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Investigation of the impact of environmental conditions on the vibration mitigation performance of typical commercial under ballast mat materials

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ABSTRACT

The performance of under ballast mats (UBMs) in mitigating vibrations caused by regular rail traffic has been the subject of numerous studies. However, most of these studies have focused on the impact of design and material properties on the vibration attenuation characteristics of UBMs, with little attention paid to the influence of environmental factors such as temperature, freeze/thaw cycling, and weathering. In this paper, we present the results of an investigation into the effect of environmental conditions on the vibration mitigation performance of typical commercial UBM materials including rubber and mixed cell polyurethane elastomers. We conducted controlled laboratory experiments in which we exposed UBM samples to a range of simulated environmental conditions. The results of these experiments were compared to the results of tests conducted under standard laboratory conditions to evaluate the impact of the environmental conditions on the vibration attenuation performance of the UBMs. The results of this investigation have important implications for the design and selection of UBMs for use in railway systems, particularly in regions with yearly Spring/Fall freeze/thaw weather cycles.

1. INTRODUCTION

Freeze/thaw performance testing is a crucial aspect in the evaluation of under ballast mat products used in rail infrastructure projects. The freeze/thaw cycle is a common phenomenon in regions with colder climates, where temperatures fluctuate between freezing and thawing over seasonal transition periods. The effect of this cycle can have a significant impact on the stability and durability of the track system, especially with regards to the dynamic properties of any under ballast mat present. The UBM serves as a support layer to reduce transmitted vibration and maintenance costs by easing the dynamic loading on the ballast itself [1].

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The results of freeze/thaw performance testing provide valuable information to stakeholders in the rail industry, including engineers, contractors, and operators, regarding the suitability and longevity of the product for a given project and environment.

1.1. DIN45673-5 vs EN17282

DIN45673-5 and EN17282 are two different standards that are used to quantify the fitness for purpose of UBMs [2,3]. The main difference between these two standards lies in the scope of the tests and the criteria used to evaluate the performance of UBMs.

DIN45673-5 is a German standard that covers the requirements and testing methods for UBMs used in railway infrastructure. The standard focuses mainly on the mechanical properties of UBMs, such as compression strength, tensile strength, and elongation at break. The standard also includes a requirement for freeze/thaw performance testing.

EN17282 introduced in the late 2010s, on the other hand, is a European standard updating the previous DIN standard that provides a modern and comprehensive evaluation of the fitness for purpose of UBMs. The standard covers not only the mechanical properties but also the durability, stability, and environmental performance of UBMs. EN17282 includes more extensive tests, such as water permeability, freeze/thaw resistance, and dimensional stability. The standard also provides more detailed requirements for product labeling and documentation.

In summary, EN17282 is a more comprehensive standard than DIN45673-5 and provides a more thorough evaluation of the fitness for purpose of UBMs. Both standards are useful for ensuring the quality and performance of UBMs, while the scope of EN17282 includes a wider range of factors.

1.2. Ballast Box vs Geometric Ballast Plate (GBP)

One of the major differences between the DIN45673-5 and more recent EN17282 standards is the introduction of the Geometric Ballast Plate to simulate the UBM/ballast contact interface when measuring the dynamic properties of the UBM more realistically. DIN45673-5 uses flat platens when measuring the same properties. Several studies have shown that the more realistic GBP yields slightly different measurements of the static and dynamic bedding modulus, with the GBP procedures more often than not yielding lower values. [4,5]

A ballast box is used to expose the UBM to long-term cycling conditions in both standards, however the EN17282 provides an alternative procedure without the need for ballast, using the Geometric Ballast Plate in its place.

The ballast box-based method involves filling a box lined with the UBM with ballast material, then cyclically compressing the ballast to simulate the load from railway traffic. The mechanical properties of the UBM are then measured and compared to pre-exposure values.

The EN17282 with GBP, on the other hand, uses a more sophisticated testing setup. The test involves placing the UBM on a specially designed plate that has a particular geometry. The plate simulates the actual load from railway traffic through the contact interface at the ballast/mat layer more accurately than previous methods involving a standard dynamic test frame.

