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Mechanical and chemical properties of sewage pipes

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ABSTRACT

Purpose: The purpose of this paper was to evaluate the compatibility of the physico-chemical properties of sewage pipes with the requirements of PN – EN ISO 1401-01: Plastics piping systems for non-pressure underground drainage and sewerage. This article is based on a research carried out for the water supply company. The article presents the results of mechanical and chemical testing of four pipes of unplasticized polyvinyl chloride and one pipe of polypropylene. All the test pipes were applicable to the sewage systems. The aim of the article was to confirm the high property thermoplastic pipes in comparison with conventional sewage system. High property mainly resulting from the flexibility of thermoplastic pipe compared to conventional rigid pipes sewers. Plastic piping systems also offer a reliable method for joining technology.

Design/methodology/approach: The subject of the study was the analysis of the macrostructure, the analysis of the mechanical and chemical properties of sewage thermoplastic pipes. The research was based on international and national standards for pipes made of thermoplastics pipes and sewage systems. During the tests we measured density, ring stiffness, longitudinal shrinkage, additional weight impact resistance and chemical resistance to dichloromethane.

Findings: The standards and literature provide the average density for the pipes with PVC-U of 1.4 g/cm^3. The research has shown that the material of all the tested PVC-U sewage pipes exceed this value. The highest specific density is 1.555 g/cm^3, which may indicate the use of large quantities of fillers.

Research limitations/implications: The main limitation of the experiment was a failure to compare the properties of samples from the properties of the pipes after long time use. When considering suggestions for future research, there should be carried out spectroscopic tests. FTIR spectrum would allow to verify that the plastic was added fillers.

Practical implications: The research shows that more frequent inspections are necessary. These inspections should include execution of pipeline technology, but also controls the material from which pipes are produced.

Originality/value: The advantage of the article are the results of the comparative analysis of a few mechanical tests and chemical resistance. The value of this article is to draw attention to the need for studies of thermoplastic pipes for sewage systems. The installation of thermoplastic pipes shows less damage, but it should not cause non-compliance with standard specifications.

Keywords: Engineering polymers; Properties; Mechanical properties; Working properties of materials and products

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PROPERTIES

1. Introduction

Sewage discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants in different concentrations. Waste water has different densities, particle sizes and hardness. These particles could erase the surface of the sewer system. The second problem of the sewer system is different pressure values of the sewage. The scale of these problems is only estimated in the design process of sewage pipelines.

During the middle of the nineteenth century, the centralized water-carriage sewer system replaced the ailing decentralized system of septic tanks. From the end of the nineteenth century to the present day, centralized management has remained the preferred urban wastewater management method, although the implemented technology has changed [1].

Pipes, in different diameters, are the most important part of centralized management. The applied pipes can have different materials and structures.

1.1. Materials for sewage pipe applications

Sewage pipes, through the ages, have been made from metals like lead, copper and bronze, iron, plus concrete, clay, ceramic, and even wood.

Nowadays, plastics pipes are the most important. Sometimes these are fibre reinforced hardening plastics, which play an important role where certain superior mechanical and corrosion resistance properties are required [2]. This materials for sewage pipes are used to create large diameter pipes, like pipes of sewage main pipelines.

Broken pipe and defective connections represent the most common damages in sewage systems. These are typical for rigid, brittle pipe materials. Thermoplastic pipes respond to loads with flexibility. Flexible pipes can deform without compromising their flow drop. Plastic piping systems also offer a reliable method for joining technology.

As a consequence of the working time, the sewage system is increasingly subjected to damages. Cracks, fractures, and splintering typically occur in sewer pipings made of brittle pipe materials when subjected to overload. However, this aspect concern flexible - thermoplastics pipes, too. As a consequence, this may result in the collapse of the sewage system (Fig. 1) [3].

The environmental impact of the average section caused by infiltration or exfiltration for flexible pipe systems is 15% (less than one-sixth) of that for rigid pipe systems. Especially in scenarios with sensitive ancillary conditions, flexible pipes show a better environmental performance than rigid systems [4]. This is undoubtedly the main reason for the application of thermoplastic materials for these market.

