International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Observing the Behavior of the Polyethylene Pipes Subjected to Radial Stress

Eugen Avrigean

Lucian Blaga University, Faculty of Engineering, No. 4, Emil Cioran Street, Sibiu 550025, Romania
Corresponing Author Email: *eugen.avrigean[at]ulbsibiu.ro*

Abstract: ***The present paper aims to observe the way in which the polyethylene pipe is deformed when acted upon by a radial stress caused by a mechanical squeeze off tool, in order to avoid that the thickness reduction in the contact area should cause a fracture in the future.***

Keywords: polyethylene, stresses and strains

1. Introduction

1.1 Types of materials and procedures used in polyethylene pipe manufacturing

The cellulose, the resins, the oil and the natural gas are the raw materials used in the production of plastics. The oil and the natural gas are the most important raw materials. In refineries, the crude oil is separated by distillation into several components. Depending on the range of the boiling temperatures, various distillation phases are obtained, such as gas, gasoline, cherosene, fuel, leaving bitumen as a residue. All these components contain hydrocarbons which are different only in the size and configuration of their molecules. The most important fraction in plastic manufacturing is the straight-run gasoline.

This gasoline is further cut and transformed through a thermal cracking process (steam cracking) into ethylene, propylene, butylene and other hydrocarbons.

Therefore, plastics are materials obtained through the chemical transformation of the natural products, or through synthesizing the organic compounds whose main components are carbon (C) and hydrogen **(H)**.

The *hydrocarbons* are the core of most plastic materials. They create the individual combinations of plastics, called *monomers*, namely monomer molecules of the same type.

The basic chemical processes used in plastic production are the following:

Polymerization is the most widely used process for the synthesis of plastics, connecting the monomers into macromolecular chains, without dissociating the extraneous matter.

This process is used to obtain polyethylene, whose raw material (the monomer) is an unsaturated hydrocarbon, either the ethene or the ethylene, which is industrially obtained from petroleum gases of up to 98% purity.

Polycondensation consists of the set of reactions by which monomers of the same or different type connect and combine with each other in macromolecular chains, simultaneously releasing a secondary substance such as water, hydrochloric acid, or other. Polycondensation is used, for example, to produce phenol formaldehyde resins and polyamides. Certain additions and substitutions in which a product of the *carbonyl* group (a carbon component) binds to substances containing the CH, CH_2 or CH_3 group, creating a new C-C bond are defined as polycondensation reactions of aldehydes and ketones.

A better known example of a polycondensation reaction is the way the bakelites (discovered by A. Baeyer in 1872) are obtained by the condensation of phenol with formaldehyde.

1.2 The analytical calculation of the radial stresses acting upon polyethylene pipes

If a tubular pipe is stressed by an internal pressure p_i and an external pressure p_e (Figure 1), a three-dimensional stress occurs. Thus, three different types of stress act in the pipe's wall [1]:

- A radial stress:

$$\sigma_i = \frac{1}{r_e^2 - r_i^2}\left[p_i r_i^2 - p_e r_e^2 + (p_e - p_i)\frac{r_e^2 r_i^2}{r^2}\right] \quad (1)$$

- A tangential stress:

$$\sigma_i = \frac{1}{r_e^2 - r_i^2}\left[p_i r_i^2 - p_e r_e^2 - (p_e - p_i)\frac{r_e^2 r_i^2}{r^2}\right] \quad (2)$$

- An axial stress:

$$\sigma_{ax} = \frac{p_i r_i^2 - p_e r_e^2}{r_e^2 - r_i^2} \quad (3)$$

In relations 1 and 2, $r_e = D/2$ is the outer radius of the pipe, and $r_i = d/2$ is its inner radius. One may notice that if r = r_i, the radial stress will be:

$$\sigma_r = -p_i \quad (4)$$

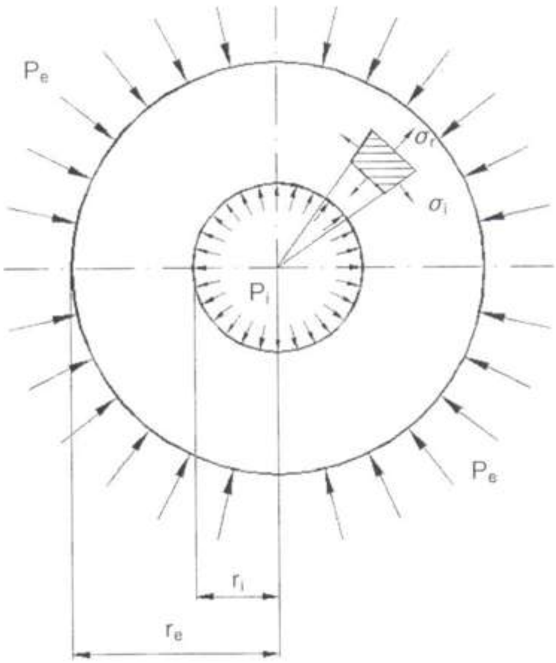

Figure 1: Distribution of stresses on the polyethylene pipe depending on the load of the external and internal pressures

