Construction and Building Materials 182 (2018) 273–283

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study of metal cushion pads for high speed railways

Isidro A. Carrascal [a], Alejandro Pérez [b], José A. Casado [a], Soraya Diego [a], Juan A. Polanco [a], Diego Ferreño [a,*], Juan J. Martín [b]

[a] LADICIM (Laboratory of Science and Engineering of Materials), University of Cantabria. E.T.S. de Ingenieros de Caminos, Canales y Puertos, Av. Los Castros 44, 39005 Santander, Spain
[b] TEJASA TC S.L. C/La Industria, 77. Parque Industrial Tirso Gonzalez, N 21 y 22-6, 39610 El Astillero (Cantabria), Spain

HIGHLIGHTS

- The use of 'metal cushion' as a novel alternative for rail pads is proposed.
- Both fatigue ageing and corrosion can be mitigated using the metal cushion.
- Static and dynamic stiffness performance is compared with some commercial pads.
- The influence of the metal cushion design parameters is analyzed.
- The electrical resistance pf metal cushion pad rises adding a thin polyamide layer.

ARTICLE INFO

Article history:
Received 25 April 2018
Received in revised form 5 June 2018
Accepted 15 June 2018

Keywords:
Rail pads
Metal cushion
Stainless steel
Stiffness
Fatigue
Electrical resistance
Corrosion resistance

ABSTRACT

The widespread use of railway concrete sleepers/slab track has led to the evolution of fastening systems towards the use of elastic rail pads. Pads are interposed between the rail and the sleeper as damping elements to minimize the transmission of shocks and vibrations to the sleeper, this function being of particular importance for high-speed railways. Polymeric materials have been extensively used to manufacture resilient rail pads. Plastics, however, suffer from a series of intrinsic limitations since the environmental agents (UV rays, temperature, air humidity, etc.) as well as the compressive fatigue loads they are subjected to, negatively affect their mechanical properties over time. This study proposes the use of a novel solution, the so-called 'metal cushion' pads, as a reliable alternative to polymer pads. Metal cushion pads are made of stainless steel wire, knitted, embossed and cold-pressed down into a mold to achieve the required shape and size. The thorough experimental scope carried out in this research includes the following tests: (i) static and dynamic stiffness, (ii) fatigue aging, (iii) electrical resistance and, (iv) corrosion resistance. The values of static and dynamic stiffness are very similar to those obtained with other traditional polymers such as EVA and TPE-M. In addition, it has been found that the stiffness of the metallic solution can be modified by changing the diameter and density of the wire. In the case of fatigue aging, the foremost wearing suffered by the metal cushion pads occurs mainly in the early cycling stages, although the total damage is comparable to that of the traditional solutions. The electrical resistance of the metal cushion does not fulfill the requirements demanded by the international standards; however, its behavior is satisfactory if the metallic solution is combined with a thin plastic sheet. Finally, the metal samples have passed the corrosion test in a saline environment without showing any signs of corrosion damage.

1. Introduction

The development and implementation of the high performance railway has been accompanied by a complete revolution in the design and manufacture of the elements of the railway superstructure. Currently, high-speed railways are based on the use of concrete sleepers (or, in some cases, slab track) and complex fastening systems between the concrete and the rails. Aiming at relieving the excessive stiffness of concrete (which can be up to five times higher than those made of wood [1]), elastic pads are placed between them and the rails. Rail pads play an indispensable role within the fastening systems since they cushion the shocks and vibrations caused by the transit of the train wheels. As a new track is subjected to repetitive loads caused by the transit of train wheels, it undergoes plastic deformations that grow over

* Corresponding author.
E-mail address: ferrenod@unican.es (D. Ferreño).

https://doi.org/10.1016/j.conbuildmat.2018.06.134

time until the system reaches the steady state. Then, a true stable elastic regime is established and the system behaves like a homogeneous solid [2,3]. Formula (1), proposed in [3], allows the influence of the stiffness of the rail pads, k_p, and the ballast platform, k_{bp}, on the overall stiffness of the rail's support, k_s, to be determined:

$$k_s = \frac{k_p.k_{bp}}{k_p + k_{bp}} \tag{1}$$

A high value of the stiffness of the rail pads will increase the dynamic overloads due to unsprung masses, accelerating the deterioration of the track; in contrast, low stiffness will cause the sinking of the track, leading to a noticeable increase in the stress state of the rails [4,5]. Consequently, it is essential to define the range of stiffness values that lead to the adequate performance of the fastening system [6,7].

Without claiming to be exhaustive, a review of the literature on the influence of the stiffness of the pad on the performance of the track is summarized next.

