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Composite brake blocks in railway freight wagons: operational problems

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The aim of this article is to present operational issues associated with the use of composite brake blocks in freight wagons, a solution intended to reduce railway noise. The primary finding of the analysis indicates that while composite blocks reduce noise and friction pair wear, they may lead to an increased braking distance at low speeds and higher thermal loading of the wheels. The article discusses the types of composite brake blocks, technical challenges (such as tread wear and reduced braking efficiency in winter conditions), interoperability issues, certification, modernisation costs, and hazardous incidents observed in Europe. The key conclusion drawn from this study is that the implementation of composite brake blocks requires careful consideration of specific operational conditions and potential risks.

1. Introduction

Rail transport is one of the most environmentally friendly modes of transportation; however, noise emissions remain a significant issue. Railway noise adversely affects the environment and the quality of life of residents living in proximity to railway tracks. Consequently, various measures have been undertaken to mitigate this problem, including infrastructure modernisation, the implementation of advanced noise suppression technologies, and the introduction of quieter rail vehicles.

One of the key solutions in combating railway noise is the use of composite brake blocks in freight wagons. These components significantly reduce the noise generated by wheel-rail friction, thereby improving acoustic comfort in urbanised areas. The adoption of such technologies represents a crucial step towards sustainable and environmentally friendly rail transport.

As early as the previous century, in an effort to reduce the environmental impact of brake blocks, the International Union of Railways (UIC) commissioned the European Rail Research Institute (ERRI) to develop technical guidelines for the use of plastic-based brake blockts within the UIC framework. Subsequent research demonstrated that composite brake blocks result in lower wheel polygonisation during operation, leading to a substantial reduction in noise emissions from vehicles equipped with them [11]. This finding served as a catalyst for the widespread implementation of composite brake blocks in railway operations.

The General Assembly of the Community of European Railways (CER) commissioned, in 1997 in Berlin, at the initiative of SBB and DB, the necessary work aimed at eliminating and replacing the cast iron brake blocks previously used in railway transport with composite blocks [1]. In 1998, UIC, CER and UIP launched an action plan to reduce noise from freight wagons by replacing cast iron brake blocks with composite blocks. However, this plan was abandoned due to high costs [15].

Nevertheless, research and development efforts continued in parallel, leading to the establishment of new requirements for composite materials and the development of several materials that reached full maturity for application [21]. This progress enabled the topic to be revisited a few years later, particularly between 2016 and 2019, within the framework of updating the Technical Specifications for Interopera-

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bility of the "Rolling Stock – Noise" subsystem (TSI Noise) [5]. In order to facilitate operations on the so-called "quieter routes" designated within European countries, railway operators have been introducing an increasing number of wagons equipped with composite brake blocks into service (Fig. 1). The share of such wagons in Poland amounted to 33.0% in 2023 [29]. However, composite brake blocks exhibit different operational characteristics compared to cast iron blocks, leading to certain challenges.

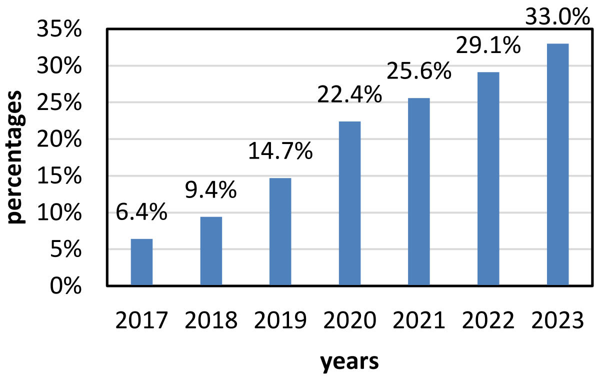

Fig. 1. Percentage of freight wagons equipped with composite brake blocks in Poland during the years 2017-2023 [28, 29]

2. Characteristics of composite brake blocks

A block brake is a mechanism in which the force generated during braking in the brake cylinder (or induced by the activation of the parking brake or hand brake) is transmitted – typically via the brake rigging – to the brake blocks, which are pressed against the rolling surfaces of the wheels (Fig. 2). The friction element of the block brake is a replaceable brake block, which may be made of cast iron or composite material [7].

