Laboratory Stiffness and Flexibility Tests of Spiral Corrugated High Density Polyethylene Pipes of Large Diameters With Metal Reinforcement

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Basic data about the behaviour of thermoplastic high density polyethylene pipe with metal reinforcement under lateral load were obtained in a controlled laboratory environment. Ring stiffness and flexibility pipe tests are conducted. The characteristics of the pipe samples are given in this paper,and a process and test methodology according to which the pipe samples are tested which is prescribed by standards are explained. Obtained stiffness and flexibility results of pipe tests are shown, as well as characteristics of used test equipment specialized for the large diameter pipe testing (up to 2 m).

Key words: laboratory tests, spiral corrugated HDPE pipe with metal reinforcement, stiffness, flexibility

1. INTRODUCTION

Testing in mechanical engineering represent a set of number of methods which are represented in various development stages, production and operation of systems and products. Their aim is to assess the state of the machine, apparatus, machine part or product. Assessment of the structure state and state of its parts is done through the information obtained in the process of testing with direct, or indirect measurements of processed measuring values that include:

1. operating condition evaluations;
2. the state of damage;
3. operational and work safety;
4. quality

The quality is characterized by a state of a machine, apparatus or products during the preparation and at the end of the production process, and also in conditions of exploitation after a certain operation period. The requirements in terms of quality is related to the accuracy prescribed by the appropriate standards which parts of the structure and eventually the entire system needs to meet.

Basic tests can be divided into: development, production and exploitation tests.

The development tests include testing a prototype which is related to laboratory conditions and are carried out in research centers and institutes with a simulation of exploatation conditions of mechanical systems. Tests in laboratory conditions provide all the necessary information about the function and quality of a construction and ensure the accuracy of relevant informations.

The tests are essentially based on the measurement of relevant parameters that determine the quality or characteristic of the observed phenomenon and determine their size, deviations from the specified parameters, register disturbances in a system, the state of damage to individual parts and assemblies and causes of failure. On this basis, testing methodology represent an objective determination of the quality of the test object or the observed phenomenon.

2. TEST SUBJECT AND EQUIPMENT

The test subject in this paper is a thermoplastic spiral corrugated HDPE (High Density Polyethylene) pipe with metal reinforcement - SPIROPIPE, nominal diameters 1000, 1200, 1500, and 1800 mm, manufactured by "PEŠTAN" from Aranđelovac. The test results of the 1500 mm nominal diameter is presented in this paper.
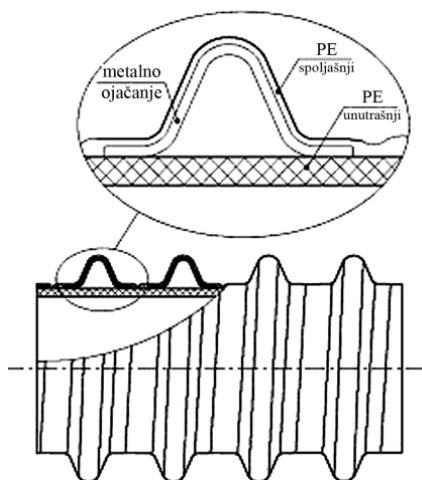

Figure 1. Profile of spiral corrugated HDPE pipe withe metal reinforcement

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Table 1: The characteristics of the tested pipes

Manufacturer		PEŠTAN Aranđelovac
Pipe type		Spiral corrugated HDPE pipe with metal reinforcement DN/ID 1500 mm SN12.5
Material	The basic pipe material	High density polyethylene (HDPE) protected name SABIC® P6006
	Metal reinforcement	Cold rolled steel sheet thickness of 1 mm quality of DC01 according to EN 10130:2006
Nominal pipe diameter		d_n=1500 mm
Outside pipe diameter		d_e=1630 mm

2.1. Test equipment and apparatus

The test is performed on the mechatronic system for mechanical element and complex structure testing "Mehatronik FTN 1000/10" in the laboratory of Mechatronics, Faculty of Technical Sciences in Čačak.

The dimensions of the testing machine is 1.4x1.2x30 m, with the possibility of fixing the stationary part of the crossbeam. Axial load (tension and compression) is achieved by two hydraulic cylinders. The maximum tensile force that can be achieved is 1200 kN.

