Plastic Pipes for the Hydraulic Transportation of Solids

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Kunststoffrohre für den hydraulischen Feststofftransport
Tubes en matière plastique pour le transport hydraulique de matières solides
Tubos de plástico para el transporte hidráulico de sólidos

固体粒子の水力輸送用プラスチックパイプ
固体液压运输塑料管
أنابيب البلاستيك المستخدمة في النقل الهيدروليكي للمواد الصلبة

Summary

Plastic pipes, in particular High Density Polyethylene (HDPE) have found wide acceptance for the hydraulic transportation of bulk materials. This paper discusses the basic properties and applications of the various types of plastic pipes currently available.

1. Introduction

Plastic pipes made from unplasticised PVC (UPVC), high density polyethylene (HDPE) and polypropylene (PP) have already been used successfully in many applications. PVC and HDPE pipes in particular, are well established for water and gas supply and effluent discharge. It seemed an obvious idea to use pipes made from such plastics for the hydraulic transportation of solids in view of their excellent corrosion resistance and ease of handling due basically to their light weight and flexibility [1, 2]. Abrasion tests show that plastic pipes, and particularly HDPE pipes, may be classified as wear resistant materials [3]. Table 1 details some of the main physical properties of these plastics together with existing standards and guidelines for their use.

In addition to the above types of plastic pipes a further type termed polyamide pipes (PA) are used extensively for flushing and gravel conveying lines, but are not employed for supply or discharge lines.

Four basic criteria determine the choice of material for hydraulic transportation pipelines:

— Strength of the pipe under internal pressure
— Abrasion resistance
— Corrosion resistance
— Friction loss

Table 1: Typical physical property values for HDPE, PP and UPVC at 20 °C

	Property	Unit	Test method	HDPE (® Hostalen GM 5010 T2)	PP Homo-polym. (® Hostalen PPH 2250)	PP Co-polym. (® Hostalen PPH 2222)	UPVC
	Density	g/cm³	DIN 53479	0.954	0.915	0.910	~1.36
	Melt index MFI 190/5	g/10 min	DIN 53735 E	0.5	0.6	0.6	—
Mechanical properties	Yield stress	N/mm²	DIN 53455	22	33	29	~50
	Elongation at yield	%	DIN 53455	15	20	17	~12
	Elongation at break	%	DIN 53455	>800	800	1100	~30
	Flexural creep modulus 1 min value	N/mm²	σ_B = 3 N/mm²	800	1200	1000	3000
	Notched impact strength	kJ/m²	DIN 53453	15	11	40	~3
Thermal properties	Crystalline melting range	°C	DIN 53736	127...131	160...165	160...164	—
	Freezing range	°C		—110...—120	—10...+5	—50...—70	+75...80
	Linear expansion coeffic.	K⁻¹	DIN 52328	$2 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$	$0.8 \cdot 10^{-4}$
	Thermal conductivity	W/m.K	DIN 52612	0.4	0.22	0.22	~0.14
Electrical properties	Volume resistivity	Ω · cm	DIN 53482	$>10^{16}$	$>10^{16}$	$>10^{16}$	$\sim 10^{16}$
	Surface resistance	Ω	DIN 53482	$>10^{12}$	$4 \cdot 10^{13}$	$4 \cdot 10^{13}$	$\sim 10^{13}$
	Relative dielectric constant ϵ_R	—	DIN 53483	2.5	2.25	2.25	~3.45

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2. Criteria for Plastic Pipelines

2.1 Internal Pressure Creep Strength

To determine the service life of a plastic pipe under constant internal pressure, it is necessary to know its rupture strength as a function of both time and temperature. HDPE, PP and PVC pipes have already been subjected to creep tests of this type for more than 20 years.

Fig. 1 shows the creep rupture curves for various high molecular HDPE types. For the reference stress plotted on the ordinate of the creep diagram applies:

$$\sigma_v = \frac{p \cdot d_m}{2s} \qquad (1)$$

where

p = internal pressure

d_m = average pipe diameter

s = wall thickness.

