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**Research paper**

# Ageing tests with high temperatures of prototype vibroacoustic isolators – under ballast mats (UBMs) based on recycled materials

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**Abstract:** This study focuses on experimental ageing tests with high temperatures carried out on prototype under ballast mats (UBMs) according to the procedure of the European standard EN 17282, which was introduced in late 2020. Most of the analysed UBM samples are based on recycled elastomeric materials, such as styrene-butadiene rubber (SBR) granules and fibres from end-of-life car tyres and rebond polyurethane waste from polyurethane product manufacturing plants. Additionally, two variations of the mat based on mineral wool are analysed. Significant differences in the values of static and dynamic characteristics measured before and after the ageing tests are demonstrated, and permanent deformations of the recycled polyurethane-based mats are shown. Moreover, it is proved that the elastomeric mats based on recycled rubber materials (SBR granules and fibres) have high durability and are an effective solution in terms of protection against vibration and structure-borne noise from railway traffic. In addition, the authors propose criteria for assessing the results of the ageing test with high temperatures of UBMs tested according to the procedure of EN 17282.

**Keywords:** ballasted track structure, ageing resistance, under ballast mat, laboratory testing of UBM, vibration isolation

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# 1. Introduction

Increasing train velocities and strict regulations with regard to the limitation of negative effects of railway traffic (vibration and structure-borne noise) on people and the environment [1] have forced scientists and engineers to develop ecologically sustainable railway track systems. Such systems are equipped with various vibration isolators, e.g. under sleeper pads (USPs), under ballast mats (UBMs), rail dampers, under slab mats (USMs), etc., which can be based on recycled materials. The use of crumbled rubber from recycled end-of-life tyres or rebond polyurethane as a material of vibroacoustic isolators may be one of the most effective ways for managing rubber and polyurethane waste.

UBMs [2] are vibroacoustic isolators installed in the ballasted track structures in order to improve their dynamic behaviour. Their thicknesses range from 15 mm to 40 mm, and they can be produced from various materials, such as elastomeric recycled-based: styrene-butadiene rubber (SBR) and rebond polyurethane (PU), or a more traditional solution based on rubber, polyurethane and mineral wool. The mats have numerous advantages: they reduce vibration and structure-borne noise; they decrease stress in the ballast layer, which results in a reduced ballast thickness; and they harmonize the deflections in transition zones.

The behaviour of UBMs in the ballasted track systems have been studied by many authors. Sol-Sánchez et al. [3,4] discussed the use of elastic elements, including UBMs, in various configurations of the railway track section, focusing on the track stiffness, energy dissipation capacity, geometry degradation, etc. Wang et al. [5] presented an overview of the recent developments on UBMs, including different kinds of mats, their fatigue strength, environmental conditions stiffness and key challenges for their widespread applications. Xu et al. [6] studied the mechanical behaviour of UBMs with different stiffnesses under different ballast loading plates. Hou et al. [7] evaluated the UBM vibration reduction effects by numerical and experimental analysis using wheelset drop tests. They showed that the use of the ballast mat decreases the mid- and high-frequency track vibration and increases the low-frequency track vibration.

Sheng et al. [8] proved that rubber-based UBMs are able to maintain good mechanical performance under repeated loading. Xin et al. [9] focused on the application of rubber mats in transition zones between two different slab tracks in high-speed railway. They demonstrated that the proposed mats can gradually change the vertical stiffness of the track. Kraśkiewicz et al. [10–12] studied the performance of UBMs both experimentally and analytically, proving that recycling-based mats exhibit good resistance to severe environmental conditions [10] and high fatigue strength [11], and showing that the mat thickness has a significant effect on the effectiveness of the vibration isolation [12]. Lapcik et al. [13] investigated dynamic stiffness of the rubber-based mats, and Horníček et al. [14] focused on the long-term behaviour of antivibration mats manufactured from recycled rubber. Sol-Sánchez et al. [15] proposed a novel sustainable solution for ballasted railways that combines the concepts of geogrids and under ballast mats (UBM) manufactured from recycled crumb rubber.

As can be seen from the above literature overview, a lot of researchers have studied the behaviour of UBMs, including the ones based on recycled materials. However, according to the best knowledge of the authors of this study, there are no papers on ageing with high temperatures of the ballast mats, just a few works on thermal ageing of the recycled materials considered in this paper. Lapcik et al. [16] studied the thermal-induced ageing of soft polyurethane foams. They demonstrated that the conditioning leads to the significant loss of the PU foam's thermal stability and the loss of its elastic mechanical performance. Naima et al. [17] investigated the effect of thermo-oxidative ageing of SBR on its mechanical and chemical properties. They confirmed that accelerated ageing leads to a decrease of the ultimate mechanical properties and an increase of the material hardness.

Several works have focused on the resistance to atmospheric conditions of various vibration isolators. Kraśkiewicz et al. [18, 19] studied resistance to severe environmental conditions of USPs, proving that the resilient elements based on recycled rubber granulate are more resistant to negative influences of atmospheric conditions than the ones based on polyurethane. Wei et al. [20] examined the temperature- and frequency-dependent dynamic properties of high-speed rail pads excited by rail vehicle's large-amplitude quasi-static loads. Kaewunruen et al. [21] investigated the wet/dry influences on the characteristics of closed-cell polymeric cross-linked foams under static, dynamic and impact loads. They proved that the tested polymeric material is not suitable for the production of USPs, however, it has a strong potential for the use as UBMs.