When r = r_e, the radial stress will have the following value:

$$\sigma_r = -p_e \quad (5)$$

The tangential stress (hoop stress) will have the following formula, if r = r_i:

$$\sigma_i = \frac{r_e^2+r_i^2}{r_e^2-r_i^2}p_i - \frac{2r_e^2}{r_e^2-r_i^2}p_e \quad (6)$$

and if r = r_e, the following relation is obtained:

$$\sigma_i = \frac{2r_i^2}{r_e^2-r_i^2}p_i - \frac{r_e^2+r_i^2}{r_e^2-r_i^2}p_e \quad (7)$$

These mathematical expressions can also be written in the following form:

$$\sigma_i = \frac{D^2+d^2}{D^2-d^2}p_i - \frac{2D^2}{D^2-d^2}p_e \quad (8)$$

and the external stress σ_e, is:

$$\sigma_i = \frac{2d^2}{D^2-d^2}p_i - \frac{D^2-d^2}{D^2+d^2}p_e \quad (9)$$

where D and d are the outer diameter and the inner diameter of the pipe.

The internal pressure is caused by the fluid flowing through the polyethylene pipe. If $p_{e=0}$, which means that the external pressure is neglected in the calculation, the formula for the radial stress (relation 2.1) is the following:

$$\sigma_r = \frac{r_i^2}{r_e^2-r_i^2}\left(1-\frac{r_e^2}{r^2}\right)p \quad (10)$$

where p =p_i.

If $r = r_i$, σ_r it has the same value given by relation (2.4), and if r = r_e, then $\sigma_r = o$.

In a similar manner, the formula of the tangential stress is:

$$\sigma_i = \frac{r_i^2}{r_e^2-r_i^2}\left(1+\frac{r_e^2}{r^2}\right) \quad (11)$$

In case $r = r_i$, this stress reaches the maximum value, with the following expression:

$$\sigma_i = \frac{r_e^2+r_i^2}{r_e^2-r_i^2}p \quad (12)$$

or

$$\sigma_i = \frac{D^2+d^2}{D^2-d^2}p \quad (13)$$

as it directly results from relation (8).

If in relation (13) we substitute D with $D = d + e_n$, (where e_n is the thickness of the pipe's wall) and omit the term which contains e_n^2, the following expression results:

$$\sigma_i = \frac{p*D}{2e_n} \quad (14)$$

if a term containing e_n^2 is omitted.

The previous formula usually serves at calculating size, because the tangential stress is the most important.

By applying the same calculation algorithm, the axial stress becomes:

$$\sigma_{ax} = \frac{r_i^2}{r_e^2-r_i^2}p \quad (15)$$

or it is:

$$\sigma_{ax} = \frac{d^2}{D^2-d^2}p \quad (16)$$

Using the same approximation of e_n^2, the axial stress is deduced by the following relation:

$$\sigma_{ax} = \frac{pd}{4e_n} \quad (17)$$

1.3 Observing the behavior of the polyethylene pipes with the high-speed cameras

There are situations in every day practice when the couplings to the natural gas distribution pipes must be done under pressure (at the free end of the pipe or through multiple squeeze-off tools) being required to use different size tools (Figure 2).

Figure 2: Squeeze-off tool used for shutting off polyethylene pipes with a diameter of 63 to 160 mm

The adjustment of this squeeze-off tool is done by means of a limit stop, a rotating knob which selects the diameter and the thickness of the pipe.

The problem which occurs in such cases is related to the radial compression of the polyethylene pipes and the behavior of the material, therefore we shall closely monitor the squeezed-off area of the pipe.

In order to determine the crushing strength (compressive resistance) of the natural gas transmission polyethylene pipes, experimental tests were conducted on a tensile, compression and buckling testing machine, Instron 5587. The samples were cut into 250 mm sections from pipes of different diameters. These tests were performed in order to determine the deformation of such a sample, the elastic recovery as well as the strains and stresses occurring in such structures. The software of the Instron machine and a Aramis 2M type optical equipment were used for these experimental measurements.