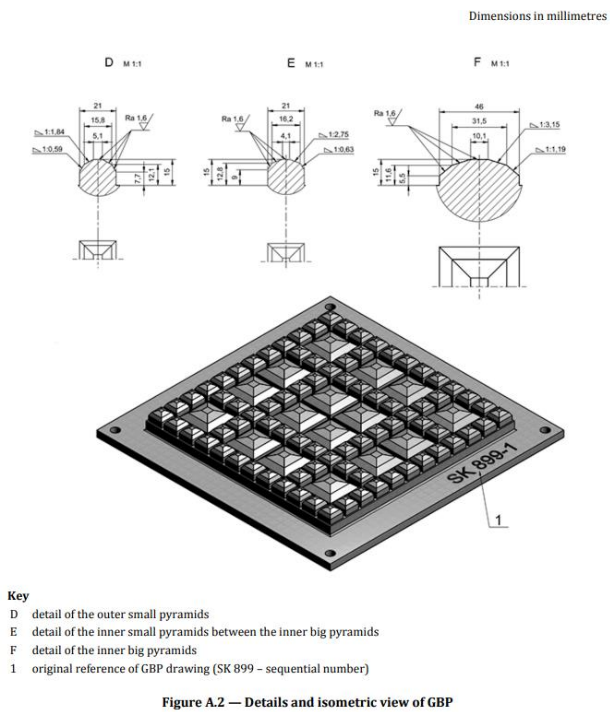


Figure 1: Detailed design drawings of the Geometric Ballast Plate prescribed in EN17282

2. Freeze/Thaw Cycling

2.1. Procedure [2]

Step 1: The UBM specimen remains fully submerged in distilled water (10 ± 5 mm above the top surface of the sample) at room temperature (23 ± 5) °C for 24 h. During the first two hours in the water bath, the UBM test sample, which has its ballast-side surface in contact with the load plate, is subjected to pulsed-load between 0.01 MPa to 0.10 MPa at a rate of 30 cycles per hour. During the next 22 h, the load plate stays on top of the UBM test sample, without any extra load. The UBM test sample remains fully submerged in distilled water.

Step 2: The water bath is drained. The sample should remain in the same position. The load plate is removed. Then place the sample inside climatic chamber for freezing at a temperature of −25 °C for 24 h in the empty water bath.

Step 3: Within 15 min after having taken the sample out of the climatic chamber, the frozen specimen is then subjected to a pulsating load (2000 load cycles) with GBP, at room temperature with a frequency of 5 Hz. Afterwards the specimen is visually inspected.

Step 4: The specimen remains at room temperature for a total duration of 24 h (including the pulsating load test duration).

Step 5: Repeat the test two additional cycles starting with Step 1.

Step 6: After Step 3 of the third cycle, the UBM test sample is stored at room temperature (23 ± 5) °C on a grid. Between 1 week and 2 weeks after test completion, the UBM test sample shall be visually inspected in order to look for evidence of damage (visually assessment of evidence of perforation, cracking or other damage) and then the static and low frequency dynamic bedding modulus (5 Hz).

2.2. Freeze/Thaw Results and Discussion

The first set of results shows the static bedding modulus (Cstat) across four track categories, where Track Category 1 (TC1) corresponds to an applied load range appropriate for light rail applications while TC4 corresponds to a load range appropriate for heavy cargo applications. The precise load ranges may be found in Annex C of EN17282.

Three similar rebonded-rubber based materials RR-1, RR-2, RR-3; and three mixed-cell polyurethane foam based materials MCPU-1, MCPU-2, MCPU-3 were tested. The Cstat values for all six mats increased after testing, indicating that the mats became stiffer.

The percentage increase of Cstat was consistent across all track categories for the rebonded-rubber materials. For the mixed-cell polyurethane materials, the percentage increase in bedding modulus was about 2-3 times that of the rubber specimens in all cases. The exception being the High Ballast Compaction TC4 load range measurements of the MCPU specimens, which could be showing the limit of the materials applied operating load where all of the air has been evacuated from the material. The before and after measurements for RR-3 are unfortunately not available due to a failed data logging step before exposure to freeze/thaw cycling.

