Long-term Behaviour of Polyethylene PE 80 Pressurized Pipes, in Presence of Longitudinal Simulated Imperfections

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The paper directs the attention to the detrimental influences exerted by longitudinal notches on the polyethylene pipe surface when subjected under high pressure to long time service. It was shown that the detrimental degree is influenced by the notch depth, working pressure and service duration. Depending on these parameters, researches evinced two types of fracture behaviour: ductile and brittle. The conditions they produce and the transition limits of the ductile – brittle behaviour were demonstrated in two different environments: water and air, at the temperature of 80°C.

Keywords: mechanical behaviour, testing duration, environment, PE 80 polyethylene, pressure, longitudinal notches, temperature, pipes

Production of new materials and / or property improvement of existing varieties are one of the priority research directions of thermoplastic and composite materials. Prior to launching on the market of a new product or material, it must be tested to evaluate its performance for exploitation in specific operational conditions.

Polyethylene has been one of the most extensively studied materials in polymer science, principally because of its structural simplicity and wide applicability [1].

Pressurized polyethylene (PE) pipes have been used successfully for more than 40 years, primarily in fuel gas and water supply systems, and substantial experience concerning the failure behaviour and the fitness for purpose of PE piping system is available [2].

In long-term application of PE pipe systems, the ageing behaviour of the material has to be considered. Knowledge of the long-term failure behaviour in the presence of imperfections [3] is essential for the lifetime and safety assessment of these pipes. Physical or chemical ageing may change material properties by influencing the morphology and molecular mass, which have a direct effect on the mechanical properties of the pipes and on the resistance to crack initiation SCG (Slow Crack Growth) [4].

Long-term characteristics and the service life prediction of PE system pipes have been widely studied and many testing method and techniques have been developed [5 - 8].

In this paper, starting from standard procedure [9] a new methodology for evaluation of the long-term behaviour of the PE pipes in the presence of defects is presented. The hydrostatic pressure tests were carrying out up to 26.000 h in different testing condition (pressure, temperature and environments). The method can be used both to assess the quality of new varieties of PE pipes and improvement of technological production process [10 - 13] and to establish the optimum welding process parameters [14].

Experimental part

In order to assess the long time service of polyethylene pipe mechanical characteristics, in the presence of simulated imperfections, an experimental program was conceived to include both long time mechanical destructive testing and structural fractographical analyses.

Experiments used pipe section of PE 80ϕ 32x3mm, SDR 11, GAZ. Samples were made for testing out of these pipe sections.

Internal pressure testing at constant temperature was performed to determine the time to the fracture under given testing conditions (pressure, temperature, environment), to identify the character and the fracture position.

Macroscopic examinations and dimensional measurements aimed to study the evolution of simulated imperfections by measuring their geometrical sizes before and after the pipe failed, to evince the fracture character, orientation of defects generated during the testing and to determine their dimensions in cross and longitudinal section.

Two categories of samples were used:

- section type samples, without imperfections;
- section type samples, with simulated defects and the depth in the range 0.15 and 1.65 mm, a characteristic depth A in the range 5 and 55%, respectively, where A is defined by the relation (1):

$$A = \frac{a}{e} \cdot 100\ [\%] \qquad (1)$$

where:

a – imperfection depth;

e – wall pipe thickness.

In a first stage pressure mechanical testing was performed at a constant temperature (80°C), on samples without imperfections made out of pipe sections PE 80 nominal diameter Ø 32 mm, wall thickness a=3 mm and section length l = 300 mm. Testing was a ”water in water” and ”water in air” type, respectively.

In the second stage of the experimental program testing was made in order to establish the behaviour at internal pressure and constant temperature loading of the PE pipes having simulated defects. Defects simulation was achieved by LASER beam cutting (LSI method), the resulting imperfections being assimilated as plane defects [15].

