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THE LABORATORY INVESTIGATIONS OF HIGH-DENSITY POLYETHYLENE DRAINS FOR APPLICATION IN TAILINGS

Abstract:

For the purposes of draining material deposited in the tailings pond under construction, there was a need to examine the properties of the high-density polyethylene drain tubes and the consisting materials in order to assess their adequacy in the specific conditions. The conducted laboratory investigations of the samples cut from the tubes included: determination of bulk density, tensile strength in the tangential direction, as well as the compressive strength in a radial direction. Representative samples of the tubes themselves were tested in two different loading dispositions, in order to record the load-deflection effects. The test results indicated the specific behavior of the tested material in service conditions.

Keywords: plastics, physical and mechanical properties, drain tubes, loading.

ЛАБОРАТОРИЈСКА ИСПИТИВАЊА ДРЕНАЖНИХ ЦЕВИ ОД ПОЛИЕТИЛЕНА ВЕЛИКЕ ГУСТИНЕ ЗА УПОТРЕБУ У ЈАЛОВИШТУ

Сажетак:

За потребе дренаже материјала одложеног на јаловишту у изградњи појавила се потреба за испитивањем карактеристика дренажних цеви од полиетилена велике густине, ради процене адекватности у конкретним условима. Спроведена испитивања материјала обухватила су одређивање запреминске масе, чврстоће при затезању у тангенцијалном правцу, као и чврстоће при притиску у радијалном правцу пружања цеви на узорцима извађеним из цеви. Узорци самих цеви испитани су при две диспозиције оптерећења у циљу снимања напонско-деформацијских ефеката. Резултати испитивања указали су на специфичности понашања конкретног материјала у условима експлоатације.

Кључне ријечи:пластичне масе, физичко-механичка својства, дренажне цеви, оптерећења.

1. INTRODUCTION

The wide use of plastic materials is enabled by their low cost, ease of production, adaptability and acceptable mechanical properties. Since the nineteenth century, many different forms of plastics were developed, replacing traditional materials such as wood, stone, clay, metals and concrete [1]. The main disadvantages of majority polymeric products include the reduced durability and overall low corrosive resistance, all connected to the properties of polymeric bonds in the product. The use of other substances such as fillers, emulsifiers and stabilizers can significantly expand the lifespan of some plastics. Therefore, plastics use is so widespread, that the plastic pollution occurs to be one of the biggest environmental concerns. Some frequently used products, such as disposable plastic bottles, bags, and other plastic containers can negatively affect the natural environment and harm plants, animals and humans. Contemporary approach to plastics manufacturing implements the principles of sustainable development, making the use of renewable materials for production of plastics more prominent [2]. This means that the affirmations of plastics can be amplified by their proper production, use and thorough knowledge of their properties.

On the basis of recent analyses, the most common thermoplastic mass produced worldwide is polyethylene and it is used for wide range of everyday applications [3]. The biggest production, according to data from 2016 [4], was Asia (53% of the worldwide production), followed by North America (20%), Europe (15%), South America (3.5%), Africa (2.5%) and other (6%). Global high density polyethylene (HDPE) market is in its steady growth, with the global annual expansion rate of approximately 3 billion US$, and was forecasted to grow more than US$84000000 by 2023. Rise in demand for plastic pipes being widely used as a substitute for domestic plumbing was recognized as the major driving force for this material in the global market. HDPE is a form of polyethylene favorable for its' high strength to density ratio. This property makes it attractive for different types of pipelines - drinkable water, sewage and drainage. The HDPE shows high water impermeability, corrosion resistance and possess significantly lower weight than many other traditional materials. It is abrasion resistant, highly resistant to stress cracks and tough. Other advantages of HDPE include good processability, lower production costs and lower transportation costs. Traditional elements for this application, concrete and steel tubes are being replaced by the HDPE, mainly due to their durability issues. The disadvantages of HDPE include high thermal expansion coefficient, bonding issues, lower strength and high deformability in comparison to traditional materials. These are the boundaries for HDPE applications, where one or more properties occur insufficient in the specific conditions. Concrete and steel remain better choices for such applications, provided that the requirements regarding durability, load bearing capacity, proper casting, placement, maintenance and other are met. To justify or rule out the use of HDPE, suitable laboratory investigations become essential, providing various simulations of exploitation conditions and data needed for assessment of material suitability.