The permissible reference stress, which is the governing criterion when dimensioning a pipe, is obtained by allowing for a safety factor which, depending on the toughness of the material (HDPE, PP, PVC), can lie between 1.3 and 2.5. For pressure pipelines, creep strength is normally the most important quality criterion. For this reason it has been included in the relevant standards.

With increasing abrasion, that is, decreasing wall thickness, the reference stress rises and the useful life diminishes.

When dimensioning the pipeline, it is therefore necessary to ensure that even after a certain rate of wear has been reached, an adequate safety margin against rupture remains.

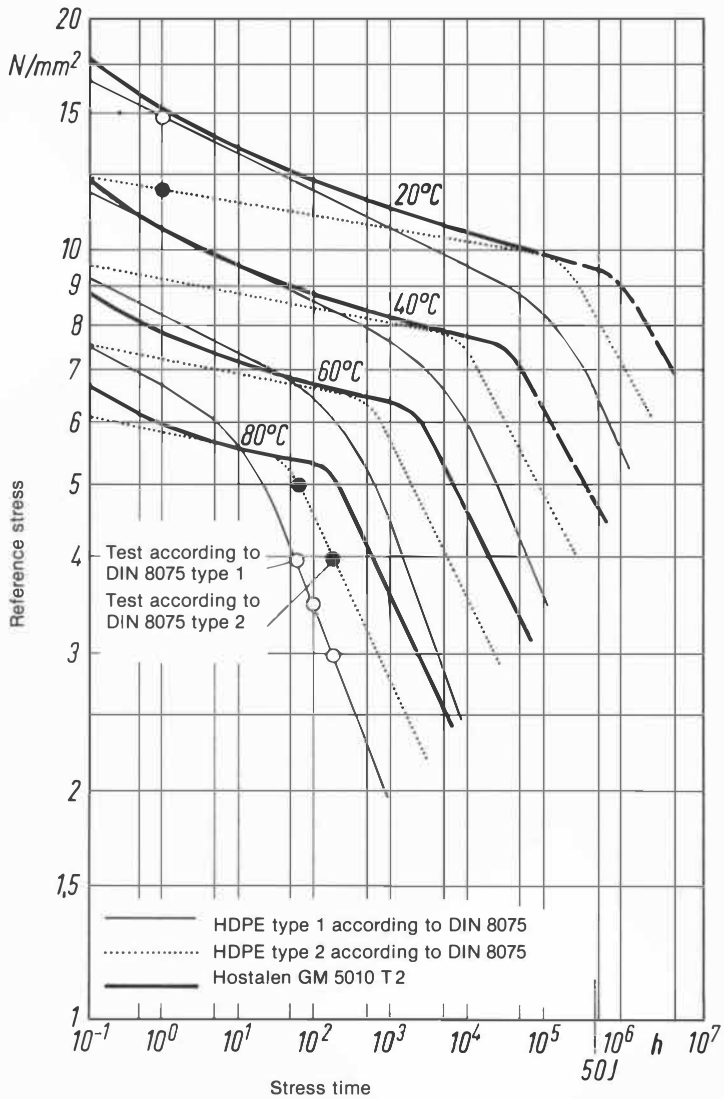

Fig. 1: Creep strength of pipes made from various HDPE types

2.2 Abrasion Resistance

Among wet methods of testing abrasion characteristics, the Darmstadt method of Kirschmer [4] and practical wear tests employing pipe sections built into a pipeline have attained a certain importance.

In the method developed at the Technische Hochschule Darmstadt, Germany, the test specimen consists of a 1 m long half section of DN 300 pipe which is tilted to and fro in a slow rocking motion at a frequency of 0.18 Hz (Fig. 2). This frequency corresponds to 21.6 stress cycles/min — a stress cycle being defined as a single movement of the abrasive material in one direction. The frequency of 0.18 Hz guarantees that the abrasive material travels the complete length of the test pipe.

