

**ENHANCING VEHICLE EFFICIENCY: HIGH-STRENGTH STEEL
SELECTION FOR IMPROVING THE LOAD-BEARING CAPACITY
OF THE CARRYING MODULE**

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Summary

Introduction. The tare weight coefficient of 1520 mm gauge freight wagons is significantly higher compared to North American freight wagons, which limits their load capacity and transportation efficiency. The main reasons for this are conservative standards for calculating welded joints and the use of low-alloy steels of the 09G2S type with insufficient strength characteristics. **Relevance.** The tare weight coefficient of 1520 mm gauge freight wagons (0.29–0.34) is almost twice as high as that of North American wagons (0.17–0.24). The global wagon building industry has been using high-strength steels with a yield strength of up to 700–960 MPa for more than 20 years, which makes it possible to create wagons with a load capacity of up to 116 tons with a tare weight of 18–25 tons. In Ukraine, this experience is almost not implemented due to the lack of scientifically based recommendations. **Purpose of the study.** The purpose of this scientific study is to identify the reasons for the significantly higher tare weight coefficient of 1520 mm gauge wagons compared to North American freight wagons and to substantiate the possibility of increasing the load capacity of gondola cars by applying optimized high-strength steel for load-bearing elements. **Results.** It has been established that when using high-strength steels, the weight of a beam can be reduced five times compared to 09G2S steel. However, the presence of a welded joint, due to low allowable stresses (recommendations of the International Institute of Welding), increases the weight of the structure almost 2 times regardless of the steel grade. Based on the optimization of the chemical composition of 09G2S steel, a material with an ultimate strength of up to 750 MPa, a yield strength of up to 570 MPa while

*maintaining an elongation of 21% was obtained. The application of such steel in the structure gondola car it possible to reduce the tare weight by 2 tons and increase the load capacity to 73 tons. Finite element calculations confirmed the compliance of the structure with the requirements of strength (safety factor 1.01–1.14), rigidity (maximum deflection of the center sill 4 mm) and stability (safety factor $n_y = 6.3 > [n_y] = 1.1–1.6$). **Conclusions.** A comprehensive approach to increasing load capacity is proposed, based on recognizing the fatigue strength of a welded joint as the main criterion for tare weight, using an optimized chemical composition of 09G2S steel obtained using integral physicochemical criteria, and practical implementation in a serial gondola car. Directions for reducing tare weight have been developed: experimental refinement of the strength of welded joints, increasing their endurance, switching to bolted joints.*

Key words: gondola car, high-strength steel, chemical composition optimization, welded structures, load capacity, fatigue strength.

ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ТРАНСПОРТНИХ ЗАСОБІВ: ВИБІР ВИСОКОМІЦНИХ СТАЛЕЙ ДЛЯ ПОЛІПШЕННЯ НЕСУЧОЇ ЗДАТНОСТІ НЕСІВНОГО МОДУЛЯ

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Анотація

Вступ. Коефіцієнт тари вантажних вагонів колії 1520 мм є суттєво вищим порівняно з вагонами Північної Америки, що обмежує їхню вантажопідйомність та ефективність перевезень. Основними причинами цього є консервативні норми розрахунку зварних з'єднань та використання низьколегованих сталей типу 09Г2С з недостатніми міцнісними характеристиками. **Актуальність.** Коефіцієнт тари вантажних вагонів колії 1520 мм (0,29–0,34) майже вдвічі вищий, ніж у вагонів Північної Америки (0,17–0,24). Світове вагонобудування вже понад 20 років використовує високоміцні сталі з межею текучості до 700–960 МПа, що дає змогу створювати вагони вантажопідйомністю до 116 т з масою тари 18–25 т. В Україні цей досвід майже не впроваджується через відсутність

науково обґрунтованих рекомендацій. **Мета дослідження.** Метою цього наукового дослідження є виявлення причин суттєво більшого коефіцієнта тари вагонів колії 1520 мм порівняно з вантажними вагонами Північної Америки й обґрунтування можливості підвищення вантажопідйомності піввагонів шляхом застосування оптимізованої високоміцної сталі для несучих елементів. **Результати.** Встановлено, що за використання високоміцних сталей масу балки можна знизити вдвічі порівняно зі сталлю 09Г2С. Проте наявність зварного з'єднання через низькі допустимі напруження (рекомендації Міжнародного інституту зварювання) збільшує масу конструкції майже вдвічі незалежно від марки сталі. На основі оптимізації хімічного складу сталі 09Г2С отримано матеріал з межею міцності до 750 МПа, межею текучості до 570 МПа за збереження відносного видовження 21 %. Застосування такої сталі в конструкції напіввагона дає змогу знизити масу тари на 2 т та підвищити вантажопідйомність до 73 т. Розрахунки за методом скінчених елементів підтвердили відповідність конструкції вимогам міцності (коефіцієнт запасу $1,01-1,14$), жорсткості (максимальний прогин хребтової балки 4 мм) та стійкості (коефіцієнт запасу $\nu = 6,3 > [\nu] = 1,1-1,6$). **Висновки.** Запропоновано комплексний підхід до підвищення вантажопідйомності, що базується на визнанні втомної міцності зварного з'єднання головним критерієм маси тари, використанні оптимізованого хімічного складу сталі 09Г2С, отриманого за допомогою інтегральних фізико-хімічних критеріїв, та практичній реалізації в серійному піввагоні. Розроблено напрями зниження тари: експериментальне уточнення міцності зварних з'єднань, підвищення їх витривалості, перехід на болтові з'єднання.

