UDC 629.463.65
DOI: 10.15587/1729-4061.2023.275547

DETERMINING PATTERNS IN LOADING THE BODY OF A GONDOLA WITH SIDE WALL CLADDING MADE FROM CORRUGATED SHEETS UNDER OPERATING MODES

Glib Vatulia
Doctor of Technical Sciences, Professor, Vice-Rector for Research**

Alyona Lovska
Corresponding author
Doctor of Technical Sciences, Associate Professor*
E-mail: alyonaLovskaya.vagons@gmail.com

Sergiy Myamlin
PhD, Researcher
Department of Electrical Power Engineering, Electrical Engineering and Electromechanics**

Andrij Rybin
PhD, Senior Lecturer*

Volodymyr Nerubatskyi
PhD, Scientific Consultant
"PA OWEN" LLC
Hvardiitsiv-Shyronintsiv str., 3A, Kharkiv, Ukraine, 61153

Denys Hordiienko
Senior Engineer
ELAKS PJSC
Akademika Proskury str., 1, Kharkiv, Ukraine, 61085

*Department of Wagon Engineering and Product Quality**
**Ukrainian State University of Railway Transport
Feuerbakh sq., 7, Kharkiv, Ukraine, 61050

The object of research is the processes of emergence, perception, and redistribution of loads in the body of a universal railroad gondola with a cladding of corrugated sheets.

To improve the strength of the sheets of cladding, it is proposed to strengthen the most loaded area in terms of height (1/3 of the bottom tie-up) with horizontal corrugations. Determination of the geometric parameters of the corrugation is carried out by the moment of resistance of the sheet. The dynamic load of the gondola body with improved cladding was determined by mathematical modeling. The fluctuations of the jump were taken into consideration, that is, the translational movements of the body relative to the vertical axis. The results of the solution of the mathematical model have made it possible to conclude that the studied dynamics indicators are within the permissible limits while the car movement is estimated as "excellent".

The calculation was performed of the strength of the body of a gondola with improved cladding. It has been established that the strength of the gondola body under the main operating load modes is ensured. According to the results of calculations of static strength, the calculation was performed of the fatigue strength of the gondola body. It must be said that the fatigue strength of the body cladding increases by 3.7 % compared to the typical one.

A feature of the results obtained is that the proposed improvement of the cladding can be carried out not only at the design stage but also during repairs of cars.

The scope of practical use of the results includes the engineering industry, in particular railroad transportation. At the same time, the conditions for the practical application of the research results are compliance with the requirements for loading and unloading operations of gondola cars.

The results of the current research will contribute to devising recommendations for the design of modern structures of gondolas and for improving the efficiency of their operation

Keywords: gondola load, body strength, cladding resistance momentum, body biaxiality indicator

Received date 09.01.2023
Accepted date 17.03.2023
Published date 30.04.2023

How to Cite: *Vatulia, G., Lovska, A., Myamlin, S., Rybin, A., Nerubatskyi, V., Hordiienko, D. (2023). Determining patterns in loading the body of a gondola with side wall cladding made from corrugated sheets under operating modes. Eastern-European Journal of Enterprise Technologies, 2 (7 (122)), 7–14. doi: https://doi.org/10.15587/1729-4061.2023.275547*

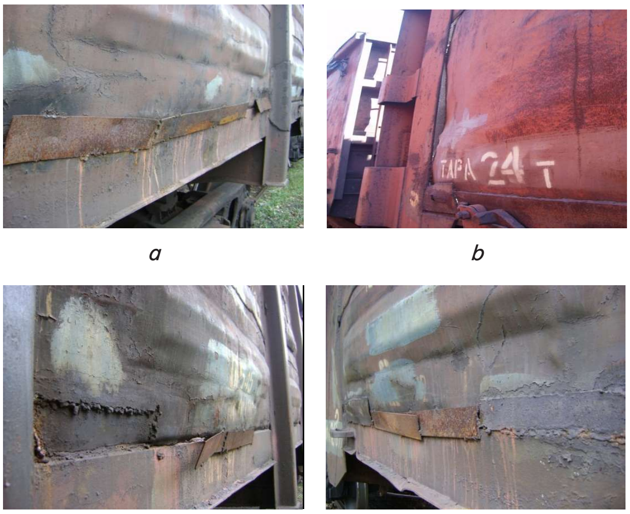
1. Introduction

The National Transport Strategy until 2030 identifies the development of rolling stock as one of the most important areas of development of railroads in Ukraine. Ensuring the competitiveness of the railroad industry necessitates the commissioning of modern rolling stock structures with improved technical, economic, and operational indicators [1, 2]. In addition, the design of such rolling stock should provide the ability to reduce the cost of its maintenance.

It is known that the most common type of car on railroads of 1520 mm gauge are gondola cars. At the same time, this type of car is one of the most damaged.

Analysis of the technical condition of gondola cars led to the conclusion that during operation there is damage to the sheets of cladding of their bodies (Fig. 1).

These damages may be caused by a violation of the technology of loading and unloading operations, the presence of a natural degree of freedom, or asymmetry of the placement of transported goods, and as a result of the additional load of the body under operating conditions [3, 4]. The presence of such damage not only affects the safety of the transported goods but also threatens the safety of train traffic, the environmental safety of the transported goods, etc. This necessitates devising measures aimed at ensuring the strength of the sheets of cladding of gondola bodies during operation. Therefore, research into this area is quite relevant.



a b

c d

Fig. 1. Damage to the sheets of cladding of the gondola body: *a, c, d* — in the zone of interaction with the lower strapping; *b* — in the zone of interaction with the corner stand

2. Literature review and problem statement

The issues of improvements in the supporting structures of gondola cars are quite relevant, which is confirmed by a large number of publications. So, for example, work [5] proposed to improve the cladding of the body of a gondola by using composite material. This solution will help improve the strength of the body, reduce its packaging, corrosion damage, etc. The study was conducted on the example of the end door of a gondola car. The results of the calculations confirmed the rationality of the proposed implementation. At the same time, the use of composite material significantly increases the cost of manufacturing a gondola car, especially at their undustrial production.