Overall, the freeze/thaw cycling results indicate that the tested UBMs showed an increase in Cstat after testing. However, it is important to note that the performance of UBMs should be evaluated based on a comprehensive set of tests, including tests for durability, stability, and environmental performance, to ensure their fitness for purpose.

Table 1: Static Bedding Modulus Before and After Freeze/Thaw Cycling

Sample I.D.	Before/After	TC1 Cstat [N/mm^3]	TC2 Cstat [N/mm^3]	TC3 Cstat [N/mm^3]	TC4 Medium Cstat [N/mm^3]	TC4 High Cstat [N/mm^3]
RR-1	Before	0.0151	0.0176	0.0210	0.0210	0.0311
RR-1	After	0.0224	0.0267	0.0314	0.0327	0.0455
		48%	52%	50%	55%	46%
RR-2	Before	0.0126	0.0146	0.0178	0.0177	0.0274
RR-2	After	0.0158	0.0188	0.0232	0.0235	0.0362
		26%	29%	31%	33%	32%
RR-3	Before	Lost	Lost	Lost	Lost	Lost
RR-3	After	0.0165	0.0198	0.0245	0.0248	0.0382
		-	-	-	-	-
MCPU-1	Before	0.0291	0.0319	0.0343	0.0333	0.0369
MCPU-1	After	0.0631	0.0661	0.0651	0.0644	0.0500
		117%	107%	90%	94%	36%
MCPU-2	Before	0.0312	0.0341	0.0370	0.0352	0.0395
MCPU-2	After	0.0694	0.0725	0.0732	0.0742	0.0582
		122%	112%	98%	110%	48%
MCPU-3	Before	0.0310	0.0339	0.0367	0.0351	0.0392
MCPU-3	After	0.0687	0.0723	0.0726	0.0738	0.0577
		122%	114%	98%	110%	47%