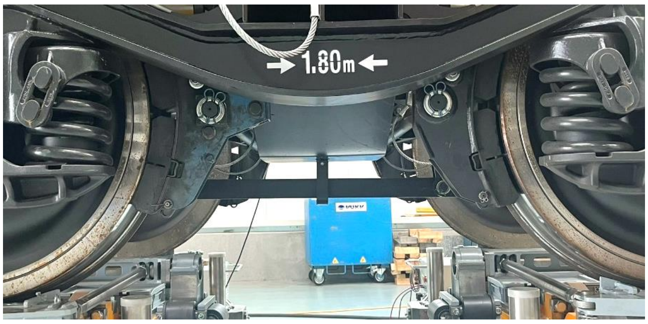

Fig. 2. Freight wagon with a block brake on a test bench

There are three primary types of composite brake blocks:

1. K-type blocks (high-friction): These blocks exhibit a higher coefficient of friction of 0.25, necessitating modifications to the wagon's braking system. They are primarily used in newly manufactured or modernised freight wagons [2, 4]. The shape and dimensions of K-type blocks comply with UIC Leaflet 541-4, and their securing mechanism – two chamfered cones on the contact surface with the brake shoe holder – prevents their installation in wagons designed for other types of blocks [17].
2. L-type blocks (medium-friction): These blocks have a moderate coefficient of friction of approximately 0.12. Their frictional characteristics, particularly in relation to axle loads and speed, are more stable compared to cast iron blocks. For this reason, they are predominantly used in passenger rolling stock and cannot be directly applied in freight wagons originally equipped with cast iron blocks without modifications to the braking system [21].
3. LL-type blocks (low-friction): These brake blocks are characterised by a low coefficient of friction, comparable to that of cast iron blocks, at approximately 0.10. These blocks offer a cost-effective alternative and are used in freight wagons as direct replacements for cast iron blocks [2].

Laboratory tests and controlled operational runs conducted in the early 21st century revealed the characteristic features of composite brake blocks [1, 2, 19]. Compared to cast iron blocks, composite blocks exhibit lower friction pair wear and a reduction in noise levels; however, they also contribute to an increase in wheel rim temperature during braking.

The friction materials used in railway brake blocks can be either organic or sintered [11]. These materials form complex structures containing between 20 and 25 different metallic and organic components. The general physical properties of brake blocks are directly dependent on the proportion and type of individual components in the final composition [26]. Unlike traditional cast iron blocks, each manufacturer of composite brake blocks employs a unique formulation, resulting in significant differences between individual products. These formulations typically include synthetic resins, elastomers, powdered friction modifiers, fillers, as well as metallic and mineral fibres [1, 18]. This diversity poses additional challenges, particularly when replacing one type of brake block with another, as each variant must be treated as a distinct product with specific properties.

Brake blocks made from composite materials are significantly lighter compared to cast iron brake blocks. A typical cast iron block weighs approximately 13 kg, whereas a composite block typically weighs between 4 and 8 kg [6]. As a result, K-type and LL-type brake blocks are easier to transport and install [1].

Research indicates that the use of composite brake blocks may lead to increased wheel wear compared to cast iron blocks. However, at the same time, composite blocks themselves exhibit lower wear under similar operating conditions [15]. The exact values are presented in Table 1. Wear rates are highly dependent on wagon load conditions and vary according to mileage and wagon type [13].

Table 1. A comparison of block and wheel wear when using composite blocks in relation to cast iron blocks (CI) [3, 13]

Wheel wear rate, expressed in the change of the flange height (ΔSh)						
type of blocks	CI empty	CI loaded	C952-1 empty	C952-1 loaded	IB116* empty	IB116* loaded
in mm per 100,000 km	0.7	0.9	0.8	2.2	0.8	1.8
in % to CI	100%	100%	109%	237%	109%	194%
Block wear						
type of blocks	CI empty	CI loaded	C952-1 empty	C952-1 loaded	IB116* empty	IB116* loaded
in mm per 100,000 km	21	80	13	41	8	17
in % to CI	100%	100%	38%	21%	61%	51%

In terms of particulate matter emissions, cast iron brake blocks emit the highest quantities of PM10, ranging from 2.65 to 28.66 g/km of braking per axle. The particles emitted by cast iron blocks are also generally larger than those produced by composite brake blocks. Composite blocks of types K and LL generate lower levels of PM10, typically within the range of 0.4 to 25.72 g/km. Higher emission values are observed with increasing initial speed, braking force, and braked mass. Among the emitted particles, elements such as iron and manganese are consistently present, whereas barium and zinc are found only in type K blocks [9].