The experimental study was conducted on pipes sized Φ63 x 5.8 and made of (PE100). The pipe's flexural rigidity can be calculated with the following relation, according to ASTM D 2412:

$$SN = \frac{E \cdot I}{D^3}, \qquad (18)$$

where: SN is the flexural rigidity, E is the elastic modulus of the pipe's material (E=1.2 GPa for a PE100 pipe); I is the moment of inertia of the cross section, calculated with relation $I = t^3/12$, where t is the pipe's thickness; and D is the pipe's median diameter.

The values listed in table 1 were obtained for the flexural rigidity of the pipes studied in this paper, by using relation (18).

Table 1: Values of the flexural rigidity of polyethylene pipes

Material	Type of pipe Φ x t [mm x mm]	SDR Φ / t	SN [N/mm^2]
PE 100	63 x 5.8	11 (10.86)	0.104

Parts approximately 250 mm long were used as samples in the study, and were subjected to a radial compression stress (Figure 3).

In order to optically acquire data by means of the Aramis 2M system, before being subjected to compression, the pipe sections were covered in a fast drying adherent matte white paint. After this, the areas exposed to the image acquisition system were sprinkled with a graphite spray. The polyethylene pipes were subjected to compression with a maximum force of 7,500 N, the upload speed being 10 mm/min, at the same time acquiring data on the pipe's deformation with the Aramis 2M system, and data on the pipe's behavior when subjected to compression with the Instron 5587 machine's software.

Figure 3: Fastening the pipe in the universal testing machine

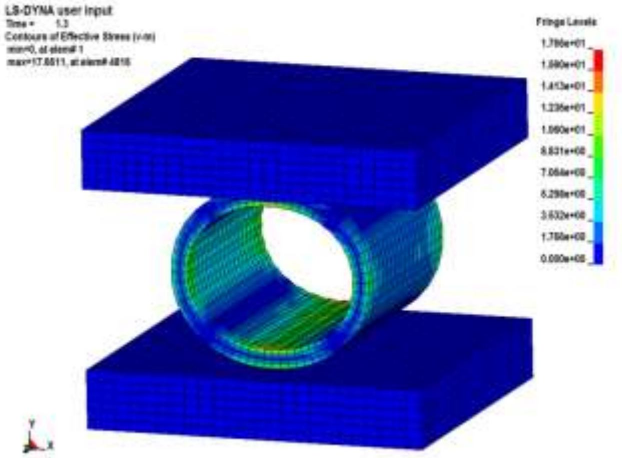

Figure 4: Simulation of the radial stress using the finite element method

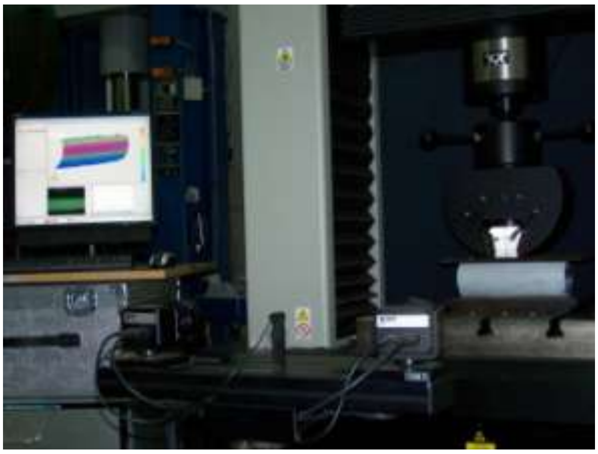

Figure 5: Equipment used for testing polyethylene pipes

Figure 5 shows the whole assembly used for the experimental testing: the Instron 5587 universal testing machine (1), the polyethylene pipe (2), the high speed cameras (3), and the data acquisition computer (4).

The following figures contain the stress – strain characteristic curves for the 63 mm diameter and PE 100 material. The next figure shows the variation of the maximum strain (corresponding to the maximum stress of 7,500 N) depending on the pipe's diameter and material (PE80 and PE100)

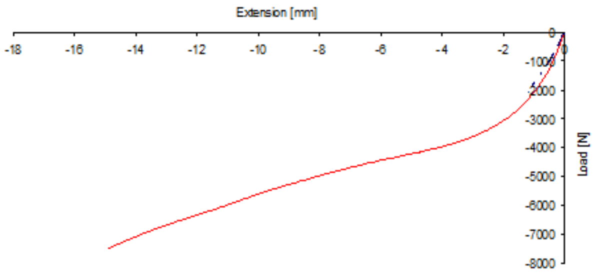

Figure 6: Experimental stress-strain characteristic curves for Φ 63 x 5.8 pipe

Using the software of the Aramis 2M equipment, the following measurements were determined: the strains (the displacements of the points on the pipe surface) on the three directions (Δx, Δy, Δz), the total strain (Δe), the major strain (ε_1), the Tresca strain (ε_T), the Von Mises strain (ε_{VM}), and the thickness reduction (δ).

