Study of the friction of the brake shoe of a freight car

Sardor Inagamov*, *Shukhrat* Djabbarov, *Bakhrom* Abdullaev, *Yadgor* Ruzmetov, *Kamoliddin* Inoyatov, and *Yahyo* Hurmatov

Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. This article explores issues related to the friction of the brake pads of a freight car. The coefficients of friction of composite and cast-iron pads of a new type, calculated for a range of different speeds, and the specific braking force during emergency braking are given. A sectional brake block for a freight car and a locomotive has been developed. The advantages of sectional brake pads have been scientifically substantiated. The obtained calculations allow us to recommend them for further study and implementation in operation on the railways.

1 Introduction

The strategy for the development of railway transport provides for the development of heavy and high-speed movement of railway cars [1-12]. The increase in the speed and axle load of the car requires the improvement of the railway track and the design of the rolling stock, in particular the brake systems [13-18].

On the rolling stock of railways, a braking system with the help of brake pads pressed against the rolling surface of the wheel has become widespread [19]. Freight rolling stock of railways around the world is almost completely equipped with such brakes [20-23]. Cast iron pads are most often used on locomotives. However, it is advisable to use composite blocks, which are widely used on freight cars, and recently have been used on locomotives.

The design and mounting methods of cast iron and composite brake pads have remained unchanged for decades. There are some differences in linear dimensions. Pads designed for certain types of rolling stock differ in shape and size.

In the process of braking a train with a friction brake, kinetic energy is converted into thermal energy, and in the contact zone of the brake pad and the rolling surface of the wheel, wear occurs, both of the pad and the wheel. In the process of wear of the friction surfaces, metal chips and defects are formed on the surface of the pads and wheels.

During the operation of composite and cast-iron brake pads on the railways of Uzbekistan, the following defects were found: tearing out and cavities of the pad filler material (35 % of the pads), enveloping of metal from the rolling surface of the wheel onto the working surface of the brake pad (33 %), wedge-shaped wear (tip up, down) of composite pads (found in 11.7 % of pads), wear from sagging of composite pads (they have up to 4.5 % of pads), fracture of the upper (lower) part of the cast iron pad 4 % [24].

*Corresponding author: author@email.org

2 Methods

The main factors affecting the distribution of contact pressures between the wheel and the brake pad are [25]:

- compliance with the geometric shape and dimensions of the wheel and pad;
- possible deformation of the pads due to pressing forces;
- thermal deformations of the pads due to heating during braking;
- pad wear during braking;
- wheel wear.

The coefficient of friction between the wheel and the rail is taken to be 0.25 [26]. The design of the friction element (pad) is of great importance for creating an optimal thermal regime in the friction unit. The distribution of heat fluxes, the heating of the friction pad wheel, depends on the characteristics of the rubbing materials [24].

The geometric parameters of the friction element of the friction pair are determined primarily by the configuration of the counter body, which is the rolling surface of the wheel or the surface of the disc. The shape and size of brake pads and linings play an essential and sometimes decisive role in shaping the basic characteristics of a brake.

The thermal mode of operation of braking devices is considered easy when the bulk temperature of the brake pad and wheel rim is within 100℃, the average temperature of the friction surface is 200 ℃, and the maximum temperature in contact is 250 ℃ [24].

When braking from the maximum speed of full-load cars, the temperature in the bulk of the materials of the friction unit reaches 250 ℃, on the friction surface 400 ℃, and the temperature at the actual contact spots at an average thermal mode of 500 ℃ [25].

Pads made of "Diaphrite K4" material have a constant coefficient of friction up to a temperature of 450°*C*, and with short-term stopping braking - up to a temperature of 800℃ [22].

The design of the brake pad is of great importance in the design of the friction unit of the braking equipment of locomotives and freight cars. Below is the proposed by the author a three-section friction unit of a brake pad for locomotives and freight cars (Figure 1).

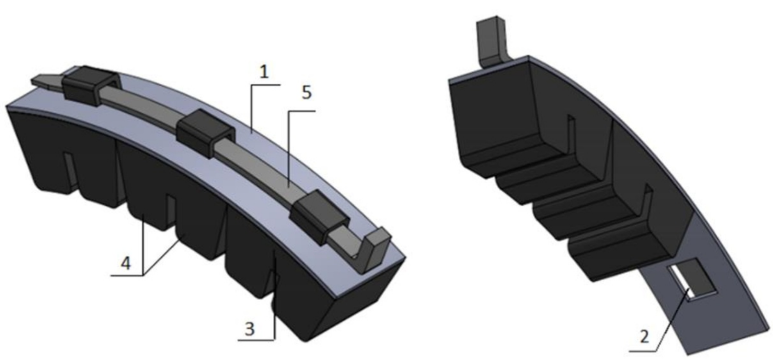

Fig. 1. New brake pad: 1 – metal frame; 2 – holes for fixing blocks; 3 – the base of the block; 4 – block sections; 5 – check.

