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Erosion resistance testing of plastic pipes

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Properties

ABSTRACT

Purpose: The purpose of this paper was to present the results of a special abrasion test of poly(vinyl chloride) and polypropylene filled with calcium carbonate pipes. Abrasion test's results for pipes were compared with results of standard abrasion test (Taber method) and hardness test.
Design/methodology/approach: Short cuts of pipe were subjected to erosion caused by erodent, usually a mixture of special kind of sand and water. The changes of pipe's wall thickness was a measure of resistance to erosion. Additionally abrasion resistance was measured using Taber method and ball-hardness was measured using Brinell apparatus.
Findings: Calcium carbonate filled polypropylene exhibited lower resistance to abrasion than hard poly(vinyl chloride). Probably it is the result of filler presence in polypropylene. No correlation between hardness and abrasion resistance was found.
Research limitations/implications: Applied method may be used to compare different pipe's materials but its results may not be applied to other plastics products and to other abrasion conditions.
Practical implications: Abrasion test used in the research may be applied to compare different materials and different pipelines components. Achieved results showed that calcium carbonate without surface preparation decrease abrasion resistance of polypropylene.
Originality/value: Applied method is rarely used for polymer materials testing. Results of presented research may be interesting for pipe manufactures and polymer pipe's formulations producers.
Keywords: Wear resistance; Abrasion; Engineering polymers; Pipes

1. Introduction

Plastic pipelines are exposed to many hazardous influences during their lifetime. To main deteriorating factors belong chemical and thermal degradation, stress corrosion, external loads and pressure. One of important deteriorating processes is wear as a result of solid abrasive particles influence. In many cases, especially in sewage pipelines, transported media may be treated as dispersion with very abrasive solid particles. Knowledge of the nature of processes occurring during flow of dispersions with solid hard particles can allow to predict the lifetime of pipeline and to apply the best material for defined media and flow conditions.

There are many theories concerning tribology and also polymers tribology [1-5]. Theoretical and experimental models on polymer composites wear are limited and more complicated [3, 6-12, 19]. There are also theories and experimental results describing abrasion wear of polymer pipeline's elements [13-16]. Most of them describe abrasion wear as a result of solid particles striking. Solid particle falling on the wall cause polymer material deformation, scratching, cutting, crushing and detaching of surface layer of pipe's wall. In the case of filled polymers erodent particles cause also detaching the filler particles from polymer matrix [17]. Solid particles as a erodent are transported by air or by different type of liquids.

There are many methods of wear resistance of polymer materials testing [3,18]. Depending on tribological systems influences all testing methods can be divided into two classes:

- Testing of polymer-metal or polymer-polymer pairs being in mutual contact with or without additional media (contact methods)
- Methods applying stream of abrasive particles or loose solid abrasive particles in air or other fluid.

In the first group of methods wear is measured after defined time or distance of sliding of testing sample on reference surface.

In the second class of methods loose abradant particles are placed between tested surfaces or stream of erodent dispersed in compressed air or water is directed at defined angle at tested surface.

The most widely applied method are:

- Dry wear using loose particles of erodent;
- Wear using particle's accelerators;
- Sand blasting;
- Shot blasting;
- Taber method;

There is a lack of Polish standards describing wear resistance testing of plastic pipelines elements. Because of this foreign standards, especially German, are applied. The most frequently applied method in Poland is the method elaborated at Technical University of Darmstadt, Germany (usually called TH Darmstadt method).

The present paper describes results of wear resistance of PVC-U and filled PP pipes. Wear resistance was tested using TH Darmstadt and Taber methods. Additionally ball hardness was measured.

2. Experimental

2.1. Methods used

Experimental programme covered three tests: wear test (TH Darmstadt test). Taber wear test and ball hardness measurement. First wear resistance test was performed according to recommendations of TH Darmstadt and DIN. 19534. Diagram of testing equipment is shown in Fig.1. The apparatus our own construction was applied. The shape of the sample is shown in Fig. 2. Test pieces were filled with water dispersion of special natural quartz gravel.

Abradant with the following particle size distribution was used:

- Mean particle diameter – $d_{50\%}$ = 6mm;
- Max. diameter of 80% of particles – $d_{80\%}$ = 8,4mm;
- Max. diameter of 20% of particles – $d_{20\%}$ = 4,2mm;
- Max. non-uniformity of particles – $U = d_{80\%} / d_{20\%} = 2$.

Samples filled with dispersion were subjected to swinging motion with angle +/- 22,5°. The frequency was 20 cycles per minute. The test lasted 400 000 cycles. Every 100 000 cycles dispersion was exchanged and every 25 000 wall thickness was measured.

Additionally, for reference purposes, Taber test was performed. In this sample with a shape of rectangular plate was mounted to a rotating table and was rubbed off by two wheels covered with erodent. Scheme of apparatus with test specimen is shown in Fig. 3.

The following conditions were fulfilled:

- Rotational speed of table – 60 rpm;
- Number of rotations – 500;
- Force pressing wheel do sample – 50 N
- Type of abrasion wheels - CS 17.