Ключові слова: піввагон, високоміцна сталь, оптимізація хімічного складу, зварні конструкції, вантажопідйомність, втомна міцність.

Introduction. The current development of the transport industry requires the promotion of innovative solutions to improve the competitiveness of transportation. One of the key directions of modernization of a dry warehouse is a reduction in the moisture content of transport means while simultaneously increasing its demand. The efficiency of the functioning of transport systems absolutely depends on the technical and economic indicators of non-constructive structures. The use of traditional construction materials often limits the possibilities of further upgrading transport modules. The curing of high-grade steels opens up new prospects for optimizing metallicity without losing value.

The market for commercial transport in 2025 demonstrates a clear regional structure. The largest share of the market is accounted for by the Asia-Pacific region with approximately \$201 billion. USA. The goal of leadership is determined, first of all, by the laborious economy of China and India, which actively invest in the development of their transport lines for the transportation of raw materials and finished products. Another place is taken by Northern America with a debt of about 100.7 billion dollars, where the US and Canada play a key role with their existing border for the transport of agricultural goods, energy and industrial advantages. Europe, with a market of approximately \$70.5 billion, rounds out the top three. Here, important transported goods are closely integrated into the EU economy, and will have a significant impact on them through

the development of industrial production. The region of the world, including Brazil, Russia, the Republic of Turkey and Turkey, receives 54.7 billion dollars of the market [1].

Relevance of the research. The tare coefficient for trailer cars with a gauge of 1520 mm (0.29–0.34) is twice as high as that for cars of Eastern America (0.17–0.24). This means that when one ton of vantage is transported, the Ukrainian slicks are transported at the same time as much as twice as much metal and water construction, which reduces the efficiency of transportation and increases the cost of cravings. The main reasons for this are:

- conservative standards for the design of welded joints, so as not to ensure the actual safety of high-grade steels;
- mass production of low-alloy steels type 09G2S with insufficient low-grade characteristics (liquidity limit less than 345 MPa).

Light railcar manufacturing (USA, Canada, EU) has already been using high-grade high-grade steel for over 20 years with a fluidity limit of up to 700–960 MPa, which allows the construction of railcars with a lifting capacity of up to 116 tons with a tare weight 18–25 tons. In Ukraine, this may not be implemented due to the number of scientifically based recommendations on the selection of materials and welding technologies [1].

Thus, the relevance of the work lies in the need to meet the gap between the potential of high-grade steels and formal conservative standards, as well as the created scientifically-based methods for selecting materials for load-bearing modules of transport vehicles. *zaobiv.*

Analysis of information sources on further research topics. The publication [2] examines constructive approaches to designing the body of a vantage car with an extended vantage point. The author analyzes the infusion of geometric parameters and the choice of materials for the structural integrity of the structure. Significant attention is paid to the optimization of mass with an immediate increase in weight. Viktoritano numerical modeling for the assessment of stress-strain steel. The results demonstrate the promise of improved designs for important transport.

In work [3], the influx of thermal forward pressure on the mechanical work of beam elements was observed. An analysis of changes in stress and deformation at the stage of manufacturing the structure was carried out. It has been established that the front thermal expansion can therefore be affected by excess stress. The authors highlight the possibility of cervicalization with these processes to improve durability. The results may have practical significance for the manufacturing technologies of carriage structures.

The publication [4] examines the optimization of the shot blasting process before upgrading the original structures of cars. The influence of processing parameters on surface softness and adhesive strength has been analyzed. Optimal modes have been established to ensure effective renewal. Viktoristan experimental and analytical methods of investigation. The results obtained indicate an increased service life of the repaired elements.

The article [5] examines the mechanisms of change in rack steel during compression. Microstructural changes and their influence on the value of the material were observed. The role of dislocation processes and phase changes has been revealed. Experimental testing was carried out for confirmation.

The work [6] investigated the advancement of mechanical power and wear resistance of rack systems. The main focus is on controlling the foldable microstructure

of the material. The relationship between microstructure and operational characteristics has been established. Vikoristan modern methods of material science for analysis. The results obtained are consistent with the creation of more reliable rack systems.

Publication [7] split bainite steels for slide rails. Their mechanical and structural characteristics were studied. The advantages of the bainitic structure in terms of wear resistance and value have been established. The authors demonstrate the feasibility of producing such steels in transport galuz. The results have significant potential for improving infrastructure reliability.

