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# Influence of select parameters of drawing process on the expansive deposition of inner PE lining in pipelines

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**Properties**

## ABSTRACT

**Purpose:** This paper shows the influence of select parameters of drawing process on the expansive deposition of inner PE lining in pipelines.

**Design/methodology/approach:** The study included assessment of the impact of diameter reduction degree, drawing die angle, temperature, introductory pipe diameter, and introductory pipe wall thickness on the viscoelastic return. Obtained dependencies were assumed to be the basis for formulation of conclusions as to the choice of essential process conditions for the technological sequence of PE lining deposition in the outer coating of installation pipes or reconstruction of a transmission channel.

**Findings:** The final effect presentation is worked out methodology used in identification of physical parameters of a PE pipe drawing model as the main phase of a viscoelastic deposition of lining in two-layer pipes. Particular attention was focused on the need to take into consideration changing friction conditions in the drawing die area and to determine the value of the friction factor.

**Research limitations/implications:** The research did not show the influence of the length of the sizing and drawing speed on the viscoelastic return.

**Practical implications:** The practical effect is to develop the characteristics of the impact of process parameters on the size of time to viscoelastic return.

**Originality/value:** Paper represents model of PE lining deposition in the outer coating of installation pipes or reconstruction of a transmission network.

**Keywords:** Polymers; Viscoelastic return; Drawing process

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## 1. Introduction

The swagelining technology is based on the plastic working technology of sinking of pipes (Fig. 1). The traditional sinking is the type of plastic working of metal or polymer materials. It is used for permanent shaping of the material, changing the physical and mechanical properties, modification of structure or generation of internal stresses [1-6, 8 -9, 11, 13].

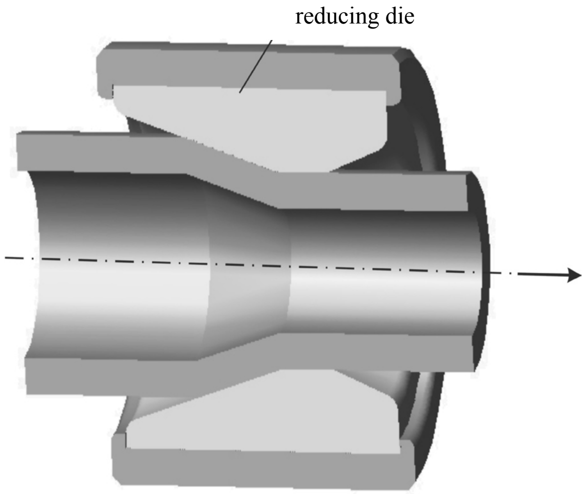



Fig. 1. Scheme of sinking of pipes

These are achieved through the plastic strain. Generally, it must be noted that the plastic working operations are accompanied by some negative effects including, but not limited to:

- springing – occurs in case of the forming of plastics due to the low value of Young's modulus (approx. 1/100 of the value for metals),
- elastic recovery – caused by viscoelastic properties of plastics [1-6].

The latter effect proves advantageous when using the sinking for the renovation of pipelines as it allows a tight fitting of the polyethylene lining inside the rehabilitated pipeline. Hence, such a use of the sinking constitutes the "viscoelastic working".

Cold plastic forming of plastics is usually performed in temperatures higher than the glass transition temperature [7, 12, 18]. However, since the glass transition temperature of some plastics (PC) is relatively high, their cold working is carried out in the glassy state. One of the most important advantages of the plastic working processes is the improvement of mechanical properties of the materials formed. However, a difference must be noted between the behaviour of thin and thick-walled pipes when pulled through the die where, in case of the former the wall thickening is observed, while the wall gets thinner in case of the latter. The sinking process itself generates significant stresses whose value depends on the diameter reduction ratio [1-5, 12]. In order not to allow the destruction (caused by high stresses) of the liner inserted into the rehabilitated host pipe, the liner remains under permanent load which enables the stresses to be partially compensated.

