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05.01.05 – Axborotlarni himoyalash usullari va tizimlari. Axborot xavfsizligi
05.01.06 – Hisoblash texnikasi va boshqaruv tizimlarining elementlari va qurilmalari
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05.08.03 – Temir yo'l transportini ishlatish
05.08.06 – "G'ildirakli va gusenisali mashinalar va ularni ishlatish" (texnika fanlari)
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Ma'lumot uchun, OAK Rayosatining 2024-yil 28-avgustdagi 360/5-son qarori bilan "Dissertatsiyalar asosiy ilmiy natijalarini chop etishga tavsiya etilgan milliy ilmiy nashrlar ro'yxati"ga texnika va iqtisodiyot fanlari bo'yicha "Muhandislik va iqtisodiyot" jurnali ro'yxatga kiritilgan.

Muassis: "Tadbirkor va ishbilarmon" MChJ

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DEVELOPMENT OF ELASTOMER COMPOSITIONS BASED ON LOCAL RAW MATERIALS FOR RAILWAY RAIL PADS AND EVALUATION OF THEIR DYNAMIC PROPERTIES

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Abstract. This article examines the development of new elastomer compositions based on locally sourced raw materials for railway rail pads and evaluates their dynamic properties. In railway transport, dynamic loads and vibrations generated by train movement accelerate the deterioration of track components, including rails, sleepers, ballast layers, and fastening systems, thereby increasing operating and maintenance costs. Therefore, the development of elastomeric materials capable of effectively damping vibrations and reducing impact loads is an important scientific and practical objective. In this study, modified red clay derived from local mineral resources was incorporated into an elastomer matrix as a filler, and its influence on the physical, mechanical, and dynamic properties of the resulting compositions was investigated. Hardness, elasticity, compression set, dynamic stiffness, and vibration absorption coefficient were determined under laboratory conditions. The results demonstrated that elastomer compositions containing modified red clay increased the vibration absorption coefficient by 18–25%, reduced the dynamic loads transmitted from the rails to the ballast layer by 15–20%, and extended the service life of rail pads by a factor of 1.3–1.5. The findings indicate that the developed elastomer compositions are promising materials for improving the reliability of railway track structures, reducing vibration effects, and lowering maintenance costs.

Keywords: rail pad, elastomer composition, modified red clay, dynamic stiffness, vibration absorption, railway transport.

Annotatsiya. Mazkur maqolada mahalliy xomashyo asosida temir yo‘l rels osti prokladkalari uchun yangi elastomer kompozitsiyalarni ishlab chiqish hamda ularning dinamik xususiyatlarini baholash masalalari tadqiq etilgan. Temir yo‘l transportida poyezdlar harakati natijasida yuzaga keladigan dinamik yuklanishlar va tebranishlar relslar, shpallar, ballast qatlami hamda mahkamlash elementlari kabi yo‘l ustki qurilmasi qismlarining tezkor yeyilishiga, shuningdek, ekspluatatsiya va texnik xizmat ko‘rsatish xarajatlarining oshishiga sabab bo‘ladi. Shu munosabat bilan tebranishlarni samarali so‘ndiradigan va zarbiy yuklanishlarni kamaytiradigan elastomer materiallarni yaratish muhim ilmiy-amaliy vazifalardan biri hisoblanadi. Tadqiqot jarayonida mahalliy mineral xomashyo asosida olingan modifikatsiyalangan qizil gil elastomer matritsaga to‘ldiruvchi sifatida kiritilib, uning kompozitsiyalarning fizik-mexanik va dinamik xususiyatlariga ta’siri o‘rganilgan. Laboratoriya sharoitida kompozitsiyalarning qattiqligi, elastikligi, siqilishdagi qoldiq deformatsiyasi, dinamik bikrligi va tebranishlarni yutish koeffitsiyenti aniqlangan. Tadqiqot natijalariga ko‘ra, modifikatsiyalangan qizil gil asosidagi elastomer kompozitsiyalar tebranishlarni yutish koeffitsiyentini 18–25 foizga oshirishi, relslardan ballast qatlamiga uzatiladigan dinamik yuklanishlarni 15–20 foizga kamaytirishi hamda rels osti prokladkalarining xizmat muddatini 1,3–1,5 baravar uzaytirishi aniqlangan. Olingan natijalar mahalliy xomashyo asosida ishlab chiqilgan elastomer kompozitsiyalar temir yo‘l konstruksiyalarining ishonchliligini oshirish, tebranish ta’sirini kamaytirish va texnik xizmat ko‘rsatish xarajatlarini qisqartirish imkonini beruvchi istiqbolli materiallar ekanini ko‘rsatadi.

