	0.053542
580.00	28.22	85.00	0.65	0.060582

Table 5.9 Results for polyisoprene at 1.5 kg for 150°C

Length/mm	Time/mins	new length/mm	Strain/mm	Strain rate/min ⁻¹
545.00	0.00	0.00	0.00	0.181440
569.00	4.26	74.00	0.42	0.075140
570.00	5.25	75.00	0.45	0.069308
571.00	6.24	76.00	0.48	0.068522
572.00	7.23	77.00	0.50	0.072017
572.50	8.22	77.50	0.52	0.079151
573.50	9.21	78.50	0.53	0.089400
573.50	10.20	78.50	0.54	0.102362
574.00	11.54	79.00	0.55	0.123749
574.50	12.26	79.50	0.56	0.136951

575.00	13.20	80.00	0.57	0.155969
575.50	14.21	80.50	0.58	0.178738
576.00	14.56	81.00	0.59	0.187229
577.00	15.32	82.00	0.60	0.206818
577.50	15.58	82.50	0.61	0.213903
578.50	16.33	83.50	0.62	0.235537
580.00	17.25	85.00	0.63	0.264753
580.50	18.16	85.50	0.65	0.296992
581.00	19.12	86.00	0.67	0.335203
582.00	19.38	87.00	0.69	0.346386
583.00	20.20	88.00	0.71	0.384259



APPENDIX B

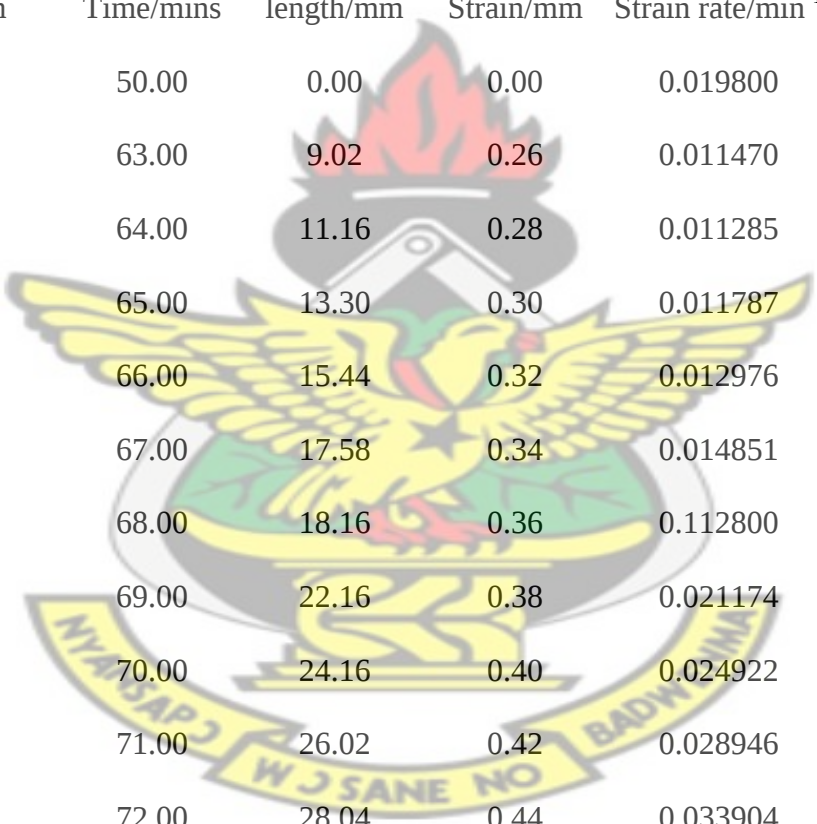
Results for polyethylene

Table 5.10 Results for polyethylene at 0.5 kg for 50°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
532.00	50.00	0.00	0.00	0.020600
542.50	60.50	15.26	0.21	0.007178
543.00	61.00	18.46	0.22	0.005604
543.50	61.50	21.06	0.23	0.004642
544.00	62.00	23.26	0.24	0.004050
544.50	62.50	25.46	0.25	0.003660
545.00	63.00	28.06	0.26	0.003463
545.50	63.50	30.16	0.27	0.003510
546.00	64.00	32.26	0.28	0.003743
546.50	64.50	34.36	0.29	0.004161
547.00	65.00	36.46	0.30	0.004764
547.50	65.50	38.56	0.31	0.005552
548.00	66.00	40.16	0.32	0.006277
548.50	66.50	41.36	0.33	0.006892
549.00	67.00	42.56	0.34	0.007566
549.50	67.50	43.48	0.35	0.008125
550.00	68.00	44.52	0.36	0.008799
550.50	68.50	45.44	0.37	0.009433

551.00	69.00	46.38	0.38	0.010117
551.50	69.50	47.42	0.39	0.010918
552.00	70.00	48.22	0.40	0.011565
552.50	70.50	49.33	0.41	0.012506

Table 5.11 Results for polyethylene at 0.5 kg for 100°C



Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
531.00	50.00	0.00	0.00	0.019800
544.00	63.00	9.02	0.26	0.011470
545.00	64.00	11.16	0.28	0.011285
546.00	65.00	13.30	0.30	0.011787
547.00	66.00	15.44	0.32	0.012976
548.00	67.00	17.58	0.34	0.014851
549.00	68.00	18.16	0.36	0.112800
550.00	69.00	22.16	0.38	0.021174
551.00	70.00	24.16	0.40	0.024922
552.00	71.00	26.02	0.42	0.028946
553.00	72.00	28.04	0.44	0.033904
554.00	73.00	30.06	0.46	0.039474
555.00	74.00	31.04	0.48	0.042397
556.00	75.00	32.02	0.50	0.045464
557.00	76.00	33.00	0.52	0.048675

Table 5.12 Results for polyethylene at 0.5 kg for 150°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
528.00	50.00	0.00	0.00	0.044350
545.00	67.00	6.52	0.34	0.036812
546.50	68.50	8.04	0.37	0.039131
547.00	69.00	9.16	0.38	0.041609
547.50	69.50	10.28	0.39	0.044664
548.00	70.00	11.40	0.40	0.048230
548.50	70.50	12.36	0.41	0.051640
549.00	71.00	13.32	0.42	0.055334
549.50	71.50	14.28	0.43	0.059268
550.00	72.00	15.24	0.44	0.063399
550.50	72.50	16.20	0.45	0.067686
551.00	73.00	17.16	0.46	0.072085
551.50	73.50	18.12	0.47	0.076555
552.00	74.00	19.06	0.48	0.080959
552.50	74.50	20.02	0.49	0.085443
553.00	75.00	20.58	0.50	0.088035
553.50	75.50	21.54	0.51	0.092411

Table 5.13 Results for polyethylene at 1.0 kg for 50°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
538.00	50.00	0.00	0.00	0.048000
552.00	64.00	11.12	0.28	0.016450
553.00	65.00	14.04	0.30	0.016420
554.00	66.00	17.06	0.32	0.016020
554.50	66.50	20.04	0.33	0.015891
555.00	67.00	23.10	0.34	0.029419
555.50	67.50	25.24	0.35	0.035626
556.00	68.00	27.38	0.36	0.042934
556.50	68.50	29.52	0.37	0.051355
557.00	69.00	32.06	0.38	0.062842
557.50	69.50	33.11	0.39	0.068082
558.00	70.00	34.16	0.40	0.073621
558.50	70.50	35.21	0.41	0.079470
559.00	71.00	37.36	0.42	0.092457
560.00	72.00	39.21	0.44	0.104788
561.00	73.00	41.22	0.46	0.119496
562.00	74.00	43.12	0.48	0.134759

Table 5.14 Results for polyethylene at 1.0 kg for 100°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
535.00	50.00	0.00	0.00	0.088060
551.00	66.00	8.26	0.38	0.041659
551.50	66.50	10.27	0.39	0.035321
552.00	67.00	12.29	0.40	0.030907
552.50	67.50	14.30	0.41	0.028458
553.00	68.00	16.32	0.42	0.027950
553.50	68.50	18.33	0.43	0.029389
554.00	69.00	19.32	0.44	0.030811
554.50	69.50	20.31	0.45	0.032703
555.00	70.00	21.30	0.46	0.035066
555.50	70.50	22.08	0.47	0.037258
556.00	71.00	22.46	0.48	0.038432
556.50	71.50	23.24	0.49	0.041059
557.00	72.00	24.02	0.50	0.043978
557.50	72.50	24.40	0.51	0.045506
558.00	73.00	25.18	0.52	0.048860