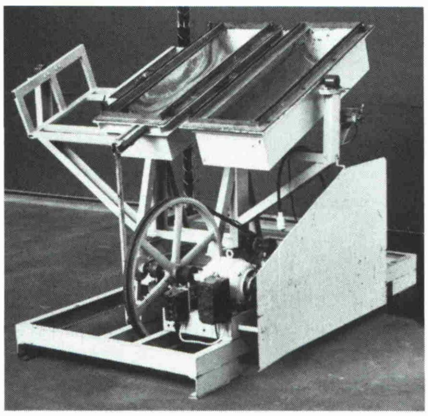

Fig. 2: Rocking device for abrasion tests

The flow rate is 0.36 m/s. The medium used is a quartz sand/gravel/water mix containing approx. 46 % by vol. quartz sand with a particle size of 0—30 mm. The abrasive material being changed every 100,000 cycles. The average reduction in wall thickness of the pipe invert after a given stress time is used as a measure of abrasion. As shown in Fig. 3 abrasion can then be plotted for different materials as a function of the number of cycles.

The HDPE pipe, with an average abrasion of 0.3 mm after 400,000 cycles (approx. 310 h), may be categorized as very good quality. The main features of this test method are time compression, high accuracy of measurement, reproducibility of results and the availability of a large number of comparative values.

