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STRESS PROPERTIES OF HIGH DENSITY POLYETHYLENE PIPES UNDER CONSTANT PRESSURE IN THE LONG TERM

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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 50oc ,60oc and 80oc 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 20oc, 25oc and 30o c and 40o c. the stress curves are essentially parallel. This led to the thought that a shift factor aT , could be applied to move from one curve to another .it may be seen from chart. 1 that the three curves from 50oc ,60oc and 80oc are separated by a uniform distance log aT Williams ,landel and Ferry developed an empirical relationship for this temperature shift factor explain below:**

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

Where c1 ,c2 are constant Tref is a reference temperature.

Index Terms—**Long Term, Hydrostatic Pressure.**

I. INTRODUCTION

The long-term strength of a thermoplastic compound cannot be determined from a short-term tensile strength test, as with most metals[1]. 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[2]. 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[3] .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 [4]. 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 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[5].

rusKhelnitzky R and Brachman. **(2013) Studie**d The impact of elevated temperatures on high-density polyethylene (HDPE) pipe deflections when deeply buried is examined. Measurements of pipe deflection from full-scale physical tests are reported where 100-mm-diameter, DR 11, HDPE pipes backfilled with sand were subjected to a vertical pressure of 500 kPa for 1000 h while at temperatures of 22, 55 and 80 °C. Short-term vertical deflections were found to increase by a factor of 1.3 when the temperature was increased from 22 to 80 °C as increased temperatures resulted in greater circumferential compression of the pipe.[6]

Juan R, Dominguez (2020) study evaluated the potential use of post-consumer HDPE from different origins in the manufacture of polyethylene pressure pipes. Different HDPE sources are blended in different ratios with raw HDPE with PE100 grade quality. Blends are fully characterized to determine their feasibility to be used for pipe applications. Properties such as tensile strength at yield, elongation at break and flexural modulus for all blends yield values above the minimum required for PE100 grades. Furthermore, two important mechanical properties of polyethylene pipes, Slow Crack Growth (SCG) and Rapid Crack Propagation (RCP)[7].

Juan R, Dominguez in (2019) he did natural weathering test with sunlight exposure time up to 24 months was performed on the PE100 class high-density polyethylene pipes. The mechanical and the chemical properties before and after the test were measured to evaluate the extent and trend of degradation, and particularly the Fourier transform infrared microscope was utilized to quantitatively investigate the oxidation degradation mechanism in the microscopic leve [8].

Shahin A, Barsoum I and Korkees F (2021) investigated in this study. The short term tensile and compressive stress-strain behavior at 23, 40, 60, and 80 °C were obtained through experiments at constant displacement rate and temperature. Tensile and compressive stress relaxation (e.g. long term) behavior at 23, 40, 50, 60, 70, and 80 °C were investigated through stress relaxation tests. The experimental results from the short term tests showed that both the tensile and compression moduli and yield strength of HDPE decrease linearly with the increase in temperature. It is also shown from the long term test that relaxation modulus in tension and compression are highly dependent on temperature.[9]

Wee J-W, Chudnovsky A and Choi B-H (2021) slow crack growth (SCG) resistances of defective and normal high density polyethylene (HDPE) pipes were measured using the stiff-constant K (SCK) specimen, where the stress intensity factor (SIF) was maintained at a constant value within a certain crack length range. A significantly reduced SCG resistance was observed in the defective pipe; a detailed procedure for evaluating SCG kinetics using the SCK specimen has been provided herein. The results of a fracture surface analysis indicate that the white window patterns, resulting from poor carbon black dispersion, are the main reason for poor SCG performance.[10]

II. MATERIAL AND METHOD

A. MATERIAL:
High density polyethylene produced by the advanced Borstar technology. (BorSasfe HE3490-LS-H ,Qatar). Applicatio
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 table1.[11]

Property		Typical Value	Unite	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		60	-	ISO 868
Hardness, Shore D				
Oxidation Induction Time	(210°C)	>20	min	EN 728
Resistance to rapid crack propagation		>10	bar	ISO 13477

B. 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.

Fig: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.

Fig: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.

Fig: 3a Test tank for hydrostatic pressure tester

Fig: 3. 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.

Fig:4 End Closures

III. TESTING PROCEDURE

We take samples of 15 pipes HDPE; we putting the variou internal pressures by hydrostatic pressure at different temperature 50C0, 60Co and 80Co. 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 (∂) on the y-axis and log time (t) on the x-axis,

IV. TECHNIQUES USED TO CALCULATE

After drawing the curve we calculate temperature shift factor using equation(1) and then use the value obtained from equation in drawing curve at temperatures of 20°C, 30 °C and 40 °C. Using the free volume theory for polymers C_1 andC_2 were computed with T_{ref} equal the glass transition temperature (Tg) .

$$\text{Log } a_t = \frac{C1\,[T1-Tg]}{C2+[T2-Tg]} - \frac{C1\,[T2-Tg]}{C2+[T2-Tg]} \text{ .... (1)}$$

C_1=17.4 and C_2=51.6

The viscosity of alkanes varies with temperature in Arrhenius manner

$$\mu t = A\exp\left[\frac{BVt}{Vt-Vo}\right] \text{..................................... (2)}$$

Taking the equation logarithm above:

$$\ln \mu t = \ln A + \frac{BVt}{Vt-Vo} \text{.................................. (3)}$$