- The stiffness of the rail pads has been related to the deterioration of the ballast. Thus, countries such as Germany, Spain, France or Greece initially adopted high-stiff rail pads for high-speed lines (k_p = 400–500 kN/mm) which, combined with the intrinsic stiffness of the rail substructure (several layers of gravel in the base), brought about the deterioration of the ballast. Because of this, a lower stiffness of the rail pads (60–100 kN/mm) was chosen to reduce the total rigidity of the assembly [1,4].
- According to [8], the variation in the overall stiffness between rail sections may lead to a 40% increase in the rail stress, due to the differential vertical displacements that take place.
- The reduction of the stiffness of the plates results in a decrease in the stress state of the sleepers. High pad high stiffness provoked cases of fractured sleepers, as described in [9]. Reducing the pad's stiffness from 250 to 40 kN/mm leads to a 20% decrease in the maximum stress of the sleeper.
- Theoretical studies on vibration and noise (based on different mechanical models such as Maxwell [10], Kelvin [11] or Poynting–Thomson [12]) have been carried out to study the material performance [13,14]. As a rule of thumb, the higher the pad's stiffness the higher the transmission of noise due to the transit of trains. On the contrary, large damping reduces the transmission of vibrations into the sleeper [15]. The influence of stiffness on the amount of transmitted sound level has been analyzed in [16]. According to this study, low stiffness allows the transmission of sound frequencies below 250 Hz, below 450 Hz for medium stiffness and 800 Hz for high stiffness.
- The non-linear mechanical response of the rail pads may have detrimental effects regarding their ability to isolate vibrations. It was shown that the second and third modes of vibration could be included in the frequency range (300 – 600 Hz) which is associated with rail corrugation effects; moreover, under some conditions, dangerous resonances may appear when rolling stocks pass over [10].
- Previous studies [17] have compared the rail pad's ability for energy absorption with its stiffness. HDPE plates can absorb up to 50%of the total incoming shock energy. The same conclusions are present in [18], in this case for TPE plates, 7.00 mm thick, with a stiffness of 100 kN/mm.
- The short-term dynamic effects on the rail, caused by the stiffness of the pads, are accompanied by some forms of long-term damage, such as the so-called rail corrugation. This term refers to the quasi-sinusoidal irregularities of the wheels and rails, caused by the mechanical interactions (vibrations and dynamic loadings) between them. Rail corrugation is also related with rail pad stiffness, so that the higher the stiffness, the higher the presence of this pernicious effect [19]. The experimental data collected in [20] show that a reduction in rail pad stiffness from 90 to 60 kN/mm, leads to a 55% decrease in corrugation amplitude and length.

Several polymeric materials such as EPDM, TPE, TPU and rubber have been extensively used to manufacture rail pads [21,22], in particular for high speed railway tracks. Unfortunately, several environmental agents, UV rays and temperature being the most common, may degrade the stiffness of these pads. Previous studies were focused on improving the aging performance of these materials. For instance, in [23] tiuram and sulfide curing treatments on SBR rail pads were compared, concluding that the latter provides the best performance. Setting aside environmental issues, as a matter of fact, the durability of the rail pads is always limited because of the repetitive loads and impacts coming from the passage of rolling stocks. Several studies confirm this statement; for instance, in [24] the loading effect in a 5.5 mm thick HDPE rail pad was measured, observing a stiffness deterioration of 13 kN/mm and a damping degradation of 41 N·s/m. Moreover, in [25] a 44% stiffness aging increment was observed in a TPE rail pad after 3 years under in-service conditions. Fatigue is another cause of material deterioration leading to the increase in stiffness [26–28]. This phenomenon is accompanied by a reduction in the ability of the part to dissipate the energy coming from load-unload cycles. The experimental data show that a fatigue increase of stiffness of 18% reduces the ability for energy absorption by 40% [27]. In addition, the fatigue loading also produced a thickness reduction of the rail pad [29].

In conclusion, the polymeric materials currently used as rail pads may suffer from severe limitations in the long run because of the modifications that their stiffness undergo as a result of the environmental conditions and the loads they are subjected to. For these reasons, the pads must be replaced over time, which negatively affects the economic performance of the track, as well as the quality of the service. These are the circumstances that motivate the present study, which is aimed at developing and validating, relying on the experimental results, a novel solution capable of overcoming the intrinsic limitations of polymeric materials. Metallic rail pads have been employed in the past, particularly in the form of plates between the rails and the wooden sleepers. This option is not applicable for concrete sleepers, due to the excessive stiffness of this solution. In this sense, we propose the use of the so-called *metallic cushion pads* (also called *metal-rubber damper*), made of stainless steel, as a superior alternative both from the mechanical point of view and from the perspective of the durability of the material against loads or environmental conditions. As proved in this study, the metal cushion-based solution allows the designer to select the most suitable stiffness to guarantee the adequate performance of the system. Metal cushion is advantageous as compared to polymers since it provides a uniform and environmentally independent performance, as well as an improved dynamic behavior regarding noise and vibrations.

The experimental campaign in this study consisted in comparing the response of six polymeric solutions, currently employed in actual railway tracks, against the behavior of themetal cushion pads. The experimental scope developed is briefly summarized hereafter. The static and dynamic stiffness of the different solutions was obtained following the guidelines of the international standards EN 13146-9+A1 [30] y EN 13481-2 [31], respectively. In order to assess the mechanical aging derived from the application of repetitive loads, static and dynamic stiffness were determined again after subjecting the pads, respectively to $3.5{\cdot}10^5$ and $3{\cdot}10^6$ fatigue cycles, following the standard EN 13146-4+A1 [32].