This study is focused on laboratory tests of ageing with high temperatures (~ 70°C) carried out on prototype under ballast mats (UBMs) according to the procedure of the European standard EN 17282 [22], which was released in late 2020. The analysed UBM samples are based on four different materials: three recycled elastomeric materials (SBR granules and SBR granules and fibres from end-of-life car tyres, and rebond PU waste from polyurethane product manufacturing plants) and mineral wool. For all considered samples, static and dynamic characteristics before and after the ageing test are determined, and the effectiveness of the solution in terms of protection against vibration and structure-borne noise from railway traffic is assessed. In addition, the authors propose criteria for assessing the results of the ageing test with high temperatures of UBMs tested according to the procedure of EN 17282 [22].

## 2. Testing procedures and requirements with regard to the ageing resistance of UBMs

### 2.1. Standards and testing procedures

Ageing test with high temperatures is one of the tests recommended by the European standard EN 17282 [22] for determination of the durability of UBM. Apart from ageing, the durability testing includes fatigue tests [11] and tests of resistance to severe environmental conditions [10]. All of these properties are very important, as they affect the service life of the track structure and the efficiency of vibration isolation.

The assessment of the durability of UBM, based on its resistance to thermal ageing, is crucial from the practical point of view. A significant decrease in the isolation effectiveness could cause the need for replacing the defective mats, which, considering the structure of the ballasted track, would lead to major repair of the whole system. This is why the durability of UBMs is so important for the railway infrastructure managers.

Resistance to thermal ageing should always be considered while designing UBMs. Even if other properties of the mat are good, choosing a mat that does not satisfy the requirements for ageing resistance could lead to a rapid increase in the bedding moduli of UBM and, as a result, a decrease in its vibration isolation effectiveness.

Prior to the release of the European standard EN 17282 [22] in 2020, UBMs were typically tested according to the German standard DIN 45673-5 [23], which assumed the use of a flat ballast plate in the tests of static and dynamic bedding moduli. The new standard EN 17282 [22] describes the testing procedures based on a geometric ballast plate (GBP), whose irregular surface simulates the interaction between the mat and sharp edges of the ballast grains [11]. Moreover, the procedures for ageing tests with high temperatures differ between the mentioned two standards, as shown in Table 1. The procedure for testing the ageing resistance according to EN 17282 [22] is described in detail in Section 3.

Table 1. Differences in the procedures of ageing tests with high temperatures of UBMs according to two standards

| ’ Test | Standard | |
|---|---|---|
| | EN 17282 [22] | DIN 45673-5 [23] |
| Ageing test with high temperatures | Bedding moduli tests between 1 and 2 weeks after the end of ageing with high temperatures | Bedding moduli test period not determined |
| | Temperature in the climatic chamber: 70 ± 3°C | Temperature in the climatic chamber: 70 ± 1°C |
| | Calculation of the variation of static and low frequency dynamic bedding modulus, and change of mass: $\Delta C_{\text{stat}}$, $\Delta C_{\text{tend}}$, $\Delta C_{\text{dyn5Hz}}$, $\Delta m$* | Calculation of the variation of static bedding modulus: $\Delta C_{\text{stat}}$ |

*$\Delta C_{\text{stat}}$ – variation of the static bedding modulus (load range $0.02 \div 0.10$ N/mm$^2$),
$\Delta C_{\text{tend}}$ – variation of the static bedding modulus (load range $0.02 \div 0.20$ N/mm$^2$),
$\Delta C_{\text{dyn5Hz}}$ – variation of the low frequency (5 Hz) dynamic bedding modulus,
$\Delta m$ – change of mass

## 2.2. Requirements for ageing resistance

Following the requirements of foreign railway infrastructure managers, Table 2 presents a comparison of the limiting values for the parameters that are of particular importance while selecting UBMs with regard to their resistance to thermal ageing. In view of the transition period related to the release of EN 17282 [22], requirements of the foreign railway infrastructure managers and recommendations of the International Union of Railways UIC [24] were treated as a starting point for formulating the authors' preliminary recommendations (see last column in Table 2). Currently, the standards [22] do not specify the limiting values of any parameters, their only aim is to provide uniform testing procedures for their determination. It is a task for railway infrastructure managers to develop such requirements, hence the preliminary recommendation of the authors, which is a suggestion of the requirements for the Polish railway.

Table 2. Requirements for the ageing resistance of UBMs based on the regulations of foreign railway infrastructure managers and the preliminary recommendation of the authors

| Property | | Israel [25] | France [26, 27] | Italy [27, 28] | UIC [24] | Authors' recommendation |
|---|---|---|---|---|---|---|
| Ageing resistance | Appearance | no data* | no data* | – | no cracks or other damage | no damages |
| | $\Delta C_{\text{stat}}$ | no data* | no data* | – | $\leq 15\%$ | $\leq 15\%$ |
| | $\Delta C_{\text{dyn5Hz}}$ | no data* | no data* | $\leq 15\%$ | $\leq 15\%$ | $\leq 15\%$ |
| | $\Delta m$ | no data* | no data* | – | $\leq 10\%$ | $\leq 0.5\%$ |

*No data – should be checked, but no limiting value specified

The authors significantly tightened the requirement for UBM mass change in relation to the UIC recommendation [24], following the example of the German railway (in relation to USP), and out of concern for the highest quality of the approved products. For example, according to the requirements of the German railway DB – guideline DBS 918 145-01 [29] for USPs in the ageing resistance test – the maximum allowed mass change is 1%. As can be seen in Section 3.5 of this study, the value recommended by the authors is realistic to achieve for the majority of the tested products.

## 3. Ageing tests with high temperatures of prototype UBMs

Over time, materials – especially synthetic polymers, which include elastomers – change their elastic and strength properties. This process is known as material ageing. This is particularly important in the case of materials that are exposed to the adverse effects of environmental conditions. In the case of elastomeric UBMs, material ageing due to varying thermal loads can affect their service properties. Due to the fact that research on the resistance to severe environmental conditions under natural conditions takes a very long time, accelerated ageing methods under laboratory conditions are used. The details of the accelerated ageing method used in this study are described below in Section 3.3.