The article [8] evaluates the effectiveness of double-ball steel as a structural material for cars. A comprehensive analysis was carried out using traditional materials. An improvement in the functional characteristics and resistance to damage was revealed. The peculiarities of the robotic material under consideration are examined. The obtained results confirm the prospects of stagnation of rich ball steels.

The work [9] provided the results of full-scale investigations of a stress-strained steel reinforced steel structure. Conducted simulation in real minds of operation. The nature of the stress distribution in structural elements has been established. We extracted the data from the selection process for the validation of rozrakhunkov models. The results improve the accuracy of predicting the service life of the structure.

The publication [10] contains a comprehensive analysis of the internal value of the frames of suspended cars. The influx of welding technology and design solutions has been monitored. The key factors that determine the durability of frames have been identified. Experimental testing was carried out to confirm the results. The removal of the pins may be subject to change when designing new cars.

In work [11], the influence of alloying and microstructure on the formability of high-grade steels was observed. The steels were examined, cut using the hardening method with a further distribution of phases. The relationship between structural parameters and plasticity of the material has been established. Vikoristan experimental and numerical approaches. The results are important for the development of new materials for transport machinery.

The article [12] investigated the non-stationary factors of the independent importance of the connection of trailer cars. A mathematical model for assessing the resource of elements has been developed. Changes in maintenance and use are ensured. An analysis of the influence of various factors on durability was carried out. The obtained results allow us to improve the accuracy of the prediction of the service life of the structure.

The article [13] has a developed mathematical model for the operational management of the characteristics of the metal structure in the minds of serial steelmaking. The main idea of the study is that at the time of forecasting we should take into account the concept of a direct chemical bond to the metal, which binds its composition, structure and power to the metal. The concept is presented, supplemented with elements of optimization of the chemical steel warehouse according to the criterion of stabilization of mechanical forces, methods of planning experiments, which resulted in the removal of intervals for the variation of the main criteria for optimization. The Optim 570 steel and mechanical characteristics were optimized.

The article [14] elaborates a method for assessing the influx of volatile elements on the kinetics of phase transformations, which opens the way to the purposeful design

of materials with improved performance characteristics. Predicting microstructural changes makes it possible to minimize defects and deformations that occur during thermal processing, thereby reducing the number of defects in the plant. The research results provide a scientifically grounded basis for the development of standards and regulatory documentation for thermal processing of steels for transport machinery.

Optimization of the chemical storage of steel 09G2S (newly optimized steel Optim 570) leads to a significant reduction in the kinetics of metadynamic recrystallization, which ensures the formation of a granular, uniform structure. This does not reduce mechanical power, but also reduces energy and technological costs, which increases the economic efficiency of production.

An analysis of scientific publications [2–14] confirms that the nutritional efficiency of transport machinery is actively developing through improved design, manufacturing technologies and updating of car elements. Much attention is paid to the development and hardening of new materials: bainite steels [7], double-ball [8] and optimized chemical storages (for example, Optim 570 [13]), which demonstrate improved mechanical properties power, durability and technology.

However, regardless of the obvious results of infusion of lamination [11], thermal transfer [3], microstructural changes [5, 6] and internal connections [10, 12], complex equal investigation high-grade steels of various classes of value in the minds of cyclic wear, typical for the operation of vans, on a daily basis. Most of the work highlights either the outside aspects of the behavior of materials or the hidden principles of design without addressing the specifics of the changing objectives.

This necessitates the need to carry out independent scientific and applied research, aimed at an up-to-date analysis of the characteristics of high-grade steels (in particular, Optim 570 modified from the traditional 09G2S) in the minds of the cyclic In order to allow lining, we recommend optimal materials for the creation of reliable and durable body structures for vantage cars with extended vantage capacity.

Investigation methods. To determine the stress-deformation of the non-strain module, the method of sheared elements (MCE) is used as the core of current software complexes. Mathematical modeling of dynamic processes was based on the methods of classical mechanics and the theory of springs. A regular analysis of the power of steels was carried out using various methods of mathematical statistics and theories for making decisions. Verification of the obtained results was carried out by compiling detailed data from the results of field testing of similar structures.

The object and subject of investigation. Object of investigation – processes of development and functioning of non-new modules of transport devices.

Subject of investigation – patterns of influx of mechanical characteristics of high-grade steels at non-structural parameters.

Aims and objectives of the study. Scientific development and development of methods for selecting rational grades of high-composition steels for structural elements of transport devices.

Investigation tasks

1. Analyze the current production of high-grade steels in light transport machinery and identify potential reserves for their production.

2. Significantly the main types and intensity of pressure that act on the new transport module in real terms of operation.

3. Conduct a thorough analysis of the non-material design of the structure with the frozen traditional and promising materials.

4. Assess the influence of technological processes of production, welding, and the mechanical characteristics of the manufactured steels in the module warehouse.

5. Establish criteria for selecting the optimal steel grade in order to ensure maximum efficiency and minimum mass.

Contribution to the main material. Reduced wagon weight for priority wagon building plants. On the tracks of Northern America, the tare coefficient for vantage cars becomes 0.17...0.24 with axle pulls of 32–35 tf. In the space of 1520 mm, this coefficient is still 0.29...0.34, which is perhaps twice as high. In the table 1 shows the characteristics of models with a minimum tare coefficient.

