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Internal Pressure Test on HDPE Pipe Ring

IOANA DANIELA MANU*
Petroleum-Gas University of Ploiesti, Doctoral School, Mechanical Engineering, 39 Bucharest Blvd., 100680, Ploiesti, Romania

Abstract: *The purpose of experiment was the highlight of the creep of ring from polyethylene pipe subjected to internal pressure. To create the internal pressure in the HDPE pipe ring, a weight of 4.5 kg was superimposed on it, in the form of a cylindrical plate. In order to evaluate the strains of the elastic element subjected to the tensile stress, respectively compression, tensometric marks 1 and 2 are placed on the outside, in the case of the circular section. The internal pressure test was performed to evaluate the strains of the material of a PE 100 polyethylene ring in two directions: one axial (longitudinal) and the other transverse (circumferential) in order to highlight the creep of the pipe material due to its structure. In a polyethylene pipe stressed at internal pressure, due to the symmetry the tangential stresses are zero. The axial strain initially showed a positive increase, followed by a decrease, reaching negative values towards the end of the experiment, while the circumferential strain recorded positive values, about 300 times higher than the initial ones. The principal stress changed approximately linearly. The circumferential stress recorded the maximum value of* σ_1*=0.33 MPa (3.3 bar) after two and a half hours of experiment. Based on such this test could be calculate Poisson's ratio* ν.

Keywords*: strain, pressure, stress, polyethylene, creep, circumferential strain, tensile*

1. Introduction

The polyethylene is the polymer which shows a variable behavior in time. This plastic can also be subjected to long-term (static) loads. Thus, during a long period of operation of the load there is a continuous change over time in the dimensions and mechanical characteristics that can persist throughout the service life of the element.

The phenomenon of variation of stress and strains over time, under the effect of applied loads, is called creep or slow flow [1]. The study of the behavior of the polyethylene pipe in terms of creep consists in analyzing the following dependence (1).

$$F(\varepsilon, \sigma, \dot{\varepsilon}, t, T) = 0 \tag{1}$$

where ε – strain, σ – stress, $\dot{\varepsilon}$ – strain rate, t – time, and T – temperature

The short-term creep data obtained on HDPE ring test are useful to prediction long-term creep of polyethylene pipe.

Creep failure occurs at stresses far lower than ultimate tensile strength [2]. For determination of load-bearing capacity of polyethylene pipe is importance knowing of creep damage-time dependence.

The relationship between strain and time for a loaded specimen of plastic is illustrated [3] in Figure 1.

In that diagram three different stages of relative strain can be distinguished. In the first stage the elastic strain ε_I takes place. The second stage follows, the retarded elastic strain (primary creep) ε_{II}. In the tertiary stage of creep there is a viscous strain or secondary creep ε_{III}, this kind of strain will never recover. Based on such behavioral dependence between strain and time, polyethylene is called viscoelastic material. This means that a new stress value produces a new equation of dependence strain-time.

**email: ioana.manu@upg-ploiesti.ro*

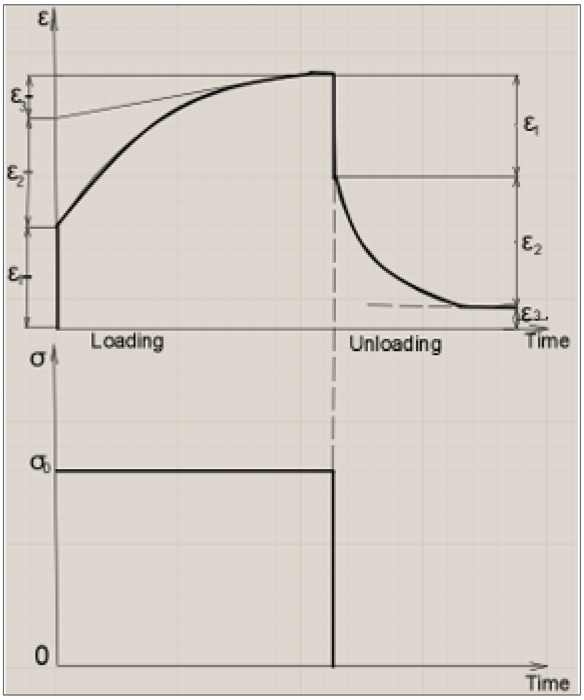

Figure 1. The relation between starin and time in a plastic specimen subjected to constant stress σ_0

In order to highlight the deformation of polyethylene over time under the action of a constant stress, a pipe ring was subjected to a long-term static test called the internal pressure test. The experimental test consists in maintaining the test piece a tension, caused by a weight of 4.5 kg, and a constant temperature of 23°C throughout the test. This approach aimed to establish the relationship stress-time, stresses caused by load, in this case principal stresses σ_1 and σ_2 and linear strains of the specimen, circumferential strain ε_1 and axial strain ε_2.