In the case described in this study, a range of laboratory tests were performed on one type of HDPE tubes (pipes), with defined geometry and materialization, to assess the applicability in the tailings site, where significant heights of deposits are expected to occur in the future. Based on the requirements of the specific application in the tailing site, key parameters were recognized and set for the tests. The tests included following: geometrical, physical, mechanical and deformational properties. This study was conducted in several phases, with common geometrical and physical tests performed in the beginning. Following these tests, new samples were obtained from the pipes delivered on site, and the load bearing capacity and deflections under deposited soil layers were investigated. Such approach implied proper sample preparation techniques, and new testing setups, which will be explained further in the paper.

2. INVESTIGATIONS OF THE USED TUBE

Physical and mechanical properties of HDPE available in the data sheets provided by the producer are shown in the Table 1. This information includes results of tests done in accordance with standard procedures BS 4962 [5] and EN 10204 [6]. Also, impact resistance and tightness of elastomeric sealing ring joint complied with the requirements, according to the relevant standards EN 744 [7] and EN ISO 13259 [8], respectively.

Table 1. *Properties of the tested HDPE tubes*

Raw material	High density polyethylene
Appearance	Smooth surface, both inside and outside
Perforation	1/3
Outside diameter	500.0-504.5 mm
Wall thickness	55.8-61.5 mm
Ovality	2.0 mm
Collective surface	630 cm^2/m, 5.2 %/m
Distance between perforation channels	56 mm
Perforation channel width	4.8 mm
Longitudinal reversion	1.5%
Compress Test maximum force	31.2 kN
Compress Test deflection at maximum force	12.1 mm
Melt flow rate of material (tube)	0.2-1.4 g/10 min
Resistance to internal pressure	180+ hours

2.2. Physical and mechanical properties

In the first phase, the geometrical properties of the samples were measured and proved to comply with the producer's datasheet. Some of the properties given in the table 1, were not subject to testing, according to the requirement given by the client.

The investigations of basic physical and mechanical properties of the HDPE were conducted on samples shown on Figure 1.

Dimensions of the samples cut out from the pipes were roughly 40 by 160 mm, 20 mm thick, for the tensile testing. Figure 1 holds more specific geometry measurements, in mm. Tensile testing velocity was set to 50 mm/min. The samples for the compressive strength were 40 mm cubes. Both the fracture point and testing velocity were set with regard to the lateral deformation of the specimen. The compressive fracture (defined by the moment when lateral deformation was visible, with no significant increase in load) was to occur between 1 min and 5 min after the start of test.

The dimensions of the specimen were chosen in order to provide samples as big as possible, with respect to the geometry of the pipes. Although HDPE can be regarded homogeneous, this had to be proved to be true in the specific geometry and form of pipes.

The conventional cutting techniques with saw, when applied to this product, result in change of the properties of the material (mainly in the superficial 3 mm thick layer), due to the higher temperatures occurring in the process. This change is visible, due to the change into the darker shade of gray of the cut part of the material. Thus, the samples were extracted from the tubes using waterjet cutting technology, in order to provide minimal change in properties of the materials induced by cutting process.

The results of these investigations are shown in Table 2. All the tests were done in triplicate.

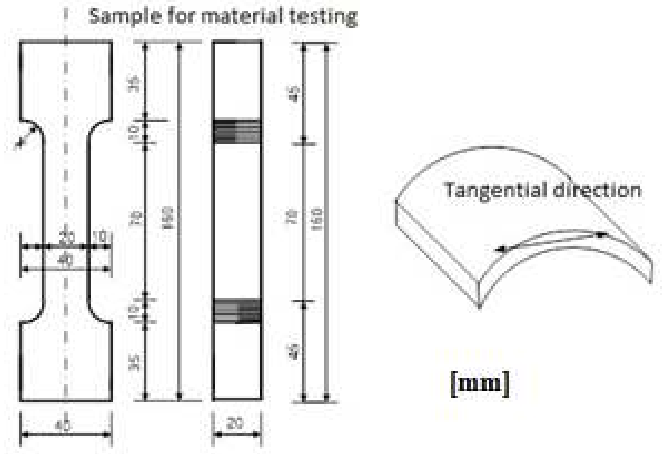

Figure 1. *Geometry of the samples for the investigations and their extraction from the HDPE tubes*

The investigation included tensile and compressive strength tests, as well as measurements of density.

