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WEAR RESISTANCE OF CAST IRON PARTS PRODUCED BY LOST FOAM CASTING

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Abstract. The article addresses the pressing issue of improving the wear resistance of cast iron parts manufactured by lost foam casting. Using a friction wedge as an example, the current state of wear-resistant components for railway rolling stock is analyzed. A methodology for accelerated testing to determine the tribological characteristics of castings is presented, based on specimen wear under conditions of external surface contact. The results of wear resistance tests conducted on samples of friction wedges are reported, enabling an assessment of component service life. Measures implemented to improve the lost foam casting process technology are also described. It is effective for casting parts weighing 10 to 20 kg, ensuring uniformity of chemical composition and the necessary stability of cast iron properties. The use of Ni, Ti, and Mo as alloying additives ensures casting hardness of up to 340 to 400 HB.

Keywords: castings; wear resistance, lost foam casting; testing; friction wedge; tribological properties; casting.

1. Introduction

Kazakhstan, ranking ninth in the world by territory, is the largest country globally without direct access to the ocean. Therefore, overland transportation is vitally important for the country. Its significance is further increased by the extremely uneven distribution of settlements and population. Despite the fact that the total length of highways (about 96,000 km) significantly exceeds that of railways (over 16,000 km), rail transport has been and remains the primary mode of freight transportation, accounting for slightly less than three quarters of the total freight turnover. Consequently, the problem of improving the operational reliability of railway rolling stock and, accordingly, reducing downtime due to repairs remains highly relevant.

Particular attention should be paid to the running bogies of freight cars. The weak point in this system is the friction vibration damper assembly (Fig. 1). It consists of two friction wedges (1) installed between the inclined surfaces of the ends of the bolster (5) and the friction plates (2) mounted on the columns (4) of the bogie side frame. The wedges rest on springs (3). Changes in the condition of the damper components during operation—especially wear—affect the duration of maintenance intervals of freight car bogies.

The influence of stable wedge operation on service life is associated with the friction force it generates to damp vertical and horizontal vibrations of the railcar body. As a result of wear of the working surfaces of the friction wedge, the friction force gradually decreases over time, which leads to an increase in the dynamic forces acting on the railcar and the track [1, 2, 3].

Wear of the wedge or its improper installation in the vibration damper assembly leads to cracking, fracture, excessive raising or lowering of the wedge relative to the supporting surface of the bolster, and results in loss of elasticity and wear of the mating components. As a result, the damping of railcar vibrations is impaired. This, in turn, causes increased loads and accelerated wear of other components (wheelset flanges, axle boxes, etc.), ultimately leading to the necessity of removing the railcar from service for repair. The most common defects of the vibration damper assembly are excessive wear of the wedge working surfaces and wear of the mating surfaces (springs, etc.).

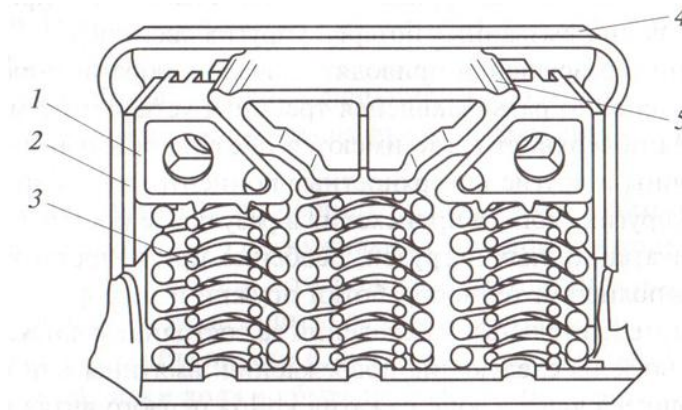


Fig.1. The main element determining the operability of the assembly is the friction wedge (Fig. 2 *a*) [1].