Table 5.15 Results for polyethylene at 1.0 kg for 150°C

Length/mm	Time/mins	new		Strain
		length/mm	Strain/mm	rate/min ⁻¹
535.00	50.00	0.00	0.00	0.166520
535.00	50.00	0.00	0.00	0.166520
553.00	68.00	5.23	0.36	0.069313
554.00	69.00	6.05	0.38	0.078681
555.50	70.50	7.07	0.41	0.093711
556.00	71.00	8.09	0.42	0.112487
556.50	71.50	9.11	0.43	0.135009
557.00	72.00	9.51	0.44	0.144863
557.50	72.50	10.42	0.45	0.169428
558.00	73.00	11.22	0.46	0.193486
558.50	73.50	12.02	0.47	0.219847
559.00	74.00	12.46	0.48	0.235328
559.50	74.50	13.06	0.49	0.257562
560.00	75.00	13.32	0.50	0.267599
560.50	75.50	13.58	0.51	0.277879
561.50	76.50	14.24	0.53	0.305068
562.50	77.50	14.58	0.55	0.319687
563.50	78.50	15.24	0.57	0.349252
564.50	79.50	15.49	0.59	0.360861

Table 5.16 Results for polyethylene at 1.5 kg for 50°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
540.00	50.00	0.00	0.00	0.162380
558.50	68.50	7.23	0.37	0.067899
559.50	69.50	8.23	0.39	0.058806
560.50	70.50	9.23	0.41	0.050679
561.50	71.50	10.23	0.43	0.043519
562.50	72.50	11.23	0.45	0.037324
563.50	73.50	13.23	0.47	0.027832
564.00	74.00	14.45	0.48	0.023940
565.00	75.00	16.07	0.50	0.020993
566.00	76.00	17.29	0.52	0.020448
567.00	77.00	18.51	0.54	0.021340
568.00	78.00	20.13	0.56	0.024747
569.00	79.00	21.35	0.58	0.028986
570.00	80.00	22.27	0.60	0.033134
571.00	81.00	23.09	0.62	0.037520
572.00	82.00	23.51	0.64	0.040018
573.00	83.00	24.33	0.66	0.045387
574.00	84.00	25.27	0.68	0.052340
575.00	85.00	26.09	0.70	0.059102
576.00	86.00	26.51	0.72	0.062817

577.00	87.00	27.33	0.74	0.070562
578.00	88.00	28.27	0.76	0.080239

Table 5.17 Results for polyethylene at 1.5 kg for 100°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
541.00	50.00	0.00	0.00	0.198600
561.50	70.50	6.24	0.41	0.083085
564.00	73.00	7.30	0.46	0.072748
565.00	74.00	8.40	0.48	0.064872
566.00	75.00	9.50	0.50	0.059900
566.50	75.50	11.00	0.51	0.057800
567.00	76.00	12.10	0.52	0.059692
568.00	77.00	13.56	0.54	0.066688
569.00	78.00	14.54	0.56	0.074254
570.00	79.00	15.52	0.58	0.084124
571.00	80.00	16.50	0.60	0.096300
572.00	81.00	17.48	0.62	0.110780
573.00	82.00	18.46	0.64	0.127566
573.50	82.50	19.12	0.65	0.140169
574.00	83.00	19.38	0.66	0.145421
574.50	83.50	20.04	0.67	0.159482
575.00	84.00	20.30	0.68	0.165308
575.50	84.50	20.56	0.69	0.171296

576.00	85.00	21.22	0.70	0.187226
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Table 5.18 Results for polyethylene at 1.5 kg for 150°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
540.00	50.00	0.00	0.00	1.200000
562.00	72.00	3.12	0.44	0.728990
563.50	73.50	4.02	0.47	0.416284
565.00	75.00	4.42	0.50	0.012023
566.50	76.50	5.42	0.53	0.242706
567.50	77.50	6.32	0.55	0.170243
568.50	78.50	7.22	0.57	0.128399
569.50	79.50	8.12	0.59	0.117172
570.00	80.00	8.42	0.60	0.120234
570.50	80.50	9.12	0.61	0.140608
571.00	81.00	9.42	0.62	0.155010
571.50	81.50	10.12	0.63	0.201844
572.00	82.00	10.42	0.64	0.227586
572.50	82.50	11.12	0.65	0.300880
573.00	83.00	11.42	0.66	0.337962
573.50	83.50	11.55	0.67	0.355087
574.00	84.00	12.08	0.68	0.431517
575.00	85.00	12.21	0.70	0.451885
576.00	86.00	12.34	0.72	0.472893

APPENDIX C

Results for PVC

Table 5.19 Results for PVC at 0.5 kg for 50°C

new

Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
530.00	50.00	0.00	0.00	0.045800
542.00	62.00	16.36	0.34	0.016051
543.00	63.00	18.34	0.36	0.014629
544.00	64.00	20.30	0.38	0.013685
545.00	65.00	22.44	0.40	0.013181
546.00	66.00	24.21	0.42	0.013179
547.00	67.00	26.27	0.44	0.013651
548.00	68.00	27.54	0.46	0.014195
549.00	69.00	29.04	0.48	0.015087
550.00	70.00	30.25	0.50	0.016004
551.00	71.00	31.46	0.52	0.017096
552.00	72.00	32.14	0.54	0.017787
553.00	73.00	33.44	0.56	0.019262
554.00	74.00	34.25	0.58	0.020284
555.00	75.00	35.16	0.60	0.021526
556.00	76.00	36.21	0.62	0.023082
557.00	77.00	37.42	0.64	0.025039

Table 5.20 Results for PVC at 0.5 kg for 100°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
532.00	50.00	0.00	0.00	0.084200
546.50	64.50	12.26	0.29	0.025692
547.50	65.50	14.24	0.31	0.024498
548.50	66.50	16.22	0.33	0.024990
549.50	67.50	17.52	0.35	0.026122
550.50	68.50	19.18	0.37	0.028383
551.50	69.50	20.44	0.39	0.030635
552.50	70.50	21.59	0.41	0.033040
553.50	71.50	23.00	0.43	0.036378
554.50	72.50	24.25	0.45	0.039636
555.50	73.50	25.32	0.47	0.042602
556.50	74.50	26.42	0.49	0.045783
557.50	75.50	27.28	0.51	0.048339
558.50	76.50	28.32	0.53	0.051482
559.50	77.50	29.22	0.55	0.054224
561.00	79.00	30.12	0.58	0.056965
562.00	80.00	31.02	0.60	0.059683

Table 5.21 Results for PVC at 0.5 kg for 150°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
535.00	50.00	0.00	0.00	0.140000
554.50	69.50	10.21	0.51	0.061557
555.50	70.50	12.26	0.53	0.037103
556.50	71.50	14.31	0.55	0.065217
557.50	72.50	15.36	0.57	0.072953
558.50	73.50	16.41	0.59	0.082411
559.50	74.50	17.46	0.61	0.093058
560.50	75.50	18.51	0.63	0.104360
561.00	76.00	19.41	0.64	0.114165
562.00	77.00	20.31	0.66	0.123724
563.00	78.00	21.21	0.68	0.132700
564.00	79.00	22.11	0.70	0.140758
565.00	80.00	23.01	0.72	0.147562
566.00	81.00	23.51	0.74	0.150676
567.00	82.00	24.41	0.76	0.154862

Table 5.22 Results for PVC at 1.0 kg for 50°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
535.00	50.00	0.00	0.00	0.211000
553.50	68.50	6.12	0.37	0.027142
555.00	70.00	8.23	0.40	0.017558
557.00	72.00	11.32	0.44	0.014709
558.00	73.00	14.32	0.46	0.021667
559.00	74.00	16.44	0.48	0.031038
559.50	74.50	18.35	0.49	0.042110
560.00	75.00	20.29	0.50	0.055671
560.50	75.50	22.43	0.51	0.073271
561.00	76.00	23.56	0.52	0.083726
561.50	76.50	25.23	0.53	0.100782
562.00	77.00	26.34	0.54	0.113283
562.50	77.50	27.55	0.55	0.128095
563.00	78.00	28.58	0.56	0.141787
564.00	79.00	29.36	0.58	0.152885