In [6], the design of a gondola with a cladding made of steel of grades 16G2AF and 18G2AFps is proposed. The use of such material for the manufacture of cladding will help reduce the body's natural weight and increase carrying capacity. The results of numerical experiments on optimizing the thickness of the components of the body, as well as testing the optimized structure for strength, are given. It must be said that the reduction of car tare contributes to an increase in the dynamic loads that act on it when driving in an empty state. In this regard, the issues of reducing the tare must necessarily be accompanied by dynamic calculations to comply with these loads within the permissible limits. However, such calculations are absent in the work.

The expediency of using magnesium alloys in the supporting structures of vehicles, including for the manufacture of cladding, is considered in [7]. This solution will help reduce the tare of cars compared to prototype designs while ensuring sufficient operational strength. At the same time, the cited paper does not investigate the impact of the proposed optimization on the dynamic indicators of car movement.

Of scientific interest is study [8], which provides a justification for the use of polymer composite materials in the construction of cars. The study was conducted on the example of flooring of the car. The results of experimental studies on the method of pressing composite in the form are highlighted. It is important to say that the possibility of using this material in the manufacture of wall cladding of bodies by the authors has not been considered.

To improve the strength of the cladding of the side walls of the freight car, the authors of work [9] proposed the introduction of laminated composite materials for its manufacture. The results of determining the optimal thickness of the walls of the car body, provided that its strength is ensured, are given. The expediency of the proposed solution has been proven. However, such material is quite expensive, which hinders its widespread use in car building.

The justification for the use of composite panels in the constructions of freight cars was carried out in [10]. This solution will help reduce damage to the components of the bodies during operation. The results of the calculation on the strength of the supporting structure of the car are given. A method of placing composite panels in the inner space of the body is proposed.

Features of the use of composite panels in the designs of freight cars are also covered in [11]. This implementation is proposed to be carried out during the modernization of wagons to protect against corrosion damage and facilitate the unloading of goods in winter conditions. The authors substantiated the use of composite elements (panels) on the example of side walls. One must say that such an implementation will rather complicate the process of maintenance and repair of cars during operation, which will cause the need for additional costs for their maintenance.

To reduce damage to the cladding of the side and end walls of gondola cars, the authors of work [12] proposed their manufacture from articulated shells filled with energy-absorbing material. The calculation is implemented on the example of foam aluminum. The results of the calculations established that, taking into account the proposed improvement, it is possible to improve the strength of the supporting structure of the gondola by 8 %. However, this implementation is quite complicated from a technical point of view, as well as in terms of cost.

Our review of literary sources [5–12] allows us to conclude that the issues of improvements in the bodies of gondola cars are quite relevant and important. At the same time, they need further development in order to increase the efficiency of their functioning.

3. The aim and objectives of the study

The aim of this study is to determine the possibilities of using corrugated sheets in the cladding of the side walls of a gondola car. This will help reduce damage to the wall cladding, and, accordingly, the cost of unscheduled repairs of gondola cars.

To accomplish the aim, the following tasks have been set:

– to substantiate the structural features of the cladding of the side walls of the gondola;

– to determine the dynamic load of the gondola body;

– to determine the strength of the gondola body under basic operational load modes.

4. The study materials and methods

The object of research is the processes of emergence, perception, and redistribution of loads in the body of a universal gondola with a cladding of corrugated sheets.

The main hypothesis of the study assumes that improving the strength of the wall cladding is possible by increasing the momentum of resistance in the most loaded areas.

Typical body cladding on most gondolas of the 1520 mm track fleet consists of sheets that are formed by stampings (Fig. 2, *a*) or are smooth (Fig. 2, *b*). On outdated structures of gondola cars, stampings are also used, but of a different configuration than in modern ones (Fig. 2, *c*). The cladding of the end walls can be represented by corrugated sheets (Fig. 2, *d*).

The thickness of the sheets of cladding of the side walls is variable in height: 5 mm – at a height of 1/3 from the lower strapping and 3 mm – at a height of 2/3 of the sheet.

To improve the strength of the sheets of cladding, it is proposed to strengthen the most loaded area in height (1/3 of the lower tying) with horizontal corrugations (Fig. 3).

To determine the dynamic load of the gondola body, mathematical modeling was carried out. The fluctuations of bouncing were accounted for, that is, the translational movements of the body relative to the vertical axis [13, 14]. It is taken into account that the car is moved in an empty state over a rail irregularity, which has the appropriate elasticity and viscosity. To determine the main indicators of the dynamics of the gondola car, an estimation scheme was drawn up, shown in Fig. 4.

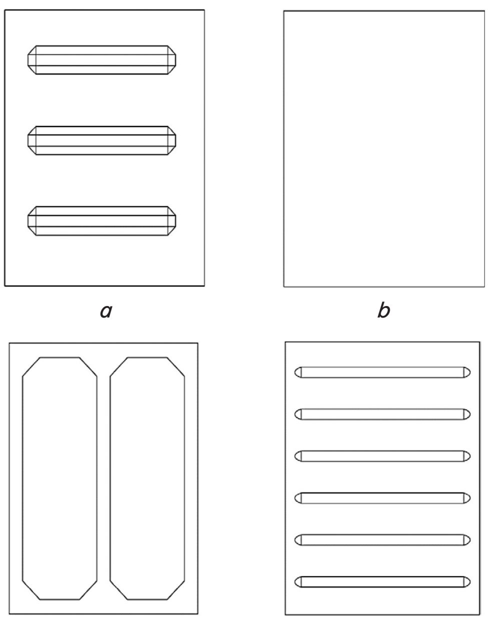


Fig. 2. Variants of the cladding of gondola bodies: *a*, *c* – stamping; *b* – smooth; *d* – corrugated