A review of the literature revealed a unique case of excessive wear (Fig. 2 *b*) [4]. According to GOST 34503-2018, friction wedges may be manufactured from cast iron (grey and ductile) as well as from various grades of cast steel. The standard specifies durability requirements for wedges, characterized by the duration of a defined stage of operation. The wedge must “ensure a service life not less than the designated operating life of the freight car bogie from the start of operation to its first scheduled overhaul or between scheduled overhauls” [5]. Based on service life and a scheduled maintenance interval of 250,000 km, friction wedges are divided into two classes. A wedge capable of ensuring a mileage not exceeding this limit is assigned to Class 2. A wedge capable of ensuring a greater mileage (but not exceeding 1 million km) is assigned to Class 1 [5].



a)



b)

Fig.2. Friction wedge (*a*) and a case of its excessive wear (*b*).

The operation of the friction pair “wedge–plate” occurs under dry friction conditions [6] and is characterized by intense abrasive wear. Despite this, the wedge must ensure at least one scheduled maintenance interval of the freight car bogie before replacement [7]. According to [8], depending on their chemical composition, friction wedges provide service life in the range from 120,000 km to 500,000 km. Other studies indicate that wedges made of grey cast iron grade SCh25 exhibit wear that prevents further operation already at a mileage of about 100,000 km [1, 9]. It should be noted that GOST 34503-2018 recommends the use of cast iron grades SCh30 and SCh35. The use of other materials is permitted only if the requirements of the standard are met. Apparently, in the cited case involving SCh25 cast iron, this requirement was not satisfied.

The stages of operation of freight cars and their running bogies are determined by maintenance mileage intervals. The standards for performing the first depot repair of freight cars of any type are established in the *Regulations on the System of Maintenance and Repair...* [7], approved by the Commonwealth of Independent States countries. With a few exceptions, this standard is 210,000 km. Already at the first repair, the friction wedge is usually replaced. From the standpoint of the theory of reliability of technical systems, this is consistent with the durability of the friction wedge as an element of a friction assembly. In other words, its wear resistance can serve as a criterion for determining the service mileage [8]. Indeed, a linear relationship between the service life of the friction wedge and the mileage parameters of freight cars has been established [10]. At present, a number of cast irons have been developed for friction wedges that are complex-alloyed with combinations of various elements, ranging from traditional chromium to rare-earth metals [11-13]. These materials ensure a service mileage of 250,000 km or more, and some of them have already been implemented in production.

Friction wedges are usually manufactured by casting in disposable sand molds. Such molds are very inexpensive but do not provide high geometric accuracy. The wedge is a critical component of the assembly; however, wedge castings are not subjected to machining, except for the removal of feeder remnants. Therefore, the wedges must be cast within the specified dimensional tolerances, which is not always achievable when using disposable sand-clay molds. To improve geometric accuracy, the use of alternative, more advanced technologies is desirable.

The aim of this work is to develop a material and a technology for the serial production of a friction wedge capable of providing a service mileage of more than 500,000 km.

2. Materials and Research Methods

Grey cast iron grade SCh35 was selected as the base material. It is more technologically efficient in production than ductile iron, the melting technology of which is labor-intensive and requires the use of expensive modifiers. Compared with steels, grey cast iron exhibits higher frictional properties. In addition, cast iron castings do not require strengthening heat treatment. However, experimental data obtained in our studies conducted in 2019–2020 revealed, first, a wide scatter in the hardness of wedges in service (grey cast iron), ranging from 100 to 240 HB (according to GOST, the hardness of SCh35 cast iron is $HB = 210\text{--}275$), as well as a scatter in other mechanical properties of the castings and a coefficient of variation of service life equal to 0.67. This indicates instability either in the chemical composition or in the material structure, both of which equally determine mechanical and operational properties. Consequently, despite the above, either the composition and structure of grey cast iron require further optimization, or they are unstable due to imperfections in the production technology. Therefore, it is necessary to study not only the influence of a wide range of alloying elements, additives, and modifiers, but also the technology of their application. As an example, treatment of the same alloy with the same modifier in a furnace, in a ladle, and in a mold yields different results. Second, the main reason for failure of the friction assembly is wear of the contact surfaces between the wedge and the friction plate. This confirms the well-known dependence of the service life of a friction wedge on wear. Wear is a complex physic mechanical process accompanied by chemical and thermal phenomena. It is determined by the type of wear and loading, the material, geometry and surface condition, as well as other factors [14].

