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STRESS FIELD IN TUBES MADE OF HIGH-DENSITY POLYETHYLENE USED IN WATER SUPPLY SYSTEMS

Sorin VLASE, Dumitru Daniel SCĂRLĂTESCU, Maria Luminiţa SCUTARU

Abstract: The paper aims to analyze the stress and strain appearing in the straight tube used in city's water supply network. As a result, the strength of such tube must be studied for a good design of such a network. It is also studied how the crack appears and propagates in the tube. The theoretical model is verified used FEM. The results obtained can be used in the current practice in the case of water supply networks made by high-density polyethylene (HDPE) pipes.

Key words: *pipeline network, tube, HDPE, crack*

1. INTRODUCTION

The use of tubes is widespread in the transport of liquids, especially for the transport of oil, gas and water for human communities. For water supply in the second half of the twentieth century, knowledge and technology allowed the appearance and production of plastic materials that became the main materials of the tubes used in water supply networks [3]. Thus, the expensive materials and technologies used to produce metal tubes have been replaced by plastics and modern, much cheaper production technologies [9]. The modern tubes thus obtained can be used in water supply networks, resulting in structures that meet all the requirements imposed on a power supply network [6].

These tubes have many advantages when compared to the conventional ones used so far. We list some of these: It allow a long exploitation time; They do not need cathodic protection systems; There is no need for additional internal and external coatings necessary for anti-corrosion protection; Maintenance costs are low. The very smooth interior surface quality offers excellent hydraulic properties that are maintained during the operation. Assembling them is easy, saving time on assembly. Secure seal is very good when required at high pressures. The construction of the joints allows for angular deviations, thus allowing directional changes, so that no special fittings are needed. Weight is reduced when compared to concrete or metal tubes. Costs are low, thus ensuring fast and cheap transportation; Large tube lengths can be achieved for which few connections are required and can be installed quickly. The materials used are thermally stable, resulting that their properties will not change at temperature changes. The pipes being commercialized are odorless, insipid, non-toxic and stable to the action of chemical agents or meteorological factors; Aging is, in these pipes, a very slow process; Pipes made of polyethylene can be used in assembly for a period of 50 years, of course if the pressures and temperatures recommended by the manufacturer are respected [14], [22], [23]. More theoretical aspects of the problems involved by the new materials are presented in [10]-[13], [25].

Recently made plastic tubes that are used in water supply systems are usual and useful due to their advantages over classical tubes[15]-[17]. Continuous development of research into new plastics and the development of modern technologies used to manufacture these tubes make the products ultimately improved. HDPE tubes are already in the third generation of material; polymerization conditions and special catalysts will give quality granules, which give the tubes thus obtained by extrusion methods outstanding properties and mechanical qualities [1], [2], [24]. High density polyethylene pipes for water transport in water supply networks, being used worldwide, proving their superiority to classical ones, deserve to be researched, knowing the current state of research in the field [28]-[33]. Tubes have proven a very good behavior in terms of strength, complex demands that they are continuously subjected to in a water supply network that has to work uninterruptedly [7], [8].

High density polyethylene obtained from polymerization has the characteristics given in [35]. The ductile crack mode is characterized in cold-rolling characteristic material with significant elongations in the immediate area of the rupture [35], [27], [34], [4], [23]. The crack looks like a "parrot break" [35].

2. CRACK IN HDPE TUBES

The ductile crack mode is characterized as cold-rolling characteristic material with significant deformations in the area near the crack [35], [34], [4], [23]. The rupture looks like a "parrot beak" [35], [36], [37], [38] as illustrated by Figure 1.

The damage of tubes dig into soil, made of high density HDPE may occur due to several conditions that can be grouped as follows [4]:

- Internal conditions (high pressure, variable pressure, temperature of the fluid);
- Installation - tube laying (defective design, laying errors, material handling errors);
- Damaged material (initial defects, incorrect tube material selection, previous crushing);
- Geothermal forces (bark movements, seismic forces, flotation);
- External loads (construction tasks, heavy traffic, explosions).

Fig.1. Ductile crack in a pressured tube [36]

Fig.2. The “parrot beak” crack [37], [38]

More complet models must consider the dynamic behaviour [18]-[21].