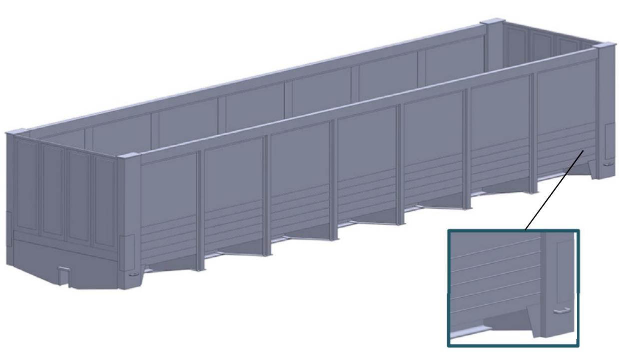


Fig. 3. The body of a gondola with improved cladding

In this case, the system of differential equations of motion of a gondola takes the form:

$$\begin{cases} M_1 \cdot \ddot{q}_1 + C_{1,1} \cdot q_1 + C_{1,2} \cdot q_2 + C_{1,3} \cdot q_3 = \\ = -F_{FR} \cdot \left(sign\left(\dot{\delta}_1\right) + sign\left(\dot{\delta}_2\right) \right), \\ M_2 \cdot \ddot{q}_2 + C_{2,1} \cdot q_1 + C_{2,2} \cdot q_2 + B_{2,2} \cdot \dot{q}_2 = \\ = F_{FR} \cdot sign\left(\dot{\delta}_1\right) + k\left(\eta_1 + \eta_2\right), \\ M_3 \cdot \ddot{q}_3 + C_{3,1} \cdot q_1 + C_{3,3} \cdot q_3 + B_{3,3} \cdot \dot{q}_3 = \\ = F_{FR} \cdot sign\left(\dot{\delta}_2\right) + k\left(\eta_3 + \eta_4\right), \end{cases} \tag{1}$$

where M_1 – the mass of the supporting structure of the gondola car; M_2, M_3 – the mass, respectively, of the first and second trolleys; C_j – elasticity characteristics of the elements of the oscillatory system, which are determined by the values of the coefficients of spring stiffness k_S; k – track rigidity; B_{ij} – dissipative coefficients; β – damping coefficient; F_{FR} – friction force in the spring set of the trolley; δ_i – deformation of elastic elements of spring suspension; η_i – irregularity of the track.

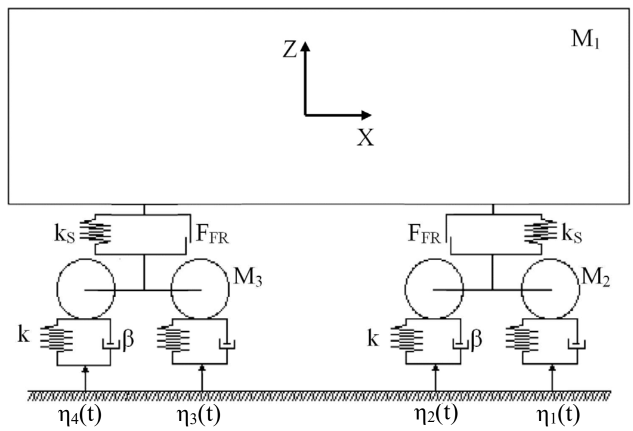


Fig. 4. Estimation scheme of the gondola

The matrix of elastic coefficients can be written as

$$C = \begin{pmatrix} 2 \cdot k_S & -k_S & -k_S \\ -k_S & -k_S + 2k & 0 \\ -k_S & 0 & -k_S + 2k \end{pmatrix}. \tag{2}$$

The matrix of dissipative coefficients is recorded as follows

$$B = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 2 \cdot \beta & 0 \\ 0 & 0 & 2 \cdot \beta \end{pmatrix}. \tag{3}$$

Track irregularity was given in the form of a periodic law

$$\eta(t) = A \cdot (1 - \cos\omega \cdot t), \tag{4}$$

where A is the amplitude of irregularity; ω – frequency of irregularity; t – the time of the oscillatory process.

The system of differential equations of motion was solved using the software suite MathCad (USA) [15, 16]. The starting conditions are set to zero [17–19]. This choice is justified by the fact that the calculation was carried out with the nominal parameters of the components of the car body.

The acceleration value obtained by mathematical modeling is taken into account when calculating the strength of the gondola body. For this purpose, the method of finite elements is applied [20–23]. This method was chosen as a calculation because it is the most common in the calculation of car structures for strength. The calculation was carried out in the software package SolidWorks Simulation (France) [24–27]. Due to the fact that the car body is made of steel, which is an isotropic material, the von Mises criterion was chosen as the calculated one. At the same time, a gondola of model 12-757 was taken as a prototype. This gondola is four-axle and has 14 covers of unloading hatches. The car tare is 25 tons, and the carrying capacity is 69 tons, the car is designed in the dimensions of 1–VM (O–T) and has a length behind the end beams of 12.8 m, and the maximum width is 3.22 m. Trolleys of the model 18–100 are installed under this type of car.

When building a spatial body model, elements that strictly interact with each other, welding or rivets are taken into account. Since the hatch covers have a hinged fastening, they were not taken into account in the model. The spatial model was created as an assembly, which then turned into a detail. These operations were carried out by importing the model into the AutoCAD software package (USA). When creating the model, welding seams were not taken into account.

When drawing up the estimation scheme of the gondola car, it is taken into account that it is affected by the vertical load P_v, the spreading pressure of the bulk cargo P_b, as well as the longitudinal load P_l (Fig. 5).

The bulk cargo spreading pressure (of coal) is calculated according to formula (5) in accordance with DSTU 7598:2014. "Freight cars". General requirements for calculations and design of new and modernized cars of 1520 mm (non-self-propelled) track. It must be said that there is a foreign analog to this standard – EN 12663–2. Railroad applications – structural requirements of railroad vehicle bodies – Part 2: Freight wagons:

$$P_p = \gamma \cdot g \cdot H \cdot \mathrm{tg}^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right), \tag{5}$$

where γ – density of bulk cargo, t/m^3;

H – height of the side wall, m;

φ – the angle of natural slope of the cargo, rad;

g – acceleration of gravity, m/s^2.

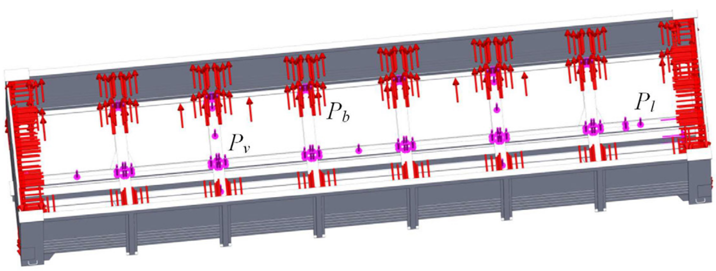


Fig. 5. Estimation scheme of the body of a gondola car

When determining the pressure of the load on the end walls, passive pressure was also taken into account. The value of the passive pressure is determined by (5), in which the square of the tangent of the difference between the two angles is replaced by the square of the tangent of their sum and taking into account the coefficient of vertical dynamics, as well as the angle of natural slope.