Table 5.23 Results for PVC at 1.0 kg for 100°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
540.00	50.00	0.00	0.00	0.261000
561.00	71.00	5.16	0.52	0.031051
562.50	72.50	7.14	0.55	0.026850
563.50	73.50	9.12	0.57	0.033613
564.50	74.50	11.10	0.59	0.034976
565.00	75.00	13.06	0.60	0.052039
566.00	76.00	14.56	0.62	0.068307
567.00	77.00	16.11	0.64	0.088201
568.00	78.00	17.11	0.66	0.103047
569.00	79.00	18.31	0.68	0.123514
570.00	80.00	19.20	0.70	0.141012
571.00	81.00	20.09	0.72	0.160939
572.00	82.00	20.58	0.74	0.173117
573.00	83.00	21.28	0.76	0.192221
574.00	84.00	21.58	0.78	0.201083
575.00	85.00	22.28	0.80	0.223509

Table 5.24 Results for PVC at 1.0 kg for 150°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
542.00	50.00	0.00	0.00	1.180000
566.00	74.00	3.52	0.56	0.035446
567.00	75.00	4.48	0.58	0.082718
567.50	75.50	5.44	0.59	0.060790
568.00	76.00	6.40	0.60	0.073660
568.50	76.50	7.36	0.61	0.109981
569.00	77.00	8.32	0.62	0.162074
569.50	77.50	9.04	0.63	0.208945
570.00	78.00	9.36	0.64	0.231746
570.00	78.00	10.08	0.64	0.287774
570.50	78.50	10.39	0.65	0.314171
571.00	79.00	11.10	0.66	0.381000
571.50	79.50	11.42	0.67	0.414613
572.00	80.00	12.12	0.68	0.497810
572.50	80.50	12.32	0.69	0.524470
573.00	81.00	12.52	0.70	0.552616
573.50	81.50	13.22	0.71	0.664664
574.00	82.00	13.42	0.72	0.701112
574.50	82.50	14.02	0.73	0.824567

Table 5.25 Results for PVC at 1.5 kg for 50°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
535.00	50.00	0.00	0.00	0.363200
557.00	72.00	7.12	0.44	0.144929
558.50	73.50	8.34	0.47	0.119739
560.50	75.50	9.50	0.51	0.099100
562.00	77.00	10.24	0.54	0.047429
563.00	78.00	12.22	0.56	0.063370
564.00	79.00	13.38	0.58	0.053533
565.00	80.00	14.58	0.60	0.046756
566.50	81.50	16.04	0.63	0.043170
567.50	82.50	17.14	0.65	0.043848
568.50	83.50	18.24	0.67	0.047429
569.50	84.50	19.35	0.69	0.053987
570.50	85.50	20.44	0.71	0.063304
571.50	86.50	21.50	0.73	0.075100
572.50	87.50	22.04	0.75	0.082146
573.50	88.50	22.44	0.77	0.087816
574.50	89.50	23.16	0.79	0.098991
575.50	90.50	23.52	0.81	0.105044

Table 5.26 Results for PVC at 1.5 kg for 100°C

new				
Length/mm	Time/mins	length/mm	Strain/mm	Strain rate/min ⁻¹
540.00	50.00	0.00	0.00	0.250700
566.00	76.00	5.11	0.52	0.053945
567.00	77.00	6.13	0.54	0.067089
568.00	78.00	7.15	0.56	0.092615
569.00	79.00	8.17	0.58	0.129656
570.00	80.00	9.19	0.60	0.177997
571.00	81.00	10.21	0.62	0.238071
572.00	82.00	11.23	0.64	0.310959
573.00	83.00	12.11	0.66	0.385451
574.00	84.00	12.59	0.68	0.431164
575.00	85.00	13.47	0.70	0.525454
576.00	86.00	14.35	0.72	0.635089
577.00	87.00	15.23	0.74	0.762485
578.00	88.00	15.43	0.76	0.794196
579.00	89.00	16.03	0.78	0.896042
580.00	90.00	16.23	0.80	0.932351
581.00	91.00	16.44	0.82	0.971817
582.00	92.00	17.05	0.84	1.094674

Table 5.27 Results for PVC at 1.5 kg for 150°C

Length/mm	Time/mins	new length/mm	Strain/mm	Strain rate/min ⁻¹
540.00	50.00	0.00	0.00	0.250700
566.00	76.00	5.11	0.52	0.053945
567.00	77.00	6.13	0.54	0.067089
568.00	78.00	7.15	0.56	0.092615
569.00	79.00	8.17	0.58	0.129656
570.00	80.00	9.19	0.60	0.177997
571.00	81.00	10.21	0.62	0.238071
572.00	82.00	11.23	0.64	0.310959
573.00	83.00	12.11	0.66	0.385451
574.00	84.00	12.59	0.68	0.431164
575.00	85.00	13.47	0.70	0.525454
576.00	86.00	14.35	0.72	0.635089
577.00	87.00	15.23	0.74	0.762485
578.00	88.00	15.43	0.76	0.794196
579.00	89.00	16.03	0.78	0.896042
580.00	90.00	16.23	0.80	0.932351
581.00	91.00	16.44	0.82	0.971817
582.00	92.00	17.05	0.84	1.094674

APPENDIX D

Results for polymeric samples under similar conditions

Table 5.28 Three samples under the same load of 0.5 kg at 50°C

Polyisoprene			Polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate/min ⁻¹
0.00	0.00	0.012200	0.00	0.00	0.020600	0.00	0.00	0.045800
18.16	0.16	0.006141	15.26	0.21	0.007178	16.36	0.24	0.016051
22.46	0.18	0.005137	18.46	0.22	0.005604	18.34	0.26	0.014629
27.15	0.20	0.004272	21.06	0.23	0.004642	20.30	0.28	0.013685
31.48	0.21	0.003704	23.26	0.24	0.004050	22.44	0.30	0.013181
35.16	0.22	0.003409	25.46	0.25	0.003660	24.21	0.32	0.013179
39.40	0.23	0.003299	28.06	0.26	0.003463	26.27	0.34	0.013651
42.46	0.24	0.003380	30.16	0.27	0.003510	27.54	0.36	0.014195
45.36	0.25	0.003588	32.26	0.28	0.003743	29.04	0.38	0.015087
48.45	0.26	0.003957	34.36	0.29	0.004161	30.25	0.40	0.016004
52.55	0.27	0.004689	36.46	0.30	0.004764	31.46	0.42	0.017096
55.46	0.28	0.005384	38.56	0.31	0.005552	32.14	0.44	0.017787
58.23	0.29	0.006188	40.16	0.32	0.006277	33.44	0.46	0.019262
60.15	0.30	0.006829	41.36	0.33	0.006892	34.25	0.48	0.020284
62.30	0.31	0.007629	42.56	0.34	0.007566	35.16	0.5	0.021526
64.45	0.31	0.008519	43.48	0.35	0.008125	36.21	0.52	0.023082
67.22	0.33	0.009802	44.52	0.36	0.008799	37.42	0.54	0.025039

69.15	0.35	0.010789	45.44	0.37	0.009433
71.32	0.37	0.011991	46.38	0.38	0.010117
73.45	0.39	0.01327	47.42	0.39	0.010918
			48.22	0.40	0.011565
			49.33	0.41	0.012506