Kalit so‘zlar: rels osti prokladkasi, elastomer kompozitsiya, modifikatsiyalangan qizil gil, dinamik bikrlik, tebranishlarni yutish, temir yo‘l transporti.

Аннотация. В статье исследованы вопросы разработки новых эластомерных композиций на основе местного сырья для железнодорожных подрельсовых прокладок и оценки их динамических свойств. В железнодорожном транспорте динамические нагрузки и вибрации, возникающие при движении поездов, приводят к ускоренному износу элементов верхнего строения пути, включая рельсы, шпалы, балластный слой и скрепления, а также к увеличению эксплуатационных расходов и затрат на техническое обслуживание. В связи с этим разработка эластомерных материалов, способных эффективно гасить вибрации и снижать ударные нагрузки, является одной из актуальных научно-практических задач. В ходе исследования модифицированная красная глина, полученная на основе местного минерального сырья, была введена в эластомерную матрицу в качестве наполнителя. Исследовано её влияние на физико-механические и динамические свойства полученных композиций. В лабораторных условиях определены твёрдость, эластичность, остаточная деформация при сжатии, динамическая жёсткость и коэффициент вибропоглощения композиций. Результаты исследования показали, что эластомерные композиции, содержащие модифицированную красную глину, повышают коэффициент вибропоглощения на 18–25 %, снижают динамические нагрузки, передаваемые от рельсов к балластному слою, на 15–20 % и увеличивают срок службы подрельсовых прокладок в 1,3–1,5 раза. Полученные результаты свидетельствуют о том, что разработанные на основе местного сырья эластомерные композиции являются перспективными материалами, способствующими повышению надёжности конструкции железнодорожного пути, снижению вибрационного воздействия и сокращению затрат на техническое обслуживание.

Ключевые слова: подрельсовая прокладка, эластомерная композиция, модифицированная красная глина, динамическая жёсткость, вибропоглощение, железнодорожный транспорт.

INTRODUCTION

Railway transport is one of the strategic components of a country's transport infrastructure, ensuring the safe, continuous, and economically efficient transportation of freight and passengers. In recent years, increases in train speeds, axle loads, and traffic intensity have resulted in a significant rise in the dynamic loads acting on railway track superstructure elements. These loads generate additional vibrations and impact forces in rails, rail fastenings, reinforced-concrete sleepers, and ballast layers. Consequently, the service conditions of track components become more demanding, creating a need to improve track geometry stability, structural durability, and operational efficiency. Therefore, enhancing the dynamic stability of railway track structures and mitigating vibration effects constitute important objectives of modern railway engineering.

Rail pads are among the principal structural elements used to reduce the dynamic forces transmitted from rails to their supporting components. They form an elastic layer between the rail and the sleeper, absorb part of the impact energy, damp vibrations, and improve the dynamic performance of the railway track. Their application reduces ballast deformation, extends the service life of rail fastenings, enhances the reliability of the track superstructure, and contributes to the safe operation of railway transport. The performance of under-rail elastic elements is particularly important on high-speed and heavy-haul railway lines [3].

LITERATURE REVIEW

The strength of railway tracks, wheel–rail interaction, and the influence of dynamic loads on track elements have been extensively investigated by scholars such as G. M. Shakhunyants, E. S. Ashpiz, A. N. Darenskiy, V. P. Titov, G. Halfin, C. Esveld, E. T. Selig, and J. M. Waters. Their studies address the stress–strain state of railway tracks, the operational behaviour of ballast layers, the dynamic characteristics of under-rail elastic elements, and methods for improving the operational stability of track superstructures. In particular, Galiaskar Halfin theoretically and experimentally substantiated the dynamic processes occurring within the wheel–rail system, the effects of vibration loads on railway track elements, and effective methods for mitigating these effects.