The model was fixed for the heels and was modeled by making rigid connections [28–30]. This did not take into account the possible friction forces between the heels and the thrust bearings.

In the preparation of the finite-element model, isoparametric tetrahedra were used [31, 32] (Fig. 6). This element was chosen due to the fact that the grid was created on a solid.

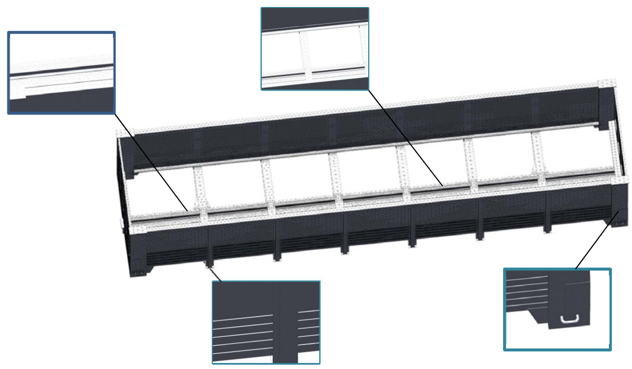


Fig. 6. Finite-element model of the body of a gondola car

The number of nodes of the model is 570153, elements – 180832. The maximum size of the element was 100 mm, the minimum – 20 mm. As a material of construction, steel of grade 09G2C is used, which is typical for the manufacture of bodies.

According to the results of calculations of static strength, the calculation was performed of the fatigue strength of the gondola body. In this case, the options of the SolidWorks Simulation software package are used. The fatigue curve is obtained based on ASME carbon steel curves. The test base was 10.7 cycles.

5. Results of determining the load of the body of a gondola car with a cladding of the side walls made of corrugated sheets

5. 1. Justification of the structural features of the cladding of the side walls of the gondola

To determine the geometric parameters of the corrugation, the lower part of the cladding sheet in height of 1/3 of the lower strapping is considered as a thin-walled slab. In this case, the moment of resistance of the sheet was used as the determining parameter. For this purpose, spatial models of sheets were built in the SolidWorks software package (France) (Fig. 7, 8) and with the help of built-in options, the moments of their inertia were determined. After that, according to the dependence known from [33, 34], the moments of resistance of the sheets were determined:

$$W = \frac{I}{z}, \tag{6}$$

where z is the distance from the geometric center of gravity of the cross section to the corresponding axis.

Using the options of the SolidWorks software package, it is established that the moment of inertia of the cross-section of a typical sheet is 15884.5 cm^4, and the moment of resistance is 4741.6 cm^3.

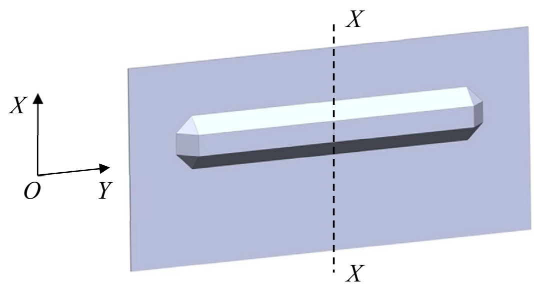


Fig. 7. Spatial model of a typical sheet

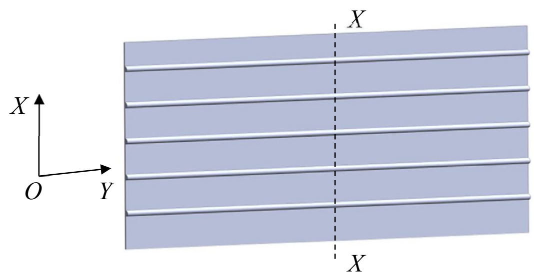


Fig. 8. Spatial model of the improved sheet

Taking into account the determined moment of inertia, the selection of the corresponding diameter of the corrugated sheet was carried out at which the moment of inertia has a value exceeding the one specified above. The thickness of the sheet is taken equal to 3 mm. Based on the calculations performed, the moment of inertia of the sheet was 18413.8 cm^4, and the moment of resistance – 7279.8 cm^3. The mass of the sheet is 6.2 % lower than the mass of a typical sheet.

5. 2. Determination of the dynamic load of the gondola car body

Evaluation of the car ride was carried out in accordance with DSTU 7598:2014. Freight cars. General requirements for calculations and design of new and modernized cars of 1520 mm (non-self-propelled) track are carried out according to accelerations in the center of mass and the coefficient of vertical dynamics. Therefore, we limited ourselves to determining only the basic parameters of the dynamics of the car.

According to the results of the solution of the mathematical model (1), accelerations were obtained, which operate in the center of mass of the car body (Fig. 9), as well as in the zones of support on trolleys (Fig. 10).

Fig. 9 shows that the maximum acceleration operating in the center of mass of the gondola car body is 2.9 m/s^2 (0.29 g). The resulting acceleration value is within the permissible values and corresponds to the "excellent" ride of the car. The acceleration of the body in the zones of rest on the trolleys is 9.2 m/s^2 (0.92 g), (Fig. 10).

An important parameter by which the dynamic qualities of the car are evaluated is the coefficient of vertical dynamics. Its definition is carried out as follows [13]:

$$k_{dv}=\frac{P_{SS}}{P_B}, \tag{7}$$

where P_{SS} is the force arising in the spring suspension of the trolley; P_B – the load force of the trolley by the car body.

To determine the force in spring suspension, the formula from [13] was used:

$$P_{SS}=k_B\cdot\delta+F_{FR}\cdot\operatorname{sign}\dot{\delta}, \tag{8}$$

where δ, $\dot{\delta}$ respectively, is the deformation of the elastic elements of spring suspension and the rate of deformation.

Taking into account the calculations performed, the force in a spring suspension was obtained (Fig. 11) and the coefficient of vertical dynamics (Fig. 12).

Therefore, the coefficient of vertical dynamics was 0.51. This value corresponds to the "excellent" ride of the car.

