Influence of fillers on the properties of under-rail gaskets

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Abstract. Using the criterion of the reduced hydration activity of inorganic materials, the choice of magnetic separation waste as a mineral filler for the production of under-rail gaskets is justified. By the methods of experimental planning, mathematical models were obtained that adequately describe the hardness (Shore A) and the conditional tensile strength of the gasket material, using which the composition of the material was developed that exceeds the physical and technical characteristics of the production composition.

1. Introduction
Consumers of rubber products (RTP) of the industry are almost all branches of production: motor vehicle engineering (automotive, tractor construction, agricultural and railway industries, aircraft construction, shipbuilding, etc.), construction, oil and gas production, production of consumer goods, medical devices, etc.

As you know, such components of RTP as rubber, technical soot, and various chemical modifiers are imported to the Republic of Uzbekistan from countries far and near abroad, which significantly increases the cost of manufactured products and is a deterrent to expanding its range and increasing production volumes.

The article presents the results of research on the development of composite sub-rail linings, the main purpose of which is to reduce the negative impact of vibrodynamic loads transmitted to the elements of the upper structure of the railway track from the rolling stock. In view of their functional purpose and large-capacity use in railway transport, when developing effective and competitive linings, it is important to develop such compositions that would provide the required indicators of physical and technical properties [1, 2].

One of the ways to implement this task is to develop RTP based on the integrated use of chemical modifiers and mineral dispersed fillers of natural and man-made origin of a wide range presented on the market of the Republic of Uzbekistan [3, 4].

2. Methods and techniques used in research
When conducting experimental studies, the generally accepted methods of conducting laboratory tests of materials, set out in the relevant standards, in particular, GOST 34078-2017 “Laying of rail fasteners of a railway track, were used. Technical conditions”, as well as non-standard methods developed by specialists of leading foreign research institutes.

3. Research results
To achieve this goal, the authors conducted studies on the quantitative assessment of the activity of dispersed mineral fillers of various nature. As a result, a criterion was proposed – the reduced hydration activity of mineral additives $P_{pga}$, which characterizes the acid-base properties of the surface of mineral fillers depending on the acidity constant $pK_a$ [5-13], calculated by the formula:

$$
P_{pga} = P_{ab} + P_{al} + 0.33P_{ad} - 0.1P_{ab},
$$

(1)
where $P_{ol}, P_{kb}, P_{ob}, P_{kl}$ are the number of adsorption centers, respectively, in the regions $0 \leq pK_a < 7$; $pK_a \geq 13$; $-4 < pK_a < 0$; $7 \leq pK_a < 13$ in $10^{-3}$ mg-ekv,g.

Based on the $P_{pga}$ criterion, the reaction activity of mineral fillers was evaluated, as shown in Table 1.

### Table 1. Values of the $P_{pga}$ criterion for the reactivity of mineral fillers

| Mineral filler  | $pK_a$ values, rel. units. | Values of the $P_{pga}$ criterion, rel. units. |
|------------------|---------------------------|---------------------------------------------|
|                  | $P_{ol}$  | $P_{kb}$  | $P_{ob}$  | $P_{kl}$  |                                    |
| Quartz sand      | 8.04     | 9.11     | 8.75     | 1.88      | 12.77                                |
| Dune sand        | 4.12     | 7.08     | 9.95     | 1.07      | 8.52                                 |
| Glizech          | 13.22    | 16.47    | 10.08    | 2.87      | 22.39                                |
| Basalt           | 23.4     | 22.15    | 11.16    | 1.96      | 30.71                                |
| ESP              | 41.2     | 5.48     | 9.34     | 1.14      | 19.28                                |
| CSW              | 6.61     | 23.88    | 16.37    | 4.32      | 28.74                                |
| Fly ash          | 43.1     | 27.61    | 11.77    | 5.32      | 46.68                                |
| ZR               | 102.1    | 24.88    | 12.62    | 2.41      | 59.44                                |
| MSW              | 112.03   | 27.82    | 13.51    | 2.45      | 67.53                                |

Note: ESP – waste of electric smelting production; CSW - waste of copper smelting production; ZR – zeolite-containing rock; MSW - waste of magnetic separation

Based on the maximum value of the $P_{pga}$ coefficient determined by equation (1), as well as the world experience of leading companies in the field of RTP, such as Hankook, Michelin, Goodyear and others, which use mainly "silica" SiO2 as a mineral filler, a regenerate – magnetic separation waste (MSW) containing 97% silicon oxide SiO2 was adopted for testing as a mineral powder.

Magnetic separation waste is a technogenic fine powder of dark gray color obtained as a result of the production of glass and glass products, consisting mainly of unrolled quartz particles and inclusions of metal oxides, carbonates, hematite and their aggregates. The particle size modulus of the powder is significantly lower than 1, and the particle content of less than 0.074 mm is 80-98%.

In the course of the conducted studies, using the planning of the experiment, the composition of the rubber mixture for the production of under-rail gaskets was selected. The variable factors were: $X_1$ – stearic acid, kg; $X_2$ – regenerate, %; $X_3$ – synthetic fibers with a length of 2 mm (a product of recycling of decommissioned tires), kg. The values of the variable factors are given in Table 2.

