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Obtaining railpad properties via dynamic mechanical analysis

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ABSTRACT

In this paper, we propose combining dynamic mechanical analysis (DMA) and the time–temperature superposition principle to determine various railpad dynamic properties. Having accurate information regarding the dynamic properties of a railpad is a fundamental requirement for designing tracks and understanding track deterioration. By testing three different railpad types, we demonstrate that the dynamic behavior of railpads over a wide frequency range can be successfully obtained under different preloads and temperatures if time–temperature superposition can be applied. To investigate railpad aging, worn railpads taken from a mainline in the Netherlands are tested. In this case, worn railpads are softer and possess a lower damping capacity than new railpads. In addition to performing these measurements, a Prony series material model is proposed to reproduce the dynamic behavior of railpads. The Prony series model is in good agreement with the measurements. Measured railpad dynamic properties and the corresponding Prony series numerical model provide valuable information for track design and modeling.

1. Introduction

Railpads are one of the main components of a railway track structure (see Fig. 1). This resilient material placed between the rail and sleeper plays a key role in the dynamic behavior of tracks because track deterioration and rolling noise strongly depend on the properties of railpads. Stiff railpads (e.g. $k = 1300$ MN/m) result in increased rolling noise [1]. Additionally, stiff railpads lead to larger wheel–rail contact forces [2], especially, at the rail ends of rail joints [3], which leads to ratcheting of the rail ends [4]. Furthermore, short pitch corrugation increases at a greater rate with stiff railpads [5,6], and squats may occur if the condition of the fastening (i.e. railpad and clamps) worsens [7,8]. To delay the growth of rail surface defects, soft railpads (e.g. $k = 130$ MN/m) are often used. Moreover, soft railpads protect the sleeper and ballast because less energy is transferred from the rail [9]. However, the displacements of tracks are larger for soft railpads than for stiff railpads; therefore, the risk of derailment is higher, and the deterioration of track components, such as rails and clamps, is accelerated. Thus, the railpad type used in practice is often a trade-off between rolling noise, rail surface defects, track component deterioration and maintenance costs. Hence, obtaining accurate information about the dynamic behavior of railpads beforehand can significantly facilitate decision-making and maintenance planning processes for infrastructure managers. In addition, this information can be useful when investigating track deterioration and the development of rail surface defects.

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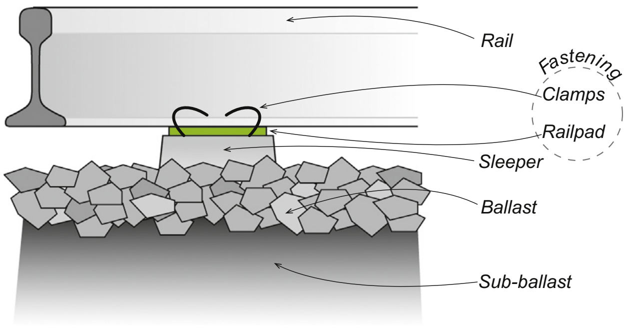

Fig. 1. Main track components.

Various studies have been performed to gain insight into the behavior of railpads and to identify four of the most relevant factors that affect railpad properties. (1) The first key factor is preload. The stiffness of railpads exhibits nonlinear behavior in the static-load–deflection curve [10,11]. More precisely, the parameters of railpads are subjected not only to momentary preload conditions but also to preload history [12]. (2) The second key factor is frequency dependence. The stiffness of a railpad increases with frequency; the opposite effect occurs for damping [10,11,13–15]. (3) The third key factor is temperature. The stiffness of a railpad increases with decreasing temperature, whereas the damping decreases [16]. (4) The fourth factor is aging. Contradictory observations of the evolution of railpad properties during aging have been reported. Whereas fatigue tests have indicated an increase in stiffness with an increase in the number of cycles [16], a comparison of worn railpads taken from the field has revealed a decrease in stiffness with increasing MGT (Million Gross Tons) [17].

Various test procedures that differently consider the effects of preload, frequency and temperature have been developed to investigate railpad behavior and derive its parameters (i.e. stiffness and damping). The standardized methods and procedures are defined in the standard NEN-EN 13146-9 [18]. In some railpad testers, the railpad is placed between plates that are tied together so that the railpad is subjected to the toe load of the clamps [12,17,19]. In other testers, a rail with support (i.e. rail, fastening and sleeper) is employed [20]. During testing, either one of the plates or the rail is vertically excited and the response to the impact force is measured. Next, the stiffness and damping of the railpad are calculated by fitting a model to the measured resonances. By performing this test at different toe loads, the effect of the preload on the railpad properties can be investigated. Other railpad testers use harmonic loading so that the frequency-dependent behavior of a railpad, in addition to the dependence on the preload, can be analyzed [11,15,21,22]. The maximum frequency is limited by the robustness of the structure of the test set-up. For instance, the maximum tested frequency was 10 Hz for a strong structure in [22], and the maximum frequency was 2500 Hz for an extremely robust custom set-up in [21]. To account for the effect of temperature, tests are performed under temperature-controlled conditions, such as within climate boxes [16].

In this paper, we propose to use the dynamic mechanical analysis method to derive the dynamic behavior of railpads over a wide frequency range while considering preload and temperature using relatively common test equipment. By accounting for preload, temperature and frequency, three key factors that affect the dynamic behavior of railpads can be considered. To examine the effect of a fourth key factor (i.e. aging), new and worn railpads are tested. In addition to the test method, we propose a material model for numerically reproducing dynamic railpad properties.

The structure of the paper is as follows. In Section 2, the concept underlying the test method is presented. In Section 3, the test-set up and tested samples are demonstrated. The dynamic properties of the tested railpads are presented in Section 4, and a numerical model that can be used to reproduce the measured data is proposed in Section 5. The results are discussed in Section 6, and the main conclusions are drawn in Section 7.

2. Test methods

Railpad materials possess both elastic and damping characteristics. As such, the properties of railpad materials resemble those of viscoelastic materials. Preload, temperature, frequency and aging, which are relevant to the behavior of railpads, are characteristics of viscoelastic materials that exhibit time-dependent dynamic behavior [23]. The behavior of viscoelastic materials combines the directly proportional stress–strain relation of elastic solids (Hooke's law) with the directly proportional stress–strain–rate relation of viscous liquids (Newton's law). To measure these dynamic properties, different experimental methods are used depending on the frequency range of interest. Whereas time-domain creep and relaxation tests are performed for frequencies lower than 1 Hz, frequency-domain tests are performed for frequencies greater than 1 Hz [23]. To perform the frequency domain tests, dynamic mechanical analysis (DMA) is commonly used.

In this paper, frequency-domain tests are performed because our focus is on obtaining the properties of railpads for a range of high-frequency loads corresponding to practical wheel loading frequencies. The test methods are introduced for linear behavior, i.e. small loads, as a first step in assessing the capacity of DMA to accurately determine railpad dynamic properties. Although various investigations have shown that railpads exhibit nonlinear behavior under static loads [10,11],