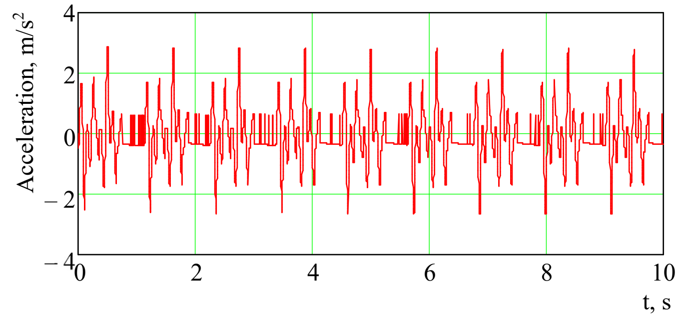


Fig. 9. Acceleration of the body in the center of mass

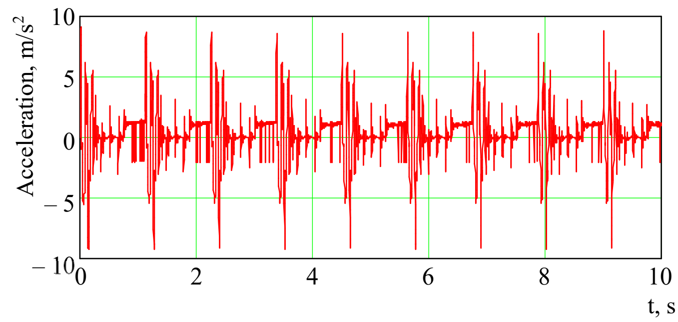


Fig. 10. Acceleration of the body in the areas of support on trolleys

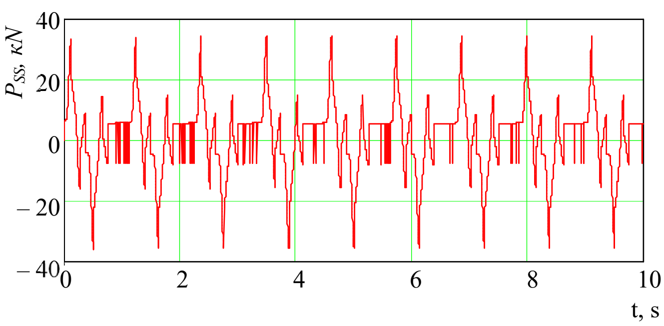


Fig. 11. Force in a spring suspension of the trolley

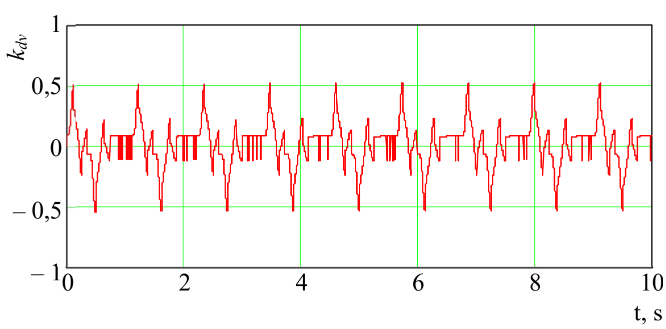


Fig. 12. Coefficient of vertical dynamics

The calculation was carried out for the movement of the gondola in the loaded state. At the same time, the acceleration of the body in the center of mass was 1.6 m/s^2 (0.16 g). Body acceleration in trolley support zones – 2.4 m/s^2 (0.24 g). The coefficient of vertical dynamics is 0.2. The calculated dynamics indicators are within the permissible values in accordance with DSTU 7598:2014. Freight cars. General requirements for calculations and design of new and modernized cars of 1520 mm (non-self-propelled) track.

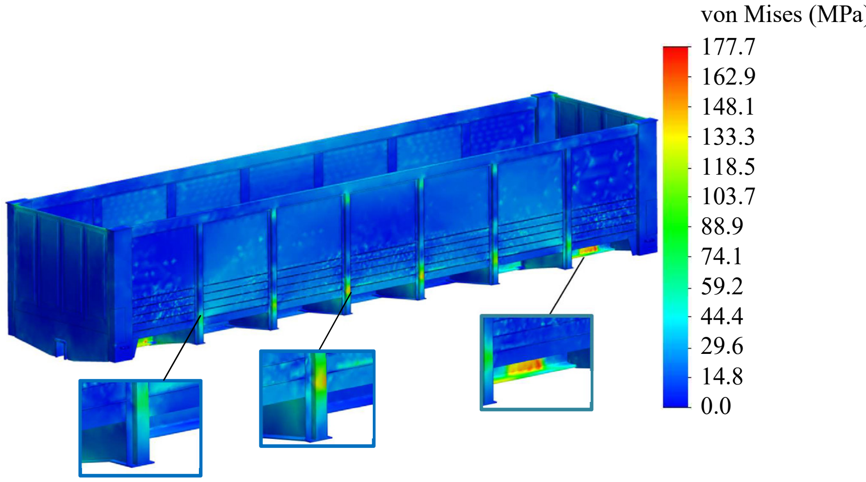


Fig. 13. The stressed state of a gondola body

5. 3. Determining the strength of a gondola body under basic operational load modes

The calculation results for the mode of movement of the car as part of a train (estimation mode III) are shown in Fig. 13–15. Analyzing these figures, we can conclude that the maximum stresses occur in the cantilever part of the girder beam and are 177.7 MPa, which is lower than the permissible ones (Fig. 13). At the same time, 210.0 MPa was taken for permissible stresses under estimation mode III, and 310.5 MPa under mode I. The numerical values of permissible stresses correspond to those specified in DSTU 7598:2014. Freight cars. General requirements for calculations and design of new and modernized cars of 1520 mm (non-self-propelled) track.

The maximum stresses in the third rack side of the console are 161.7 MPa (Fig. 14). The maximum movements in the body of the gondola are fixed in the upper strapping and are equal to 5.8 mm (Fig. 15).

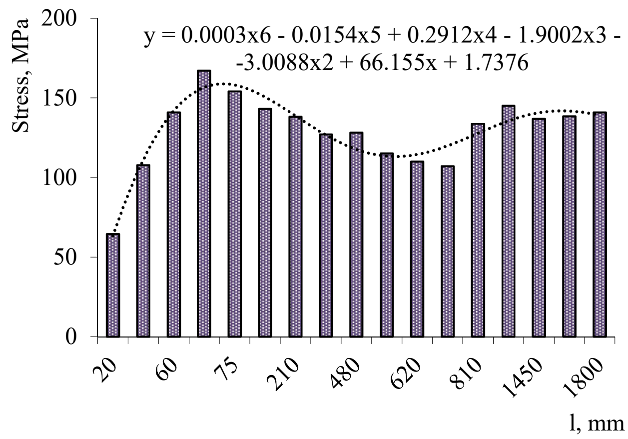


Fig. 14. Distribution of stresses by the height of the vertical stand

Also, the calculation was carried out for other estimation modes. The results of the calculation are given in Table 1.