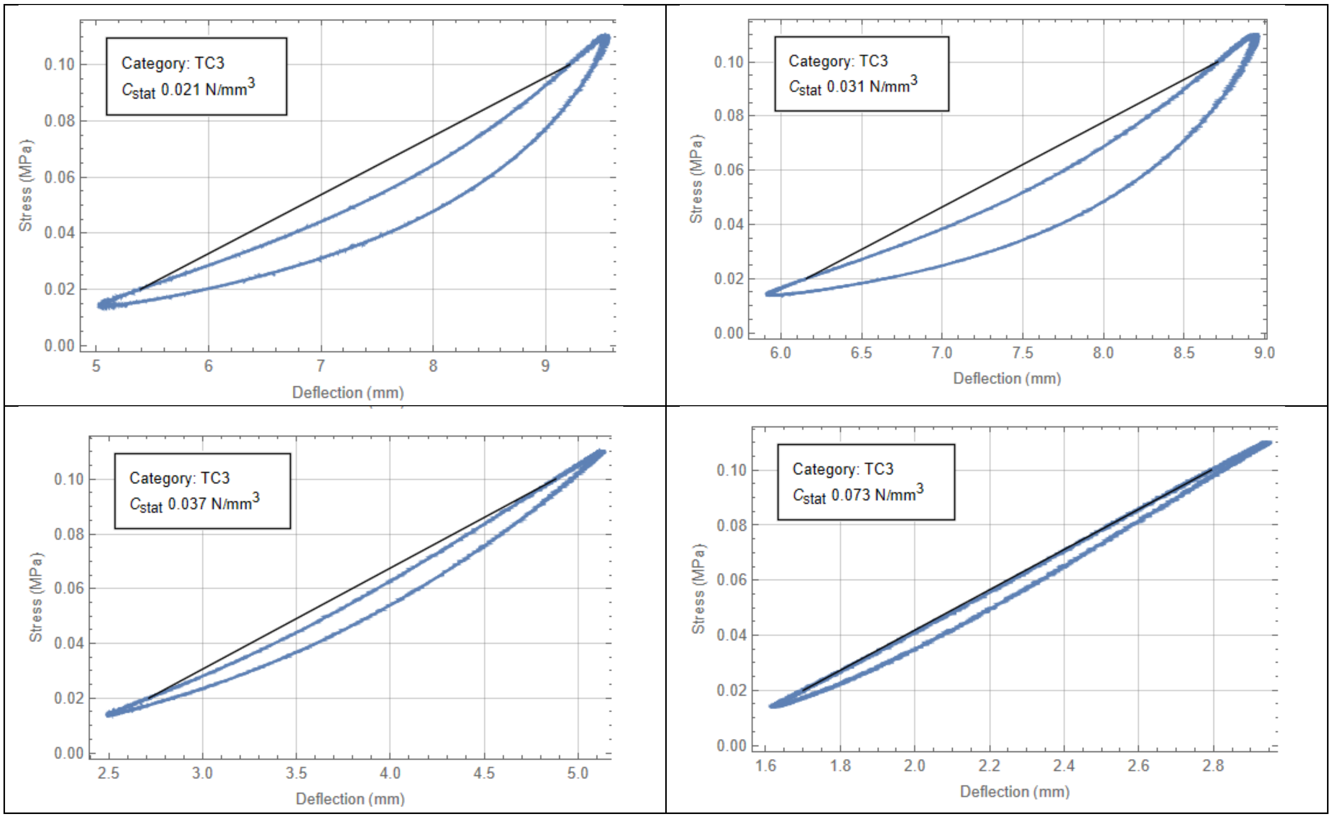


Figure 2: Example of Static Bedding Modulus Before (Left) and After (Right) Freeze/Thaw cycling with RR-1 (Top) and MCPU-2 (Bottom)

The results show the measurements of the lower frequency dynamic modulus (Cdyn) before and after freeze/thaw cycling rebonded-rubber and mixed cell polyurethane foam based materials. The measurements were taken at a frequency of 5 Hz and under TC3 conditions.

The results indicate that all tested UBMs showed an increase in the lower frequency dynamic modulus (Cdyn) after freeze/thaw cycling. The percentage increase in Cdyn was highest for the mixed-cell polyurethane material at around a 90% increase, and the lowest increase was observed for the rebonded-rubber based material at around a 30-50% increase.

The results of the Cdyn measurements are consistent with the results of the Cstat measurements provided earlier, which also indicated an increase in stiffness after testing of about 2-3 times as much occurring in the mixed-cell polyurethane based materials.

Table 2: Low Frequency Dynamic Bedding Modulus TC3 Before and After Freeze/Thaw Cycling

SAMPLE I.D. C_{dyn}(5 HZ, TC3)	**BEFORE [N/mm^3]**	**AFTER [N/mm^3]**	**% DIFF**
RR-1	0.0275	0.0413	50%
RR-2	0.0230	0.0304	33%
RR-3	0.0245	0.0320	30%
MCPU-1	0.0351	0.0661	88%
MCPU-2	0.0382	0.0741	94%
MCPU-3	0.0383	0.0735	92%