Table 1

Characteristics of vantage railcars

Model of the carriage, region, producer	Load capacity, t	Tare weight, t	Body volume, m ³	Axial load, t/vs	Tare coefficient
12-4106, Ukraine (TOV TAS DNIPROVAGONMASH)	70	23.9	78	23.5	0.34
12-7023, Ukraine (KVZ)	70.3	23.7	90	23.5	0.33
12-8520, Ukraine (DMZ Carpathia)	71	23	81.4	23.5	0.32
12-9933, Ukraine (Diesel plant)	70	24	78	23.5	0.34
12-9745, Ukraine	70	24	76	23.5	0.34
Greenbrier, USA	98.7	31.1	86.2	32.5	0.31
37MILL GONDOLA, USA, American Railcar Industries	105	24.7	70.8	32	0.24
GONDOLA-MILL, Canada, National Steel Car	116	24.3	76	35	0.21
Hybrid Gon, USA, Freight Car America	108.1	21.79	115	32.5	0.20
Beth GonAeroflo, USA, Freight Car America	110	18.9	110	32	0.17

The analysis showed that the cars of Eastern America, in most cases, have a lower tare ratio equal to the cars produced in Ukraine. Salvage transport should be carried out to metal galleries and the highest survivability of metal products. Robots [13, 14] have demonstrated the cost-effectiveness of using new materials – high-grade steels, corrosion-resistant steels, aluminum alloys, the use of which will ensure a reduction in the weight of the packaging materials. wagons.

Behind the cordon, the depletion of high-grade materials from the production of vantage cars began approximately 20 years ago. At the railcar edges, SND steels with increased pressure (up to 390 MPa) in the elements of the main cars began to be used during the production of the new generation of cars. The main reinforced components [9] are the center beam of the car frame, the sheets of the pivot and intermediate beams of the carriage frames, the vertical pillars of the car body, the shell sheets and bottoms of the tank car boilers, the lining of the car body. Although such a decision would allow a change in the tare weight, the reduction in the tare coefficient for new cars is insignificant.

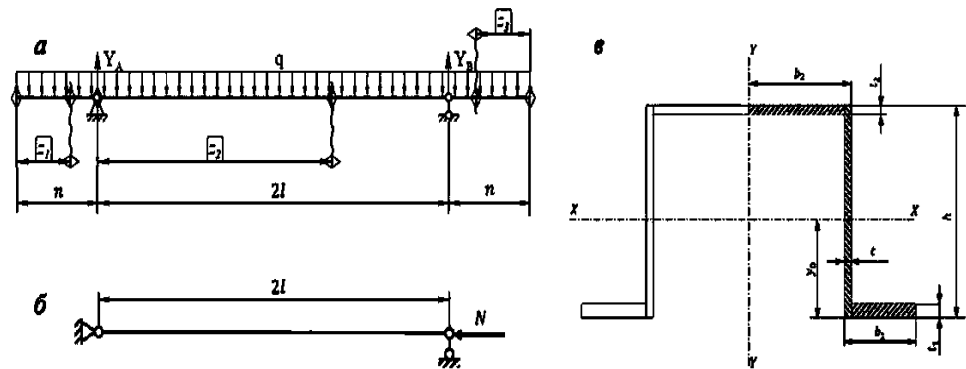
Placing the possibility of stagnation of high-grade steel during the preparation of load-bearing elements of vantage cars with extended vantage capacity

It is important to supply technical components to structural materials for load-bearing elements of vantage cars [standards].

The assessment of the suitability of rolled metal from high-grade steels for welded structures of vantage cars must be carried out in accordance with the complex of indicators of the operational authorities of the metal in welded structures. Before such displays:

- inter-linearity, time-of-hour support, daily subordination;
- sensitivity to stress concentration, which indicates the strength of the structure;
- cold resistance, which means support for harsh collapse when low temperatures;
- corrosion resistance in atmospheric conditions and in contact with materials being transported;
- flexibility of widening of external cracks (survivability);
- weldability (including with other steels that are stagnant at the car manufacturing plant) and production in the minds of continuous production at car factories and depots.

Based on the assessment of the possibility of stagnation of high-grade steel during the preparation of load-bearing elements of vantage cars, an investigation was carried out to determine the flow rate of steel on the surface. designs according to the criteria of value and rigidity for a hinged beam with a riser between supports $2l$, m, with protruding cantilever sections of length n , m (Fig. 2, a), evenly anchored division by age q , kN/m, as well as the criterion of stability of the compressed structure of the beam (rod), stressed by a compressive force N , kN (Fig. 2, b) [16,17].



