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The influence of selected parameters on the elasticity modulus of conveyor belts with a polyester-polyamide core

The article compiles information on the influence of selected factors on the elasticity modulus of conveyor belts with a textile core. It presents a laboratory method for testing the modulus of elasticity, highlighting how its value changes depending on the load range and temperature. The modulus of elasticity is a parameter essential for the proper design of conveyor belts, especially those that are long or unconventional.

Key words: *conveyor belts, modulus of elasticity, influence of temperature and load*

1. INTRODUCTION

Conveyor belts play a crucial role in industry as a reliable means of transporting materials over limited distances. They are used in various applications but achieve their highest performance parameters in the mining industry [1, 2]. The mining sector in Poland, where conveyors are particularly significant, includes primarily open-pit lignite and rock material mines, as well as underground coal and copper ore mines. Conveyors used in lignite mines are often equipped with belts featuring steel cord cores. The impact of external factors such as temperature on the elastic and damping properties of such belts is minimal [2].

Underground mining operations are increasingly carried out at greater depths. This results in rises in temperature which not only affect humans but also the components of machinery and equipment [3]. Geological measurements indicate that subsurface conditions vary significantly depending on their location on Earth. Changes in temperature beneath the Earth's surface are described by the geothermal gradient [m/°C], which represents the depth at which the temperature increases by 1°C. The average geothermal gradient in Europe is 33 m/°C, while in Poland, it is 47 m/°C. This means that, assuming an average annual surface temperature of 10°C, the temperature at a depth of 1 km is approximately 30°C. However, even within Poland, rock temperatures at a depth of 2 km can vary widely depending on the location, ranging from 35°C to as high as 90°C [4].

In Figure 1, it can be observed that the highest temperatures occur in the Upper Silesia region as well as in areas where copper ore is mined. The working temperature for people in a mine should not exceed 28°C, with a threshold value of 33°C at which all operations must be halted. Currently, the rock temperature in copper ore mining areas reaches up to 45°C [1], necessitating forced cooling systems. High temperatures not only adversely affect human health but also impact the performance and durability of machine components.

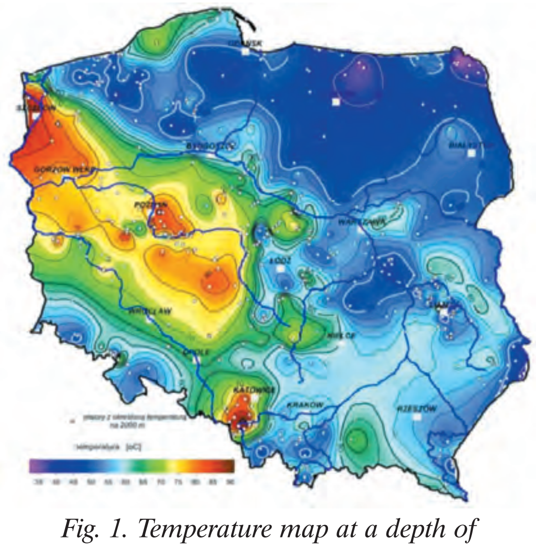

Fig. 1. Temperature map at a depth of 2000 m [4]

Conveyor belts used in underground mines are typically equipped with textile cores, whose elastic properties are closely dependent on temperature [5]. The standard operating temperature range for belts with rubber core fillings is –25°C to +60°C, while for belts with PVC core fillings, it is +5°C to +60°C. As can be seen, this range does not exceed the temperature values encountered even at the greatest depths of current coal or copper ore mining operations. However, the properties of conveyor belts vary significantly under extreme temperature conditions. One example of a property that changes significantly with ambient temperature is the modulus of elasticity, which describes the relationship between elongation and stress during uniaxial tension [5–7]. The modulus of elasticity for textile belts with the same strength may differ greatly due to the use of different fabrics in the core construction and the design of the core itself.

Another factor influencing the modulus of elasticity of conveyor belts may be the range and nature of the load. During normal conveyor operation, the belt is subjected to cyclic loading and unloading in the drive area of the conveyor. The range of forces varies from maximum S_1 to minimum S_2. For a properly selected belt, the value of force S_1 is typically around 10% of the belt's tensile strength (K_r), while S_2 is approximately 2% of K_r. The range of the belt load in a conveyor results from the requirement for proper frictional engagement between the belt and the drum, as well as the need to minimize belt sag between idler sets [1, 2].