Based on the data provided in Table 1, we can conclude that the strength of the body of the gondola is ensured under operational load modes.

According to the results of calculating the static strength of the gondola body, the calculation for fatigue strength was carried out using the options of the SolidWorks Simulation software package. The results of these calculations led to the conclusion that the fatigue strength of the body with the applied test base is ensured. It must be said that the fatigue strength of the body cladding increases by 3.7 % compared to the typical one.

Also, as part of the study, an indicator of the biaxiality of the gondola body was determined (Fig. 16).

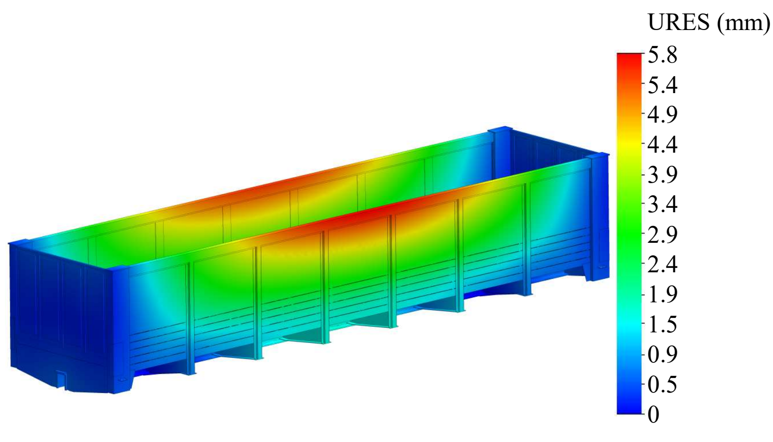


Fig. 15. Movement in the nodes of a gondola car body

Table 1

Indicators of the gondola body strength under operational load modes

Strength indicator	Load mode					
	Mode I				Mode III	
	impact	pull	compression	stretching	impact-compression	pull-stretching
Stress, MPa	307.4	287.4	282.3	279.4	177.7	164.3
Movement in nodes, mm	5.8	5.8	5.7	5.7	5.8	5.7

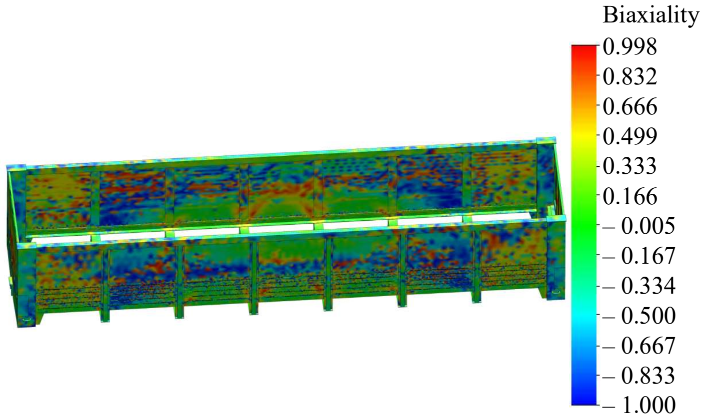


Fig. 16. Indicator of the biaxiality of the supporting structure of the gondola

This indicator characterizes the ratio of the minimum stress arising in the body to the maximum.

6. Discussion of results of determining the load of the body of a gondola car with a wall cladding made from corrugated sheets

To improve the strength of the sheets of cladding, it is proposed to strengthen the most loaded area in height (1/3 of the bottom tie-up) with horizontal corrugations. Determination of the parameters of the corrugation is carried out at the moment of resistance of the cladding sheet, provided that it is maintained higher than that of the typical one. The thickness of the sheet is assumed to be 3 mm. Based on the calculations performed, the resistance moment was 7279.8 cm^3. The sheet weight is 6.2 % lower than the mass of a typical sheet.

To determine the dynamic loads that act on the body of a gondola car, taking into account the proposed technical solutions, mathematical modeling was carried out. It was established that the maximum acceleration acting in the center of mass of the gondola car body is 2.9 m/s^2 (Fig. 9). The resulting acceleration value is within the permissible values and corresponds to the "excellent" ride of the car. Other indicators of dynamics are also within the permissible limits.

The results of strength calculations showed that the maximum stresses in the third rack on the side of the console are 161.7 MPa (Fig. 14). These stresses occur at the bottom of the rack. In its middle part, they decrease and further, in height of the racks, increase slightly and amount to about 150 MPa. In the cladding, the maximum stresses were about 80 MPa. At the same time, the maximum movements in the body of the gondola appear in the upper strapping and are equal to 5.8 mm (Fig. 15).

The calculation was performed of the fatigue strength of the gondola body. It was found that the fatigue strength of the body cladding increases by 3.7 % compared to the typical one. We calculated an indicator of biaxiality of the body. Its greatest value is observed in the second sections from the console part (Fig. 16). This can be explained by the fact that the model is fixed on the heels and, accordingly, the greatest biaxiality arises along this section of the body.

The resulting acceleration value is taken into account when calculating the strength of the gondola body. The results of the calculations showed that the maximum stresses in the body structure under the main operating modes do not exceed the permissible values (Table 1). According to the static calculations carried out, the determination of the fatigue strength of the gondola body was carried out. It was established that the fatigue strength of the body cladding, taking into account the proposed improvement, increases by 3.7 % compared to the typical one.

The advantage of this study in comparison with [5, 8–12] is that the proposed improvement does not necessitate significant capital investments for its commissioning. In comparison with the measures covered in works [6, 7], the improvement of the gondola car body is justified not only in terms of strength but also in the dynamic qualities of the car.

The limitation of this study is that it does not take into account the overtime modes of body loading: loading and unloading, transportation on railroad ferries, etc. That is, the most common modes of operation of the car – I and III – are taken into account.

The disadvantage of this study is that the calculation of strength is implemented in quasi-statics.

As a further development of this study, it is necessary to note the need for a physical experiment. It is advisable to apply methods of likeness and electrical strain gauge. These issues will be considered in the future.