In our case, we are dealing with dry friction of flat surfaces under sliding conditions with an intensive cyclic load. The material of the cast part is unstrengthened grey cast iron without mechanical machining, and there is also a possibility of oxidation. Wear debris is not removed. The roughness of the contacting untreated surfaces with relative movement/sliding due to the applied external force should also be taken into account [15]. The choice of the wear testing methodology was based on the advantages of evaluating wear in terms of reduced duration and cost of these studies, which makes it possible to avoid shutdown and disassembly of units under actual operating conditions of the rolling stock fleet.

The use of statistical data on the reliability of cast iron components of railcar bogies proved impossible due to the limited amount of reliable information. The fact is that castings of these products already represent finished parts. This means that the possibility of influencing their surface layers by mechanical and thermal treatments—to create compressive stresses, the required surface roughness and hardness, as well as to remove defective structures—is excluded. When using new materials for vibration damping unit parts, full-scale bench tests are recommended to evaluate their frictional properties [16]. When preparing such products for serial production, a large body of statistical data is required, whereas in practice only a pilot batch of castings is

usually available. Moreover, to register the wear rate of the surfaces of castings weighing more than 10 kg (the wedge mass is 10.5 kg), an operating time of at least 500–1000 hours and significant labor input are required.

Thus, the problem arises of developing an accelerated method for studying the wear of the working surfaces of a friction wedge under foundry shop conditions. At the same time, experiments must be carried out under conditions that most strongly affect the wear of the working surfaces. Solving this problem is inextricably linked to conducting a large number of experiments to reveal the mechanism of surface property formation in castings, as well as to obtain and systematize data on the wear resistance of the objects under study.

A solution was found in the use of cast pilot specimens as test sections of the wedge. To achieve the closest possible correspondence to real operating conditions, a fixture was developed that allows adjustment of the duration and the force of interaction between the friction surfaces. In addition, based on the considerations outlined above, a guidance document entitled “*Methodology for Evaluating the Wear Resistance of Castings Made of Cast Iron Alloys*” was developed, which establishes a method for assessing surface wear parameters of castings. It is based on testing specimens by wear on a test rig according to the “roller–block” scheme. The roller material was U8A steel with a hardness of 280–300 HB.

The cast iron was melted in an induction furnace of the PPU-0.16 type. The technology for producing grey cast iron castings by the lost foam casting (LFC) method was developed. Compared with conventional sand–clay mold casting, LFC makes it possible to obtain higher-quality castings with improved dimensional and geometric accuracy. In order to reduce material consumption, surface alloying of the castings in the mold was applied.

Specimens for tribological testing were cast iron blocks in the form of square bars 50 mm in length and 15 mm in width. This geometry was chosen based on the need to conduct a large number of multivariate tests in order to ensure the required confidence level.

The choice of the testing method and a custom-made laboratory setup meets the above-mentioned environmental and friction conditions. Reproduction of operating regimes using this methodology was ensured by the requirements of tribological testing for parts having a complex elemental composition due to the combination of base and alloying or modifying elements: C, O, Mn, Mg, Si, Ca, Fe, Ni, Cu, Mo, V, Co, Cr, Ti, and B. The investigations included determination of hardness, as well as qualitative and quantitative analysis of the surface chemical composition before and after testing.

3. Results and Discussion

Friction pair tests were carried out at a constant sliding speed of 0.5 m/s under moderate heating conditions. The test duration for one contact pair was 0.2 h. Each experimental series included at least three tests. The surface wear per unit sliding distance was adopted as the evaluation criterion. Visual examination of the specimen surfaces revealed no signs of plastic deformation; the surfaces remained smooth, without adhesion or material buildup. Dark inclusions were observed on the block surfaces, indicating phase heterogeneity; no brittle structural constituents were detected. As follows from Table 1, the chemical composition of the contact surfaces of the specimens after testing does not differ from the initial composition.