Table 2. *Results of compressive strength, tensile strength and density of the HDPE*

Conducted test	Individual test results	Average (stdev)
Density (kg/m^3)	929	932 (5.20)
	929	
	938	
Compressive strength (kPa)	33.3	33.9 (0.98)
	33.3	
	35.0	
Tensile strength (kPa)	28.9	27.6 (1.28)
	26.3	
	27.7	

For measurement of dimensions, a digital caliper "Controls" with range of 100 mm and precision of 0.01 mm was used. The mass of the samples was recorded using hydrostatic balance "Kern" with range of 35 kg and precision of 0.1 g. Tensile strength was obtained on "Shimadzu" tensile testing machine with the range of 200 kN and precision of 0.1 kN. Compressive strength tests were performed with the aid of "Amsler" compressive testing machine, with the range of 20 kN and the precision of 0.1 kN. The results of these investigations are shown in table 2. After testing of compressive and tensile strength, the samples have shown substantial plastic deformation, without signs of spalling or crumbling (Figure 2).

Figure 2. *The appearance of the samples after failure in cases of testing compressive strength (left) and tensile strength (right)*

2.3. Investigations of load bearing capacity of the hdpe tube

As already noted, the intended use of the perforated tubes was for the tailings disposal area, to be filled with the 35 meters high layer of tailing soil above the tubes, with the density of approximately 2000 kg/m^3. According to that condition, exploitation requirement have arisen for the tube to withstand the load of 70 t/m^2. Having in mind that the tube was 0.5 m wide, the equivalent linear load (for 1.0 m long tube segment) was therefore $V_{rač}$ = 0.5·1.0·70.0 = 35 t/m = 350 kN/m.

Furthermore, the technical requirements for the application of the tubes in this case state the safety factor of 1.3, meaning that the tube has to withstand 30% higher load values, equivalent to the depth of 45.5 m in the tailings soil. This value is equivalent to the load of 45.5·2.0 = 91.0 t/m^2 = 910 kN/m^2 = 910 kPa for the soil with 2000 kg/m^3.

Besides the stated requirement defined for the load bearing capacity, there was another requirement regarding deformability of the tube. The deflection of the tube under the stated load was set to be lower than 30 mm, representing the ultimate deformation of 6% of the total diameter of the tube. The investigations were conducted in accordance to the standard ATV-DVWK-A 127E [9].

For this analysis, two possible dispositions were adopted for the investigation, one in which the tube had free lateral deflections, and the second one, where the lateral deflections were limited by the rigid frame. The later disposition was adopted to simulate the lateral soil pressure acting on the tube in the exploitation conditions.

2.3.1. The investigation of the tube with free lateral deflections

Due to the space limitations between the plates of the compressive testing machine, the investigation was conducted on the 25 cm long sample, with free lateral deflections of the samples, according to the disposition shown in Figure 3. The force-controlled load V was applied, while the vertical deflections Δv were measured during the process.