The internal pressure testing was made on a computer controlled testing installation (fig. 1), which assured the automatic control of the prescribed testing parameters (pressure and temperature). The installation used consists of:

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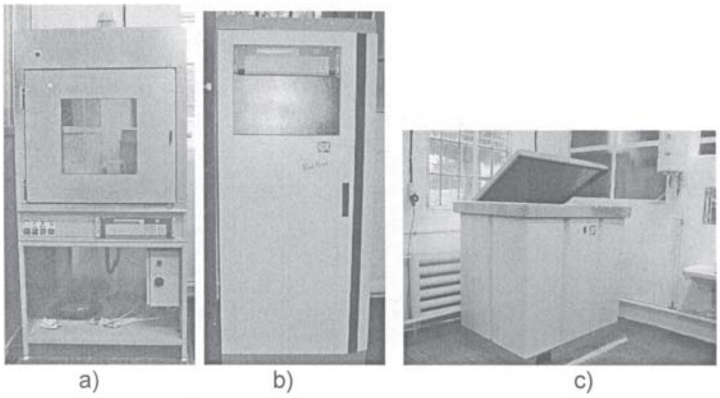

Fig. 1. Installation for constant temperature pressure testing [16]
a)Testing oven; b) Pressurization module; c) Temperature controlled bath

- devices to assure the testing samples tightness and flexible connections to the pressurisation module;
- module to realize and control of pressure testing that assures a maximum deviation of $^{+2}_{-1}$ % during the testing operation;
- temperature controlled bath and testing oven that allows to maintain the constant temperature with a maximum deviation of ± 1 °C.

Results and discussion

Figures 2 and 3 present the long time strength of samples having simulated imperfections, in the two working environments (water and air).

Testing were made at the temperature of 80°C, using 4 pressure stages p=8, 9, 10 and 11 bars. As it can be noticed the obtained results have been transposed in a semi logarithmic representation system and allow the formulation of the following observations:

- testing pressure has a major influence on the service life; for a given value of the characteristic size of the defect (A), the of service life due to the variation of pressure ($\Delta t/\Delta p$) may reach and even exceed two orders of magnitude;
- in all cases curves present inflexions after durations of over 5000 h;
- the obtained results for the ”water in water” type testing are systematically inferior to those obtained for ”water in air” testing type;
-the characteristic dimension of superficial imperfections on pipes has a very important role in the rheological behaviour of pipes.

Ductile behaviour of PE 80 pipes

The modification points of the bent marked in the diagrams from figures 2 and 3 can be associated with the fracture limit behaviour mode of pipes. The macroscopic analyses of fracture and the microfractographic analyses of fracture surfaces pointed out the following aspects.

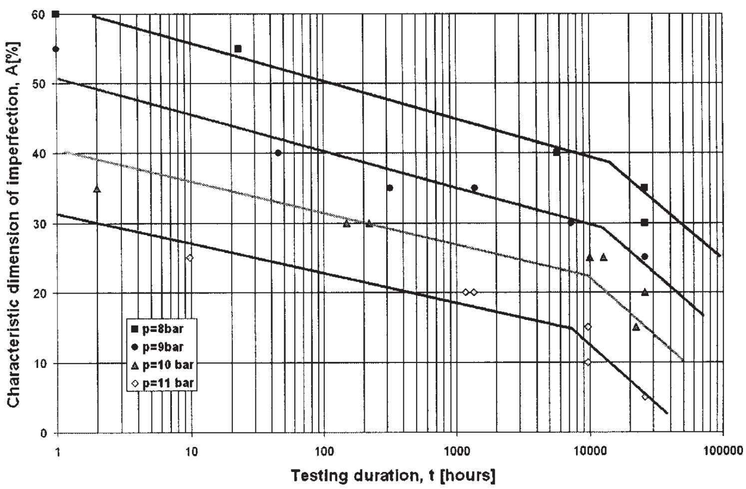

Fig. 2. Long time strength of samples having imperfections, testing environment: water at 80°C