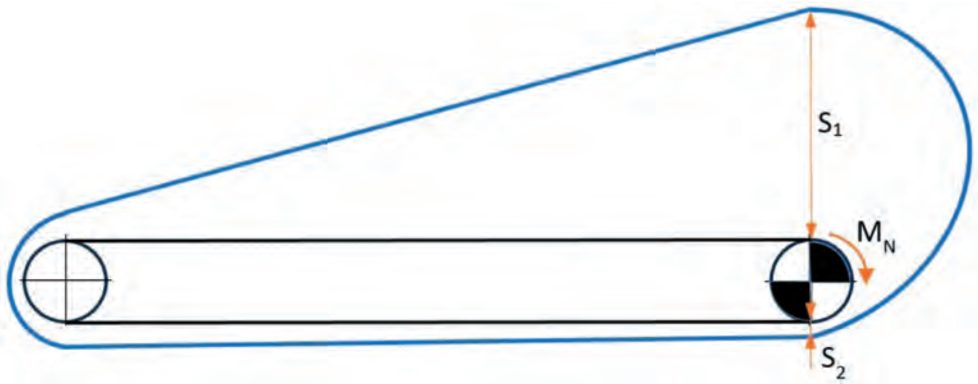

Fig. 2. Graph of forces in a conveyor belt during steady-state operation

In underground copper ore or hard coal mines, polyester-polyamide fabric belts with varying numbers of plies are most commonly used. This combination of fabrics results in minimal longitudinal elongation while ensuring good troughability [2].

During the conveyor design process, knowledge of the belt's modulus of elasticity is essential for [1, 8–10]:

- calculating the length of the belt tensioning path during transient operating states of the conveyor,
- analyzing the load distribution on the drive pulleys,
- determining the propagation speed of the stress wave in the belt during conveyor start-up,
- constructing a mathematical model of the conveyor and analyzing dynamic phenomena occurring during its transient states of operation.

2. REASERCH METHODOLOGY

According to PN-EN ISO 9856 [11], testing the modulus of elasticity requires preparing samples with a width of 50 mm and a length of 500 mm, cut along the conveyor belt's longitudinal axis. The sample is subjected to a sinusoidal load with a frequency of f = 0.1 Hz, varying within the range of 2–10% of the nominal tensile strength (K_r). After 200 loading cycles, the permanent elongation "Δl_p" and elastic elongation "Δl_e" of the tested sample are determined from the force-elongation graph. The diagram below illustrates the hysteresis loop, with the relevant values marked for reference.

The modulus of elasticity E, defined as the ratio of the increase in stress ΔF to the resulting elastic deformation of the belt Δl_e (Fig. 3), is calculated using the formula:

$$E = \frac{\Delta F}{\varepsilon_{elast}} \ [\mathrm{kN \cdot m^{-1}}] \tag{1}$$

where ΔF [$\mathrm{kN \cdot m^{-1}}$] – the increase in stress in the sample causing its relative elastic deformation:

$$\varepsilon_{elast} = \frac{\Delta l_e}{l_o} \ [-] \tag{2}$$

where l_o – the initial length of the reference section (equal to 200 mm).

