

Chapter One

Introduction

1.1 Introduction

Materials are plays a vital role in this modern age of science and technology. Various kinds of materials are used in industry, housing, agriculture, transportation and etc. The rapid developments in the field of quantum theory of solids have opened vast opportunities for better understanding and utilization of various materials. Different materials possess different properties to meet the various requirements for engineering purposes. Material that fall within the scope of material science and engineering may be classified into one of the following group metals, ceramic and organic polymers these materials are carbon compounds in which carbon is chemically bonded with hydrogen, oxygen and other non-metallic substances. The structure of these compounds is complex. Common organic materials are plastics, synthetic rubbers and natural rubber ^[1].

1.2 The Objective of Research

Understanding of swelling properties of the materials and identify their effect on the polymers at different temperature.

1.3 The Problem of Research

Swelling occurs in some polymers that are used in the manufacture of many materials used in our life, chemistry and petroleum laboratories such as containers, bags plastics and rubbers used in packing, subsequently swelling occurs damage in containers and product that replace them.

1.4 Literature Review

There are many studies that have been conducted in this field

1. Elastomer behavior was tested for swelling in different sample geometries (unconfined samples and samples mounted on steel plate) were tested for a total duration of 1000 h (roughly 45 days) in salt solutions of different concentrations and at different temperatures. Found the swelling elastomer showed significant volume/thickness increase with increasing test temperature and decreasing salt concentration [2].
2. Swelling data of 9 thin polymer films that are commonly used for organic solvent nanofiltration swollen by 10 common solvents. Describes the swelling dynamics during short-term solvent exposure (0–8 h), assesses the stability upon long-term solvent exposure (up to 2 months). Found For many polymers, the swelling changes over long timescales of up to 2 months and longer [3].

1.5 Layout of Research

In this research the study of swelling and it is effect on polymers at different temperature is the main task.

Chapter one show the introduction of the research, in chapter two the materials and properties, in chapter three the polymers, and finally chapter four present the results and discussion.

Chapter Two

Material and Properties

2.1 Introduction

This chapter introduces some physical background about the materials, structure, classification and properties.

Materials are made up of atoms and the nature of these atoms and the way that they are bonded together to make a material. Transportation, housing, clothing, communication and food production virtually every segment of our everyday lives is influenced to one degree or another by materials [4,5].

The properties of materials mainly depend on the internal arrangement of the atoms on molecules. Pure metal is a single type atom and binary alloys composed of two components, as ternary alloys, composed of three components or as multi component alloys [1].

2.2 Classification of Material

Material classified to three

2.2.1 Metals: Materials in this group are composed of one or more metallic elements (such as iron, aluminum, copper, titanium, gold, and nickel), and often also nonmetallic elements (for example, carbon, nitrogen, and oxygen) in relatively small amounts.

2.2.2 Ceramics: Ceramics are compounds between metallic and nonmetallic elements they are most frequently oxides, nitrides, and carbides. For example, some of the common ceramic materials include aluminum oxide (or *alumina*, Al_2O_3), silicon dioxide (or *silica*, SiO_2), silicon carbide (SiC) and silicon nitride (Si_3N_4) [6,5].

2.2.3 Polymer: Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (O, N, and Si).

2.3 The Properties of Materials

There are major properties of materials

2.3.1 The Optical Properties

2.3.1.1 Refraction: is transmitted of light into the interior of transparent materials experiences a decrease in velocity.

2.3.1.2 Index of Refraction n : is ratio of the velocity in vacuum c to the velocity in the vacuum v [5].

2.3.1.3 Dispersion: is the magnitude of the refractive index depends on the wavelength of the incident light.

2.3.1.4 Reflection: is the ratio between the reflected intensity I_R and the incoming intensity I_0 of the light serves.

2.3.1.5 Transmission: is ratio between the transmitted intensity I_T and the impinging light intensity [7].

2.3.2 The Electrical Properties

Conductivity and resistivity are few important electrical properties of a material. A material which offers little resistance to the passage of an electric current is said to be a good conductor of electricity.

2.3.2.1 Resistivity (ρ): The ability of a metal due to which it opposes the flow of current through it. The unit of resistivity is ($\Omega.m$).

