DEVELOPMENTS IN MECHANICAL ENGINEERING
ISSN: 2720-0639 DOI: 10.37660/dme.2022.18.10.1 **18(10)2022**

Friction brakes in railway vehicles – the phenomenon of friction pairs contact

Mikołaj Szyca

Bydgoszcz University of Science and Technology, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland; e-mail: mikolaj.szyca@pbs.edu.pl

Summary: Rail vehicle brakes have evolved in recent years by applying the first results of research on new friction materials that replace cast iron. The article discusses the phenomena occurring in the friction pairs of rail vehicle brakes in relation to the current issues related to the implementation of composite materials for commercial applications. The article aims to analyze the key aspects of the use of friction brakes in railways and begins research in this field.

Key words: railway, friction pair, friction brake, composite materials

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Hamulce cierne pojazdów szynowych – zjawiska kontaktu par ciernych

Mikołaj Szyca

Politechnika Bydgoska im. Jana i Jędrzeja Śniadeckich, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Polska; e-mail: mikolaj.szyca@pbs.edu.pl

Streszczenie: Pierwsze rezultaty badań nad nowymi materiałami ciernymi zastępującymi żeliwo spowodowały w ciągu ostatnich lat zmiany hamulców pojazdów szynowych. W artykule omówiono zjawiska występujące w parach ciernych hamulców pojazdów szynowych w odniesieniu do bieżących zagadnień dotyczących wdrażania materiałów kompozytowych do zastosowań komercyjnych. Przeanalizowano kluczowe aspekty w zakresie eksploatacji hamulców ciernych w kolejnictwie, co stanowi wstęp do badań w tym zakresie.

Słowa kluczowe: kolejnictwo, para cierna, hamulec cierny, materiały kompozytowe

1. Introduction

Research on friction pairs in rail vehicles has been going on since the middle of the 19th century, when primitive efforts were made to find the causes of damages in correlation to measurable parameters. Research conducted on the railway components were introduced and developed in many departments of mechanics, which resulted from the large number of possible cases to study, as well as the high amount of energy transmitted by locomotives. One of the key issues for engineers has become a controlled enforcement deceleration by trainsets. Massive trains had to limit their movement resistance in order to reduce the amount of fossil material needed to overcome the force resulting from friction of the cooperating elements. Obtaining optimally low friction coefficients and reducing the pressures in the friction pairs, consequently, leads to the need to introduce an additional friction element, which would make it possible to control deceleration. The braking process is implemented practically from the beginning of the railway using a friction pair of a railway wheel – a brake shoe (block brake). It is natural that both inorganic and organic materials were tested, but only organic ones were put into common use [6, 38].

In the 19th and 20th centuries, the main material used for brake shoes was cast iron, while since the 1990s, new organic composite materials for brake shoes and friction linings for disc brakes have been intensively developed in the world. Currently, the most common constituent materials of composite friction materials in rail vehicle brakes are thermosetting organic resins, rubbers, friction modifiers and various types of fibers to strengthen the structure [25]. Sintered metals are also used for friction linings and brake shoes [31, 35].

The approval for use of the material for brake shoes / friction linings with obtain a traffic approval lasts about 5 years, while for the brake shoes it will be necessary to meet standards such as UIC 541-4 (bench tests, operational tests) [28], UIC 544-1 (operational tests) [27], UIC 541-00 (in-service tests) [26], TSI 4.2.4.3.3. (heat effect) [5].

Compliance with all standards by materials placed on the market is necessary, but at the same time it excludes most samples of prototype materials at the early stages of development, although it happens that materials are rejected at an advanced stage of testing on dynamometric stands, while they do not fulfill the admittance conditions in the most extreme trials [6].

This article describes the contact phenomena occurring in block and disc brakes of rail vehicles. The tribological and non-tribological phenomena occurring in the relation of non-cast iron friction materials to the interacting wheels / discs are described. The publication is intended for recipients interested in the subject of tribology and railways, in particular the development of braking technology in rail vehicles.

2. Tribological phenomena

For 50 years, the concept of Godet, called the third body that allows the analysis of physical and physicochemical phenomena in contact mechanics. The concept assumes the functioning of the third body in the contact of the shoe / lining with the wheel / disc. The rheology and flow of the third active body during contact are closely related to the materials with which the elements of the friction pair are made. Therefore, the study of these physical phenomena requires taking into account all three elements of the tribological triple (elements of the friction pair, the third body and the mechanism) [6].

