Aspects Regarding the Braking Capacity of Composite Brake Shoes for Railway Vehicles

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The main target of the study is to highlight, by means of numerical simulations, the advantages and possible drawbacks of using composite materials instead of the classical cast iron to equip the brake system of railway freight vehicles. The qualitative and quantitative evaluations refer mainly to the braking capacity by considering as main parameter the stopping distance, in various operational conditions. Results indicate that composite materials are more efficient in the braking process, but in the case of low speeds, the recommendation is to perform earlier and/or stronger braking actions than usual, in classical cast iron equipment on rolling stock.

Keywords: railway vehicle, composite brake blocks, cast iron brake shoes, braking capacity

Railway is generally recognised as a very advantageous mean of transportation: environmentally friendly and sustainable, large and rapid carrying capacity over long distances, almost unaffected by weather conditions, reduced chances of accidents and breakdowns are certainly strong arguments. The specific very low rolling resistance associated to the actual tendency of increasing running speeds and tonnages of trains make more attractive the railway transport, but require special safety rules and put supplementary pressure on the braking system [1, 2].

Braking system is essential for the traffic safety, providing controlled reduction of velocity in order to ensure stopping to a fixed point, reaching a certain lower speed or keeping it to an appropriate level when running on long and important slopes. For this purpose, the rolling stock has to be equipped with a system capable to ensure consistent and controllable retardation forces that can be efficiently applied on the entire range of the vehicles' designed speed domain.

Usually, vehicles designed to run with less than 160 km/h are equipped for tread braking, based on a relatively simple mechanism, which is efficient, failsafe and less expensive in operation [2, 3]. Such systems are based on the friction forces developed by the brake shoes applied and pressed against the wheels tread. So, during the braking action, the kinetic and the potential energy (when running on slopes) are dissipated in the form of heat generated at wheel/brake blocks interface and the velocity of the train decreases accordingly.

It is to notice that all systems relying on retardation torques generated directly on the wheelset are wheel/rail adhesion dependent and therefore the maximum brake force is limited to the actual available adhesion force. In particular, the brake shoes naturally grind and clean the wheel tread, favourable acting to improve the wheel/rail adhesion conditions. However, the severe thermal regime of the friction couple can affect and even damage both wheels and brake shoes.

As important components for the traffic safety, brake blocks have to fulfil certain requirements such as a high and stable friction coefficient, independent of speed, clamping force, specific pressure, temperature and environmental condition. Low wear rate, light weight, low noise and corrosion resistance, favourable thermodynamic properties are also qualities requested in operation for such materials. Of course, affordability and acceptable costs versus performance are nevertheless to be taken into account.

Composite materials for friction brakes

Composites represent a combination of two or more components, with different properties which, put together, produce a new material that reaches characteristics which cannot be provided by any of its constituents separately or not even by their mere sum. Each component can be distinctly found in the composite, maintaining its own physical and chemical properties, but the new material makes better use of their virtues, while diminishing to some extent the effects of their deficiencies. By certain synergistic effects, the composite material gets to have improved properties when compared with the individual constituent materials [4].

Basically, the different components of composite materials have two fundamental roles: to take over the external loads (the matrix) and to transmit the bulk of external loads (the reinforcement). The reinforcement is usually a discontinuous phase that provides strength and rigidity. The individual particles of the reinforcement are surrounded and bind together by the matrix, generally a continuous phase that provides protection against external influences. In order to obtain the targeted properties and characteristics, mainly a stable coefficient of friction and acceptable wear rate, the brake friction materials are composed of four main constituents - reinforcement, binder, friction modifier and fillers -so, in the composition, one may find more than 20 components [5, 6].

The usual structural materials in composite brake blocks are fibres of metal, glass, iron powder, aluminium and copper. These components provide hardness, the necessary rigidity, strength, wear resistance, thermal stability at high temperatures and, very important, the stability of the friction coefficient for the main body [7].

Typical binder materials – mostly phenolic or modified resins, eventually with the addition of rubber -have to keep together the rest of the ingredients and to maintain the structural integrity of the whole brake block under mechanical and thermal stress.

Fillers are generally used as an extender and, in particular for brake pads, may contribute to increase braking effectiveness, mechanical durability and hardness.