### 3.1. Description of the samples

Prototype UBMs considered in this study may be classified with regard to the material that was used to produce the mats. Most of the tested UBM samples were made of two types of recycled elastomeric materials: SBR granules and fibres from crumbled end-of-life car tyres, and rebond polyurethane (PU) obtained from mechanically crumbled polyurethane waste, both glued with polyurethane adhesive. Additionally, for comparison purposes, two tested UBM samples were made of mineral wool, which cannot be classified as elastomer. Photographs of selected samples are shown in Fig. 1, and parameters of all tested samples are gathered in Tables 3–6.

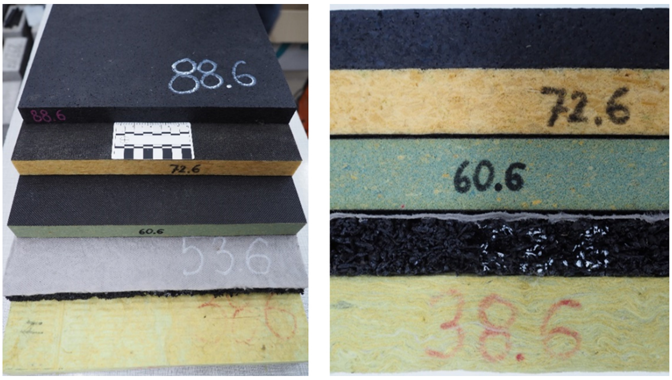

Fig. 1. Photographs of selected UBM samples, from the bottom: No. 38.6 (mineral wool), No. 53.6 (SBR granules and fibres), No. 60.6 (PU), No. 72.6 (PU), and No. 88.6 (SBR granules)

Tables 3–6 provide two basic parameters by which the bedding moduli values of UBMs can be controlled: thickness and density. The influence of these two parameters on various properties of vibration isolators was described in [12] with regard to UBMs, and in [30] for USPs. Regardless of the material used, the mats are selected based on these parameters. They may affect the results of the ageing resistance test and therefore, such tests should be carried out for each combination (thickness and density). All materials to be used in the future on Polish railways as UBMs, regardless of the parameters (e.g. thickness and density) and production technology (plant-specific), should be tested according to the uniform procedure of the standard EN 17282 [22].

Table 3. Parameters of UBM samples based on mineral wool

| Sample No. | Thickness [mm] | Density [kg/m$^3$] |
|---|---|---|
| 38.6 | 35 | 230 |
| 39.6 | 35 | 230 |

Table 4. Parameters of UBM samples based on SBR granules

| Sample No. | Thickness [mm] | Density [kg/m$^3$] | Sample No. | Thickness [mm] | Density [kg/m$^3$] |
|---|---|---|---|---|---|
| 40.6 | 25 | 1050 | 90.6 | 23 | 1000 |
| 41.6 | 25 | 1000 | 91.6 | 23 | 850 |
| 42.6 | 25 | 850 | 92.6 | 23 | 750 |
| 43.6 | 25 | 650 | 93.6 | 23 | 700 |
| 88.6 | 23 | 1100 | 94.6 | 23 | 650 |
| 89.6 | 23 | 1050 | | | |

Table 5. Parameters of UBM samples based on SBR granules and fibres

| Sample No. | Thickness [mm] | Density [kg/m$^3$] | Sample No. | Thickness [mm] | Density [kg/m$^3$] |
|---|---|---|---|---|---|
| 44.6 | 15 | 700 | 51.6 | 30 | 600 |
| 45.6 | 20 | 700 | 52.6 | 15 | 500 |
| 46.6 | 25 | 700 | 53.6 | 20 | 500 |
| 47.6 | 30 | 700 | 54.6 | 25 | 500 |
| 48.6 | 15 | 600 | 55.6 | 30 | 500 |
| 49.6 | 20 | 600 | 56.6 | 20 | 550 |
| 50.6 | 25 | 600 | | | |

Table 6. Parameters of UBM samples based on PU

| Sample No. | Thickness [mm] | Density [kg/m$^3$] | Sample No. | Thickness [mm] | Density [kg/m$^3$] |
|---|---|---|---|---|---|
| 57.6 | 13 | 180 | 70.6 | 15 | 120 |
| 58.6 | 15 | 180 | 71.6 | 20 | 120 |
| 59.6 | 20 | 180 | 72.6 | 25 | 120 |
| 60.6 | 25 | 180 | 111.6 | 15 | 200 |
| 61.6 | 15 | 160 | 112.6 | 20 | 200 |
| 62.6 | 20 | 160 | 113.6 | 25 | 200 |
| 63.6 | 25 | 160 | 114.6 | 15 | 240 |
| 64.6 | 15 | 150 | 115.6 | 20 | 240 |
| 65.6 | 20 | 150 | 116.6 | 25 | 240 |
| 66.6 | 25 | 150 | 117.6 | 15 | 220 |
| 67.6 | 15 | 140 | 118.6 | 20 | 220 |
| 68.6 | 20 | 140 | 119.6 | 25 | 220 |
| , 69.6 | 25 | 140 | | | |

## 3.2. Test stand

Static and dynamic elastic characteristics of UBMs were tested in a universal testing machine INSTRON 8802 with two steel plates: lower (support plate) with the dimensions of 320 × 320 mm and upper – GBP for UBMs (Fig. 2). During the tests, displacements in four points were measured, using the displacement inductive sensors (WA-T type by HBM, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) together with HBM's Spider8 data acquisition and signal conditioning system and dedicated software – Catman AP (version 3.4).