Based on such this test could be calculate Poisson's ratio ν. Poisson's ratio represents a measure of the Poisson's effect. The Poisson's effect has an important contribution in pressurized pipe flow. For instance, when the water inside a polyethylene pipe is highly pressurized it acts strongly inside the pipe causing the circumferential stress to appear in the wall of the pipe. Due to Poisson's effect, the hoop stress will lead to increase of pipe's diameter and slightly decrease of pipe's length. The influence of Poisson's effect is the deformation of material recorded in perpendicular direction to the specific direction of loading. Poisson’s ratio describes the degree to which a material contracts (expands) transversally when axially strained [4]. Poisson's ratio is a positive dimensionless number calculated as the ratio between transverse (circumferential) strain ε_1 and axial strain ε_2. The value of Poisson's ratio is for most materials it is between 0.0 and 0.5.

The creep test shows an increase in the deformation of the material over time, at constant stresses and temperatures. The creep of PE pipes is, according to [5], the slow, long-lasting variation of the unit tensile stresses and the deformations of the material subjected to a continuous stress. It has been found that HDPE exhibits a strong non-linear behaviour even at a very low stress level [6].

2. Materials and methods

2.1. Materials

A testing sample can help to determine standard basic mechanical proprieties such as: tensile strength, yield strength, elastic modulus and Poisson’s ratio [10].

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The pipe ring subjected to the internal pressure test was taken at random from a HDPE water pipe section, *PE 100 (Ø 90×6.7) SDR 13.6; PN 10 bar*. Physical-mechanical characteristics for the pipe are shown in Table 1, provided by the pipe supplier.

Table 1. Physical-mechanical characteristics for the pipe
PE 100 (Ø 90×6.7) SDR 13.6; PN 10 bar

Physical Characteristics	**Method**	**UM**	**Values**
Density, kg/m^3, at 23 ^{0}C	ISO 1183	g/cm^3	958÷960
Mechanical Characteristics	**Method**	**UM**	**Values**
Yield strength	Tensile test	MPa	26.2
Tensile strength, at 23ºC at 100 mm/min	ISO 527	MPa	30÷36
Tensile elongation, at 23ºC at 100 mm/min	ISO 527	%	>600%
Young(’s) modulus, at 23ºC	ISO 527	MPa	900÷1100

After cutting, the ends of the ring were smoothed to ensure a good positioning in relation to the support plane, respectively to support the load.

2.2. Method

Creep test has long been used to evaluate suitability of plastic materials for load-carrying products such as pressurized pipes [7]. According to ISO 9080 [8] and ASTM D2837 [9] can to determine long-term hydrostatic strength (LTHS) for plastic pipe. Also from these standard tests can to determine the maximum allowable stress for a specified service life.

The internal pressure test was performed to evaluate the strains of the material of a PE 100 poly-ethylene ring in two directions: one axial (longitudinal) and the other transverse (circumferential) in order to highlight the creep of the pipe material due to its structure.

The assembly for experimental determinations at the internal pressure of the polyethylene ring also contains a digitized ESAM *TRAVELER Mini* signal amplification system used for the stationary measurement of mechanical quantities. The associated software offers the possibility to record and store the measured data. The experimental set is shown in Figure 2. Two tensometric marks or resistive transducers were used. These resistive transducers turn the variation of a mechanical quantity into variation of an electric quantity [11].

The circular ring from PE pipe, which is shown in Figure 3, is subjected to a stress determined by the internal pressure P_i.