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	Organic composite C180 type brake blocks	Phosphoric iron type P 10 brake shoes
Ambient conditions for operation	Temperature: -50° C ... 60° C Maximum relative humidity: 80% at 20° C	Temperature: -40° C ÷ 45° C Average annual relative humidity: ≤ 75 %
Functional, mechanical and physical characteristics	Mean friction coefficient: 0.25 Density: 2.6 g/cm³ Specific pressure ≤150 N/cm² Temperature sustained: 400° C Temperature momentarily: 600° C Plastic hardness HRX: 55 Specific heat capacity: 0.92 kJ/kg K	Brinell hardness: 197 < HB < 255 Impact test conditions: - mass of striker: M = 50...150 kg - distance between supports: L = 160 mm ... length of brake shoe - height H: in respect to H · L · M = 4.8 kg·m²

Table 1
REQUIREMENTS REGARDING BRAKE BLOCKS FOR RAILWAY VEHICLES

Normally they are low cost minerals such as clay, calcium carbonate and barites and serve also for improving thermal and frictional stability. By using appropriate fillers, positive influences are obtained regarding the density of the brake blocks and wear resistance, with beneficial effects on cost and production. Frictional modifiers are mainly used in order to enhance frictional stability and to control the wear rates of both brake blocks and wheel running surface. The amount of alumina and silica, typical abrasive particles, increase the friction coefficient, but also the wear, so the composition has to be carefully balanced in order to satisfy two important requests: high friction levels and low wear rates [8].

Composite and cast iron brake blocks
Mechanical, physical and chemical characteristics have to meet the requirements of [9] for composite, respectively [10, 11] in the case of phosphoric iron brake blocks. Some of them are presented in table 1. Common aspects refer to consistent performance under varying environmental conditions, without being dangerous to health and environment and without affecting the security, or the safety of work.

Regarding the specifications of the chemical composition, the organic composite brake blocks consist of numerous components such as phenolic and modified resins, iron and aluminium oxides, silica, brass as typically 62% Cu - 38% Zn alloy, barium sulphate, etc. [5] in various combinations and proportions. For the brake shoes of cast iron grade P 10, the content of phosphorus must be between 0.8 ... 1.1%, the manganese content has to be lower than 1%, but higher than a limit depending on the sulphur content of the iron, while the recommended total carbon and silicon contents are also clearly specified [11].

In accordance with UIC regulations, the brake blocks for trailed railway vehicles are characterised by a standard length of 320 (single block, Bg configuration), respectively 250 mm (double block, Bgu configuration). The preferred width is 80 mm and the preferred thickness is 60 mm. It is to notice that the contact surface between brake shoes, brake holder and cotter has to prevent the fitting by mistake of brake blocks from composite materials instead of cast iron ones [9-11].

Analitical aspects and modelling
The friction coefficient between brake blocks and wheel tread is essential in designing the brake system. The influence of certain parameters, such as velocity, friction element force (normal application force) and specific pressure exerted on the wheel tread/brake shoe contact surface is decisive for the braking capacity.

In this regard, the friction coefficient in the case of composite brake blocks μ_c is quite high and almost independent of the above mentioned parameters

$$\mu_c = 0.25 \tag{1}$$

In the case of cast iron P 10 brake shoes, the friction coefficient μ_s has a multiple dependency on all of these parameters. Increasing instantaneous running speed V and normal application force N determines lower friction capacity, while decrease of the specific pressure p_s engenders higher friction coefficient. In practical calculus, there are recommended different empirical relations, e.g. [12, 13]. One of the most frequently in use is (g stands for the gravitational acceleration):

$$\mu_s(V, N) = 0.6 \cdot \frac{V+100}{5V+100} \cdot \frac{16N/g+100}{80N/g+100} \tag{2}$$

More defining are the correspondent braking characteristics, as speed dependency of the maximum braking forces for a vehicle featured with n brake blocks:

$$F_b = \mu(V, N \dots) \sum_{j=1}^{n} N_j \tag{3}$$

These have to be associated to the limitations given by the wheel/rail adhesion forces F_a depending on the adhesion coefficient μ_a and on the mass m of the vehicle [12, 13]:

$$F_a = \mu_a(V) \cdot m \cdot g \leq F_b \tag{4}$$

Qualitative braking characteristics for identical vehicles equipped with composite, respectively cast iron brake shoes, are presented in figure 1.