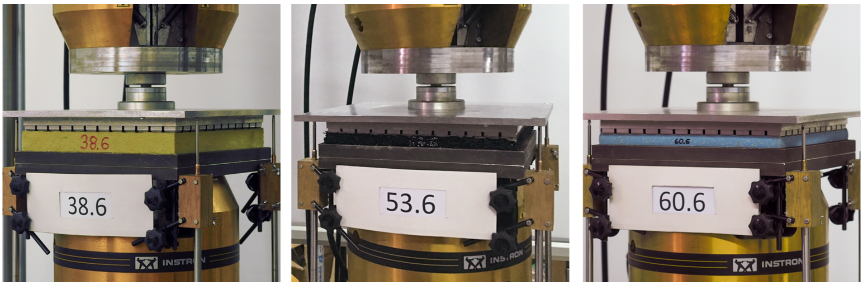

Fig. 2. UBM samples during the static and dynamic bedding moduli tests, conducted before the ageing test: a) sample no. 38.6 based on mineral wool; b) sample no. 53.6 based on SBR granules and fibres; c) sample no. 60.6 based on PU

## 3.3. Testing procedure

The ageing test with high temperatures was conducted according to the procedure described in EN 17282 [22] (Annex I). First, all tested UBM samples were visually inspected in order to look for damages, such as perforation, cracking or other damage, caused by installation, transport or manipulation of the mats. After the visual inspection (no damages were found), UBM samples were tested for static and low frequency dynamic bedding moduli, and the mass of samples was measured. Then, the samples were placed for 168 hours (7 days) in the climatic chamber, at a temperature of $70pm3$°C with forced air circulation (Fig. 3). After the test, UBM samples were kept in a temperature of 23 ± 5°C.

Between 1 week and 2 weeks after the end of the ageing test with high temperatures (according to the requirements of EN 17282), the following steps were undertaken:

- UBM samples were visually inspected in order to look for damages (perforation, cracking or other damage) – no damages were observed (see Fig. 1);
- static and low frequency dynamic bedding moduli were identified;
- the mass of UBM samples was measured.

Variations of the determined values of bedding moduli and change of mass were calculated using the expressions given in EN 17282 [22]:

$$\Delta C_{\text{stat}} = \frac{C_{\text{stat,post}} - C_{\text{stat,pre}}}{C_{\text{stat,pre}}} \cdot 100\ [\%] \tag{3.1}$$

Fig. 3. UBM samples no. 88.6 during the ageing test with high temperatures: a) sample during the mass measurement; b) samples in the climatic chamber

$$\Delta C_{\mathrm{tend}} = \frac{C_{\mathrm{tend,post}} - C_{\mathrm{tend,pre}}}{C_{\mathrm{tend,pre}}} \cdot 100\ [\%] \tag{3.2}$$

$$\Delta C_{\mathrm{dyn5Hz}} = \frac{C_{\mathrm{dyn5Hz,post}} - C_{\mathrm{dyn5Hz,pre}}}{C_{\mathrm{dyn5Hz,pre}}} \cdot 100\ [\%] \tag{3.3}$$

$$\Delta m = \frac{m_{\mathrm{post}} - m_{\mathrm{pre}}}{m_{\mathrm{pre}}} \cdot 100\ [\%] \tag{3.4}$$

where: $C_{\mathrm{stat,pre}}$, $C_{\mathrm{stat,post}}$ – static bedding modulus (for the load range $0.02 \div 0.10$ N/mm$^2$) measured before and after the ageing test, correspondingly,

$C_{\mathrm{tend,pre}}$, $C_{\mathrm{tend,post}}$ – static bedding modulus (for the load range $0.02 \div 0.20$ N/mm$^2$) measured before and after the ageing test, correspondingly,

$C_{\mathrm{dyn5Hz,pre}}$, $C_{\mathrm{dyn5Hz,post}}$ – low frequency (5 Hz) dynamic bedding modulus measured before and after the ageing test, correspondingly,

$m_{\mathrm{pre}}$, $m_{\mathrm{post}}$ – mass of the sample measured before and after the ageing test, correspondingly.

## 3.4. Detailed test results for selected UBM samples

This section presents detailed results of the ageing test with high temperatures carried out on five selected UBM samples differing in material and thickness, representing five tested material types:

- sample No. 38.6 – mineral wool (density 230 kg/m$^3$, thickness 35 mm);
- sample No. 53.6 – SBR granules and fibres (density 500 kg/m$^3$, thickness 20 mm);
- sample No. 60.6 – PU (density 180 kg/m$^3$, thickness 25 mm);
- sample No. 72.6 – PU (density 120 kg/m$^3$, thickness 25 mm);
- sample No. 88.6 – SBR granules (density 1100 kg/m$^3$, thickness 23 mm).

Mats No. 60.6 and 72.6 are based on the same raw material (rebound PU), they come from the same production plant, but differ in density (see Table 6). The rebound polyurethane used is a mechanically crumbled polyurethane waste, such as particles of polyurethane foams from car and furniture upholstery, sports mats etc., glued with polyurethane adhesive.

All tested samples had the same dimensions of 300 mm x 300 mm. The rubber-based sample (No. 53.6) had an additional protective layer made of grey geotextile at one side, and polyurethane-based samples (No. 60.6 and 72.6) had black geotextile layers at both sides.

Results of the static and dynamic bedding moduli tests for five selected UBM samples are presented Tables 7–11 and in Figs. 4–8. They include initial values (determined before the ageing test, marked as "pre") and final values (determined between 1 and 2 weeks after the ageing test, marked as "post"). Additionally, Tables 7–11 contain results of the mass measurements before and after the ageing test.