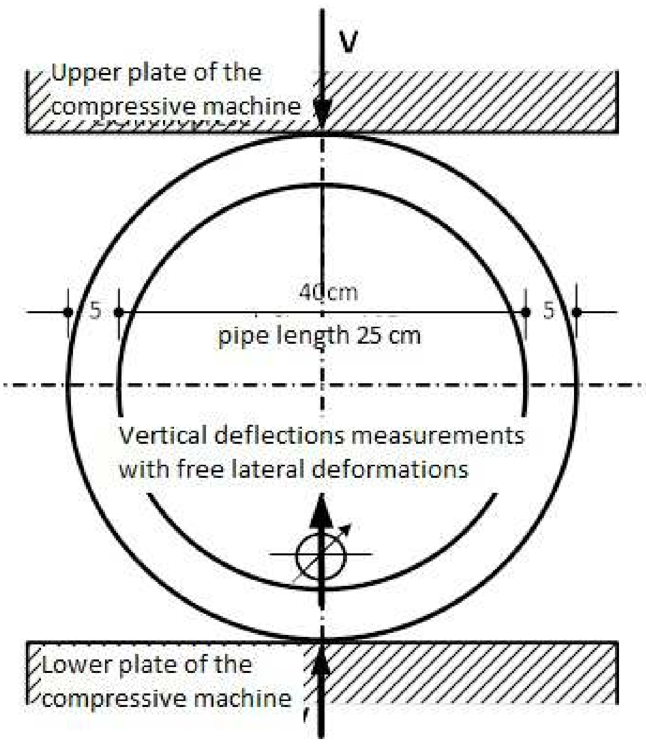

Figure 3. *Investigations of the tubes with free lateral deflections – defining the function Δv(V)*

According to the investigation plan, force V was set to grow and reach maximum value of maxV = max$V_{rač}$·0.25 = 45.5·0.25 = 11.4 t = 114 kN. Nevertheless, as the force of V = 35 kN was passed, deflections were more than 30 mm (Δv = 31.08 mm), so the further investigation was terminated at the level of V = 40 kN and deflection of Δv = 42.23 mm. The recorded function Δv(V) is shown in Table 3, while the Figure 4 illustrates the investigation setup.

Table 3. *Function Δv(V) obtained during the investigation with free lateral deflections*

V(kN)	0	5	10	15	20	25	30	35	40
Δv (mm)	0.00	2.13	5.12	8.56	12.30	17.01	23.05	31.08	42.23

Note: Values Δ_v (mm) have been obtained as the average of two measurements.

Figure 4. *One of the photographs taken at the course of the investigations*

2.3.2. The investigation of the tube with limited lateral deflections

The second setup investigation was conducted on the 25 cm long sample, with limited lateral deflections, according to the disposition shown on Figure 5. The limitation was constructed as a rigid frame, consisting of two "U" shaped steel profiles connected through the inner space of the tube by two steel rods (studs). The force-controlled load V was applied, while the vertical deflections Δ_v were measured during the process. Also, in order to provide an insight in lateral pressure, two strain gauges with 10 mm bases were used.

Table 4 contains values of Δ_v and V, obtained during this investigation. As it can be seen, the investigation was terminated at the level of 107 kN – which was very close to the limit for the maximum allowed deflection maxΔ_v of 30 mm.

Table 4. *Function Δv(V) obtained during the investigation with free lateral deflections*

V (kN)	0	10	20	30	40	50	60	70	80	90	100	107
Δ_v (mm)	0	6.14	8.08	9.65	11.22	12.74	14.43	16.31	18.79	21.75	26.23	28.78

Note: Values Δ_v (mm) have been obtained as the average of two measurements.

