DOI 10.52209/2706-977X_2025_2_80 **IRSTI 55.03.03** **UDC 681.87**

Investigation of Strength of Belt Conveyor Roller Bearing Shells

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Abstract. The article is devoted to the study of the characteristics of a sand-polymer composite (SPC) and a comparison of its strength properties with those of a traditional structural material, St10 steel, using the example of a roller support shell for a belt conveyor. Numerical modeling using the finite element method was used to evaluate the stress-strain state of the structure. It was found that the proposed sand-polymer composite provides a sufficient level of strength, with maximum stresses in the part reaching 7.3 MPa, which does not exceed the material's yield strength of 30 MPa. The minimum safety factor for the SPC shell was 3.216, which is 3.2 times higher than the standard. The maximum displacement at the point of load application for the SPC shell was 0.1645 mm. Compared to the steel counterpart (St10), which has maximum stresses of 3.2 MPa and a safety factor of 9.6, the sand-polymer composite reduces the weight of the product by 3.5 times (the weight of the SPC shell is 1.73 kg, while that of the St10 steel shell is 6.185 kg). The results obtained confirm the feasibility of using sand-polymer material to optimize roller bearing designs, providing the required strength characteristics at a lower weight, as well as economic efficiency due to the lower cost of the material.

Keywords: shell, sand-polymer composite, stress-strain state, safety factor

Introduction

Belt conveyors are widely used in various industries for transporting bulk materials [1]. One of the key components of a conveyor is the roller support, which provides support and guides the movement of the conveyor belt [2]. The efficiency of the conveyor largely depends on the reliability and durability of the roller supports, and therefore on the strength of their main elements, in particular the shell.

The shell of the roller support absorbs significant loads arising during operation, including the weight of the transported cargo, dynamic impacts, and vibrations [2]. A violation of the strength of the shell can lead to roller failure, increased resistance to belt movement, and, as a result, to the shutdown of the entire conveyor line. The shell forms the outer surface of the roller that contacts the conveyor belt. It must be strong and rigid enough to withstand significant loads from the transported material and the weight of the belt itself, preventing deformation of the roller. This ensures even load distribution across the entire width of the belt. The shell serves as a protective cover for the bearings and roller axle. It prevents dust, dirt, moisture, and abrasive particles from entering the mechanism, which could cause premature wear and failure of the bearings.

Various materials are used to manufacture shells, such as cast iron, pressed or stamped steel, and polymer composite materials [3]. The use of metal shells for roller supports in conveyor systems has a number of disadvantages. First, metal shells are susceptible to corrosion under the influence of climatic factors, which reduces the service life of the product [4]. Second, metal shells are significantly heavier than similar products made of polymer materials, which can create additional loads on the structure [5]. Third, the vibration that happens when the conveyor is running leads to increased wear on both the bearings and the metal roller shafts because of friction [6, 7]. Although polymer composites have a good strength-to-weight ratio, they may be inferior to metals in terms of absolute strength and stiffness [8, 9].

The physical and mechanical properties of the roller bearing shell determine its ability to perform its intended function, taking into account its durability. Tensile strength and yield strength determine the shell's ability to withstand axial and radial loads without failure or residual deformation. The hardness of the material used is important for resistance to abrasive wear from the conveyor belt and the material being transported. High hardness contributes to increased service life. Fatigue strength determines the ability of the material to withstand repeated cyclic loads without failure. Rollers are constantly subjected to cyclic loads from the weight of the belt and cargo.

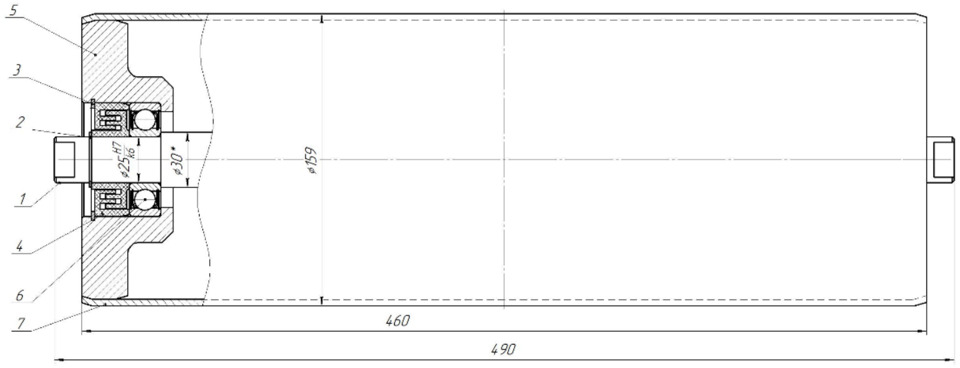
As a result, consumers, when choosing the material for roller bearings, are forced to find a balance between the advantages and disadvantages of each option, since there is no ideal solution at the moment.