Mass loss was measured after 200 and 500 rotations.

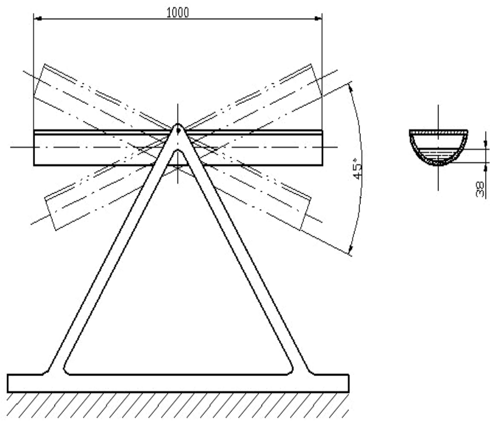

Fig. 1. Schematic diagram of wear resistance testing apparatus according to TH Darmstadt requirements

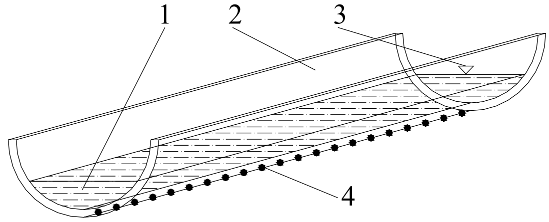

Fig. 2. Test sample: 1 – water with abradant, 2 - test sample, 3 - water level, 4 - wall thickness measuring points

Additionally ball hardness was evaluated according to EN ISO 2039-1 2004 standard. The following conditions were fulfilled:

- Temperature: 23 +/- 2°C;
- Force acting on penetrator: 358 N.

Ten measurements were taken and mean values were calculated.

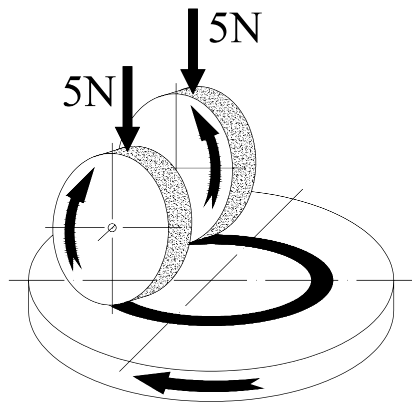

Fig. 3. Principle of Taber test

2.2. Materials

Three layer unplasticized polyvinyl chloride PVC-U pipes, with foamed middle layer, were produced by Plastimex, Psary, Poland. Polypropylene filled 30% by weight with natural $CaCO_3$ (PP + 30%$CaCO_3$) pipes were produced by PPH Czapliński, Syców, Poland

2.3. Results

Results of TH Darmstadt wear test are given in Table 1. Relative wear ratio (w) was calculated according to the relation:

$$w = \frac{e_0 - e}{e_0} \cdot 100\%$$

where: e –wall thickness after wear; e_0 – before wear.

Table 1.
Results of TH Darmstadt wear resistance test

Property	Compound	
	PP+30%$CaCO_3$	PVC–U
Initial mean wall thickness, mm	2,80	5,69
Max. wall thickness decrease, mm	0,50	0,54
Mean wall thickness decrease, mm	0,36	0,28
Max. relative wear, %	17,87	9,49
Mean relative wear, %	12,86	4,92

Table 2.
Results of Taber wear resistance test

Compound	Mass loss after 200 rotations, mg	Mass loss after 500 rotations,mg
PP+30%$CaCO_3$	0,0041	0,0110
PVC–U	0,0145	0,0213

Table 3.
Results of ball hardness measurements

Compound	Ball hardness, N/mm^2	St. deviation, N/mm^2
PP+30%$CaCO_3$	163,3	8,96
PVC–U	95,03	3,55

Experimental results of Taber's test are given in Table 2. Results of ball hardness are presented in Table 3.

3. Discussion

Complicated process of abrasion in TH Darmstadt method caused significant differences in wall thickness after wear. Profiles of pipe's wall thickness before and after 100 000 wear cycles are presented in Fig. 4 and Fig. 5. The greatest wall thickness decrease occurred in the middle of test pieces. In this region the greatest velocity of dispersion was observed. Observation and analysis of abradant motion at the ends of sample showed that abrasion wear should be here much lower than in the middle of test specimen.

Observed scatter of experimental results was probably the consequence of complicated abrasion mechanism Greater results scatter was observed for PVC-U pipe. (Fig. 5)