2.3.2.2 Conductivity (σ): The reciprocal of resistivity. The unit of conductivity is $\text{Ohm}^{-1}\cdot\text{m}^{-1}$.

$$\sigma = 1/\rho \tag{2.1}$$

Where

σ is conductivity

ρ is resistivity

2.3.3 The Magnetic Properties

Materials in which a state of magnetism can be induced are termed magnetic material. There are five classes into which magnetic materials may be grouped diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic and ferromagnetic. Iron, cobalt nickel and some of their alloys and compounds possess spontaneous magnetization [1].

2.3.4 The Thermal Properties

2.3.4.1 Heat Capacity: is the amount of heat which needs to be transferred to a substance to raise its temperature

$$C = dQ/dT \quad (2.2)$$

Where

C is heat capacity

dQ is the quantity of heat transferred to the body

dT is the rise in temperature

Unit of heat capacity is (J/K)

2.3.4.2 Specific Heat: is heat capacity per unit mass.

$$c = C/M \quad (2.3)$$

Where

c is specific heat

C is heat capacity

M is the mass

Unit of specific heat is (J/Kg.K)

2.3.4.3 Thermal Conductivity: is transported of heat from high to low temperature regions of substance [7].

2.3.4.4 Thermal Expansion: is the indicative of the extend to which a material expands upon heating.

2.3.4.5 Melting Point: is change temperature of substance from solid to liquid state.

2.3.4.6 Thermal Stresses: the stresses are induced in material body as a result of changes in temperature; these stresses can lead to fracture or undesirable plastic deformation [5,1].

2.3.5 Mechanical Properties

There are many mechanical properties

2.3.5.1 Stress: is quotient of force and cross-sectional area

$$\sigma = F/A \quad (2.4)$$

Where

σ is stress

F is the force

A is area

Unit of stress is N/m^2

2.3.5.2 Strain: is the change in length, area or volume. Or is the resistance of the body to deformation due to application of external force [8].

2.3.5.3 Deformation: is the change of material in their dimensions or forms under the acting of applied forces. Deformation can be classified to elastic and plastic deformation.

I. Elastic Deformation: The solid material when subjected to force or load behave elastically, the solid material deforms when loaded but returns to its original shape and size position when unloaded. Such type of behavior is common to metals, ceramics, rubbers and polymers. Elastic deformation in a solid can take place due to change in pressure or by an application of force or load. We have read the elasticity has its origin in the forces between atoms of the solid and therefore depends on both the chemical bonding and the structure of solid.

II. Plastic Deformation: If the force acting on the body is increased then a critical value

of the force can be surpassed beyond which after release of the force a shape change partly restoring the original shape occurs but a permanent deformation remains [9].

2.3.5.4 Ductility: is a measure of the degree of plastic deformation that has been sustained at fracture.

2.3.5.5 Hardness: is a measure of the resistance to localized plastic deformation.

2.3.5.6 Resilience: is the capacity of a material to absorb energy when it is deformed elastically and then upon unloading to have this energy recovered.

2.3.5.7 Toughness: is a measure of the ability of a material to absorb energy up to fracture.

2.3.5.8 Tensile Strength: It is the maximum tensile stress which a material is capable of developing when subjected to loading up to rupture.

2.3.5.9 Compressive Strength: is the value of load applied to break it off by crushing.

2.3.5.10 Shear Strength: is the value of load applied tangentially to shear it off across the resisting section.

2.3.5.11 Bending Strength: is that value of load which can break the metal off by bending it across the resisting section.

2.3.5.12 Torsional Strength: is that value of load applied to break the metal by twisting across the resisting section [5,1].

2.3.5.13 Swelling

Polymers are exposed to liquids the main forms of degradation are swelling and dissolution. With swelling, the liquid or solute diffuses into and is absorbed within the polymer the small solute molecules fit into and occupy positions among the polymer molecules. Thus the macromolecules are forced apart such that the specimen expands or swells. Furthermore, this increase in chain separation results in a reduction of the secondary intermolecular bonding forces; as a consequence, the material becomes softer and more ductile. The liquid

solute also lowers the glass transition temperature and, if depressed below the ambient temperature, will cause a once strong material to become rubbery and weak [5].

Chapter Three

Polymers

3.1 Introduction

This chapter will introduce some physical background about the polymers, structure classification and details about type.