Currently, there are a number of methods for assessing the strength of metal-polymer conveyor rollers based on FEM analysis [10-12]. Research is focused on creating new, more reliable and durable roller support designs that can withstand increasing loads and operate in aggressive environments. Other studies [13, 14] describe the developed mathematical models of stress-strain state based on a system of differential equations, taking into account the geometric parameters of the roller, deflection, and load pressure. Works [15-17] consider the optimization of conveyor rollers according to various criteria.

In this regard, the specific purpose of this article is to study the strength characteristics of roller support shells made of different materials, analyze the stress-strain state, and identify factors affecting its reliability. Conducting such studies allows optimizing the design of the roller support, increasing its service life, and minimizing the risk of accidents.

1. Materials and methods

The object of the study is the roller support shell of a belt conveyor (Figure 1), which bears the load from the belt and the transported material.



1 – shaft; 2,3 – retaining rings; 4 – labyrinth seal; 5 – bearing assembly housing; 6 – bearing; 7 – side plate

Fig. 1. – General view of a belt conveyor roller

The criterion for optimizing the shell when selecting material using the Davison-Fletcher-Powell method is determined by the formula [17, 18]:

$$F = \frac{m}{m_0} + V \sum_{i=1}^{n} \frac{1}{\varphi_i}, \quad (1)$$

where $\varphi_i = (1/(1 - g_i))$ - penalty functions;

g_i - restrictions;

V – construction volume;

m_0 - initial mass of the structure;

m - final mass of the structure.

The optimal design solution when selecting material for a belt conveyor shell is determined by criteria such as efficiency F (shell mass) and quality g_0 (shell strength). In this case, the quality function is the dependence of mass on strength: $\Phi = g_0(F)$

The shell design will be considered optimal if $F(x) \rightarrow \min$; $g(x) = g_0$.

Furthermore, $F(x)$ and $g(x)$ are given functions of the design variables. Constraints are formed on the safety factor. ($n \geq 1.6$) [19].

The materials selected for testing were St10 carbon steel, which is most commonly used in the manufacture of shells, and an experimental sand-polymer composite (SPC – 60 wt% quartz), as shown in Table 1.

Table 1. Physical and mechanical properties of bearing unit housing materials

Parametr	Sand-polymer composite (SPC – 60 wt% quartz)	Steel St10 (GOST 1050-2013)
Yield strength, MPa	30	200
Ultimate tensile strength, MPa	80	325
Modulus of elasticity, GPa	5	215
Poisson's ratio	0,25	0,3
Density, kg/m^3	2200	7800

To study the load characteristics of the roller bearing shell made of PPC [20], a static analysis was performed in APM FEM, including the following steps:

- creation of a 3D model of the roller bearing;
- assignment of physical and mechanical properties to parts (Table 1);
- selection of the fastening type. In this case, “Roller support” and “Fixed hinge” were selected for fastening (Figure 2);
- setting the load.

The pressure of bulk cargo on the horizontal section of the belt can be calculated as hydrostatic, then the normal force applied to this section is equal to [1-3].

$$N = 0{,}5 \cdot l_{on} \cdot l_p \cdot p \left[2 \cdot l_r \cdot sina + \left(b - \frac{l_p^2}{12 \cdot b_c} \right) \cdot tg\varphi_H \right], \quad (2)$$

where l_{on} – distance between roller supports;

$l_p = K_p \cdot B$ – conveyor belt width;

K_p = 0,39 – proportionality coefficient;

B – conveyor belt width;

$\varphi_{и}$ – The angle of repose of the load or the angle of natural slope when moving on the belt depends on φ – the angle of natural slope for the state of rest..

Based on formula (1), a force N equal to 4000 N was set as the external load.

- creation of a mesh with the smallest elements set to 1.5 mm and 0.5 mm, respectively, on the edges at the point of load application and the point of attachment of the roller support shaft (Figure 3);
- calculation and analysis of results.