The best adherence of the PE pipe (PE pipes are used of the nominal diameter higher by 2-5% than the inner diameter of the rehabilitated pipe) is achieved when pulling the pipe through the die with the approach angle of 10-15% at the speed of 3-5 m/min [1-6, 8-9, 11]. The result of the operation is the diameter reduction of approx. 12% which enables to insert the PE pipe, without any additional resistance, into the rehabilitated host pipe. The important problem is selection parametrs of process which influence the expansive deposition of inner PE lining in pipelines. Parameters are diameter reduction degree, drawing die angle, temperature, introductory pipe diameter, and introductory pipe wall thickness. Temperature decreases viscoelastic return. The higher temperature, the smaller viscoelastic return.

Once the repair is completed the PE pipe expands and its construction becomes strengthened under the conditions of tight fitting in the rehabilitated pipeline which is of particular importance if a possibility exists to exceed the self-support limit under conditions of ground factors influence.

A number of advantages can be noticed resulting from the pulling process being performed in "cold" conditions. The advantages include: reduction of the number of additional equipment, possibility of quicker stopping the process which enables to weld the joint with additional service lines and to resume and complete the installation.

Another significant problem is the reconstruction efficiency measured by the flow rate in the new pipe to the flow ratio in the old conduit ratio, the pressure drop value being maintained. The research carried out by ERS British Gas [16, 17] showed that the increase in the flow rate can be achieved through the wall thickness reduction.

## 2. Stress analysis in the reducing die

The drawing process causes the material to deform due to following external forces: efforts (active forces) (N – drawing load) and reactions (Q – tool reaction, T – friction force) – Fig. 2. The above forces cause the internal stresses to occur in the material drawn. The axial – symmetric stresses are characteristic for the sinking of pipes where the following stresses are observed axial stresses (tensile stresses) $\sigma_1$, radial stresses (compressive stresses) $\sigma_r$ ($\sigma_3$) circumferential stresses (compressive stresses) $\sigma_\varphi$ ($\sigma_2$) [12, 14, 15].

The value of the drawing load F depends on the properties, dimensions, size and elastic recovery of the material drawn as well as on the tool geometry. There is also a significant, indirect dependence on the process temperature [4, 5, 15].

The process analysis shows that the material in the die zone is partially plasticized. On leaving the die, a rapid diameter increase or swelling are observed and therefore the pipe remains under load.

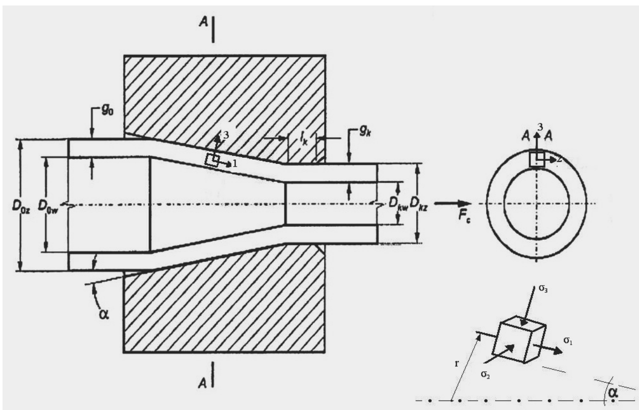


Fig. 2. State of stress and strain components in a pipe wall in the drawing die area [15]

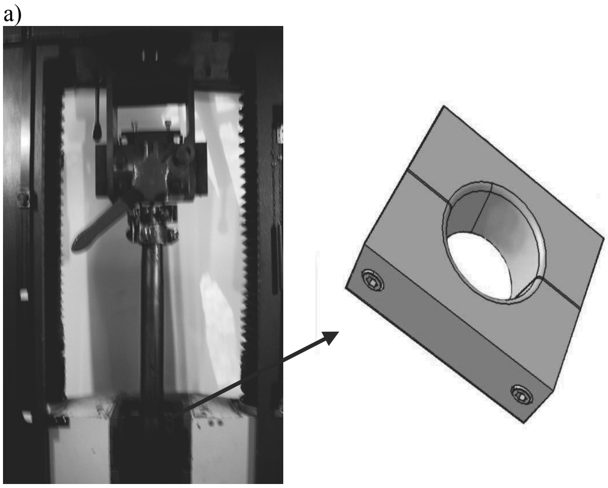
Starting with stresses described with formulas (1) and assuming average radial stress value ($\sigma_3$) equal to half of a unit pressure q(r), it is possible to determine the state of stress components.

