SUDAN UNIVRSITY OF SCIENCES & TECHNOLOGY

**College of Graduate Studies**

# Stress properties of plastic pipe under constant pressure in the long term

# خواص الاجهاد للمواسير البلاستيكية تحت ضغط ثابت على المدى الطويل

**A Thesis Submitted in Partial Fulfillment for the Requirements for the Degree of Master of Plastic Engineering**

*Prepared by:*

*Salma Agaballh Ali Agaballh*

*Supervisor:*

*Dr. Mohamed Deen Hussien*

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# الآية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

{الْـحَـمْـدُ لله ِ رَبِّ الْـعَالَـمِينَ {2} الرَّحْـمَن الرَّحِيمِ {3}مَلِكِ يَـوْمِ الدِّينِ {4} إِيَّـاكَ نَـعْـبُـدُ وإِيَّـاكَ نَـسْتعِينُ {5} اهدِنَـا الصِّرَاطَ الـمُستَقِيمَ {6} صِراطَالَّـذِينَ أَنعَمتَ عَلَيهِمْ غَيرِ الـمَغضُوبِ عَلَيهِمْ وَلاَ الضَّالّـِينَ {7}

سورة الفاتحة الآيات (1-7)

**Dedication**

To my mother and my father for taking a good care of me

1

To all my friends

To supporting me

To anyone helped me through to finish this research

## ACKNOWLEDGEMENT

I would like to express my gratitude to Dr. Mohamed Deen Hussien, my advisor, for his constant guidance and constructive criticism which have helped me to accomplish this work and improve my technical abilities.

This is an opportunity to express my sincere thanks also to the each teacher in the Department of Plastic Engineering for the help and advice I received over the years and to all my friends for their continuous support here at Sudan University and Science technology – Engineering callege. I would also like to thank my colleague Us. Muhab Salah Aldien , Saad Kamal and Montaser Mahgoub for they help during every stage of this work.

Finally, I would like to thank my dear mother and  for their priceless support, love and never failing faith in me.

## ABSTRACT

Due to its durability, plastics pipes are normally used for water transport. It replaced the metal pipes .the long term hydrostatic pressure test according to ASTMD2837-02 and EN921 -1994 requires very long periods for testing from 1000~ 10000 hours ,which makes the test is expensive and consuming, the

objective of this research to find a method to use a short –term test result predict the behavior of the plastic pipe for the long –term .for this purpose the short –term tests are carried at elevated temperatures $50^{o}c$ ,$60^{o}c$ and $80^{o}c$ and the curves of stress versus time were plotted . A time –temperature superposition approach is used to predict the creep curves at lower temperatures such as $20^{o}c$, $25^{o}c$ and $30^{o}c$ and $40^{o}c$. the stress curves are essentially parallel. This led to the thought that a shift factor $a_T$ , could be applied to move from one curve to another .it may be seen from figure 4.1 that the three curves from $50^{o}c$ ,$60^{o}c$ and $80^{o}c$  are separated by a uniform distance log $a_T$ Williams ,landel and Ferry developed an empirical relationship for this temperature shift factor explain below:

$$Log\ a_t = \frac{C1[T1-Tg]}{C2+[T2-Tg]} - \frac{C1[T2-Tg]}{C2+[T2-Tg]}$$

Where $c_1$ ,$c_2$ are constant  $T_{ref}$  is a reference temperature .

# المستخلص

نظرا لقوة التحمل, تستخدم مواسير البلاستيك لنقل المياة .بدلا عن المواسير المعدنية ,اختبار الضغط الهايدروستاتيكى على المدى الطويل وفقا 1994 -EN921  and  ASTMD2837-02 يتطلب فترات

زمنيه طويله جدا للإختبار يبداء من1000 الى 10000 ساعه , الامر الذى يجعل الاختبار مكلف ومستهلك للزمن. فإن الهدف من هذا البحث إيجاد طريقة نستخدم فيها نتيجة الاختبار قصير الأجل بإستخدام درجات الحراره c50 ,c60 و c80. ودراسة منحنيات الاجهاد ضد الزمن واستخدام هذه المنهجيه للتنبؤ بمنحنيات التحرك ببطء( الكريب) فى درجات حراره مثل c20 ,c25.,c30 and c40. منحنيات الاجهاد تكون متوازية .ادى هذا الى فكرة عامل التحول ,الذى يمكن تطبيقها على الانتقال من منحنى الى الاخر. وهذا يكون واضحا فى الشكل 4.2 , المنحنيات تكون مفصوله بمسافه ثابته Log a$_t$ وليم ولاند وفيرى وضعوا علاقه تجريبية لهذا العامل موضحه ادناه:

$$\text{Log a}_t = \frac{C1[T1-Tg]}{C2+[T2-Tg]} - \frac{C1[T2-Tg]}{C2+[T2-Tg]}$$

حيث ان $C1$ و $C2$ و T$_{ref}$ ثوابت و $Tg$ تساوى وهى درجة الحراره المرجعيه.

# Table of contents

| Item | Page |
|------|------|

# LIST OF FIGURES & CHARTS

## List of abbreviation

| Symbol | Description | Units |
|--------|-------------|-------|
|        |             |       |

| | | |
|---|---|---|
| HDS | Hydrostatic design stress | $N/m^2$ |
| HDB | hydrostatic design basic | $N/m^2$ |
| DF | design factor | - |
| S | Stress | $N/m^2$ |
| P | Pressure | Mm |
| Dm | Mean diameter | Mm |
| t | Thickness | Mm |
| Do | Outside diameter | Mm |
| PR | Pressure ratings | $N/m^2$ |
| Di | Inside diameter | Mm |
| At | Shift factor | - |
| $C_1$ | Constant (17.4) | - |
| $C_2$ | Constant (51.6) | - |
| Tg | Transition temperature | $^0C$ |
| $T_1$ | Lower temperature | $^0C$ |
| $\beta$ | Constant | - |
| $\Delta\alpha$ | Constant | - |
| $Vt$ | Total volume | $M^3$ |
| $V_O$ | Reference volume | $M^3$ |

# CHAPTAER ONE

## 1.1 Introduction:

The long-term strength of a thermoplastic compound cannot be determined from a short-term tensile strength test, as with most metals. As such, testing and evaluation methodologies have been developed which take into account not only the stress-rupture response of thermoplastics when subjected to only hydrostatic pressure, but that also take into account the potential changes in failure mode when subjected to stresses induced by other loadings than just hydrostatic pressure. This more comprehensive evaluation allows for the making of a more engineering appropriate forecast of the long-term strength of these materials so they can be safely used in a pressure pipe application .The common method for the forecasting of long-term strength relies on putting specimens under multiple continuous stress levels until failure. These data points are then used in a log-log linear regression evaluation. This regression equation is then extrapolated to a point sufficiently further out in time to where a long-term strength can be forecast. It has been clearly established for many thermoplastics, including PE, that a failure mechanism which occurs at ambient temperature can be maintained and greatly accelerated by elevating the testing temperature. This acceleration has been shown to follow an Arrhenius, or rate process, behavior that is common to many chemical and mechanical processes. However, some thermoplastics, such as PVC, do not lend themselves to these types of accelerated testing methodologies, since they change phase at these elevated test temperatures and such testing would no longer be evaluating the same material properties. By testing at elevated temperatures it can be "validated" that the extrapolation remains linear and ductile beyond the actual test data. This and other criteria established by ASTM D2837 and the Plastics Pipe Institute's Hydrostatic Stress Board policies in Technical Report-3 (TR-3) allow for establishing an appropriate maximum working stress that will assure a very long design life—well in excess of the stress regression extrapolation time.