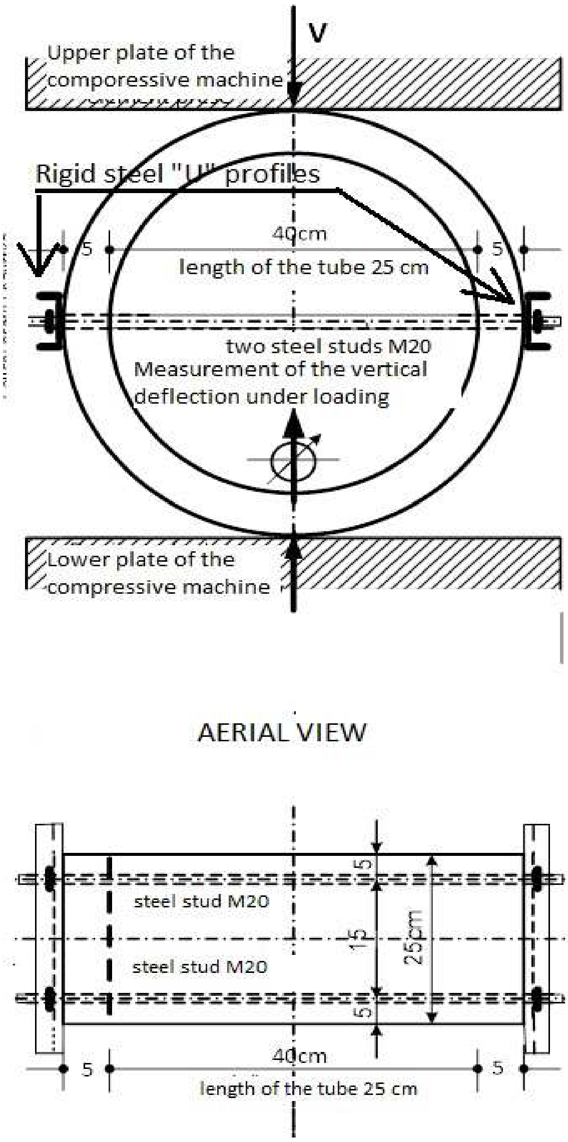

Figure 5. *Disposition of the investigation of tube with limited lateral deflections*

A graphical representation of the obtained function Δv(V) is given in Figure 6.

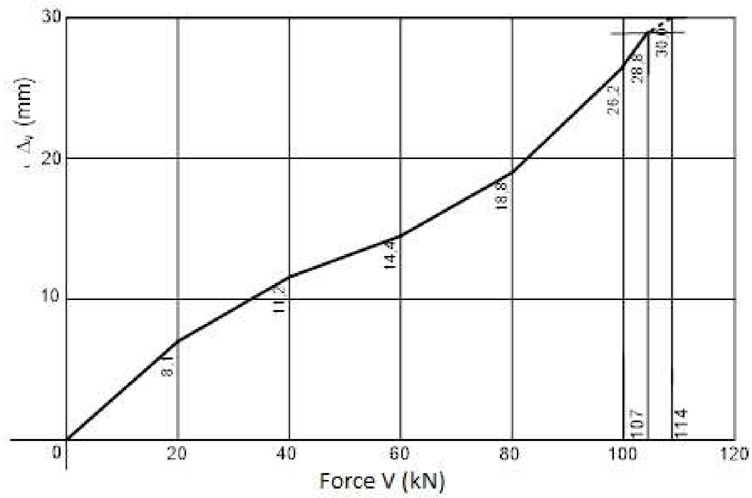

Figure 6. *The obtained function $\Delta_v(V)$ for the disposition with limited lateral deflections*

Based on the measurements made by strain gauges, the lateral deflection at the highest force was maxΔh = 0.625/2 = 0.3225 mm = 0.03225 cm. Figure 7 shows the course of the investigation with substantial change in geometry of the investigated tubes.

Figure 7. *The photographs made during the investigation of the tubes with limited lateral deflections*

3. CONCLUSIONS

The constant progress in materials enables new areas of applications with respect to the good engineering practice, economic analysis and scientific research. In boundary cases, where the suitability of the materials is in question, a wide range of investigations are needed to complement the usual standard procedures, in order to ensure specific applications and provide proper data to the responsible personnel. Having in mind the fact that many properties, including mechanical given in the table 1 were not tested according to the agreement with the user, it was concluded as follows:

- the investigated tubes had required geometry, while their material had appropriate density, tensile and compressive strengths, in accordance with this kind of HDPE;
- a maximum vertical deflection of 30 mm which relates to the 6% of the tube's deformation, was reached under load conditions of 45.5·2.0 = 91.0 t / m2 = 910 kPa;
- the stated deflection was achieved by testing a sample under the conditions of limited lateral deflection, which simulates the conservative loading case represented by linearly applied loading, while the real exploitation conditions are when the tube is expected to be surrounded (both vertically and laterally) by a tailing material, with density of 2000 kg/m^3, as distributed loading over the external tube surface.

Although the positive results obtained in these investigations enable the use of the specific HDPE tubes satisfying testing conditions, a number of challenges regarding the proper installation, handle, connection and system maintenance still remain, and have to be correctly addressed to provide confidence in this solution.

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