## 3. Experimental

The research aim was to term the influence of select parameters of drawing process on the viscoelastic return. The research was carried out in the laboratory of the Derpartment of Processing of Metals and Polymer Materials. A Heckert FPZ 100/1 testing machine (Fig. 3) was adapted for the purpose of testing. Geometric parameters of reducing die shown in Table 1.

The research, in order to determine the subject elastic recovery, the following PE pipes were used: diameter – 63 mm, pipe wall thickness – 5.6 mm (SDR 11) and 3.8 mm (SDR 17). The tests were carried out in the ambient temperature of 20°C±2°C (Fig. 3a), and the sharp temperature of 25, 30, 40 and 50°C ± 2°C (Fig. 3b). During the testing the outer diameters were measured in specific intervals and the tensile force was recorded.

a)



b)

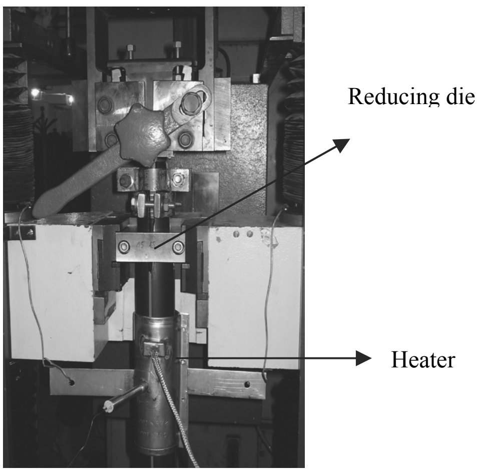



Fig. 3. Test stand a) for cold, b) for hot

Table 1.
Geometric parameters of reducing die

| Angle of die | 12.5° | 15° | 17.5° |
|---|---|---|---|
| Degree of reduction | | 10%<br>15%<br>20% | |

Pre-heating was performed with a circumferential heater situated under the drawing zone – the initial temperatures of the pipe were: 25±2, 30±2, 40±2 and 50±2°C. The tools used were drawing dies with various reduction degrees and approach angles.

In order to determine the elastic recovery of the pipe the outer diameter was measured. The diameter was measured in fixed intervals counted from the drawing process completion. Due to the ovality of the pipes drawn the arithmetic mean of five measurements was assumed. Diameter change as a function of time illustrated diagram – see Fig. 4 and Fig. 5 – shows relationship between viscoelastic return and various temperatures during drawing process.

The process analysis demonstrates that the material in the die zone is plasticized. On leaving the die, a rapid diameter increase or swelling caused by the release of the alternating load are observed. Further stage is the process of the viscoelastic recovery under conditions of the axial load and after the release there.

The diagrams illustrate the successive stages of the elastic recovery – pulling through the die (die), "swelling" (up to 1 min after leaving the die), tension release (after 1 minute), further return to the original diameter (from 1 minute to 3000 minutes – Fig. 4 and 1440 minutes – Fig. 5).

The results of the tests performed enabled the determination of the dependence of the drawing force on the geometric parameters of the die for the series of the pipes tested – see Fig. 6. There are two areas visible in the figure, first of them for SDR 11 – values from 6.8 kN to 10.9 kN and the other one – for SDR 17 with significantly lower force values ranging from 4.3 kN to 7.4 kN which is the result of the wall thickness. Influence drawing process in reduction die zone as described in section 4 of temperature on the temperature process show Fig. 7.

Knowledge of this force is important for physical modeling of drawing process in reduction die zone as described in section 4.