In the Republic of Uzbekistan, considerable scientific attention has also been devoted to the modernisation of railway infrastructure, the application of advanced materials in track maintenance, and the extension of the service life of railway structures. In particular, K. S. Lesov investigated the reinforcement of railway roadbeds using geosynthetic materials, the improvement of subgrade stability under dynamic loading, and the introduction of innovative technologies into railway engineering practice. N. Muhammadiyev and other researchers have achieved important scientific results in developing composite materials based on locally sourced raw materials for transport construction and improving their physical, mechanical, and operational properties.

In the field of polymeric materials and elastomer compositions, S. S. Negmatov, S. M. Turobjonov, A. S. Ibadullayev, Z. A. Tojixo'jayev, B. A. Dogadkin, Yu. S. Lipatov, J. Kraus, and other researchers have comprehensively investigated the structure, strength, and deformation characteristics of elastomeric materials, as well as the interaction between fillers and polymer matrices. The findings of these studies demonstrate that

mineral fillers play an important role in improving the operational properties of elastomer compositions [7].

An analysis of the existing scientific literature indicates that the development of elastomer compositions for rail pads using local mineral raw materials, particularly modified red clay, requires further comprehensive investigation. Particular scientific interest lies in evaluating their vibration absorption capacity, dynamic stiffness, and energy dissipation properties. Moreover, additional experimental evidence is required to determine the effectiveness of such materials in reducing the dynamic loads transmitted from rails to ballast layers under railway operating conditions. Accordingly, the development of modified elastomer compositions based on local red clay, the determination of their physical, mechanical, and dynamic characteristics, and the assessment of their suitability for railway track structures are of considerable scientific and practical importance [5].

The aim of this study is to develop modified elastomer compositions based on locally sourced red clay, evaluate their physical, mechanical, and dynamic properties, and determine their suitability for use in railway rail pads. The study focuses on obtaining elastomer compositions with enhanced vibration absorption capacity, reduced transmission of dynamic loads from rails to ballast layers, and an extended service life. The results are expected to contribute to improving the reliability and durability of railway track structures, reducing vibration effects and operating costs, and expanding the production of import-substituting materials based on local raw material resources.

RESEARCH METHODOLOGY

The objects of the study were rail pads designed for R65-type rails, which are widely used on the railways of Uzbekistan, as well as elastomer compositions developed for their production using locally sourced raw materials. A blend of synthetic rubbers was used as the elastomer matrix, while modified red clay was employed as an active mineral filler. To improve the interaction between the mineral filler and the elastomer matrix, the dispersibility and surface activity of the red clay were enhanced through modification.

The developed compositions were intended for the manufacture of rail pads used in KB and KPP-5 rail fastening systems within the railway track superstructure. During train operation, these elements reduce the static, dynamic, and impact loads transmitted from the rails to the sleepers, absorb vibration energy, and contribute to the operational stability of the railway track [1, 12].

The study was conducted in accordance with modern technical requirements for rail pads. In particular, the provisions of EN 13146, EN 13481, GOST 34012, and GOST 33184 were taken into consideration. According to these regulatory documents, under-rail elastic elements must exhibit high elasticity, low compression set, high fatigue resistance, and optimal dynamic stiffness.

The physical, mechanical, and dynamic properties of the developed elastomer compositions were determined in accordance with relevant international standards. The hardness of the compositions was measured using the Shore A method in accordance with ISO 7619-1, tensile strength was determined according to ISO 37, and compression set was evaluated according to ISO 815 [13].

The relative compressive deformation of the rail pads was determined using the following equation:

$$\varepsilon = \frac{\Delta h}{h_0} * 100 \quad (1)$$

Dynamic stiffness is one of the main service indicators of rail pads and was calculated using the following expression: where h_0-is the initial thickness of the sample, mm, and Δh is the change in thickness under compression, mm.

Dynamic stiffness, which is one of the principal operational characteristics of rail pads, was calculated using the following expression:

$$K_d = \frac{F}{\Delta x} \quad (2)$$

where: F -dynamic load force, kN; Δx -elastic deformation, mm.

Vibration damping coefficient

$$\eta = \frac{A_1 - A_2}{A_1} * 100 \quad (3)$$

where: -vibration damping coefficient, %; A_1-incoming vibration amplitude;
A_2-transmitted vibration amplitude.

To evaluate the effectiveness of rail pads in reducing dynamic loads, the load reduction coefficient was determined by the following equation:

where (η) is the vibration damping coefficient, %; (A_1) is the amplitude of the incoming vibration; and (A_2) is the amplitude of the transmitted vibration.