*Fig. 1. Spine beam with completed structure
a – a hinged beam for monitoring the flow of steel between the longitudinal layers onto the structure according to the criteria of value and rigidity; b – shear with hinged ends; c - transverse section of the completed structure*

The tension value q , kN/m, is chosen in such a way as to ensure maximum stress in the beam, which is representative of the stresses that arise at the spinal beam during the expansion of the car body. The fluidity of the beam material varied in the range from 200 to 600 MPa. Today, low-alloy steel grade 09G2S is most widely used for load-bearing structures of cars according to DSTU [20, 21]. The most frequently used products

are those of class 325 (pivot beam, around car elements with a thickness of 10 mm or more) and 345 (around car elements with a thickness of less than 10 mm). At the same time, in other areas of important mechanical engineering, higher mechanical authorities have become widely involved. So, for example, for the preparation and repair of mining equipment, quarry equipment and suspended equipment, power structures of lifting mechanisms and motor vehicles, high-grade steel is used to stool the edges fluidity of 400 MPa or more [20]. This is due to the occurrence of stagnation in railcar steels with a fluidity limit of 600 MPa or more [15; 16].

On the basis of inspection of the steels that are assembled at the machine, we see grades that indicate the strength of the load-bearing elements of the cars (Table 2), based on the optimization of the chemical warehouse (reduction of carbon, sulfur, phosphorus), steel was extracted with a fluidity limit of 570 MPa – in the table it is designated as Optim 570 which are indicative of the benefits of [13; 8].

Table 2

Grades of high-grade steels for machine-made steels

Country / Region	Steel grade	Yield limit (σ_s , MPa)	Daily life (δ), %	Chemical warehouse (main alloying elements, %)	Floating on strength
Ukraine	09G2S	345	21	$C \leq 0.12$	$Mn \leq 1.40$
USA (ASTM)	A572 Gr.50	345	18	$C \leq 0.26$	$Mn \geq 0.80$
Europe (EN)	S355NL	355	20–22	$C \leq 0.18$	$Mn \leq 0.90–1.65$
Japan (JIS)	SM490A	355	19	$C \leq 0.22$	$Mn \leq 1.60$
Ukraine	Optim 570 [13, 14]	570	21	$C \leq 0.091$	$Mn \leq 1.71$
Germany (DIN)	X20Cr13 (1.4021)	640	10–12	$C \leq 0.16–0.25$	$Cr = 12.0–14.0$
USA (ASTM)	A514	690	18	$C = 0.12–0.21$	$Mn \leq 0.95–1.30$
Europe (EN)	S690QL	690	14–16	$C \leq 0.20$	$Mn \leq 1.70$
Ukraine	30KhGSA	735	10	$C = 0.28–0.34$	$Mn = 0.80–1.10$
Ukraine	40XH2MA	780–980	11–13	$C = 0.37–0.44$	$Mn = 0.50–0.80$
Ukraine	35KhGSA	835	10	$C = 0.32–0.39$	$Mn = 0.80–1.10$
Finland	Optim 960QC	960	7	$C \leq 0.11$	$Si \leq 0.25$
Finland	AR 400 (SSAB)	~965	10–12	$C \leq 0.18$	$Mn \leq 1.70$
Finland	AR 500 (SSAB)	~1100	~8	$C \sim 0.30$	$Si \leq 0.70$

To assess the possibility of reducing metal capacity, the dimensions of an I-beam of minimal weight (Fig. 1) with steels 09G2S, 30KhGSA and Optim 960QC and steel Optim 570 were determined, value, vibrancy and resistance to formal norms.

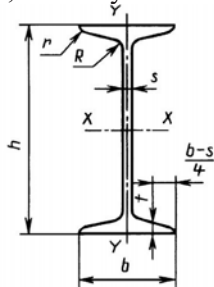


Fig. 2. I-beamridge beam [17]

Expansion of static value I-beams are calculated using the formula:

$$P = \frac{[\sigma] \cdot 4J_x}{2L_1 \cdot h} \quad (1)$$

P – attachment to the beam,
 $[\sigma]$ – acceptable stress,
 J_x – moment of inertia across the cut,
 L_1 – stand between the supports,
 h – beam height.

A beam was assembled, made from steel 09G2S with a moment of inertia of 3016 cm⁴. With a static tension of 447 Pst kN, the stresses in this balance reach the fluidity limit. At the first stage of development, the values of the parameters of beams made from high-tensile steels were determined so that the maximum stresses in them matched the fluidity limits [18, 21].

Table 3

**Characteristics of the beam from the point of view
of non-excess of fluidity boundaries**

Parameter	09G2S	Optim 570 [13, 14]	30KhGSA	Optim 960QC
σ_T , MPa	345	570	835	960
Wall thickness, mm	10	6	4	3.2
Beam weight, kg	40	24	16	13

With static tension, the weight of the beam made of Optim 960QC steel changes three times.

Formulas for determining the boundaries of vivacity (intrinsic value) of a smooth eye

$$\sigma_{-1} \approx 0.50 \cdot \sigma_B$$

$$\sigma_{-1} \approx (0.55 - 0.001 \cdot \sigma_B) \cdot \sigma_B \quad (2)$$

- σ_{-1} – the limit of vitriol during the symmetrical cycle of avancement,
- σ_B – the boundary of the value of the material.