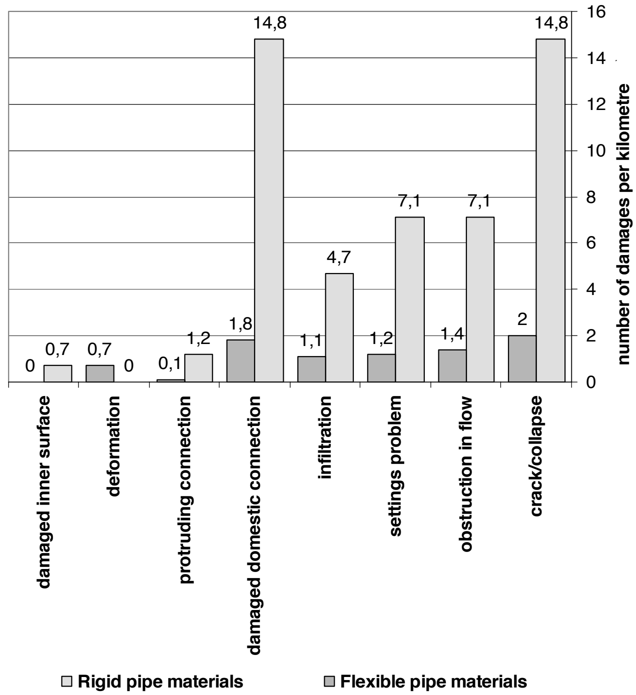


Fig. 1. Number of damages per kilometre (2006 y. in Germany) [3]

Table 1.
European consumption of major thermoplastics for tubes, pipes, conduits and fitting [5]

	Consumption in tubes, pipes, conduits and fittings, 1000 tonnes	Total consumption for each thermoplastic family, 1000 tonnes	Shares of tubes and pipes versus total for polymer family, %	Polymer shares versus total for pipes and tubes, %
PVC-U	1654	4026	41	57
HDPE	740	4775	15	26
PVC-P*	188	1849	10	6
PP**	170	7360	2	6
LDPE	93	4636	2	3
LLDPE	39	2384	2	1
ABS	24	633	4	1
Total of identified thermoplastics	2908	25 663	11	100

Legend:
* Including other profiles; ** Not listed in economic statistics, estimated; PVC-U rigid polyvinyl chloride; HDPE high density polyethylene; PVC-P soft polyvinyl chloride; PP polypropylene; LDPE low density polyethylene; LLDPE linear low density polyethylene; ABS copolymer of acrylonitrile, butadiene and styrene.

With a consumption of 20.6% of all thermoplastics, the buildings and civil engineering market is the second (after packing market - 39%) largest outlet for thermoplastics [5].

Table 1 shows for Western Europe, the annual consumption (in the year 2006) of major plastic for tubes, pipes, conduits and fitting for all applications [6]. Other polymers are used but are not listed in economic statistics. Nearly 3 million tons of plastics are consumed by this sector, accounting for 7.4% of all kind of plastics. Consequently, commodity thermoplastics are mostly used, with rigid polyvinyl chloride (PVC-U) and soft polyvinyl chloride (PVC-P) [5].

Sewage pipes are created from thermoplastic materials such as polyvinyl chloride (PVC), polypropylene (PP) and high density polyethylene (HDPE) [2]. This plastics are popular for middle and low diameters of pipes.

Adverse effect of the use of thermoplastic pipes is ageing which also occurs under the influence of liquid [7, 8, 9]. However, studies indicate that the pipeline service life of such pipes may reach more than 50 years [3].

Discussing materials for sewage applications, the role of coatings should also be mentioned. Due to its low prices and ease of processing, concrete has been the most widely used construction material applied in treatment plants, and open channels. However, concrete suffers from deterioration and rapid degradation of concrete structures which has been reported in wastewater facilities. To protect concrete structures from physical, chemical, or biological degradation, protective surface coating materials can be used. The coatings can stay in contact with concrete and provide long term effective protection under severe condition with low maintenance costs. The researchers use chlorinated rubbers, acrylic, polyethylene, polyester, epoxy, and polyurethane) to protect the concrete surface against corrosion [10-13].

