

Estimation of strength parameters of small-bore metal-polymer pipes

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Abstract The paper presents results from a set of laboratory studies of strength parameters of small-bore metal-polymer pipes of type TG-5/15. A wave method was used to estimate the provisional modulus of elasticity of the metal-polymer material of the pipes. Longitudinal deformation, transverse deformation and leak-off pressure were determined experimentally, with considerations for mechanical damage and pipe bend.

1. Introduction

Reinforcement of polymer pipes allows creating high endurance structures with a general reduction of material consumption and cost [1]. The small-bore polymer reinforced plastic matrix (RPM) pipe has recently found a wide range of application in diverse processes in oil and gas facilities [2]. Structurally, the pipe consists of thermoplastic polymer reinforced with a wire sleeve consisting of two layers in counter winding (Figure 1).

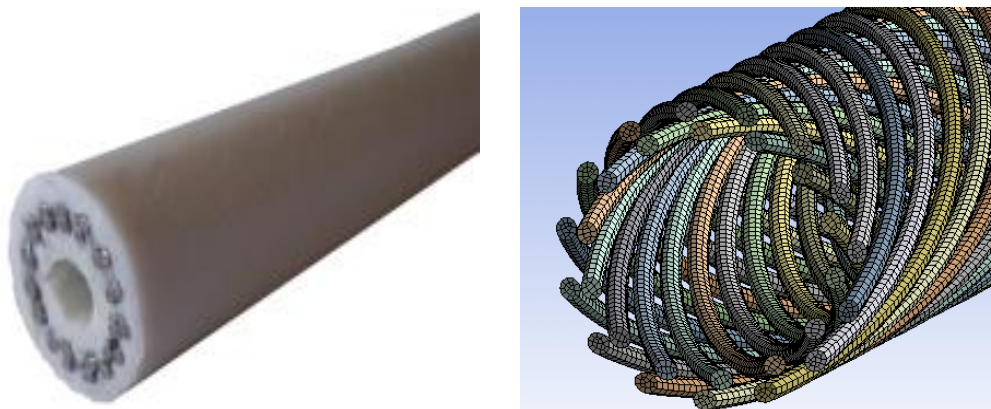


Figure 1. RPM pipe and location of reinforcing wire

The internal diameter is 3...8 mm; the outer diameter is 10...17 mm. The operating pressure is 15... 30 MPa. A structural feature of such pipes is that when loaded with internal pressure, axial load

and accompanying radial and axial deformation, there is a displacement of the polymer matrix with respect to the wire frame. This phenomenon complicates strength calculations of the pipes with Hooke's law and Navier equations [3]. Such being the case, verification strength test in situ is required. A complex non-linear structure of the pipe leads to unsatisfactory results when applying traditional methods to determination of the modulus of elasticity. Due to this, an experimental non-destructive method is proposed for determination of mechanical characteristics of RPM pipes. The method employs dependency of pressure wave speed on the modulus of elasticity of the pipe, with correction for thick walls. This paper studies strength characteristics of RPM pipe as exemplified by pipe type TG-5/15.

2. Materials and methods

The pipe is manufactured by layered extrusion of copolymer 02015-302 KM and reinforcement with 14x0.8 mm high endurance galvanized steel wire, with maximum strength of 190 kg/mm². Pipe TG-5/15 (ID 5 mm, OD 15 mm) manufactured by INKOMP-neft (Ufa, Russia) in accordance with the specification TU 3666-022-45213414-2017 [2] was subjected to testing. Hydraulic fluid is Tosol A40m (ethylene glycol-based).

Test method for Modulus of elasticity

The wave method for determination of material's modulus of elasticity is based upon creating a pressure wave and finding τ which is a difference between the values of pressure wave transmission time in liquid and in pipe material. For the pipes under consideration, due to anisotropy of their structure, the concept of the modulus of elasticity is inapplicable in its pure form, thus, let us introduce *pipe material provisional modulus of elasticity*, corresponding to a modulus of elasticity of a uniform structure, which shows the same mechanical characteristics as the pipe under consideration in the given operating conditions. The pipe material provisional modulus of elasticity was determined with Zhukovsky formula [4] applied with corrections for thick walls:

$$E_{fr} = k \frac{E_l}{\left(\frac{E_l}{\rho \left(\frac{l}{\tau} \right)^2} - 1 \right) \cdot \frac{\delta}{D}}$$

where E_{fr} is the pipe material provisional modulus of elasticity, Pa;