Table 5.29 The three samples under the same load of 0.5 kg at 100°C

Polyisoprene			Polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.023300	0.00	0.00	0.019800	0.00	0.00	0.0842000
12.22	0.21	0.010793	9.02	0.26	0.011470	12.26	0.29	0.0256919
15.25	0.24	0.008500	11.16	0.28	0.011285	14.24	0.31	0.0244983
18.26	0.26	0.006607	13.30	0.30	0.011787	16.22	0.33	0.0249901
21.22	0.28	0.005150	15.44	0.32	0.012976	17.52	0.35	0.0261219
24.12	0.30	0.004144	17.58	0.34	0.014851	19.18	0.37	0.0283826
27.22	0.32	0.003561	20.12	0.36	0.017969	20.44	0.39	0.0306347
29.51	0.33	0.003478	22.16	0.38	0.021174	21.59	0.41	0.0330400
31.46	0.34	0.003652	24.16	0.40	0.024922	23.00	0.43	0.0363784
33.58	0.35	0.004108	26.02	0.42	0.028946	24.25	0.45	0.0396358
36.22	0.36	0.005082	28.04	0.44	0.033904	25.32	0.47	0.0426020
37.15	0.37	0.005536	30.06	0.46	0.039474	26.42	0.49	0.0457832
38.3	0.38	0.006179	31.04	0.48	0.042397	27.28	0.51	0.0483390
39.46	0.39	0.006922	32.02	0.50	0.045464	28.32	0.53	0.0514817

40.52	0.40	0.007684	33.00	0.52	0.048675	29.22	0.55	0.0542238
41.6	0.41	0.008545				30.12	0.58	0.0569646
42.26	0.42	0.009113				31.02	0.60	0.0596832
43.52	0.43	0.010289						
44.09	0.44	0.010861						

Table 5.30 Three samples under the same load of 0.5 kg at 150°C

Polyisoprene			Polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.071200	0.00	0.00	0.04435	0.00	0.00	0.140000
8.02	0.24	0.016760	6.52	0.34	0.036812	10.21	0.51	0.061557
9.52	0.26	0.015146	8.04	0.36	0.039131	12.26	0.53	0.057103
11.4	0.28	0.016936	9.16	0.38	0.041609	14.31	0.55	0.065217
13.3	0.30	0.023054	10.28	0.40	0.044664	15.36	0.57	0.072953
15.2	0.32	0.033504	11.4	0.42	0.04823	16.41	0.59	0.082411
17.12	0.34	0.048465	12.36	0.44	0.05164	17.46	0.61	0.093058
18.13	0.36	0.05811	13.32	0.46	0.055334	18.51	0.63	0.10436
19.21	0.38	0.069778	14.28	0.48	0.059268	19.41	0.64	0.114165
20.10	0.40	0.080446	15.24	0.50	0.063399	20.31	0.66	0.123724
21.14	0.42	0.094116	16.2	0.52	0.067686	21.21	0.68	0.1327
22.10	0.44	0.107886	17.16	0.54	0.072085	22.11	0.70	0.140758
23.32	0.46	0.126981	18.12	0.56	0.076555	23.01	0.72	0.147562
24.10	0.48	0.140126	19.06	0.58	0.080959	23.51	0.74	0.150676
25.09	0.50	0.157861	20.02	0.60	0.085443	24.41	0.76	0.154862

20.58	0.62	0.088035	0.154862
21.54	0.64	0.092411	
22.50	0.66	0.096663	
22.35	0.68	0.100499	
23.05	0.7	0.100665	
24.35	0.74	0.104351	

Table 5.31 The three samples under the same load of 1.0 kg at 50°C

Polyisoprene			polyethylene			PVC		
time	strain	strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.024000	0.00	0.00	0.048000	0.00	0.00	0.211000
14.20	0.25	0.010590	11.12	0.28	0.016450	6.12	0.37	0.027142
17.25	0.27	0.008656	14.04	0.30	0.015891	8.23	0.40	0.017558
20.40	0.28	0.007011	17.06	0.32	0.017985	11.32	0.44	0.014709
23.55	0.29	0.005723	20.08	0.33	0.022551	14.32	0.46	0.021667
27.10	0.31	0.004699	23.10	0.34	0.029419	16.44	0.48	0.031038
30.45	0.33	0.004150	25.24	0.35	0.035626	18.35	0.49	0.042110
32.47	0.34	0.004013	27.38	0.36	0.042934	20.29	0.50	0.055671
34.49	0.35	0.004024	29.52	0.37	0.051355	22.43	0.51	0.073271
36.51	0.36	0.004182	32.06	0.38	0.062842	23.56	0.52	0.083726
38.53	0.37	0.004486	33.11	0.39	0.068082	25.23	0.53	0.100782
40.55	0.38	0.004937	34.16	0.40	0.073621	26.34	0.54	0.113283
42.57	0.39	0.005536	35.21	0.41	0.079470	27.55	0.55	0.128095

44.59	0.40	0.006281	37.36	0.42	0.092457	28.58	0.56	0.141787
46.01	0.41	0.006893	39.21	0.44	0.104788	29.36	0.58	0.152885
48.03	0.42	0.007888	41.22	0.46	0.119496	30.33	0.59	0.167648
50.05	0.43	0.009030	43.12	0.48	0.134759	31.22	0.60	0.182218
51.15	0.44	0.009714				32.00	0.61	0.195868
52.25	0.46	0.010441				32.32	0.62	0.201722
53.35	0.48	0.011212						
54.45	0.50	0.012026						

Table 5.32 The three samples under the same load of 1.0 kg at 100°C

polyisoprene			polyethylene			PVC		
time	strain	Strain rate	Time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.0251	0.00	0.00	0.088060	0.00	0.00	0.166800
10.02	0.31	0.007176	8.26	0.38	0.041659	5.16	0.52	0.031051
12.12	0.34	0.005143	10.27	0.39	0.035321	7.14	0.55	0.020850
14.54	0.36	0.00403	12.29	0.40	0.030907	9.12	0.57	0.023613
16.42	0.37	0.004079	14.3	0.41	0.028458	11.10	0.59	0.034976
18.30	0.38	0.004904	16.32	0.42	0.027950	13.06	0.60	0.052039
20.26	0.40	0.006567	18.33	0.43	0.029389	14.56	0.62	0.068307
21.58	0.42	0.008143	19.32	0.44	0.030811	16.11	0.64	0.088201
23.00	0.44	0.010255	20.31	0.45	0.032703	17.11	0.66	0.103047
24.28	0.45	0.012546	21.3	0.46	0.035066	18.31	0.68	0.123514

25.46	0.46	0.015008	22.08	0.47	0.037258	19.20	0.70	0.141012
26.57	0.48	0.017662	22.46	0.48	0.038432	20.09	0.72	0.160939
27.59	0.50	0.020422	23.24	0.49	0.041059	20.58	0.74	0.173117
28.52	0.52	0.023238	24.02	0.50	0.043978	21.28	0.76	0.192221
29.52	0.54	0.026627	24.40	0.51	0.045506	21.58	0.78	0.201083
30.40	0.56	0.029957	25.18	0.52	0.048860	22.28	0.80	0.223509
31.22	0.58	0.033390						
32.00	0.59	0.036987						
33.00	0.62	0.042129						

Table 5.33 The three samples under the same load of 1.0 kg at 150°C

isoprene			polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.088760	0.00	0.00	0.166520	0.00	0.00	1.18000
6.12	0.36	0.013049	5.23	0.36	0.069313	3.52	0.56	0.15446
7.27	0.38	0.009719	6.05	0.38	0.078681	4.48	0.58	0.082718
8.42	0.39	0.008362	7.07	0.41	0.093711	5.44	0.59	0.060790
9.57	0.40	0.008558	8.09	0.42	0.112487	6.40	0.60	0.073660
10.30	0.41	0.009333	9.11	0.43	0.135009	7.36	0.61	0.109981
11.25	0.42	0.010967	9.51	0.44	0.144863	8.32	0.62	0.162074
12.32	0.43	0.013530	10.42	0.45	0.169428	9.04	0.63	0.208945
13.47	0.44	0.017038	11.22	0.46	0.193486	9.36	0.64	0.231746
14.40	0.45	0.020421	12.02	0.47	0.219847	10.08	0.64	0.287774