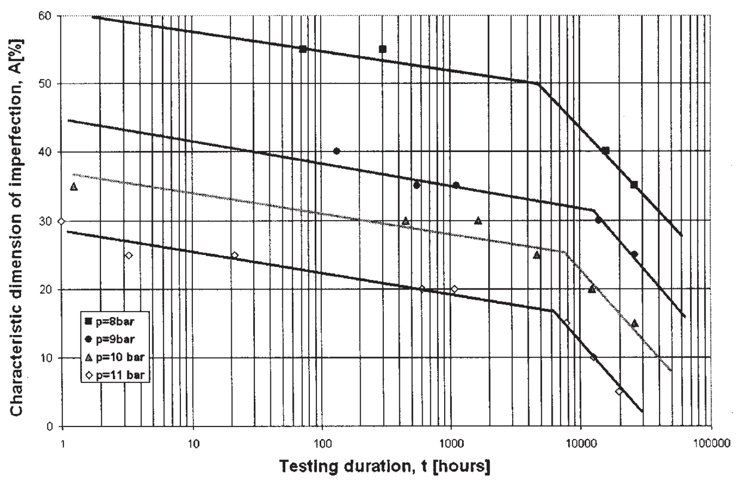

Fig. 3. Long time strength of samples having imperfections, testing environment: air at 80°C

The ductile fracture appears under high pressures after short loading periods. In this case fracture occurs by pipe expending as well as the wall thinning up to the failure. The crack has a perpendicular direction on the pipe axes (fig. 4) due to the neighbourhood of the meridional stress component to that of the circumferential stress, once the local shape is changed.

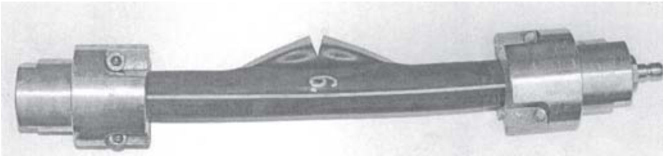

Fig. 4. Ductile fracture – Base material

It is noticed that both in the case of the ductile fracture and of the brittle ones, the base material of the pipe always failed in the yellow pigment marked area of the pipes (which points out their type – GAS) it leads us to the conclusion that marking by this method affects the quality of gas pipes (a statement valid for the tested pipe batch).

Brittle behaviour of PE 80 pipes

The brittle fracture appears after long time testing periods, and failure occurs without an important deformation of the pipe. Cracks which appear are very fine and close once the pressure in the pipe is released (fig. 5). As in this case the pipe is not importantly deformed, failure occurs by developing cracks oriented on the longitudinal direction against the pipe axes. These cracks evolve perpendicularly on the maximum loading direction.

Fig. 5. Brittle fracture – Base material

PE 80 pipes behaviour in the presence of simulated longitudinal cracks

Longitudinal simulated cracks develop both on longitudinal direction (D_A) and on the cross direction (D_T), producing a widening of the cracked area and the thinning of the initial ligament in the same time.

The evolution of the crack against the initial depth is presented in figure 6. The development of cracks is more accentuated on cross direction (D_T), as compared with the longitudinal one (D_A), which leads to the failure on this direction.

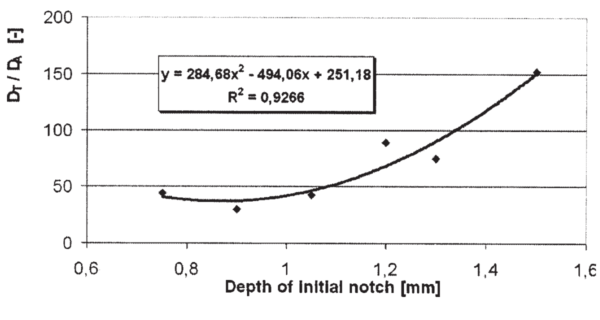

Fig. 6. Evolution of notch type simulated defects at the pressure testing

The microfractographic analyses of the fracture surface

The microfractographic analyses by Scanning Electronic Microscopy, SEM of the area including cracks, evinced a fibrous texture of the material (fig. 7), with parallel fibres with the pipe axis. The symmetrically developed cracks