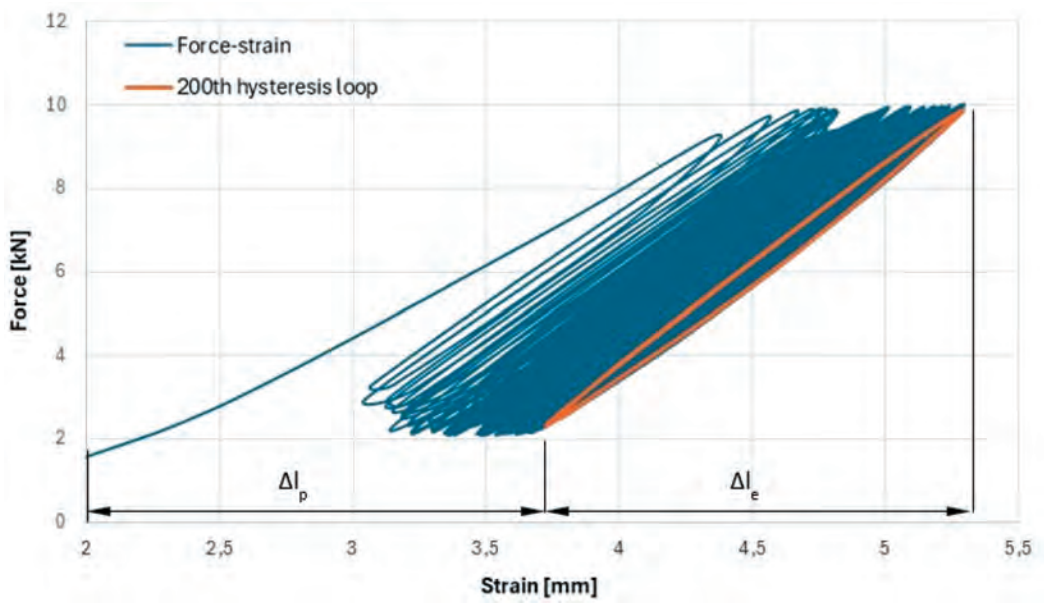

Fig. 3. Hysteresis loop on the force-deformation graph

Polish standards do not specify requirements regarding permanent elongation, but only provide requirements for elongation under working load and at break. The elongation of polyester belts under a load equal to 10% of the nominal tensile strength (K_r) should not exceed 3.5%. Additionally, the elongation at the point of break should not be less than 10% [2].

2.1. Test stand for measuring the modulus of elasticity of conveyor belts

Standard tests for the modulus of elasticity of belts are conducted using a testing machine with an appropriate range of applied forces [12]. Due to the time required to perform a single modulus of elasticity test, it is not feasible to carry out such tests with a standard testing machine at temperatures other than ambient temperature. Therefore, the tests were conducted using a testing stand with compact dimensions, allowing it to be fully placed inside a climate chamber. This chamber can set temperatures ranging from –30°C to +50°C [10, 11]. This is crucial, since temperature changes significantly affect the operational properties of the belt [5].

The test stand (Fig. 4) is equipped with a pneumatic actuator that drives a lever, mounted on the frame of the device, to which one end of the belt sample is attached. The other end of the sample is connected to a force sensor, mounted in clamps, and then linked to the frame. Additionally, the system is equipped with a proportional valve that allows the air pressure to be regulated. A deformation sensor is attached to the belt sample, recording its elongation.

Fig. 4. Test stand for measuring the modulus of elasticity of belts in a climate chamber

2.2. Test conditions

The tests were conducted under conditions consistent with the guidelines specified in the PN-EN ISO 9856 standard and were designated as reference conditions (load range 1). Additionally, tests were performed under conditions of varying load range and at elevated temperatures.

When designing conveyor belts, and especially when selecting the appropriate belt, the utmost care must always be taken. This ensures that the equipment can operate for a long period, and the investment costs are not excessive [1, 2]. However, it often happens that due to modifications to the conveyor, the belt operates within a lower or higher load range. This can result from elongation or shortening of the route, moisture or dust accumulation on the drive pulley, or changes in the amount of material being fed.

On Figure 5, the cyclic load range applied to the belt samples is presented graphically.