The application of composite brake blocks, particularly of type K, in freight wagons gives rise to specific technical issues. The most significant of these include the increased thermal load on wheels resulting from braking with such blocks, the susceptibility of composite blocks to thermal cracking, as well as the previously mentioned heightened wear of the wheel tread surfaces [30]. Composite brake blocks contribute more significantly to the increase in wheel temperature during vehicle braking, as they dissipate only around 5% of the generated heat, whereas cast iron brake blocks dissipate approximately 30–40% [12]. Figure 3 presents a thermographic image illustrating the temperature distribution on the brake block and wheel. The authors' study, simulating constant-power braking (representative of a train traversing the Saint Gotthard Pass), was conducted using a certified railway brake test rig. Both phenomena contribute to a greater occurrence of tread surface damage in wheelsets, necessitating more frequent re-profiling. Furthermore, composite brake blocks are susceptible to thermal cracking [23].

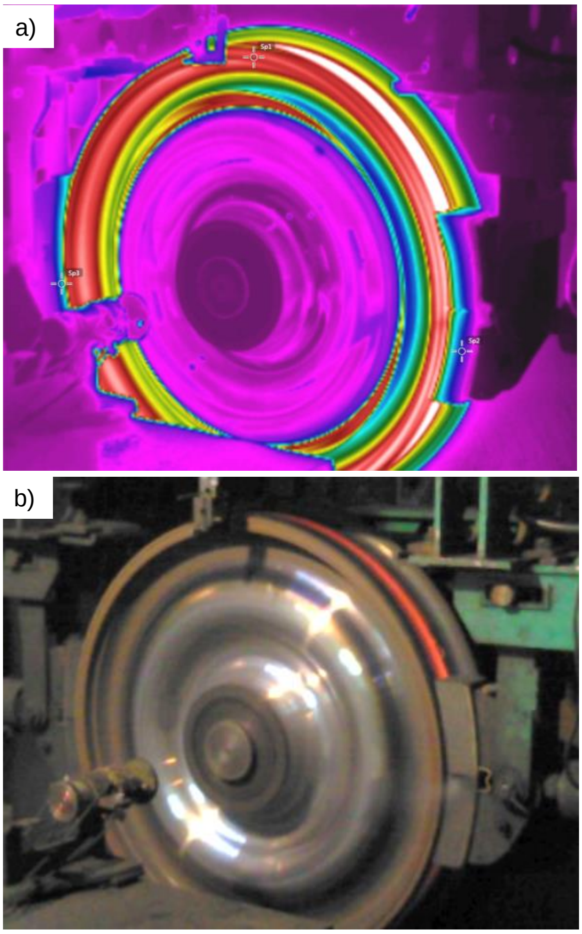

Fig. 3. View: (a) from a thermal imaging camera, (b) from a digital camera, showing wheel braking with a composite insert during simulated constant-power braking

The primary factor driving the implementation of composite brake blocks is their impact on train noise emissions. Rolling noise in railway systems is generated by irregularities on the surfaces of wheels and rails. The use of smooth wheels and rails facilitates noise reduction. Replacing cast iron brake blocks with composite ones results in the smoothing of the wheel tread surfaces, which directly contributes to a reduction in the noise emitted by the train [2, 20]. This type of brake block not only eliminates the unpleasant "squealing" noise during braking but also significantly reduces overall noise levels, thereby enhancing comfort for both passengers and individuals in the vicinity of the train [27]. At a speed of 100 km/h, this reduction may amount to approximately 10–15 dB in comparison with conventional cast iron brake blocks. This is the preferred method for achieving significant noise mitigation. However, the reduction in train noise becomes noticeable only if at least 75–80% of the wagons in a trainset are equipped with composite brake blocks [4].