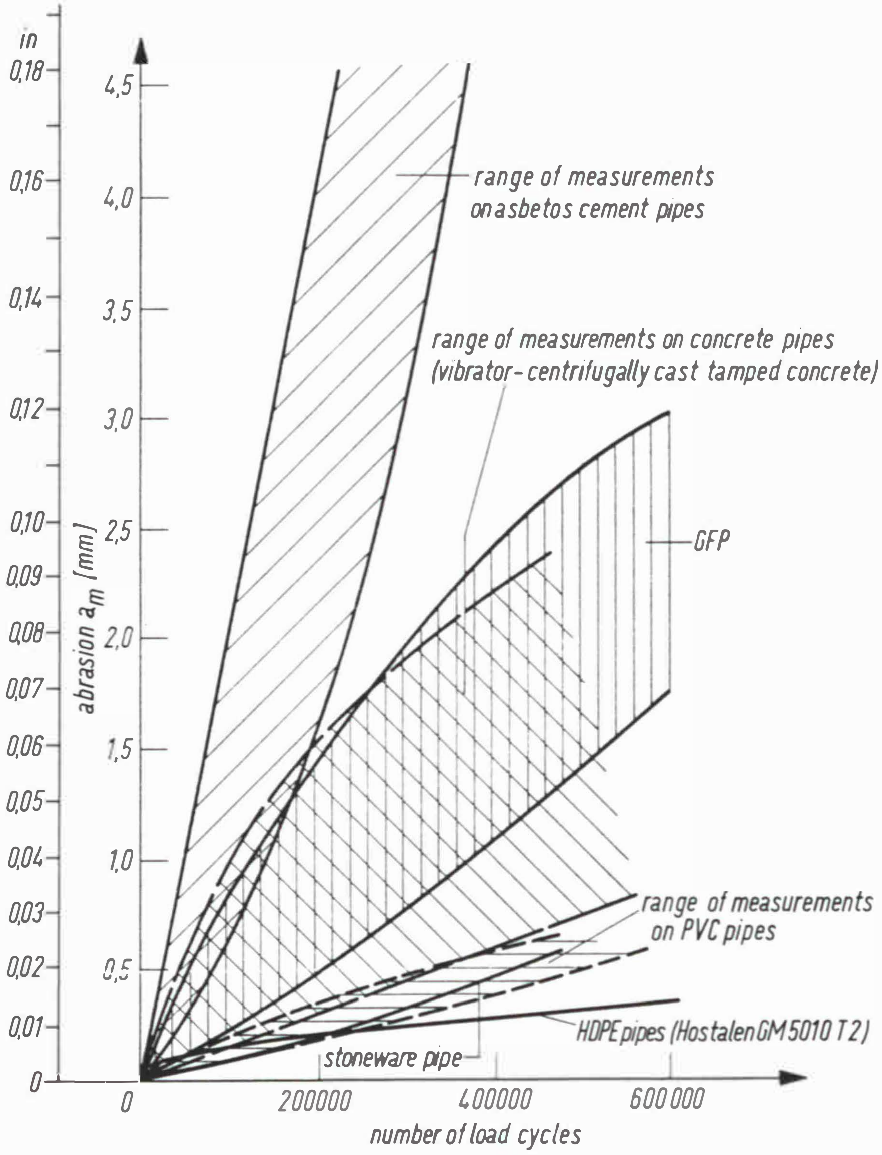

Fig. 3: Average abrasion values for pipes made from various materials

Fig. 4 Hostalen, steel and rubber lines (Ho) (st) (ru)
d = pipe diameter (63 mm)

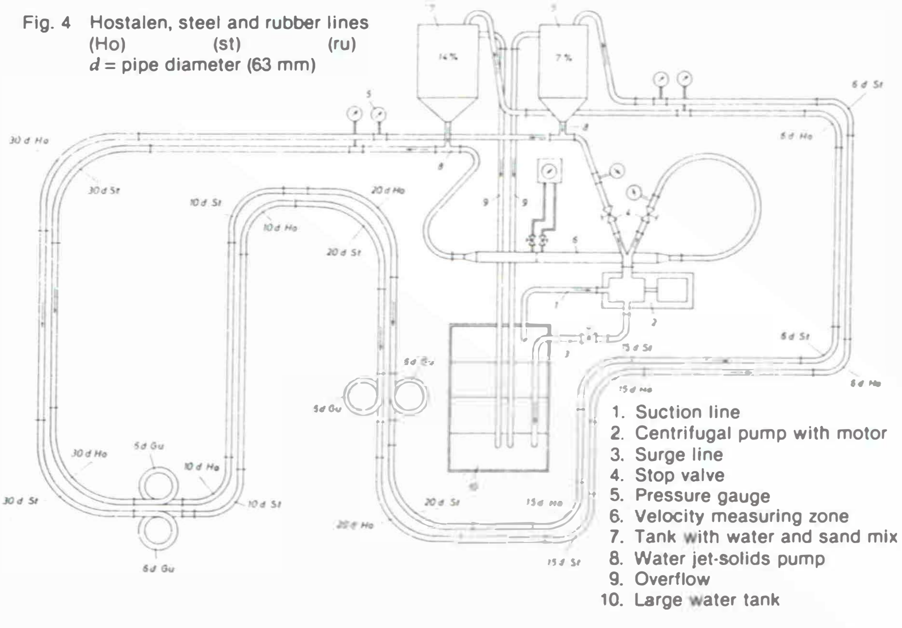

Fig. 4: Test rig for pipe wear tests

The conditions used in this test do not really reflect the actual conditions occurring in hydraulic transportation of solids (much higher speeds, movement of the medium in one direction only). More closely related to practical conditions are tests in which the medium is pumped through pipe specimens built into a pipeline. Thus St 37 steel pipes and HDPE DN 50 pipes in the pressure class PN 10 with a wall thickness of 6 mm and pipe bends with bend radii from 6 d to 30 d were tested until the appearance of a hole (Fig. 4) [7]. The material transported consisted of a quartz sand/water mix with 7 and 14 % by vol. quartz sand (particle size distribution 1—2.5 mm).

The average flow velocity was 7 m/s, the internal pressure 1.4 bar and the water temperature 30—35 °C. The sand was changed every 60/45 hours. Fig. 5 shows the effect of bend radius on the testing time up to the appearance of a hole. The plotted values were measured up to about 8,000 hours and the values above that extrapolated. The wear behaviour of bends is independent of bend radius up to bend radii of about 12 d. The weight loss determined during the test period as a measure of abrasion rose in proportion to the duration of the test period. Pipes and bends made from HDPE which showed signs of impact and frictional wear lasted four times as long as pipes and bends made from steel in which frictional wear was more marked.