The pad consists of three blocks that are fixed in the shoe. The length of each block L_{B1} = 130 mm excluding the recess between the block sections, L_{C1} = 120 mm, respectively, the friction area S_{C1} = 0.0096 m^2 for a new block, as it wears out, it reaches S_{B1} = 0.0103 m^2 with a pad thickness of 65 mm, a width of 80 mm. The radius of the friction surface is 530 mm, and the friction area changes depending on the wear and the diameter of the wheel, just like with serial pads. The choice of pad material depends on the operating conditions, since a cast iron brake pad and a composite brake pad have their own advantages and disadvantages. To select the optimal option, we will consider some hybrid (two composite blocks and one cast iron block, two cast iron blocks and one composite block) brake pad options, since it consists of separate independent blocks.

Option 1. The block consists of three blocks, 2 composite, 1 cast iron. The area of composite blocks S_{CB} = 192 mm^2, with wear up to S_{CB} = 206 mm^2, and the area of the cast iron block S_{IB} = 96 mm^2, with wear S_{IB} = 103 mm^2.

Option 2. The block consists of three blocks, 2 cast iron, 1 composite. The area of cast iron blocks is S_{IB} = 192 mm^2, with wear up to S_{IB} = 206 mm^2 and the area of the composite block S_{CB} = 96 mm^2, with wear S_{CB} = 103 mm^2.

Option 3. The block consists of three cast iron blocks. Area S_{IB} = 288 mm^2, with wear up to S_{CB} = 309 mm^2.

Option 4. The block consists of three composite blocks. Area S_{CB} = 288 mm^2, with wear up to S_{CB} = 309 mm^2.

The coefficient of friction shows the relationship between the braking force and the pressing force of the friction element against the counter body. Its value depends on the material of the rubbing bodies, the pressure in contact, the speed of friction, the presence of moisture or grease between them. It is very difficult to quantify the influence of most random factors on the value of the coefficient of friction. It differs with different pressing forces and different braking speeds, the heating temperature of the friction element and the wheel rim in the zone of their contact depends on this. Therefore, the friction coefficient formulas used for brake calculations are empirical. It is known that the coefficient of friction depends on the area of friction, therefore, it is possible to study its dependence on the specific pressing force, which is more objective than the dependence on the pressing force, since the friction area of the pads can be different with wear [24]. When the axial load of the locomotive is 245 kN, sectional composite brake pads are used with one-sided pressing, which have a high coefficient of friction [23]. The coefficient of friction depends on the force of pressing the pads and the speed (formula 1, 2):

- for cast iron pads:

$$\phi_B = 0,5 \cdot \frac{1,6K+100}{5,2K+100} \cdot \frac{v+100}{5v+100}, \tag{1}$$

- for composite pads:

$$\phi_B = 0,44 \cdot \frac{0,1K+20}{0,4K+20} \cdot \frac{v+150}{2v+150}. \tag{2}$$

Imagine the relationship between pressing force and pressure:

$$p = \frac{K}{S_{CB}+S_{IB}} \tag{3}$$

where K – pressing force, kN; p – allowable pressure, kN/m^2; S_{CB}, S_{IB} – area of the composite and cast iron parts of the shoe, respectively, m^2.

Since the dimensions of the pads are determined by the dimensions of the block, formulas 1 and 2 have the following form:

$$\varphi_B = 0.5 \cdot \frac{1.6pS_B + 100}{5.2pS_B + 100} \cdot \frac{v + 100}{5v + 100} \qquad (4)$$

$$\varphi_B = 0.44 \cdot \frac{0.1pS_B + 20}{0.4pS_B + 20} \cdot \frac{v + 150}{2v + 150} \qquad (5)$$

and for the composite and cast iron parts of the pad:

$$K_B = p\, S_{CB}, \quad K_I = p\, S_{IB}. \qquad (6)$$

Pressing force of the brake shoe with variant 1 and variant 2:

$$K = P \cdot (2S_{CB} + S_{IB})$$
$$K = P \cdot (2S_{IB} + S_{CB})$$

Combined shoe parameters:
Option 1:
- area of the composite part $S_C = L_C \cdot b = 0.0192$ m^2, where the working length is $L_C = 2 \times 0.12$ m, the width of the block is m;
- area of the cast-iron part m^2, where m;
- the total area of the friction part of the pads m^2.

