Special purpose composite materials for wheel-rail contact

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Abstract. The paper deals with special-purpose friction materials for the contact «wheel-rail», designed to improve the adhesion of the locomotive wheels with the rails, reducing the resistance to the movement of the impact on the track, increasing the rolling stock wheels and rails resource. The authors used the generalized world and native experience in the application of existing and developed devices designed for the activators and modifiers applying in the contact zone «wheel-rail», as well as test results. The requirements to the methods of physical and chemical properties testing, to the values of the main indicators of physical, chemical and mechanical properties of friction activators and modifiers are presented, the requirements of the modifier and friction activator resource and friction coefficients from their application are substantiated. Needs to values of operational characteristics of activators and modifiers of friction which are established by results of field and operational tests carried out by special programs and techniques have been formulated.

One of the effective methods of friction control is the technology that allows by introducing special materials into the friction contact zone to create boundary layers with specified friction characteristics on the contacting surfaces. Modifiers and friction activators of the contact zone «wheel-rail» are the example of special materials effective use that form an adjusted level of friction in the friction contact. Friction modifiers are materials designed to reduce the forces of resistance to the movement of rolling stock and energy consumption for traction of trains, providing an adjustable reduction in the coefficient of friction on the surface of rolling rails. Friction activators are materials designed to increase the traction of locomotive wheel pairs with rails, providing an adjustable increase in the traction forces of locomotive wheels with rails by changing the friction characteristics in the contact zone of the rolling surface of locomotive wheels with rails. The creation of modifiers and friction activators with high functional characteristics, the introduction of which into the friction contact zone allows to change the value of the sliding friction force under the interaction relative motion/displacement of one of the contacting/interacting bodies relative to another is an urgent task of scientific research.

One of the mandatory requirements for the development of new materials is the generalization of foreign experience, analysis of existing and developing devices for their application, as well as the results of testing analogues. As the main sources of information that were used in the analysis of the state of the issue in this area were:

- book of the International Association of heavy traffic (IHHA) «Generalization of best practices of heavy traffic. Issues of wheel-rail interaction» [1];
According to molecular-mechanical concepts of external friction, the coefficient of adhesion $\psi_{sc}$, realized in the contact of solids, is equal to the sum of molecular $\psi_{mol}$ and mechanical $\psi_{meh}$ its components (1):

$$\psi_{sc} = \psi_{mol} + \psi_{meh}$$  \hspace{1cm} (1)

The increase of the molecular component $\psi_{mol}$ is carried out by affecting the physical and chemical state of the wheels and rails surfaces and increasing on this basis the total coefficient of adhesion realized in contact. Various methods of cleaning the interacting surfaces are mostly widespread in this regard are. At present, none of the methods of cleaning that have found application in practice is a solution to the problem of stable implementation of the coefficient of adhesion high values. Now the coupling coefficient increasing system has received absolute distribution by input of sand in contact of a wheel with a rail. Because of the low cost, sand is the main material used to increase friction in the contact of wheel and rail. More than a century of sand application to increase adhesion has been accompanied by a comprehensive study of various aspects of the problem. However, as noted in [6], there is still no single point of view on the friction mechanism in the presence of solid particles (including sand) in the contact zone of the wheel and rail. Under operating conditions, due to the different state of the contact surfaces of the wheels and rails (changes in humidity, temperature, composition of surface contamination, the presence of lubricant, water, snow and ice) there is a spread of friction coefficient values within 0.1–0.6 [7] in the area of friction contact. As operational magnitude of friction depends on the composition of the separating layer between the wheel and the rail greatly, the only means of controlling friction in the separation layer and eliminate the negative effects of pollutants is the introduction of special material with a given magnitude of friction – modifier/activator of friction into the zone of friction contact. One of the main technical problems of effective friction control in the wheel-rail system is the proximity of the lubrication zones, which makes it difficult to apply the modifier and the friction activator for antifriction and friction purposes simultaneously. Therefore, the only effective way to supply the modifier is the contact method and the corresponding type of material. The task of friction control is to maintain the coefficient of friction at a certain level. With regard to the processes in the wheel-rail system, three levels of friction can be distinguished, characterized by the value of the friction coefficient: low (0.2 and less), medium (0.2 – 0.4) and high (0.4 and more) [7]. Friction control is based on the concept that allows to create layers on the corresponding surfaces in contact with the wheel and rail that have the specified friction characteristics by selection of special materials (friction modifiers). The amount of friction depends on the thickness of the layer and the functional characteristics of the friction modifier. The new generation of friction modifiers is usually used in the form of a solid briquette or lubricating rod and is applied with special devices installed on locomotives or mobile vehicles. Unlike thick grease and sand, the modifiers are stored in the same place where they were applied. Due to this method, they can be simultaneously applied to the side face of the rail and to the surface of the rolling wheel and rail [8-10]. Solid materials in the form of rods are convenient for applying directly to the surface of the wheel, from which they are transferred to the rail. The binder is selected so that it burns out at a high temperature in the contact of the wheel and rail, leaving a layer of dry friction modifier on the surface of the micron thickness, filling the cavities of the metal surfaces roughness.