The word polymers are derived from classical Greek poly meaning many and meres meaning parts.

Polymer is a large molecule (macromolecule) built up by the repetition of small chemical units called monomer [10].

3.2 The Structures Polymers

There are different structures of polymers

3.2.1 Linear Chains Polymers

The repeat units are held by strong covalent bonds while different molecules are held together by weaker secondary forces. When thermal energy is supplied to the polymer, it increases the random motion of the molecules which tries to overcome the secondary forces. When all forces are overcome, the molecules become free to move around and the polymer melts which explains the thermoplastic nature of polymers.

3.2.2 Branched Chain Polymer

Branched polymers contain molecules having a linear backbone with branches emanating randomly from it. In order to from this class of material the monomer must have a capability of growing in more than two directions. The branched

chains shown are formed only for low conversions of monomers. This implies that the polymer formed is definitely of low molecular weight.

3.2.3 Network Polymer

The network polymer is high molecular weight. If allowed to react up to large conversions, the polymer becomes a three-dimensional. In fact whenever a multifunctional monomer is polymerized the polymer evolves through a collection of linear chains to a collection of branched chains which ultimately forms a network polymer [11].

3.3 Classification of Polymers

Polymers can be classified in many different ways. The most obvious classification on the based on the origin of the polymer is natural and synthetic

3.3.1 Natural and Synthetic

Polymers may either be naturally occurring or purely synthetic. All the conversion processes occurring in our body (e.g. generation of energy from our food intake) are due to the presence of enzymes. Life itself may cease if there is a deficiency of these enzymes. Enzymes nucleic acids and proteins are polymers biological origin. Their structures which are normally very complex were not understood until very recently. Starch a staple food in most cultures cellulose and natural rubber on the other hand are examples of polymers of plant origin and have relatively simpler structures than those of enzymes or proteins. There are a large number of synthetic (man-made) polymers consisting of various families: fibers, elastomers, plastics and adhesives. Each family itself has subgroups [10].

3.4 Types of Polymers

There are many types of different polymer materials

3.4.1 Plastics

Plastics are materials that have some structural rigidity under load and are used in general purpose application [5]. There are two types of plastics

3.4.1.1 Thermoset: Thermoset has all of the chains tied together with covalent bond in network. It cannot be reprocessed once network. Typical of thermosets include epoxy, polyester, phenolic, polyurethane and silicon.

3.4.1.2 Thermoplastic: Thermoplastic material is a high molecular weight polymer that is not network, it can exist in a linear or branched structure. Upon heating a thermoplastic a highly viscous liquid is formed that can be shaped using plastic processing equipment. Material in this type can be reprocessed by heating to the appropriate temperature. Typical of thermoplastics includes nylon, polyvinyl chloride, polypropylene and polyethylene, it converted to usable product by melt processing (injection molding, extrusion, blow molding and thermoforming) [12,13].

I. Polyethylene (PE):

Polyethylene (PE) is the highest volume polymer in the world. Its high toughness, ductility, excellent chemical resistance, low water vapor permeability and very low water absorption. PE is limited by its relatively low modulus, stress and melting point. It is used to make containers, bottles, film and pipes. The repeated structure of PE is written as $(\text{CH}_2\text{CH}_2)_x$ rather than polyethylene $(\text{CH}_2)_x$ in deference to the various ethylene polymerization mechanisms. PE homopolymers are made up exclusively of carbon and hydrogen atoms, and just as the properties of diamond and graphite vary tremendously different grades of PE have markedly different thermal and mechanical properties. Whilst PE is generally a whitish translucent polymer it's available in grades of density that range from 0.91 to 0.97 g/cm^3 . Commercially available grades are: very low

density PE (VLDPE), linear low density PE (LLDPE), ultra high molecular weight PE (UHMWPE), high density PE (HDPE) and low density PE (LDPE).

I.I Low Density Polyethylene

LDPE combines high impact strength, toughness, and ductility to make it the material of choice for packaging films, which is one of its largest applications. Films range from shrink film, thin film for automatic packaging, heavy sacking, and multilayer films (both laminated and coextruded) where LDPE acts as a seal layer or a water vapor barrier. The application of this type include packaging products, bags, industrial sheeting, piping and tubing, films, garbage cans, industrial containers, household items [14].