## 1.2 BACKGROUND

## 1.2.1 POLYMERS:

Polymers are substances whose molecules have high molar masses and are composed of a large number of repeating units. There are both naturally occurring and synthetic polymers. Among naturally occurring polymers are proteins, starches, cellulose, and latex. Synthetic polymers are produced commercially on a very large scale and have a wide range of properties and uses. The materials commonly called plastics are all synthetic polymers. Polymers are formed by chemical reactions in which a large number of molecules called monomers are joined sequentially, forming a chain. In many polymers, only one monomer is used. In others, two or three different monomers may be combined. Polymers are classified by the characteristics of the reactions by which they are formed. If all atoms in the monomers are incorporated into the polymer, the polymer is called an addition polymer. If some of the atoms of the monomers are released into small molecules, such as water, the polymer is called a condensation polymer. Most addition polymers are made from monomers containing a double bond between carbon atoms. Such monomers are called olefins, and most commercial addition polymers are polyolefin's. Condensation polymers are made from monomers that have two different groups of atoms which can join together to form, for example, ester or amide links. Polyesters are an important class of commercial polymers, as are polyamides (nylon).

**1.2.2 Plastics:**

Plastics are solid materials that contain one or more polymeric substances which can be shaped by flow. Polymers, the basic ingredient of plastics, compose a broad class of materials that include natural and synthetic polymers. Nearly all plastics are made from the latter. Plastics are divided into two basic groups, thermoplastics and thermosets, both of which are used to produce plastic pipe. Thermoplastics include compositions of PE, polypropylene, and polyvinyl chloride (PVC). These can be re-melted upon the application of heat. Thermoset plastics are similar to thermoplastics prior to "curing," a chemical reaction by which polymer chains are chemically bonded to each other by new cross-links.

**a. Thermoplastics**:

In a thermoplastic material the very long chain-like molecules are held together by relatively weak Van der Waals forces. A useful image of the structure is a mass of randomly distributed long strands of sticky wool. 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. When the material is allowed to cool it solidifies again. This cycle of softening by heat and solidifying on cooling can be repeated more or less indefinitely and is a major advantage in that it is the basis of most processing methods for these materials. It does have its drawbacks, however, because it means that the properties of thermoplastics are heat sensitive. A useful analogy which is often used to describe these materials is that, like candle wax, they can be repeatedly softened by heat and will solidify when  cooled .Examples of thermoplastics are polyethylene, polyvinyl chloride, polystyrene, nylon, cellulose acetate, acetal, polycarbonate, polymethyl methacrylate and polypropylene.

**b. Thermosetting Plastics:**

A thermosetting plastic 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 molding, usually under the application of heat and pressure. The resultant moulding will be rigid when cooled but a close network structure has been set up within the material. During the second stage the long molecular chains have been interlinked by strong bonds so that the material cannot be softened again by the application of heat. If excess heat is applied to these materials they will char and degrade. This type of behaviour is analogous to boiling an egg. Once the egg has cooled and is hard, it cannot be softened again by the application of heat. Since the cross-linking of molecules is by strong chemical bonds, thermosetting materials are characteristically quite rigid materials and their mechanical properties are not heat sensitive. Examples of thermosets are phenol formaldehyde, melamine formaldehyde, urea formaldehyde, epoxies and some polyester.

## 1.3. Objectives of present study:

In this research used high density polyethylene pipes and by using hydrostatic pressure tester, , it is then recorded readings of failure has occurred in different temperature, these data points are then used in a log-log linear regression evaluation.

- To shorten the test periods of ASTM D2837and EN pipe testing to reasonable one.
- The performance of the pipes at elevated temperatures that are encountered in Sahara regions like North Sudan.
- Durability of polyethylene pipes and thermal resistance to rupture when exposed different pressure and different temperature.

**Thesis out line:**

This thesis is divided into five chapters

- Chapter one gives relevant information on Classification of polymer.
- Chapter two presents introduction of Manufacture of polyethylene and Polyethylene Characteristics, Stress and Fracture Behavior and the Determination of Working Strength, polyethylene 100 Materials (ISO Pipe Material Designation Code), polymer processing, a literature review and objectives of present study.
- Chapter three Review the way the device used with a description of its parts and the method of operation of the device, Techniques used to calculate shift factor $a_t$.
- Chapter four present all of charts of high density polyethylene
- Chapter five the conclusion and recommendations based on this study are summarized in this chapter.

# CHAPTER TWO

# Literature review

## 2.1. Introduction:

There are many papers that were published with regard to this research, but before the presentation of these papers want to clarify some of the basic information regarding the article and used some of the properties affecting the design of the pipe. Plastics are often used as spillway and lake drain pipes in dam construction and repair. The most common plastic pipes are high-density polyethylene and polyvinyl chloride .The advantages of using plastic pipe include excellent abrasion resistance, chemical corrosion resistance, low maintenance, and long life expectancy. Naturally occurring chemicals in soils will not degrade plastic pipe and cause it to rot or corrode. Plastic pipes are also much easier to handle and install compared to heavier concrete and steel pipes.

## 2.2. Manufacture of polyethylene:

Polymers are large molecules formed by the polymerization of repeating small molecular units. To produce PE, the starting unit is ethylene, a colorless gas composed of two double-bonded carbon atoms and four hydrogen atoms (see Figure 2 .1).
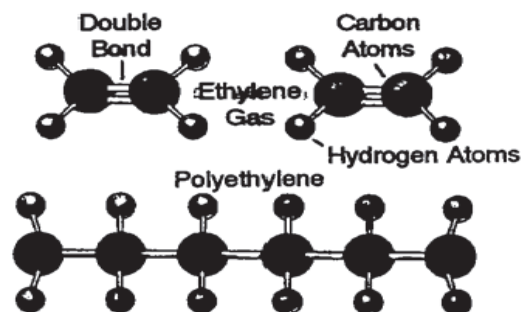


Source: Ref.1

Figure: 2.1.  Manufacture of polyethylene

There are currently three primary low-pressure methods for producing PE: gas phase, solution and slurry (liquid phase). The polymerization of ethylene may take

place with various types of catalysts, under varying conditions of pressure and temperature and in reactor systems of radically different design. Ethylene can also be copolymerized with small amounts of other   type of copolymerization results in small modifications in chemical structure, which are reflected in certain differences in properties, such as density, ductility, hardness, etc. Resins that are produced without comonomer are Called homopolymers.   Regardless of process type, the chemical process is the same. Under reaction conditions, the double bond between the carbon atoms is broken, allowing a bond to form with another carbon atom as shown in Figure 2.1. Thus, a single chain of PE is formed. This process is repeated until the reaction is terminated and the chain length is fixed. PE is made by the linking of thousands of monomeric units of ethylene. PE resins can be described by three basic characteristics that greatly influence the processing and end-use properties: density, molecular weight and molecular weight distribution.