Option 2:
- the area of the cast-iron part $S_I = L_I \cdot b = 0.0192$ m^2, where the working length is $L_I = 2 \times 0.12$ m, the width of the block is m;
- area of the composite part $S_C = L_C \cdot b = 0{,}0096$ m^2, where $L_C = 0{,}12$ m;
- the total area of the friction part of the pad $S = S_C + S_I = 0.0288$ m^2.

Option 3:
- the total area of the composite pad m^2, the pad material is composite.

Option 4:
- total area of cast iron shoe $S = 0.0288$ m^2, shoe material cast iron

Brake pad pressing force

$$K_I = 10^2 \cdot p \cdot (S_{C1} + S_{I1} + S_{C2}) \qquad (7)$$

where $S_{C1} + S_{I1} + S_{C2}$ – the area of the blocks of the pad, respectively, $S_{C1} = S_{I1} = S_{C2}$ m^2.

$$K_2 = 10^3 \cdot p \cdot (S_{I1} + S_{C1} + S_{I2}), \qquad (8)$$

where $S_{I1} + S_{C1} + S_{I2}$ – the area of the blocks of the pad, respectively, m^2.

$$K_3 = 10^3 \cdot p \cdot S_I \qquad (9)$$
$$K_4 = 10^3 \cdot p \cdot S_C. \qquad (10)$$

The friction force between the wheel and the block is several times less than the force K of pressing the block on the wheel [22, 23].

Since the block is hybrid and has blocks of both composite material and cast iron material, we assume that the pressing force is distributed over the friction area of all blocks, Figure 2, evenly.

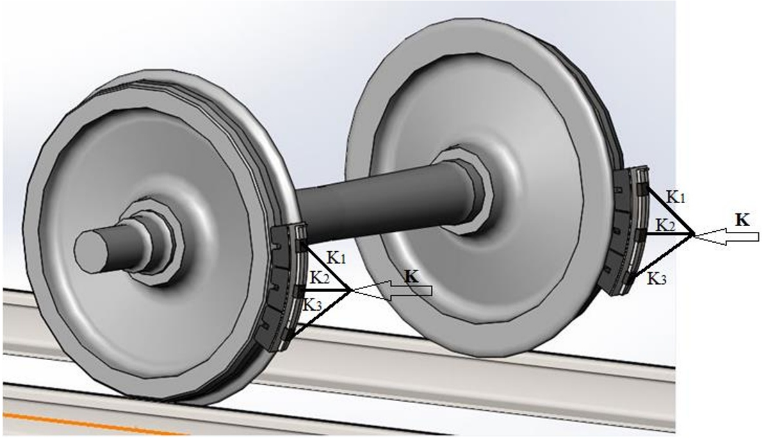

Fig. 2. Distribution of the pressing force *K* on the combined brake pad by blocks

3 Results and Discussion

Proceeding from the fact that the maximum permissible pressure value p = 1.3 MPa on a cast iron pad and p = 0.9 MPa on a composite pad, the pressing force on the combined brake pad (option 1, 2) and the composite brake pad (option 4) is determined according to formulas (7, 8, 10) [24, 25]. When using composite and cast iron material for the block of pads, the maximum allowable pressure is p = 0.9 MPa.

$$K_{PER} = 10^3 \cdot 0.9 \cdot 0.0288 = 25.92 \text{ kN}.$$

Maximum allowable pressure at pressing force kN p = 900 kN / m^2 (0.9 MPa).
Option 1: Coefficient of friction of the composite part *S*

$$\varphi_B = 0.44 \cdot \frac{0.1pS_C+20}{0.4pS_C+20} \cdot \frac{v+150}{2v+150} = 0.44 \cdot \frac{0.1\cdot900\cdot0.0192+20}{0.4\cdot900\cdot0.0192+20} \cdot \varphi_B(v) = 0.355 \cdot \varphi_B(v)$$

Cast iron friction coefficient

$$\varphi_B = 0.5 \cdot \frac{1.6pS_I+100}{5.2pS_I+100} \cdot \frac{v+100}{5v+100} = 0.5 \cdot \frac{1.6\cdot900\cdot0.0096+100}{5.2\cdot900\cdot0.0096+100} \cdot \varphi_B(v) = 0.393 \cdot \varphi_B(v)$$