1.2. Types of sewage pipes

Going back to theme of thermoplastic pipes for sewage applications, they differ not only with respect to material but also as to a kind of structure. The most often encountered types of sewage pipes structure are:

- solid structure pipes (Fig. 2 a),
- multilayer structure pipes (Fig. 2 b),
- and corrugated pipes(Fig. 2 c).

Solid structure pipes are created from all kind, typical for sewage applications, thermoplastics (e.g. PVC, PP, HDPE). The pipes are produced in the extrusion process and the variation of the microstructure is a result of the cooling process of hot pipes.

Multilayer structure pipes (or pipes with foaming core) are produced in the co-extrusion process. In this process, usually three polymers materials are extrusion, in this same time, by one extrusion head. The middle layer is extruded of polymer with a blowing agent. Typical thermoplastic used to production this type of pipe are PVC and PP.

Some manufacturers using multilayer extrusion heads, feed all the path of head with this same materials with identical properties. According to Polish Standard PN-EN 1401-1:2009 is considered as solid structure pipe.

Corrugated pipes which are used for sewage are a full circular dual-wall cross section, with an outer corrugated pipe wall and a smooth inner liner. This is not the only kind of corrugated pipes, but only this one we can use to transport waste water. This pipes are produced commonly from HDPE.

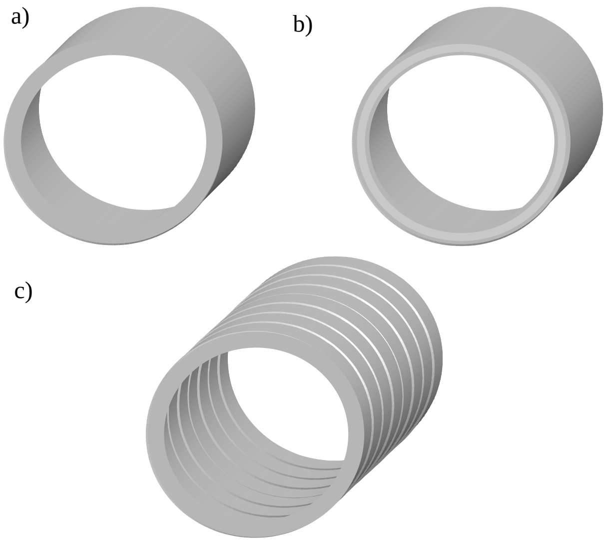


Fig. 2. Types of sewage pipes structure

The main advantages of use of thermoplastic pipes are economic, technological and practical reasons. Thermoplastics are cheap and light - which makes it cheaper to transport, and extrusion technology used is well mastered and is also relatively cheap.

Connecting pipes in the pipeline is easy and there are many assembling systems adapted to different situations. We can distinguish separable connections, such as bell-and-spigot pipe joint, screw pipe joint, flange pipe joint, etc., and the total joint - mainly welding.

The big advantage is the possibility of the use of such pipes in trenchless renovation of old sewage pipelines [14, 15]. Usually solid structure pipes are used in these methods of renovations.

1.3. Reasons of damage the sewage pipelines

The destruction of sewage pipelines may be caused by many aspects. Some of these errors relate to technology, others result from the conditions of storage and transportation, and some to conditions of use.

First, let us consider the technological errors. These can be divided into errors made during the production of pipes, their merger, and the laying of pipeline. The pipes are directed to any error in the choice of material. They result mainly from the financial savings. Dishonest manufacturers' plastics are filled with chalk, talc, etc., which significantly lowers the cost of the material but also the mechanical properties. Another treatment is the use of recycled plastics, often of unknown origin. The use of such plastic is environmentally friendly, unfortunately, usually affects the deterioration of mechanical properties and chemical and biological resistance. Such practices are difficult to detect because they may manifest the destruction of the pipeline only after a long period of time. Another mistake is the extrusion technology with the use of too high speed screw rotation, which increases the efficiency of the processing line but the material plasticity takes the wrong way. Unfortunately, errors of this kind are visible on the surface of the pipe in the forms of streaks and the so-called "fish eyes". Such effects are propagators of the material cracks. Another mistake that affects the quality of the cooling pipe is incorrect, too rapid cooling which causes the edge of the crystal structure in amorphous semi-crystalline plastics such as polyethylene or polypropylene [16]. This reduces the mechanical properties of the material. To summarize, the production of thermoplastic pipes is a difficult compromise between the desire for profit and ensuring product quality.