3.4.2 Elastomers

Elastomer materials include natural and synthetic rubber

3.4.2.1 Synthetic Rubber

This group of elastomers is known as synthetic rubbers. It can be expected to be about 11 million metric tons in 2000 and about 12 million metric tons in 2003, based on earlier reporting (1999) by the International Institute of Synthetic Rubber Producers. Elastomers in this group butadiene rubber (BR), butyl rubber (IIR), fluoroelastomers (FKM), folyacrylate (ACM), polybutadiene (PB), polychloroprene (CR),polyisoprene (IR), polysulfide rubber (PSR), silicone rubber (SiR) and other.

3.4.2.2 Natural Rubber

Natural rubber the original elastomer still plays an important role among elastomers. Worldwide consumption of NR in 2000 is expected to be about 7 million metric tons/y, based on earlier reporting by the International Rubber Study Group. Chemically, natural rubber is occurs in Hevea rubber trees. NR tapped from other rubber trees is the trans isomer of polyisoprene. NR's principal uses are automotive tires, tire tread, and mechanical goods. Automotive

applications are always compounded with carbon black to impart UV resistance and to increase mechanical properties. Latex concentrate is used for dipped goods, adhesives, and latex thread. Latex concentrate is produced by centrifuge-concentrating field latex tapped from rubber trees. The dry rubber content is subsequently increased from 30 to 40 to 60% minimum. NR has good resilience; high tensile strength; low compression set resistance and good electrical properties [12].

Chapter Four

Result and Discussion

4.1 Introduction

This experiment was conducted in solid state physics laboratory, Sudan University of science and technology, college of science. In this chapter the effect of swelling on some polymers with different carbon black at different temperature has been studied in four different solvents: gasoline, acetone, benzene and water and two types of polymer rubber and plastic. Where was studied in water at different temperature and other solvents at room temperature.

4.2 Materials and Devices

4.2.1 Materials

(1) Rubbers high carbon black, low carbon black.

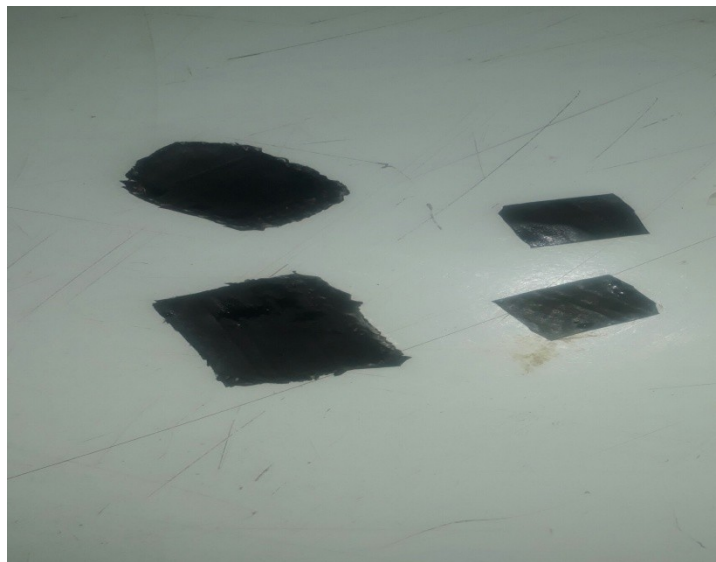


Figure (4.1): shows rubbers samples

(2)Plastics contain carbon black, and not contain it.



Figure (4.2): shows plastics samples

(3)Gasoline

Gasoline is a complex manufactured mixture that does not exist naturally in the environment. Gasoline is produced from petroleum in the refining process. Physical properties of gasoline molecular weight = 108, color is pale brown, physical state is liquid and density = 0.7 to 0.8 [15].

(4)Acetone

Acetone is a colorless liquid with a distinct smell evaporates readily into the air and mixes well with water. Physical properties of acetone molecular weight = 58.08, colorless, physical state is liquid and density = 0.78 [16].

(5)Benzene

Benzene is liquid highly flammable and evaporates into air very quickly and dissolves slightly in water. Physical properties of benzene molecular weight = 78.11, color is yellow, physical state is liquid and density = 0.8787 [17].