A crucial aspect of brake blocks is their impact on a trainset's braking performance. In this context, the key advantages of using composite brake blocks instead of conventional cast iron blocks include a noticeable improvement in braking capacity (particularly at high speeds and in the fast-acting P mode of the UIC braking system), significantly greater efficiency on steep gradients resulting in shorter braking distances, and the possibility of using smaller brake cylinders, which directly leads to reduced compressed air consumption across the entire system.

However, as a potential drawback, numerical simulation results indicate that at low braking speeds, below 40–30 km/h, braking performance is reduced compared to cast iron brake blocks [6]. Figure 4 illustrates the relationship between stopping distance and initial speed for wagons equipped with cast iron and composite brake blocks, under braking conditions on both level track and track with a gradient of 30 mm/m.

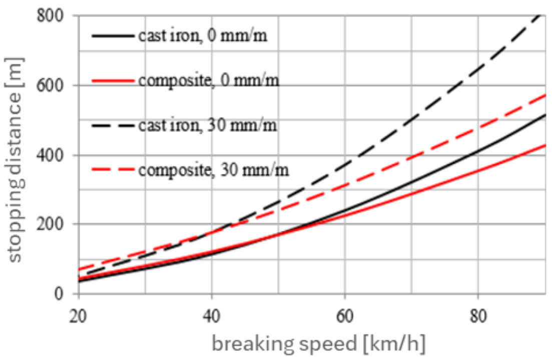

Fig. 4. Stopping distance dependency on braking speed for G mode action [6]

The braking distance may be up to twice as long as that of cast iron blockts (Fig. 5) [27]. In operational use, when travelling at low speeds, it is recommended to apply braking earlier and more forcefully than would typically be required with conventional cast iron railway brakes [6].

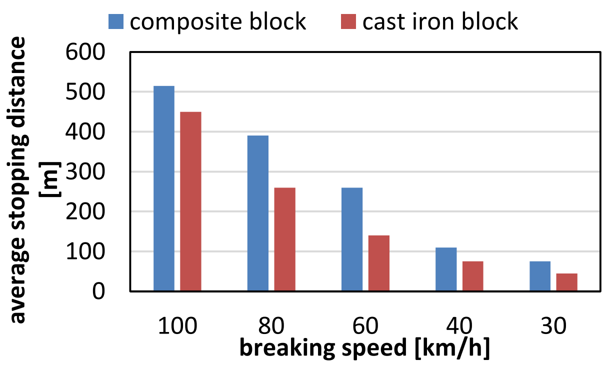

Fig. 5. Comparison of stopping distances with composite and cast iron blocks at different speeds [27]

Cast iron exhibits superior braking efficiency compared to composite brake blocks in winter conditions. Ice accumulates more readily on composite brake blocks than on cast iron, leading to a significant difference in ice thickness [35]. Studies have shown that the nature of composite block materials (organic or sintered) influences the extent to which the friction coefficient may vary under icy conditions. Notably, sintered composite materials exhibit a higher friction coefficient than cast iron, particularly C333, although with significant variability. The sintered LL-type material, C952, demonstrated considerably different wear behaviour compared to cast iron [15].

An additional challenge associated with the use of composite brake blocks is the reduction in wheel–rail adhesion as the roughness of the wheel tread surface decreases. It has been observed that this effect is more pronounced in the case of LL-type blocks made from organic materials than in K-type blocks. This phenomenon is attributed to the lubricating effect of certain material components, which reduce the friction coefficient to the required level [21].

Furthermore, during operational observations of composite brake blocks, a subtle yet distinct odour was detected during intensive braking. This phenomenon is characteristic of composite friction materials [2].

3. Placing into service of wagons with composite brake blocks

Between December 2010 and the end of September 2012, the EuropeTrain – a train composed of various types of freight wagons carrying different types of cargo ordered by multiple railway operators – travelled across Sweden, Germany, France, Poland, Switzerland, Italy, Austria, Slovakia, Hungary, and Luxembourg, equipped with LL brake blocks (Fig. 6) [34]. The objective of this initiative was to provide essential data and practical insights required for assessing braking performance, the wear of both brake blocks and wheelsets, operational safety implications, and the impact on railway infrastructure. The EuropeTrain project aimed to test the brake blocks under real-world operating conditions across diverse railway lines and to investigate their performance under varying climatic and topographical conditions. This was intended to support the commencement of series production for the retrofitting of the existing European freight wagon fleet [8].