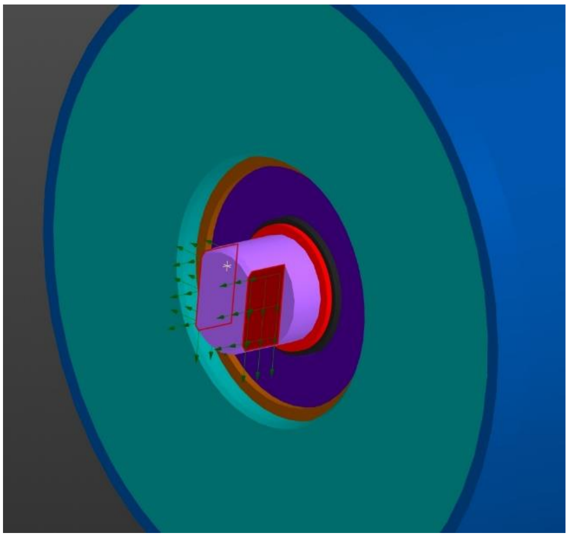


Fig. 2. – Selecting a fastener

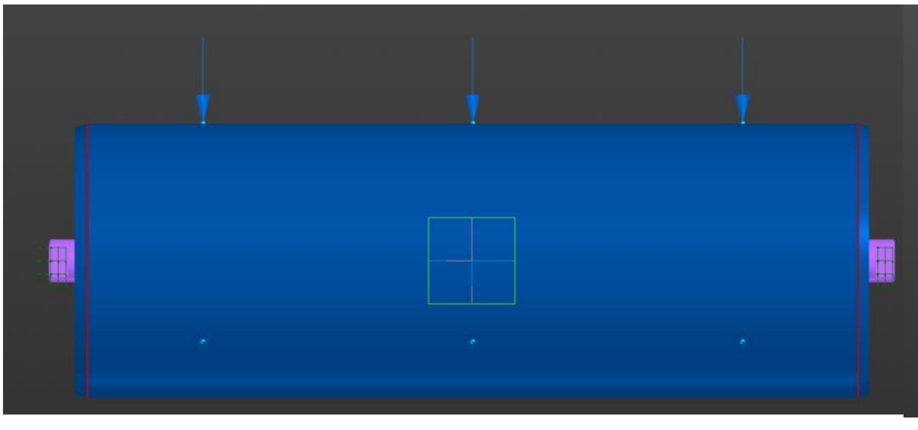


Fig. 3. – Load assignment

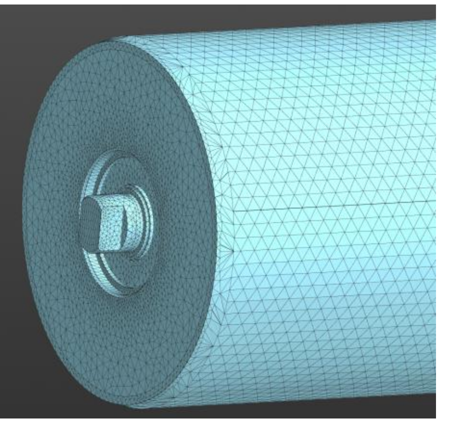


Fig. 4. – Creating a grid

2. Results and discussion

The results of the static calculation are presented in the form of diagrams in Figures 4-7.

Analysis of the figures allows us to note the following:

- the maximum displacement at the point of load application was 0.1645 mm (Figure 8);
- the stresses obtained in the part do not exceed the yield strength of the material, which is 30 MPa;
- the maximum stresses are concentrated on the shaft and amount to 7.3 MPa (Figure 5);
- the minimum safety factor of the polymer k_s = 4.503 (Figure 7);