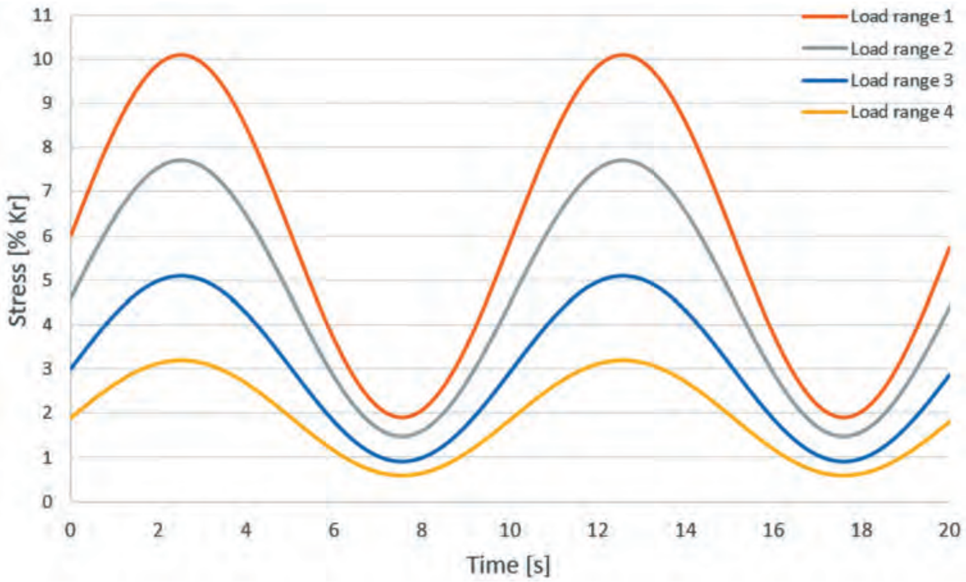

Fig. 5. Load cycles applied during the modulus of elasticity tests

For a belt with a tensile strength of 2000 kN/m and a width of 1000 mm, the standard load range, i.e., 2–10% of K_r , is 40–200 kN. When these values are applied to a sample with a width of 50 mm, the load range becomes 2–10 kN (load range 1). For the applied loads marked as 2–4, the force range is as follows: 1.6–8 kN, 1–5 kN, and 0.7–3 kN, respectively. Testing of the modulus of elasticity was not performed for loads exceeding 10% of K_r.

The modulus of elasticity tests were conducted at ambient temperature, i.e., 22 ± 2°C, and at an elevated temperature of 50 ± 2°C. The temperature of 50°C does not exceed the applicable range for fabric conveyor belts and is slightly higher than the highest temperatures typically recorded in underground mines. Therefore, this value was chosen for the tests.

3. LABORATORY TESTS OF THE MODULUS OF ELASTICITY

Two samples of new belts with the same nominal tensile strength but different core constructions were selected for testing. The width of the samples was 50 mm. The conditioning time at the specified temperatures was 8 hours.

Tests were performed three times for each load range and at the specified temperatures. The average values and standard deviations were determined. The analysis focused on the 200th hysteresis loop of stress as a function of elastic elongation.

3.1. EP 2000 belt

The sample marked EP 2000 is a multi-ply belt with a tensile strength of 2000 kN/m, constructed using polyester fabrics along the warp threads and polyamide fabrics along the weft. The belt has 4 plies and rubber covers. The standard temperature range for its use is –25°C to +60°C.

Figure 6 presents a summary of 200-h hysteresis loops obtained during tests of the EP 2000 belt under the assumed test conditions. The left side of the graph shows the results obtained during tests at a temperature of 22°C, while the right side shows the results at an elevated temperature.

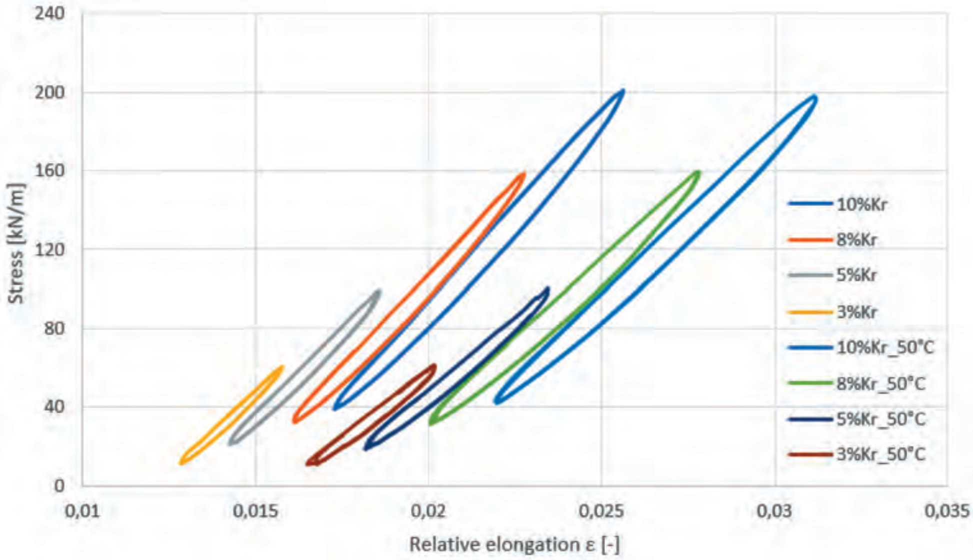

Fig. 6. Comparison of the 200th hysteresis loops for the EP 2000 belt under all adopted conditions

By comparing the shape and slope of the loops, it can be observed that the loops obtained during testing at 50°C have a slightly steeper slope and a larger surface area, which indicates higher energy losses during each loading cycle.