Another technological mistake is not applying the right parameters of joining pipes. Sewage pipes systems must be leak-tight so that any exfiltration of sewage water into the soil and groundwater as well as infiltration of pressing groundwater into the network are prevented. These types of errors occur during welding by rejecting ambient conditions (for example, in the cold) or the incorrect preparation of pipe ends before they are joined.

A huge source of damage pipes are ways of laying them in the ground. Sewage pipes made of plastic can be laid in the ground by various methods. The most popular is the traditional open trench method. However, more and more frequently used methods are narrow and trenchless narrowly-excavation, which is associated with an increase in the rate of work and minimize the difficulties associated with, for example, occupation and reconstruction of roadway. Application of trenchless and narrowly-excavation methods are associated with damage of to the surface of the pipeline. In narrowly-excavation methods such as milling or plough-in laid pipe is exposed to the pressure point of the stones found in the excavated ground. The effect of pressure point, especially in the pressure pipelines in the wall where there are tensions, it may be localized creep pipe material, which will eventually lead to the failure of the pipeline.

In turn, trenchless methods, while dragging, the pipes are prone to scratches from hard elements in the ground (rocks, boulders, remnants of old buildings), and at the end of the drag on them derived from the pressure point. The pipelines pressure, scratching the surface of pipe can cause rupture of the wall. It is connected with the phenomenon of slow crack growth which can occur under favourable conditions, such as cracks size and shape and sufficiently large stresses in the pipe wall. It is assumed that the scratches are acceptable with a depth of up to 10% wall thickness. Therefore, it is recommended that using the methods and trenchless narrowly-excavation, to use pipes with increased resistance to slow crack growth and the pressure point. These pipes can also be used in case of not doing the traditional excavation and backfilling sand ballast [17].

Another risk of damage to pipelines is the migration of ground. This phenomenon may occur due to the flow of the ground under the load, for example, due to landslides from slopes, or slides of mud. These phenomena are difficult to predict because they are the work of nature. However, the ground may migrate due to proximity to roads or the source of vibration. These sources of destruction, are generally known during the design phase and should be taken into consideration. In summary the biggest problem during the laying of the pipeline is the quality of the ground. The most secure method of exploitation of the sewage system is to provide sand ballast, without stones, around the pipes.

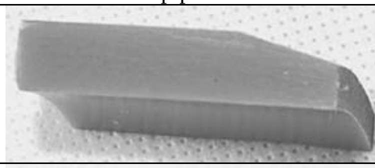
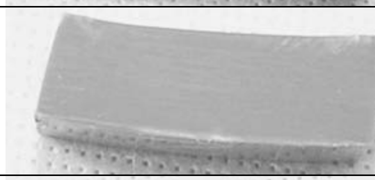
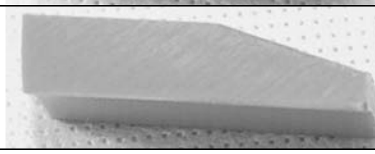
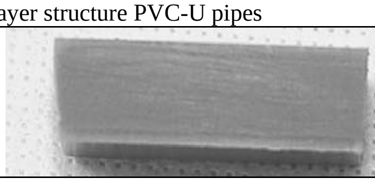
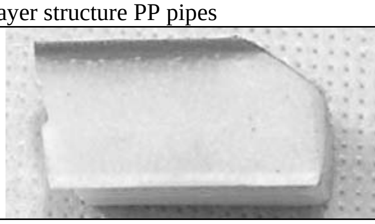
The last of the biggest problems is transport and storing pipes before laying. Generally pipes are delivered directly to the building site by the manufacturer or distributor and are the responsibility of proper transportation. Upon receipt pipes, check if they have no visible damage in the form of deep scratches and abrasions. Particular attention should be paid to the torn pipes bundles - there is a high probability that during the transport pipes could moved and wiping on the sharp parts of the car [17].