Table 7. Ageing test with high temperatures – static and dynamic bedding moduli, and mass of UBM sample No. 38.6

| Property | 38.6_pre | 38.6_post | Δ [%] |
|---|---|---|---|
| $C_{\text{stat}}$ [N/mm$^3$] | 0.025 | 0.022 | –12.0 |
| $C_{\text{tend}}$ [N/mm$^3$] | 0.036 | 0.032 | –11.1 |
| $C_{\text{dyn5Hz}}$ [N/mm$^3$] | 0.031 | 0.027 | –12.9 |
| $m$ [g] | 725.9 | 725 | –0.12 |

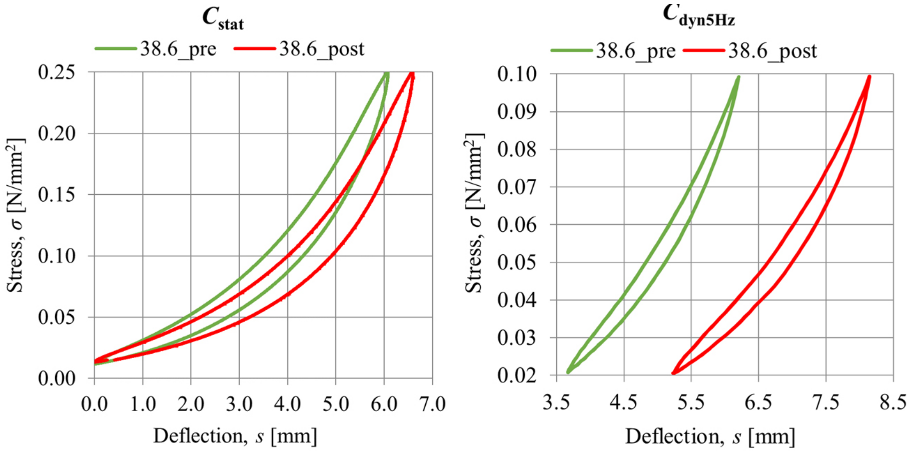

Fig. 4. Ageing test with high temperatures – static and low frequency dynamic bedding modulus of UBM sample No. 38.6

Table 8. Ageing test with high temperatures – static and dynamic bedding moduli, and mass of UBM sample No. 53.6

| Property | 53.6_pre | 53.6_post | Δ [%] |
|---|---|---|---|
| $C_{\text{stat}}$ [N/mm$^3$] | 0.023 | 0.024 | 4.3 |
| $C_{\text{tend}}$ [N/mm$^3$] | 0.035 | 0.036 | 2.9 |
| $C_{\text{dyn5Hz}}$ [N/mm$^3$] | 0.040 | 0.042 | 5.0 |
| $m$ [g] | 799.4 | 800.3 | 0.11 |

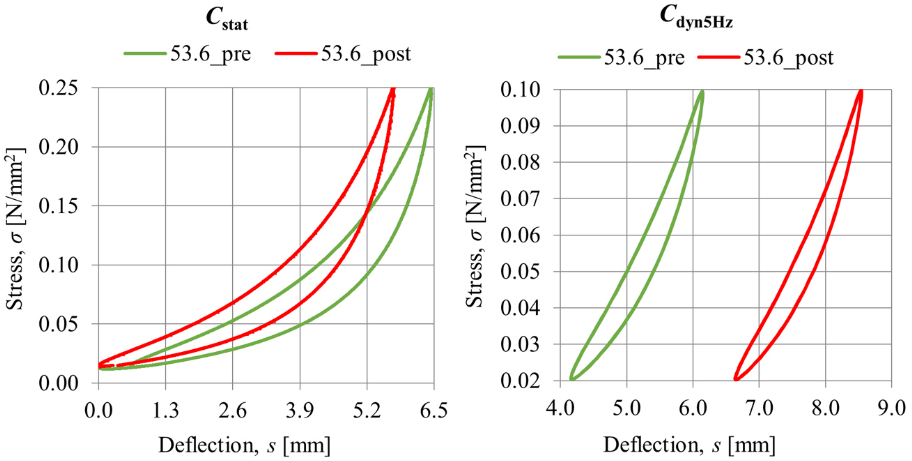

Fig. 5. Ageing test with high temperatures – static and low frequency dynamic bedding modulus of UBM sample No. 53.6

Table 9. Ageing test with high temperatures – static and dynamic bedding moduli, and mass of UBM sample No. 60.6

| Property | 60.6_pre | 60.6_post | Δ [%] |
|---|---|---|---|
| $C_{stat}$ [N/mm$^3$] | 0.019 | 0.021 | 10.5 |
| $C_{tend}$ [N/mm$^3$] | 0.029 | 0.031 | 6.9 |
| $C_{dyn5Hz}$ [N/mm$^3$] | 0.032 | 0.036 | 12.5 |
| $m$ [g] | 459.0 | 457.4 | -0.35 |

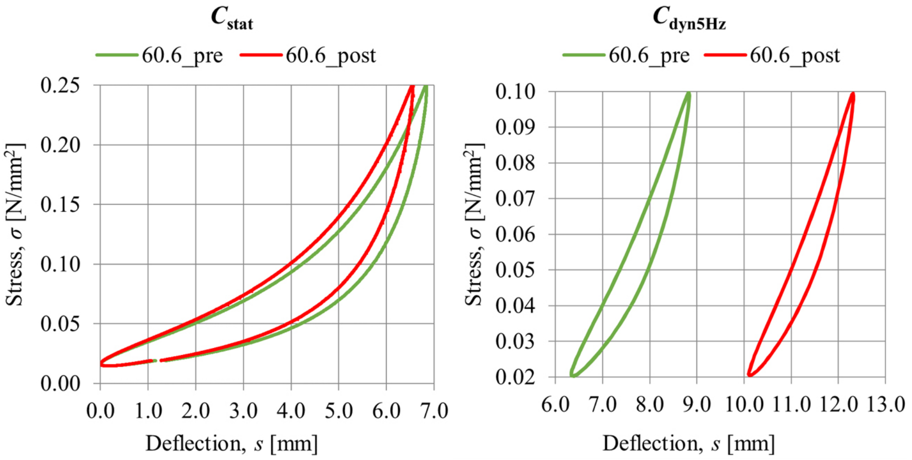

Fig. 6. Ageing test with high temperatures – static and low frequency dynamic bedding modulus of UBM sample No. 60.6