A special equipment (Figure 2) which consists of three frames with sheet metal ribs and four steel pipes 4 meters in length had to be designed for test purposes. Bushigs are welded to the frames numbered 4 and 7 in Figure 2 through which the steel pipe can pass and fixed in cetrain position (defined by pipe diameter) by special safety bolt. Support plates made of hard plastic are fixed on the frames numebered 6 and 7 in Figure 2 in between which the test pipe sample is placed. The middle frame (6) is fixed to the stationary part of the traverse of the mechatronic systems, and holes are drilled through the support plate to serve as guides of steel pipes which pass through them. Since the diameters of the holes are larger than the diameter of the steel pipes passing through them, and the contact surface is small, also considering the fact that the support plate is made out of plastic, the friction between the steel pipes and the support plate is minimal and can be ignored.
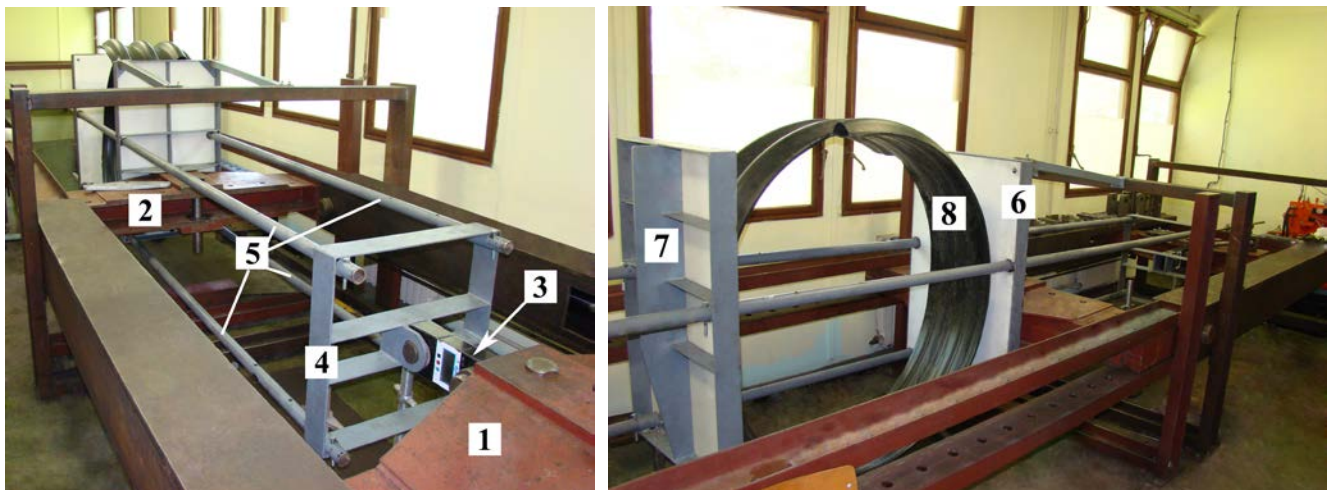

Figure 2. The test equipment and apparatus: 1.movable crossbeam of the mechatonic system; 2. stationary crossbeam of the mechatronic system; 3.the dynamometer; 4 the.first frame with bushings through which steel pipes are placed and fixed; 5.the steel pipes that transmit force; 6. the second frame with supports which is fixed to the stationary crossbeam; 7.the third moveable frame which acts by pressing on the pipe sample; 8.the spiral corrugated HDPE pipe sample

The value of the deformation force is measured with a measuring device manufactured by TRACTEL®. The dynamometer type is Dynafor LLX-25 (Figure 3). A measuring range of the device is up to 250 kN, with an accuracy of ± 0.5 kN.

Figure 3. The device used for force measuring - dynamometer Dynafor LLX – 25

The inside diameters is measured by a hand caliper with a large measuring range.

3. TEST METHOD

A structure, mechanical system, assembly and element tests are conducted by special procedures - methods. In a number of cases the test methods are strictly established, standardized and included in internal, national or international standards and regulations, and they are often defined for each of the particular test cases depending on the aim of research, applied test installation and measuring equipment.

The pipe samples testing are carried out according to the standards specified for the products of this type, as follows:

- EN ISO 3126 - Plastics piping systems-Plastics components - Determination of dimensions;
- EN ISO 9969 - Thermoplastics pipes - Determination of ring stiffness;
- EN ISO 13968 - Plastics piping and ducting systems - Thermoplastics pipes - Determination of ring flexibility.

The pipe tests according to the last two above-mentioned standards will be discussed in this paper.

3.1. Determination of the ring stiffness

The ring stiffness is determined by measuring the force and the deflection while deflecting the pipe at a constant deflection speed.