Option 2: Coefficient of friction of the composite part

$$\varphi_B = 0.44 \cdot \frac{0.1pS_C+20}{0.4pS_C+20} \cdot \frac{v+150}{2v+150} = 0.44 \cdot \frac{0.1\cdot900\cdot0.0096+20}{0.4\cdot900\cdot0.0096+20} \cdot \varphi_B(v) = 0.391 \cdot \varphi_B(v)$$

Cast iron friction coefficient

$$\varphi_B = 0.5 \cdot \frac{1.6pS_I+100}{5.2pS_I+100} \cdot \frac{v+100}{5v+100} = 0.5 \cdot \frac{1.6\cdot900\cdot0.0192+100}{5.2\cdot900\cdot0.0192+100} \cdot \varphi_B(v) = 0.336 \cdot \varphi_B(v)$$

The permissible pressing force on the cast-iron brake pad (option 3) is determined by the formula (9)

$$K_{PER} = 10^3 \cdot 0.0288 \cdot 1.3 = 37.44 \text{ kN}$$

Maximum allowable pressure at pressing force K = 37.44 kN, p = 1300 kN/m^2 (1.3 MPa).
Option 3 (Figure 3-4).

$$\varphi_B = 0.44 \cdot \frac{0.1pS_C+20}{0.4pS_C+20} \cdot \frac{v+150}{2v+150} = 0.44 \cdot \frac{0.1 \cdot 900 \cdot 0.0288+20}{0.4 \cdot 900 \cdot 0.0288+20} \cdot \varphi_B(v) = 0.327 \cdot \varphi_B(v)$$

Option 4

$$\varphi_B = 0.5 \cdot \frac{1.6pS_C+100}{5.2pS_C+100} \cdot \frac{v+100}{5v+100} = 0.5 \cdot \frac{1.6 \cdot 1300 \cdot 0.0288+100}{5.2 \cdot 1300 \cdot 0.0288+100} \cdot \varphi_B(v) = 0.333 \cdot \varphi_B(v)$$

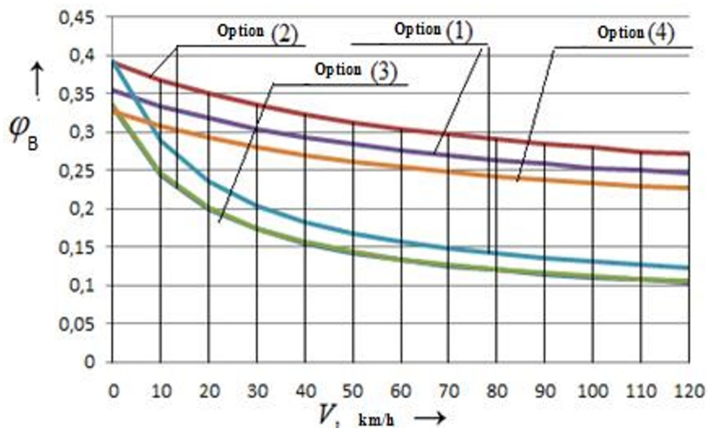

Fig. 3. Dependence of the coefficient of friction on the speed of movement at the maximum permissible pressing forces

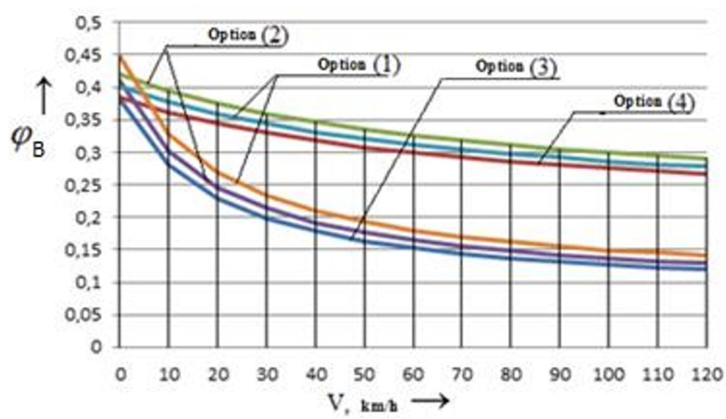

Fig. 4. Dependence of the coefficient of friction on the speed of movement with a pressing force K = 10 kN

Consider the specific braking force b_T, N / t of the proposed pads:

$$b_T = \frac{10^3 n \cdot p \left(S_C \cdot \ \varphi_B(C) + S_I \cdot \ \varphi_B(I) \right)}{q_0} \tag{10}$$

where n is the number of brake pads on the axle, n = 2 pcs; q_0 – axial load, q_0 = 23.5 t/axle; S_{CB} – area of friction of one block of non-running-in pads, m^2; φ_B – coefficient of friction of the brake pad; p – pressure in frictional contact, kN / m^2. (Figure 5).