The results obtained by using the Aramis 2M optic system, for the PE100 polyethylene pipe of 63 mm diameter and 5.8 mm thickness, are shown below.

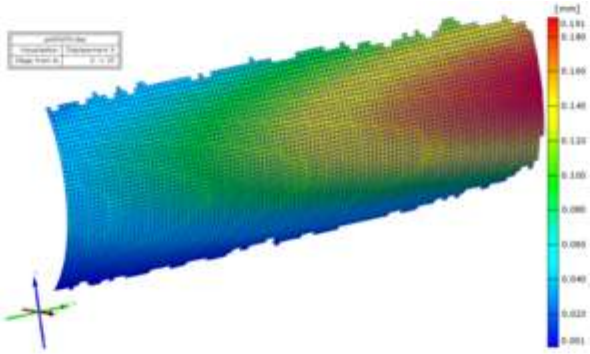

Figure 6: Displacement of the pipe on axial direction (Ox) [mm]

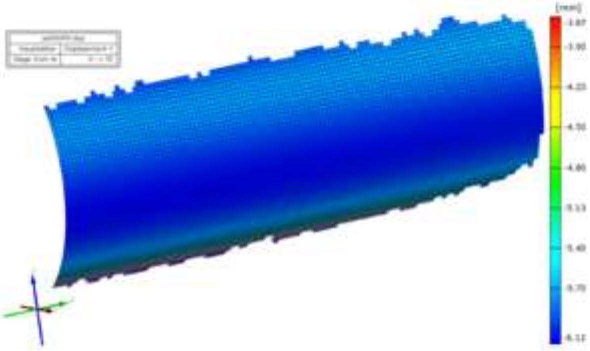

Figure 7: Displacement of the pipe on vertical direction (Oy) [mm]

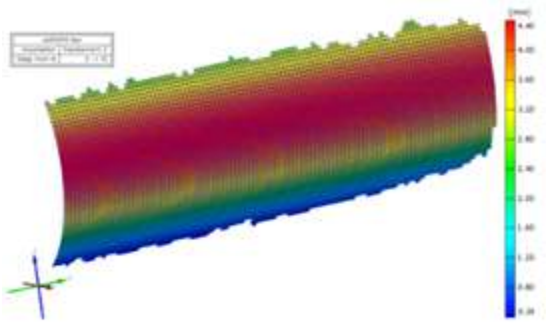

Figure 8: Displacement of the pipe on radial direction (Oz) [mm]

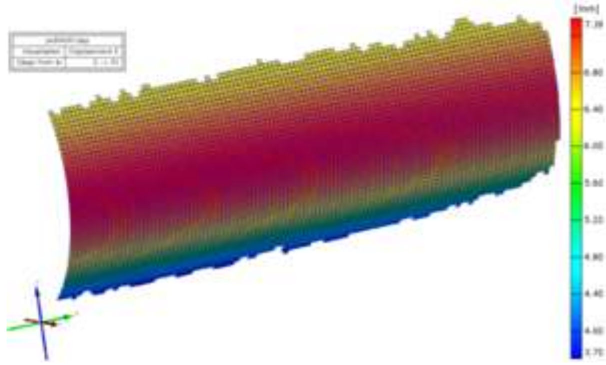

Figure 9: Total displacement of the pipe [mm]

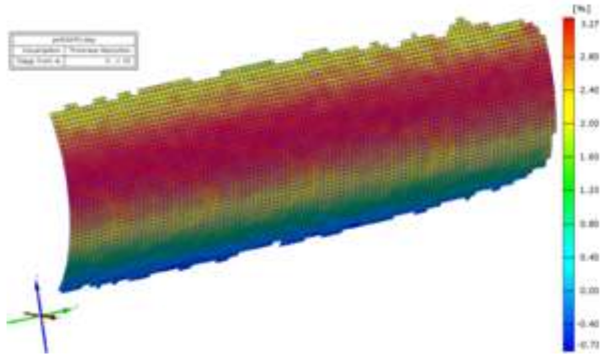

Figure 10: Thickness reduction (δ) [%]