Damage to HDPE pipes is caused by ductile crack (Fig.1) or by brittle crack due to microcracks [6], [26].

For the prediction of the crack growth using Linear Elastic Fracture Mechanics and Finite Elements Methods three basic parameters are required:

- Stress Intensity Factors- **SIF**;
- Crack Propagation Direction – **CPD;**
- material patterns with crack growth.

ZENCRACK software calculates automatically the stress intensity factors from the analysis results of the cracked model. The crack growth occurs by the extension of the crack positioning. A regenerated model is then created, which is used for the growth simulation.

There are a few approaches for calculating the stress intensity factors such as:

- Crack Tip Opening Displacement-**CTOD**, named δ;
- the crack stress field;
- the **SIF** extraction method from J integral.

The ductile crack in the pressured pipe, made of HDPE is produced as is shown in (fig. 5.25) [34] The relations used in the numerical analysis by ZENCRACK are the following [34]:

$$\delta = \frac{8}{\pi}\frac{p_c}{E}c = \frac{K_I^{\,2}}{p_c \cdot E} \tag{1}$$

$$G = \frac{K_I^{\,2}}{E} = \delta \cdot p_c \tag{2}$$

$$K_I = p_c\sqrt{2\pi(4c/\pi)} \tag{3}$$

where:

K_I - the stress intensity factor corresponding to mode I of crack opening;

p_c - uniform stress which actions on the c zone length;

E - Young's Modulus;

G - energy release rate.

3. FEM ANALYSIS OF PRESSURED HDPE TUBE

Two different system of tubes with different dimensions were analyzed in the paper. The model required for the analysis is the same, only the input data differs. As inputs were taken:

- pressure inside the tube, considered normal to the inner surface of the tube;
- bounadry conditions at the end of the tube.

The geometric model obtained is shown in Fig.3.

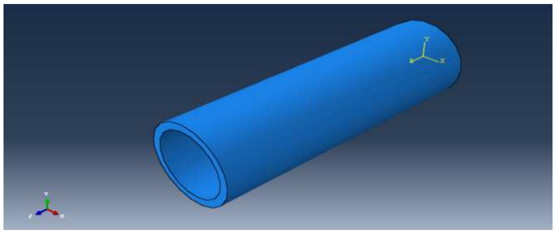

Fig. 3 The geometric model of the tube DN 315

The inner pressure in the tube are expresses by radial loads and determine circumferential stresses as shown in Figure 4.

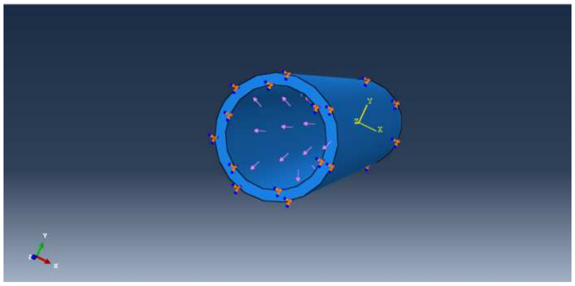

Fig. 4 The geometric model of the tube DN 315 with inner pressure

To perform numerical analysis with FEA, using ABAQUS, it is created the meshed analysis model shown in Figure 5.

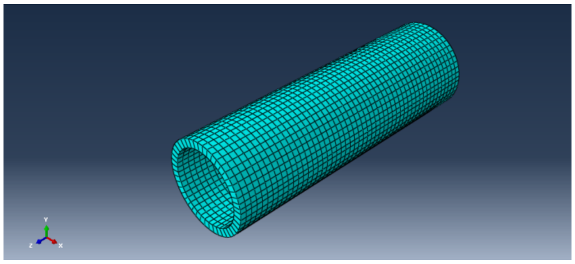

Fig. 5 The meshed analysis model of the tube DN 315

The meshing was performed using C3D8R parallelepiped elements. 2300 elements were generated for the model obtained. Some results are presented in the following figures (Fig. 6 -9).