Table 10. Ageing test with high temperatures – static and dynamic bedding moduli, and mass of UBM sample No. 72.6

| Property | 72.6_pre | 72.6_post | Δ [%] |
|---|---|---|---|
| $C_{\text{stat}}$ [N/mm$^3$] | 0.027 | 0.030 | 11.1 |
| $C_{\text{tend}}$ [N/mm$^3$] | 0.043 | 0.046 | 7.0 |
| $C_{\text{dyn5Hz}}$ [N/mm$^3$] | 0.046 | 0.055 | 19.6 |
| $m$ [g] | 277.3 | 275.4 | -0.69 |

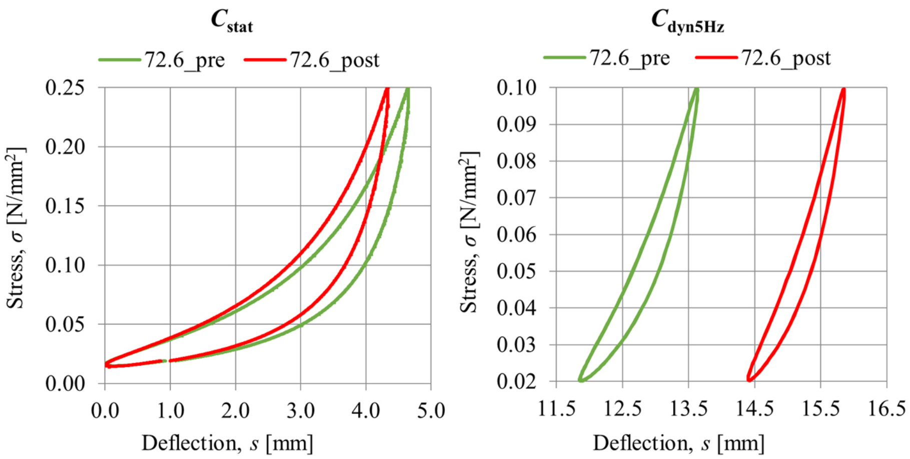

Fig. 7. Ageing test with high temperatures – static and low frequency dynamic bedding modulus of UBM sample No. 72.6

Table 11. Ageing test with high temperatures – static and dynamic bedding moduli, and mass of UBM sample No. 88.6

| Property | 88.6_pre | 88.6_post | Δ [%] |
|---|---|---|---|
| $C_{\text{stat}}$ [N/mm$^3$] | 0.122 | 0.122 | 0.0 |
| $C_{\text{tend}}$ [N/mm$^3$] | 0.150 | 0.152 | 1.3 |
| $C_{\text{dyn5Hz}}$ [N/mm$^3$] | 0.166 | 0.166 | 0.0 |
| $m$ [g] | 2277.1 | 2274.1 | -0.13 |

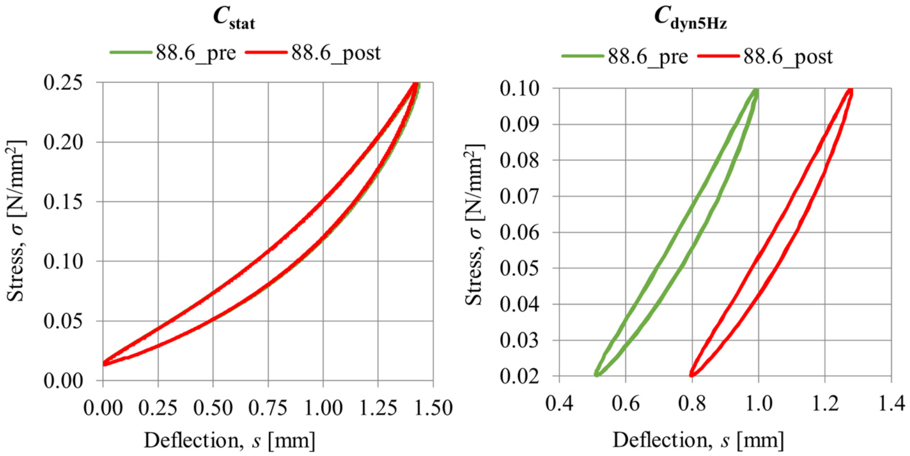

Fig. 8. Ageing test with high temperatures – static and low frequency dynamic bedding modulus of UBM sample No. 88.6

## 3.5. Full test results for all UBM samples

Tables 12–15 present full results of the ageing test with high temperatures carried out on all prototype UBM samples. It should be noted that no perforation, cracking or other damage was observed in any of the tested samples. Values which do not fulfil the proposed requirements are marked in red.