## 2.3. Polyethylene Characteristics:

PE resins can be described by three basic characteristics that greatly influence the processing and end-use properties density, molecular weight and molecular weight distribution. The physical properties and processing characteristics of any PE resin require an understanding of the roles played by these three major parameters.

### 2.3.1 Density:

The earliest production of PE was done using the high-pressure process which resulted in a product that contained considerable "side branching." Side branching is the random bonding of short polymer chains to the main polymer chain. Since branched chains are unable to pack together very tightly, the resulting material had a relatively low density, which led to it being named low-density PE (LDPE). As time passed and PE of different degrees of branching were produced see table 2.1.

Table 2.1 classify the resin according to density

| Type | Density |
|------|---------|
| 1 | 0.910 - 0.925 (low) |
| 2 | 0.926 - 0.940 (medium |
| 3 | 0.941 - 0.959 (high) |
| 4 | 0.960 and above (high, homopolymer) |

Source: Ref.1

Controlled branching results in improved performance in applications where certain types of stresses are involved. Type 4 resins are referred to as homopolymers since only ethylene is used in the polymerization process, which results in least-branched and highest-possible-density material.

### 2.3.2 Crystallinity:

The amount of side branching determines the density of the PE molecule. The more side branches, the lower the density. The packing phenomenon that occurs in PE can also be explained in terms of crystalline versus non-crystalline or amorphous regions as illustrated in Figure 2.2. When molecules pack together in tight formation, the intermolecular spacing is reduced.
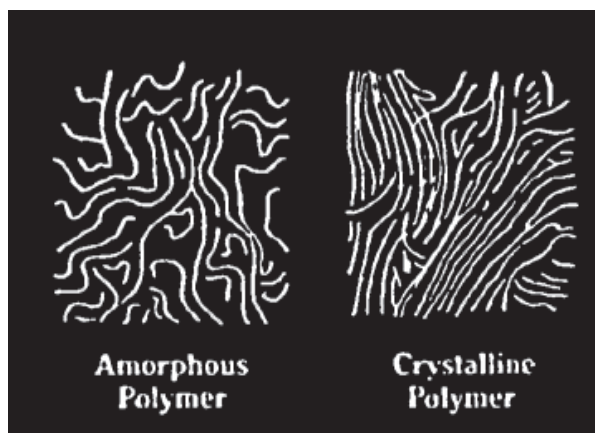


Source: Ref.1

Figure: 2.2. Crystallinity in polyethylene

PE is one of a number of polymers in which portions of the polymer chain in certain regions align themselves in closely packed and very well ordered arrangements of polyhedral-shaped, microscopic crystals called spherulites. Other portions of the polymer chain lie in amorphous regions having no definite molecular arrangement. Since polyethylene contains both crystalline and amorphous regions, it is called a semicrystalline material. Certain grades of high density PE can consist of up to 90% crystalline regions compared to 40% for low density PE. Because of their closer packing, crystalline regions are denser than amorphous regions. Polymer density, therefore, reflects the degree of crystallinity

### 2.3.3. Molecular Weight:

The size of a polymer molecule is represented by its molecular weight, which is the total of the atomic weights of all the atoms that make up the molecule. Molecular weight exerts a great influence on the processability and the final physical and mechanical properties of the polymer.

Molecular weight is controlled during the manufacturing process. The amount of length variation is usually determined by catalyst, conditions of polymerization, and type of process used. During the production of polyethylene, not all molecules grow to the same length.

## 2.4. Stress and Fracture Behavior and the Determination of Working Strength:

Successful design requires that the working strength of a material be defined in relation to the various conditions under which it is intended to be used and in recognition of its structural behavior. The working tensile strength of PE is affected by essentially the same variables that affect its stress/strain relationship, principally magnitude of load, duration of loading, temperature and environment. However, there is one important difference. Whereas strain response is in reaction to the nominal value (the so called bulk or, average value) of applied stress,

fracture can result from either the effect of a nominal stress, or from that of a local intensified stress. Under an excessively large nominal stress PE continues to slowly deform until a sufficiently large deformation is reached at which the material begins to yield. Yielding is then quickly followed by structural failure. This failure mechanism, because it is preceded by yielding or plastic deformation, occurs in what is referred to as the ductile state. In contrast, a locally intensified stress can sometimes lead to the initiation and subsequent propagation of a localized and very slowly growing crack. When the crack grows to a size that spans from the inside to the outside wall of a pressure pipe a leak is the end result. Even though a failure in PE pipe which results from slow crack growth is greatly resistant of its propagation into a larger crack – a very beneficial feature of PE pipe – it is identified as brittle-like because it occurs absent of any localized yielding or plastic deformation. Such absence is symptomatic of the fracture process that occurs in what is known as the brittle state. The working strength of each commercial grade of PE pipe material is determined in consideration of both of these possible failure mechanisms.

In a pressure pipe application the major nominal stress is that which is induced by internal hydrostatic pressure. Accordingly, standards for pressure rated PE pipe require that each material from which a PE pipe is made have an experimentally established long-term hydrostatic strength (LTHS). The standard basis for determining an LTHS value for PE piping materials is from results of pressure testing in water, or air, for the base temperature of (23°C). However, many commercial grades of PE materials also have an LTHS that has been determined at an elevated temperature. The determination of an LTHS involves three steps, as follows:

　　1. Circumferential (hoop) stress versus time-to -rupture data are obtained by means of longer-term sustained hydrostatic pressure tests that are conducted on pipe specimens made from the material under evaluation. This testing is performed in accordance with ASTM D1598, Time to Failure of Plastic Pipe under Constant

Internal Pressure. Sufficient stress-rupture data points are obtained for the adequate defining of the material's stress-rupture behavior from about 10hrs to not less than 10,000hrs.

2. The obtained data are then analyzed in accordance with ASTM D2837, obtaining hydrostatic design basis for thermoplastic pipe materials, to determine if it constitutes an acceptable basis for forecasting a PE's LTHS. To be acceptable, the data must satisfy the following two requirements:

a. A statistical analysis of the stress-rupture data must confirm that a plot of the logarithm of hoop stress versus the logarithm of time-to-fail yields a straight lined.

b. An analysis of separately obtained elevated temperature stress-rupture data that are obtained on the same population of pipe specimens must validate the expectation that the above experimentally established straight line behavior shall continue significantly past the experimental period, through at least 100,000hrs (11.4 years). For the case of materials that are labeled high performance, it must be demonstrated that this straight line behavior shall continue through at least the 50-year intercept. This latter demonstration is labeled substantiation. A description of the validation and substantiation methods appears later in this discussion.

3. When both of the above (2a and 2b) requirements are satisfied this qualifies the mathematical representation of the stress-rupture behavior that is indicated by the experimental data. This mathematical model is then used for forecasting the average stress at which failure will occur at the 100,000hr intercept. The resultant value is labeled the long-term hydrostatic strength (LTHS) of the material under evaluation.

