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Mechanical properties of thermoelastoplasts for hoses of improved wear resistance

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Abstract. Peristaltic pump units are used in medicine, for pumping blood and its components, and in mechanical engineering for working with aggressive media. The only element in this pump that comes into contact with the working medium is the hose. Such hose characteristics as chemical resistance and wear resistance directly affect the operating life of the entire pump. The purpose of this work is to increase the service life of the peristaltic pump unit by developing a hose with improved wear resistance (WRH). During the study, the following problems were solved: the process of obtaining 3 different polymer materials for the manufacture of WRHs was selected, the technology for manufacturing WRHs was selected, and the mechanical properties of the resulting structure were studied. As a result, it was determined that all selected materials and design were workable, however, a sample made of ethylene-propylene rubber (EPDM) and polypropylene (PP) with a mass percentage of 75/25 (75% EPDM and 25 % PP) material, has the greatest wear resistance in comparison with other samples, which makes it optimal for making a hose.

1 Introduction

Today, peristaltic pump units (PPU) are used to pump various media, making their development and modification an increasingly urgent task [1]. The PPU uses the principle of peristalsis, which imitates a process similar to the passage of food through the esophagus in the human body. Unlike the human body, a peristaltic pump pumps the working medium using a flexible hose [2]. The hose is compressed using blades or shoes, which creates movement of the working medium. Thus, only the hose is in contact with the pumped substance, which makes the pump suitable for working with aggressive, abrasive and high-density liquid media [3]. The main parts of the PPU, in addition to the hoses and shoe, are the rotor [4]. To ensure safe operation of the pump, the hose in contact with aggressive media must have increased wear resistance [5].

The development of thermoplastic elastomers has opened new horizons in improving the mechanical characteristics of hoses, including increasing their wear resistance. It is also

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possible to improve the mechanical properties using different coatings [6]. When choosing materials for hoses, the main attention is paid to their mechanical properties, namely wear resistance, elasticity, chemical resistance, and flexibility [7]. However, despite the progress achieved, serious problems remain related to ensuring optimal properties of hoses, especially in terms of ensuring resistance to aggressive media pumped by PPU [8]. Modern research in this area is aimed at developing new materials and technologies that can increase the durability of hoses, reduce their cost and ensure performance in difficult conditions [9, 10]. Such progress will not only improve the performance of hoses, but also expand their areas of application. It will provide new opportunities for the industry, increasing the overall efficiency and reliability of systems that use such hoses [11]. Therefore, continued research and development in this area is not only technical, but also economically important, contributing to further development and innovation in industry [12].

In this context, the main challenge lies in confirming the performance and durability of high-wear hoses, which is a prerequisite for their effective use in peristaltic pump units. The performance of a product can be confirmed in various ways, including mathematical modeling, but in this work the authors conduct laboratory tests. Thus, the purpose of this study is to increase the working life of a hose with increased wear resistance. For this purpose, certain materials and a manufacturing method are selected, after which the performance and wear resistance of the structure is confirmed by determining its mechanical characteristics and the material with the best properties is selected for the manufacture of the WRH.

2 Technological parameters for obtaining and processing components of WRH structural materials

An analysis of technological parameters and processes was carried out, on the basis of which basic recommendations were developed for the production and processing of mixed thermoplastic materials in relation to WRH based on ethylene-propylene rubber (EPDM) and polypropylene (PP) with a mass percentage of 85/15 (85% EPDM and 15 % PP) and 75/25 (75% EPDM and 25% PP), characteristic TPV and TPO respectively.

The technological process for obtaining the structural base material for the production of WRH is carried out by copolymerizing ethylene with propylene and diene with a Ziegler-Natta catalyst in solution and includes the following operations:

1. Preparation of raw materials. Hydrocarbons are used as feedstock for EPDM.
2. Mixing the copolymer components. The mixing process occurs in one stage and is carried out in a closed rubber mixer. Mixing is carried out in a mixer with a catalyst consisting of vanadium oxytrichloride, aluminum monomethyl dichloride and aluminum diethyl monochloride. The pressure in the reactors is 15.4 atm, and the temperature is 10...66 °C.
3. Polymerization of components. Polymerization of monomers in suspension is carried out in liquid propylene at temperatures from -20 °C to +40 °C. After mixing, the components are introduced into the reactor.

