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STUDIES AND RESEARCHES ON THE AGGRESSIVE BODIES THAT CAN AFFECT THE INTEGRITY OF THE POLYETHYLENE PIPES USED IN NATURAL GAS TRANSPORTATION

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ABSTRACT The work aims to analyze the bodies existing in the environment where the polyethylene pipes used in natural gas distribution are laid and the way in which they can threaten their integrity. They are analyzed from the theoretical point of view of the computational relations and the way they are stressed.

KEYWORDS : insulation, polyethylene, mechanical action.

1. Introduction

Lately, the development of natural gas distribution networks has led to the massive use of high density polyethylene pipes PE 100 SDR 11, and thus various exploitation problems have been identified.

The problem we intend to find a solution for comes from the bibliographic study, in which due to the inappropriate use of the polyethylene pipe protection factor (sand with specific granulation) pinches of various forms appear on the surface of the pipeline unprotected by the latter and other elements (stones, metal parts, etc.) destroy the superficial protective layer and create cracks on the surface of the pipe. [2]

Compared to the fracture of metals, the study of the fracture resistance of polymers is in an early stage [2]. Many of the required theoretical supports are not fully finalized and there are many situations where the concepts of fracture mechanics that apply to metals are no longer applicable to other materials. The fracture resistance of polymer materials has become a major concern recently, when they begun to be used for critical structures.

In the case of metals, fracture and yield follow a yielding mechanism. Fragile fracture occurs in materials where deformability is low. Ductile metals, by definition, suffer extensive plastic deformations prior to fracturing. Low temperatures, high deformation rates, and the stress triaxiality favor brittle fracture even in the case of a material that, under normal conditions, has a tenacious behavior. [2]

From a general point of view, these principles can also be applied to polymers, but the microscopic details of the yield and fracture of plastics are much more different than for metals.

2. The Current Stage with Regard to the Possible Defects Occurring in the Exploitation of Polyethylene

2.1. Fracture of Polyethylene Due to Stress Concentrations Produced by External Mechanical Factors

Figure 1 shows the yield mechanism through cracks in homogeneous vitreous polymers At sufficiently large deformations, the molecule chains form packages of aligned molecules called fibrils. Micro voids are formed between the fibrils due to the irregularity of the deformation in the vicinity of the fibrils. The structure of the aligned molecules allows the fibrils to withstand the high stress applied to the non-deformable amorphous state, since the covalent bonds are more resilient and rigid than the secondary bonds. The fibrils (aligned molecular chains beams) are elongated by incorporating additional material, as shown in Figure 1, and voids form between them. The cracked areas increase by the inclusion of additional material in the fibrils. [2,5]

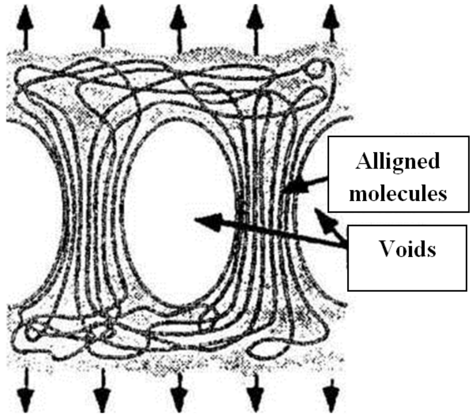


Fig. 1. Design - Craze formations in polymers [2]

In the case of polyethylene pipes, brittle fracture occurs at low stresses and long stress times, without deforming the pipe. This type of fracture originates in the crystalline domains of the material. At the beginning, a crack occurs which, due to the concentration of stress concentration on its tip, propagates into the material.

The mechanical properties are slightly affected by the size of the spherulites, and especially by the crystalline lamellas during the bottleneck propagation, the spherulites are completely destroyed and the structure becomes fibrillated [1]. As shown in Part I of Figure 2, in the separation of the crystalline lamellas as a result of stress there is a component that normally favors the appearance of micro voids in the amorphous inter-lamellar component, at the beginning of the cracking process [1].