The three pipe samples are tested: *a*, *b* and *c*, diameter of DN/ID 1500 (nominal dimensions of the pipe inside diameter $d_n = 1500$ mm), prepared in the way that is specified by the European norms [2]. Considering that this is spirally corrugated pipe, all the samples is cut at the mid point between the corrugations, such that each test piece contains two whole ribs. In this way, the pipe samples meets the requirements prescribed by this standard, ie. pipes with nominal diameter exceeding 1500 mm in length should be at least $0.2d_n$ in length. The each sample is measured along six generatrices evenly distributed around the circumference of pipe, and then it is calculated for the each six obtained values as the mean length value of the individual samples. The obtained length values are shown in Table 3.

Measurements of inside diameters d_{ia}, d_{ib}, and d_{ic} are obtained for each of the pipe test samples *a*, *b* and *c* as the arithmetic mean of the four values obtained by measuring the internal diameter of the pipe at the measuring points each rotated by 45°. The measurements were carried out and then is calculated a mean value of the pipe sample inside diameter according to these three obtained values d_{ia}, d_{ib}, and d_{ic}, as follows:

$$d_i = \frac{d_{ia} + d_{ib} + d_{ic}}{3} \quad (1)$$

The calculated values are shown in Table 3.

At the time tests are conducted, the all samples are between 18 and 20 days old, which corresponds to the norms prescribed in standard [3]. A laboratory temperature at the time of tests is 21°C, which also corresponds to the norms prescribed in the mentioned standard. It is probable that the test temperature has an influence on the ring stiffness.

During the test of ring stiffness, sample is placed between two flat parallel plates as shown in Figure 2 and 4. The force is gradually raised to a value that corresponds to a 3 % pipe deflection of the inside pipe diameter d_i. Deflection is monitored by measuring the change of the inside diameter of the pipe d_i. According to [3], the test samples *b* and *c* are positioned so that they are rotated respectively 120° and 240° in relation to the position of the first test piece *a*. The deflection speed is held around 45mm/min as required by the standard.

Table 2: Deflection speeds

Nominal diameter, d_n, of pipe [mm]	Deflection speed mm/min
$d_n < 100$	2±0.1
$100 < d_n < 200$	5±0.25
$200 < d_n < 400$	10±0.5
$400 < d_n < 710$	20±1
$d_n > 710$	0.03xd_i±5%*

*d_i shall be determined in accordance with the equation (1)

For the each of the three samples *a*, *b* i *c* the ring stiffness is calculated, according to the equations:

$$S_a = \left(0.0186 + 0.025 \frac{y_a}{d_i} \right) \frac{F_a}{L_a y_a} \left[\frac{\text{kN}}{\text{m}^2} \right]$$

$$S_b = \left(0.0186 + 0.025 \frac{y_b}{d_i} \right) \frac{F_b}{L_b y_b} \left[\frac{\text{kN}}{\text{m}^2} \right] \quad (2)$$

$$S_c = \left(0.0186 + 0.025 \frac{y_c}{d_i} \right) \frac{F_c}{L_c y_c} \left[\frac{\text{kN}}{\text{m}^2} \right]$$

where:
- *F* is the force, in kilonewtons, that corresponds to a 3 % pipe deflection;
- *L* is the calculated average length of the test sample, in millimeters;
- *y* is the deflection, in millimeters, that corresponds to a 3 % deflection, i.e.

$$\frac{y}{d_i} = 0.03 \quad (3)$$

The relevant ring stiffness is calculated as a mean value:

$$S = \frac{S_a + S_b + S_c}{3} \left[\frac{\text{kN}}{\text{m}^2} \right] \quad (4)$$

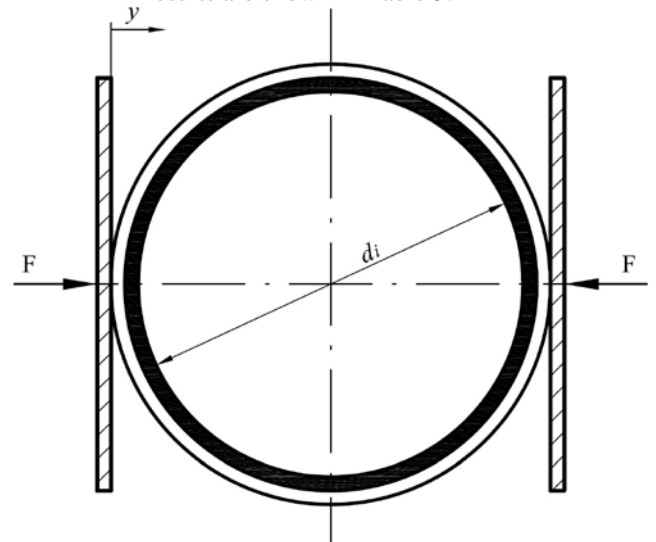All results are shown in Table 3.