15.5	0.46	0.025088	12.46	0.48	0.235328	10.39	0.65	0.314171
16.48	0.47	0.029938	13.06	0.49	0.257562	11.10	0.66	0.381000
17.51	0.48	0.035879	13.32	0.50	0.267599	11.42	0.67	0.414613
18.59	0.49	0.043258	13.58	0.51	0.277879	12.12	0.68	0.497810
19.57	0.5	0.051217	14.24	0.53	0.305068	12.32	0.69	0.524470
20.52	0.51	0.060346	14.58	0.55	0.319687	12.52	0.70	0.552616
21.47	0.53	0.071157	15.24	0.57	0.349252	13.22	0.71	0.664664
22.42	0.55	0.083983	15.49	0.59	0.360861	13.42	0.72	0.701112
23.13	0.57	0.095106				14.02	0.73	0.824567
24.08	0.59	0.11237						

Table 5.34 The three samples under the same load of 1.5 kg at 50°C

isoprene			polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.0473	0.00	0.00	0.16238	0.00	0.00	0.363200
10.51	0.34	0.021507	7.23	0.37	0.067899	7.12	0.44	0.144929
11.31	0.37	0.020358	8.23	0.39	0.058806	8.34	0.47	0.119739
12.11	0.38	0.019325	9.23	0.41	0.050679	9.50	0.51	0.099100
13.51	0.39	0.017793	10.23	0.43	0.043519	11.06	0.54	0.076436
14.31	0.4	0.017076	11.23	0.45	0.037324	12.22	0.56	0.063370
15.11	0.41	0.016474	13.23	0.47	0.027832	13.38	0.58	0.053533
16.50	0.42	0.015703	14.45	0.48	0.023940	14.58	0.60	0.046756
17.30	0.43	0.015416	16.07	0.50	0.020993	16.04	0.63	0.043170

18.10	0.44	0.015245	17.29	0.52	0.020448	17.14	0.65	0.043848
18.50	0.45	0.015203	18.51	0.54	0.02134	18.24	0.67	0.047429
19.30	0.46	0.015204	20.13	0.56	0.024747	19.35	0.69	0.053987
20.10	0.47	0.015321	21.35	0.58	0.028986	20.44	0.71	0.063304
21.50	0.48	0.015803	22.27	0.60	0.033134	21.50	0.73	0.075100
22.30	0.49	0.016236	23.09	0.62	0.03752	22.04	0.75	0.082146
23.10	0.50	0.016785	23.51	0.64	0.040018	22.44	0.77	0.087816
24.50	0.51	0.018023	24.33	0.66	0.045387	23.16	0.79	0.098991
25.30	0.52	0.018888	25.27	0.68	0.052340	23.52	0.81	0.105044
26.10	0.53	0.019869	26.09	0.70	0.059102			
27.50	0.54	0.021863	26.51	0.72	0.062817			
28.30	0.55	0.023160	27.33	0.74	0.070562			
29.42	0.56	0.02517	28.27	0.76	0.080239			
30.54	0.57	0.027406						
31.06	0.58	0.028521						
32.18	0.6	0.031088						
33.3	0.62	0.03388						
34.42	0.64	0.036898						
35.54	0.66	0.040142						
36.06	0.68	0.041725						

Table 5.35 The three samples under the same load of 1.5 kg at 100°C

isoprene			polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.072500	0.00	0.00	0.099300	0.00	0.00	0.250700
8.02	0.38	0.026659	6.24	0.41	0.041543	5.11	0.52	0.053945
9.23	0.42	0.022089	7.30	0.46	0.036374	6.13	0.54	0.067089
10.44	0.44	0.018133	8.40	0.48	0.032436	7.15	0.56	0.092615
12.05	0.46	0.013823	9.50	0.50	0.029950	8.17	0.58	0.129656
13.26	0.47	0.011300	11.00	0.51	0.028900	9.19	0.60	0.177997
14.47	0.48	0.009392	12.10	0.52	0.029846	10.21	0.62	0.238071
16.08	0.49	0.007807	13.56	0.54	0.033344	11.23	0.64	0.310959
17.29	0.5	0.007332	14.54	0.56	0.037127	12.11	0.66	0.385451
18.50	0.51	0.007473	15.52	0.58	0.042062	12.59	0.68	0.431164
19.56	0.52	0.008101	16.5	0.6	0.048150	13.47	0.70	0.525454
20.57	0.53	0.009138	17.48	0.62	0.055390	14.35	0.72	0.635089
21.58	0.54	0.010604	18.46	0.64	0.063783	15.23	0.74	0.762485
22.59	0.55	0.012499	19.12	0.65	0.070085	15.43	0.76	0.794196
24.00	0.57	0.015860	19.38	0.66	0.072711	16.03	0.78	0.896042
24.32	0.58	0.016739	20.04	0.67	0.079741	16.23	0.8	0.932351
25.02	0.59	0.018812	20.30	0.68	0.082654	16.44	0.82	0.971817
25.34	0.60	0.019828	20.56	0.69	0.085648	17.05	0.84	1.094674
26.06	0.61	0.022272	21.22	0.70	0.093613			
27.38	0.63	0.027318						

28.22 0.65 0.030909

Table 5.36 The three samples under the same load of 1.5 kg at 150°C

isoprene			polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.172800	0.00	0.00	0.189500	0.00	0.00	0.416000
4.26	0.42	0.071562	3.12	0.44	0.080999	3.14	0.62	0.066063
5.25	0.45	0.066007	4.02	0.47	0.059469	3.50	0.65	0.053181
6.24	0.48	0.065259	4.52	0.5	0.049398	4.40	0.68	0.037030
7.23	0.50	0.068588	5.42	0.53	0.034672	5.38	0.71	0.040744
8.22	0.52	0.075382	6.32	0.55	0.02432	6.30	0.72	0.060319
9.21	0.53	0.085143	7.22	0.57	0.018343	7.20	0.75	0.092380
10.2	0.54	0.097488	8.12	0.59	0.016739	8.19	0.78	0.141907
11.54	0.55	0.117856	8.42	0.6	0.017176	8.52	0.81	0.161950
12.26	0.56	0.13043	9.12	0.61	0.020087	9.38	0.84	0.223664
13.2	0.57	0.148542	9.42	0.62	0.022144	10.3	0.87	0.307754
14.21	0.58	0.170227	10.12	0.63	0.028835	10.56	0.9	0.335578
14.56	0.59	0.178313	10.42	0.64	0.032512	11.42	0.93	0.443038
15.32	0.60	0.196969	11.12	0.65	0.042983	12.00	0.96	0.531200
15.58	0.61	0.203717	11.42	0.66	0.04828	12.42	0.99	0.604368
16.33	0.62	0.224321	11.55	0.67	0.050727	13.2	1.02	0.764543
17.25	0.63	0.252146	12.08	0.68	0.061645	13.56	1.05	0.850605
18.16	0.65	0.282849	12.21	0.7	0.064555			

19.12	0.67	0.319241	12.34	0.72	0.067556
19.38	0.69	0.329892			
20.2	0.71	0.365961			

Table 5.37 Same temperature of 50°C for the different materials at the same load of 0.5kg

isoprene			polyethylene			PVC		
Time	Strain	Strain Rate	Time	Strain	Strain Rate	Time	Strain	Strain Rate
0.00	0.00	0.012200	0.00	0.00	0.020600	0.00	0.00	0.045800
18.16	0.16	0.006141	15.26	0.21	0.007178	16.36	0.34	0.016051
22.46	0.18	0.005137	18.46	0.22	0.005604	18.34	0.36	0.014629
27.15	0.20	0.004272	21.06	0.23	0.004642	20.30	0.38	0.013685
31.48	0.21	0.003704	23.26	0.24	0.00405	22.44	0.4	0.013181
35.16	0.22	0.003409	25.46	0.25	0.00366	24.21	0.42	0.013179
39.4	0.23	0.003299	28.06	0.26	0.003463	26.27	0.44	0.013651
42.46	0.24	0.00338	30.16	0.27	0.00351	27.54	0.46	0.014195
45.36	0.25	0.003588	32.26	0.28	0.003743	29.04	0.48	0.015087
48.45	0.26	0.003957	34.36	0.29	0.004161	30.25	0.50	0.016004
52.55	0.27	0.004689	36.46	0.30	0.004764	31.46	0.52	0.017096
55.46	0.28	0.005384	38.56	0.31	0.005552	32.14	0.54	0.017787
58.23	0.29	0.006188	40.16	0.32	0.006277	33.44	0.56	0.019262
60.15	0.30	0.006829	41.36	0.33	0.006892	34.25	0.58	0.020284
62.3	0.31	0.007629	42.56	0.34	0.007566	35.16	0.6	0.021526
64.45	0.31	0.008519	43.48	0.35	0.008125	36.21	0.62	0.023082
67.22	0.33	0.009802	44.52	0.36	0.008799	37.42	0.64	0.025039