The technological process of processing EPDM base material for WRH includes the following operations:

1. The EPDM base material for WRH is processed by calendering or extrusion. The recommended method for the manufacturing process of the WRH structure is the extrusion method. EPDM enters the extruder and is heated to a temperature of 95 °C, where the process of molding the product occurs.
2. EPDM vulcanization. The vulcanization process of the EPDM polymer base is carried out at a temperature of 150...180°C for 10-60 minutes using the main vulcanizing agents to accelerate vulcanization:
   - cumyl peroxide;

- tert-butyl peroxide.

The technological process for producing mixed thermoplastic elastomer TPV for the WRH design includes the following technological processes:

1. Preparation of EPDM and PP polymer base samples:
    - The process of drying components. It involves removing moisture by drying the ingredients at 100°C in a vacuum for four hours.
    - Extraction of industrial stabilizers from EPDM. It is recommended to extract stabilizers by treating them in boiling toluene for 16 hours.
2. Mixing TPV components. Mixing of the EPDM and PP components is carried out in a closed mixer at 190 °C and a rotor speed of 90 rpm for 15 minutes.
3. The vulcanizing group is introduced at high temperature, resulting in cross-linking of EPDM and PP.
4. Cooling of the resulting material.

The technological process of processing mixed thermoplastic elastomer TPV for the manufacture of the WRH structure includes the following main processes:

1. Preparatory operations. Preparation of material for extrusion.
2. Extrusion of prepared TPV structural material for WRH. The extrusion process is carried out with electrical heating up to 220°C individually in 4 zones of the body and the extruder head. During the extrusion process, the temperature of the cooling and polishing rollers should be in the range of 60...80 ° C, to eliminate the possibility of the melt sticking to the rollers. Screw rotation speed parameters 30…90 rpm.
3. Cooling of the resulting material. After the polymer material passes through the slot forming head, the resulting material base is placed on the rolling equipment, where it is pressed using a roller.

The technological process for producing mixed thermoplastic elastomer TPO for the WRH design includes the following technological processes:

1. Preparation of EPDM and PP polymer base samples:
    - The process of drying components. It involves removing moisture by drying the ingredients at 100°C in a vacuum for four hours.
    - Extraction of industrial stabilizers from EPDM. It is recommended to elute stabilizers by treating them in boiling toluene for 16 hours.
2. Mixing TPO components. Mixing of the components is carried out in a closed mixer at 190 °C and a rotor speed of 90 rpm for 10 minutes.
3. Cooling of the resulting material.

The technological process for processing mixed thermoplastic elastomer TPO for the manufacture of the WHR structure includes the following main processes:

1. Preparatory operations. Preparation of material for extrusion.
2. Extrusion of prepared TPO structural material for WRH. The extrusion process is carried out with electrical heating up to 220°C individually in 4 zones of the body and the extruder die head. During the extrusion process, the temperature of the cooling and polishing rollers should be in the range of 60...80 °C, to eliminate the possibility of the melt sticking to the rollers. Recommended screw rotation speed parameters are from 30 to 90 rpm.
3. Cooling of the resulting material. After the polymer material passes through the slot forming head, the resulting material base is placed on the rolling equipment, where it is pressed using a roller.
4. It is recommended to start TPO processing at a temperature greater than or equal to 100 °C. The loading volume (filling the composition) for one mixing cycle should be 10 - 15% higher than the loading volume of conventional rubber compounds.

2.1 WRH manufacturing technology

After developing the technology for obtaining and processing WRH materials, it is necessary to select a manufacturing process. The braiding method is considered optimal, providing the following advantages. Using only one production line, you can perform several assembly operations and simultaneously carry out several hose braids at once. As a result, the finished product will consist of 2-3 braided threads, due to which it becomes more flexible and lighter. This method also uses a flexible mandrel, which allows the production of longer hoses with precise compliance with the specified parameters along their entire length.