The purpose of the research is to control the friction characteristics in the wheel-rail contact based on the development of technical requirements for solid composite materials – modifiers and friction activators.

Theoretical and experimental investigations of the surface layers modification under the conditions of introduction into the friction contact zone of solid composites filled with active silicate-carbon components processes allowed to prove theoretically the composition of solid composites, as well as
to formulate the modification processes. The first mechanism of active influence on the processes is the formation of silicate films as a result of the surface chemical reaction of silicates with the formation of iron silicates at a ratio of N2O/SiO2 components of at least 0.25.

The second mechanism is the friction modification of friction surfaces when creating conditions for the transition of solid sodium meta-and orthosilicate to the molten state and creating conditions for the formation of strong frictional bonds between the molten silicate and the contact surface of the wheel and rail, as well as the implementation of the process of synthesizing secondary silicon carbide from its fine silicon component and carbon at a ratio of N2O/SiO2 components is not more than 0.2, the presence of carbon in the lubricant is not less than 5%. Characteristic reactions of silicon carbide formation are as follows: SiO2+3C=SiC+2CO (t = 2000-2200°C) or direct synthesis from Si and C (carbon) (t = 1220 to 1410°C) [11]. That is, a prerequisite for the possibility of the formation of SIS is the presence of temperature flashes in the friction contact zone of at least 1300°C. The theoretical background of the mechanism of stabilization and the adhesion coefficient increase of the wheel to the rail with the introduction of a friction composite in the contact zone are based on the molecular mechanical theory of friction, the main thesis of which are developed by I. V. Kragelsky [11]. Based on the concepts of the discrete structure of the contact, I. V. Kragelsky proposed to calculate the friction force by summing the resistances arising from the molecular and mechanical interaction at individual contact sites (2):

\[ F = \tau_{mol} A_r mol + \tau_{mech} A_r mech, \tag{2} \]

where \( \tau_{mol} \), \( \tau_{mech} \) - specific molecular and mechanical interactions or friction forces; 
\( A_r mol \), \( A_r mech \) - the actual area of molecular and mechanical contacts.

Then the coefficient of friction is (3):

\[ f = \frac{\tau_{mol} A_r mol + \tau_{mech} A_r mech}{N} \tag{3} \]

It is assumed that the introduction of a friction destination into the contact zone of a composite, similar to the introduction of a chemically active abrasive material with high adhesive ability and, consequently, a mechanism to increase the adhesion coefficient is based on an increase in the strength of molecular interaction at the contact site. The increase in the molecular component is carried out under the condition that the contact temperatures must be above the melting point of silicate powder (above 1,020 °C), which is the main component of the composite friction destination. In this case, an increase in the adhesion coefficient occurs due to the process of simultaneous transition of the silicate powder to a viscous-plastic state and return to the dry state with the possibility of strong adhesion (due to the adhesive activity of the silicate melt) with the contact surfaces of the wheel and rail. At the same time, the external main controlling factor of “switching on” the mode of modification and stabilization of the friction coefficient is of course the amount of wheel slippage along the rail, due to the increase of which temperature flashes occur in the areas of frictional links. A side mechanism for increasing the friction coefficient is the formation (at surface temperatures above 1200 °C) of silicon carbide in the areas of actual contact of the wheel with the rail. Since silicon carbide is an abrasive material, the mechanism for increasing the adhesion of the wheel to the rail is similar to that of sand and consists in the active mutual introduction of harder particles of abrasive into the surface of the wheel and rail, increasing the mechanical component of the friction force.