Figure 2. The assembly for experimental determinations

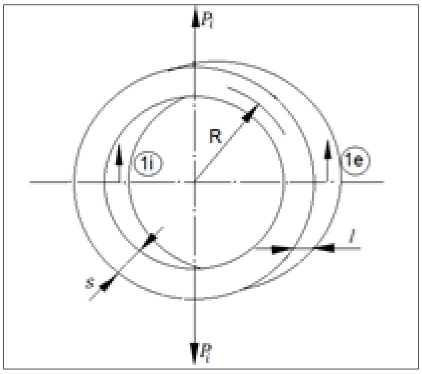


Figure 3. Circular ring

In ISO 8495:2013 Metallic materials - Tube - Ring-expanding test [12] is specified that this method may used to assed the ability of tubes to undergo plastic deformation. The tubes which is subjected to the ring-expanding test may have the next geometrical characteristics: outside diameter between 18–150 mm and wall thickness between 2-16 mm. This method of testing shall be carried out using a device specially designed for pipes experiment, with the following components:

- a conical mandrel with a top angle of 10^0 and a length of 100 mm, having the role of inducing internal pressure in the pipe ring, *1*;
- tanks *2*, with simultaneous opening and automatic centering, in number of 3;
- a three-piece ring arranged at 120^o with an outer diameter of 76.6 mm, *3*.

The components of device described above are represented, according to [13], in Figure 4. The schematic of the internal pressure test of a PE 100 pipe ring is shown in Figure 5.

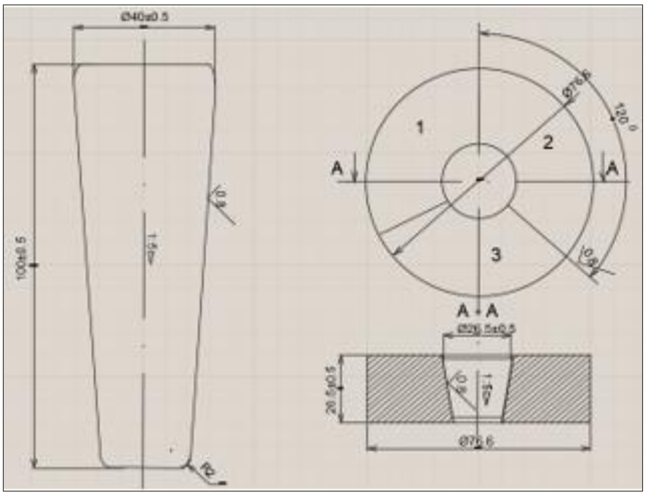


Figure 4. Device used in internal pressure test on PEHD ring

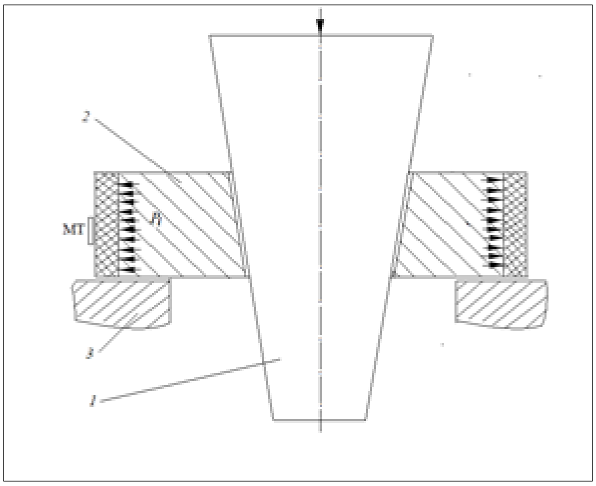


Figure 5. Schematic of the internal pressure test of a PE100 pipe ring

To create the internal pressure in the PE pipe ring, a weight of 4.5 kg was superimposed on it, in the form of a cylindrical plate. In order to evaluate the strains of the elastic element subjected to the tensile stress, respectively compression, according to [15], tensometric marks 1 and 2 were placed on the outside, in the case of the circular section, arrangement shown schematically in Figure 6. The appearance of the tensometric marks is shown in Figure 7.