69.15	0.35	0.010789	45.44	0.37	0.009433
71.32	0.37	0.011991	46.38	0.38	0.010117
73.45	0.39	0.013270	47.42	0.39	0.010918
			48.22	0.40	0.011565
			49.33	0.41	0.012506

Table 5.38 Same temperature of 100°C for the different materials at a load of 1.0 kg

Polyisoprene				Polyethylene			PVC		
Time	strain	Strain rate		time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.00	0.023300	0.00	0.00	0.019800	0.00	0.00	0.088060
12.22	58.00	0.21	0.010793	9.02	0.26	0.011470	8.26	0.38	0.041659
15.25	59.00	0.24	0.008500	11.16	0.28	0.011285	10.27	0.39	0.035321
18.26	60.00	0.26	0.006607	13.3	0.30	0.011787	12.29	0.40	0.030907
21.22	60.50	0.28	0.00515	15.44	0.32	0.012976	14.30	0.41	0.028458
24.12	61.50	0.3	0.004144	17.58	0.34	0.014851	16.32	0.42	0.027950
27.22	62.00	0.32	0.003561	20.12	0.36	0.017969	18.33	0.43	0.029389
29.51	63.00	0.33	0.003478	22.16	0.38	0.021174	19.32	0.44	0.030811
31.46	64.00	0.34	0.003652	24.16	0.40	0.024922	20.31	0.45	0.032703
33.58	65.00	0.35	0.004108	26.02	0.42	0.028946	21.3	0.46	0.035066
36.22	66.00	0.36	0.005082	28.04	0.44	0.033904	22.08	0.47	0.037258
37.15	66.5	0.37	0.005536	30.06	0.46	0.039474	22.46	0.48	0.038432
38.3	67.5	0.38	0.006179	31.04	0.48	0.042397	23.24	0.49	0.041059
39.46	68.00	0.39	0.006922	32.02	0.50	0.045464	24.02	0.50	0.043978

40.52	69.00	0.4	0.007684	33.00	0.52	0.048675	24.40	0.51	0.045506
41.60	69.50	0.41	0.008545	12.00	0.54	0.011400	25.18	0.52	0.04886
42.26	70.00	0.42	0.009113						
43.52	71.00	0.43	0.010289						
44.09	72.00	0.44	0.010861						

Table 5.39 Same temperature of 150°C for the different materials at a load of 0.5 kg

Polyisoprene				Polyethylene			PVC		
Time	strain	Strain rate		time	strain	Strain rate	Time	strain	Strain rate
0.00	0.00	0.00	0.01220	0.00	0.00	0.020600	0.00	0.00	0.140000
18.16	55.00	0.16	0.006141	15.26	0.21	0.007178	10.21	0.51	0.061557
22.46	56.00	0.18	0.005137	18.46	0.22	0.005604	12.26	0.53	0.057103
27.15	56.50	0.20	0.004272	21.06	0.23	0.004642	14.31	0.55	0.065217
31.48	57.50	0.21	0.003704	23.26	0.24	0.004050	15.36	0.57	0.072953
35.16	58.00	0.22	0.003409	25.46	0.25	0.003660	16.41	0.59	0.082411
39.4	59.00	0.23	0.003299	28.06	0.26	0.003463	17.46	0.61	0.093058
42.46	60.00	0.24	0.003380	30.16	0.27	0.003510	18.51	0.63	0.104360
45.36	61.00	0.25	0.003588	32.26	0.28	0.003743	19.41	0.64	0.114165
48.45	62.00	0.26	0.003957	34.36	0.29	0.004161	20.31	0.66	0.123724
52.55	63.00	0.27	0.004689	36.46	0.3	0.004764	21.21	0.68	0.132700
55.46	64.00	0.28	0.005384	38.56	0.31	0.005552	22.11	0.7	0.140758
58.23	65.00	0.29	0.006188	40.16	0.32	0.006277	23.01	0.72	0.147562
60.15	66.00	0.30	0.006829	41.36	0.33	0.006892	23.51	0.74	0.150676

62.30	67.00	0.31	0.007629	42.56	0.34	0.007566	24.41	0.76	0.154862
64.45	68.00	0.31	0.008519	43.48	0.35	0.008125			
67.22	69.00	0.33	0.009802	44.52	0.36	0.008799			
69.15	70.00	0.35	0.010789	45.44	0.37	0.009433			
71.32	71.00	0.37	0.011991	46.38	0.38	0.010117			
73.45	72.00	0.39	0.013270	47.42	0.39	0.010918			
				48.22	0.40	0.011565			
				49.33	0.41	0.012506			

Table 5.40 Same temperature of 50°C for the different materials at the same load of 1.0 kg

Polyisoprene				Polyethylene			PVC		
Time	strain	Strain rate		Time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.00	0.024000	0.00	0.00	0.048000	0.00	0.00	0.211000
14.20	60.00	0.25	0.010590	11.12	0.28	0.016450	6.12	0.37	0.027142
17.25	61.00	0.27	0.008656	14.04	0.30	0.015891	8.23	0.40	0.017558
20.40	62.00	0.28	0.007011	17.06	0.32	0.017985	11.32	0.44	0.014709
23.55	62.50	0.29	0.005723	20.08	0.33	0.022551	14.32	0.46	0.021667
27.10	63.00	0.31	0.004699	23.10	0.34	0.029419	16.44	0.48	0.031038
30.45	63.50	0.33	0.004150	25.24	0.35	0.035626	18.35	0.49	0.042110
32.47	64.00	0.34	0.004013	27.38	0.36	0.042934	20.29	0.50	0.055671
34.49	65.00	0.35	0.004024	29.52	0.37	0.051355	22.43	0.51	0.073271
36.51	66.00	0.36	0.004182	32.06	0.38	0.062842	23.56	0.52	0.083726
38.53	67.00	0.37	0.004486	33.11	0.39	0.068082	25.23	0.53	0.100782

40.55	68.00	0.38	0.004937	34.16	0.4	0.073621	26.34	0.54	0.113283
42.57	69.00	0.39	0.005536	35.21	0.41	0.07947	27.55	0.55	0.128095
44.59	70.00	0.40	0.006281	37.36	0.42	0.092457	28.58	0.56	0.141787
46.01	71.00	0.41	0.006893	39.21	0.44	0.104788	29.36	0.58	0.152885
48.03	72.00	0.42	0.007888	41.22	0.46	0.119496	30.33	0.59	0.167648
50.05	73.00	0.43	0.009030	43.12	0.48	0.134759	31.22	0.60	0.182218
51.15	74.00	0.44	0.009714				32.00	0.61	0.195868
52.25	75.00	0.46	0.010441				32.32	0.62	0.201722
53.35	76.00	0.48	0.011212						
54.45	77.00	0.50	0.012026						

Table 5.41 Same temperature of 100°C for the different materials at the same load of 1.0 kg

Polyisoprene				Polyethylene			PVC		
Time	strain	Strain rate		time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.00	0.025100	0.00	0.00	0.088060	0.00	0.00	0.261000
10.02	65.00	0.31	0.007176	8.26	0.38	0.041659	5.16	0.52	0.031051
12.12	66.00	0.34	0.005143	10.27	0.39	0.035321	7.14	0.55	0.020850
14.54	67.00	0.36	0.004030	12.29	0.40	0.030907	9.12	0.57	0.023613
16.42	67.50	0.37	0.004079	14.30	0.41	0.028458	11.10	0.59	0.034976
18.3	68.00	0.38	0.004904	16.32	0.42	0.027950	13.06	0.60	0.052039
20.26	69.00	0.40	0.006567	18.33	0.43	0.029389	14.56	0.62	0.068307
21.58	70.00	0.42	0.008143	19.32	0.44	0.030811	16.11	0.64	0.088201
23.00	71.00	0.44	0.010255	20.31	0.45	0.032703	17.11	0.66	0.103047