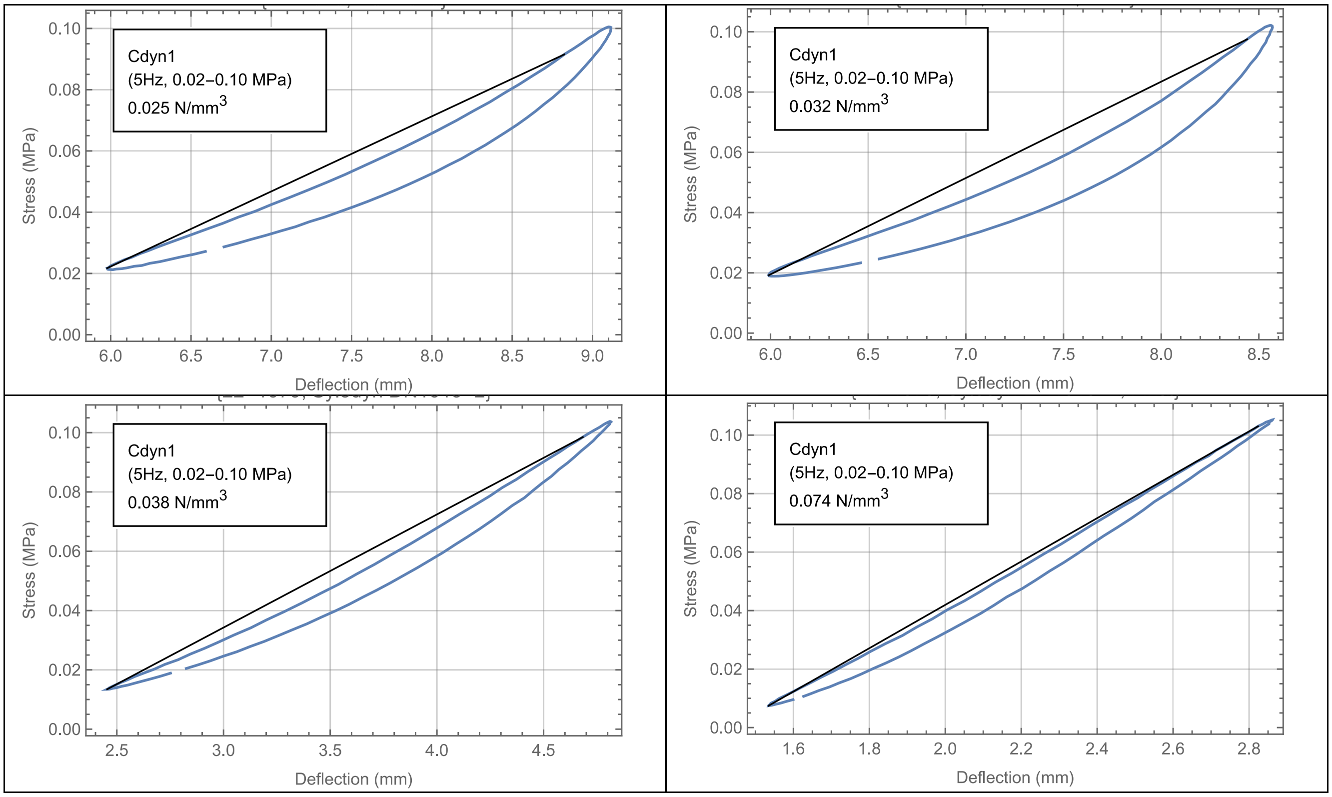


Figure 3: Example of Before (Left) and After (Right) between RR-3 (Top) and MCPU-3 (Bottom).

3. Fatigue

3.1. Procedure

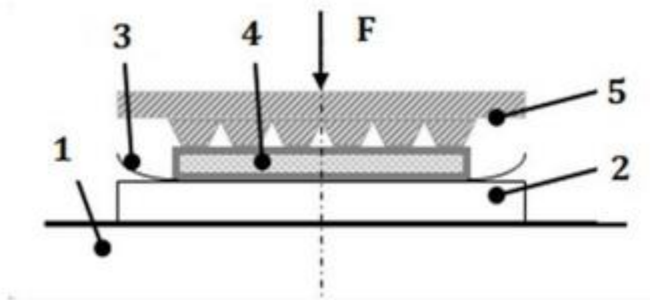
The fatigue test is based on the procedure provided in EN 17282 - Annex E, slightly modified to accommodate the specific test frame available. [2]

In this fatigue test, a cyclic force is applied normal to the UBM whilst placed on the Geometric Ballast Plate (GBP) between 0.01 MPa and 0.10 MPa at 10 Hz for 3M cycles. The bedding modulus is measured before and after the fatigue test. The GBP is connected to the actuator and therefore, the effect of weight is included in the measured force.

The dimensions of the dedicated test samples were 253 mm × 253 mm. A rigid steel support plate was used (minimum dimension 320 mm × 320 mm). The support plate is connected to a non-deformable support (key 1 of Figure E.1 in EN 17282, reproduced in Figure 4 below).