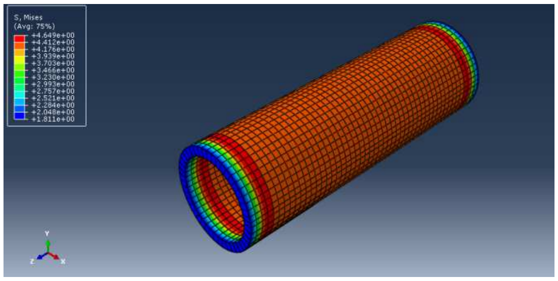

Fig. 6 Von Misses stresses in the tube DN 315 [MPa]

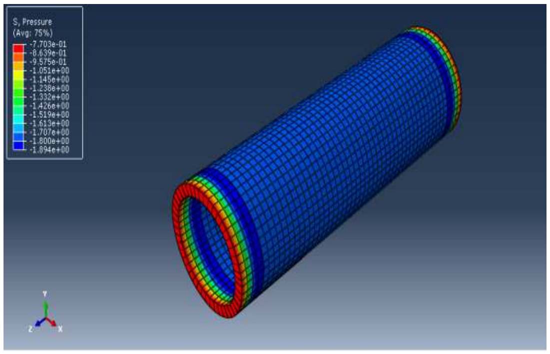

Fig. 7 Stress due to the inner pressure in the tube DN315 [MPa]

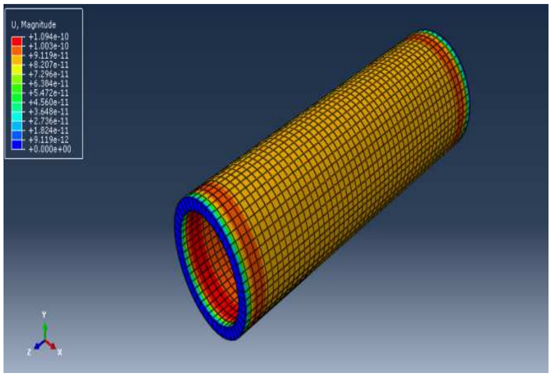

Fig. 8 Strains in the tube DN 315 [%]

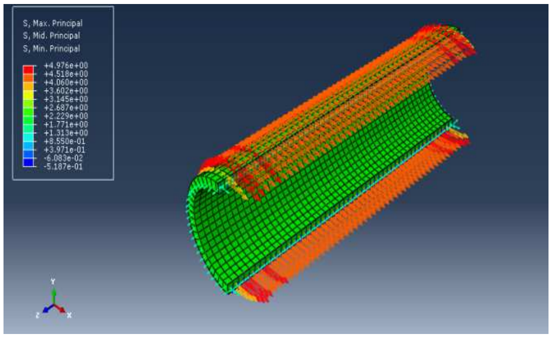

Fig. 9 Circumferential stresses [MPa]

4. SIMULATION OF DUCTILE CRACK OF DN 315 PIPE

In numerical crack analysis, Abaqus / CAE 6.14-5 with XFEM is used. The simulation will be carried out on DN90 distribution pipes and DN315 arteries. The tube model will be created using a solid body type. The chosen material of the tube is HDPE. Only the stresses and strains caused by the internal pressure to which they are subjected within the water distribution network are monitored in the tube analysis. The geometric model required for numerical analysis is shown in Figure 10 for the pipe DN315.

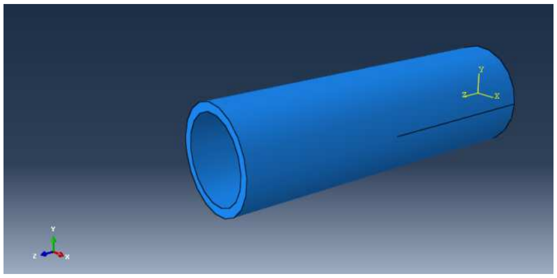

Fig. 10 The geometric model of the tube DN 315 for the study of the crack propagation

On the geometric model created for the tube DN315 in Figure 10 can be distinguished the boundary conditions and the crack. The mesh analysis model is shown in Figure 11.