Often, the contractors and inspectors, raise concerns about changing the colour or the distant production date of pipes. Discoloration are the effect of solar radiation and more precisely, ultraviolet light (UV). Because, sewage pipes made of plastic, are designed to be laid in the ground, the producers do not add to them, UV stabilizers that provide long-term stability of mechanical properties. Only in black HDPE pipes, pigment is used as soot which is also UV absorber [17].

2. Testing procedure

The subject of the study was to evaluate the compatibility of the physico-chemical properties of sewage pipes with the requirements of PN - EN ISO 1401-01: Plastics piping systems for non-pressure underground drainage and sewerage.

Table 2.
Tested sewage pipes

No	Picture	Size and type
Solid structure PVC-U pipes		
1.		200 × 5.9 SN8
2.		250 × 7.3 SN8
3.		200 × 5.9 SN8
Multilayer structure PVC-U pipes		
4.		250 × 7.3 SN8
Multilayer structure PP pipes		
5.		250 × 7.3 SN8

All tests were performed in the laboratories of the Department for Processing of Metals and Polymers that is a part of the Institute of Engineering Materials and Biomaterials on Silesian University of Technology.

2.1. The samples of sewage pipes

Sewage pipes were tested from different manufacturers. Pipes were obtained from the building site. Pipes were not previously used. Selected for the tests were pipes with range of diameters from 200 to 250 mm and ring stiffness of 8 kN/m^2. To provide this ring stiffness for pipe the wall thickness should be 5.9 mm or more for 200 mm diameter and 7.3 mm or more for 250 mm diameter. Declared material and dimensions of the pipes was read from the description on the outer wall of the pipes . Types of sewage pipes were identified by visual inspection of the macroscopic cross-section of the pipe wall. Table 2 shows macrostructure of tested pipes.

2.2. Work methodology

Basic documents referenced in this article ratings and reviews are standards:

- PN-EN ISO 1401-1: Plastics piping systems for non-pressure underground drainage and sewerage - Unplasticized poly(vinyl chloride) (PVC-U);
- PN-EN ISO 1183-1:2004: ISO 1183-1:2004: Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pycnometer method and titration method;
- PN-EN ISO 9969:2007: Thermoplastics pipes - Determination of ring stiffness;
- PN-EN ISO 2505:2005: Thermoplastics pipes - Longitudinal reversion - Test method and parameters;
- PN-EN 744:1997 Thermoplastics pipes. Tests method for resistance to external blows by the round-the-clock method (This is Polish equivalent of ISO 3127:1994);
- PN-EN 580:2005: Plastics piping systems - unplasticized poly(vinyl chloride) (PVC-U) pipes - Test method for the resistance to dichloromethane at a specified temperature (DCMT) (This is Polish equivalent of ISO 9852:2007).

2.3. Density measurement

The density of the sample is determined from these measurements of mass and volume. When the sample is placed in a pycnometer filled with a liquid of known density, the volume of the liquid which will overflow is equal to the volume of the sample. The mass of the liquid which will overflow is determined as the difference between the sum of the mass of the pycnometer filled with liquid plus the mass of the sample and the mass of the pycnometer filled with liquid after the sample has been placed inside. In this method it is necessary to apply the liquid wetting the surface of the sample well, and also one in which the sample will sink. The results are shown in Table 3.

2.4. Ring stiffness

The ring stiffness shall be determined by measuring the force and the deflection while deflecting the pipe at a constant rate. A length of pipe supported horizontally shall be compressed vertically between two parallel flat plates moved at a constant speed, which is dependent upon the diameter of the pipe. The ring stiffness shall be calculated as a function of the force necessary to produce a deflection of 3% diametrically across the pipe.

Table 3.
The results of the research

Pipe No	Item	Material	Density, g/cm^3	Ring stiffness, kN/m^2	Longitudinal shrinkage, %	Resistance to external blows by the round-the-clock method (temp. 20^{o}C)	Chemical resistance to dichloro-methane
Recommendations of the standards →		✓	PVC-U ≈ 1.4 PP ≈ 0.9	Minimum 8 kN/m^2	Maximum 5 %	no marks and damages	No change in surface area
1.	200 × 5.9 SN8	PVC-U	1.471	10.31	0.0%	24 impact, no damage, though everywhere visible white marks on the inside wall of the pipe	large changes
2.	250 × 7.3 SN8	PVC-U	1.555	9.73	3.6%	10 impact, 2 longitudinal cracks	large changes
3.	200 × 5.9 SN8.	PVC-U	1.495	13.14	2.5%	24 impact, no damage, though everywhere visible white marks on the inside wall of the pipe	little change
4.	250 × 7.3 SN8. Multilayer	PVC-U	1.475	8.73	1.2%	24 impact, no damage, though everywhere visible white marks on the inside wall of the pipe	large changes
5.	250 × 7.3 SN8. Multilayer	PP	0.855	10.21	1.0%	24 impact, no visible damage and marks	Not tested – method only for PVC