## 2.5 PE 100 Materials (ISO Pipe Material Designation Code):

The ISO pipe material designation code uses similar letters for the type of material as the ASTM code. Examples are PE for polyethylene, PA for polyamide or PVC for poly vinyl chloride. These letters are followed by numbers that are simply the MRS (from ISO 9080 and ISO 12162) times ten. For example, PE 100 is a PE material with an MRS of 10 MPa. Note that there are no physical property or

performance requirements in the ISO pipe material designation code, or information about the design coefficient. The ISO pipe material designation code is simply the material and the MRS. One industry myth is that all PE 100 materials have superior SCG and RCP properties. This is not true. The term PE 100 simply means that the material is PE and the MRS is 10 MPa. Generally, the SCG and RCP performance requirements for PE 100 materials are in the product standards.

### 2.5.1 Polyethylene (PE80 and PE100):

In piping systems the most common type of PE is high density polyethylene. Due to the extensive range of HDPE materials, the first grade of HDPE is generally known as PE80. PE80 is a black color material that is 100% UV resistant. PE80 has fairly good chemical resistance to strong and weak acids, as well as many base chemicals. It has a maximum operating temperature range of 140° F. PE80 also has fairly ductile properties in cold temperature conditions. PE80 is generally used for simple, less aggressive applications. It can be readily applied in double containment pipe systems, and is ideal for wastewater applications. The other material, HDPE, is PE100. This is a special high grade PE that is not commonly available. For certain applications, only PE100 can be used. PE100 is available in both blue and black color depending on the application, but it is not limited to those colors. PE100 is a further development of PE materials by modifying the polymerization process. PE100 has a higher density than PE80. PE100 also has superior mechanical strength and a higher cell classification as compared to PE80. It provides higher pressure ratings and higher safety factors in all applications. It is one of few materials available to the market that meets Cal-OSHA requirements for thermoplastic use in unprotected compressed gas applications. Due to its extremely ductile nature, it will resist shattering in all failure modes and even in cold temperatures. PE100 has a maximum temperature rating of 140° F. It is available in multiple pressure ratings and is commonly available in a high pressure rated version of 230 psi at 70° F. In general, PE100 material offers higher pressure

rated piping systems without the addition of more material or a thicker wall, which can lead to greater pressure drop in larger diameter systems.

### 2.5.2 PE 4710 Materials:

When the superior performing bimodal PE 100 materials were brought to North America, they were pressure rated as a PE 3408 using the ASTM D 2837 pressure rating method. Many of the key performance attributes of PE 100 were not recognized in the PE 3408 pipe material designation code. Also, as seen from the above calculations, a PE 100 SDR 11 pipe could be operated at 145 psig using the ISO pressure rating system for a gas application. That same SDR 11 pipe as a PE 3408 could only be operated at 100 psig using the ASTM pressure rating method for the same gas application. That is a 45% difference for the same PE material, the same pipe SDR, for the same application. In an effort to bring the ASTM and ISO systems closer together, PPI in conjunction with the Hydrostatic Stress Board (HSB) formed an HDB/MRS committee. The purpose of

this committee was to define the high performance parameters through ASTM standards that would justify a higher design factor of 0.63 for water applications or 0.40 for gas applications for these higher performing PE materials. This 25% increase in design factor would reduce the gap between ASTM and ISO from 45% to 15%. Several changes to ASTM standards were required to accomplish this. The materials that qualify for this higher design factor are called "high performance" PE materials and require a PENT value (ASTM F 1473) of 500 hours. The new pipe material designation code for PE 3408 became PE 4710 to indicate that these high performance materials qualified for the higher design factor. This new ASTM pipe material designation code of PE 4710 again provides a physical property (density), a performance property (slow crack growth) and the design stress for water applications (HDB times the water design factor). The PE 4710 density is higher than PE 3408– (0.947 to 0.955 g/cc) compared to (0.940 to 0.946 g/cc).

## 2.6. Processes of plastics pipes industry:

### 2.6.1. Extrusion:

Extrusion techniques can be used to process most thermoplastics and some thermoset plastics. Plastic extrusion of tube, hose and pipe is a steady-state process for converting a thermoplastic raw material to a finished or near-finished annular product. The raw material is usually in the form of plastic pellets or powder. The conversion takes place by forming a homogeneous molten mass in the extruder and forcing it under pressure through an extrusion die orifice that defines the shape of the product's cross section. The formed material, or extrudate, is cooled and drawn away from the die exit at a controlled rate. The extrudate can then be wound on a spool, cut to a specified length, or directed into another in-line process. Solid wall PE pipe is currently produced in sizes ranging from 1/2 inch to 63 inches in diameter.
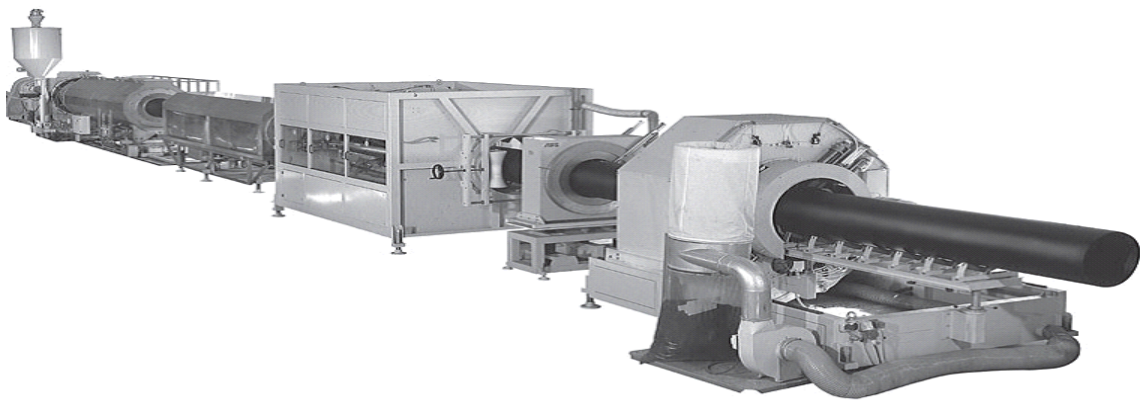


Source: Ref.1

Figure: 2. 3a Typical Conventional Extrusion Line
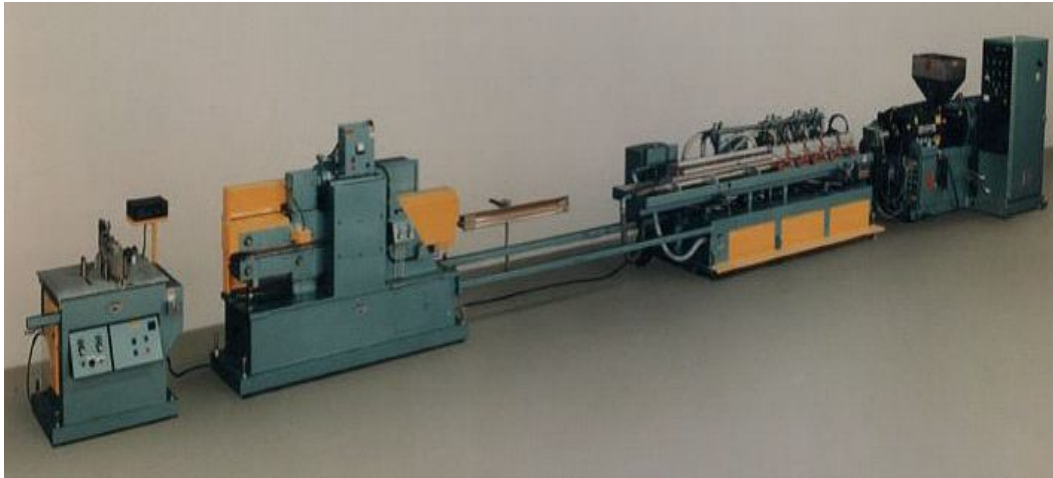
Figure:  2.3b.Typical Conventional Extrusion Line