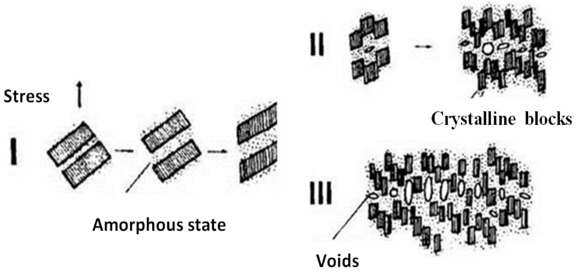


Fig. 2. The stages of cracking in a semi-crystalline polymer, according to Friedrich [2]

In stage II, when the stress reaches its critical value (yield strength), the crystalline phase becomes deformed and blocks of 10 to 30 nm are formed which detach from the crystal [1]. The crystalline phase can be deformed in several ways (mechanical mixing, phase transformations), but crystalline slip is the main reason for deformation, as it can generate major deformations.

Under these conditions, the fibrils that are formed are made up of crystalline blocks connected to each other by molecules of the partially stretched bonds and are separated by cavities [1].

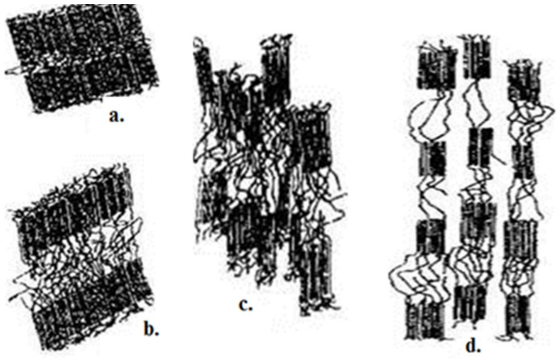


Fig. 3.The deformation in the diagonal area of the spherulites [2]: a) undeformed state; b) the amorphous phase extension; c) the fragmentation of the crystalline lamellae; d) the alignment of the fragments according to direction of traction

In the third stage, the breakdown of the chains starts from the fracturing surface of the blocks which bind the crystalline, leading to the complete extension of these fibrils. Figure 3.d shows the alignment of the blocks corresponding to the stress direction.

In conclusion, crack formation (schematized in Figure 4) is a cavitation phenomenon, during which the material turns from a spherulitic structure into a strongly stretched fibrous structure, surrounded by many voids. The development of these cracks in perpendicular planes to the stress axis is accomplished by extracting material from the adjacent surfaces and extending the voids between the fibrils, as the internal stresses increase [1].

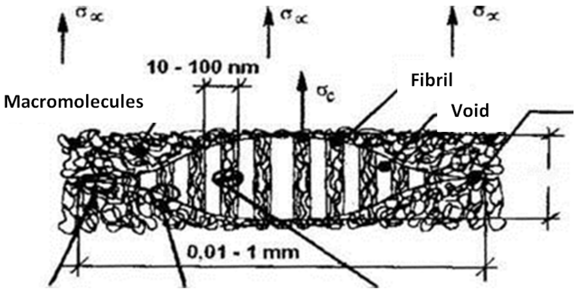


Fig. 4. Schematization of a crack [2] - a) - fibril formation; b) - fibril growth; c) - fibril fracture

The fracture of the semi-crystalline polyethylene materials is done by the occurrence of a crack at the center of the fracture, by breaking the fibrils after they reach their maximum elongation [2]. The causes of the fibril fracture in the PE are a controversial subject. There are two opposing theories to this regard. The first one implies a fracture through the chains' entwinement during the slip and implicitly the untangling of the folded molecules [1]. The second theory takes into account the cleavage of the chains forming the fibrils [1]. The argument results from the fact that there is a strong analogy between inter-lamellar fracture and the cracking of the vitreous polymers [2], and from the fact that the two processes were observed in the case of vitreous polymers. Indeed, for temperatures close to the vitrification temperature, Tg and masses close to the critical mass, the fibril can fracture by the chains' slip into the vitreous material. For the semi-crystalline polymers with high molar mass, it seems that for temperatures T ranging between Tg and the melting temperature Tf, the crystalline phase prevents the molecular slip in the chains of the fracture and they yield rather by the fracturing of the chains than by untangling [1], free radicals being observed during the traction stress of the polyethylene [1].