The value of a smooth beam (Table 4).

Table 4

Characteristics of the structural beam (without a welded seam)

Parameter	09G2S	Optim 570 [13, 14]	Optim 960QC	30KhGSA
$\sigma_{a,N}$ (0.5 σ_B), MPa	151	260	503	333
Beam weight, kg	40	20	6	6

High-quality steel allows you to reduce the weight by 6–7 times.

Formula for determining the boundary of the vibration of a beam with the regulation of the stress concentrator [18]

$$\sigma_{a,N} = \frac{\sigma_{-1}}{K_\sigma} \quad (3)$$

$\sigma_{a,N}$ – the boundary of the vibration of the part (beam) at the basis of cycles, N

σ_{-1} – the border of the vibrancy of the smooth eye,

K_{σ} – a significant coefficient for reducing the limit of vibration (the statistic is used for beams without a welded seam and with a welded seam).

$$K_{\sigma} = 1,5K_{\sigma} = 2,4$$

Formula for dividing the boundary of the welded joint by the method of the International Institute of Welding (IIW) [17]

$$\sigma_{a,N} = \frac{1}{2} \sqrt{\frac{2 \cdot 10^6 \cdot (\text{FAT})^3}{10^7}} \quad (4)$$

$\sigma_{a,N}$ – limit of vibration of the welded joint at the basis of cycles, 10^7

FAT – class of internal value of the welded joint (at the MPa statistic),

FAT = 80

$2 \cdot 10^6$ – testing base for FAT,

10^7 – rozrakhunka cycle base.

The intrinsic value of a beam with a welded seam (Table 5).

Table 5

Beam with welded joint

Parameter	09G2S	Optim 570 [13, 14]	Optim 960QC	30KhGSA
σ_a , N [8], MPa	94	110	175	189
Beam weight, kg	40	28	20	18
σ_a , N [6] and [16], MPa	23.5	23.5	23.5	23.5
Beam weight, kg	~200	~200	~200	~200

Apparently, before the re-melting, steel was processed with a linearity limit of 570 MPa. Comprehensive research was carried out to confirm the feasibility of stagnation for the production of non-fresh elements for cars with advanced vantage capacity on the same level.

The results of the investigation revealed that rolled products made of high-grade steel with a lamination limit of 570 MPa are based on the chemical storage of the base metal, the mechanical characteristics of the base metal and the vitrification limit

Apparently, according to the standards [6, 16], recommendations of the International Institute of Welding), it is permissible for the stress for a welded joint to be greater than 23.5 MPa, regardless of the value of the base metal. This leads to a paradoxical increase in the weight of the structure by 5 times.

Based on the optimized steel warehouse, a model was divided into a car (Fig. 3). Elements made from new steel (liquidity limit 570 MPa – it is possible to move up to 570 MPa), green color shows optimal steel and orange color shows 09G2S steel:

- cladding of side and end walls;
- top trim;
- horizontal chords and vertical posts of the end walls;
- end beam;
- vertical and bottom sheets of the intermediate beams of the frame.

For the structural assessment of the strength, rigidity and durability of the load-bearing structure of the sub-vehicle with advanced load-bearing capacity, a cross-sectional element model of the sub-car was established, so composed of high-grade steel

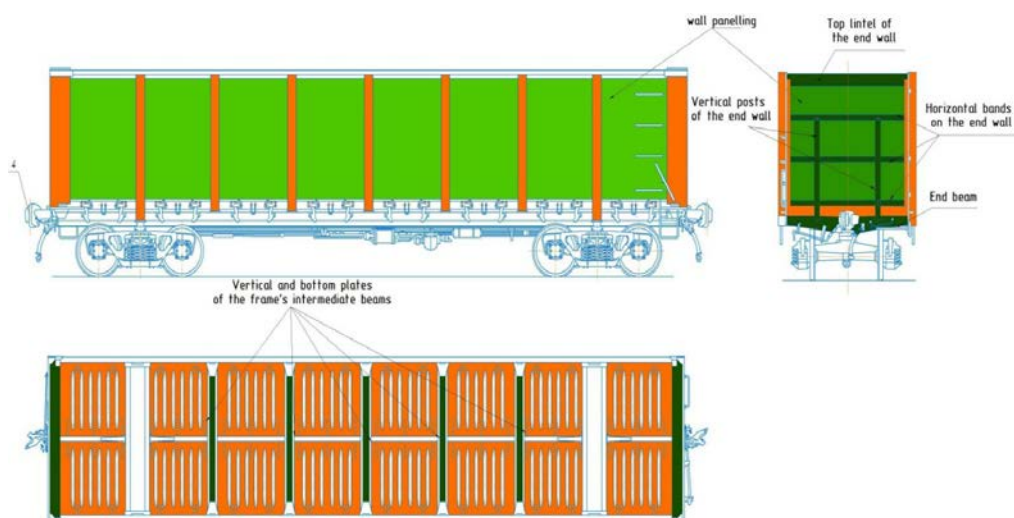


Fig. 3. Elements made of high-grade steel with a fluidity limit of 570 MPa in the structure of a rubber car

elements with a yield limit of 570 MPa (Fig. 4). To confirm the functional characteristics of the fragmented filling car, a set of regulatory developments was carried out based on the terminal element method [15].