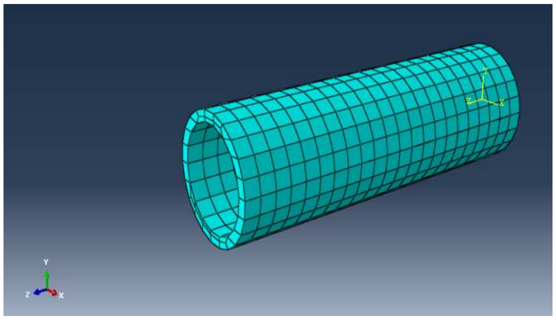

Fig. 11 FEA Analysis model of the tube DN315

The model showing the crack interaction as well as the crack line is presented in Figure 12.

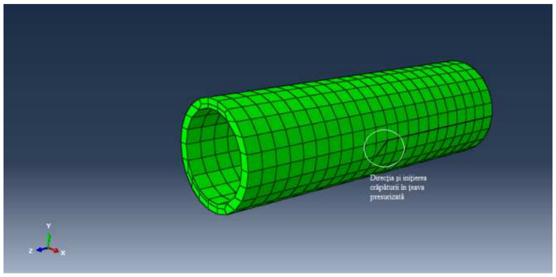

Fig. 12 Analysis model of the crack propagations DN 315

It is now possible to present the broken model in Figure 13. The crack is ductile and resembles the "parrot beak" described in [35].

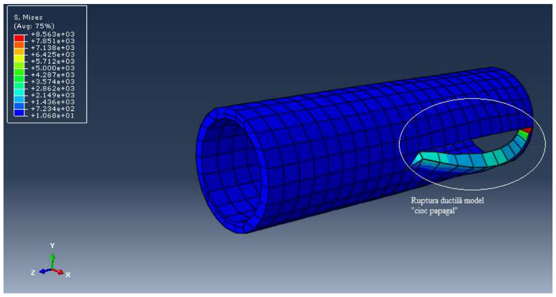

Fig. 13 Broken model of the tube DN 315

Breaking stress is 8563 MPa. The node of the model containing a gap that favors the crack initiation as well as the cracked model is shown in Figure 14.

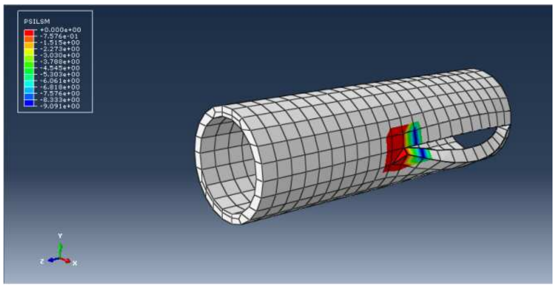

Fig. 14 Stress arround the crack in the tube DN315

Displacements arround the crack are presented in Figure 15.

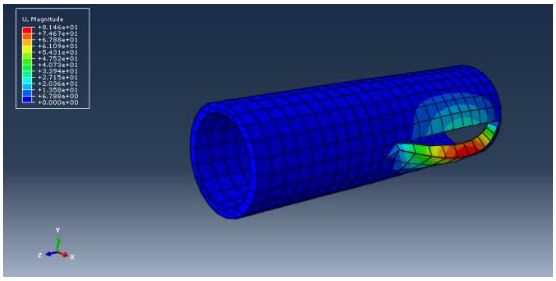

Fig. 15 Displacements arround the crack of the tube DN315

It will further study the simulation of the break of the tube DN90. The steps of the analysis are identical to those described above for the DN315 tube. The geometric pattern created and the crackline is shown in Figure 16.

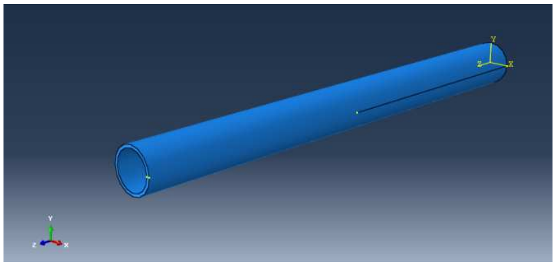

Fig. 16 The geometric pattern created and the crackline of the tube DN90

The meshed analysis model with the crack line is shown in Figure 17.