Strength layers of WRH are made of mutually intertwined single or several textile threads, applied at an angle of 45°. To improve adhesive strength and elasticity, an intermediate layer of squeegee is placed between the layers of braid. The layers of windings do not have interlacing power threads, which increases the strength, flexibility and service life of the hose. To enhance the rigidity and elasticity of the developed hose, it is recommended to use reinforcement using nylon thread. This requirement arises from the design features of the hose. To improve the adhesion of the spiral to the main polymer material of the inner and outer layers, an adhesive squeegee is used.

2.2 Description of WRH

The developed hose of increased wear resistance should be suitable for:

- Transport of aggressive media;
- Working environment temperature of no more than – 25°C;
- The density of the working environment is no more than 1500 kg/m^3;
- The size of solid inclusions in the working environment is no more than 0.2 mm;
- The volumetric concentration of solid inclusions in the working environment is no more than 0.1%.

The high wear resistance hose is a multi-layer structure consisting of:

- internal polymer layer (1);
- outer polymer layer (2);
- reinforcing cord (3) with an adhesive layer - squidge. The reinforcing layer of cord (3) is wound onto the inner polymer layer (1) at an angle of 45° (Figure 1).

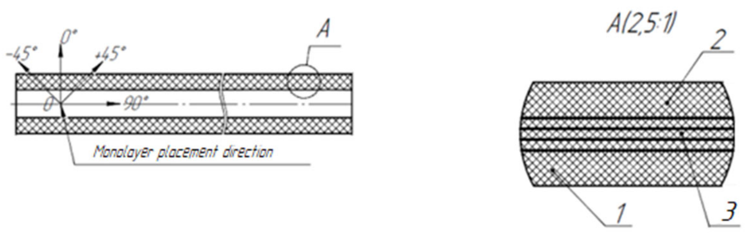


Fig. 1. WRH drawing.

Next, we will consider the main technical characteristics of the WRH.

In order to control the mechanical characteristics and performance of the hose under conditions close to the operating conditions on the prototypes, a series of tests were carried out.

2.3 Determining the properties of the WRH

2.3.1 Control of Mechanical Characteristics

Mechanical testing is performed in accordance with ASTM D412-06a on specimens that have not been subjected to other types of testing. At the beginning, the test objects are monitored and checked by a visual method for the absence of defects. Before testing, experimental samples are conditioned for at least 88 hours at 23 ± 2 °C and 50 ± 5% relative humidity.

When determining the mechanical properties, the sample is installed in clamps in the dynamic-mechanical thermal analyzer DMA 232 NETZSCH Geratebau GmbH with such a tightening force to prevent the sample from slipping under any test conditions. If there is a dependence of the measurement results on the tightening force of the clamps, then, if possible, it is necessary to use a constant tightening force in all measurements, especially those carried out taking into account the correction for length. To simulate environmental conditions, the temperature in the thermal analyzer is set to + 10 °C and with a constant heating rate of 5 °C/min. increase to + 40 °C. At each step of temperature change, the test sample is subjected to sinusoidal transverse loading at a frequency from 1 to 100 Hz. The DMA 232 NETZSCH Geratebau GmbH automatically records the values of the dynamic modulus of elasticity E' and the dynamic modulus of mechanical loss E" at each step.

Next, the experimental data is processed. First, the mechanical loss tangent tg(T) is calculated depending on the temperature using Eq. 1:

$$tg\delta(T) = \frac{E''(T)}{E'(T)} \tag{1}$$

Where $tg\delta$ is the mechanical loss tangent - a dimensionless quantity showing the ratio of the loss modulus (E″) to the elastic modulus (E′).

Secondly, a graph of the dependence tg(T) is plotted.

Thirdly, the fulfillment of condition (2) is checked:

$$\frac{dT}{dtg\delta(T)} \neq 0 \tag{2}$$

The fulfillment of condition (2) is checked using the constructed graph of the dependence tg(T). There should be no extremum points of the function on the graph. The equality to zero of the first derivative of the tangent of the mechanical loss angle characterizes a change in the physical state of the sample.

2.3.2 Wear resistance control

Tests are carried out in laboratory conditions in accordance with ASTMG99-17 to determine wear resistance by comparatively assessing the wear of experimental samples (ES) of the WRH to confirm wear resistance.