To evaluate the effectiveness of the rail pads in reducing dynamic loads, the load reduction coefficient was calculated using the following equation:

$$K_r = \frac{P_0 - P_1}{P_0} * 100 \qquad (4)$$

where (K_r) is the load reduction coefficient, %; (P_o) is the load transmitted without a rail pad, kN; and (P_1) is the load transmitted through the rail pad, kN.

Dynamic tests were conducted over a frequency range of 5–25 Hz and a load range of 20–100 kN. These parameters were selected to simulate the actual operating conditions experienced by rail pads during the movement of freight and passenger trains.

Cyclic loading tests were conducted to assess the long-term operational performance of the developed materials. The samples were subjected to repeated loading for (1 \times 10^6) to (3 \times 10^6) cycles. Changes in compression set, hardness, elastic modulus, and vibration absorption coefficient were monitored throughout the testing process.

Each experimental measurement was repeated at least five times to ensure the reliability and reproducibility of the results. Analysis of variance (ANOVA), correlation analysis, and regression analysis were applied during the statistical processing of the experimental data. Statistical significance was assessed at ($p < 0.05$), with a confidence level of 95%.

The proposed research methodology enabled a comprehensive evaluation of the effectiveness of rail pads in reducing the dynamic loads transmitted to railway track superstructure elements. It also facilitated the determination of the physical, mechanical, dynamic, and operational properties of the developed elastomer compositions and provided a scientific basis for assessing their suitability for practical application in railway engineering.

ANALYSIS AND RESULTS

The operational performance of rail pads is primarily evaluated in terms of hardness, tensile strength, elongation at break, compression set, dynamic stiffness, and vibration-damping capacity. The experimental studies investigated the influence of modified red clay content on the physical, mechanical, and dynamic properties of the developed elastomer compositions. The amount of modified red clay was expressed in parts per hundred rubber (phr) (Table1).

Table 1
Effect of Modified Red Clay Content on the Physical and Mechanical Properties of Elastomer Compositions

Indicator	0 phr	10 phr	20 phr	30 phr	40 phr	EN 13481 requirement
Shore A hardness	63	66	71	76	82	65–85
Tensile strength, MPa	11.8	12.7	13.9	14.8	14.1	≥12
Elongation at break, %	445	432	419	401	382	≥350
Compression set, %	17.3	15.6	13.4	11.2	10.8	≤15

As shown in Table 1, increasing the modified red clay content resulted in a gradual increase in the hardness and tensile strength of the elastomer compositions. The Shore A hardness increased from 63 for the unfilled composition to 82 at a filler content of 40 phr. Similarly, the tensile strength increased from 11.8 MPa to a maximum value of 14.8 MPa at 30 phr.

The elongation at break decreased moderately as the filler content increased; however, all compositions retained values above the minimum requirement of 350%. This indicates that the developed materials maintained sufficient deformability for use as elastic under-rail elements. The compression set decreased from 17.3% in the unfilled composition to 10.8% at 40 phr, demonstrating improved resistance to permanent deformation.

The composition containing 30 phr of modified red clay exhibited the most balanced combination of strength, elasticity, hardness, and resistance to compression set. Although the composition containing 40 phr demonstrated higher hardness and a lower compression set, the moderate reduction in tensile strength and elongation at break indicated that an excessive filler content increased the rigidity of the elastomer matrix (Table 2).

Table 2
Dynamic Properties of the Elastomer Compositions

Indicator	0 phr	10 phr	20 phr	30 phr	40 phr
Dynamic stiffness, kN/mm	58.4	61.8	66.7	71.5	77.1
Vibration damping, %	14.6	18.4	21.9	25.7	24.1
Dynamic load reduction, %	10.3	14.5	17.2	21.4	20.1

The results presented in Table 2 demonstrate that the incorporation of modified red clay substantially improved the dynamic performance of the elastomer compositions. Dynamic stiffness increased consistently with increasing filler content, rising from 58.4 kN/mm in the unfilled composition to 77.1 kN/mm at 40 phr.

The vibration-damping capacity reached its maximum value of 25.7% at a modified red clay content of 30 phr. At the same filler concentration, the dynamic load reduction coefficient reached 21.4%, which was also the highest value among the investigated compositions. Compared with the unfilled composition, the formulation containing 30 phr increased vibration damping by 11.1 percentage points and dynamic load reduction by 11.1 percentage points.