Before the fatigue test with UBM test sample and GBP starts, the following information is taken: — a visual inspection of the UBM is performed in order to check for damage resulting from installation, transport or handling of the UBM (perforation, cracking or other damage shall be documented by photographs); — the UBM test sample shall be tested according to the procedure for bedding modulus described in Annex C of EN17282: static and low frequency dynamic bedding modulus at 5 Hz.

After 3 million cycles, the load is removed from the sample. Between 1 week and 2 weeks after the test completion, the static and low frequency dynamic bedding modulus (5 Hz) are measured again. After the end of fatigue test and the end of bedding modulus test, the UBM shall be visually inspected in order to document any evidence of damage (visual assessment of evidence of perforation, cracking or other damage).



1 non-deformable support
2 support plate
3 abrasive cloth (abrasive side in contact with UBM test sample)
4 UBM test sample: the surface in contact with ballast when applied in track shall be in contact with GBP
5 GBP

Figure 4: Fatigue test set-up, reproduced from EN17282 Annex E.

3.2. Fatigue Results and Discussion

The results shown in Table 3 include before and after fatigue cycling measurements of a rebonded rubber-based UBM (RR-4) under different track category loading ranges. Cycling took place between 0.01 MPa and 0.10 MPa at 10Hz for 3M cycles. The measurements were taken for Cdyn at 5 Hz and 10 Hz, and for tan(δ) at 5 Hz and 10 Hz.

The results indicate that for all track categories, the Cdyn values increased after fatigue cycling by less than 12% in all cases. The results also indicate that there was little change in the tan(δ) values after fatigue cycling, indicating little impact on the materials damping properties.

It is worth noting that the percentage increase in Cdyn after fatigue cycling varied minimally across the different track categories. This indicates that the performance of UBMs is not strongly influenced by the track category in which they are installed. Therefore, an engineered rebonded rubber based material is appropriate for mixed traffic rail lines without a loss in performance due to fatigue.

Table 3: Lower Frequency Dynamic Bedding Modulus Measured Before and After 3M Cycles

TRACK CATEGORY	SAMPLE I.D.	BEFORE/AFTER	C_{DYN}(5 HZ) [N/mm^3]	C_{DYN}(10 HZ) [N/mm^3]	tan(δ) 5 HZ	tan(δ) 10 HZ
20-50 kPa	RR-4	Before	0.0169	0.0164	0.166	0.166
20-50 kPa	RR-4	After	0.0182	0.0178	0.167	0.167
			7%	8%	1%	0%
20-70 kPa	RR-4	Before	0.0189	0.0179	0.175	0.175
20-70 kPa	RR-4	After	0.0209	0.0198	0.171	0.170
			10%	10%	-2%	-3%
20-100 kPa	RR-4	Before	0.0214	0.0200	0.180	0.179
20-100 kPa	RR-4	After	0.0239	0.0225	0.171	0.169
			10%	11%	-5%	-6%
20-140 kPa	RR-4	Before	0.0242	0.0229	0.184	0.181
20-140 kPa	RR-4	After	0.0270	0.0259	0.175	0.173
			10%	11%	-5%	-5%