Below (Fig. 7), the average values of the modulus of elasticity for all the adopted testing conditions are presented in a bar chart. The standard deviations are also marked as error bars. The red envelope of the bars represents the tests conducted at a temperature of 50°C.

For the load range designated as 1 and a temperature of 22°C, the maximum value of the modulus of elasticity for the EP 2000 belt was achieved, which is 19 119 ± 336 kN/m. For the same load range but at an elevated temperature of 50°C, the modulus value was 16 019 ± 635 kN/m. The modulus of elasticity testing conducted at 50°C resulted in a 16% decrease in its value.

The modulus of elasticity of the EP 2000 belt tested for extremely low loads (load range 4) is 16 680 kN/m, which represents a 13% decrease compared to the reference conditions. However, when considering the additional high temperature (50°C), the modulus value is 13 680 ± 305 kN/m, indicating a decrease of over 28% compared to the reference conditions.

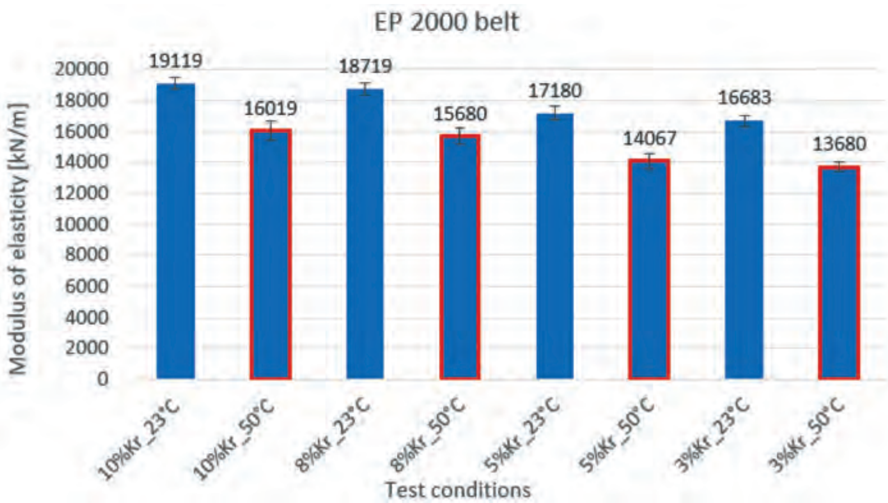

Fig. 7. Comparison of the average modulus of elasticity values for the EP 2000 belt

From Table 1, which contains the average values of the modulus of elasticity for the EP 2000 belt, it can be concluded that testing at elevated temperatures reduces the modulus of elasticity by 16–18% compared to the value obtained at 22°C. The temperature has a greater impact on the change in the modulus of elasticity of the EP 2000 belt than the load.

Table 1

Values of the modulus of elasticity for the EP 2000 belt tested under the adopted conditions

	Load range			
	2–10%K_r	1,6–8%K_r	1–5%K_r	0,7–3%K_r
	Modulus of elasticity [kN/m]			
22°C	**19 119** ± 335	18 719 ± 391	17 180 ± 428	16 683 ± 350
50°C	16 019 ± 631	15 680 ± 515	14 067 ± 463	**13 680** ± 303
Percentage change	16%	16%	18%	18%

3.2. PVC 2000 belt

The sample marked PVC 2000 is a single-ply belt with a tensile strength of 2000 kN/m, whose core is made of polyester fibers in the warp direction and polyamide fibers in the weft direction. The belt has a uniformly woven core impregnated with polyvinyl chloride (PVC) and rubber covers. The standard temperature range for its use is 0°C to +50°C.

The same range of tests was performed for the PVC 2000 belt. Below, the bar chart presents the average values of the modulus of elasticity for all the adopted testing conditions for the PVC 2000 belt. As with the previous belt, the standard deviation values are indicated, and the red envelope of the bars represents testing at 50°C.

For the load range 1 and a temperature of 22°C, the maximum value of the modulus of elasticity for the PV C2000 belt was achieved, which is 23 613 ± 692 kN/m. For the same load range but at an elevated temperature of 50°C, the modulus value is 19 980 ± 734 kN/m. Testing the modulus of elasticity at 50°C results in a 15% decrease in its value.