The analyzes of the wheel-rail friction pairs showed that an additional microscopic white etching layer (WEL) is formed on the interacting surfaces [4, 14, 17, 29, 33, 36, 37]. The formation of the WEL layer is associated with the occurrence of rolling contact fatigue (RCF), and more generally – Tribological Transformation of Surface (TTS). WEL may be the cause of the spalling phenomenon on the surface of railway wheel rims. The modification of the microstructure related to the WEL consists in the combination of the phase transformation and the grinding of grains with grain sizes from tens to hundreds of nanometers [7, 24, 32, 33, 36]. WELs consist of ferrites, martensite and the coexistence of various phases of highly deformed perlite, nanofarticular martensite, austenite and carbides for various initial microstructures and loading conditions, they are characterized by high hardness (400 HV–1200 HV) [4, 24, 33]. According to Hosseini et al. [10] mechanisms of WEL formation are either thermally induced by phase transitions (T-WL) or mechanically induced by severe plastic strain (M-WL). WEL undeniably occurs in the wheel-rail friction pair, but it is not unequivocally stated that this also applies to the disc-lining pair, which opens up new possibilities for analyzing this phenomenon and its consequences.

The WEL phenomenon created functions on the border of tribological and non-tribological mechanisms, because the formation of the layer may be associated with thermal processes, but in the conditions of wheel-rail cooperation, due to the presence of anti-skid systems, it rarely takes place [2, 4, 11, 15, 24]. In Fig. 1 the micrograph of WEL is shown.

The rotation of the wheel during driving may be blocked and thus temporarily make a linear friction in relation to the rail, rather than a rotary friction. This phenomenon can lead to a wheel flat. Wheel flat causes RCF discontinuity, which generates noise and heating of the wheel, but it can also damage the brake shoe [4]. Wheel flat is a phenomenon commonly occurring in the operation of rail vehicles, but each time it may constitute a safety hazard [4, 12, 18]. The formation of wheel flat is related to the braking force exceeds adhesive force in the wheel / rail interface. Thus, flattening will occur when the friction coefficient is decreased (adhesion reduction), e.g. in winter conditions or rainfall [4, 34]. Fig. 2 shows the surface and section sampling position in the wheel flat zone.

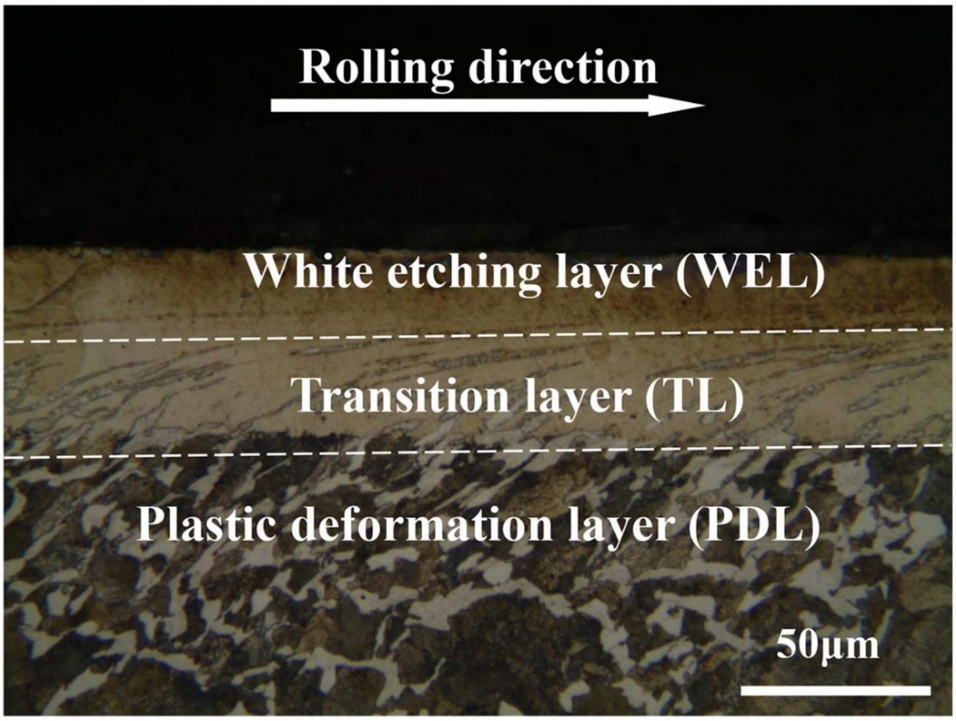

Fig. 1. Micrograph of WEL [4]