7. Conclusions

1. The substantiation of the structural features of the cladding of the side walls of the gondola was carried out. In this case, it is proposed to strengthen the most loaded zone in terms of height (1/3 of the lower strapping) with horizontal corrugations. The calculation of the parameters of the corrugation is carried out according to the moment of resistance of the cladding sheet. It must be said that the mass of such a sheet is 6.2 % lower than the mass of a typical sheet.

2. The determination of the dynamic load of the gondola body is carried out. The maximum acceleration, which operates in the center of mass of the gondola body, was 2.9 m/s^2 (0.29 g). The resulting acceleration value is within the permissible values and corresponds to the "excellent" ride of the car. The acceleration of the body in the zones of support on the trolleys is 9.2 m/s^2 (0.92 g). The coefficient of vertical dynamics was 0.51.

The calculation was performed for the case of the movement of the gondola in the loaded state. The acceleration of the body in the center of mass was 1.6 m/s^2 (0.16 g). The acceleration of the body in the zones of support on the trolleys – 2.4 m/s^2 (0.24 g). The coefficient of vertical dynamics is 0.2. The calculated dynamics indicators are within the permissible limits.

3. The strength of the gondola body under the basic operational load modes is determined. It was established that under the most unfavorable mode of operation (impact), the maximum stresses occur in the cantilever part of the spinal beam and amount to 177.7 MPa, which is lower than the permissible. In the cladding, the maximum stresses were about 80 MPa. The maximum movements in the body of the gondola are fixed in the upper strapping and are equal to 5.8 mm.

The calculation was performed of the fatigue strength of the improved structure of the gondola body. The calculations carried out showed that the fatigue strength of the body of a gondola with a test base is provided. The fatigue strength of the body cladding increases by 3.7 % compared to the typical one.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available in the main text of the manuscript.

References

1. Šťastniak, P., Kurčík, P., Pavlík, A. (2018). Design of a new railway wagon for intermodal transport with the adaptable loading platform. MATEC Web of Conferences, 235, 00030. doi: https://doi.org/10.1051/matecconf/201823500030
2. Fedosov-Nikonov, D. V., Sulym, A. O., Ilchyshyn, V. V., Safronov, O. M., Kelrikh, M. B. (2020). Study of strength characteristics of the long wheelbase flat cars. IOP Conference Series: Materials Science and Engineering, 985 (1), 012029. doi: https://doi.org/10.1088/1757-899x/985/1/012029
3. Viznyak, R. I., Gudko, A. V. (2014). Design improvements filler assembly interim rack bar body in order to ensure gondola cars of strength in service. Zbirnyk naukovykh prats UkrDAZT, 147, 18–22. Available at: http://csw.kart.edu.ua/article/download/74033/69463
4. Fedosov-Nikonov, D. V., Strynzha, A. A., Shamshei, D. A., Poluliakh, V. N., Fedorov, V. V., Shushmarchenko, V. A. (2019). The study of corrosion damage to car components during technical diagnostics. Visnyk Skhidnoukrainskoho natsionalnoho universytetu imeni Volodymyra Dalia, 3 (251), 181–185. Available at: http://dspace.luguniv.edu.ua/xmlui/handle/123456789/4845
5. Baier, A., Majzner, M. (2012). Application of feature based method in constructing innovative sheathing of railway wagons. Journal of Achievements in Materials and Manufacturing Engineering, 52 (2), 91–98. Available at: https://delibra.bg.polsl.pl/dlibra/publication/35794/edition/32231
6. Galimova, F., Khurmatov, Y., Abdulloev, M., Jumabekov, B., Sultonaliev, D., Ergeshova, D. (2021). Modern Gondola with Lightweight Body. Lecture Notes in Networks and Systems, 1043–1050. doi: https://doi.org/10.1007/978-3-030-80946-1_94
7. Lee, W. G., Kim, J.-S., Sun, S.-J., Lim, J.-Y. (2016). The next generation material for lightweight railway car body structures: Magnesium alloys. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 232 (1), 25–42. doi: https://doi.org/10.1177/0954409716646140
8. Olmos Irikovich, Z., Rustam Vyacheslavovich, R., Mahmod Lafta, W., Yadgor Ozodovich, R. (2020). Development of new polymer composite materials for the flooring of rail carriage. International Journal of Engineering & Technology, 9 (2), 378. doi: https://doi.org/10.14419/ijet.v9i2.30519
9. Patrascu, A. I., Hadar, A., Pastrama, S. D. (2019). Structural Analysis of a Freight Wagon with Composite Walls. Materiale Plastice, 57 (2), 140–151. doi: https://doi.org/10.37358/mp.20.2.5360
10. Buchacz, A., Baier, A., Herbuś, K., Majzner, M., Ociepka, P. (2015). Examination of a Cargo Space of a Freight Wagon Modified with Composite Panels. Applied Mechanics and Materials, 809-810, 944–949. doi: https://doi.org/10.4028/www.scientific.net/amm.809-810.944
11. Płaczek, M., Wróbel, A., Olesiejuk, M. (2017). Modelling and arrangement of composite panels in modernized freight cars. MATEC Web of Conferences, 112, 06022. doi: https://doi.org/10.1051/matecconf/201711206022
12. Fomin, O., Gorbunov, M., Gerlici, J., Vatulia, G., Lovska, A., Kravchenko, K. (2021). Research into the Strength of an Open Wagon with Double Sidewalls Filled with Aluminium Foam. Materials, 14 (12), 3420. doi: https://doi.org/10.3390/ma14123420
13. Domin, Yu. V., Cherniak, H. Yu. (2003). Osnovy dynamiky vahoniv. Kyiv: KUETT, 269.
14. Fomin, O., Lovska, A., Skurikhin, D., Nerubatskyi, V., Sushko, D. (2022). Special Features of the Vertical Loading on a Flat Car Transporting Containers with Elastic-Viscous Links in their Interaction Units. 26th International Scientific Conference Transport Means 2022. Kaunas, 629–633.
15. Bohach, I. V., Krakovetskyi, O. Yu., Kylyk, L. V. (2020). Chyselni metody rozviazannia dyferentsialnykh rivnian zasobamy MathCad. Vinnytsia, 106. Available at: http://pdf.lib.vntu.edu.ua/books/IRVC/Bogach_2020_106.pdf
16. Sobolenko, O. V., Petrechuk, L. M., Ivashchenko, Yu. S., Yehortseva, Ye. Ye. (2020). Metody rishennia matematychnykh zadach u seredovyshchi Mathcad. Dnipro, 60. Available at: https://nmetau.edu.ua/file/navch_posibn_mathcad_2020_petrechuk.pdf
17. Pievtsov, H., Turinskyi, O., Zhyvotovskyi, R., Sova, O., Zvieriev, O., Lanetskii, B., Shyshatskyi, A. (2020). Development of an advanced method of finding solutions for neuro-fuzzy expert systems of analysis of the radioelectronic situation. EUREKA: Physics and Engineering, 4, 78–89. doi: https://doi.org/10.21303/2461-4262.2020.001353
18. Nerubatskyi, V., Plakhtii, O., Hordiienko, D. (2021). Control and Accounting of Parameters of Electricity Consumption in Distribution Networks. 2021 XXXI International Scientific Symposium Metrology and Metrology Assurance (MMA). doi: https://doi.org/10.1109/mma52675.2021.9610907