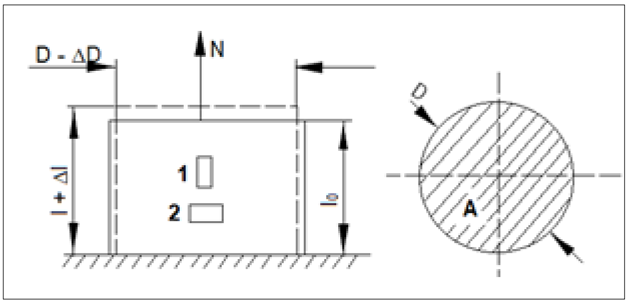


Figure 6. Location of TER on the elastic element

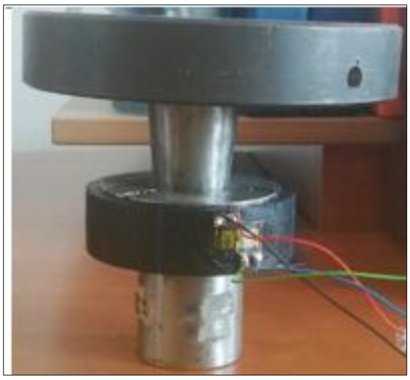


Figure 7. The appearance of the tensometric marks on the body under test

The cross-sectional area of the sample specimens continues to decrease with time under a fixed external load [14]. Also, the internal stress is not held constant through the thickness of the specimen even although the applied load is constant [14].

The analytical calculation of the internal pressure determined by the constant load produced by the cylindrical piece of 4.5 kg was performed based on the diagram in the Figure 8 and the relationship (2).

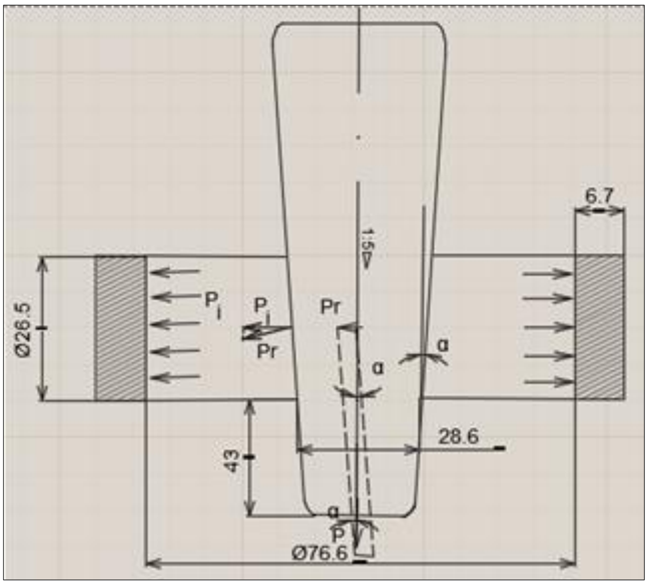


Figure 8. The diagram for the analytical calculation of the internal pressure

$$P_i = \frac{P \cdot \sin\alpha}{\pi D_i \cdot l} \tag{2}$$

where:

$P = 4.5 \cdot 9.81 = 44.145\text{N}$

$P_r = P \cdot tg\alpha$

P_r - radial force, [N]

α - the angle obtained from the truncated cone shape, [^{0}]

D_i - inner diameter, [mm].

From manufacturing, the value of the angle obtained from the truncated cone shape is $2\alpha=11.42^0$ for tgα=1/10. Under the internal pressure produced by the superimposed weight, tgα changed its value according to the ratio Δ*D*/2·Δ*l*.

3. Results and discussions

Through the computer program, the data was recorded and stored. The frequency of reading the records is x step: 0.20 s. 14 reading intervals were performed in approximately 2.5 h of testing, totaling 725 data sets. Examples of data recording sequences are shown in Figure 9*a* and 9*b*.

a b

Figure 9. Display of measurement data

The data obtained in the experiment were tabulated. Thus, examples of records showing the time dependence of linear strains are listed in Table 2.

Table 2. Dependence between linear strains and time

Time, *t* [s]	**Axial strain, ε_2 [μm/m]**	**Circumferential strain, ε_1 [μm/m]**
33	7.13	8.2
33.2	7.29	8.51
33.4	7.21	8.35
33.6	7.29	8.51
33.8	7.21	8.51
…	…	…
9089	-153.7	309.03
9089.2	-153,62	309.26
9089.4	-153.7	308.96
9089.6	-153.85	308.88
9089.8	-153.85	308.96

Measuring the increasing Δε for a range of time Δt is used to calculate strain rate, according relationship (3).