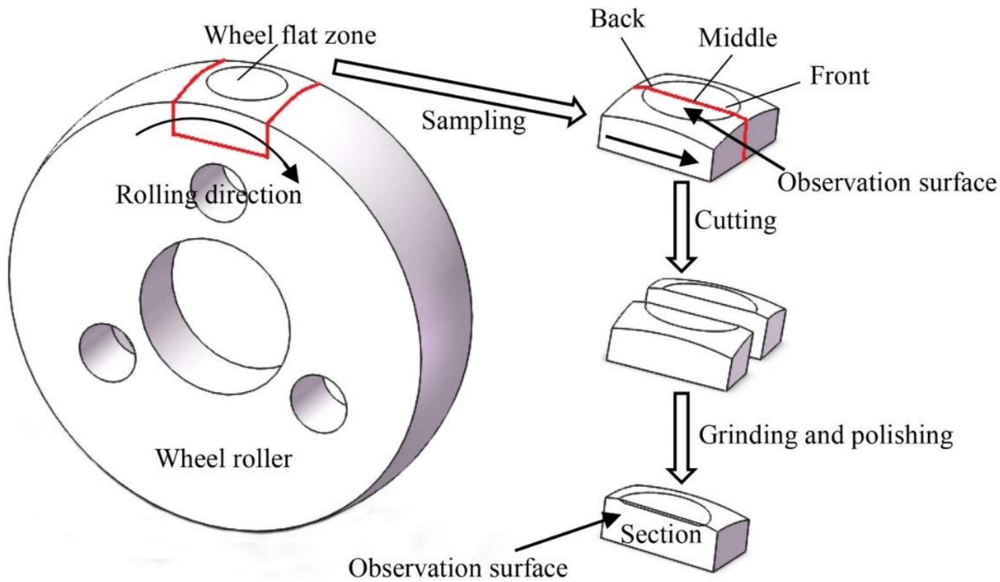

Fig. 2. Surface and section sampling position in the wheel flat zone [4]

3. Non-tribological phenomena

Non-tribological phenomena occurring in pairs of friction brakes of rail vehicles constitute a widely discussed problem in scientific research [1, 9, 16, 19–23, 30, 33, 35, 37, 39, 40]. Particular attention in most of the works is paid to thermal influences such as hot spots, overheating or radial cracks [33]. Compared to disc brakes, which work at up to three times higher rotational speeds; block brakes do not have to exhibit such high resistance to thermal influences [33, 38].

Initial and control tests of friction materials should be performed in accordance with the EN 16452: 2015 + A1: 2019 [8] standard and the UIC 541-3 [3] sheet. As stated in the above-mentioned standard, shoes made of both organic and sintered materials during preliminary tests determining the applicability of a given material should be subjected to chemical composition analysis. In the case of sintered materials, the analysis also covers the macrographic structure and high temperature stability, which is the result of balancing the energy in the friction pair lining / shoes – disc / wheel. The standard also states that each individual series should be subjected to quality tests in terms of hardness, friction coefficient and material density. It should be noted that the friction coefficient in the preliminary tests should be determined with greater accuracy than in the control tests. The correct definition of the friction coefficient is necessary for the subsequent perception of the properties of the temperature field for the analysis of the thermal effects in the friction pair during braking [16, 22]. Initial tests of the friction coefficient and the influence of temperature are performed on specially designed dynamometric stands [9, 19, 35].

Previous research show that the distribution of high temperature zones caused by thermal shock is uneven on the friction surface during the heating and cooling stages during braking [38]. Calculation of the temperature of the brake friction elements is the subject of many scientific studies [16, 23, 30], but in most cases – the influence of the friction coefficient is simplified to a constant value during braking, which in the friction pairs cannot take place due to the presence of slips between the elements that change depending on the speed, and moreover, the temperature itself will also have an influence on the friction coefficient [23, 35]. Fig. 3 shows the temperature distribution in brake disc during 300 km·h^{-1} emergency braking.