19. Nerubatskyi, V., Plakhtii, O., Hordiienko, D. (2022). Adaptive Modulation Frequency Selection System in Power Active Filter. 2022 IEEE 8th International Conference on Energy Smart Systems (ESS). doi: https://doi.org/10.1109/ess57819.2022.9969261
20. Kondratiev, A. V., Gaidachuk, V. E. (2021). Mathematical Analysis of Technological Parameters for Producing Superfine Prepregs by Flattening Carbon Fibers. Mechanics of Composite Materials, 57 (1), 91–100. doi: https://doi.org/10.1007/s11029-021-09936-3
21. Vambol, O., Kondratiev, A., Purhina, S., Shevtsova, M. (2021). Determining the parameters for a 3D-printing process using the fused deposition modeling in order to manufacture an article with the required structural parameters. Eastern-European Journal of Enterprise Technologies, 2 (1 (110)), 70–80. doi: https://doi.org/10.15587/1729-4061.2021.227075
22. Harak, S. S., Sharma, S. C., Harsha, S. P. (2014). Structural Dynamic Analysis of Freight Railway Wagon Using Finite Element Method. Procedia Materials Science, 6, 1891–1898. doi: https://doi.org/10.1016/j.mspro.2014.07.221
23. Fomin, O., Lovska, A., Khara, M., Nikolaienko, I., Lytvynenko, A., Sova, S. (2022). Adapting the load-bearing structure of a gondola car for transporting high-temperature cargoes. Eastern-European Journal of Enterprise Technologies, 2 (7 (116)), 6–13. doi: https://doi.org/10.15587/1729-4061.2022.253770
24. Fomin, O., Lovska, A. (2021). Determination of dynamic loading of bearing structures of freight wagons with actual dimensions. Eastern-European Journal of Enterprise Technologies, 2 (7 (110)), 6–14. doi: https://doi.org/10.15587/1729-4061.2021.220534
25. Lovska, A., Fomin, O., Píštěk, V., Kučera, P. (2020). Dynamic Load and Strength Determination of Carrying Structure of Wagons Transported by Ferries. Journal of Marine Science and Engineering, 8 (11), 902. doi: https://doi.org/10.3390/jmse8110902
26. Lovska, A. (2014). Assessment of dynamic efforts to bodies of wagons at transportation with railway ferries. Eastern-European Journal of Enterprise Technologies, 3 (4 (69)), 36–41. doi: https://doi.org/10.15587/1729-4061.2014.24997
27. Panchenko, S., Vatulia, G., Lovska, A., Ravlyuk, V., Elyazov, I., Huseynov, I. (2022). Influence of structural solutions of an improved brake cylinder of a freight car of railway transport on its load in operation. EUREKA: Physics and Engineering, 6, 45–55. doi: https://doi.org/10.21303/2461-4262.2022.002638
28. Panchenko, S., Gerlici, J., Vatulia, G., Lovska, A., Pavliuchenkov, M., Kravchenko, K. (2022). The Analysis of the Loading and the Strength of the FLAT RACK Removable Module with Viscoelastic Bonds in the Fittings. Applied Sciences, 13 (1), 79. doi: https://doi.org/10.3390/app13010079
29. Dižo, J., Harušinec, J., Blatnický, M. (2017). Structural Analysis of a Modified Freight Wagon Bogie Frame. MATEC Web of Conferences, 134, 00010. doi: https://doi.org/10.1051/matecconf/201713400010
30. Dižo, J., Blatnický, M., Steišūnas, S., Skočilasová, B. (2018). Assessment of a rail vehicle running with the damaged wheel on a ride comfort for passengers. MATEC Web of Conferences, 157, 03004. doi: https://doi.org/10.1051/matecconf/201815703004
31. Koziar, M. M., Feshchuk, Yu. V., Parfeniuk, O. V. (2018). Kompiuterna hrafika: SolidWorks. Kherson: Oldi-plius, 252. Available at: https://ep3.nuwm.edu.ua/22175/1/%D0%9A%D0%BE%D0%BC%D0%BF%27%D1%8E%D1%82%D0%B5%D1%80%D0%BD%D0%B0%20%D0%B3%D1%80%D0%B0%D1%84%D1%96%D0%BA%D0%B0.pdf
32. Pustiulha, S. I., Samostian, V. R., Klak, Yu. V. (2018). Inzhenerna hrafika v SolidWorks. Lutsk: Vezha, 172. Available at: https://lib.lntu.edu.ua/sites/default/files/2021-02/%D0%86%D0%BD%D0%B6%D0%B5%D0%BD%D0%B5%D1%80%D0%BD%D0%B0%20%D0%B3%D1%80%D0%B0%D1%84%D1%96%D0%BA%D0%B0%20%D0%B2%20SolidWorks.pdf
33. Chykhladze, E. D. (2011). Opir materialiv. Kharkiv: UkrDAZT, 360. Available at: http://lib.kart.edu.ua/handle/123456789/4985
34. Shvabiuk, V. I. (2016). Opir materialiv. Kyiv: Znannia, 400. Available at: https://btpm.nmu.org.ua/ua/download/navch-posib/%D0%A8%D0%B2%D0%B0%D0%B1%D1%8E%D0%BA.%D0%9E%D0%9C.%D0%9F%D1%96%D0%B4%D1%80%D1%83%D1%87%D0%BD%D0%B8%D0%BA.pdf