The size of the samples, according to the standard, was 300 ±10 mm. Deformation rate during testing was 10 mm/min. The results shown in Table 3.

2.5. Longitudinal shrinkage

A pipe of specified length is placed in air oven at a specified temperature for a specified time. A marked length of this portion of pipe is measured, under identical conditions, before and after heating. The reversion is calculated as a percentage of the change in length in relation to the initial length. The surface appearance of the test piece shall not be changed after heating.

Length of test samples was 200 mm. Temperature of used air oven: 150°C, Duration of exposure: 60 minute. The results of longitudinal shrinkage shown in Table 3.

2.6. Resistance to external blows by the round-the-clock method

The samples are subjected to blows from a falling weight dropped from a specified height to specified positions around the circumference of the pipe, with a test temperature of 0°C or -20°C.

Fig. 3. Sample No. 2 after tests method for resistance to external blows by the round-the-clock method

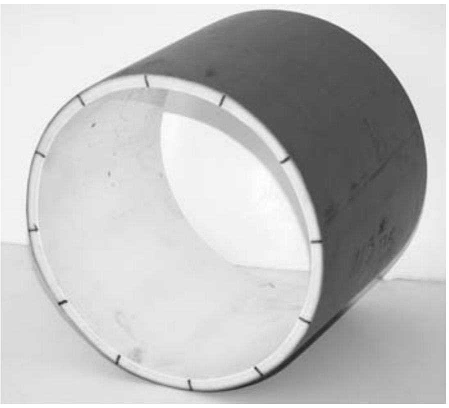


Fig. 4. Sample No. 5 after tests method for resistance to external blows by the round-the-clock method. No marks on the pipe

In countries where a less stringent impact resistance is permitted, a test temperature of 23°C can be applied. The test conditions differed from those listed in the standard (test performed at 20°C) despite the lower stiffness of the material obtained poor results (Table 3). Consider the test sample as a failure if the impact causes shattering or any crack or split on the inside surface of the pipe that can be seen without magnification. Fig. 3 shown the worst sample. Fig. 4 shown the best sample. Fig. 5 shown example of the rest of samples which have very similar marks after this test.

Fig. 5. Sample No. 1 after tests method for resistance to external blows by the round-the-clock method. White marks on the pipe

2.7. Chemical resistance testing

Research subject pipes (No. from 1 to 4) made of polyvinyl chloride. Pipe 250 × 7.3 SN8 PP (No. 5) is not subject to testing because of the high level of chemical resistance of polypropylene.

The samples should be immersed in chemically pure dichloromethane for 30 minutes. After removal from test container, the sample should be examined for sign of attack which may involve lifting, rasing or removal of material from its surface.

Research samples of pipe should be chamfered on the edge. For a wall thickness of less than 8 mm chamfering should be 10 degrees. The test made at a temperature of 23°C. Figs. 6 and 7 shown the best and the worst sample after immersion in dichloromethane.

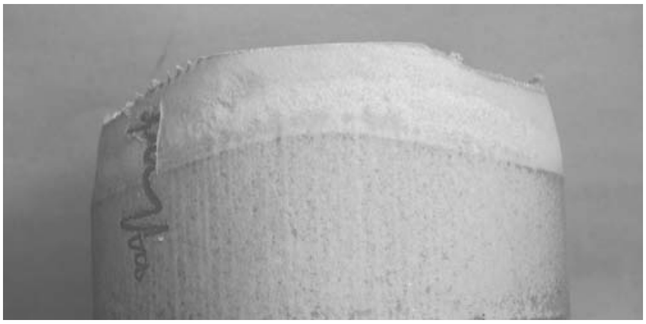


Fig. 6. Samples No.1 after immersion in dichloromethane (Samples No. 2 and 4 look very similar)