Table 12. Ageing test with high temperatures – variations of static and dynamic bedding moduli, and mass obtained for UBM samples based on mineral wool

| Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled |
|---|---|---|---|---|
| 38.6 | –12.0 | –12.9 | –0.12 | + |
| 39.6 | –9.1 | –3.7 | –0.14 | + |

Table 13. Ageing test with high temperatures – variations of static and dynamic bedding moduli, and mass obtained for UBM samples based on SBR granules

| Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled | Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled |
|---|---|---|---|---|---|---|---|---|---|
| 40.6 | 2.8 | 2.7 | 0.03 | + | 90.6 | 0.0 | 0.8 | –0.11 | + |
| 41.6 | 0.0 | 1.7 | 0.20 | + | 91.6 | –1.3 | 0.0 | –0.15 | + |
| 42.6 | 0.0 | 2.3 | 0.22 | + | 92.6 | –2.1 | –1.4 | –0.20 | + |
| 43.6 | 0.0 | 3.2 | 0.21 | + | 93.6 | –2.6 | –1.7 | –0.22 | + |
| 88.6 | 0.0 | 0.0 | -0.13 | + | 94.6 | –2.9 | 0.0 | –0.25 | + |
| 89.6 | 0.8 | 1.2 | -0.12 | + | | | | | |

Table 14. Ageing test with high temperatures – variations of static and dynamic bedding moduli, and mass obtained for UBM samples based on SBR granules and fibres

| Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled | Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled |
|---|---|---|---|---|---|---|---|---|---|
| 44.6 | −1.7 | 2.4 | 0.27 | + | 51.6 | −4.2 |  | 0.19 | + |
| 45.6 | −2.4 | −1.7 | 0.15 | + | 52.6 |  | 6.0 | 0.21 | + |
| 46.6 | −2.2 |  | 0.18 | + | 53.6 | 4.3 | 5.0 | 0.11 | + |
| 47.6 | −2.7 |  | 0.18 | + | 54.6 |  |  | 0.14 | + |
| 48.6 |  | 1.7 | 0.17 | + | 55.6 |  | 4.0 | 0.16 | + |
| 49.6 |  |  | 0.16 | + | 56.6 | 3.7 | 4.7 | −0.24 | + |
| 50.6 |  |  | 0.19 | + |  |  |  |  |  |

Table 15. Ageing test with high temperatures – variations of static and dynamic bedding moduli, and mass obtained for UBM samples based on PU

| Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled | Sample No. | $\Delta C_{\text{stat}}$ [%] | $\Delta C_{\text{dyn5Hz}}$ [%] | $\Delta m$ [%] | Reqs. fulfilled |
|---|---|---|---|---|---|---|---|---|---|
| 57.6 |  | 8.5 | −0.27 | + | 70.6 | 7.0 | 17.8 | −0.72 | – |
| 58.6 | 8.3 | 15.3 | −0.33 | – | 71.6 | 5.9 | 17.2 | −0.75 | – |
| 59.6 | 3.8 | 14.3 | −0.34 | + | 72.6 | 11.1 | 19.6 | −0.69 | – |
| 60.6 | 10.5 | 12.5 | −0.35 | + | 111.6 | 7.7 | 12.0 | −0.68 | – |
| 61.6 | 9.1 | 20.4 | −0.36 | – | 112.6 | −10.0 |  | −0.55 | – |
| 62.6 | 4.2 | 15.0 | −0.33 | + | 113.6 | −6.7 |  | −0.57 | – |
| 63.6 | 4.5 | 13.5 | −0.27 | + | 114.6 | −15.2 | −7.8 | −0.72 | – |
| 64.6 | 7.1 | 8.9 | −0.26 | + | 115.6 | −16.0 | −10.2 | −0.73 | – |
| 65.6 | 4.8 | 5.7 | −0.31 | + | 116.6 |  | −2.6 | −0.74 | – |
| 66.6 | 5.9 | 7.4 | −0.40 | + | 117.6 | −12.9 | −6.3 | −0.55 | – |
| 67.6 | 5.1 | 13.8 | −0.30 | + | 118.6 | −12.5 | −8.3 | −0.45 | + |
| 68.6 | 10.3 | 14.3 | −0.27 | + | 119.6 | −15.8 | −5.3 | −0.53 | – |
| 69.6 | 4.5 | 20.0 | −0.73 | – |  |  |  |  |  |

## 3.6. Discussion of results

The following conclusions can be drawn from the performed laboratory tests:

- the EN 17282 procedure [22] is appropriate for assessing the ageing resistance of UBMs;
- among five UBM samples presented in detail in Section 3.4, material No. 88.6 shows the best ageing resistance (Table 11, max. variation of the bedding moduli approx. 1.3%, variation of the mass approx. 0.1%), and material No. 72.6 exhibits the worst

properties (Table 10, max. variation of the bedding moduli approx. 20%, variation of the mass approx. 0.7%);

- among samples with similar values of the initial bedding moduli, the SBR-based mat (No. 53.6, Table 8) shows higher ageing resistance than the mineral wool-based mat (No. 38.6, Table 7);
- curves of the dynamic elastic characteristics obtained for five UBM samples (Section 3.4) between 1 and 2 weeks after the end of the ageing test (Figs. 4–8) show significant shifts in the deflection values (from approx. 0.3 mm in Fig. 8 to approx. 4 mm in Fig. 6) relative to the position of the initial curves, which indicates a loss of permanent elasticity due to exposure to high temperatures;
- 14 samples of UBMs (No. 58.6, 61.6, 69.6-72.6, 111.6-117.6 and 119.6) do not show sufficient resistance to ageing with high temperatures, and the remaining 37 UBM samples show sufficient ageing resistance (Tables 12–15);
- the observed decrease in mass is probably caused by chipping of sample fragments as a result of oxidation (PU-based mats), while the increase in sample mass is due to absorption of moisture from the air (SBR- and mineral wool-based mats);
- the mass variations for all tested SBR- and mineral wool-based samples are small and do not exceed 0.25% of the initial mass, while they are larger for PU-based samples (mostly below 0.4%, max. value 0.75%);
- an important feature that determines the ageing resistance of the mat is the absence of damage both before and after the ageing test, as well as the percentage change in the static and low-frequency dynamic bedding moduli, and the variation of the mass (the smaller the values of mass variation the better);
- in laboratory tests for ageing resistance performed in accordance with the procedure of EN 17282 [22], the authors recommend the following requirements:
  - no perforations, cracks or other visible damage before and after the test,
  - variation of the static bedding modulus $\Delta C_{\mathrm{stat}} \leq 15\%$,
  - variation of the dynamic bedding modulus $\Delta C_{\mathrm{dyn5Hz}} \leq 15\%$,
  - variation of the mass $\Delta m \leq 0.5\%$.