Experimental samples are tested using the installation shown in Figure 2. The cylinder on which the sandpaper is attached rotates at a given speed of 40 rpm, ensuring abrasion of the sample fixed in the cartridge with glue.

At the beginning, as in previous tests, control and verification of test objects is carried out. Before testing, experimental samples are conditioned. The required number of revolutions of the cylinder of the testing machine (TM) n is determined based on Eq. 3:

$$n = \frac{10}{\pi D} \tag{3}$$

where D is the diameter of the TM cylinder, m.

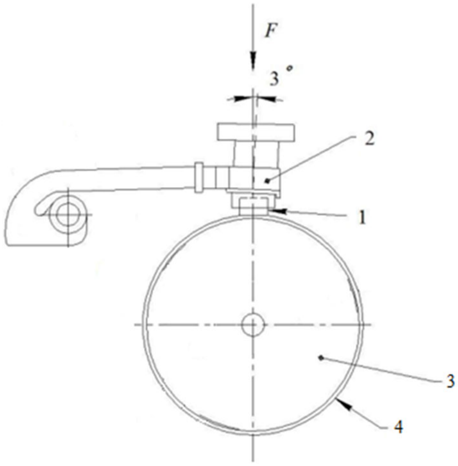


Fig. 2. Wear resistance testing machine: 1 – experimental sample, 2 – fastening of the experimental sample, 3 – rotation cylinder, 4 – sandpaper.

Tests include the following operations:

- Grinding of the sample to the abrasive surface. To do this, the sample is fixed in a cartridge or holder, and the load is set. The grinding is considered complete when signs of wear appear on the entire surface of the sample.
- Cleaning the sample from wear and dust.
- Determination of the mass of the sample after lapping.
- Abrasion of the sample. This process is carried out on previously unused sandpaper, securing the sample in the cartridge in the position as during lapping.
- Cleaning the sample from wear and dust.
- Determination of sample mass after abrasion.

Next, the results are processed.

The sample's operating time to failure T_0 is calculated using Eq. 4:

$$T_0 = \frac{0.15G}{V_1 k} \tag{4}$$

where G is the mass of the sample after grinding, [g];

Vl – sample abrasion index, [g/hour];

k=0.011 – proportionality coefficient characterizing the conditions of accelerated tests.

The sample abrasion index Vl, g/hour, is calculated using Eq. 5:

$$V_1 = \frac{(G - G_1)}{t} \tag{5}$$

where G_1 is the mass after testing the sample, [g]; t – abrasion time, [hour].

Knowing the operating time before failure of the experimental sample T_0, we can calculate the operating time before failure of the WRH T_{WRH} using Eq. 6:

$$T_{WRH} = T_0 \cdot \gamma \tag{6}$$

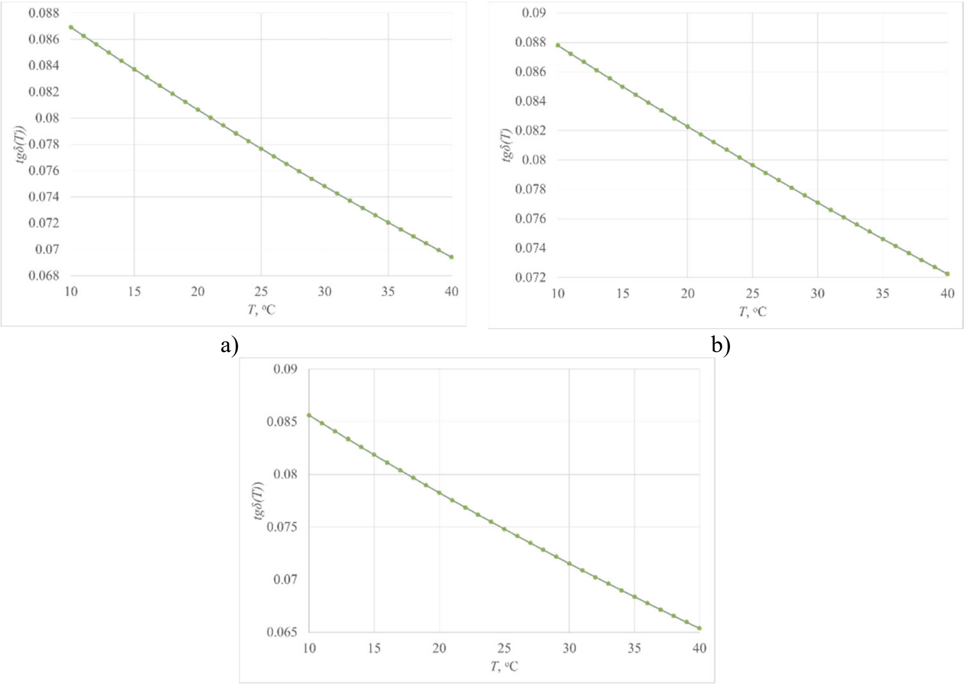
where $\gamma = 0.185$ is a scale proportionality factor associated with the ratio of the sample width to the outer diameter of the spindle.