## 2.7. Design Factor and Hydrostatic Design Stress:

Once the HDB has been determined for a thermoplastic compound, it is necessary to then reduce this strength into an allowable working stress (i.e., the stress induced only by the internal pressure) for a long term design in a way that will assure an indefinite design life with a satisfactory margin of safety, even when stresses other than those induced from internal pressure exist on the piping system (e.g., soil loads, bends, joints, rock impingement, scratches, gouges, )This maximum allowable stress, or the hydrostatic design stress (HDS), is derived by multiplying the HDB by a strength reduction factor called the design factor (DF), which should not be confused with the traditional safety factor.

HDS= HDB * DF……………………………………………………………(2.1)

### 2.7.1 Pressure ratings of thermoplastics:

The mechanical properties of plastic pipes are referenced at 20C. Thermoplastics generally decrease in strength and increase in ductility as the temperature rises and design stresses must be adjusted accordingly. Circumferential stress is the largest stress present in any pressurized piping system. It is this factor that determines the pressure that a section of pipe can with stand.

## 2.7.2 Standard Equation for Determining the Major Stress Induced in a Pressurized Pipe:

There are two major stresses which are induced in the wall of a closed cylindrical vessel, such as a pipe, when it is subjected to internal fluid pressure. One runs along the axis of the vessel, often called the axial (longitudinal) stress, and the other, which is often called the hoop stress, runs along its circumference. Since the magnitude of the hoop stress is about twice that of the axial stress the hoop stress is considered as the significant stress for purposes of pressure pipe design. The hoop stress is not constant across a pipe's wall thickness. It tends to be larger on the inside than on the outside of a pipe. And, this tendency is heightened in the case of materials having high stiffness and in thicker walled pipes. However, in the case of pipes made from thermoplastics – materials which are characterized by significantly lower stiffness than metals – it has long been accepted that the hoop stress is constant through the pipe's wall thickness. For such case the so called thin-walsled hoop stress equation is accepted as satisfactory and it has been adopted by standards which cover thermoplastics pipe. This equation, which more commonly is identified as the ISO (International Organization for Standardization) equation because it has been also adopted for thermoplastic pipes by that organization, is as follows:

$$S = \frac{P \, Dm}{2t} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(2.2)}$$

Because PE pipe is made either to controlled outside diameters or in some cases, to controlled inside diameters the above equation appears in PE pipe standards in one of the following forms:

When the pipe is made to a controlled outside diameter:

$$S = \frac{P}{2} \, \frac{Do}{t} - 1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(2.3)}$$

$$S = \frac{P}{2} \frac{Do}{t} + 1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(2.4)}$$

For purposes of pressure pipe design, the pipe's pressure rating (PR) is determined by the hydrostatic design stress (HDS) that is assigned to the material from which the pipe is made. Therefore, Equation (2) can be re-arranged and written in terms of HDS and as follows:

$$PR = \frac{2(HDS)}{\frac{Do}{t} - 1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(2.5)}$$

Equation (2.4) becomes:

$$PR = \frac{2(HDS)}{\frac{Do}{t} + 1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(2.6)}$$

The term Do/t is referred to as the outside diameter dimension ratio and the term Di/t as the inside diameter dimension ratio.

## 2.8. Standard Diameters:

Standard specifications for PE pipe allow the pipe to be made to either controlled inside diameters or, to controlled outside diameters. The inside diameter system, applicable to small diameter sizes only, is intended for use with insert type fittings for which the pipe must have a predicable inside diameter, independent of pipe wall thickness. And the outside diameter systems are intended for use with fittings that require a predictable outside diameter, also independent of wall thickness.

## 2.9. Review of literature:

Even though the parent pipe itself may have adequate mechanical properties, the presence of joints can affect the overall structural integrity of the system. Therefore, there is a need for reliable standard test procedures to evaluate the mechanical properties of the plastics pipes [2]. At present, there are a number of different mechanical test methods that can be used either short-term or long-term. For quality control purposes, short-term coupon tests are preferred, since these are inexpensive and provide data quickly. However, since the pipe is more likely to fail in the long-term in service, it is important that the results from these tests should correlate with those from long-term tests. To date, little work has been done to correlate results from one test with those from another, or to correlate results from short-term tests with those from long term tests [2].

## 2.9.1 Long-Term Strength

The common method for the forecasting of long-term strength relies on putting specimens under multiple continuous stress levels until failure. These data points are then used in a log-log linear regression evaluation [3]. This regression equation is then extrapolated to a point sufficiently further out in time to where a long-term strength can be forecast [2]. It has been clearly established for many thermoplastics, including PE, that a failure mechanism which occurs at ambient temperature can be maintained and greatly accelerated by elevating the testing temperature. This acceleration has been shown to follow an Arrhenius, or rate process, behavior that is common to many chemical and mechanical processes. However, some thermoplastics, such as PVC, do not lend themselves to these types of accelerated testing methodologies, since they change phase at these elevated test temperatures and such testing would no longer be evaluating the same material properties. By testing at elevated temperatures it can be "validated" that the extrapolation remains linear and ductile beyond the actual test data. This and other

criteria established by ASTM D2837 and the Plastics Pipe Institute's Hydrostatic Stress Board policies in Technical Report-3 (TR-3) allow for establishing an appropriate maximum working stress that will assure a very long design life—well in excess of the stress regression extrapolation time [3].

To quote an example, Assessment of Damage and Long-Term Strength of Polyethylene [4].Tensile strength of polyethylene is examined at various crosshead speeds using cylindrical specimens of 20 mm in gauge length. Through monotonic stretch with intermittent halt for load relaxation, the study shows that long-term tensile strength of polyethylene should be around half of the short-term strength determined in the standard test conditions. The study discovers a transition in the localized deformation(commonly known as necking), of which the appearance changes from opaque white to translucent when the crosshead speed is reduced from 0.05 to0.01 mm/min, possibly due to the suppression of cavitations damage at the low crosshead speed [4]. Ata sufficiently high crosshead speed, damage generation can occur at a threshold strain as low as 4%which is way below the yield strain of the material. It is therefore concluded that determining long-term tensile strength of polyethylene needs to consider accumulation of the damage. Since this type of damage is not quantified in any of current standard methods, the study suggests that results from those tests need to be analyzed carefully to ascertain their validity for characterizing long-term performance of polyethylene products.