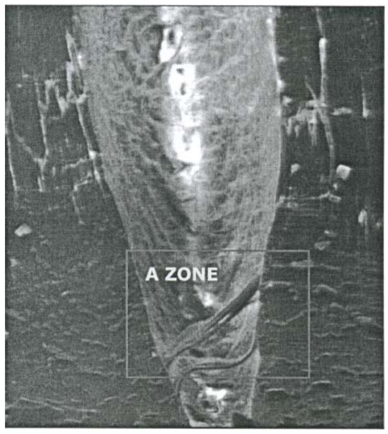

Fig. 7. SEM micro-fractographic analysis of the crack, magnification 120x

against the initial notch axis have an elliptical shape with two tips which are local notched raised stress.

There were noticed both plastic deformations of fibres (zone A – of initiation) situated in the vicinity of the two tips of the crack, and fibre fractures (zone B – central, figs. 8 and 9).

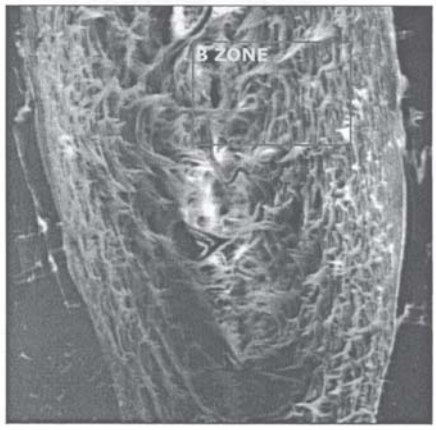

Fig. 8.SEM micro-fractographic analysis SEM of the crack, magnification 240x

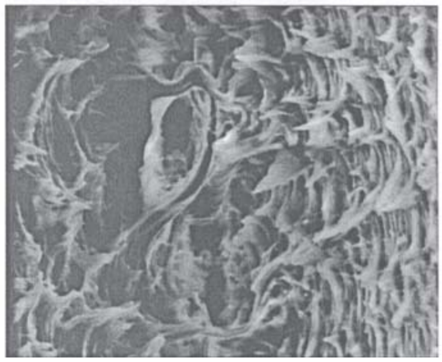

Fig. 9. SEM micro-fractographic analysis of the crack, zone B detail, magnification 480x

Ductile – brittle transition

As a synthesis, figure 10 presents results of researches through long time pressure tests, on the basis of macroscopic and micrographic aspect of fracture surfaces. The two transition curves are evinced from the ductile and brittle fracture, as a function of the testing pressure, the characteristic size of artificial imperfections made on the pipe surface as well as of the testing environment.

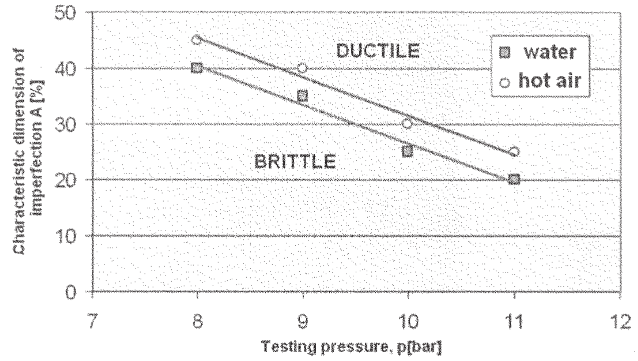

Fig. 10. Ductile – brittle transition curves at the temperature T=80°C

Conclusions

Aiming the simulation of very severe service conditions for PE 80 polyethylene pipes, the experimental program referred to the long time hydrostatic pressure testing of pipes with simulated defects under the form of longitudinal notches. So, it was possible to evince two distinct modes of the pipes mechanical behaviour, ductile and brittle:

- the ductile fracture appears under high pressures after short loading periods. Fracture occurs by the expending of the pipe and the thinning of its wall up to the failure. The produced crack has a perpendicular direction on the pipe axis due to the redistribution of the stress components in the fracture area;

- the brittle fracture appears after long time periods of testing, the failure of the pipe produces without an important deformation by developing defects on the longitudinal direction against the pipe axis. These defects are very fine and they close after the pressure in the pipe is released.