The free volume theory:

$$\frac{Vt}{Vt-Vo} = \frac{1}{ft} \text{ .... (4)}$$

$$\ln \mu = \ln A + \frac{B}{ft} \text{.................................. (5)}$$

To eliminate lnA conceder tow temperature T,Tg

By subtraction:

$$\ln \frac{\mu t}{\mu g} = \beta\left[\frac{1}{ft} - \frac{1}{fTg}\right] \text{........................ (6)}$$

But:

$$ftg + \Delta\acute{\alpha} + [T - Tg] \text{.................................(7)}$$

$$ftg - ft = \frac{\beta - \Delta\alpha(T-Tg)}{[ftg+\Delta\alpha(T-Tg)]ftg} = -\frac{\beta}{ftg}\,\frac{T-Tg}{\frac{ftg}{\Delta\alpha}+(T-Tg)} \text{...(8)}$$

$$C1 = \frac{-\beta}{ftg} \text{ ....(9)}$$

$$C2 = \frac{ftg}{\Delta\alpha} \text{....................................(10)}$$

For most polymers:

$\beta = .453$

$ftg = .025$

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

After all that can be calculated from C1and C2:

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

$$C2 = \frac{0.025}{4.84\times10^{-4}} = 51.6$$

Using the above method the long term properties of plastics pipes were predicted.[14]

V. RESULT AND DISSCUTION

C. RESULT:

In this Research 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 trend line to draw a curve of a log-log linear regression evaluation

Table 2: Test results between pressure and time to failure**:**

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

Table 3**:** calculation of temperature shift factor

Temperature (^{O}C)	Log a_T
50-60	.15030
60 -80	.15030
80-90	.15030

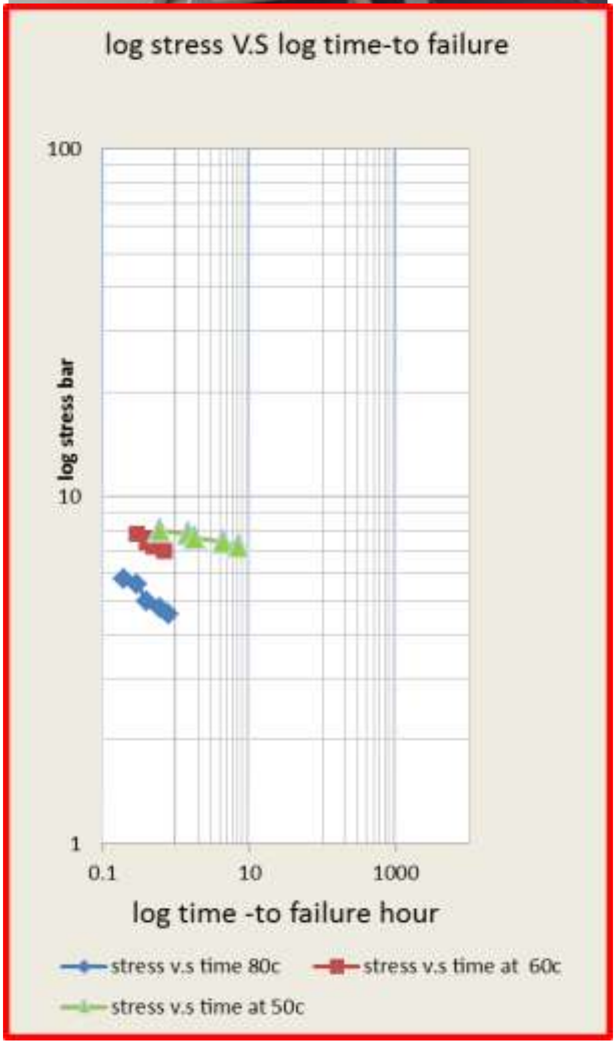

Chart: 1. Stress curve versus time at temperatures (50^{o}c ,60^{o}c and 80^{o}c) of high polyethylene pipe where all failure points .

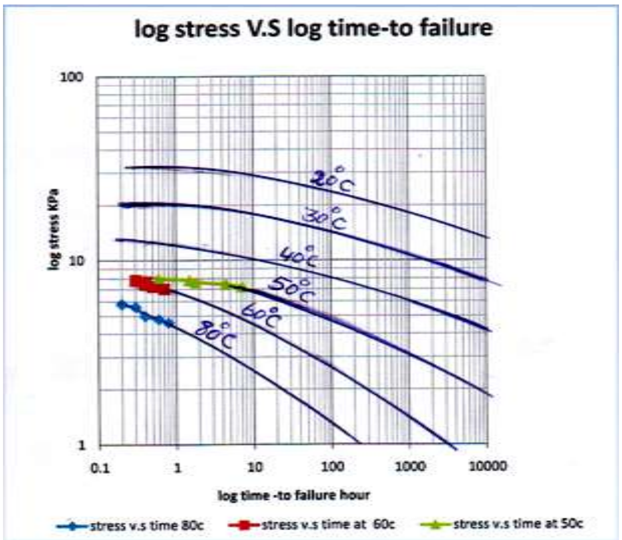

Chart: 2. Stress curve versus time to predict at temperatures (20^{o}c, 25^{o}c , 30^o c and 40^o c) of high polyethylene pipes .

B . 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.

VI. CONCLUSION

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 500C, 600C and 800C, 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 20oC, 25oC and 30o C and 40o C and time1000~ 10000 hours.

APPENDIX

Photos Hydrostatic Pressures and Samples after Failure

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