The inside surface of straight pipe was worn in the invert region over about 150 ° of the periphery. The section of greatest wear was in pipe bends between angles 75 ° and 90 ° as measured from the input end of the bend in the direction of flow (Fig. 6). In an earlier design, in which the flanges were fixed immediately at each end of the bend, it was found that the disturbance caused by the pipe connection was superimposed on a second disturbance resulting from the change of flow direction at the end of the straight section of pipe. In tests at that time, a hole frequently appeared first directly behind the pipe connection in the straight section of pipe (Fig. 7).

More recent comparative abrasion tests with pipes made from HDPE (® Hostalen GM 5010 T 2) and steel (St 35.8) in which a quartz sand/water mix containing 25 % by vol. sand was pumped through the pipes at a pressure of 2.5 bar and a flow velocity of 5.5 m/s showed that the wear per unit of time in steel pipes is

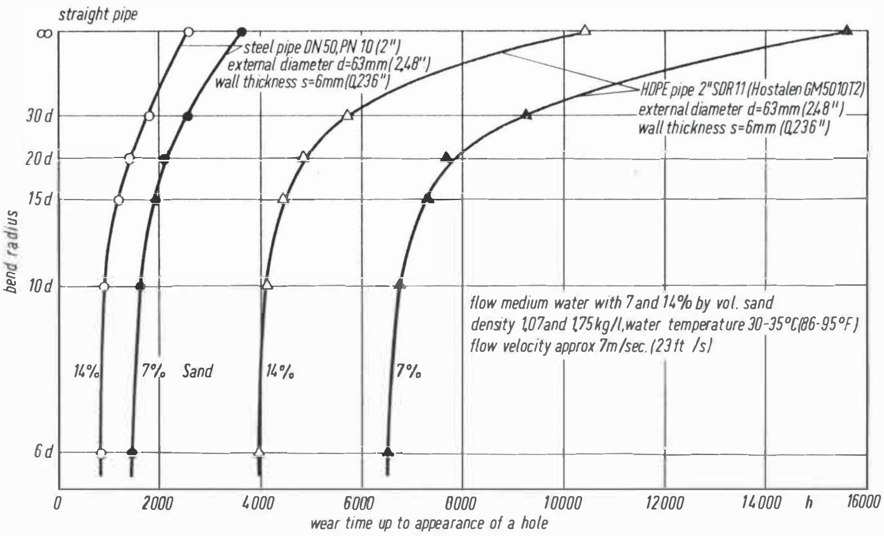

Fig. 5: Abrasion resistance of pipes and bends made from HDPE and steel

2.4 Abrasion Loss

Plastic pipes have very low inherent roughness. According to the latest studies with pure water as the medium, the roughness value k according to the Prandtl-Colebrook formula used for hydraulic design calculations is 0.005 mm for a DN 300 HDPE pipe and 0.013 mm for a DN 450 HDPE pipe [9].

There is only a small amount of pressure loss data available for plastic pipes transporting solids/water mixes. The few measurements which have been carried out and experience so far would indicate that in many cases a lower pressure loss can be expected than with steel pipes. For example, in hydraulic transportation of basalt chips [10] and sand [11], there was a 20 % reduction in pressure loss.