$$\dot{\varepsilon} = \frac{\Delta\varepsilon}{\Delta t} \tag{3}$$

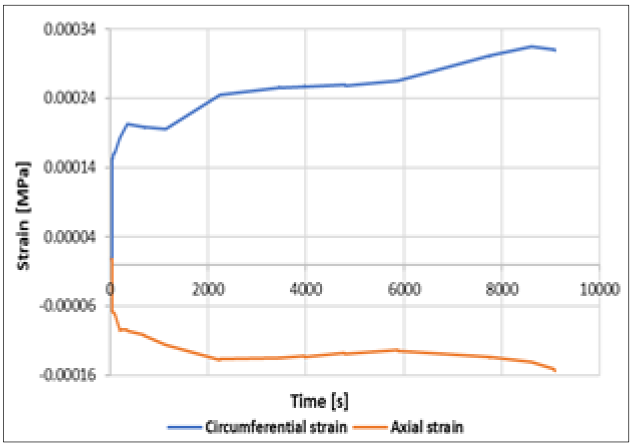
According to measurements, for $\Delta\varepsilon = 0.3001 \cdot 10^{-3}$ and $\Delta t = 9056.8$s, strain rate was $3.32 \cdot 10^{-8}$ m/s.

Axial strains have been recorded with positive values in descreasing, between 7.13 μm/m and 2.48 μm/m, after that the values changed in ones negative, from -27.5 μm/m until -153.85 μm/m.

Circumferential strains were recorded only with positive values in growing, between 8.2 μm/m and 308.96 μm/m.

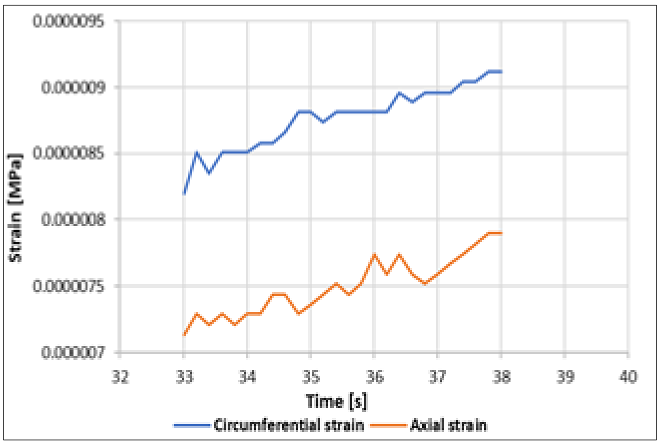
The diagrams shown in Figure 10*a* was made with data recorded and gave in Table 2. Until the second 38, the polyethylene had a linear behavior and the elastics strains were developed, as in Figure 10*b*.

The short-time creep strain of polyethylene was 4.69%.



a

Figure 10a. Strains-time variations



b

Figure 10b. Elastic strains zone

Poisson's ratio is defined for isotropic linear elastic solids in simple tension by the equation (4) [16].

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}} \tag{4}$$

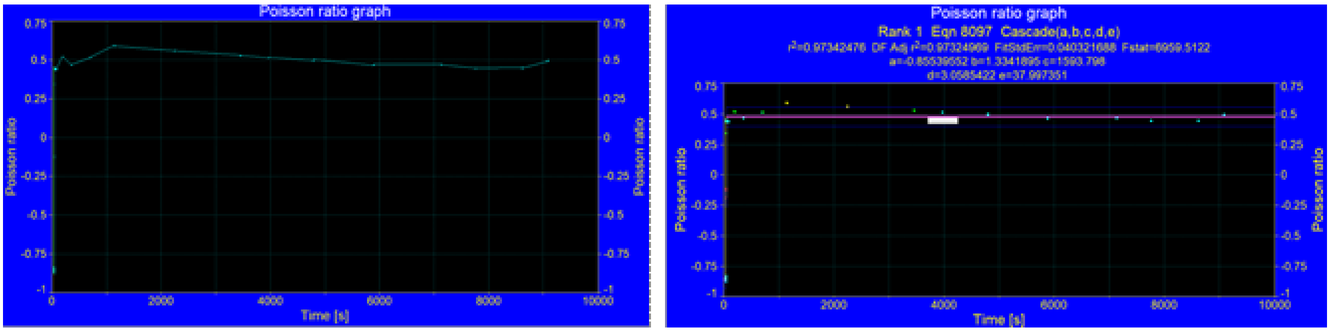
Because the polyethylene ring is subjected to compression, the Poisson's ratio ν was calculated as the ratio between the unitary thickening in the perpendicular direction of the stress divided by the unitary compression in the direction of the stress, namely transverse (circumferential) ε_1 strains and longitudinal (axial) ε_2, using data from the associated software system [17] and relationship (5).