To assess the rigidity of the structure, we measured the deformation of the main load-bearing elements when the car was pulled up to full load capacity. The maximum displacements in the main non-bearing elements were summed up:

- maximum deflection of the spinal beam – 4 mm;
- maximum displacement of the points of the upper frame of the beam walls – 9 mm;
- maximum displacement of the points of the beam walls – 9 mm;
- the maximum displacement of the points of the upper frame of the end walls is 1 mm.

Results of end-element analysis (MCE). To confirm the end-element characteristics, a set of regulatory developments was carried out based on the established method of end-element elements. Rigidity of the structure (flex):

- maximum deflection of the spinal beam – 4 mm;
- The maximum movement of the upper frame of the beam walls is 9 mm.

Table 6

Impact power of 3.5 MN (I mode):

Structural element	Stress σ_{ekty} , MPa	Stock ratio
Bottom frame of the end wall	369.87	1.02
Upper frame of the end wall	354.83	1.07
Vertical stands	330.92	1.14
Joining the top sheet of the end beam	290.39	1.01

Let's say the stress is MPa. The coefficients will be 1.01–1.14 $[\sigma] = 378,00$

Frame stability: safety factor (allowable for [20] $n_y = 6,3 [n_y] = 1,1$

Uniqueness to resonance: the first frequency of the body's internal vibrations is

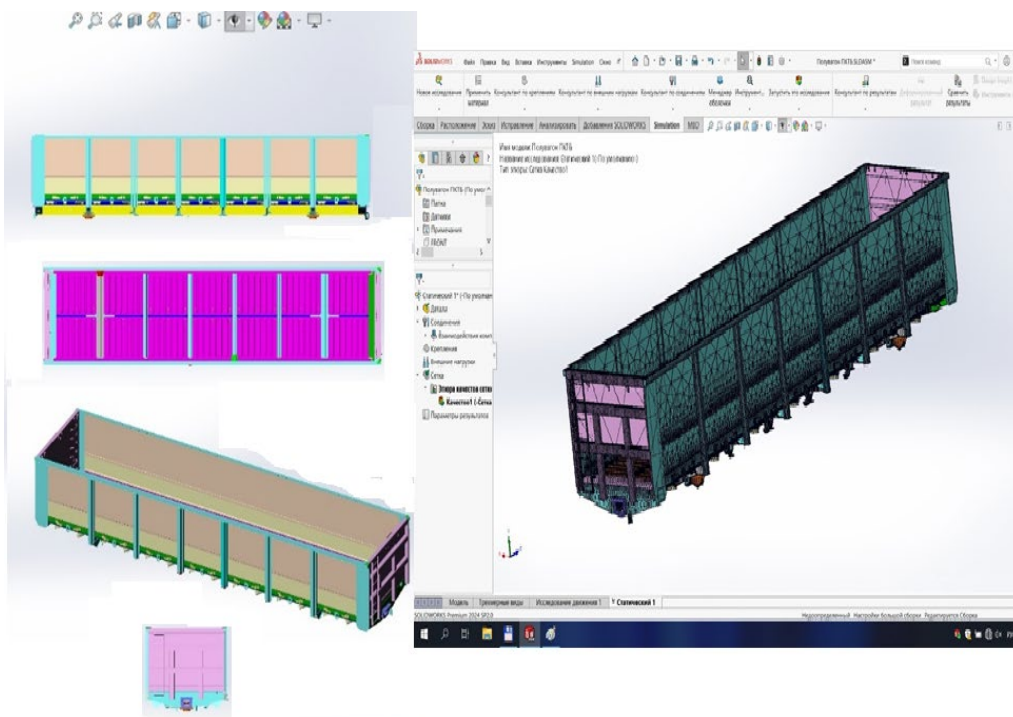


Fig. 4. A shear-element model of a car with elements made of high-component steel with a yield limit of 570 MPa has been developed

36.46 Hz, the frequency of the vibrations on the rears is 4.42 Hz → change $8.25 > 1.5$.

Development of strength, hardness and resilience

Main results:

Impact power 3.5 MN (I mode):

equivalent stress $\sigma_{eq} = 369.87$ MPa (lower frame of the end wall) with a tolerance $[\sigma] = 378$ MPa → safety factor $1.02 \dots 1.14$.

Harshness when increased to full intensity:

the maximum deflection of the spinal beam is 4 mm (permissible for mental resonance – much more).

Frame resistance at late-life force 2.5 MN:

durability factor $n_y = 6.3$ (acceptable $[n_y] = 1.1$ for [20])

Uniqueness to resonance: the first frequency of the power flexions of the body is 36.46 Hz, the frequency of the oscillation of the rears is 4.42 Hz → change $8.25 > 1.5$.

All developments have confirmed the validity of the existing standards [20–24].