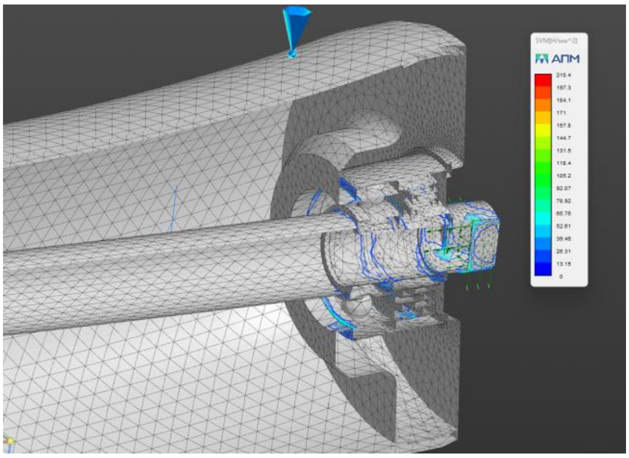


Fig. 5. – Equivalent stress according to Mises for a shell made of SPC

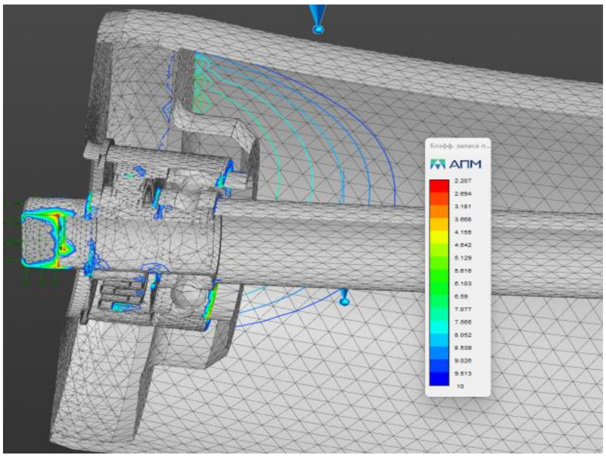


Fig. 6. – Yield strength safety factor for SPC shell

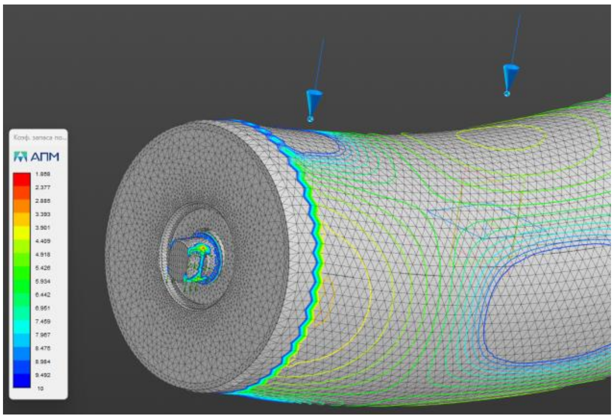


Fig. 7. – Fatigue strength safety factor for a shell made of SPC

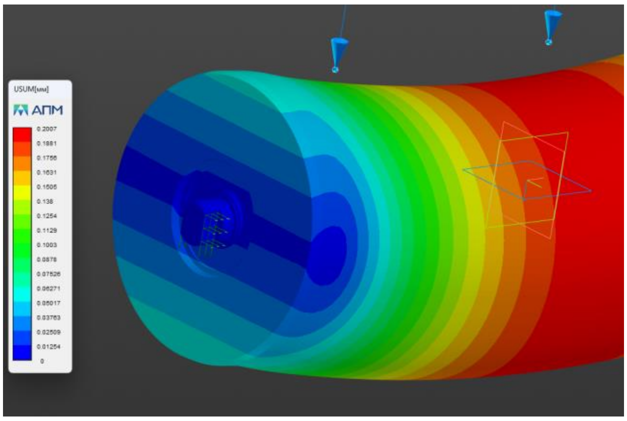


Fig. 8. – Total linear displacement for a shell made of SPC

For comparison purposes, calculations were performed for a roller bearing shell made of St10 steel. The results of the comparison of the strength characteristics and mass of the bearing assembly housing made of SPC and St10 are shown in Table 2.

Table 2. Strength characteristics of roller bearing shells made from different materials

Parametr	SPC	St0
Maximum displacement, mm	0.1645	0.01283
Maximum stresses, MPa	7.3	3.2
Safety factor	3.216	9.6
Weight, kg	1.73	6.185

Table 2 shows that the safety factor is maintained for both steel and SPC shells. At the same time, the safety factor for the sand-polymer composite shell is 3.2 times higher than the standard, and the safety factor for the steel shell is 9.6 times higher. This indicates that parts made from both materials are not overloaded. However, taking into account the efficiency F (mass) and quality g_0 (strength), as well as the cost of materials, it is recommended to use sand-polymer composites for the manufacture of shells.

Conclusions

The following results were obtained as a result of the research conducted:

1) Numerical modeling using the finite element method showed that the maximum displacements for the SPC shell were 0.1645 mm, and the maximum stresses were 7.3 MPa, which does not exceed the yield strength of the material (30 MPa). For the steel shell, the maximum displacements were 0.01283 mm, and the maximum stresses were 3.2 MPa;

2) The safety factor for the PPC shell was 3.216, which is more than 3.2 times higher than the standard value. For the steel shell, this indicator was significantly higher – 9.6. Despite the fact that steel has a higher safety factor, this indicates that the design made of both materials is not overloaded;

3) An important result of the study is the confirmation of the feasibility of using sand-polymer composite to optimize roller bearing designs. The use of SPC reduces the weight of the product by 3.5 times compared to its steel

counterpart. In addition, sand-polymer composite increases the corrosion resistance of the product, which is a significant advantage, since metal shells are susceptible to corrosion under the influence of climatic factors. The use of SPC also contributes to economic efficiency due to the lower cost of the material;

4) Both sand-polymer composite (SPC) and steel are suitable for the manufacture of belt conveyor roller bearings in terms of strength characteristics;

5) It is recommended to use sand-polymer composite (SPC) for the manufacture of belt conveyor roller shells, which, with a lower product weight, provides the required strength characteristics, as well as economic efficiency achieved due to the lower cost of SPC.

Aknowledgment

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant AP19680121 “Development of compositions of sand-polymer composite materials and technological support for their processing into products for mechanical engineering”).

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