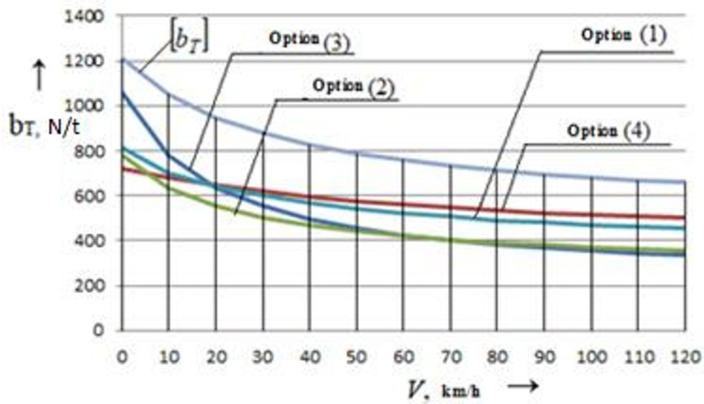

Fig. 5. Specific braking force during emergency braking depending on the speed and pressing force on the block

- specific braking force allowed under adhesion conditions, N/t,

$$b_T \leq [b_T] = 10^3 g \psi_B k_C, \tag{11}$$

where b_T is the realizable specific braking force, N / t; [b_T] - specific braking force per admissible adhesion, N / t; g – acceleration due to gravity, g = 9.81 m / s^2; k_C – coefficient of use of the adhesion margin – power reserve during emergency braking, for freight cars 0.85.

To assess the power reserve of operated and prospective brakes, a dimensionless criterion can be used - the coefficient of instantaneous use of the adhesion margin kc (v) during emergency braking. Taking into account the actual forces of pressing the brake pads, the coefficient has the form (formula 12) [1]: (Figure 6).

$$k_C(v) = \frac{b_T(v)}{[b_T(v)]} = \frac{mK\varphi_B(C,v)}{g q_0 \psi_B(q_0,v)} \tag{12}$$

https://doi.org/10.1051/e3sconf/202340105036

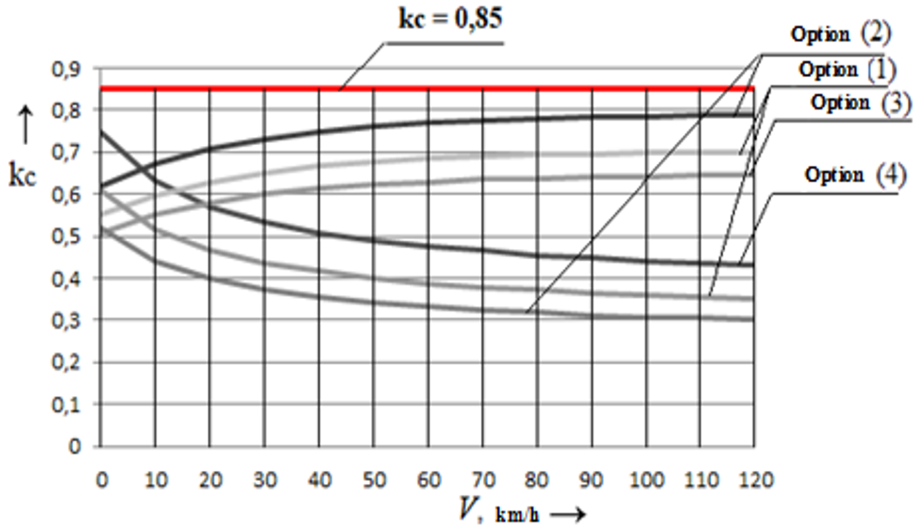

Fig. 6. Coefficient of use of the adhesion margin

4 Conclusions

Therefore, various options for a combined composite-cast-iron brake pad for rolling stock have been proposed. The braking force has been calculated for each version with maximum and lower pressing force at an allowable pressure of up to 0.9 MPa.

The use of a cast-iron insert, of the same area as the composite insert, makes it possible to lighten the thermal load of the friction unit during a prolonged braking process.

The proposed design can be used primarily on locomotives and freight cars operating on mountainous areas of railways.

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