Analysis of the return runs indicates their similarity as far as temperature range 20-40°C is concerned. Uniform decrease of the modulus of elasticity and the yield point in the given temperature range, and in the conditions in which the drawing speed and reduction level are constant, may explain the deformation state after drawing. Moreover, the after-deformation return has a similar course in balanced temperature conditions, which indicates lack of significant and permanent changes in the viscoelastic properties of the material. However, a process running in conditions with the initial temperature of 50°C shows a significantly different course. Local loss of pipe stability effect was observed during the drawing in the section with increased temperature. Local reduction of diameter occurred that can be called "formation" and which does not reflex the assumed description method of the diameter change diagram (Figs. 4 and 5). Moreover, the lengthening value increased significantly, which means that softening started and the sample plasticity increased considerably. On the basis of the determined properties of after-deformation returns, both circumferential and longitudinal, it was found that the temperature should not exceed 40°C,

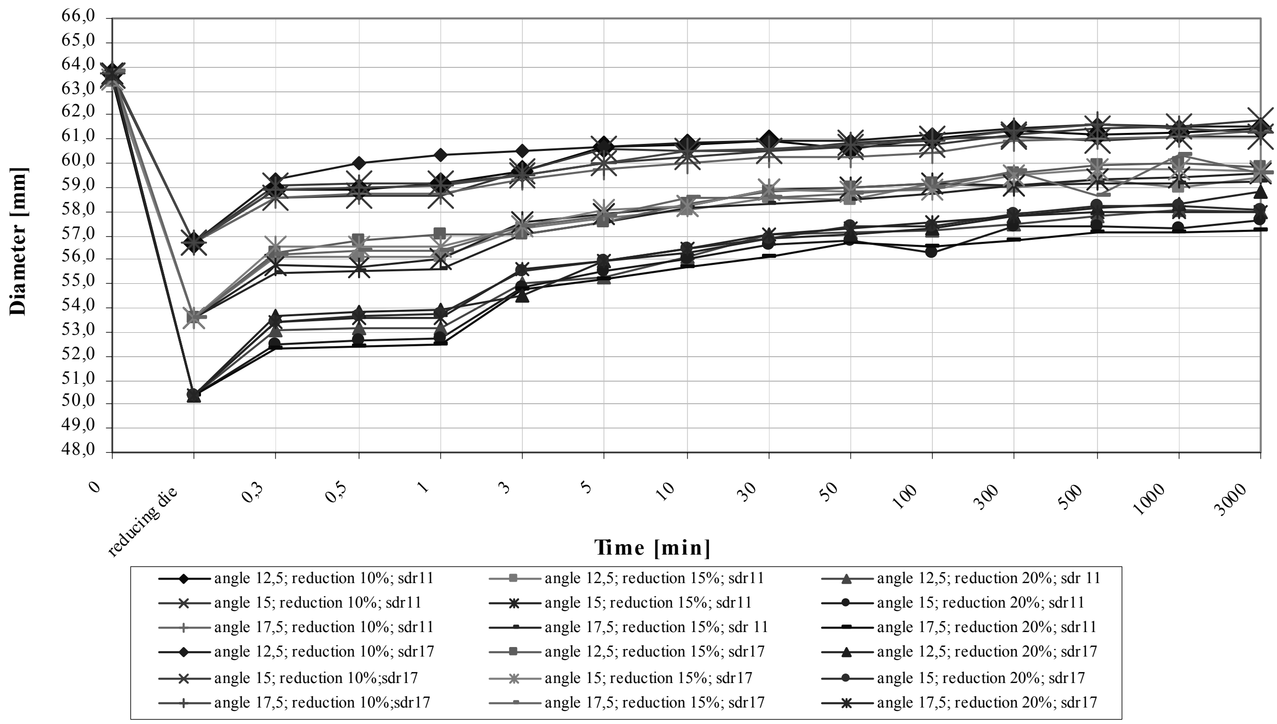



Fig. 4. Course of change of polyethylene pipe diameter as a function of time for various wall thickness – 5.6 mm (SDR 11) and 3.8 mm (SDR 17)

