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Numerical and experimental characterization of the mechanical behavior of a new recycled elastomer for vibration isolation in railway applications

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HIGHLIGHTS

- A new material was validated to produce anti-vibration mats for railway applications.
- The mechanical properties and the efficiency against vibrations were measured.
- A Finite Element model was validated.

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ABSTRACT

This research has been developed in the frame of a European project involving several partners with the aim of developing an elastomeric "eco-friendly" material based on end-of-life tyres. It is a material specifically designed for the manufacture of anti-vibration mats to be used under ballasted railway tracks or under concrete slab tracks to avoid or to reduce the ground-borne vibration transmission. This paper describes the experimental, analytical and numerical results of the characterization of the mechanical behavior of this new elastomeric material. The process of validation was developed in three domains: firstly, a thorough characterization of the behavior of mats manufactured in this new material under different situations was conducted. Test were carried out for determining the static and dynamic modules, the behavior under fatigue conditions and the ability of the material to resist mechanical actions in the presence of frost as well as the aging influence of water and temperature. Second, a study on the capacity of this type of mats to reduce the vibrations generated by rail traffic was carried out. To this end, the mechanical system constituted by the track, sleepers, ballast and soil, was modeled analytically, introducing also the effect derived from the presence of the anti-vibration mats. Finally, a Finite Element model in which the mechanical behavior of the material has been described using a Mooney-Rivlin model has been experimentally validated. Although this is a purely theoretical exercise, this result is a cause for optimism as it confirms the suitability of the use of the Finite Element method as a predictive tool for the behavior of anti-vibration mats under in-service conditions or in the process of pre-validation of new geometries.

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1. Introduction and aim

According to the European Tyre & Rubber Manufacturers' Association (ETRMA), more than 300 million tyres were removed in Europe in the year 2007 which resulted in the generation of some 3.4 million tonnes of waste [1]. Moreover, the European Commission's 2008 Waste Framework Directive [2] states that all products derived from end-of-life tyres (ELT) should no longer be considered as waste but as a resource and as a secondary material for new applications. This implies a pressing need to explore and develop new uses for ELTs and environmentally friendly processes for delivering useable materials. As this paper demonstrates, the railway sector provides an excellent opportunity for the manufacture of components by recycling ELTs.

Rail traffic creates vibrations that are transmitted through the track structure causing noise pollution and, occasionally, may even

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Nomenclature

BT ballasted (railway) track
BT-UBM ballasted (railway) track provided with an UBM
c_{10}, c_{01}, c_{20}, c_{11} and c_{02} five free parameters of the Money-Rivlin model
c_f, c_b, c_{ubm} fasteners, ballast and UBM viscous dampings
C_{dyn} dynamic modulus of the mat.
$C_{dyn,10Hz}$ dynamic modulus ob the mat obtained at a frequency of 10 Hz
C_{sta} static modulus of the mat
$C_{sta,i}$ initial value of C_{sta}, before performing the frost damage test
$C_{sta,f}$ final value of C_{sta}, after performing the frost damage test
$C_{sta.h}$ horizontal static modulus of the mat
D_{Pg} and D_{Sg} P- and S-waves associated damping coefficient
E_{ij} components of the strain tensor.
E_r rail Young's modulus.
ETRMA European Tyre & Rubber Manufacturers' Association
ELT end-of-life tyres
f frequency
F deformation gradient
FE Finite Elements
IL Insertion Loss
I_r rail moment of inertia
J total volume ratio
J^{el} elastic volume ratio
J^{th} thermal volume ratio
k_f, k_b, k_{ubm} fasteners, ballast and UBM stiffnesses
L_0 initial diameter of the specimen used to determine the Poisson's ratio
LVDT linear variable differential transformer
m_s and m_b sleepers and ballast distributed masses
RE relative error (of the FE fitting procedure)
SD standard deviation
S_0 cross section of the mats used to determine C_{sta} or C_{dyn}
S_r rail cross-section area
T test temperature
T_{ij} components of the stress tensor
T_i^{test} experimental stress value
T_i^{th} nominal stress value
tgα loss factor
U strain energy potential
UBM under-ballast mat
U_{dev} deviatoric component of the strain energy potential
UIC Union Internationale Des Chemins De Fer (International Union of Railways)
U_{g1}^{Uniso} unisolated receptance of the ground surface
U_{g1}^{Iso} isolated receptance of the ground surface
U_{vol} volumetric component of the strain energy potential
x and y spatial coordinates (analytical model)
z_r rail vertical displacement (analytical model)
z_s sleepers vertical displacement (analytical model)
z_{bd} ballast bottom vertical displacement (analytical model)
z_{g1} subgrade surface vertical displacement (analytical model)
δ_{perm} permanent displacement after performing a $C_{sta,h}$ test
ΔC_{sta} variation of the static modulus after performing the frost damage test
$\Delta\delta_m$ change of the thickness of the mat as a consequence of ΔF during the C_{sta} or C_{dyn} tests
ε_L longitudinal strain of the specimen (determination of Poisson's ratio)
ε_T transversal strain of the specimen (determination of Poisson's ratio)
ε^{th} thermal strain
η_f, η_b and η_{ubm} fasteners, ballast and UBM structural damping coefficients
η_r rail structural damping coefficient
λ_g first Lamé's constant
λ_i principal stretches
λ'_i deviatoric stretches
μ_g second Lamé's constant
ν Poisson's ratio
ρ_g subgrade density
ρ_r rail density
$Ø_0$ initial diameter of the specimen used to determine the Poisson's ratio
ω Frequency

cause structural damage to the nearby buildings. This represents one of the major impacts upon the environment from rail systems. For this reason, anti-vibration mats are commonly placed under ballasted railway tracks or under concrete slab tracks to avoid or to reduce the ground-borne vibration transmission. The most used anti-vibration elements are made of rockwool, rubber or cork.

This contribution was developed in the context of a research project under the financial support of the European Commission. Its overall objective was to demonstrate the reliability of using elastomeric particles recycled from ELTs and blended with resin as a new option to produce an "eco-friendly" anti-vibration solution in the form of elastomeric under-ballast mats (UBM). This solution appears as an environmental imperative provided the current large accumulations of used tyres as well as the future prospects in this regard. Specifically, this alternative is an interesting application for urban railways (metro) as well as for conventional railway lines, mainly in urban areas. The aim of this work is to demonstrate that this kind of environmental-friendly elastomeric material, manufactured in the form of mats, can satisfy the current vibration mitigation needs of modern railway lines as well as the requirements imposed by the Railway Administrations. The validation of this material for these purposes would open the door to the recycling of millions of tyres that are currently stored as waste, with the corresponding environmental improvement. In addition, valuable experimental information concerning this material is provided, suitable to be used in the design of new railway lines.

The paper is broken down into three parts:

- Experimental validation: A number of mats were tested under static and dynamic regimes to determine their response subjected to in-service conditions. In addition, accelerated fatigue tests were carried out on a section of ballasted track. Finally, mats were subjected to adverse environmental conditions to simulate frost damage, thermal and water aging.
- Study of the efficiency for vibration attenuation: The Insertion Loss (IL) parameter was determined considering the influence of antivibration mats. In order to properly interpret the experimental results, an analytical model of the superstructure was developed, considering both the presence and the absence of the UBM.

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