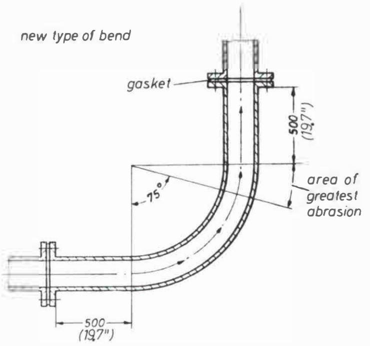

Fig. 6: Region of greatest wear in HDPE bends

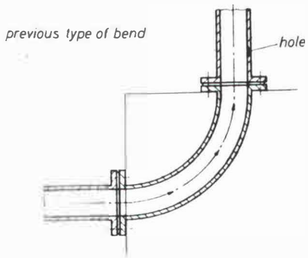

Fig. 7: Unfavourable bend design with flange connections at the end of each bend

3. Pipeline Systems

The dimensions and pressure classes of HDPE pipes are standardized in DIN 8074, and quality requirements in DIN 8075. The relevant standards for PP pipes are DIN 8077 and DIN 8078. In these standards [12, 13, 14], the wall thicknesses of the pipes were established on the basis of a permissible reference stress of 5 N/mm² at 20 °C after 50 years. In cases where the requirements in respect of service life are

about 2.5 times greater than in HDPE pipes [8].

Abrasion in HDPE pipes here was about 1 μ/h. In practice, this means that, for approximately the same price, an HDPE pipe 250 x 22.8 mm/PN 10 operating at a pressure of 6 bar will last at least 10 times as long as the corresponding 219.1 x 5.9 mm steel pipe which is almost twice as heavy. The criterion here is that the pipes should retain a safety factor of 1.5 against rupture from internal pressure after the service period (Table 2).

2.3 Corrosion and UV Resistance

The plastic pipes described here generally have good chemical resistance to the solids/water mixes normally encountered in practice, i.e., their creep strength is not lower than when in contact with water alone.

When plastic pipes are laid aboveground, they may in the course of time be damaged by the action of UV radiation. Outdoor weathering tests carried out in our latitudes over a period of many years have shown that quality pipes made from HDPE in which carbon black is the sole UV stabilizer remain undamaged even after 10 years' outdoor exposure, i.e., they conform to DIN quality requirements.

Table 2: Comparison of the service life of steel and Hostalen pipes DN 200/PN 10 transporting sand/water mix with 25 % by vol. sand at an operating pressure of 6 bar and at a temperature of 20 °C

Steel Pipe St 35.8		HDPE Pipe made from Hostalen GM 5010 T 2
Outside diameter	d = 219.1 mm	d = 250.0 mm
Wall thickness	s = 5.9 mm	s = 22.8 mm
Mass	w = 31.0 kg/m	w = 16.2 kg/m
Cost	70.00 DM/m	75.00 DM/m
Abrasion	a_{steel} = (2.5—4) μ/h	a_{HDPE} = 1 μ/h
Calculated wall thickness (s_f = 1.5)	s' = 3.2 mm	s' = 12.0 mm
Available wall thickness (s—s')	Δs = 2.7 mm	Δs = 10.8 mm
Service period $\Delta s/a_{steel}$	t_1 = 675 to 1080 h	t_1(HDPE) = (11 to 17) t_1 (st)

lower, wall thickness can be calculated with the aid of the formula for pipes. The permissible reference stress can be taken from the creep diagram in Fig. 1 with allowance being made for a safety factor for the required service life. HDPE and PP pressure pipes in pressure classes PN 10 and 16 are manufactured with outside diameters up to about 500 or 400 mm, pressure pipes in pressure class 3.2 up to 1600 mm diameter. The pipes can be connected by heated tool butt welding to form pressure-tight joints with good longitudinal thrust sealing. Detachable joints are obtained by a combination of a fixed welded flange and a loose flange made of steel. Pipe joints and sections of pressure pipeline made from HDPE and PP are covered by DIN 16963 and 16962.

The flexibility, particularly of HDPE pipes, enables changes in direction to be made simply by bending the pipes. For pipes in pressure class PN 10, for example, bend radii of up to 20 times the outside pipe diameter are permissible. The lengths of pipe delivered depend entirely on the transport facilities available.