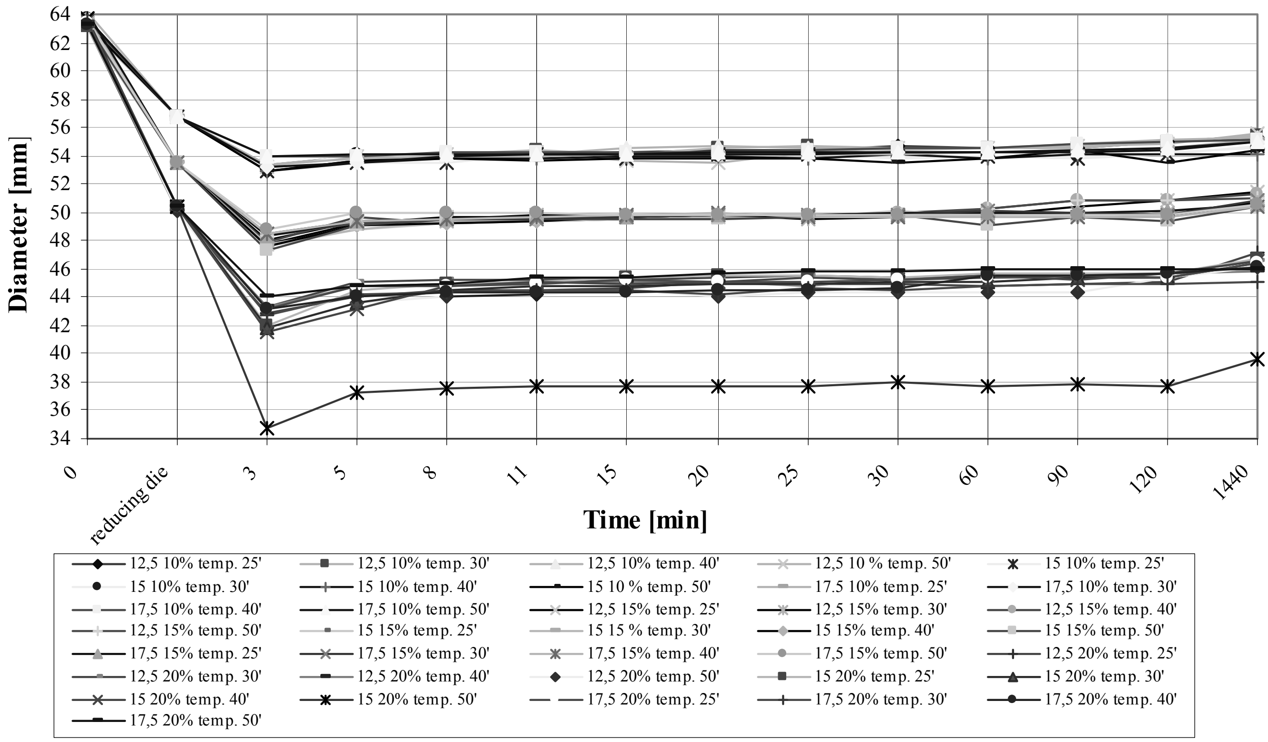



Fig. 5. Course of changes of diameter polyethylene pipe as a function of time for various temperature of process (5.6 mm wall thickness)

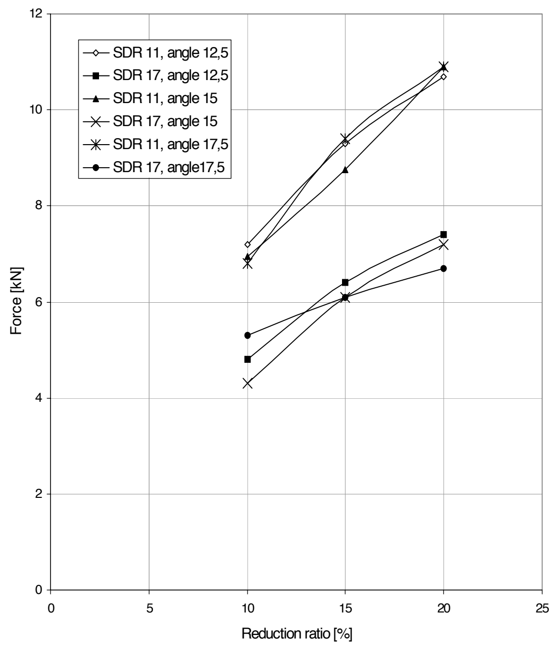



Fig. 6. The dependence of the drawing force versus the reduction ratio for different pipe wall thickness