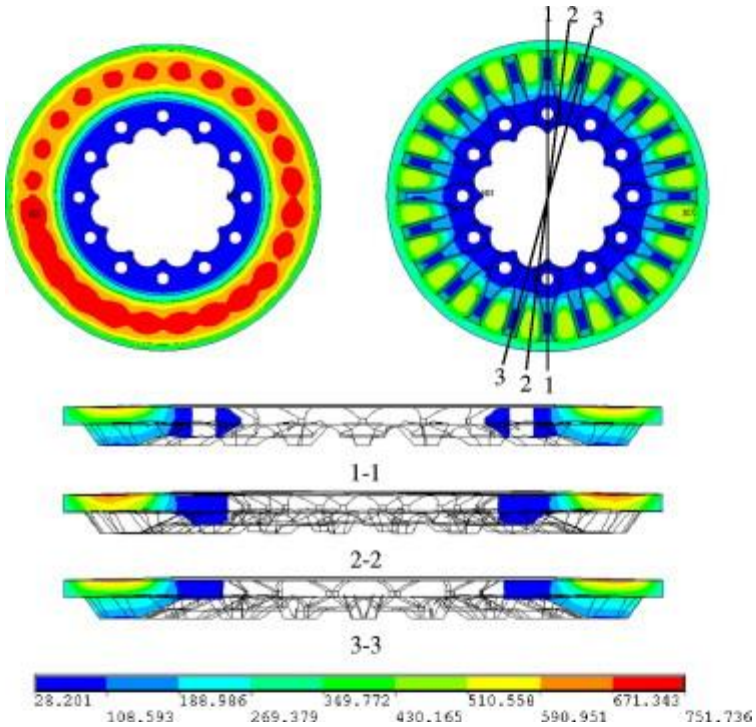

Fig. 3. Temperature distribution in brake disc during 300 km·h^{-1} emergency braking [38]

Stabilization of the braking force is currently based on the feedback in automatic systems regulating the pressure pressing the brake block [21], which allows not only to regulate the intensity of braking, but also to extend the service life of the brake blocks. Yevtushenko et al. [39, 40] proposed the use of a graph of five experimental curves that are to present the dependence of the friction coefficient on temperature and the temperature gradient. Belhocine and Bouchetara [1] showed that thermal gradients depend on the heat dissipated by friction and the heat convection coefficient. In [30], the influence of structural changes and process intensity on changes in the friction coefficient was negated. Sawczuk et al. [21] indicate, however, that any changes in the geometrical structure of the brake-disc friction pair may lead to braking deceleration. However, changes in geometric structures are inevitable when the temperature of the brake disc during braking can reach up to 600°C. A drastic increase in the temperature of the friction pair causes a large amount of energy to dissipate on the friction surfaces and a phenomenon known as "hot spots" can develop. These contact areas are characterized by high stresses resulting from strong thermal gradients, which often leads to the formation of fatigue-thermal cracks, plastic deformations and tribological surface transformations [1, 13, 20, 23, 33].

Thermal cracking, which is one of the most harmful to the friction pair, is a consequence of high temperatures generated during braking; occurs after a certain number of cycles and leads to uneven wear of the areas of the friction material and the mating material. Thermal cracks tend to appear mainly in the areas limiting hot spots, which tend to reduce the area of influence during crack formation [38].

4. Conclusions

The paper presents articles devoted to operational tests of friction brakes on rail vehicles. The articles discussed raised issues such as:

- the formation of a white etching layer on the surfaces cooperating in the brakes of rail vehicles increases the hardness, but at the same time significantly increases the brittleness of the surface;
- the white etching layer is a layer that can be described as consistent with Godet's hypothesis about the third body;
- in general terms, the main issues related to the operation of brake shoes and friction linings of rail vehicles can be divided into contact mechanics and thermodynamics;
- tribology and thermal phenomena are closely related to each other in the operation of rail vehicles and the violation of the structure of the friction pair in a short time affects both tribological and non-tribological phenomena, and consequently leads to accelerated wear of the cooperating elements.

The production of modern friction materials for the friction brakes of rail vehicles requires taking into account many operational aspects in terms of material, geometry and dynamics. The white etching layer is not a new issue in the field of operational research of rail vehicles, but in the last decade it has gained special attention in the world of science, which may be related to the increased pressure on the part of public transport organizers to reduce the noise caused by rail vehicles, which consequently requires thorough research friction pairs in terms of the possibility of limiting the emission of undesirable noise.

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