Analysing figure 1, some important aspects have to be highlighted. For the same vehicle type, characterised by a certain mass and a maximum constructive velocity V_{max}, within identical wheel-rail adhesion conditions, in respect to (4), the braking force is generally higher in the case of composite (solid red line) than of cast iron (solid black line) brake shoes. More than that, it is to observe that at maximum velocity, cast iron as friction material determines much lower brake forces than composite brake blocks and this inequality is true on a large speed domain. Taking into account that a braking characteristic is more favourable as the braking force is closer to the adhesion force, it is clearly advantageous to use composite materials.
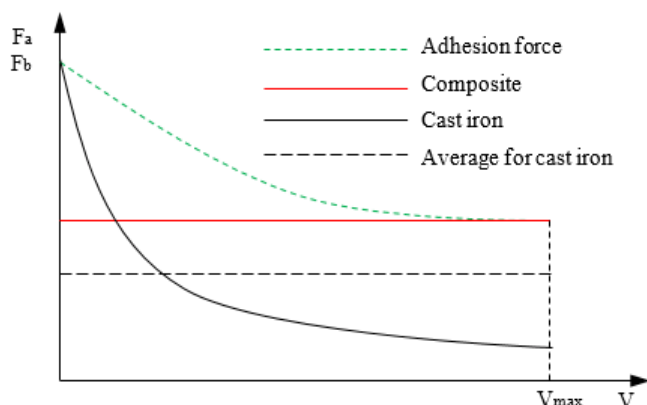
Fig. 1. Braking characteristics for composite and cast iron brake shoes

Considering the mechanical braking power as the product (F_b . V) and the equivalent average braking force affordable by using cast iron shoes (dashed black line in fig. 1), the higher efficiency of composite brake blocks is practically revealed. At the same time, this will mean shorter braking distances and increased traffic safety.

It is however to notice that it is a low speed domain characterised by a higher efficiency of cast iron brake shoes. So, it is to expect that stopping distances have to be longer when braking actions are performed at low velocities for vehicles fitted with composite brake blocks. More than that, given the specific filling characteristics of the cylinders, the operation as slow acting braking system (type G - filling time 18-30 s) in current use on freight vehicles in long trains, is more sensitive than operating as fast acting system (type P - filling time 3-5 s), usually specific for passenger traffic or short freight trains operated with 100 km/h or more.

Numerical simulations were performed with the aim of a quantitative evaluation for the braking capacity of the same vehicle, in identical conditions, featured with composite, respectively cast iron brake blocks. The simulations were focused on the most problematic situations concerning the traffic safety: full loaded wagon, running on straight and horizontal track, respectively on important slopes. The braking process simulation programs for individual vehicles, developed under MATLAB environment (see for instance [13]), integrates the movement equation:

$$F_b(t, \dot{x}, p_c) + \frac{m_v g}{1000} w_p(t, \dot{x}^2) \mp \frac{m_v g}{1000} i + W_s = m_e \ddot{x} \quad (5)$$

There were considered x the travelled distance, F_b the braking force depending essentially on the air pressure p_c in brake cylinders and velocity [13], w_p the main specific resistance, i the declivity of the track, W_s other supplementary resistances (given by running in curves, wind etc. if case). While m_v is the vehicle's mass, the equivalent mass m_e takes supplementary into account the mechanical effects of the inertia of rotating masses [2].

Results and discussions

It was considered a typical four axles freight wagon, destined for 120 km/h maximum running speed, submitted to emergency braking action. It is featured with classical UIC air brake system [1], capable of operating both in fast acting (P type) and slow acting (G type) modes. The last case is common for long freight trains operated with less than 90 km/h. The vehicles have symmetrical brake rigging, in bilateral configuration, with two friction elements per shoe holder (2Bgu type – 32 brake shoes), as prescribed in such cases.

The main simulation data are summarised in table 2.

In order to get results as accurate as possible, in the simulation programs were implemented experimental data acquisitioned on the computerized brake systems in the Laboratories of the Faculty of Transports in POLITEHNICA University of Bucharest. The air pressure evolution in brake cylinders up to the stabilisation at the maximum 3.86 bar, obtained with a KE 1c-SL air distributor, currently equipping freight vehicles in operation, is presented in figure 2.

The maximum normal forces N acting on each friction element were determined so that the braking forces respect condition (4): 17 kN/brake shoe in the case of cast iron equipment, respectively 13.95 kN/brake shoe when using composite brake blocks. By numerical simulations, there were determined the correspondent braking capacities, in terms of computed stopping distances versus initial braking speed. The most relevant results are summarised in the diagrams presented in figure 3 for fast-acting (P) mode, respectively in figure 4 for operation in slow-acting (G) mode.

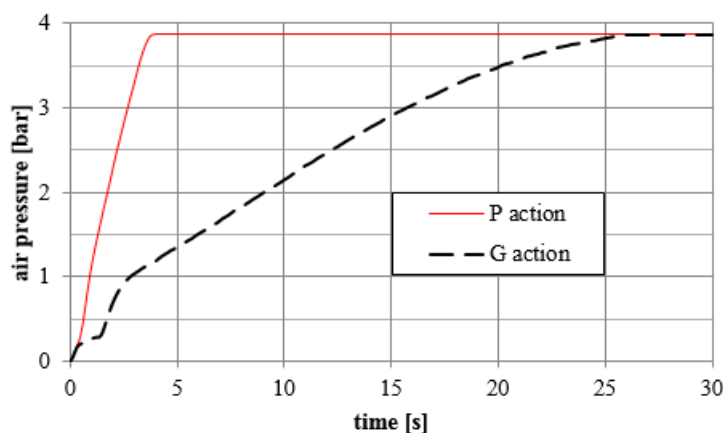| Friction element type	Initial braking speed [km/h]		Slope [mm/m]	Filling time [s]		Vehicle mass [t]	
	P	G		P	G	Tare	Maxim
cast iron	120...20	90...20	0...30	3.4	22.32	25	80
composite							