E_l is modulus of incompressibility of a liquid, Pa;

δ is pipe wall thickness, m;

D is pipe inner diameter, m;

ρ is liquid density, kg/m³;

l is a length of pipe between the pressure sensors, m;

k is a coefficient accounting for stress distribution through the pipe wall thickness. For a thick-walled pipe ($\delta \geq 0.05D$),

$$k = \frac{D}{(D + \delta)}.$$

The modulus of elasticity of the test facility includes a pump of ND 2,5 40/40 K 14 A type, a discharge drum, a surge tank whereto the studied pipe is attached, being provided with pressure sensors and valving on both sides. Pressure sensors type PDI-011 operating at a frequency of 100 Hz are connected to a computer through a data gateway GW-485.01 (RS-232/RS-485 converter). Liquid from the pump arrives to the surge tank, through the piping being studied and is dumped into the discharge drum. A pressure wave is created by an abrupt opening of a ball valve. During the tests the pipe was also connected directly to the pump without the surge tank to measure and record the pressure impulse at the head and tail ends of the pipe.

Leak-off pressure determination was carried out at a test facility consisting of a pump and a testing unit with a thick-walled jacket where the tested pipe was placed. The jacket is filled with a neutral

liquid and temperature may be maintained at a desired level in the range of 10-100°C. Liquid may be supplied into the pipe or into the jacket with possibility to maintain desired pressure of up to 35 MPa for a prolonged period of time. Excess pressure may be created both inside and outside the pipe. A section of pipe up to 1080 mm long may be placed inside the jacket, or, alternatively, a deformed pipe section with 180° bend at a predefined radius.

The following objects were subjected to testing:

1. Linear pipe section loaded with a constant pressure of 15 MPa.
2. Linear pipe section with pulsating pressure 15+/- 3 MPa at a frequency of 0.5 Hz.
3. Linear pipe section loaded with a constant pressure of 15 MPa with preliminary damage to: top layer only; top layer and steel sleeve.
4. 180° pipe bend section with a 25 mm radius loaded with a constant pressure of 15 MPa.

Exposure time for all the specimens under 15 MPa of pressure was 720 hours at a temperature of 20° C. After this exposure, the pressure was increased at a 0.5 MPa/min rate until the specimen leak-off. Changes in diameter and length of the pipe were registered during the test.

3. Test results for RPM pipe type TG-5/15

A series of measurements of pressure wave travel time between the sensors located at 20 m of a pipe under pressure ranging from 0.5 to 3.5 MPa in 0.5 MPa increments were conducted to determine the provisional modulus of elasticity. Average pressure wave travel time was 0.024 sec. Experimental value of the provisional module of elasticity of the RPM pipe type TG-5/15 amounted to 622 MPa with accuracy ranging within 8%.

A record of pressure amplitude during the direct connection of the pipe to the pump is shown in Figure 2, 3. In the beginning, an average pressure amplitude in the pipe was 0.53 MPa and 20 m farther, at the end of the pipe, the amplitude was 0.105 MPa. Pulsation reduction due to elastic characteristics of the TG-5/15 pipe is over 80%, corresponding to a relative reduction of dynamic component of the flow by a factor of 5 at a length of 20 m.

At an average pressure of 25 MPa (with maximum value of 35 MPa), a leak-off appears at a distance of 10-15 mm from the connecting element bushing

Cyclic change in internal pressure was found having no influence on the leak-off pressure.

Damage to external polymer layer does not influence the leak off pressure. Damage of both external polymer layer and wire sleeve reduces the leak-off pressure to 17 MPa.

A bend of 180° with 25 mm radius reduces the leak-off pressure to 20 MPa.

At excess inner pressure, pipe length changes (reduces) by up to 20% (Figure 4) while pipe diameter changes by up to 50% (Figure 5) due to displacement of polymer material with respect to reinforcing wire