Figure 4: The test scheme of the spiral corrugated HDPE pipes with metal reinforcement

3.2. Determination of the ring flexibility

In the following test, the each pipe sample is further gradually loaded to the specified value of 30%

deflection in relation to the outside diameter d_e, of the pipe for determination of flexibility [4].

According to the standard [4], the deformation process is visually monitored while recording a force values for the each of the characteristic events that may occur: cracking or crazing in any part of the wall structure, wall delamination, permanent buckling in any part of the structure of the pipe wall, or any other structural change of the pipe wall. A value of force in which deflection reach 30 % of the outside diameter d_e is also noted.

All results are shown in Table 3.

The force-deflection diagram achieved while testing flexibility one of the pipe samples is shown in Figure 6.

4. TEST RESULTS

4.1. The results of the ring stiffness

Table 3: The test results of the spiral corrugated HDPE pipes with metal reinforcement DN/ID 1500 mm SN12.5

Nominal pipe diameter	$d_n = 1500$ mm		
Outside pipe diameter	$d_e = 1630$ mm		
Nominal stiffness	$S_n = 12.5$ kN/m^2		
Test temperature	21 °C		
Test sample lengths	$L_a = 385$ mm	$L_b = 392$ mm	$L_c = 376$ mm
Inside diameter measurements of test samples (mean measured values)	$d_{ia} = 1505$ mm	$d_{ib} = 1500$ mm	$d_{ic} = 1503$ mm
Relevant mean value of inside diameter	$d_i = 1503$ mm		
Intensity of the deformation force that corresponds to a 3 % pipe deflection of the inside diameter	$F_a = 12.6$ kN	$F_b = 12.9$ kN	$F_c = 12.8$ kN
Deflection, in millimeters, that corresponds to a 3 % deflection of the inside diameter	$y_a = 45.1$ mm	$y_b = 45$ mm	$y_c = 45.1$ mm
Calculated values of ring stiffness for individual samples	$S_a = 14.042$ kN/m^2	$S_b = 14.149$ kN/m^2	$S_c = 14.606$ kN/m^2
Calculated mean value of ring stiffness	$S = 14.27$ kN/m^2		
Intensity of the deformation force that corresponds to a 30 % pipe deflection of the inside diameter	$F = 22.6$ kN		

Figure 5. Display of measurement during stiffness test - value of force in decanewtons that corresponds to a 3 % deflection of one of the pipe sample inside diameter

In the Table 3, the calculated mean value of the tested ring stiffness is rather higher than the nominal stiffness value for the SN12.5 stiffness class mark. It may also be noted that force that corresponds to a 3 %

deflection in all three pipe samples are approximate values, indicating the reproducibility and stability of a pipe production process, and the accuracy of the tests, but also the equipment used for testing.

A higher class of the pipe stiffness can be achieved by increasing the thickness of the sheet metal used for the pipe reinforcement, eg. SN16.