Extruded pressure pipes made from unplasticized PVC are manufactured with outside diameters up to 630 mm. Dimensions and weights as well as general supply specifications and tests are contained in standards DIN 8062 and 8061. The pressure classes listed there relate to a reference stress of 10 N/mm² at 20 °C after a service life of 50 years. Pipe joints and pipeline parts for pressure pipelines made from unplasticized PVC are standardized in DIN 8063. Suitable methods of jointing are the insert socket joint with rubber ring which, however, does not provide 'longitudinal thrust sealing joint' or 'tensile strength of joints', the solvent bonded joint, and the flange joint [12]. The pipes are supplied in stock lengths of 6 and 12 m.

4. Practical Experience

4.1 HDPE Pipes

In Malaysia, HDPE pipes have been used for some years to transport tin ore/water slurries. The steel pipes previously used were found to have a service life of only 6—12 months (Fig. 8). The 355 x 11.1 mm plastic pipes scored over steel pipes in their absolute corrosion resistance, 40 % higher service life and 60 % lower weight.

In a 560 x 31.7/PN 6 test pipe used for flushing work in wet dredging, approx. 7 mm wear was measured in the area of the pipe invert after the solids throughput had reached about 1 million m³. The pipe had not been turned during this period. The medium conveyed consisted of a sand/water mix with 10 to 25 % by vol. sand with widely differing grain size and shape. The flow velocity was up to 5 m/s, the delivery pressure up to 7 bar.

For the last 4½ years, HDPE 250 x 16.2 mm/PN 6 pipes have been tested in a sand works for transporting a quartz sand/water mix from a flooded gravel pit.

Fig. 8: HDPE pipes made from Hostalen GM 5010 T 2 for conveying tin ore water slurries in Malaysia

The mix consisting of 70 % by vol. water and 30 % by vol. sand with angular grain up to 1.3 mm in size with an average diameter of 0.3 mm is conveyed at a pressure of 6 bar with a flow velocity of 2.3—3.9 m/s. With an annual production of 400,000 t sand, it has not been possible to establish any appreciable wear up to now. The decision to install HDPE pipes for washing the sand within the works where sand/water mixes of up to 70 % by vol. sand are conveyed has thus been justified.

At a brown coal mine, the pulp obtained in coal preparation, which is a mixture of coal, pyrites and water containing approx. 10 % by vol. solids with a grain size up to 0.5 mm, has for about 3 years now been conveyed to a worked-out open-cast mine in a 3 km HDPE pipeline laid aboveground, (Fig. 9). The pipes in pressure class PN 10 have an outside diameter of 250 mm and a wall thickness of 22.8 mm. The delivery pressure is 7 bar, the temperature 20 °C. With a throughput of 260 m³/h, wear is in the order of a mere thousandth of a millimetre.

4.2. UPVC Pipes

The use of PVC pipes for dressing operations in mines was reported in [1].

At a coal mine in Germany, the pulp in the flotation dumps, obtained during coal preparation, has for more than 6 years been conveyed from the thickener to the evaporation pond in a 1 km long underground unplasticized PVC pipeline DIN 100/PN 10 without any appreciable wear having occurred up to now.

Fig. 9: Transportation of coal pulp in HDPE pipeline

The pipes have a wall thickness of 8.2 mm and are joined together by solvent- bonded sleeves. The operating pressure is 5 to 6 bar, the flow velocity about 2 m/s. The pulp has a solids content of 45 % by vol. with a grain size of up to 0.06 mm (75 % of the solids) and 0.5 mm (25 % of the solids). The steel pipes previously used had to be replaced after about 2 years.

4.3 Polyamide Pipes

Polyamide (PA) pipes up to nominal diameters of 750 mm have recently been supplied for flushing lines and gravel conveying lines. The pipes, which are fitted at both ends with a fixed flange, are available in standard lengths of 6 m. From data published so far it is not clear to what pressure class the creep strength of the pipes relates.

Since PA has a tendency to absorb water, its mechanical properties must be considered in relation to moisture content. Reversible water absorption entails a certain change in volume and dimension. In their dry state, the PA grades are hard and more or less brittle. When conditioned, they become very tough and abrasion-resistant.

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