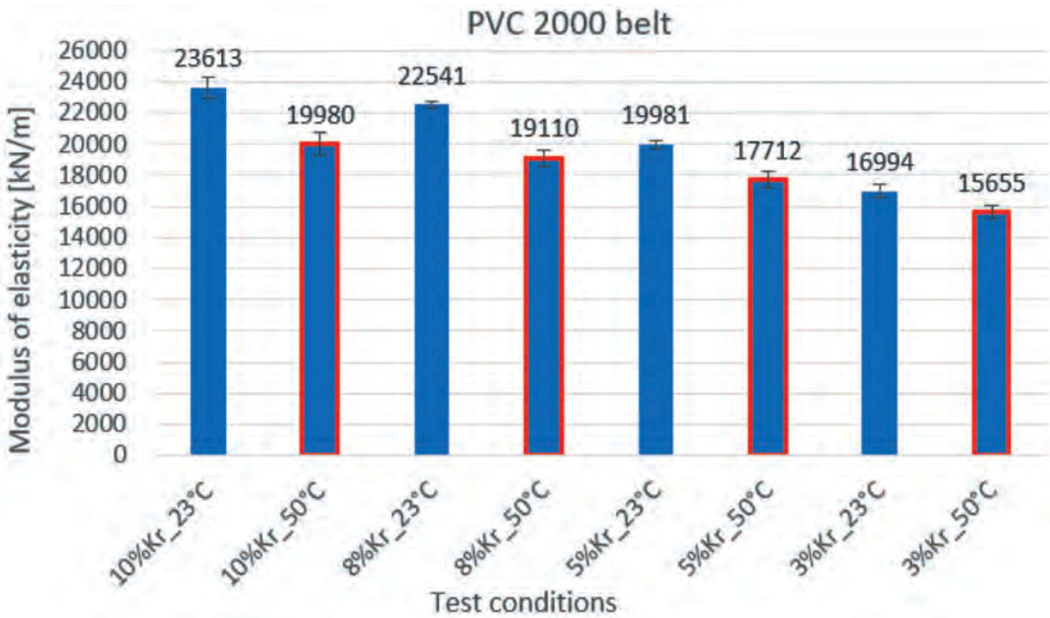

Fig. 8. Comparison of the average modulus of elasticity values for the PVC 2000 belt

The modulus of elasticity of the PVC 2000 belt tested for extremely low loads (load range 4) is 16 994 ± 380 kN/m, which represents a 28% decrease compared to the reference conditions. When considering the low load (load range 4) and the elevated temperature (50°C), the modulus value is 15 955 ± 320 kN/m, indicating a decrease of over 33% compared to the reference conditions.

From Table 2, which contains the average values of the modulus of elasticity for the PVC 2000 belt, it can be concluded that testing at elevated temperatures reduces the modulus of elasticity by 8–15% compared to the value obtained at 22°C.

Table 2

Values of the modulus of elasticity for the PVC 2000 belt tested under the adopted conditions

	Load range			
	2–10%K_r	1,6–8%K_r	1–5%K_r	0,7–3%K_r
	Modulus of elasticity [kN/m]			
22°C	**23 613** ± 692	22 541 ± 223	19 981 ± 299	16 494 ± 380
50°C	19 980 ± 734	19 110 ± 504	17 712 ± 507	**15 955** ± 320
Percentage change	15%	15%	11%	8%

4. SUMMARY AND FINAL CONCLUSIONS

1) Performing reliable tests of the modulus of elasticity of conveyor belts at low or high temperatures is only possible using a stand that can be enclosed in a climatic chamber together with the sample for the entire period of the actual tests.
2) Depending on the load range, the modulus of elasticity of a mono-ply belt ($E = 23\ 613 \pm 692$ kN/m) is higher by 13–19% than the modulus of elasticity of a multi-ply belt ($E = 19\ 119 \pm 336$ kN/m).
3) Testing the belt at high temperature causes a decrease in its modulus of elasticity. For the EP 2000 belt, the modulus value decreases in the range of 16–18%, while for the PVC 2000 belt by 8–15%.
4) Taking into account the extremely low load and high temperature (50°C), the value of the modulus of elasticity may decrease for the tested belts by 28–33% compared to the reference conditions.

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