The WRH is considered to have passed the test if the calculated value of the time to failure of the WRH is at least 150 hours.

2.4 Test results

As a result of mechanical tests of experimental samples, the dynamic modulus of elasticity and the dynamic modulus of mechanical losses were measured at temperatures from 10 to 40 °C.

Next, the mechanical loss tangent was calculated using eq. (1). The obtained values are shown in Figure 3. The values of tanδ(T) for samples 1, 2, 3 coincide (with an accuracy of 10^{-4}).



a) b)

c)

Fig. 3. Mechanical loss tangent tgδ(T) a) ES WRH TPV b) ES WRH TPO c) ES WRH EPDM.

When testing to determine wear resistance, the mass of the samples before abrasion and the mass of the samples after abrasion were measured. The test time was measured. Next, abrasion indicators were calculated. The obtained values are shown in Table 1.

As a result of mechanical tests, the performance of the developed hose with increased wear resistance was confirmed in normal mode under conditions of exposure to ambient temperatures from +10 to +40 °C.

All materials selected for the WRH passed the tests, since the resulting graphs of the mechanical loss tangent tgδ(T) are strictly monotonic in nature and there are no extrema in the given temperature range on the graph tgδ(T).

As a result of tests to determine the wear resistance of the WRH, all samples passed the tests. The time to failure of each material exceeds 150 hours. Based on the experiment, we can conclude that the thermoplastic material ES WRH TPO has the best resistance to wear, and the material ES WRH EPDM has the least resistance.

Table 1. Time to failure.

Name and designation of the test object		Calculated values			
		Abrasion rate V_l, g/h	Time to failure, T_0, h	Run-to-failure T_{WRH}, h	
				sample	average
ES WRH TPV	Sample 1	0.036	508,500	94.0725	157.528
	Sample 2	0.018	1023.750	189.3938	
	Sample 3	0.018	1022.250	189.1163	
ES WRH TPO	Sample 1	0.018	998,250	184.6763	184.260
	Sample 2	0.018	996,000	184.260	
	Sample 3	0.018	993,750	183.8438	
ES WRH EPDM	Sample 1	0.036	505.125	93.44812	156.256
	Sample 2	0.018	1011,000	187.0350	
	Sample 3	0.018	1017.750	188.2838	

3 Conclusion

As a result of the study, in accordance with the design and technological requirements, the three most suitable materials (TPV, TPO and EPDM) were selected, suitable for the manufacture of WRH. The hose manufacturing technology was selected and described. In order to confirm the performance of the products, test results are presented, as a result of which TPO can be called the most suitable for the manufacture of WRHs, since this material has the longest operating time before abrasion.

The work assumes that the climatic conditions in the testing laboratory are constant throughout the entire testing period, which does not affect the obtained characteristics of the experimental WRH samples.

The theoretical significance of the study is the presented method for assessing the working life of an experimental hose sample. This method can be used not only in this work, but also to estimate the abrasion time of any polymer product.

The practical significance lies in the demonstration of the developed technological method for increasing the working life of WRH, providing increased performance properties, allowing to improve the quality of the product, through the use of unique compositions of structural material and reinforcing layer.

In the future, this research will make it possible to reduce the percentage of defects due to automation of the production process, as well as to improve the manufacturability of the process of obtaining the WRH design.

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