4.2. Results of the ring flexibility

During the ring flexibility test of pipe samples DN/ID 1500 mm, there is a change in the shape of pipes and plastic deformation of the ribs with a metal reinforcement on the contact area between the pipes and supports, as it is expected. There is no cracking or crazing in any part of the wall structure, wall delamination, permanent buckling in any part of the structure of the pipe wall, or any other mechanical failure or structural change of the pipe wall even with deformations exceeding 30 % of the outer pipe diameter d_e which can be seen in Figures 7 and 8.
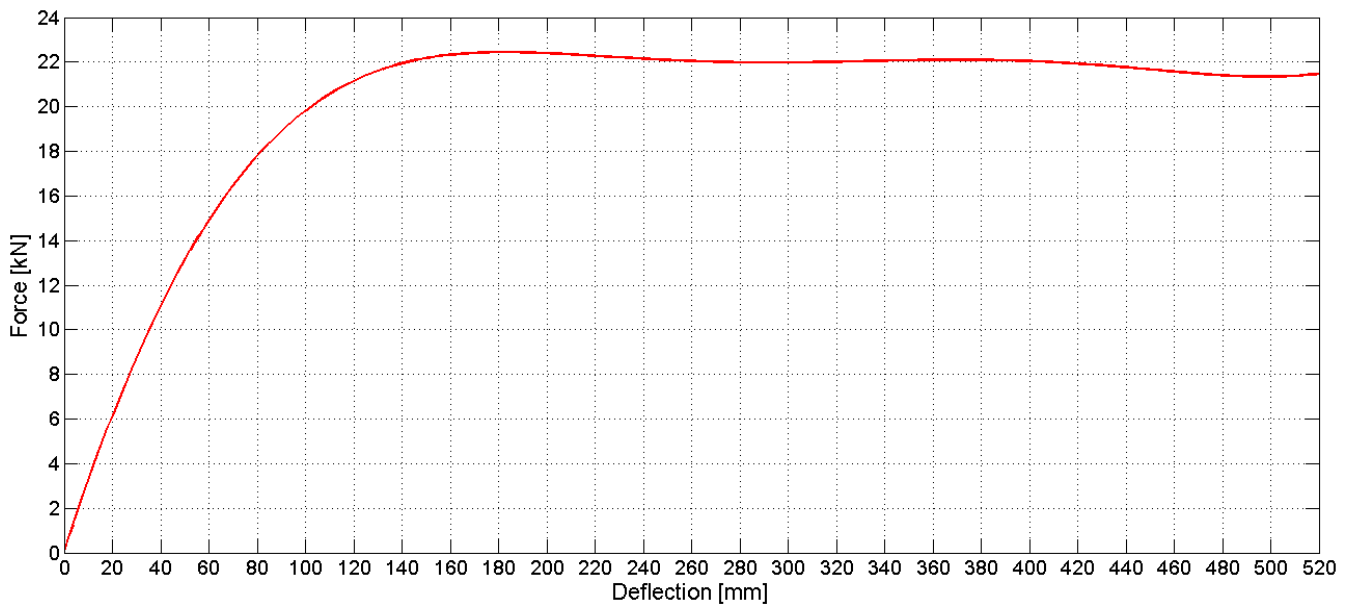
Figure 6. The force-deflection diagram achieved while testing the flexibility of one of the spiral corrugated HDPE pipe samples with metal reinforcement DN/ID 1500 mm SN12.5

Figure 7. The flexibility testing process and appearance of the permanently deformed spiral corrugated HDPE pipe samples with metal reinforcement DN/ID 1500 mm SN12.5
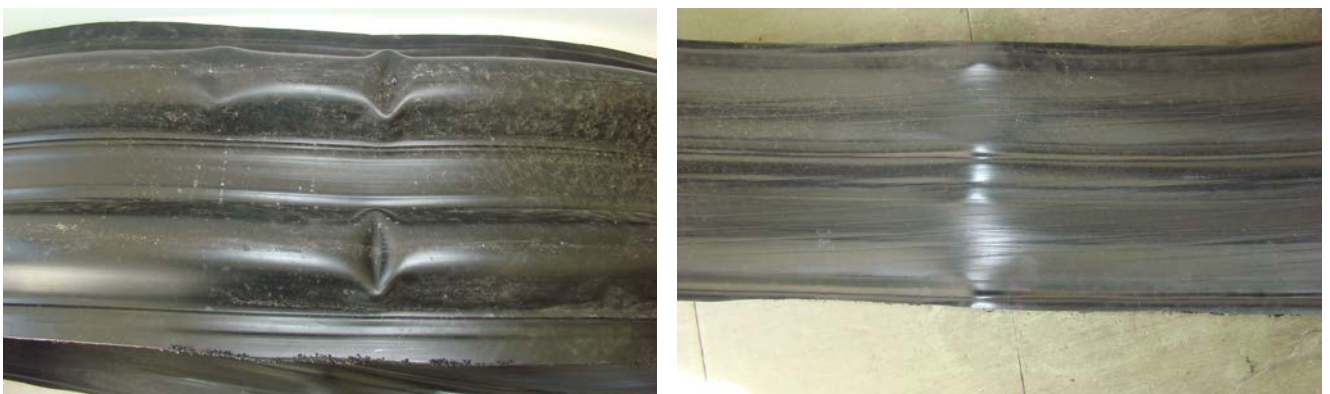

Figure 8. The appearance of the outer and inner pipe surface at the end of the flexibility testing one of the spiral corrugated HDPE pipe samples with metal reinforcement DN/ID 1500 mm SN12.5

5. CONCLUSION

The method and the test equipment used for testing the spiral corrugated HDPE pipe of large diameters with metal reinforcements to the standards [3,4] is presented in this paper.

The results partially presented in this paper may be used for future research in several ways.

For example, FEM (finite elementh method) can be used to predict optimal cross-sectional pipe dimensions (thickness of plastic and thickness of metal reinforcement) in order to obtain the desired class of stiffness with minimal use of the materials. The validity of the results can be verified by direct comparison with the experimental results obtained by the already completed tests.

Also, the obtained experimental results can be used to develop a method for obtaining optimum parameters of the pipe by using a genetic algorithms.

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