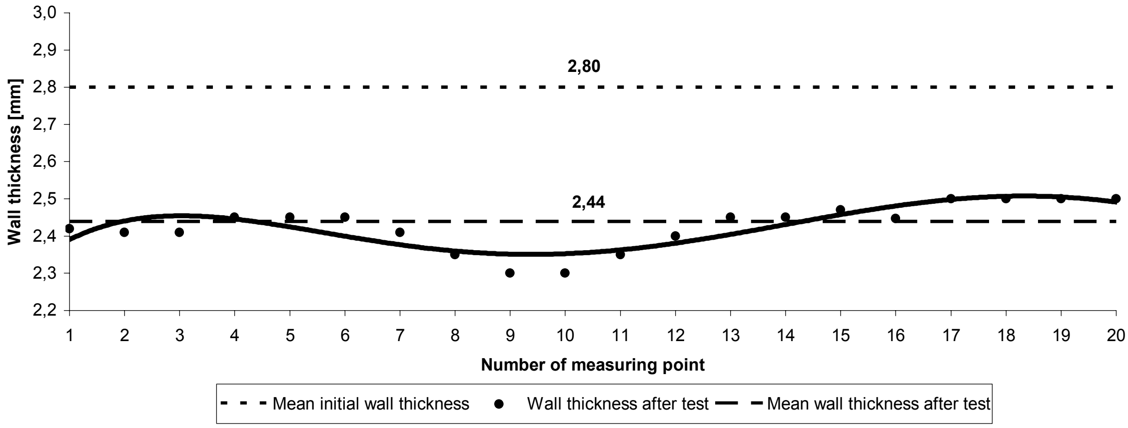

Fig. 4. Wall thickness decrease as a result of abrasion for PP+30%$CaCO_3$ pipe test piece after 100 000 wear cycles

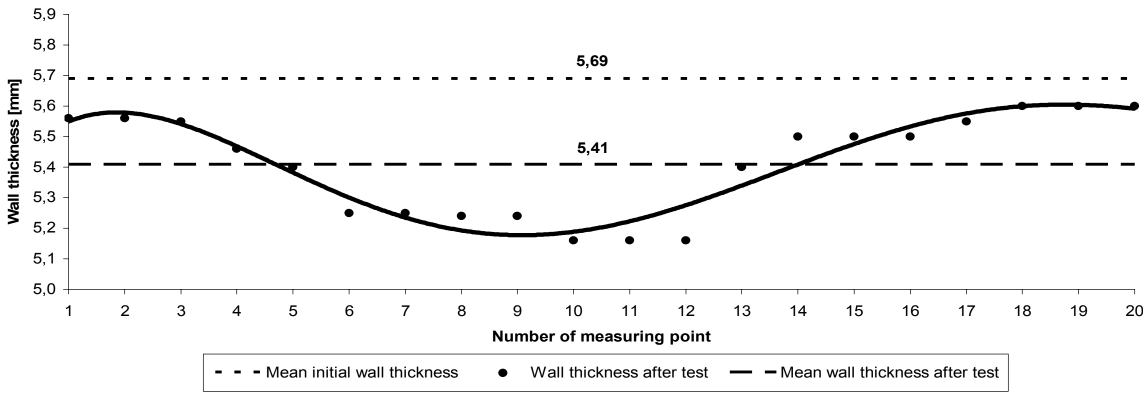

Fig. 5. Wall thickness decrease as a result of abrasion for PVC-U pipe test piece after 100 000 wear cycles

Results shown that PVC-U possessed higher wear resistance than filled polypropylene. These results are unexpected taking into account most often given wear test's result for unfilled polyolefin. Probably it is the result of filler incorporation into polypropylene matrix. The filler was introduced without surface modification. In general, the weak bond between the filler and a thermoplastic polymer matrix leads to the filler particles detaching from the matrix causing accelerated wear [6]. In order to enhance wear resistance of this composite it is recommended to apply filler particles surface modification.

Dependence between mass loss in Taber test and the number of rotations are shown in Fig. 6. Greater mass loss was observed for PVC-U. Achieved results are quite contrary to that observed in TH Darmstadt method. The difference can be explained by different wear mechanisms. It confirms the importance of testing method selection. The selected method should take into consideration working conditions of pipeline. TH Darmstadt method is specially devoted to compare abrasion resistance of plastic pipes materials. Because of complicated mechanism of wall abrasion it is hardly to compare results achieved using this and other methods.

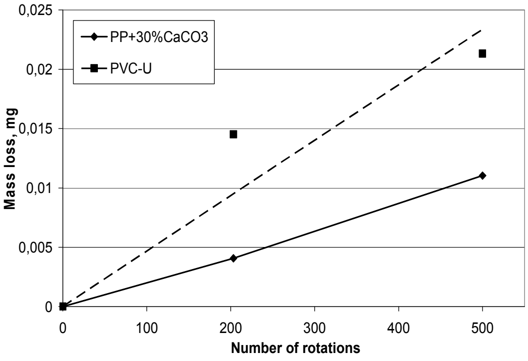

Fig. 6. Mass loss in Taber test in relation to the number of rotations

Results of ball hardness shown that filled polypropylene has higher hardness than unplasticized poly(vinyl chloride). It is the result of presence of hard fillers particles in polymer matrix. Comparing wear resistance and hardness results it can be seen that higher hardness is not necessarily connected with higher wear resistance. Filler presence can alter this commonly accepted results.

4. Conclusions

PVC-U pipes exhibited higher resistance to abrasion than filled PP when tested with TH Darmstad methodology. Opposite results were achieved with Taber method.

Higher ball hardness values were achieved for PP+$CaCO_3$ than for PVC-U.

Higher hardness results are not necessarily connected with higher wear resistance results.

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