$$\nu = -\frac{\varepsilon_1}{\varepsilon_2} \quad (5)$$

According to [18], if a rod with diameter *d* and length *L* is subject to tension so that its length will change by Δ*L* then its diameter *d* will change by relationship (6).

$$\frac{\Delta d}{d} = -\nu \frac{\Delta L}{L} \quad (6)$$

In Figure 11*a* and 11*b* are presented the Poisson's ratio graphs plotted with the TableCurve program.



a b

Figure 11. Poisson's ratio graphs

According to [1], the calculation relations, applicable in the case of axially symmetrical vessels subjected to internal pressure, of the principal stresses σ_1 (circumferential) and σ_2 (axial) are (7) and (8).

$$\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_2) \quad (7)$$

$$\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu\varepsilon_1) \quad (8)$$

Taking into account the data in Table 2, the calculation relationships (4-8) and the values of the Young's modulus of PE, values such as those in Table 3 were determined.

Table 3. Circumferential and axial stresses values

Young's modulus, *E* [MPa]	Poisson's ratio ν	Circumference stress, σ_1 [MPa]	Axial stress, σ_2 [MPa]
1100	0.5	0.015736	0.014924
		0.016263	0.015337
		0.015992	0.015128
		0.016263	0.015337
		0.016213	0.015227
		…	…
		0.330848	-0.02019
		0.331215	-0.01994
		0.330752	-0.02023
		0.330548	-0.02049
		0.330659	-0.02044

Using the processed data, such as those in Table 3, the diagram shown in Figure 12 was drawn.

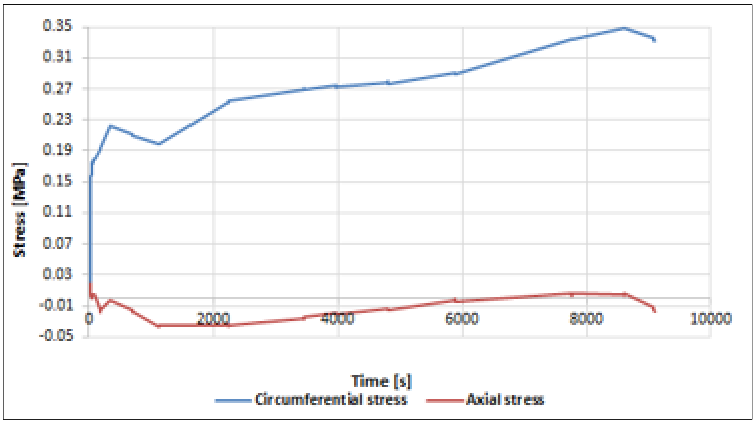


Figure 12. Stresses-time variations

The analytical values of internal pressure determines with relationship (1) are listed in Table 4.

For check the internal pressure *Pi* to which the ring has been subjected, from circumferential strain and axial strain registered on the outside the ring, according [1], was used the relationships from calculation of equivalent stress or von Mises stress (9).

$$P_i = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2} \cdot \cos\alpha \quad (9)$$

Table 4. Internal pressure values P_i

TAN α	SIN α	Internal pressure, $P_{i\ analytic}$ [MPa]	$\Delta D=\varepsilon_1 \cdot D/100$ [mm]	$\Delta l=\varepsilon_2 \cdot l/100$ [mm]	TAN α	COS α	Internal pressure, $P_{i\ experimental}$ [MPa]
0.1	0.02439	0.0001688	7.38	1.88945	1.95294	0.008937	0.0001371
			7.659	1.93185	1.98229	0.008804	0.0004312
			7.515	1.91065	1.96660	0.008874	0.0004246
			7.659	1.93185	1.98229	0.008804	0.0004312
			7.659	1.91065	2.00429	0.008708	0.0004291
			...				
			278.127	-40.7305	-3.41423	0.005112	-0.0093277
			278.334	-40.7093	-3.41855	0.005105	-0.0093340
			278.064	-40.7305	-3.41346	0.005113	-0.0093257
			277.992	-40.77025	-3.40925	0.005119	-0.0093240
			278.064	-40.77025	-3.41013	0.005118	-0.0093263

With the help of the data recorded and specified in Table 4, the diagram shown in Figures 13 was made. These highlighted values of strains similar to those presented in the literature. Because the ring loading was not strong enough, only the initial deformations area and primary (unregulated) creep shown by the material can be seen in diagrams.