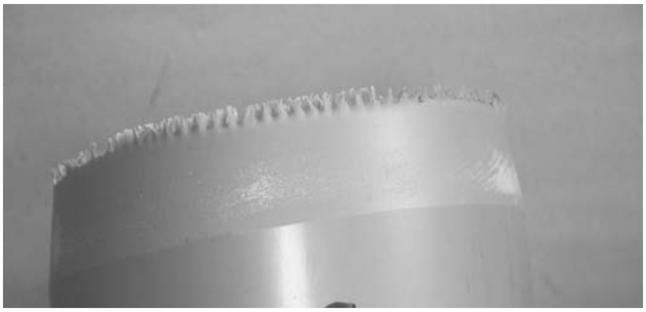


Fig. 7. Samples No.3 after immersion in dichloromethane - the best surface sample after this test

3. Description of achieved results

Standard PN-EN ISO 1401-1, Annex B provides the average density for the pipes with PVC-U of 1.4 g/cm^3. Research has shown that the material of all pipes exceed this value. Literature gives the density values for PVC-U in the range 1.38 to 1.55 g/cm^3. The highest specific density is characterized by the sample No. 2 (1.555 g/cm^3), which may indicate the use of large quantities of fillers.

All test tubes meet the requirements of PN-EN ISO 1401-1 for ring stiffness. For the test pipe ring stiffness shall be greater than or equal to 8 kN/m^2. The lowest value was obtained for sample No. 4 (8.73 kN/m^2).

Requirements standard PN-EN 744 definitely does not meet the tube No. 2, which was destroyed (Fig. 3). Other tubes of PVC-U does not exhibit damage within the meaning of the PN-EN 744, although it should be noted that the study made at ambient temperature. Under these conditions, however, observed white marks on the inside wall of the tube, suggesting the possibility of damage to the lower temperature tests. Pipe made of PP, there was no evidence of any impact of the weight.

All tested samples meet the requirements of PN-EN 743 and shall not exceed 5% longitudinal shrinkage.

According to the standard PN-EN 580 should not occur any change in the structure. Studies have shown that only tube No. 3 is characterized by minimal changes in the structure. Other tubes do not meet the requirements of the standard.

4. Conclusions

Based on the survey, according to PN-EN 1401-01, and international and national standards cited in the chapter 2.2, only samples of pipes No. 3 and 5 satisfy the quality criteria.

Both pipes are characterized by high chemical resistance in case No. 5 resulted from the use of polypropylene, while in No. 3, with the proper gelation unplasticized polyvinyl chloride.

Other pipes strongly interact with dichloromethane, which proves unsatisfactory gelled of polyvinyl chloride. Other pipes strongly interact with dichloromethane, which proves unsatisfactory gelled of polyvinyl chloride. This may in future lead to chemical reactions pipes with sewage. Both pipes have a good ring stiffness. Well above than the declared by the manufacturers. In test method for resistance to external blows by the round-the-clock method fared best pipe No 5. On the pipe No. 3, are the visible signs of strokes.

Also pipes No.1 and 4 meet the criteria for resistance pipes, and are characterized by the lowest among the tested pipes stiffness of ring, but still it is a value satisfying requirements of the standard PN EN 1401-1. In this research both pipes of similar resistance to impact determined by test method for resistance to external blows by the round-the-clock method. Evaluation of the possibility of their use should be preceded by an analysis of the requirements for chemical resistance of the transported medium, since both pipes reacted with dichloromethane, which proves unsatisfactory unplasticized gelled of polyvinyl chloride.

The lowest scores on the examinations obtained tube No. 2, which had a low chemical resistance, providing a poor unplasticized gelled of polyvinyl chloride. This pipe, was also the only one that was destroyed in a sample of the weight falling. The high stiffness and high specific gravity suggest the use of high content of fillers, which also revealed flaws observed on the surfaces of the pipe. We recognize that the worst of pipe examined.

To summarize the research shows more frequent inspections are necessary. These inspections should include execution of pipeline technology, but also control the material from which pipes are produced.

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