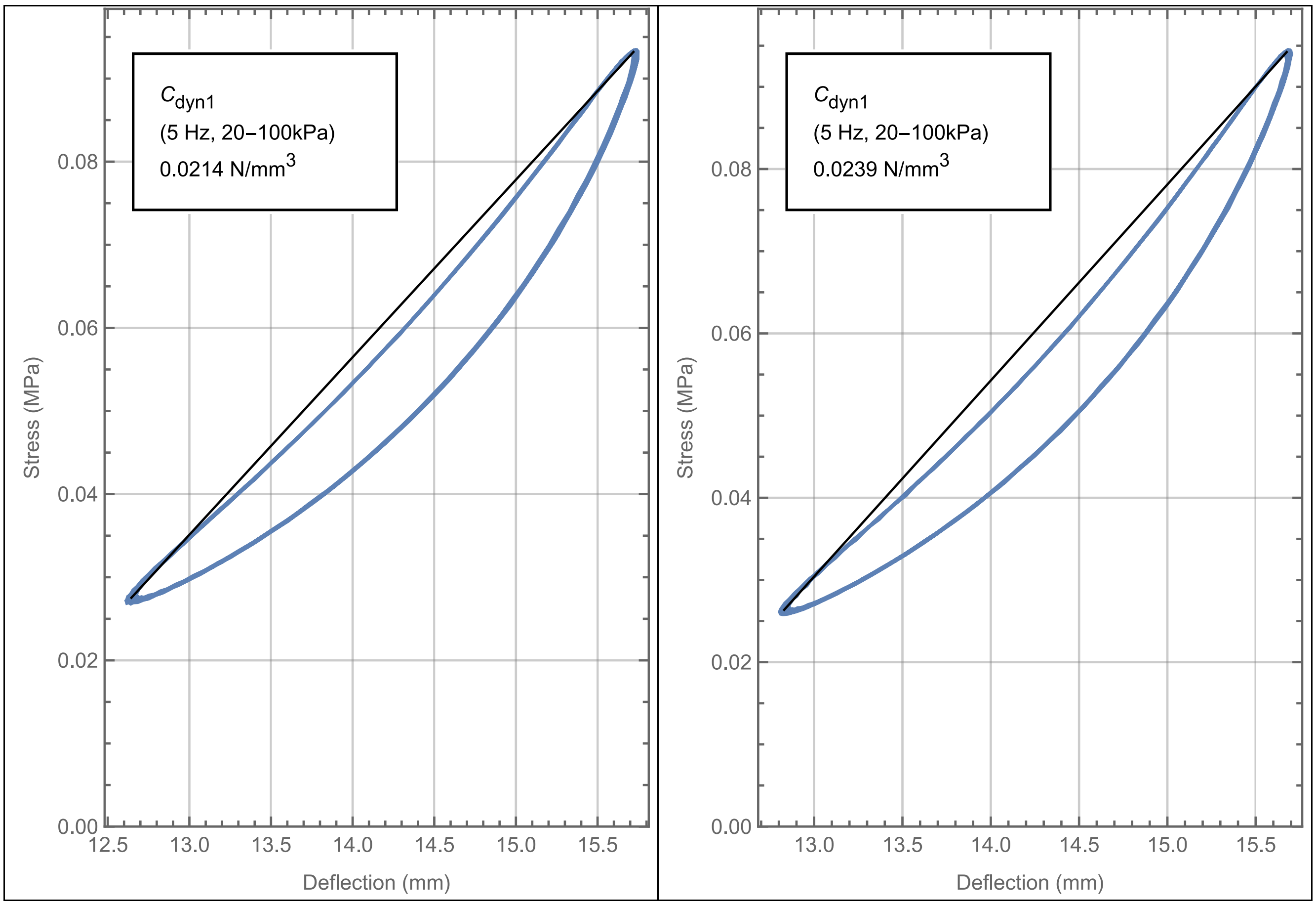


Figure 5: Example of Cdyn (5 Hz, 20-100 kPa) measured before (left) and after (right) 3M cyclic loading.

4. Conclusion

The results of the freeze/thaw cycling and fatigue testing of rebonded-rubber based material (RR) and mixed-cell polyurethane-based material (MCPU) provide valuable insights into the performance of these materials in railway infrastructure.

The freeze/thaw performance testing of these materials indicate that both are able to maintain their structural integrity, while the static and dynamic bedding modulus increase. The RR materials consistently showed lower sensitivity to this environmental exposure by a factor of about 2-3x less than the MCPU material.

The results of fatigue testing of the RR-4 specimen indicate that the material's low frequency dynamic bedding modulus shows minor degradation of ~10% across all track categories with very little impact on it's damping properties, which is a desirable characteristic for UBMs.

These results suggest that the incorporation of the impact to performance due to environmental cycling in the evaluation of UBMs is important to ensure their fitness for purpose in railway infrastructure.

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