The research results allowed to develop requirements for special composite non-metallic materials for the wheel-rail contact. Were formed:

1. Recommendations of friction levels for friction activators / modifiers (figure 1).
2. The main types of tests and their phasing:
   - laboratory/bench check-out tests carried out according to standardized methods in the laboratory and on test equipment to assess their physical, chemical and mechanical characteristics;
   - field/operational tests carried out at test sites and in real operating conditions to assess their characteristics in different operating and climatic conditions, including the establishment of technological regulations for their use and determine the technical and economic efficiency. Tests are carried out according to non-standardized programs and methods.

3. Requirements for physical, chemical and mechanical properties of solid modifiers and friction activators (in table 1).

   **Table 1.** Basic indicators of physical, chemical and mechanical properties of solid modifiers and friction activators.

   | Name of property indicator | Unit of measure | Value indicator | Method tests' |
   |-----------------------------|-----------------|----------------|---------------|
   | Shore Hardness, method D, not less | ed | 60 | GOST 24621 |
   | Ball indentation Hardness, H, for F_m 132 H, not less \( \frac{n}{\text{mm}^2} \) | 40 | GOST 4670 |
   | Determination of temperature of bending under load, not less \( ^\circ \text{C} \) | 200 | GOST 32657 |
   | Evaluation of Flammability | - | no Flammability | GOST 56206 |
   | Flammability Rating | - | does not support burning | GOST 56206 |
   | Determination of Biodegradability. 28-day test. The degree of decomposition of the substrate, not less \( \% \) | 70 | GOST 32427 |

4. Requirements for operating characteristics of the activators and the friction modifier for the lubrication of the contact zone of wheels and rails are established by the results of field and operational tests for specific operational situations, taking into account the specifics of the traffic areas, climatic zones and the initial characteristics of the friction condition of the rails in the table 2).
Table 2. The range of recommended values for the friction coefficient.

| Name of the indicator | Value of the indicator |
|-----------------------|------------------------|
| IHHA                  | Manufacturers          | Authors of the work |
| Range of recommended values of friction coefficient formed by friction modifiers on the surface of rolling rails | 0,15…0,3 | 0,15…0,40 | 0,20…0,35 |
| Range of recommended friction coefficients formed by friction activators in the contact zone of the rolling surface of the locomotive wheel and rail | 0,35…0,6 | 0,40…0,70 | 0,35…0,45 |

The recommendations of the International Association of Heavy Traffic (IHHA) according to the effectiveness of friction control using friction modifiers are given in table 3.

Table 3. Recommendations of the International Association of Heavy Traffic (IHHA) on the effectiveness of friction management using friction modifiers.

| Name of the indicator | Value of the indicator |
|-----------------------|------------------------|
| Reduction of lateral forces on the track | 25…45% |
| Fuel economy on train traction | 10…13% |
| Reduced rail wear | 23…60% |

The paper presents materials that analyze the characteristics and conditions of friction materials applying for special purpose contact «wheel-rail», designed to improve the adhesion of the wheels of the locomotive with the rails, and applied to the surface of the rolling contact zone «wheel-rail» to reduce the resistance to movement, the impact on the track, to increase the life of the wheels of rolling stock and rails.

In the course of work the generalized world and national experience of modifiers and activators application, the analysis of the existing and developed devices intended for drawing activators and modifiers in a contact zone «wheel-rail», and also results of tests were used.

The requirements to the methods of physical and chemical properties testing, to the values of the main indicators of physical, chemical and mechanical properties of friction activators and modifiers are presented. The requirements of the resource and the friction modifier activator and friction coefficients from their application are substantiated. Requirements to values of operational characteristics of activators and modifiers of friction which are established by results of field and operational tests carried out by special programs and techniques are formulated.

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