The tests conducted by classical destructive means provide information on the structure and the strength of the material in its original state, or estimates for different periods of operation under safe conditions. In order to make a product, in many cases, the choice of material type is influenced by the stability of its features over time. [1]

As a result of this tendency, for the study of the new types of material and their comprehensive characterization, new examination techniques have been developed based on the concepts and theories on the fracture of materials. [1]

Thus, in order to evaluate the deformation and the fracture behavior of the polymers, hybrid testing techniques can be used which combine the classical mechanical tests with non-destructive examination methods (acoustic emission, thermography, laser extensometer tests). By simultaneously applying these hybrid techniques, quantitative determinations of the correlations of the morphologic properties can be made [1].

In the case of composite and thermoplastic materials, active and passive infrared radiation thermography [3] has become a common technique for monitoring mechanical tests. Active thermography allows the detection and the characterization of the exfoliations [1] between the layers at different stages of the testing, while the passive one allows the localization of the fractures.

2.2. The Stress Concentration Concept

Any material that contains a geometrical discontinuity will show an increased stress in its neighborhood. This stress concentration effect is caused by the redistribution of the force transmission lines through the material when encountering the discontinuity. The stress concentrators can be holes, notches, grooves, edges, as shown in Figure 5. [5]

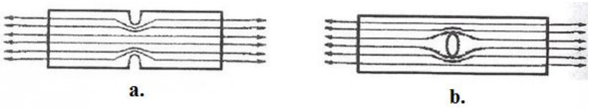


Fig. 5. Stress Concentration [5]: a. bilateral notch imperfection; b. hole imperfection

The classical equation for calculating the size of the stress concentration in the defect, as shown in Figure 5, is:

$$\sigma_c = \sigma \ \left(1 + 2\sqrt{a/r}\right) \qquad (1)$$

- σ_c – local stress;
- σ nominal stress in the material;
- a – size of the defect;
- r – radius of the respective defect.

The parameter represents the stress concentration factor (Kt). For example, for a hole a = r, we obtain: $K_t = 3$. The stress at the edge of the hole is three times bigger than the nominal stress in the material.

It should be mentioned, however, the case of a crack defect. Obviously this does not appear in practice. This would mean that a material containing a crack cannot withstand any applied force. Therefore, it is obvious that the method of stress concentration is not suitable for assessing the effects of the cracks. In order to solve this issue, the methods of fracture mechanics are applied.

2.3. Strains in High Density Polyethylene Pipes Due to the Operating and Environmental Conditons [1,4]

If an internal pressure p_e (Figure 6) act on a tubular pipe, we notice the occurrence of a three-dimensional stress.

There are three different types of stress in the pipe's wall [1]:

- A radial stress:

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

- A tangential stress:

$$\sigma_i = \frac{1}{r_e^2 - r_i^2}\left[p_i r_i^2 - p_e r_e^2 - (p_e - p_i)\frac{r_e^2 r_i^2}{r^2}\right] \qquad (3)$$

- An axial stress:

$$\sigma_{ax} = \frac{p_i r_i^2 - p_e r_e^2}{r_e^2 - r_i^2} \qquad (4)$$

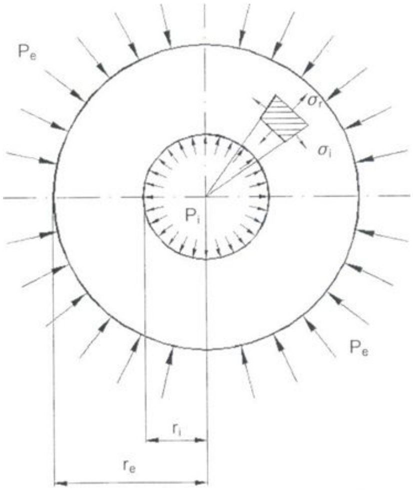


Fig. 6. Distribution of the stresses on the polyethylene pipe according to the application of the external and internal pressures