Table 2
MAIN SIMULATION INPUT DATA

Fig. 2. Filling characteristics of brake cylinder determined experimentally
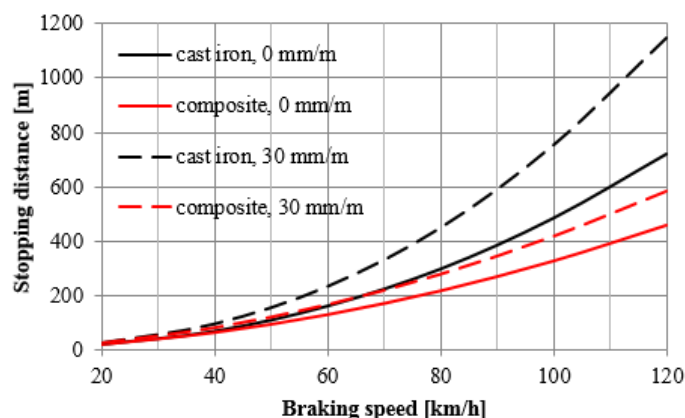
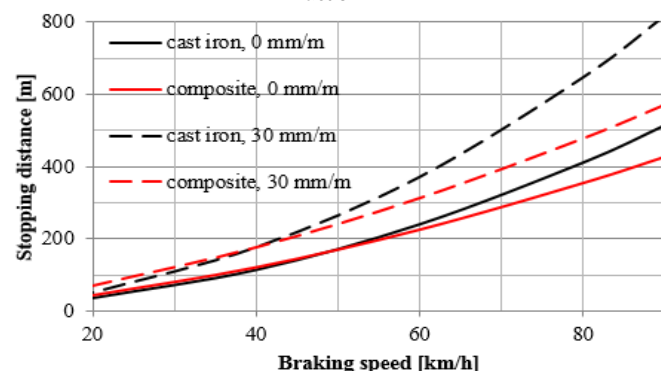Fig. 3. Stopping distance dependency on braking speed for P mode action

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

Based on analysis of these diagrams, the most important aspect to reveal is that braking power is higher for composite brake blocks, even more as the initial braking speed is higher. For composite brake blocks, shorter stopping distances, up to 36%, respectively 50%, resulted for emergency braking in P mode from 120 km/h for running on horizontal, respectively on 30 mm/m slope track. If the system is set for G mode, it is still advantageous to rely on composite brake blocks, but the braking capacity is only 17%, respectively 30% higher compared with cast iron brake shoes for braking from 90 km/h in same conditions.

It is still to notice that in the case of braking actions performed at low velocities (under 40-30 km/h), the stopping distances become shorter for cast iron featured vehicles. This aspect becomes more obvious on important slopes, but it is to mention that, given the small velocities, braking distances are anyway shorter.

Relative to the normal forces acting on the friction elements, a decrease from 17kN/shoe to 13.995 kN/ shoe in the case of composite brake blocks can be materialized in about 40% reduction in the diameter of the brake cylinders and a corresponding decrease in compressed air consumption. These aspects have to be also considered as contributions to a higher energetic efficiency of railway mode of transport.

Conclusions

Following the main target of the study, qualitative and quantitative evaluations of using composites instead of the classical cast iron for equipping the brake system of railway freight vehicles were presented. Considering the traffic safety as essential, the study refers mainly to the braking capacity by considering as parameter only the stopping distance, in various operational conditions.

The most important advantages of using composite brake blocks instead of the classical cast iron brake shoes can be synthesized as follows:

- noticeable increase of the braking capacity, which is more pronounced the higher the braking speed is and mainly in fast action (P) operational mode of UIC brake system;

- generally, more performing on important slopes, determining shorter stopping distances;

- smaller dimensions of brake cylinders with corresponding decrease in compressed air consumption.

As a possible drawback, the numerical simulations results indicate that for low braking actions initiated from low speeds, under 40...30 km/h, the braking capacity decreases, compared to cast iron brake shoes system. So, in operation, the recommendation in case of running with low velocities is to perform earlier and/or stronger braking actions than usual in classical cast iron equipment on rolling stock.

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