Another example long-term hydrostatic strength and design of thermoplastic piping compounds [3]. There has been tremendous growth in the use of thermoplastic piping systems since their introduction more than 50 years ago. They bring a host of benefits in the form of long-term performance and reliability, ease of installation, and not being prone to corrosion and tuberculation [2-3]. It was clear early on that thermoplastics could not be evaluated in the same way metallic components would be in similar applications. However, over time the understanding of these materials has matured, and as this understanding continues

to develop we must not lose sight of the evaluation methodologies used for establishing the long-term hydrostatic strength of these compounds, and how that strength has been successfully used in designing these systems. The paper will gave an overview of the basic methodology used to establish the long-term hydrostatic strength of thermoplastic compounds, and how that strength is used for engineering design in a safe and reliable manner [3].

Furthermore the test may be used for predict the hydrostatic strength of thermoplastics material such as A new engineering approach to predict the hydrostatic strength of uPVC pipes [4]. Extruded Unplasticised Poly (Vinyl Chloride) (uPVC) pipes are certified using pressurized pipe tests. During these tests the pipe are subjected to a certain temperature and internal pressure, while the time-to-failure, the time at which the internal pressure drops due to rupture or fracture, is measured. These tests are time consuming and are therefore costly. To circumvent these costs a model-based approach is proposed where the time-to-failure is predicted. The input parameters for this approach can be determined using short term measurements [3-4]. The approach uses the observation that the time to- failure kinetics of uPVC pipes subjected to an internal pressure is independent of the type of failure mode (ductile, semi-ductile or brittle). This supports their statement that the underlying mechanism that initiates failure is similar for these types of failure. Local deformation of the material up to a critical value of the elastic strain is believed to determine the start of failure of the material. This critical strain appears to be constant for the testing conditions used during this study. A pressure modified Eyring expression is employed to calculate the strain rate resulting from the applied stress at a certain temperature [2-4]. The time-to-failure follows from the calculated strain rate and the critical strain of the material. This approach has been verified against literature data and shown to hold quantitatively. Furthermore, the model seems to hold for different processing conditions [4].

Also the test describes behavior of composite material. Quote an example is behavior of composite pipes under multi-axial stress [5]. This thesis described an experimental investigation of the behavior of filament wound glass fiber reinforced epoxy (GRE) composite pipe under hydrostatic and biaxial load conditions at temperatures up to 95°C. The project was intended to lead to improvements in reliability and quality, and ultimately a reduction in the cost of qualifying GRE oil and gas pipelines. The experiments were designed to be compatible with the procedure currently used by Future Pipe Industries (FPI), employing the concept of ultimate elastic wall stress (UEWS) in the qualification and production control of GRE pipe. The UEWS test appears to provide an attractive means of rating GRE pipes, where weep age resulting from the accumulation of matrix cracks is a common failure mechanism [2]. A novel test rig capable of performing UEWS tests under various loading conditions from hydrostatic to multi-axial loadings was designed and developed. UEWS tests were conducted under six different stress ratios ranging from pure axial to pure hoop loading at room temperature (RT), 65°C and 95°C. The tests involved the application of groups of ten 1-minute hydrostatic pressure cycles at increasing pressure levels. The intention is to identify, by examining the stress-strain response, a stress level below which damage growth is either negligible or at least sufficiently low to prevent long term failure within the design life. In addition, acoustic emission measurements were also conducted to investigate the nature of the damage mechanisms involved as well as its compatibility to the UEWS results.  Three distinct failure modes were observed: tensile axial failure under pure axial loading, weep age under axial dominated loading from 0.5:1 to 2:1 and localized leakage failure under hoop dominated loading of 4:1 and 1:0. Full tensile-tensile UEWS and leakage based failure envelopes were developed at a range of temperatures from 20°C (RT) to 95°C. Both envelopes showed a strong dependence on stress ratio and test temperature. It was also shown that the UEWS based failure envelope at elevated.

Also the work concluded the temperatures generally degraded, except for the 2:1 loading where UEWS strength increased [5]. The Miners law model developed, gives a good account of the effects of cyclic and static loading in UEWS tests. Using a crack growth model similar to Paris Law, damage development can be directly linked to the progressive nucleation of matrix micro cracks. It is also shown that cyclic rather than static loading dominates the UEWS test response. The general lifetime damage model developed in the study shows good agreement with the experimental data from the multi axial UEWS tests. This approach may therefore be an appropriate procedure for describing the long term performance of GRE pipes under any required combination of static, cyclic fatigue, hydrostatic and non-hydrostatic loading [5].

# CHAPTER THREE

# MATARIAL AND METHOD

## 3.1. Introduction:

High density polyethylene produced by the advanced Borstar technology. (BorSasfe HE3490-LS-H ,Qatar ).

Application**:** Drinking water, Natural Gas, Pressure sewerage.

It is especially designed for the production of larger diameter, thick wall pipe, but can be processed for the whole range of diameters.

 Physical Properties of material explain in table 3.1

Table 3.1: Physical Properties of material

| Property | | Typical Value* | Unit | Test Method |
|---|---|---|---|---|
| Density | (Base resin) | 949 | kg/m3 | ISO1183/ISO 1872-2B |
| Density | (Compound) | 959 | kg/m3 | ISO1183/ISO 1872-2B |
| Melt Flow Rate | (190°C/5.0kg) | 0.25 | g/10 min | ISO 1133 |
| Tensile Modulus | (1mm/min) | 1100 | MPa | ISO 527-2 |
| Tensile Stress at Yield | (50 mm/min) | 25 | Mpa | ISO 527-2 |
| Tensile Strain at Break | | >600 | % | ISO 527-2 |
| Carbon Black content | | 2-2.5 | % | ISO 6964 |
| Hardness, Shore D | | 60 | - | ISO 868 |
| Oxidation Induction Time | (210°C) | >20 | min | EN 728 |
| Resistance to rapid crack propagation | | >10 | bar | ISO 13477 |

## 3.2. Method:

**Test Specimens**:

Material high density polyethylene, shape: Pipe Specimen, Length is 50mm; the nominal outside diameter of the Pipe is110mm, pressure applied 6 bars.



Figure: 3.1 sample of test High density polyethylene pipe.

**Hydrostatic Pressure Tester was used it:**

- HPT-series Hydrostatic Pressure Testers:

The HPT-10A series Hydrostatic Pressure Tester is mainly used to determine time-to failures of plastic pipe under constant internal pressure according to ISO 1167, ASTM D 1598. The test stations work fully independently of another according to the client's requirements. A fast processor and corresponding software supports the automatic adjustment of the pressure in the test samples. The test parameters can

be set in via the touch screen, where the operator can also follow the actual test status.

Technical parameters:

-Pressure: 0-16MPa

-Pressure controlling Accuracy: +2% -1%

-Display Accuracy of the Pressure: 0.001MPa

-The Temperature Range of the test tank: room temp. ~95 or 15 to room temperature.

The Temperature Controlling Accuracy of the test tank: ±1

The Working Time of the Timer: 0-10000h

The Interface of Pressure: one to twenty (Upon order)

Enclosure suitable for 16 to 630mm diameter pipes and fittings.