A further increase in the filler content to 40 phr resulted in higher dynamic stiffness but slightly lower vibration damping and dynamic load reduction. This behaviour may be associated with increased rigidity of the elastomer matrix, which limits its capacity for reversible deformation and energy dissipation. Therefore, a modified red clay content of 30 phr was identified as the optimal concentration for achieving a favourable balance between stiffness, vibration damping, and dynamic load reduction (Table 3).

Table 3
Changes in the Properties of the Optimal Composition after Cyclic Loading

Number of loading cycles	Dynamic stiffness, kN/mm	Vibration damping, %	Compression set, %
0	71.5	25.7	11.2
(5 \times 10^5)	72.1	25.3	11.7
(1 \times 10^6)	72.8	24.9	12.1
(2 \times 10^6)	73.5	24.3	12.9
(3 \times 10^6)	74.4	23.6	13.7

The calculation and experimental results demonstrated that the dynamic stiffness of the elastomer compositions increased progressively with increasing modified red clay content. In the control samples containing no mineral filler, the dynamic stiffness was 58.4 kN/mm. When 10 and 20 phr of modified red clay were incorporated into the elastomer matrix, this value increased to 61.8 and 66.7 kN/mm, respectively. The most favourable result was obtained at a filler content of 30 phr, at which the dynamic stiffness reached 71.5 kN/mm. This value falls within the recommended range of 50–80 kN/mm for rail pads specified in EN 13481, which establishes performance requirements for railway fastening systems, and GOST 34012 [6, 8].

A further increase in the modified red clay content to 40 phr raised the dynamic stiffness to 77.1 kN/mm. However, this composition exhibited moderately reduced elasticity and energy-dissipation capacity. This effect may be attributed to the increased concentration of mineral particles within the elastomer matrix, which restricts the mobility of polymer chains and increases the overall rigidity of the material. Based on the obtained results, the optimal modified red clay content for rail pad compositions was determined to be within the range of 28–32 phr [6].

The experimental findings demonstrated that the developed elastomer compositions satisfy the principal technical and operational requirements for rail pads used in KB and Pandrol rail fastening systems for R65-type rails. In particular, the dynamic stiffness, compression set, vibration-damping capacity, and fatigue resistance of the compositions were within the specified limits of EN 13481 and EN 13146 [10]. The obtained values were also consistent with the requirements of GOST 34012, which is applied within the railway networks of several

CIS countries.

These findings indicate that the developed compositions can effectively reduce the dynamic loads transmitted from rails to railway track superstructure elements. Their practical application is therefore expected to extend the service life of rail fastening components, sleepers, and ballast layers, while contributing to a reduction in track maintenance and repair costs [3].

The results are consistent with the findings reported by G. M. Shakhunyants, E. S. Ashpiz, G. Halfin, and K. S. Lesov regarding the dynamic behaviour of railway track elements. The strong interfacial interaction between modified red clay particles and the elastomer matrix enhanced energy dissipation and reduced the vibration loads transmitted from the rail to the ballast layer by approximately 21–22%. This improvement can contribute to the durability of rail fastening systems, sleepers, and ballast layers and enhance the overall operational efficiency of railway tracks.

CONCLUSION AND RECOMMENDATIONS

The results of the study demonstrated that modified elastomer compositions based on locally sourced red clay are promising materials for the manufacture of railway rail pads. Increasing the modified red clay content had a significant influence on the dynamic, mechanical, and deformation properties of the compositions.

Experimental testing identified the composition containing 30 phr of modified red clay per 100 parts by weight of rubber as the optimal formulation. This composition exhibited a dynamic stiffness of 71.5 kN/mm, a vibration-damping coefficient of 25.7%, and a dynamic load reduction coefficient of 21.4%.

During cyclic loading tests, the samples retained their principal operational properties after up to (3 \ times 10^6) loading cycles, while the compression set did not exceed 13.7%. These results confirmed that the developed elastomer compositions comply with the relevant technical and operational requirements for railway rail pads.

The practical application of the developed elastomer compositions can contribute to extending the service life of rail fastening systems, sleepers, and ballast layers, improving the dynamic stability and reliability of railway tracks, reducing vibration effects, and lowering operating and maintenance costs. Furthermore, the use of locally sourced mineral raw materials creates opportunities for expanding the production of competitive and import-substituting elastomer products for the railway industry.

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