The introduction of a new composite brake block material to the market, along with obtaining the necessary certifications and approvals, takes approximately five years and requires the completion of the following tests and trials: bench tests (according to UIC 541-4), operational tests (according to UIC 544-

1), thermal load resistance tests (in accordance with TSI 4.2.4.3.3 requirements), winter trials on track (according to UIC 541-4), and in-service trials (according to UIC 541-4 and UIC 541-00) [31]. One of the key aspects during the approval process for LL blocks is the assessment of their impact on equivalent conicity. This is a calculated value used to evaluate how vehicles interact with the track. However, as this requires complex measurements and calculations, UIC has developed an alternative method [33].

Fig. 6. Route of the Europe Train Project [34]

The list of composite brake blocks approved at the EU level is included in Annex G of the TSI Freight Wagons. However, this annex is gradually being phased out, as the "wheel tread brake friction element" is defined as an interoperability constituent under both TSI Noise and TSI Freight Wagons. Consequently, the conformity assessment of composite brake blocks is now the responsibility of notified bodies. Some historical brake blocks are also listed in Annex G of TSI Noise. If the conformity assessment is successful, the notified body issues certificates of conformity or suitability for use to the manufacturer, who then issues an EC declaration of conformity or suitability for use. These certificates and declarations can be found in ERADIS. Additionally, UIC publishes a list of approved composite brake blocks on its website. However, this list may only be used within the framework of EU legislation to confirm compliance with point 14 of Annex C to the TSI Freight Wagons, bearing in mind that Annex C of the TSI Freight Wagons is voluntary in nature.

Another important aspect is cost. The purchase of new wagons equipped with K or LL blocks instead of cast iron blocks does not increase the total cost of the vehicle. However, the modernisation of existing wagons to accommodate K blocks generates additional costs ranging from €4,000 to €10,000 per vehicle, depending on the number of axles and the type of wagon [20]. In contrast, modernisation using LL blocks is significantly cheaper and may even be cost-neutral. Although LL brake blocks are currently about four times more expensive than cast iron blocks, the cost of adapting wagons for LL blocks is estimated at approximately €2,000 per four-axle wagon. This estimate includes material costs, labour costs, and additional expenses for the workshop to replace 32 cast iron blocks with 32 composite LL blocks, as well as flat-rate transport costs to and from the workshop and downtime costs when the wagon is out of service [33]. It should be noted that the approval process entails substantial costs for each wagon type. Consequently, wagon classes consisting of only a few vehicles are not the primary focus of modernisation efforts. The most cost-effective approach is to carry out modernisation during the mandatory freight wagon inspection, which must be conducted at least every six years. Across Europe, approximately 600,000 wagons require modernisation [20].

From an interoperability perspective, it is worth noting that in 2009, UIC published a catalogue of damages related to composite brake blocks [32]. Additionally, an annex addressing when composite blocks should and should not be replaced was incorporated into both the General Contract of Use for Freight Wagons (GCU) and the technical inspection conditions for UIC transition wagons (2006) [10]. A further complication is the lack of interchangeability among UIC-approved friction materials used for brake blocks. In practice, this prevents the optimisation of wheelset maintenance by selecting brake block materials with lower thermal aggressiveness. This limitation negatively impacts maintenance costs by reducing the service life of wheels and significantly disrupting the established freight wagon maintenance system [30]. Nevertheless, a key advantage is that newly manufactured freight wagons compliant with all TSI requirements can be operated throughout the entire EU based on an authorisation issued in the first EU member state. This provision significantly enhances the interoperability of freight transport operations [29].

4. Hazardous incidents during the operation of wagons with composite brake blocks

During dynamic tests and observed operation of electric multiple units (EMUs) equipped with FR502 brake blocks, an increase in braking distance was noted for speeds below 80 km/h compared to P10 cast iron blocks. This effect results from the difference in the variation of the average friction coefficient as a function of the initial braking speed for both materials. The FR502 material, like most composite materials, is characterised by a quasi-constant friction coefficient [1].