HPT-10B Burst tester The HPT-10B: tester is used to determine of the resistance of either thermoplastic or reinforced thermosetting resin pipe, tubing, or fittings to hydrostatic pressure in a short time period. Procedure A is used to determine burst pressure of a specimen if the mode of failure is to be determined. Increase the pressure uniformly and continuously until the specimen fails, measuring the time with a stop watch. If the failure time is less than 60s, reduce the rate of the loading and repeat the test. The time to failure for all specimens shall be between 60s and 70s. Procedure B is used to determine that a specimen complied with a minimum burst requirement. Increase the pressure uniformly and continuously, measuring the time. To determine that the specimen shall burst between 60 and 70s, or the minimum bust pressure shall be reached or exceeded between 60 and 70s. Standard: ASTM D 1599.

Figure: 3.2 hydrostatic pressure tester

- Test tank for hydrostatic pressure tester:

Our test tank for hydrostatic pressure tester is made of stainless steel together with all the parts with stainless steel. It also has a 100 mm thickness heat-protection layer. There are two cycling pumps inside the test tank which could run alternatively and separately when troubleshooting happens. It has the temperature control system with accuracy of 2. The lid of the test tank could be opened automatically via a pneumatic device. The size and the interface of the test tank can be customized based on customer's requirements.

Figure: 3.3a Test tank for hydrostatic pressure tester

Figure: 3.3b Test tank for hydrostatic pressure tester

## 3. End Closure:

An extensive range of End closures suitable for various diameters according to ASTM, ISO, DIN, EN and other standards.
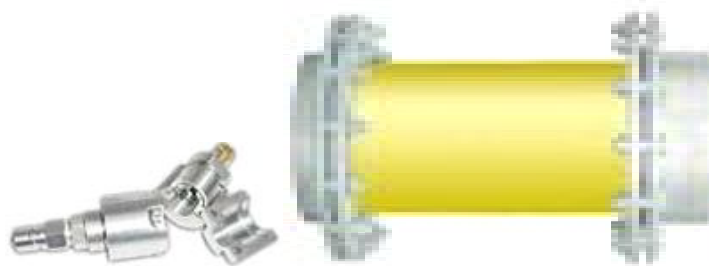


Figure: 3.4 End Closures

## 3.3. Testing procedure:

We take samples of 15 pipes HDPE; we putting the various internal pressures by hydrostatic pressure at different temperature $50C^0$, $60C^o$ and $80C^o$. Record the time that the failure has occurred. These data points are then used in a log-log linear regression evaluation. Even though it is traditional to plot log stress ($\partial$) on the y-axis and log time (t) on the x-axis,

## 3.4. Techniques used to calculate:

After drawing the curve we calculate temperature shift factor using equation 3.2 and then use the value obtained from equation in drawing curve at temperatures of $20^oC$, $30\,^oC$ and $40\,^oC$. Using the free volume theory for polymers $C_1$ and $C_2$ were computed with $T_{ref}$ equal the glass transition temperature (Tg) .

$$\text{Log } a_t = \frac{C1[T1-Tg]}{C2+[T2-Tg]} - \frac{C1[T2-Tg]}{C2+[T2-Tg]} \quad \text{..............................................} \quad (3.2)$$

$$C_1 = 17.4 \quad \text{and} \quad C_2 = 51.6$$

The viscosity of alkanes varies with temperature in Arrhenius manner

$$\mu t = \text{Aexp}[\frac{BVt}{Vt-Vo}] \text{................................................................} \quad (3.3)$$

Taking the equation logarithm above:

$$ln\mu t = \ln A + \frac{BVt}{Vt-Vo} \text{................................................................} \quad (3.4)$$

The free volume theory:

$$\frac{Vt}{Vt-Vo} = \frac{1}{ft} \text{................................................................} \quad (3.5)$$

$$ln\mu = \ln A + \frac{B}{ft} \text{................................................................} \quad (3.6)$$

To eliminate lnA conceder tow temperature T,Tg

By subtraction:

$$ln\frac{\mu t}{\mu g} = \beta \left[\frac{1}{ft} - \frac{1}{fTg}\right] \quad \text{.................................................} (3.7)$$

But:

$$ftg + \Delta\acute{\alpha} + [T - Tg] \quad \text{.........................................................}(3.8)$$

$$ftg - ft = \frac{\beta - \Delta\alpha(T-Tg)}{[ftg+\Delta\alpha(T-Tg)]ftg} = -\frac{\beta}{ftg}\frac{T-Tg}{\frac{ftg}{\Delta\alpha}+(T-Tg)} \quad \text{................................}(3.9)$$

$$C1 = \frac{-\beta}{ftg} \quad \text{.................................................................}(3.10)$$

$$C2 = \frac{ftg}{\Delta\alpha} \quad \text{....................................................................}(3.11)$$

For most polymers:

$$\beta = .453$$

$$ftg = .025$$

$$\Delta\alpha = 4.845 \times 10^{-4}$$

After all that can be calculated from C1 and C2:

$$C1 = \frac{-0.435}{0.025} = -17$$

$$C2 = \frac{0.025}{4.84 \times 10^{-4}} = 51.6$$

Using the above method the long term properties of plastics pipes were predicted.

# CHAPTER FOURE

# RESULT AND DISCUSSION

## 4.1. Introduction:

In this chapter we present our experimental data in two charts, in this research used Excel program to draw the data in the form of curves and extract trendline to draw a curve of a log-log linear regression evaluation.

**Test results between pressure and time to failure:**

Table 4.1:

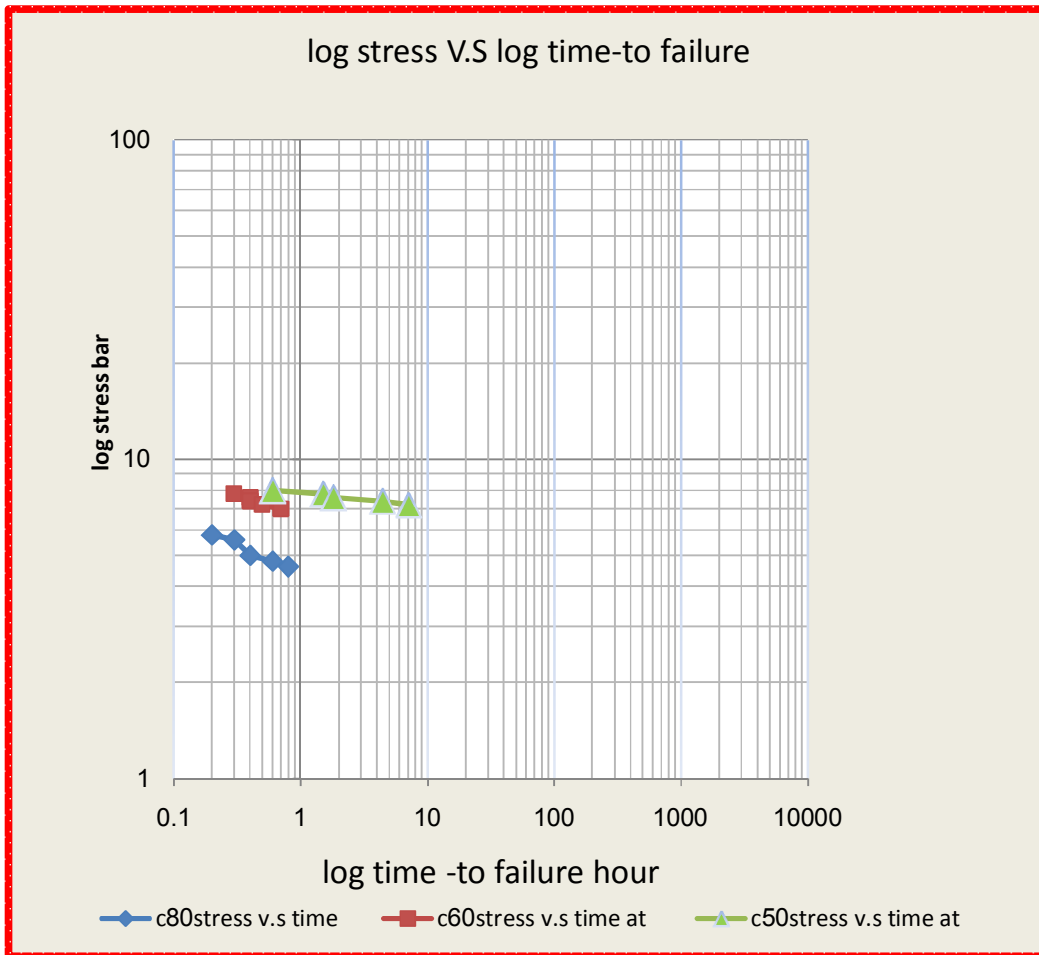| Temperature | Sample number | Pressure (kpa) | Time (min) |
|---|---|---|---|
| 50$^0$C | 1 | 800 | 36 |
| | 2 | 780 | 90 |
| | 3 | 760 | 108 |
| | 4 | 740 | 264 |
| | 5 | 720 | |
| 60$^0$C | 1 | 780 | 18 |
| | 2 | 760 | 24 |
| | 3 | 740 | 25 |
| | 4 | 720 | 30 |
| | 5 | 700 | 42 |
| 80$^0$C | 1 | 580 | 12 |
| | 2 | 560 | 18 |
| | 3 | 500 | 24 |
| | 4 | 480 | 36 |
| | 5 | 460 | 48 |

Chart: 4.1. Stress curve versus time at temperatures (50$^{o}$c ,60$^{o}$c and 80$^{o}$c) of high polyethylene pipe  where all failure points .

Table 4.2: calculation of temperature shift factor

| Temperature ($^{O}$C) | Log $a_T$ |
|---|---|
| 50-60 | 0.1503 |
| 60 -80 | 0.1503 |
| 80-90 | 0.1503 |
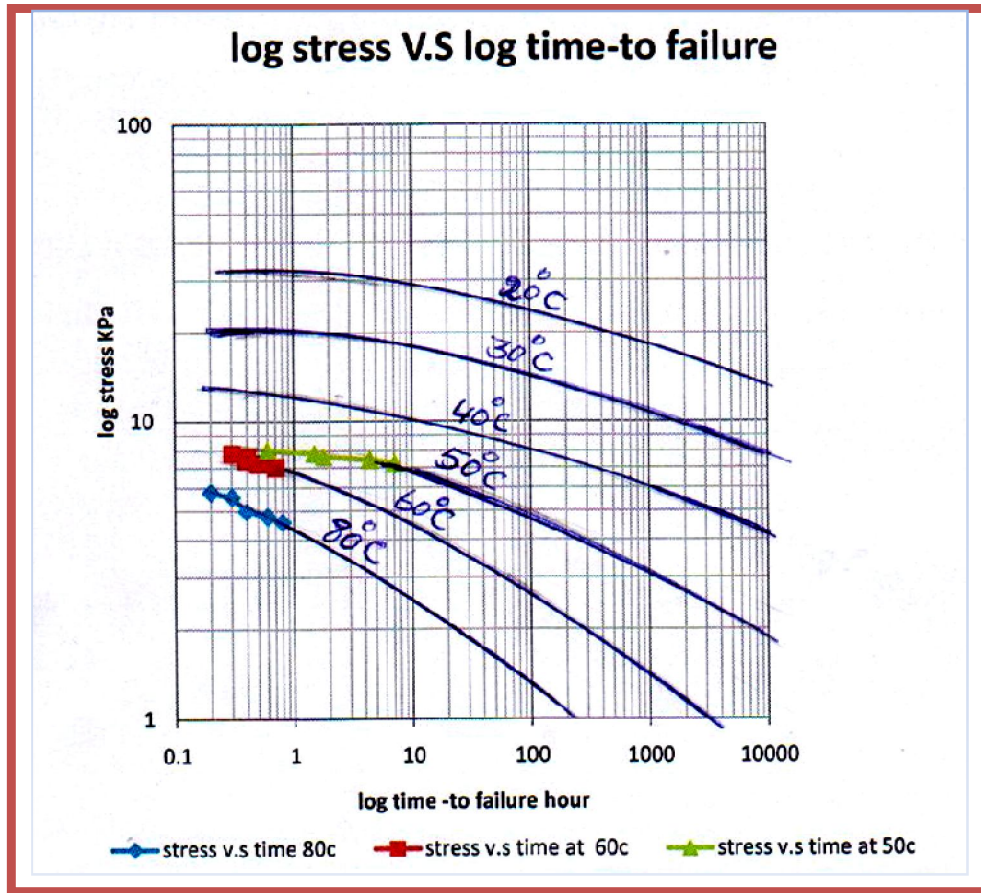
Chart: 4.2. Stress curve versus time to predict at temperatures ($20^{o}$c, $25^{o}$c , $30^{o}$c and $40^{o}$c) of high polyethylene pipes .

## 4.2. DISCUSSION:

The results we have obtained are shown in table 4.1 in appendix (A).drawing logarithm pressure with logarithm time that has occurred failure showing in figure 4.1 increasing temperature of the pipes fail in short time, the relationship between pressures and temperature inverse relationship. We benefited from temperature, using temperature shift factor drawing scheme shown in figure 4.2 in order to predict the value of stress at $20^{o}$C, $25^{o}$C , $30^{o}$C and $40^{o}$C and 1000~ 10000 hours.

Photos Hydrostatic Pressures and Samples after Failure

# CHAPTER FIVE

# CONCLUSIONS

**The Conclusions of this study are summarized as follows:**

- The mechanical properties of plastic pipes are referenced at 20C. Thermoplastics generally decrease in strength and increase in ductility as the temperature rises and design stresses must be adjusted accordingly.

- Circumferential stress is the largest stress present in any pressurized piping system. It is this factor that determines the pressure that a section of pipe can with stand.

- The hydrostatic pressure tester used to measure pressure in normal condition (in room temperature) and at high temperature and matching plastic piping specifications.

- Effect of temperature on plastic pipe; reduce durability when exposed to temperature. For the relationship between stress and time we used different temperatures $50^0$C, $60^0$C and $80^0$C, to draw a curve using the linear regression equation using the excel program and then using temperature shift factor ,drawing curve in order to predict the value of stress at $20^o$C, $25^o$C and $30^o$C and $40^o$C and time1000~ 10000 hours.

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