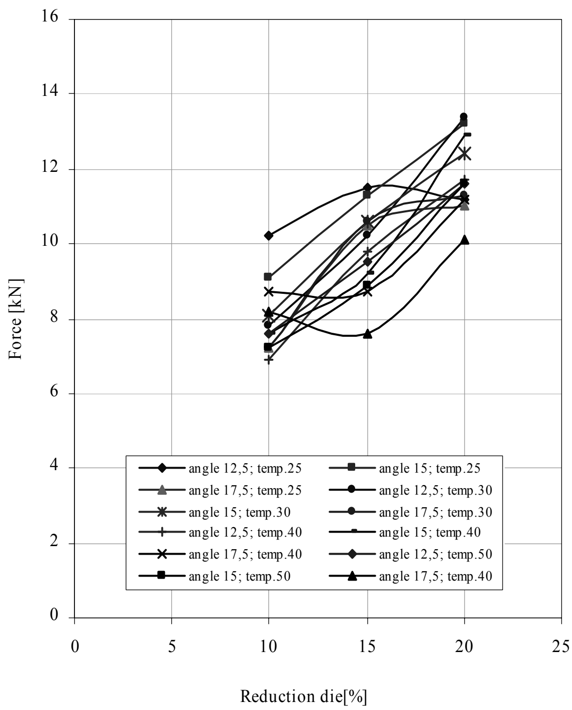



Fig. 7. The dependence of the drawing force versus the reduction ratio for various temperatures

as far as efficiency of the process is concerned. Estimation of the best temperature value requires assessment of other properties of the process, such as the drawing force and changes of the strength properties of the material. In order to examine even closer the deformation mechanism which occurs in the drawing die zone and which is essential for the latter pipe diameter and length reversion, it is necessary to determine the thermal conditions in that zone. They depend on the initial temperature of the material but also on the drawing conditions – type of the material, tools, drawing speed, etc. Further research of that issue is anticipated, taking into consideration analysis of the actual temperature profile in the drawing die zone measured with use of the infrared mapping technique.

## 4. Physical model

The drawing force depends upon many parameters, the most important of which are: diameter reduction degree (X), drawing die angle (α), introductory pipe diameter ($D_{oz}$) and introductory pipe wall thickness (g). The model assumes plasticization of a part of the pipe wall being a result of pressure caused by the tool. The state of stress and strain is presented in Fig. 2, part 2.

Starting with stresses described with formulas (1) and assuming the longitudal ($\sigma_1$) and radial ($\sigma_3$) stress value adequate to an average unit pressure q(r), it is possible to determine the state of stress components:

$$\sigma_1(r) = \frac{N\cos^2\alpha}{2\pi g r\sin\alpha}, \tag{1}$$

$$\sigma_2(r) = -\frac{q_o(\cos\alpha - \mu\sin\alpha) r tg\alpha}{g},$$

$$\sigma_3(r) = -q_o, \tag{2}$$

$$\tau(r) = \mu q_o,$$

where:
N – drawing force value,
g – introductory pipe wall thickness,
$q_o$ – average unit pressure,
α – inclination angle of the cone element.

Drawing force value N depends upon properties of a drawn material, its dimensions, value and velocity of strain and geometric features of the tool. Intermediately, it significantly depends upon temperature of the process.

N(r) distribution is described in a form of differential dependence:

$$dN(r) = \frac{-q_o(\sin\alpha + \mu\cos\alpha)2\pi tg\alpha}{\cos\alpha} rdr, \tag{3}$$

where:
r – axial coordinate describing cross-section position,
μ – sliding friction coefficient for the contact surface.

Plasticization of the outer layer of a pipe with **z** thickness causes decrease of negative stress in this layer with simultaneous additional load of the inner elastic layer.