(6)Water

Water is a major component of all living things. Some are essential for life while others have profound effects on the size and shape of living organisms Physical properties of water molecular weight = 18, density = 0.998 [18].

4.2.2 Devices

(1) Sensitive balance

Product name: AS220.R analytical balance

Max capacity: 220

Readability (d): 0.1mg

Pan size ϕ 100mm



Figure (4.3): shows sensitive balance

(2) Electric heater



Figure (4.4): shows electric heater

(3) Thermometer division 10

(4) Tongs

(5) Stop watch

(6) Glass cups

4.3 Theorem

$$W = W_w - W_0 \tag{3.1}$$

$$W = W_g - W_0$$

$$W = W_a - W_0$$

$$W = W_b - W_0$$

Where:

W: Net weight

W_0 : Initial weight

W_w : Weight in water

W_g : Weight in gasoline

W_a : Weight in acetone

W_b : Weight in benzene

4.4 Methods

This experiment was performed in two stages at different temperature in water and at room temperature 28°C in gasoline, acetone and benzene

4.4.1 Different Temperature

Water was placed in glass cup and then placed in electric heater. The different samples of polymers were weighted before placing in the water, the three types of samples polymers were putted in the cup and ran the heater to raise the temperature, the samples weighted again at different temperature $(40,60,80)^{\circ}\text{C}$ for rubber high carbon black and the other samples at $(30,40,50)^{\circ}\text{C}$ to observe the swelling as shown in table below.

4.4.2 Room Temperature 28°C

Gasoline, acetone and benzene was placed in glass cups at room temperature the samples of different polymers were weighted before placed in the solutions, then three pieces of rubber samples and four of plastics was putted in the different solutions for period 2 hours in rubber and 1 hour in plastic, the samples were

weighted again, this experiment has repeated at (2,3,4)hours to observe the swelling as shown in table below.



Figure (4.5): shows different polymers samples in containers

4.5 Results

Tables below shows the results at different temperature

Table (4.1): shows the results of rubber high carbon black

$$W_0 = 0.9000\text{g}$$

$T(^{\circ}\text{C})$	$w_w(\text{g})$	$W(\text{g})$
40	1.071	0.2071
60	1.1089	0.2089
80	1.1204	0.2204