24.28	71.50	0.45	0.012546	21.30	0.46	0.035066	18.31	0.68	0.123514
25.46	72.00	0.46	0.015008	22.08	0.47	0.037258	19.20	0.70	0.141012
26.57	73.00	0.48	0.017662	22.46	0.48	0.038432	20.09	0.72	0.160939
27.59	74.00	0.50	0.020422	23.24	0.49	0.041059	20.58	0.74	0.173117
28.52	75.00	0.52	0.023238	24.02	0.50	0.043978	21.28	0.76	0.192221
29.52	76.00	0.54	0.026627	24.40	0.51	0.045506	21.58	0.78	0.201083
30.40	77.00	0.56	0.029957	25.18	0.52	0.048860	22.28	0.80	0.223509
31.22	78.00	0.58	0.033390						
32.00	78.50	0.59	0.036987						
33.00	80.00	0.62	0.042129						

Table 5.42 Same temperature of 150°C for the different materials at the same load of 1.0 kg

Polyisoprene			Polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	Strain	Strain rate
0.00	0.00	0.088760	0.00	0.00	0.166520	0.00	0.00	1.180000
6.12	0.36	0.013049	5.23	0.36	0.069313	3.52	0.56	0.154460
7.27	0.38	0.009719	6.05	0.38	0.078681	4.48	0.58	0.082718
8.42	0.39	0.008362	7.07	0.41	0.093711	5.44	0.59	0.060790
9.57	0.40	0.008558	8.09	0.42	0.112487	6.40	0.60	0.073660
10.30	0.41	0.009333	9.11	0.43	0.135009	7.36	0.61	0.109981
11.25	0.42	0.010967	9.51	0.44	0.144863	8.32	0.62	0.162074
12.32	0.43	0.013530	10.42	0.45	0.169428	9.04	0.63	0.208945
13.47	0.44	0.017038	11.22	0.46	0.193486	9.36	0.64	0.231746
14.40	0.45	0.020421	12.02	0.47	0.219847	10.08	0.64	0.287774

15.50	0.46	0.025088	12.46	0.48	0.235328	10.39	0.65	0.314171
16.48	0.47	0.029938	13.06	0.49	0.257562	11.10	0.66	0.381000
17.51	0.48	0.035879	13.32	0.50	0.267599	11.42	0.67	0.414613
18.59	0.49	0.043258	13.58	0.51	0.277879	12.12	0.68	0.497810
19.57	0.50	0.051217	14.24	0.53	0.305068	12.32	0.69	0.524470
20.52	0.51	0.060346	14.58	0.55	0.319687	12.52	0.70	0.552616
21.47	0.53	0.071157	15.24	0.57	0.349252	13.22	0.71	0.664664
22.42	0.55	0.083983	15.49	0.59	0.360861	13.42	0.72	0.701112
23.13	0.57	0.095106				14.02	0.73	0.824567
24.08	0.59	0.112370						

Table 5.43 Same temperature of 50°C for the different materials at the same load of 1.5 kg

Polyisoprene			Polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.047300	0.00	0.00	0.16238	0.00	0.00	0.363200
10.51	0.34	0.021507	7.23	0.37	0.067899	7.12	0.44	0.144929
11.31	0.37	0.020358	8.23	0.39	0.058806	8.34	0.47	0.119739
12.11	0.38	0.019325	9.23	0.41	0.050679	9.50	0.51	0.099100
13.51	0.39	0.017793	10.23	0.43	0.043519	11.06	0.54	0.076436
14.31	0.40	0.017076	11.23	0.45	0.037324	12.22	0.56	0.063370
15.11	0.41	0.016474	13.23	0.47	0.027832	13.38	0.58	0.053533
16.50	0.42	0.015703	14.45	0.48	0.023940	14.58	0.6	0.046756
17.3	0.43	0.015416	16.07	0.50	0.020993	16.04	0.63	0.043170

18.10	0.44	0.015245	17.29	0.52	0.020448	17.14	0.65	0.043848
18.50	0.45	0.015203	18.51	0.54	0.021340	18.24	0.67	0.047429
19.30	0.46	0.015204	20.13	0.56	0.024747	19.35	0.69	0.053987
20.10	0.47	0.015321	21.35	0.58	0.028986	20.44	0.71	0.063304
21.50	0.48	0.015803	22.27	0.60	0.033134	21.50	0.73	0.075100
22.30	0.49	0.016236	23.09	0.62	0.037520	22.04	0.75	0.082146
23.10	0.50	0.016785	23.51	0.64	0.040018	22.44	0.77	0.087816
24.50	0.51	0.018023	24.33	0.66	0.045387	23.16	0.79	0.098991
25.30	0.52	0.018888	25.27	0.68	0.052340	23.52	0.81	0.105044
26.10	0.53	0.019869	26.09	0.70	0.059102			
27.50	0.54	0.021863	26.51	0.72	0.062817			
28.30	0.55	0.023160	27.33	0.74	0.070562			
29.42	0.56	0.025170	28.27	0.76	0.080239			
30.54	0.57	0.027406						

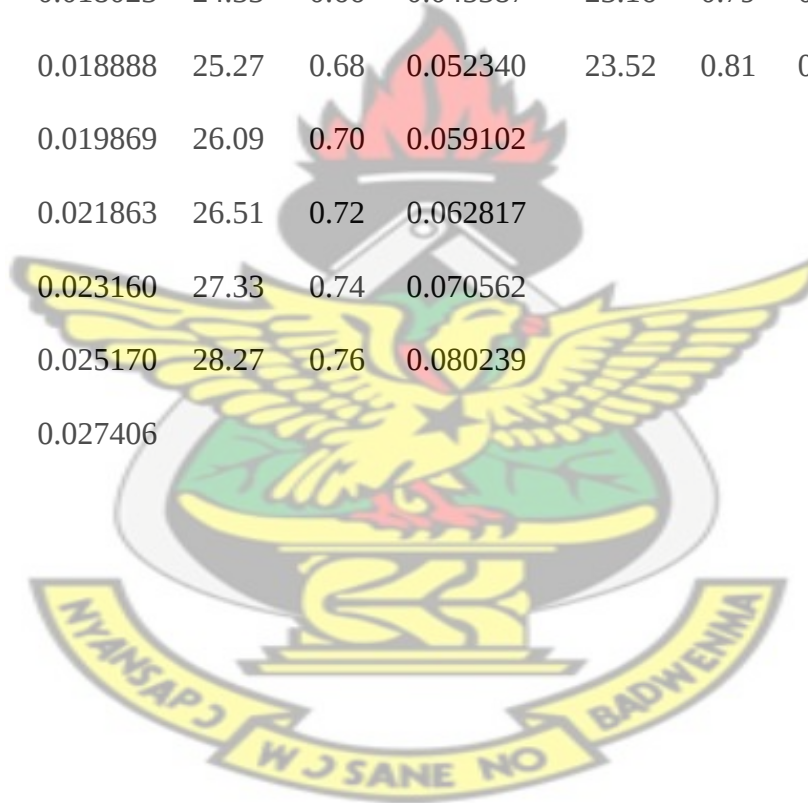


Table 5.44 Same temperature of 100°C for the different materials at the same load of 1.5 kg