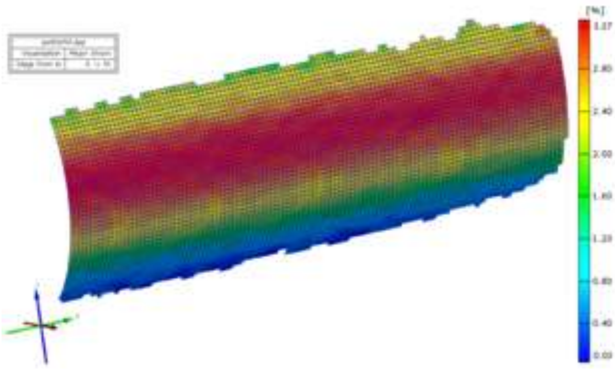

Figure 11: Major strain (ε_1) [%]

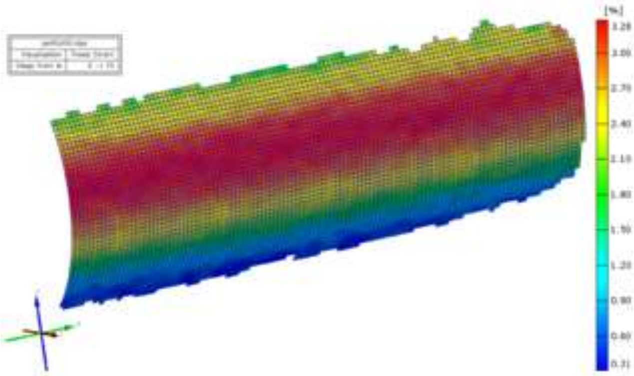

Figure 12: Tresca strain (ε_T) [%]

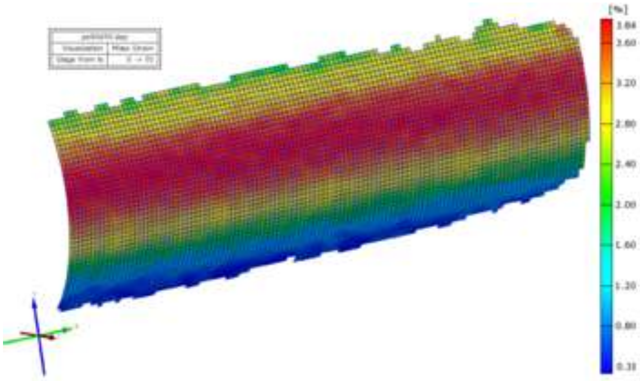

Figure 13: Von Mises Strain (ε_{VM}) [%]

The experimental results, both those provided by the software of the universal testing machine and those obtained by using the Aramis 2M optical acquisition system have shown that both materials (PE80 and PE100) subjected to the same maximum compression stress (7,500 N) reach the lowest strain at 63 mm diameter and 5.8 mm thickness. At the same time, a decrease of the strains in PE100 pipes by approximately 17 to 18% is noticeable in pipes with 32 mm and 63 mm diameters and by approximately 88% in pipes 90 mm in diameter. The same trend is observed at the strains on the (Oy) direction of applying the stress, determined with the Aramis optical system, which are lower for PE100 pipes by approximately 24% in the case of 32 mm diameter pipes, by approximately 13% in 63 mm diameter pipes and by about 65% for a 90 mm diameter pipe.

The limitation of these tests is that only one test was performed for each pipe size, which can lead to obtaining different results. However, the advantage of the method used is that it can help measure the thickness reduction of the tested pipes, which is very important in terms of the safety in operation of these pipes, given the fact that they are used for natural gas transportation.

2. Conclusions

Following the conducted studies, we reached the conclusion that this type of material has an admissible behavior when subjected to radial compression. This intervention on the polyethylene pipes will be correlated with the temperature, so that this action shall be avoided at temperatures that lead to the stiffening of the polyethylene material.

It is noted that the thickness reduction caused by the squeeze off tool can strain the pipe, which must be verified not to exceed 15% of the thickness of the material.

The cylinders of the squeeze off tool will be checked to avoid any possible irregularities that could cause cracks on the pipes that will spread and create a fracture of the polyethylene pipe.

References

[1] Avrigean, E. Studii teoretice si experimentale asupra comportarii mecanice a ansamblurilor sudate de tevi si fitinguri din polietilena de inalta densitate. "Lucian Blaga" University Publishing House, Sibiu, 2015.

[2] BALAN, M.L. Contributii la optimizarea procedeului de sudare cap la cap a tevilor din polietilena destinate transportului si distributiei gazelor naturale. Doctoral thesis. Sibiu. 2009..

[3] Lupu, N.I. Conducte din polietilena in sistemele de distributie. "Lucian Blaga" University Publishing House, Sibiu, 2010.

[4] Oleksik, V., Pascu, A.M. Proiectarea optimala a maşinilor si utilajelor, “Lucian Blaga” University Publishing House, Sibiu, 2017.