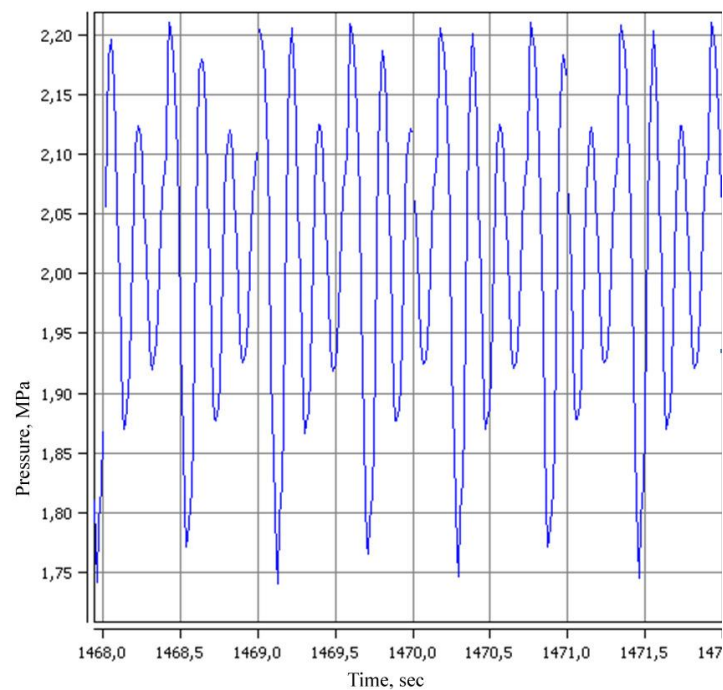


Figure 2. Records of pressure pulses at the head end of a 20 m pipe

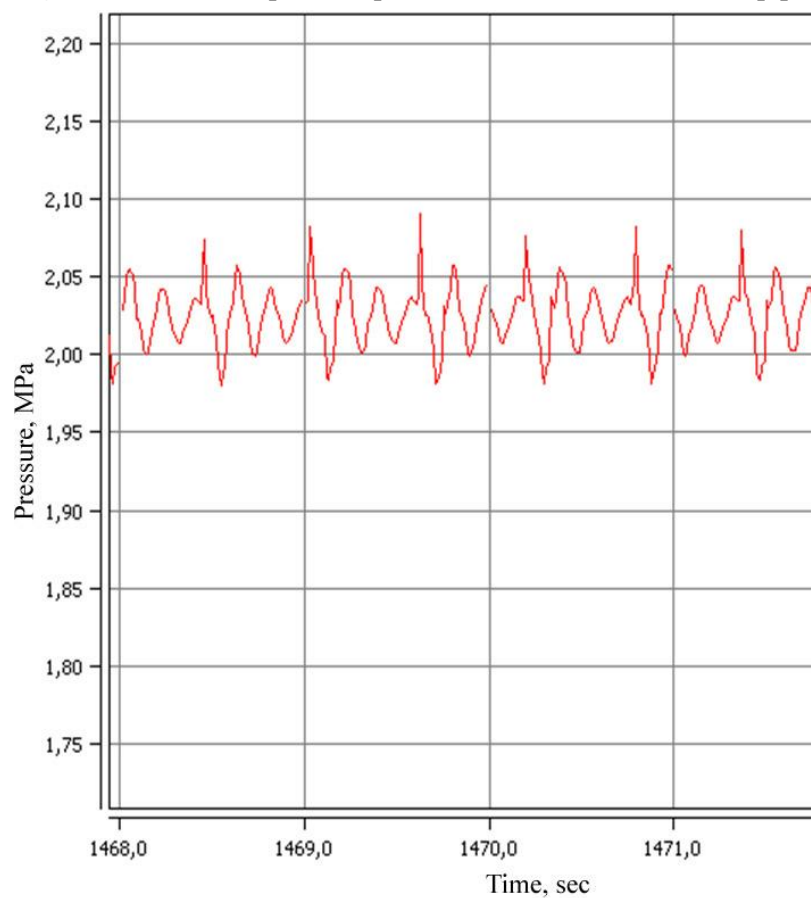


Figure 3. Records of pressure pulses at the tail end of a 20 m pipe

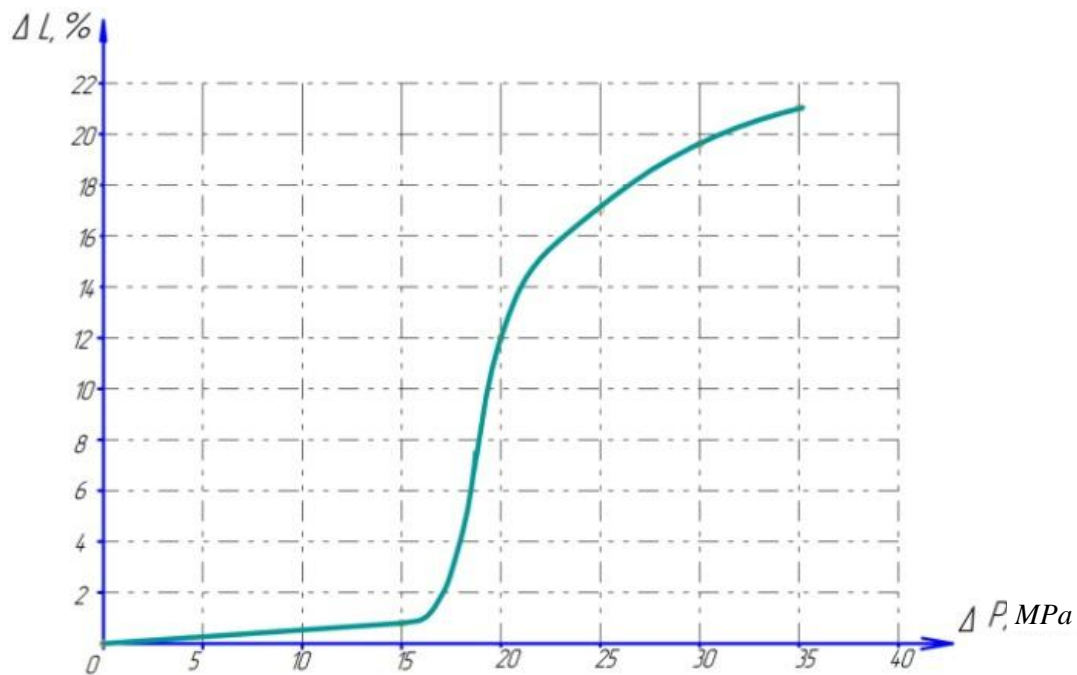


Figure 4. Changes in pipe relative length due to pressure changes

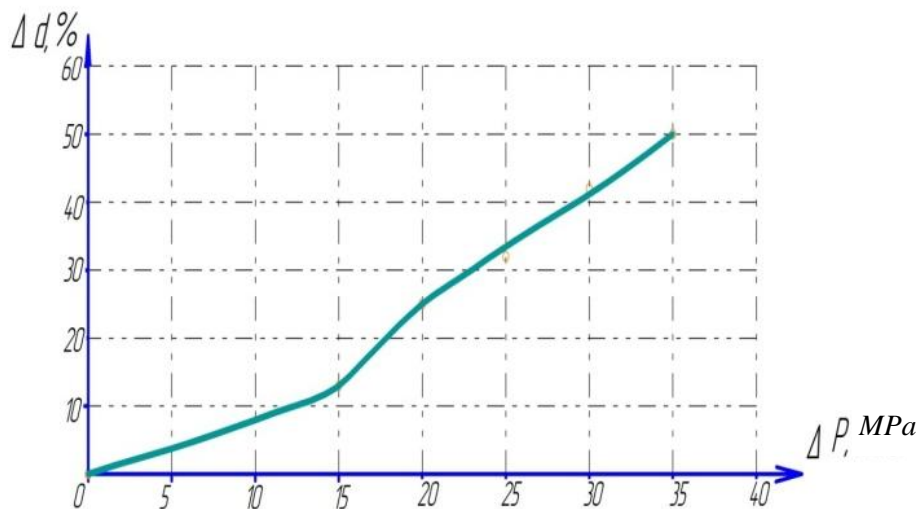


Figure 5. Changes in pipe relative diameter due to pressure changes

4. Conclusions

Laboratory tests of the RPM pipe type TG-5/15 have shown the following results:

1. A value of provisional module of elasticity was estimated with the wave method, for material of type TG-5/15 pipe it amounts to 622 MPa
2. Reduction of pulsation at 20 m length of the TG-5/15 pipe was found to exceed 80%
3. Leak-off pressure of the TG-5/15 is 25 MPa for normal conditions; at that, damage to external polymer layer does not influence the leak-off pressure, while damage to both the external polymer layer and wire sleeve reduced the leak-off pressure to 17 MPa.
4. Pipe bend of 180° with the radius of 25 mm reduces the leak-off pressure to 20 MPa.
5. Loading the pipe with internal pressure causes relative shortening of the pipe by a value of up to 20% and increase in its relative diameter by up to 40% without destruction.

5. Acknowledgments

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