Polyisoprene				Polyethylene			PVC		
time	strain	Strain rate		time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.00	0.142100	0.00	0.00	0.198600	0.00	0.00	0.250700
8.02	69.00	0.38	0.052252	6.24	0.41	0.083085	5.11	0.52	0.053945
9.23	70.00	0.42	0.043293	7.30	0.46	0.072748	6.13	0.54	0.067089
10.44	71.00	0.44	0.035540	8.40	0.48	0.064872	7.15	0.56	0.092615
12.05	72.00	0.46	0.027092	9.50	0.5	0.059900	8.17	0.58	0.129656
13.26	72.50	0.47	0.022148	11.00	0.51	0.057800	9.19	0.6	0.177997
14.47	73.00	0.48	0.018408	12.10	0.52	0.059692	10.21	0.62	0.238071
16.08	73.50	0.49	0.015302	13.56	0.54	0.066688	11.23	0.64	0.310959
17.29	74.00	0.5	0.014371	14.54	0.56	0.074254	12.11	0.66	0.385451
18.50	75.00	0.51	0.014646	15.52	0.58	0.084124	12.59	0.68	0.431164
19.56	76.00	0.52	0.015877	16.50	0.6	0.096300	13.47	0.70	0.525454
20.57	77.00	0.53	0.017911	17.48	0.62	0.11078	14.35	0.72	0.635089
21.58	78.00	0.54	0.020784	18.46	0.64	0.127566	15.23	0.74	0.762485
22.59	79.00	0.55	0.024497	19.12	0.65	0.140169	15.43	0.76	0.794196
24.00	80.50	0.57	0.031086	19.38	0.66	0.145421	16.03	0.78	0.896042
24.32	81.00	0.58	0.032809	20.04	0.67	0.159482	16.23	0.80	0.932351
25.02	82.00	0.59	0.036872	20.3	0.68	0.165308	16.44	0.82	0.971817
25.34	82.50	0.60	0.038863	20.56	0.69	0.171296	17.05	0.84	1.094674
26.06	83.00	0.61	0.043653	21.22	0.70	0.187226			
27.38	84.00	0.63	0.053542						

28.22 85.00 0.65 0.060582

Table 5.45 Same temperature of 150°C for the different materials at the same load of 1.5 kg

Polyisoprene			Polyethylene			PVC		
time	strain	Strain rate	time	strain	Strain rate	time	strain	Strain rate
0.00	0.00	0.181440	0.00	0.00	1.200000	0.00	0.00	1.248000
4.26	0.42	0.075140	3.12	0.44	0.728990	3.14	0.62	0.198188
5.25	0.45	0.069308	4.02	0.47	0.416284	3.50	0.65	0.159544
6.24	0.48	0.068522	4.52	0.5	0.345787	4.40	0.68	0.111089
7.23	0.50	0.072017	5.42	0.53	0.242706	5.38	0.71	0.122231
8.22	0.52	0.079151	6.32	0.55	0.170243	6.30	0.72	0.180957
9.21	0.53	0.089400	7.22	0.57	0.128399	7.20	0.75	0.277140
10.20	0.54	0.102362	8.12	0.59	0.117172	8.19	0.78	0.425722
11.54	0.55	0.123749	8.42	0.6	0.120234	8.52	0.81	0.485849
12.26	0.56	0.136951	9.12	0.61	0.140608	9.38	0.84	0.670991
13.20	0.57	0.155969	9.42	0.62	0.155010	10.30	0.87	0.923263
14.21	0.58	0.178738	10.12	0.63	0.201844	10.56	0.90	1.006734
14.56	0.59	0.187229	10.42	0.64	0.227586	11.42	0.93	1.329114
15.32	0.6	0.206818	11.12	0.65	0.300880	12.00	0.96	1.593600
15.58	0.61	0.213903	11.42	0.66	0.337962	12.42	0.99	1.813105
16.33	0.62	0.235537	11.55	0.67	0.355087	13.2	1.02	2.293630
17.25	0.63	0.264753	12.08	0.68	0.431517	13.56	1.05	2.551815

18.16	0.65	0.296992	12.21	0.70	0.451885
19.12	0.67	0.335203	12.34	0.72	0.472893
19.38	0.69	0.346386			
20.20	0.71	0.384259			

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APPENDIX E

Equations of the strain rates

Table 1 Equations for polyisoprene under a load of 0.5 kg

50°C	$y = 4.0 \times 10^{-9} x^4 + 1.0 \times 10^{-6} x^3 - 0.0002x^2 + 0.0122x + 0.0005$
100°C	$y = 5.0 \times 10^{-8} x^4 + 4.0 \times 10^{-6} x^3 - 0.0006x^2 + 0.0233x + 0.0003$
150°C	$y = 4.0 \times 10^{-6} x^4 + 0.0003x^3 + 0.0068x^2 + 0.0765x - 6.0 \times 10^{-5}$

Table 2 Equations for polyisoprene under a load of 1.0 kg

50°C	$y = 6.0 \times 10^{-6} x^3 - 0.0006x^2 - 0.024x + 0.0031$
100°C	$y = 2.0 \times 10^{-9} x^6 + 2.0 \times 10^{-7} x^5 + 8.0 \times 10^{-6} x^4 - 9.0 \times 10^{-5} x^3 + 0.0016x^2 + 0.0502x - 3.0 \times 10^{-5}$
150°C	$y = 6.0 \times 10^{-7} x^5 - 4.0 \times 10^{-5} x^4 + 0.0012x^3 - 0.0172x^2 + 0.1268x - 0.0001$

Table 3 Equations for polyisoprene under a load of 1.5 kg

50°C	$y = 3.0 \times 10^{-5} x^3 - 0.0017x^2 - 0.0473x + 0.0025$
100°C	$y = 7.0 \times 10^{-5} x^3 - 0.0037x^2 - 0.0725x + 0.0024$
150°C	$y = 1.0 \times 10^{-6} x^5 - 6.0 \times 10^{-5} x^4 + 0.0018x^3 - 0.024x^2 + 0.01728x - 0.0001$

Table 4 Equations for polyethylene under a load of 0.5 kg

50°C	$y = 7.0 \times 10^{-6} x^3 + 0.0006 x^2 - 0.0206 x + 0.0014$
100°C	$y = 3.0 \times 10^{-5} x^3 - 0.0016 x^2 - 0.0396 x + 0.0024$
150°C	$y = -4.0 \times 10^{-6} x^4 + 0.0003 x^3 - 0.0075 x^2 + 0.0887 x + 0.0009$

Table 5 Equations for polyethylene under a load of 1.0 kg

50°C	$y = 8.0 \times 10^{-9} x^5 - 1.0 \times 10^{-6} x^4 + 9.0 \times 10^{-5} x^3 - 0.0029 x^2 + 0.0482 x - 3.0 \times 10^{-5}$
100°C	$y = 1.0 \times 10^{-4} x^3 - 0.0046 x^2 - 0.0745 x + 0.0028$
150°C	$y = 0.0004 x^3 - 0.0111 x^2 - 0.0116 x + 0.0002$

Table 6 Equations for polyethylene under a load of 1.5 kg

50°C	$y = 7.0 \times 10^{-5} x^3 - 0.0036 x^2 - 0.0706 x + 0.0064$
100°C	$y = 0.0002 x^3 - 0.0065 x^2 - 0.0993 x + 0.0034$
150°C	$y = 0.0009 x^3 - 0.0216 x^2 + 0.1895 x + 0.0055$

Table 7 Equations for PVC under a load of 0.5 kg

50°C	$y = -6.0 \times 10^{-7} x^4 + 7.0 \times 10^{-5} x^3 - 0.0023x^2 + 0.0421x + 0.0001$
100°C	$y = 2.0 \times 10^{-5} x^3 - 0.0012x^2 + 0.0346x + 0.0005$
150°C	$y = -6.0 \times 10^{-6} x^4 + 0.0004x^3 - 0.01x^2 + 0.115x + 0.0001$

Table 8 Equations for PVC under a load of 1.0 kg

50°C	$y = 1.0 \times 10^{-7} x^5 - 1.0 \times 10^{-5} x^4 + 0.0005x^3 - 0.0103x^2 + 0.1055x - 0.0007$
100°C	$y = 1.0 \times 10^{-6} x^5 - 8.0 \times 10^{-5} x^4 + 0.0024x^3 - 0.0318x^2 + 0.212x - 0.0002$
150°C	$y = 1.0 \times 10^{-5} x^5 - 0.0005x^4 + 0.0093x^3 - 0.082x^2 + 0.3514x - 0.0002$

Table 9 Equations for PVC under a load of 1.5 kg

50°C	$y = 0.0001x^3 - 0.0049x^2 - 0.0903x + 0.001$
100°C	$y = 5.0 \times 10^{-6} x^5 - 0.0002x^4 + 0.005x^3 - 0.0488x^2 + 0.2507x + 3.0 \times 10^{-5}$
150°C	$y = 2.0 \times 10^{-5} x^5 - 0.0007x^4 + 0.0123x^3 - 0.1014x^2 + 0.416x - 0.0001$

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