Economical effect of the high-speed carriages will ensure additional load capacity of up to 200 t per train compared to standard analogues (axle load 23.5 t); This promotes transport capacity on plots with limited throughput capacity.

Scientific novelty. The investigation is based on a thorough theoretical approach to the development of new modules of transport devices in order to identify the specifics of the work of high-component steels at peak pressures. First, a number of conditions were established between the indicator of the fluidity of the material and the possibility

of changing the thickness of the walls of non-porous elements without losing the strength of the structure. The methodology of rich criteria for optimization of the selection of materials for transport structures that operate in the cyclic mode of transportation has undergone further development. A new model has been proposed for assessing the durability of welded joints made from high-grade steels of different alloying grades. Rational ranges of steel values have been identified for which the maximum effect of reducing transport costs is achieved. The need for correction of the coefficients of the reserve of tissue in the presence of thin-walled high-committee profiles in transport workers has been brought up. A scientific approach has been formed to integrate digital models of materials into a global system for automated design of dry warehouses. The research results provide further knowledge about the mechanics of the structure of modern composite metal structures for transport purposes.

Practical value. The work is focused on the development of specific engineering techniques that will allow the transport volume to be changed by 15–20% while saving design costs. To improve the results, it will be possible for the textile industry to create a dry warehouse, which indicates the shortest light patterns behind the indicator of vanity. Recommendations for the selection of steels will ensure the shortening of terms in the design of new models of transport vehicles. Removing this data allows you to reduce the cost of fire per unit of transport robot and also reduce the number of non-new modules. Advanced technological capabilities prior to welding high-grade steels increase the toughness and durability of the finished product. The results of the investigation may be used during the modernization of the existing fleet of equipment to extend the term of its service. The economical effect is achieved by increasing the cost of transportation by one transport vehicle and reducing costs for repairs. The materials can be integrated into initial courses for the training of design engineers in the transport profile.

Discussion of results. Both scientific and applied results confirm the hypothesis about the critical influx of the mechanical characteristics of steel on the core rigidity of the non-structural module. During the discussion, it was established that the transition to high-grade steel would require not only a change in rolling stock, but also a reconsideration of the configuration of the main power units of the structure. The results of the rozrokhunki testify to the ambiguous reaction of various steel grades to thermal injection during welding, which requires careful control of the production modes. A tendency has been revealed to increase the strength of thin-walled elements to the loss of joint resistance at high stresses. It is controversial to provide optimal compatibility between the material's strength and its toughness at extremely low temperatures. Practical testing of the results on models showed a significant improvement in the dynamic characteristics of the lightweight transport module. Analysis of the obtained data indicates the strength of the vigor of steels beyond the fluidity limit of over 500-700 MPa for the greatest stress zones. In general, the results of the discussion convey the prospects for a radical increase in the efficiency of transport.

Conclusions. The hardening of high-grade steels is a strategic priority for the development of daily transport machinery. It has been proven that a rational choice of materials allows one to adequately protect the quality of the modules while minimizing their damage. Mathematical modeling confirmed the possibility of reducing metallicity without damaging the minds of value and hardness. It has been established that high-tensile steels

absorb overvoltage stress in the structure more evenly. The developed methodology for selecting steels is based on a comprehensive consideration of mechanical, technological and economic parameters. Improving the results of the investigation allows us to increase the demand for transport services in the average by 12%. It has been discovered that the key factor in reliability is the strength of welded joints, which depends on the correct selection of welding materials. The use of high-grade steel will ensure the long service life of the transport module in folding road storage units. The economical benefit of using expensive steel is offset by a significant return on energy efficiency. The conducted research will fill the existing vacuum in the design methods of a lightweight dry warehouse. Scientifically based recommendations can become the basis for updating Galou-zian design standards. The results of the work create the foundation for the transition to the development of transport services of a new generation. Further research will focus entirely on the development of materials during high-temperature cycles of avancement.

The main criterion that determines the weight of the current welded cars is the value of the welded joint. Official standards (GOST 33211-2014, recommendations of the International Institute of Welding) stipulate low limits of vibration (23.5 MPa) for high-grade steels, which minimizes their advantages.

Based on the optimization of the chemical stock of steel 09G2S (Optim 570), a material with a fluidity limit of 570 MPa (Optim 570) was extracted, which ensures a uniform yield of 21% and can also be used for production load-bearing elements of carriages.

A model has been developed into a car with non-supporting elements made from high-grade Optim 570 steel. This has made it possible to reduce the tare weight by 2 tons and increase the lifting capacity to 73 tons.

Terminal element analysis confirmed:

- value during shock attacks (reserve coefficient 1.01–1.14);
- rigidity (deflection of the spinal beam 4 mm);
- durability (reserve factor 6.3);
- sensitivity to resonance (frequencies 36.46 Hz versus 4.42 Hz).

To further reduce the tariff you need to:

- carry out testing of welded joints from new steel for waste use;
- develop methods for increasing the vibration of welded seams;
- Frequently replace welded joints with bolts.

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