According to [19], the pipe contains the rotating cover determined by a meridian curve, and cross sections on the longitudinal axis are circles. The pipe cover to behaves like a membrane, subjected to tensile only. For this reason, the study of pipes to performes in the membrane theory or the theory without moments. The required condition is that the internal pressure, in a normal plane on the axis, to be constant.

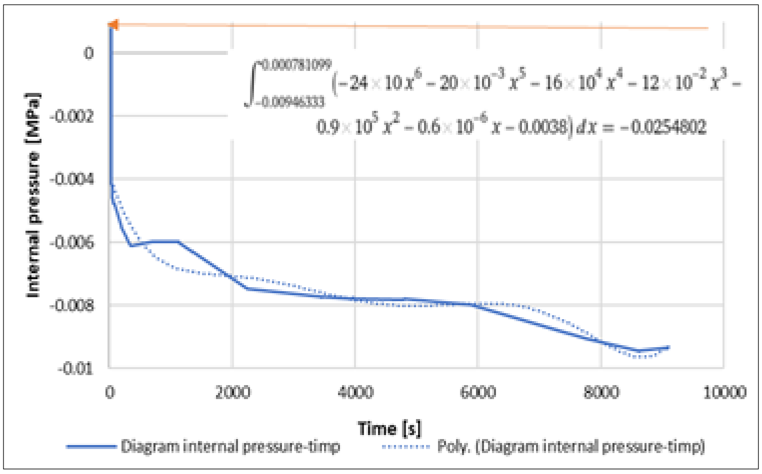


Figure 13. Internal pressure-time variation

From the pipe, considered rotating vessel, axially symetrically loaded, a ring of definited height was taken. The ring was subjected to an intrenal pressure created by the jaws driven by the cylindrical rod which had a constant weight superimposed.

The presence of the ring was noticed due to the use of tensometric marks, which recommends as a way to evaluate the dimensional changes of polyethylene pipes these resistive electrotensometric transducers. The values of the recorded deformations, presented by the pipe ring, showed changes over time. Thus, the axial deformation initially showed a positive increase, followed by a decrease, reaching negative values towards the end of the experiment, while the circumferential strain recorded positive values, about 300 times higher than the initial ones.

The principal stress changed approximately linearly. The circumferential stress recorded the maximum value of σ_1=0,33 MPa (3,3 bar) after 2 and a half hours of experiment.

The internal pressure has initially positive values, until to $P_{i,max}$ = 0.000781099 MPa, according to axial deformation ε_2=2.56 μm/m and circumferential strain ε_1=22.7 μm/m. After that internal pressure was decreased and its graphical representation in time was shown in Figure 13.

In order to accurately determine the stresses recorded by the polyethylene ring, it is necessary for the experiment to continue for a longer period of time, an ongoing process. After the successive measurement carried out in time and reproduced in Table 5, the ring's high and its outer and inner diameter were modified.

Table 5. The changes in the geometric characteristics of the ring PEHD produced over time

Ring width, *l* [mm]	**Ring outer diameter, D_1 [mm]**	**Ring inner diameter, D_2 [mm]**	**Time**
26.49	90.27	89.99	150 minutes
26.56	90.35	89.99	30 days
	90.43	90.33	60 days
	90.44	90.36	75 days
	90.45	90.37	120 days
	90.55	90.50	195 days

4. Conclusions

The internal pressure test aimed at evaluating the strains of the material of a PE 100 polyethylene ring in two directions: one axial and the other transverse (circumferential) to highlight the creep of the polyethylene pipes. The tested body was subjected to the experiment using a device specially designed for this experiment, consisting of a conical rod, three jaws and a support element. The creep test shows an increase in the deformation of the material over time, at constant stresses and temperatures. The strains of the elastic element subjected to the tensile stress, respectively compression were assessed with tensometric marks 1 and 2, which were placed on the outside, in the case of the circular section. From the values of the circumferential strain, using the corresponding calculation relation, the values of the internal pressure were determined.

The highlighted values of strains were similar to those presented in the literature. Because the ring loading was not strong enough, only the initial deformations area and primary (unstabilized) creep shown by the material were represented in diagrams.

The maximum circumferential stress recorded was σ_1=0,33 MPa (3,3 bar).

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