Following a railway accident on 19 December 2005 on the Jeleśnia–Żywiec Sporys railway line (Poland), the Accident Investigation Commission conducted an initial assessment based, among other sources, on a control test report from 28 December 2005 involving a train composed of EMUs. The findings indicated that LL-type FR502 composite brake blocks used on railway vehicles posed a risk to railway traffic safety and the safe operation of rolling stock. As a result, the President of the Office of Rail Transport (UTK), pursuant to §10 of the Regulation of the Minister of Infrastructure dated 30 April 2004, issued Decision No. 2/TSI/2006 on 31 January 2006, revoking the operational approval of FR-type LL composite brake blocks [19].

On 27 May 2016, near the city of Breda (Netherlands), a brake blockage in one of the LPG wagons led to an excessive rise in the temperature of the wheels and brake blocks. The heat reached such a high level that all brake blocks in the affected wagon burned out, and the wheel tread deformed, creating a risk of derailment. The wagon was equipped with LL-type composite brake blocks. Unlike cast iron blocks, composite brake blocks do not conduct heat, meaning that all the heat must be absorbed by the wheel [14].

In Swedish railway operations, incidents have been observed in which trains equipped with composite brake blocks experienced a significant and sudden loss of braking efficiency under winter conditions. A 2017 incident report by the Swedish Transport Agency highlighted the reduction in braking performance (extended braking distances) of trains using composite brake blocks when operating at temperatures below 0°C. Furthermore, it was noted that ice formed on composite brake blocks, whereas this phenomenon was not observed with cast iron brake blocks (Fig. 7). A case study on trains operating within the Swedish railway system further emphasised that braking performance loss was more pronounced in empty or lightly loaded trains, due to lower braking force. This issue was particularly severe at temperatures below –15°C and in snowy conditions, and was observed both immediately after train start-up and during operation [22].

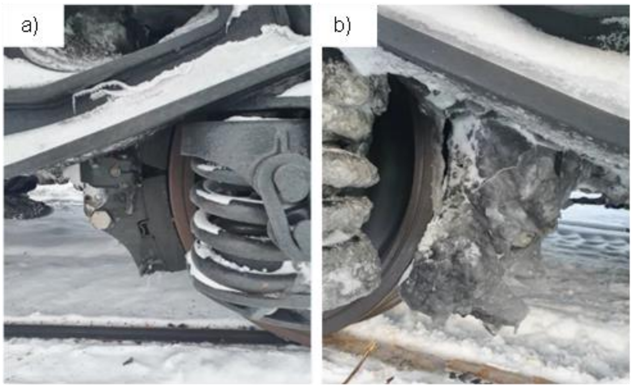

Fig. 7. Difference in degree of icing between: (a) brake block C333 (sintered) with slight icing (b) brake block K J822 (organic) with severe icing. The wagons travelled approximately 200 km in the same train with the empty wagons [25]

In the 2020 report by the Swedish Transport Agency, it was noted that incidents occurring between February 2015 and August 2019 were reported to Green Cargo, while those from December 2017 to March 2020 were reported to Hector Rail. During this period, approximately ten incidents were recorded, leading to the activation of overspeed protection or sudden brake failures. Since these reports are based on incidents submitted by two railway companies, it can be assumed that similar occurrences may have taken place in other railway enterprises as well [25].

During the winter of 2020/2021, one incident was recorded that could be directly or partially linked to the braking system equipped with brake blocks. This incident involved a train travelling from Gällivare towards Luleå, which subsequently experienced failures in Boden [25]. Additionally, train cancellations were often due to the braking system with composite blocks failing to achieve the required braking efficiency. Delays occurred despite several trains departing ahead of schedule to allow for preliminary intensive braking. In several cases, delays were also caused by the necessity of performing shunting operations at very low speeds due to reduced braking capacity. This issue was partially mitigated by initiating shunting operations earlier during the winter period [25]. Furthermore, in 2020, solution proposals were developed for the Nordic countries [24].

In the mechanical brake system, during winter technical inspections of a train's braking equipment, the inspecting personnel must pay particular attention to ensuring that the brake blocks are not frozen to the wheels. If cast iron blocks are frozen, they should be released by striking them with a hammer. In the case of composite blocks, a full braking application should be performed by reducing the main brake pipe pressure by 0.15 MPa, followed by a release and verification to check whether the blocks have been freed.

Direct hammering of composite blocks is not permitted [7].