In the ratios 2.1...2.2, $r_e = D/2$ is the external radius of the pipe, and $r_i = d/2$ is the interior radius thereof. We notice that if r = r_i, the radial stress will be:

$$\sigma_r = -p_i \qquad (5)$$

In the situation where r = r_e, the radial stress will have the following value:

$$\sigma_r = -p_e \qquad (6)$$

In what the circumferential stress is concerned, if r = r_i the following formula results:

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

and if r = r_e, we obtain the fraction:

$$\sigma_i = \frac{2r_i^2}{r_e^2 - r_i^2} p_i - \frac{r_e^2 + r_i^2}{r_e^2 - r_i^2} p_e \qquad (8)$$

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

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

namely, the external stress σ_e, is:

$$\sigma_i = \frac{2d^2}{D^2 - d^2} p_i - \frac{D^2 - d^2}{D^2 + d^2} p_e \qquad (10)$$

where D and d are the external radius and the internal radius of the pipe.

The internal pressure is due to the fluid running 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 (ratio 2.1) is:

$$\sigma_r = \frac{r_i^2}{r_e^2 - r_i^2}\left(1 - \frac{r_e^2}{r^2}\right) p \qquad (11)$$

where p = p_i.

If $r = r_i$, σ_r maintains its value given by the ratio (2.4), and if r = r_e, then $\sigma_r = o$.

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

$$\sigma_i = \frac{r_i^2}{r_e^2 - r_i^2}\left(1 + \frac{r_e^2}{r^2}\right) \qquad (12)$$

For $r = r_i$, this stress reaches the maximum value, having the following formula:

$$\sigma_i = \frac{r_e^2 + r_i^2}{r_e^2 - r_i^2} p \qquad (13)$$

or

$$\sigma_i = \frac{D^2 + d^2}{D^2 - d^2} p \qquad (14)$$

as it directly results from the ratio (5.8).

If in the ratio (5.13) we replace $D = d + e_n$, (e_n being the thickness of the pipe's wall) and omit the term which contains e_n^2, this formula results:

$$\sigma_i = \frac{p * D}{2e_n} \qquad (15)$$

if a term containing e_n^2 is omitted.

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

In terms of the axial stress, following the same calculation algorithm, it becomes:

$$\sigma_{ax} = \frac{r_i^2}{r_e^2 - r_i^2} p \qquad (16)$$

or it is:

$$\sigma_{ax} = \frac{d^2}{D^2 - d^2} p \qquad (17)$$

By the same approximation on e_n^2 we can say that the axial stress is deduced by the ratio:

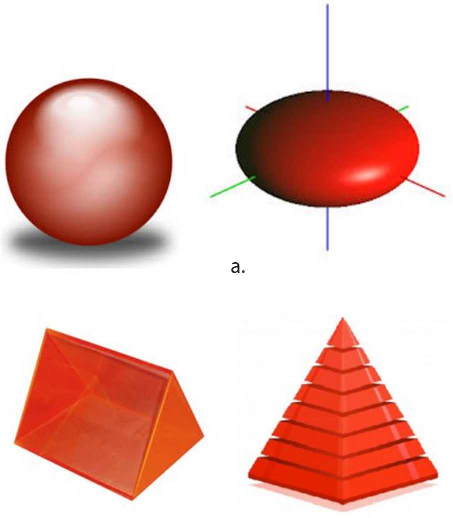
$$\sigma_{ax} = \frac{pd}{4e_n} \qquad (18)$$

3. Shapes and Sizes of Aggressive Particles that Can Damage the High Density Polyethylene Pipe

Fig. 7. Shapes of rock that can interact with the polyethylene pipes

In day-to-day practice, there are various shapes of the soil rocks that can accidentally come in contact with the polyethylene pipe. They are shown in Figure 7.

The study resulted in the establishment of four representative models (sphere, ellipsoid, triangular prism, right pyramid) which are presented in Figure 8.



a.

b.

Fig. 8. Representative shapes of the mechanical elements that can affect the integrity of the polyethylene pipe

4.Conclusions

The conducted studies led to the identification of the main bodies encountered in practice and which will be the subject of the following studies by taking into consideration the established relationships and the body that can deteriorate the integrity of the polyethylene pipe.

Future studies will rely both on the finite elements study as well as on experiments conducted in the laboratory.

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