State of inner loads in a plasticized layer can be determined using the Huber-Mises-Hancky non-dilatational energy strain hypothesis on reduction of the stress state, which assumes the following form for the above mentioned conditions:

$$\sigma_2^2 + (\sigma_2 - \sigma_3)^2 + \sigma_3^2 + 6\tau^2 = 2\,\mathrm{Re}^2 \tag{4}$$

From the balance condition for the whole pipe and on the assumption that distribution of load is constant q(r ) = $q_o$, the value of drawing force can be determined:

$$N(r) = \frac{-r^2 q_o(\sin\alpha + \mu\cos\alpha)\pi tg\alpha}{\cos\alpha} + C \tag{5}$$

From boundary condition:

$$N\left(\frac{d_o}{2\tan\alpha}\right) = 0 \tag{6}$$

an integration constant C can be determined.

As an example, for the cold sink drawing process of a PE 100 polyethylene pipe from a SDR11 series of types with outside diameter of 63 mm, the following material data were taken on the considerations: $\alpha$ = 15 [°], X = 10 [%], $g_o$ = 5.6 [mm], Re = 20.607 [MPa], $\mu$ =0.488.

The unit pressure was calculated from the Huber-Mises-Huncky hypothesis and it amounts to q = 1.806 [MPa], therefore the force in the pipe outlet area of the drawing die, with outside diameter of $D_{kz}$ = (1-X)$D_{oz}$, calculated using the (4) formula amounts to N = 6.952 [kN].

Following a similar course of calculations and with use of empirically determined values of the drawing force, values of the friction coefficient for various drawing conditions – were determined – the results are presented in Table 2.

The conducted analysis shows that the friction coefficient depends upon the diameter reduction degree.

According to Williams and Tickell [8], the maximal permissible drawing force cannot exceed 50% of the yield point of a given material. This limitation is necessary due to assumed layer reversion process.

The analysis of the process shows that the material becomes plasticized in the drawing die area. After it leaves the drawing die, rapid diameter of swelling occur, therefore the pipe is left under load. Release of the pull causes a PE pipe to recover to its primary dimensions. Natural return of a pipe to its primary dimensions occurs as a consequence of a viscoelastic recovery. The course of the process comprises of a more rapid elastic recovery after leaving the drawing die area and after releasing the pull. In the remaining time, a slower recovery occurs under conditions of a fixed pull or its complete absence – after the pipe is fully released. Its final purpose is to tight fit the drawn PE pipe inside a reconstructed pipeline. However, in the analysis of the process, plastic strains that cause permanent dimension reduction of the introduced pipe, should not be omitted. These strains are results of partial plasticization of the material in the drawing die area.

Velocity of the diameter viscoelastic recovery depends upon the geometric parameters of the drawing die, drawing force and velocity as well as the temperature in which the process occurs. Laboratory tests conducted by the British Gas company show that a preheated and rapidly cooled pipe proves to be more stable and recovers to its initial state slower than a pipe shaped in ambient temperature [3, 4, 16, 17 ].

Table 2.
Experimental forces and friction factor for 25±2°C and 20±2°C

| Drawing die geometry | | | SDR 11 | | SDR 17 | |
|---|---|---|---|---|---|---|
| Temperature | α, ° | X, % | friction factor, μ | experimental force, kN | friction factor, μ | experimental force, kN |
| 25±2°C | 12.5 | 10 | 0.478 | 7.2 | 0.5 | 4.8 |
| | | 15 | 0.611 | 9.3 | 0.66 | 6.4 |
| | | 20 | 0.68 | 10.7 | 0.727 | 7.4 |
| | 15 | 10 | 0.511 | 6.95 | 0.488 | 4.3 |
| | | 15 | 0.633 | 8.75 | 0.69 | 6.1 |
| | | 20 | 0.76 | 10.9 | 0.774 | 7.2 |
| | 17.5 | 10 | 0.537 | 6.8 | 0.668 | 5.3 |
| | | 15 | 0.73 | 9.4 | 0.733 | 6.1 |
| | | 20 | 0.802 | 10.8 | 0.772 | 6.7 |
| 20±2°C | 12.5 | 10 | 0.511 | 7.6 | 7.6 | 0.533 |
| | | 15 | 0.643 | 9.7 | 9.704 | 0.693 |
| | | 20 | 0.71 | 11.1 | 11.19 | 0.76 |
| | 15 | 10 | 0.542 | 7.3 | 7.294 | 0.52 |
| | | 15 | 0.671 | 9.2 | 9.201 | 0.726 |
| | | 20 | 0.79 | 11.3 | 11.29 | 0.807 |
| | 17.5 | 10 | 0.569 | 7.1 | 7.094 | 0.72 |
| | | 15 | 0.756 | 9.7 | 9.7 | 0.77 |
| | | 20 | 0.833 | 11.2 | 11.21 | 0.805 |