### Table 2. Values of variable factors

| Variable factors  | Levels of variation in the coded $x$ scale |
|-------------------|------------------------------------------|
|                   | $x_{min} = -1$ | $x_0 = 0$ | $x_{max} = +1$ |
| Consumption of stearic acid $X_1$, kg | 0.2 | 0.5 | 0.8 |
| Regenerate consumption $X_2$, % | 2 | 5 | 8 |
| Fiber consumption $X_3$, kg | 1.0 | 1.5 | 2.0 |

The response functions were such properties of the gasket material as the hardness $T$ (Shore A), standard units, and the conditional tensile strength $R_p$, MPa. As an experimental plan, we used plan B3, which is close to the D-optimal plan. The matrices of the plan and the results of the active experiment are shown in Table 3.

### Table 3. Matrix and arithmetic mean values of the response functions at the points of the experiment plan

| Experiencenumber | Values of variable factors on a coded scale | Hardness $T$, standard units | Strength $R_p$, MPa |
|------------------|------------------------------------------|-----------------------------|-------------------|
| $X_1$ | $X_2$ | $X_3$ | $X_1$ | $X_2$ | $X_3$ | $X_1$ | $X_2$ | $X_3$ |
As a result of processing the experimental data, polynomial mathematical models were obtained that adequately describe the hardness T (Shore A), standard units, and the conditional tensile strength Rp, MPa, of the gaskets:

\[
T = 34.45 + 19.5X_1 - 0.126X_1^2 - 12.81X_2 + 1.03X_2^2 + 10.32X_3 + 0.30X_3^2, \tag{2}
\]

\[
R_p = 13.4 + 1.8X_1 - 0.41X_1X_2 + 12.81X_2 - 1.03X_2^2 + 8.32X_3 + 0.30X_3^2. \tag{3}
\]

The analysis of the obtained regression equations showed that the chemical modifier—steoric acid—has the main influence on the properties of the under-rail gaskets among the variable factors. By varying the content of the variable factors \( X_i \) (\( i = 1, 2, 3 \)), it is possible to obtain gaskets with a wide range of response function values that differ more than twice in both Shore A hardness (from 40.2 US units in Experiment 1 to 84.5 US units in Experiment 6) and conditional tensile strength (from 13 MPa in experiments 6, 9 to 27 MPa in experiment 10).

Using the obtained mathematical models (2) and (3), rational compositions of under-rail gaskets were established that provide a Shore A hardness of not less than 65 US units (permissible range according to GOST 34078-2017 from 65 to 90 US units) and a conditional tensile strength of not less than 15 MPa, which corresponds to gaskets of increased durability (gaskets of category II, version “PD”), providing 1.1 billion tons of gross cargo passed and operated in the air in the temperature range from minus 60°C to plus 60°C, not only in sleepers, but also in the bars of switches.

The compositions of experimental gaskets were tested at the Toshkent Rubber Products company. As a mineral filler, magnetic separation waste with a \( \text{SiO}_2 \) content of 92% was selected, modified by surfactants during grinding in a ball mill to a specific surface area of \( \text{Sud} = 3000 \text{ g/cm}^2 \). The production and developed compositions for the production of pilot batches of gaskets are shown in Table 4.

| Name of the components | Consumption of the components in the compositions |
|------------------------|-------------------------------------------------|
|                        | PS  | №1 | №2  | №3 | №4 |
| Rubber, kg             | 15.0| 13.5| 12   | 13.5| 12.0|
| CB carbon black 803, kg| 15  | 13  | 13   | 13  | 13  |
| Technical oil, L       | -   | 6   | 6    | 6   |
| Chalk, kg              | 10  | -   | -    | -   | -   |
| Sulfur, kg             | 0.50| 0.65| 0.65 | 0.65| 0.65|
The results of physical and technical tests shown in Table 5 show that the proposed rational compositions of the material of under-rail gaskets according to the properties normalized by GOST 34078-2017 have higher indicators compared to the production composition: in terms of conditional tensile strength by 1.9 times (composition No. 4), elongation at break by 1.6 times (composition No. 4), abrasion by 25% (composition No. 4), at the same time providing less rigidity of the railway track-the hardness of gaskets on Shore A is lower to 31% (composition #4). At the same time, other properties in comparison with the production composition differ slightly (plasticity, compositions no.2 and No. 4; viscosity, composition No. 1; elasticity at 20°C for composition No. 4 and at 1000C for composition No. 1; coefficient of temperature resistance at 1000C) or a significant improvement is achieved (for composition No. 4, resistance to sub-vulcanization increased by 16%, conditional stress at fixed elongation by 52%, tear resistance by 17%, resistance to crack growth by 33%, coefficient of thermal aging in strength by 25% and elongation by 20%, multiple stretching at 70°C by 1.4 times).

The analysis of rational compositions No. 1-No. 4 according to the complex of physical and technical indicators achieved by them allowed us to recommend composition No. 4 as a composition that provides the best normalized GOST 34078-2017 and production indicators. With the introduction of this composition in the production of under-rail gaskets, a number of technological parameters were improved, in particular, reducing the temperature and rolling time by 200C (from 80 to 600C) and 25 minutes, respectively, increasing productivity by 17% and reducing the cost of production due to the use of local man-made raw materials.

4. Conclusions
Based on the criterion of the reduced hydration activity of inorganic Ppga materials developed by the authors of the article, the choice of magnetic separation waste in the production of glass products as a mineral filler for the manufacture of under-rail gaskets is scientifically justified. Using the methods of planning active experiments, rational compositions of the material of under-rail gaskets were established, which provide an improvement in their physical and technical properties in comparison with the composition adopted in production. At the same time, the introduction of composition No. 4 in production has improved the technological parameters, increased productivity and reduced the cost of production due to the use of local man-made raw materials.

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