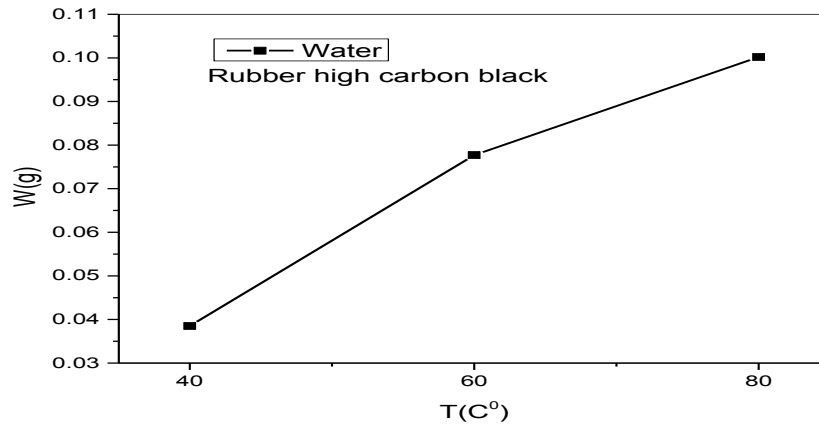


Figure (4.6): shows the results of rubber high carbon black

Table (4.2): shows the result of rubber low carbon black

$$W_0=0.0241\text{g}$$

T(C°)	w _w (g)	W(g)
30	0.0626	0.0385
40	0.1018	0.0777
50	0.1243	0.1002

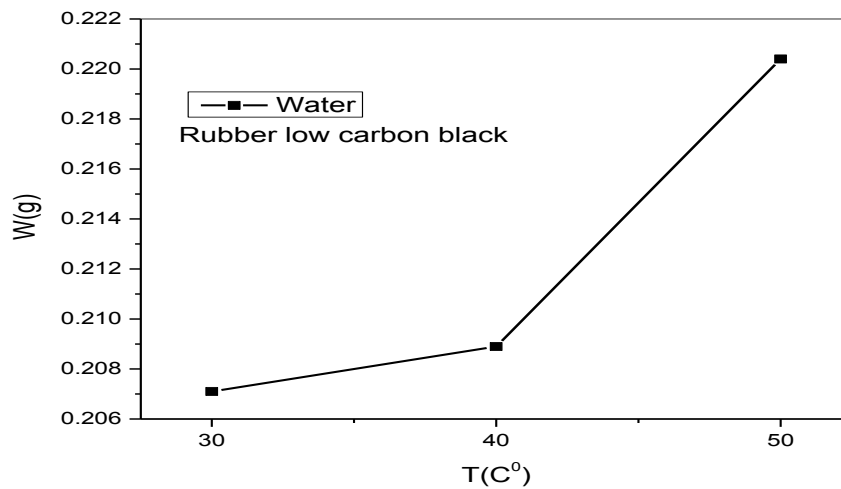


Figure (4.7): shows the result of rubber low carbon black

Table (4.3): shows the result of plastic contain carbon black

$$W_0=0.0080\text{g}$$

$T(^{\circ}\text{C})$	$w_w(\text{g})$	$W(\text{g})$
30	0.0534	0.0454
40	0.0563	0.0483
50	0.0613	0.0533

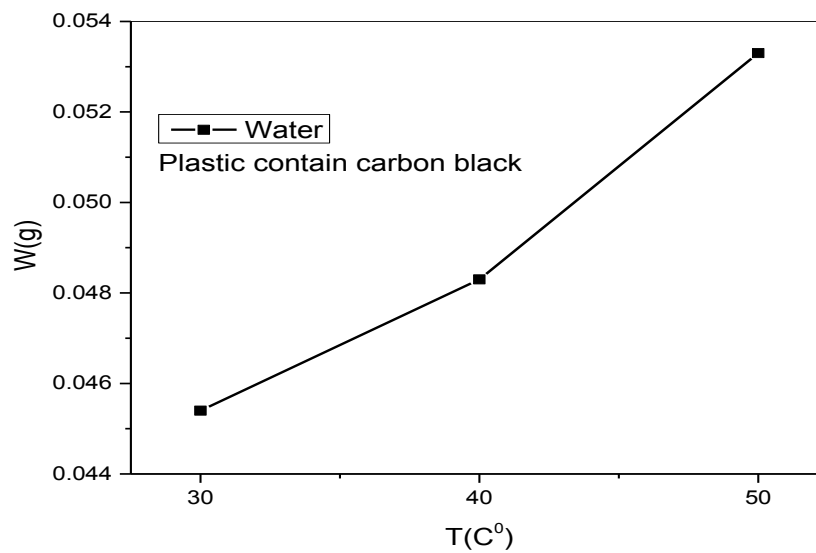


Figure (4.8): shows the result of plastic contain carbon black

Table (4.4): shows the result of plastic does not contain carbon black

$$W_0=0.0040\text{g}$$

$T(^{\circ}\text{C})$	$w_w(\text{g})$	$W(\text{g})$
30	0.0259	0.0219
40	0.0264	0.0224
50	0.0290	0.025

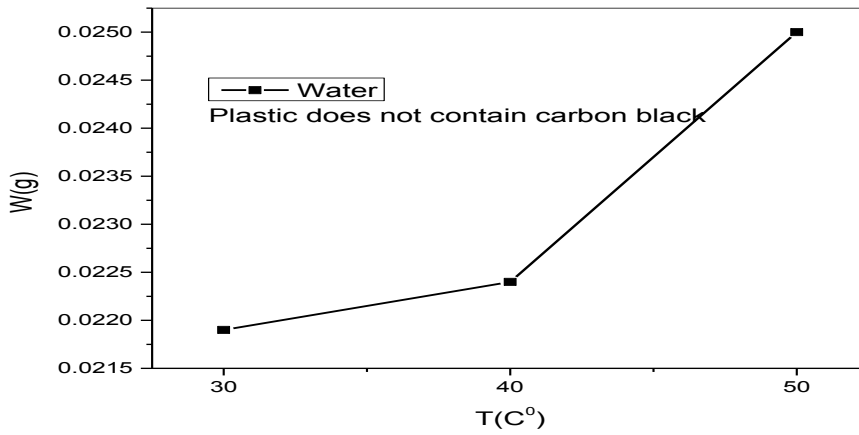


Figure (4.9): shows the result of plastic does not contain carbon black

Tables below shows the result at room temperature.