As a continuation of analysis of the state of stress in a pipe drawn in the drawing die area state of stress constituents as a functions of radial coordinate z were assumed. Hence having assumed that the half-ring balance for $\sigma_2$(z) = const, $\sigma_3$ was determined:

$$\sigma_3 = q_o\left[\frac{g-z}{g} + \mu z\tan\alpha\,\frac{\dfrac{g-z}{\sin\alpha} + r}{g\left(r - \dfrac{z}{\sin\alpha}\right)}\right] \tag{7}$$

The normal stress $\sigma_3$, perpendicular to the element of a cone of the drawing die, was determined for the outlet area of a pipe coming out of the drawing die, while $r = \frac{(1-X)D_{oz}}{2\tan\alpha}$ and, for appropriate boundary conditions. The circumferential stress $\sigma_2$ is determined with the formula (1).

The shearing stress is determined from the balance condition for the axial vector in the plasticization area of **z** thickness:

$$t(r)r\sin\alpha = \tau_{13}(z)(r\sin\alpha - z) \tag{8}$$

To compute the reduced stress from the Huber-Misses-Huncky hypothesis it is possible to determine the thickness of the outside plasticized layer, which in the above mentioned example amounts to z = 0,071 mm.

As a result of analysis of the above mentioned model, it was determined that an increase of the reduction level is accompanied with an increase of friction, which influences the thickness of the outside plasticized layer. It was observed that the increase of friction coefficient causes increased thickness of the said outside layer in both tested SDR 11 and SDR 17 series of types pipes. Thickness of the plasticized layer for the SDR 11 types of series pipes tested is higher than in case of SDR 17 types of series pipes, yet in both cases these thickness values are of hundredths of millimetre ranges. Therefore, it can be assumed that it is the surface layer that undergoes plasticization, surface meaning here the outside layer having changed physical and sometimes chemical properties in comparison to properties of the material core [1-5,7, 10, 13].

On the basis of established thickness of the plasticized layer, elongation of a given pipe can be estimated, as the plasticized outside layer is responsible for permanent longitudinal strains, while the inside elastic layer with g-z thickness is responsible for elastic strain causing tight fitting of a lining pipe inside a reconstructed pipeline.

## 5. Conclusions

The elastic recovery varies according to the die angle and the reduction ratio. The elastic recovery increases as the die angle and the reduction ratio increase. The thicker the wall the more intense the recovery

The most intense elastic recovery of the pipe tested takes place during the initial 30 minutes after the completion of the drawing test.

The functional effect of the conducted research is a possibility of rational choice of conditions during a reverse drawing operation, as far as the deposition effect of the drawn pipe in lining canals with considerable rigidity is concerned. It is realised with tight fitting of a drawn pipe after the load of drawing ends and when the pipe temperature levels with the ambient temperature.

The research proved the necessity of individual design of operations for particular geometrical and material conditions. In such cases, the temperature of the material is an essential value, yet – in some circumstances - it may be altered as fit.

As a result of the conducted analysis and having used experimental data concerning changes of the drawing force according to the conditions in which the process is performed, it was found that there is a need to take into consideration the changes of the friction coefficient for the pipe - drawing die contact surface in the model of the above mentioned process. These changes can be explained with changing thickness of the plasticization area. Recognition of physical connections that determine properties of the material and of the process gives a starting point for their rationalisation in the design phase of production technology as well as in reconstruction of two-layer pipes with PE lining.

Quantitative characteristics of the process will be used in the procedures of selecting tools and materials for individual reconstructions.

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