Table 1. Chemical composition of the surface of sample SCH35 before (1) and after (2) testing.

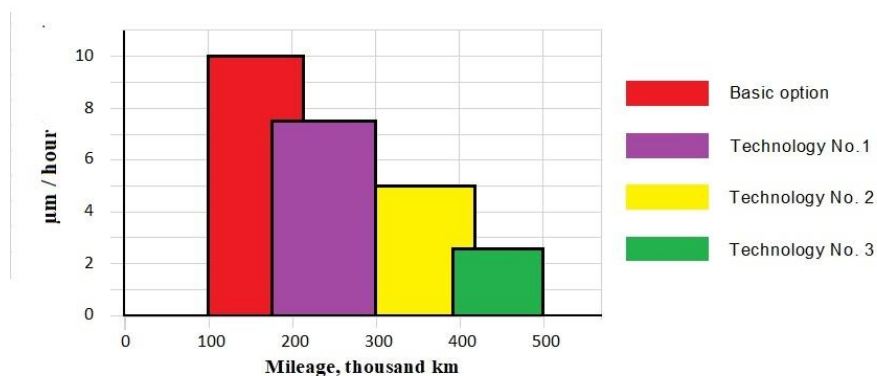
Sample	Content of elements, in fractions							
	C	Si	Mn	Cr	Cu	Ni	P	S
No. 1	2,83	1,56	0,97	0,22	0,37	0,13	0,12	0,09
No. 2	2,83	1,56	0,97	0,22	0,37	0,13	0,12	0,09

This indicates that no oxidation of the component surfaces occurs during operation. Table 2 shows the results of wear resistance tests. The influence of the alloying element on the hardness of the specimens is clearly observed. At the same time, the hardness of all specimens falls within the range acceptable for friction wedges, namely 230–444 HB. Once again, the dependence of wear resistance on hardness is confirmed.

Table 2. Results of tribological wear tests.

Technological scheme	Sample material	Hardness, HB	Wear resistance, $\mu\text{m}/\text{hour}$
Basic option	SCH35	285	9,5
Technology No. 1	Mo = 0,6 %	340	7,1
Technology No. 2	Ni = 0,4 %	360	6,6
Technology No. 3	Ti = 0,3 %	420	4,6

The positive results of the study demonstrate the prospects for their application in the production of castings for railway transport. This approach makes it possible to predict the service life of friction wedges (Fig. 3). For example, at a wear rate of 2.5 to 5 $\mu\text{m}/\text{h}$, the service life of this component may reach 300,000–400,000 km, which is achievable through the implementation of certain casting technologies using appropriate alloying additions. In this regard, it is recommended that the working surfaces of both the friction wedge and the friction plate of a freight car bogie have the same hardness.

**Fig.3.** Wear rate of samples (friction wedge) under steady-state friction conditions.

The choice of gray cast iron as the base material was determined by the results of developing the LFC technology. Options for casting the wedge from ductile (nodular) and gray cast iron were considered. Pilot batches of castings were produced under industrial conditions. Patterns were made from granulated expanded polystyrene by foaming in heated molds. The finished casting patterns and elements of the gating system were bonded into a single cluster and coated with an anti-stick (refractory) paint (Fig. 4).

**Fig.4.** Block of friction wedge models.

After the coating had dried, the patterns were placed in flasks and molded with dry fine-grained sand. The molds were evacuated and then poured on a foundry conveyor with the vacuum pump operating continuously. Subsequent operations were carried out in the same manner as in conventional sand casting. The casting technologies for gray and ductile iron differed only in that the latter was produced by treating the liquid superheated iron with a powdered modifier in the ladle prior to pouring the molds.