Table (4.5): shows the result of rubber high carbon black

$$W_{0g}=2.7929g$$

$$W_{0a}=2.8019g$$

$$W_{0b}=3.7779g$$

t/hours	w _g (g)	W(g)	w _a (g)	W(g)	w _b (g)	W(g)
2	3.1657	0.3728	3.0027	0.2008	4.9090	1.1311
3	3.2660	0.4731	3.1187	0.3168	5.3499	1.572
4	3.3265	0.5336	3.1189	0.317	5.436	1.6581

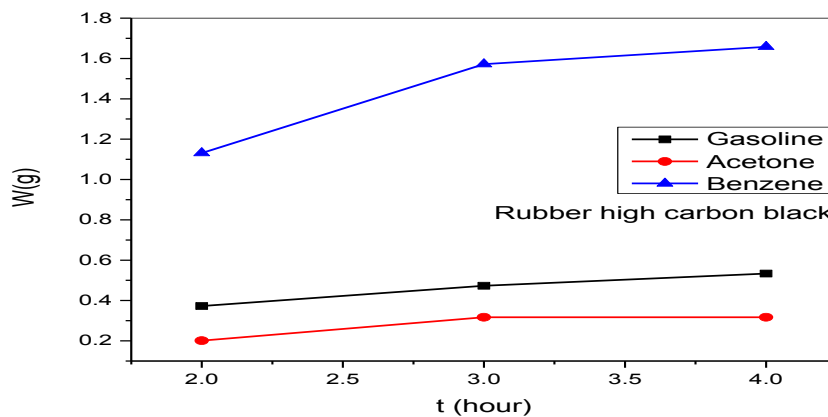


Figure (4.10): shows the result of rubber high carbon black

Table (4.6): shows the result of rubber low carbon black

$$W_0=0.9632g$$

t/hours	w _g (g)	W(g)	w _a (g)	W(g)	w _b (g)	W(g)
2	1.0967	0.1335	1.0312	0.068	1.2960	0.3328
3	1.1335	0.1703	1.0530	0.089	1.3130	0.3498
4	1.2051	0.2419	1.0619	0.0987	1.3212	0.358

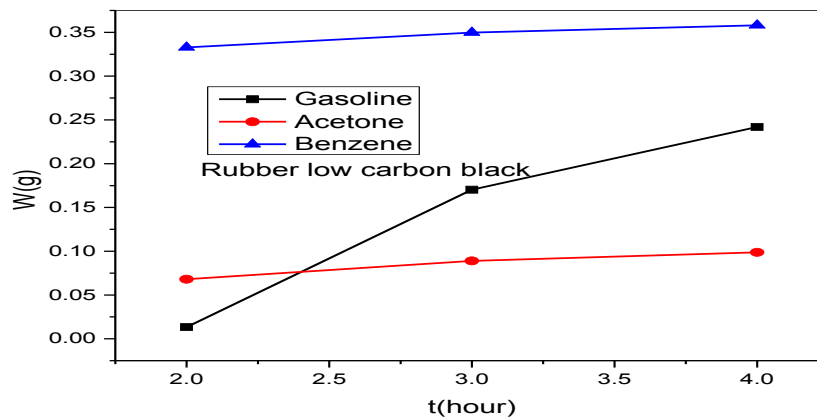


Figure (4.11): shows the result of rubber low carbon black

Table (4.7): shows the result of plastic contain carbon black

$$W_0=0.0100g$$

t/hours	w _g (g)	W(g)	w _a (g)	W(g)	w _b (g)	W(g)
1	0.0858	0.0758	0.0971	0.0871	0.1093	0.0993
2	0.1242	0.1142	0.1303	0.1202	0.1117	0.1017
3	0.2049	0.1949	0.2035	0.1935	0.1963	0.1863
4	0.2076	0.1976	0.2231	0.2131	0.2000	0.1900