In 2021, a series of incidents related to parking brakes in freight wagons occurred in Italy. Many of these wagons were equipped with LL brake blocks made of organic composite material. In some cases, LL brake blocks failed to dissipate heat sufficiently to prevent secondary damage, such as trackside fires and wheel damage [16]. Due to the reduced effectiveness of the parking brakes in wagons fitted with composite blocks, different values should be used in braking mass calculations for the manual brake of a train [7].

5. Conclusions

Composite brake blocks represent an effective alternative to traditional cast iron blocks. However, K-type blocks require modifications to the braking system, L-type blocks are not used in freight rolling stock, while LL-type blocks are the most easily applicable replacement for cast iron blocks.

The main advantages of composite blocks include significant noise reduction (by 10–15 dB), reduction of PM10 dust emissions (by up to 6–11 times), lower weight (4–8 kg vs 13 kg), reduced block wear, and improved braking performance at high speeds. However, the retrofitting of existing wagons to accommodate K-type brake blocks entails additional costs (€4,000–10,000 per wagon). Moreover, there are several other significant drawbacks, such as increased thermal load on the wheels, greater wear of the wheel tread surface, more emissions of fine particulate matter PM2.5 and PM1, reduced braking efficiency at low temperatures and speeds below 40 km/h, as well as higher production and operational costs. A summary of the most important parameters and features is presented in Table 2.

Operational experience has demonstrated that composite brake blocks may impact safety. Several specific hazardous incidents related to the use of composite blocks have been documented, including an accident in Poland, incidents in the Netherlands and Italy, as well as braking issues in winter conditions in Sweden. These cases highlight the need for further research and optimisation of these solutions, particularly in the context of variable weather and temperature conditions.

Table 2. Comparative characteristics of brake block types [Own work based on 2–4, 6, 9, 12, 13, 20, 35]

Parameter	**CI block**	**K-block**	**LL-block**
Friction coefficient	0.08–0.40	0.25	0.10
Block weight [kg]	13	4–8	4–8
Brake system compatibility	Fully compatible with most current wagons	Requires major modifications or new wagons	Direct replacement with CI block
Application	Passenger & freight wagons	Freight wagons only	Freight wagons only
Wagon adapting cost [€]	–	4000–10000	~2000
Wheel wear (empty/loaded) [mm/100,000km]	~0.7/~0.9	~1.5/~1.9	~0.8/~2.0
Block wear (empty/loaded) [mm/100,000 km]	~21/~80	~10/~37	~11/~29
Heat dissipation efficiency [%]	30–40	5	10–20
Noise level [dB]	92–96	77–84	82–90
PM10 emission [g/km of braking per axle]	2.65–28.66	0.4–4.2	0.4–25.72
Share of PM2.5 / PM1 in PM10 [%]	16.8/14.6	44.0/31.5	48.0/36.0
High-speed braking effectiveness	Lower than composites	Higher than CI	Higher than CI
Low-speed braking effectiveness (< 40 km/h)	Better than composites	Lower than CI	Lower than CI
Winter braking effectiveness	Good	Reduced (risk of icing)	Reduced (risk of icing)
Dust emission	High	Low–moderate	Moderate
Noise emission	High	Low	Low
Wheel thermal load	Low	High	High

The introduction of composite brake blocks into operation has been supported by European regulations; however, their widespread implementation requires further studies on their effectiveness under diverse operating conditions. Advances in material technologies and testing procedures will enable the broader application of these innovative solutions. Composite brake blocks represent the future of railway transport due to their environmental benefits, increased durability, and noise reduction capabilities. However, their full implementation requires braking system optimisation and adaptation of operational procedures to ensure safety and reliability.

Nomenclature

CER	The Community of European Railway and Infrastructure Companies
CI	cast iron
DB	Deutsche Bahn
EC	European Community
ERADIS	European Railway Agency Database of Interoperability and Safety
ERRI	European Rail Research Institute

GCU	The General Contract of Use for Wagons	UIC	International Union of Railways
LPG	liquefied petroleum gas	UIP	International Union of Private Wagons Owners
SBB	Schweizerische Bundesbahnen		
TSI	Technical Specification for Interoperability	UTK	Railway Transport Office in Poland
UE	European Union		

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