Castings made of ductile iron were characterized by increased hardness and required heat treatment—quenching followed by tempering—to improve the microstructure. In addition, a surface defect, a shrinkage cavity, was observed on some of the castings (Fig. 5 *a, b*). The initial solution was a conventional one—the installation of a riser (Fig. 5 *c*). However, this led to increased material consumption and additional labor associated with riser removal and surface cleaning of its remnants. An alternative measure was then applied: the use of chills. Installing them directly on the casting proved to be impractical due to the appearance of chill imprints on the casting surface and the risk of metal adhesion. The final solution was to place the chills on the pattern (Fig. 5 *d*). After this modification, the defect was no longer observed. Nevertheless, the labor intensity of manufacturing the product still increased. In addition, during LGM, the nature of the formation of sound signals is preserved, which affects fatigue from receiving castings [17].

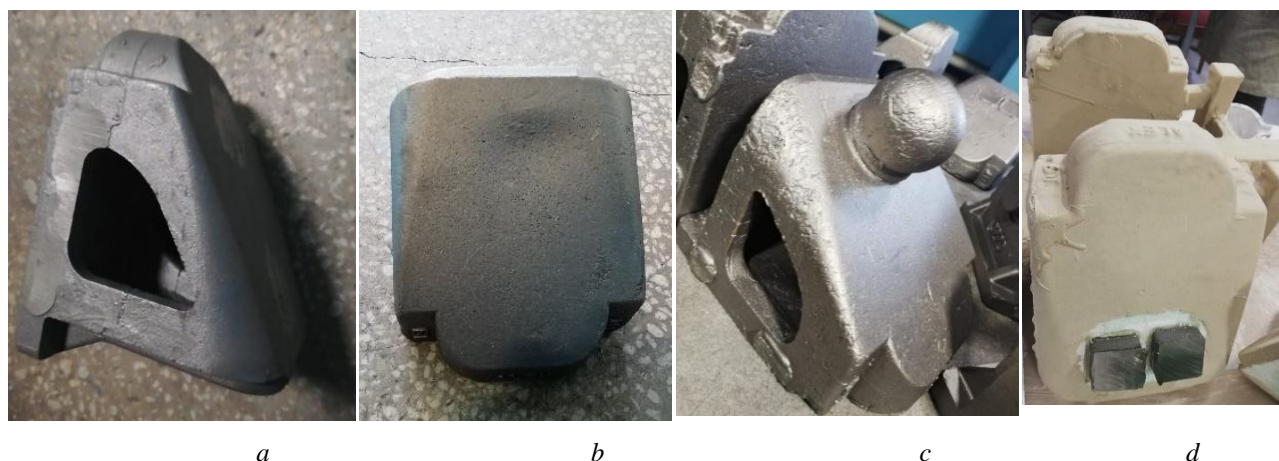


Fig.5. Sink (*a, b*) on the wedge casting, riser (*c*) and refrigerators (*d*).

Pilot batches of gray cast iron castings demonstrated an almost complete absence of defects and satisfactory service properties (hardness and tensile strength) without additional labor input. Therefore, gray cast iron was selected for subsequent studies of wear resistance.

4. Conclusion

The research results demonstrated the effectiveness of the LFC for producing castings with a mass of 10–20 kg, ensuring uniformity of chemical composition and the required stability of cast iron properties.

The use of Ni, Ti, and Mo as alloying additions provides casting hardness in the range of 340–400 HB.

Changes in the physic mechanical condition of the casting surface after alloying resulted in a 1.4–1.5-fold increase in wear resistance compared with the baseline variant (serial parts), which corresponds to an increase in the service mileage of friction wedges up to rejection by 70–85 thousand km.

Conflict of interest statement. The authors declare that the re-search was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

CRediT author statement.

Yeszhanov G.S.: Conceptualization, Investigation; Writing – original draft preparation; **Kuzembayev S.B.:** Methodology; Writing – review and editing, Supervision, **Abdrakhmanova S.T.:** Resources, Validation; **Zhanshuakova R.M.:** Data curation, Visualization. The final manuscript was read and approved by all authors

Statement on the use of Artificial Intelligence.

The authors declare that no artificial intelligence tools were used to generate scientific content, results, or conclusions of this article.

Data Availability Statement

The data that has been used is confidential.

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