The characteristic size A [%] of imperfections and pressure affects the long time behaviour of the polyethylene pipe material by reducing its long term strength, the service life under safety conditions; the reduction of the service life (Δt / Δp) may reach and even exceed two orders of magnitude.

In the case of polyethylene the testing / exploitation environment influences the long time service behaviour of the material as it results analysing the transition curves. The "water in water" type testing is more severe, the testing environment water leads to the restriction of the ductile fracture range. For a defect with a given characteristic size, in water the brittle fracture appears under smaller testing pressure than in the case of air testing.

References

1.NITTA, K.-h; MAEDA, H.: Creep behaviour of high density polyethylene under a constant true stress, Polymer Testing, 2009, doi:10.1016/j.polimertesting. 2009.09.005.
2.PINTER, G; HAAGER, M; BALIKA, W; LANG, R.W.: Cyclic crack growth tests with CRB specimens for the evaluation of the long-term performance of PE pipe grades, Polymer Testing 26, 2007, p.180
3.MURARIU, A.; SAFTA, V; FLEŞER, T.: Investigation regarding the thermoplastic resistance evaluation with simulated imperfections. Key Engineering Materials Vol. 399 Trans Tech Publications, Switzerland, 2009, ISSN 1013-9826, p.131
4.FRANK, A; PINTER, G.; LANG, R.W.: Prediction of the remaining lifetime of polyethylene pipes after up to 30 years in use, Polymer Testing 28, 2009, p.737
5.ZANASI, T.; FABBRI, E.; PILATI, F.: Qualification of pipe-grade HDPEs: Part 1, development of a suitable accelerated ageing method, Polymer Testing 28, 2009, p.96
6.KRATOCHVILLA, T.; MUSCHIK, H.; DRAGAUN, H.: Experiences with modified test condition for notch pipe testing, Polymer Testing 27, 2008, p.158
7.FARSHAD, M: Determination of the long-term hydrostatic strength of multilayer pipes, Polymer Testing 24, 2005, p.1041
8.FARSHAD, M: Two criteria for the service life prediction of plastics pipes, Polymer Testing 23, 2004, p. 967
9.*** EN ISO 9080: Plastics piping and ducting systems. Determination of the long term hydrostatic strength of thermoplastics materials in pipe form by extrapolation, 2003
10.JIPA, S; ZAHARESCU, T.; STENESCU, R., MAT. PLAST., **42**, no. 1, 2005, p.5
11.FETECAU, C; STAN, F., Mat. Plast., **44**, no. 4, 2007, p.263
12.COCARD, M.; GROZAV, I.; IACOB, M.; CÂNEPARU, A., Mat. Plast., **44**, no. 2, 2007, p.103
13. PUPAZESCU, A., Mat. Plast., **44**, no. 2, 2007, p.103
14. PUPAZESCU, A., ZECHERU, G., Mat. Plast., **43**, nr. 2, 2006, p.109
15.MURARIU, A.; BÎRDEANU, V.: Experimental Method (LSI) for Planar Simulated Imperfections for Remaining Life Assessment of the Thermoplastic Pipe Networks, At: The International Conference On Structural Analysis Of Advanced Materials - ICSAM 2007, Patras, Greece, 2-6 sept. 2007
16.MURARIU, A: Modern Methods to assess the quality of thermoplastic pipelines, The 1st South-East European Welding Congress, **3**: Welding and joining technologies for a sustainable development and environment, Section Quality management & environment", ISBN (10) 973-8359-40-6; ISBN (13) 978-973-8359-40-6, Timisoara, 2006, p. 368

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