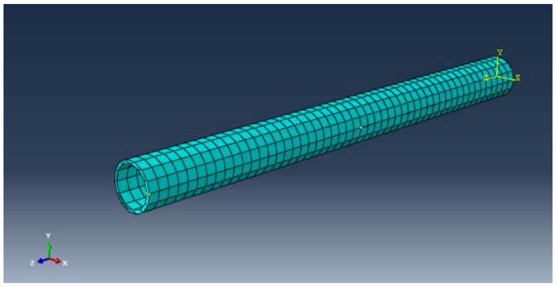

Fig. 17 The meshed analysis model with the crack line of the tube DN90

The crack analysis model is shown in Figure 18.

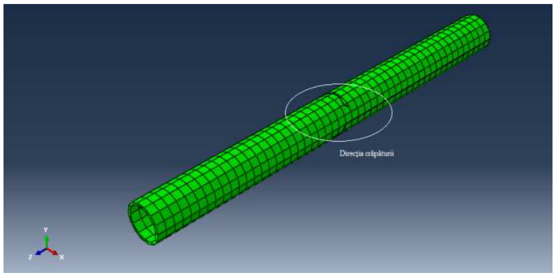

Fig. 18 The crack analysis model of the tube DN 90

The presentation of the broken model is shown in Figure 19. The crack is ductile and resembles the "parrot beak described in [35].

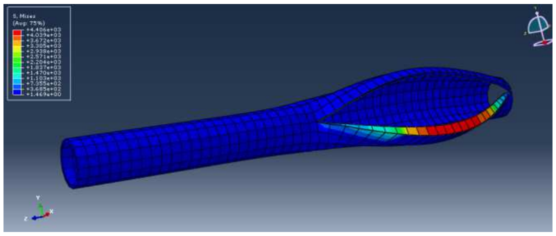

Fig. 19 Broken tube DN 90

7. CONCLUSION

The most suitable plastic material currently used to produce the tubes needed to transport water to modern water supply networks has been shown to be HDPE. Tubes and fittings obtained are characterized by a long service life and their maintenance costs are reduced. Tubes and fittings made of high density polyethylene follow quality standards and are remarkable for their outstanding strength and low weight. Both the rehabilitation, development and construction of a new water supply network are currently being carried out using high density polyethylene tubes, so that manufacturers of this type of pipes have the ability to quickly sale at prices that are not negligible. It is therefore necessary for the user to know the characteristics of the material, the type of extruder used in the manufacture of the tubes and the catalysts used in the manufacture of the granules. For the same pipe size but from different manufacturers, a user can make a difference, not just on the basis of price, but on the characteristics of the material resulting from the mechanical tests. As a result, the ductile behavior of the tubes is good to be well known and studied. This paper has contributed to this HDPE study, used in the network water supply.

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Câmpul de tensiuni în tuburile făcute din polietilenă de înaltă rezistență utilizate în rețelele de alimentare cu apă

Rezumat : Lucrarea își propune să analizeze câmpul de tensiuni și deformații care apar în tuburile utilizate la rețelele de elimentare cu apă ale orașelor. Rezistența unui astfel de tub este studiată în vederea obținerii unui proiect corespunzător. Sunt studiate de asemenea fisurile care apar și se propagă în tub. Modelul theoretic de calcul este verificat utilizând Metoda Elementelor Finite. Rezultatele obținute pot fi utilizate în pracctica curentă în cazul rețelelor de alimentare cu apă făcute din polietilenă de înaltă rezistență.

VLASE Sorin, Prof. Dr.hab., Head of Department, Transylvania University of Brașov, Department of Mechanical Engineering, svlase@unitbv.ro, Office phone: +40-268-418992, 30, Castelului, 500014, Brașov, home phone: +40-722-643020.

SCĂRLĂTESCU Dumitru Daniel, M.D., Eng., Transylvania University of Brașov, Department of Mechanical Engineering, scarlatescudumitrudaniel@yahoo.com, Office phone: +40-268-418992, 29, B-dul Eroilor, Brașov, home phone: +40-745-046190.

SCUTARU Maria Luminiţa, Professor, Dr. hab., Transylvania University of Brașov, Department of Mechanical Engineering, lscutaru@unitbv.ro, Office phone: +40-268-418992, 29, B-dul Eroilor, 500036, Brașov, home phone: +40-723-242735.