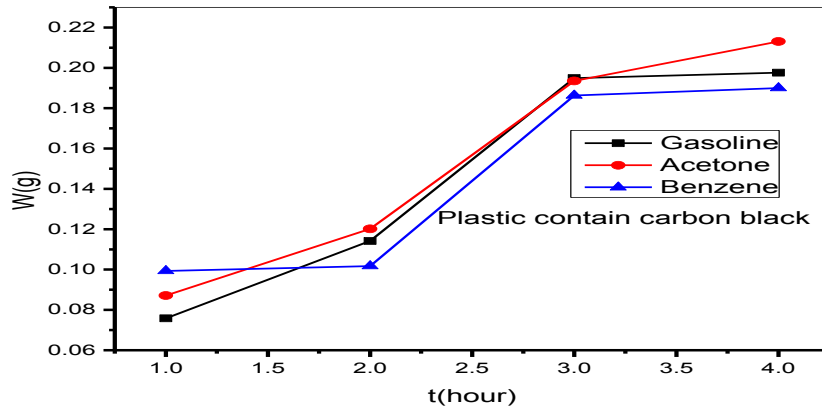


Figure (4.12): shows the result of plastic contain carbon black

Table (4.8): shows the result of plastic does not contain carbon black

$$W_0=0.0043g$$

t/hours	w _g (g)	W(g)	w _a (g)	W(g)	w _b (g)	W(g)
1	0.1011	0.0968	0.1057	0.1014	0.1004	0.0961
2	0.1882	0.1839	0.1891	0.1848	0.1798	0.1755
3	0.2279	0.2236	0.2291	0.2248	0.1970	0.1927
4	0.2286	0.2243	0.2458	0.2415	0.2345	0.2302

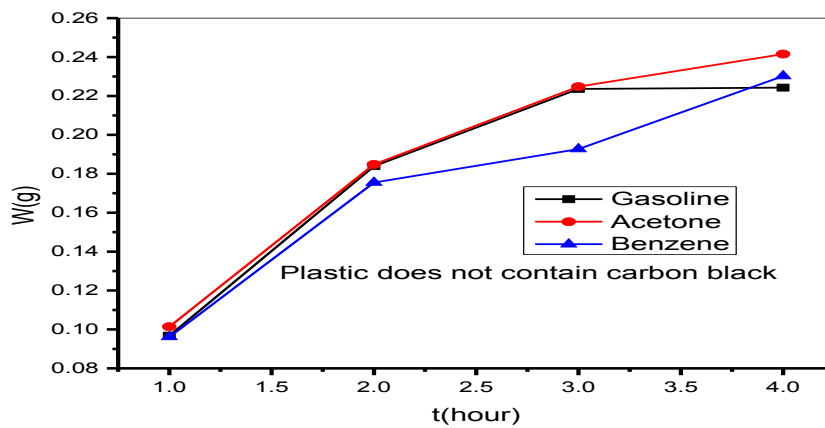


Figure (4.13): shows the result of plastic does not contain carbon black

4.6 Discussion

4.6.1 Different Temperature

Swelling occurs as a result of the expansion of the distance between the polymer molecules due to the high temperature, so water through enters these distances and thus the polymers weight increases and swelling high at high temperature so swelling increase with increasing temperature.

4.6.2 Room Temperature

In tables (4.6) and (4.7) found high swelling in benzene then gasoline and acetone respectively, where find that the samples weight increased significantly after two hour in benzene this due to the similar structure of rubber, benzene and gasoline as they are all hydrocarbons that interact with each other more than other compounds. The bonds are dissolved in the rubber by the butane gas in benzene and gasoline thus the solvent enters the polymer and increases the weight.

In tables (4.9) and (4.10) found high swelling in acetone then gasoline and benzene respectively where found that the samples weight increased significantly after one hour in acetone due to the presence of the polar bond and the structural of the plastic because the plastic is the linear structure facilitates the dismantling of its buttons by the polar bound of acetone.

4.7 Conclusion

It showed that the swelling have great impact on polymers especially at polymer high carbon black it can swell at short exposure time and temperature.

4.8 Recommendation

1. Conduct broader experiment by increasing the time periods on different polymers.
2. Unification the weight of all types of polymers to observe the swelling more clearly.
3. Use different concentration solvents to see effect of low and high concentration on swelling.
4. Conduct this experiment on rubber that does not contain carbon black.

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