## 4. Conclusions

The aim of this study was to research the ageing resistance of prototype UBMs by performing laboratory ageing tests with high temperatures according to the procedure of the European standard EN 17282 [22]. Low resistance to ageing, defined as a change in the static and dynamic bedding moduli of the mats and their mass, has the effect of reducing their effectiveness in damping the vibration and structure-borne noise caused by railway traffic.

The authors analysed UBM samples produced from four different materials, among which three were recycled elastomeric materials: SBR granules, SBR granules and fibres, and rebond PU. Additionally, for comparison purposes, two mineral wool-based samples were tested. For all considered samples, static and dynamic characteristics before and after the ageing tests were determined, and the effectiveness of the solution in terms of protection against vibration and structure-borne noise from railway traffic was assessed. Out of 51 tested UBM samples, 14 samples (all based on PU) did not show sufficient resistance to ageing with high temperatures, and the remaining 37 samples (produced from all four materials) showed sufficient ageing resistance.

In addition to the laboratory research, the authors proposed criteria for assessing the results of the ageing test with high temperatures of UBMs tested according to the procedure of EN 17282 [22]: $\Delta C_{\text{stat}} \leq 15\%$, $\Delta C_{\text{dyn5Hz}} \leq 15\%$, and $\Delta m \leq 0.5\%$. These recommendations are a suggestion of the requirements for the Polish railway.

The experimental data obtained in this study can be used to design an isolation system for the reduction of vibrations and structure borne noise generated by rail traffic, which would reduce the vibration amplitudes compared to a reference system without UBMs over the lifetime of the railroad. Currently, the authors of this paper are focusing on development of original rheological systems that would simulate the viscoelastic behavior of UBMs, taking into account degradation effects (e.g. the influence of cyclic loading, severe environmental conditions or accelerated ageing).

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# Badanie odporności na starzenie w wysokich temperaturach prototypowych izolatorów wibroakustycznych – mat podpodsypkowych (UBMS) na bazie materiałów z recyklingu

**Słowa kluczowe:** podsypkowa nawierzchnia torowa, odporność na starzenie, mata podpodsypkowa, badania laboratoryjne UBM, wibroizolacja

## Streszczenie:

W artykule przedstawiono badania laboratoryjne odporności na starzenie w wysokich temperaturach prototypowych mat podpodsypkowych UBM, zrealizowane według procedury wprowadzonej do stosowania pod koniec 2020 r. normy europejskiej EN 17282. Niska odporność na starzenie w wysokich temperaturach, określona jako zmiana wartości statycznego i dynamicznego modułu sztywności mat UBM oraz ich masy może mieć wpływ na zmniejszenie ich skuteczności w zakresie tłumienia wibracji i hałasu wtórnego od ruchu kolejowego. Analizie poddano maty UBM na bazie materiałów elastomerowych z recyklingu (granulat i włókna gumowe SBR pochodzące ze zużytych opon samochodowych oraz poliuretan wtórnie wiązany pochodzący z odpadków z zakładów produkcji wyrobów poliuretanowych), a także – w celach porównawczych – dwie odmiany maty na bazie wełny kamiennej. Wykazano znaczące różnice wartości charakterystyk statycznych i dynamicznych względem wartości przed badaniem odporności na starzenie oraz trwałe odkształcenia w odniesieniu do mat na bazie poliuretanu z recyklingu. W przypadku mat elastomerowych na bazie gumowych materiałów recyklingowych (granulat i włókna gumowe SBR) wykazano zasadność ich stosowania biorąc pod uwagę trwałość eksploatacyjną oraz skuteczność w zakresie ochrony przed wibracjami i hałasem wtórnym pochodzących od ruchu kolejowego. Dodatkowo, na podstawie dokonanego przeglądu wymagań zagranicznych zarządców infrastruktury kolejowej oraz rekomendacji Międzynarodowego Związku Kolejowego (UIC), autorzy w artykule zaproponowali kryteria oceny wyniku badania odporności na starzenie w wysokich temperaturach w odniesieniu do mat UBM badanych według procedury nowej normy europejskiej EN 17282. Sformułowano następujące wymagania:

- brak perforacji, pęknięć i innych widocznych uszkodzeń w trakcie i po badaniu;
- zmiana statycznego modułu sztywności: $\Delta C_{\text{stat}} \leq 15\%$;
- zmiana dynamicznego modułu sztywności: $\Delta C_{\text{dyn5Hz}} \leq 15\%$;
- zmiana masy: $\Delta m \leq 0,5\%$.

Otrzymane dane z badań laboratoryjnych mogą posłużyć do zaprojektowania odpowiedniego systemu redukcji wibracji i hałasu wtórnego generowanych przez ruch pojazdów szynowych, który pozwalałby na zmniejszenie amplitud drgań w stosunku do systemu referencyjnego konstrukcji drogi szynowej bez mat UBM w całym okresie jej eksploatacji. W ramach rozwinięcia badań laboratoryjnych przedstawionych w niniejszym artykule planowane jest opracowanie oryginalnych systemów reologicznych, które symulowałyby lepkosprężyste zachowanie mat UBM, biorąc pod uwagę efekty degradacji (np. wpływu cyklicznych obciążeń, skrajnych warunków atmosferycznych lub przyśpieszonego starzenia).

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