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Research paper

Laboratory tests of resistance to severe environmental conditions of prototypical under sleeper pads applied in the ballasted track structures

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Abstract: The present paper focuses on the analysis of resistance of several prototypical under sleeper pads (USP) to severe environmental conditions. Taking into account the climate in Poland, evaluation of USP in regard to water and frost resistance should be performed and the influence of high temperatures should be analyzed. In the present paper results of several tests carried out on the selected USP are presented. The tests were performed in accordance with the rules given in PN-EN 16730. Concrete blocks with USP were immersed in water at room temperature for 24 h and then placed in a climatic chamber for resistance testing. The results show that the severe environmental conditions influence the damping-related parameters of USP, which affects the effectiveness of the vibration isolation. The performed analyses allowed the authors to indicate the most resistant pads that will undergo further testing. Additionally, requirements of several railway infrastructure managers as well as authors' recommendations concerning the properties of USP were given.

Keywords: under sleeper pads, vibration damping, resistance to severe environmental conditions

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1. Introduction

The main purpose of under sleeper pads (USP) installed in the ballasted track structures is to provide protection against vibration, preserve the ballast under the tracks and improve track stability [1, 2]. They reduce dynamic effects that are transferred from the rolling stock through the rails, fastening elements, rail supporting structure (sleepers or turnout bearers) to the ballast.

USP are produced from elastomeric materials. In the present paper two groups of materials are considered: polyurethane (with closed or open pores) and rubber (blends of natural rubber and/or synthetic rubber). The resilient pads are attached to the bottom surface of the sleepers or turnout bearers and can cover either fully or partially (in the area of the main transmission of vertical pressure) the bottom surface of the sleeper. They are assembled during the manufacturing process of the sleepers (or turnout bearers), by placing them in the formworks prior to the concrete pouring or by gluing them to the already made sleepers (or turnout bearers) with the use of a fast hardening adhesive (i.e. epoxy glue).

There are various types of USP available, that vary in geometrical and mechanical properties – they can be used in a wide range of ballasted track systems, including the high-speed rail lines and lines with high axle loads. While selecting the USP type, two main criteria must be taken into account: the maximum deflection of the rail and the natural frequency of the whole system.

USP used in the ballasted track structures have three main functions: effective vibration isolation, reduction of stress, increase of technical lifespan. They reduce the impact of vibrations and secondary noise, including the protection against stray current. By increasing the contact area between the sleeper and the ballast layer they improve the sustainability and durability of this layer. Moreover, they should maintain a long-term ability to fulfil above functions in real operating conditions, with maximum 15–25% of variability of main parameters during the laboratory fatigue tests conducted under extreme operating conditions.

In the literature there are various studies on the behaviour of USP and other vibration isolators used in ballasted track systems. Elastic elements designed for railway tracks are considered in [3]. The authors discuss different aspects of track stiffness, noise, vibrations, geometry degradation etc. The paper [4] focuses on a laboratory research on the mechanical behaviour of selected resilient elements. Various track sections are considered and solutions that reduce the track stiffness and increase the energy dissipation capacity are indicated. The authors in [5] analyze rail pads made of deconstructed end-of-life tires and assess the impact of the pads thickness on their mechanical characteristics when subjected to loads that simulate a rolling stock. The described end-of-life tires may also be used in the production of a crumb rubber that is applied as elastic aggregates mixed with ballast particles [6]. The proposed solution is aimed at reducing the ballast degradation and increase its capacity of energy dissipation. Another work [7] proposes polymer reinforced ballast tracks as a means of reducing track settlements. In [8] the authors study the vibration impairment at rail joints using elastic pads attached to concrete sleepers. In [9] it is proved that the subsidence of the track can be controlled using the resilient USP. Another paper [10] shows that the application of resilient pads can lead to reduction of the maintenance requirements and whole-life costs for the track. In [11] the authors analyze performance of USP which are aimed at reducing the ballast degradation and decreasing permanent deformation of the track. The study presented in [12] focuses on laboratory tests of fatigue strength of USP. The authors compare several USP types and indicate the pads with favourable properties from the point of view of energy dissipation and reduction of structure-borne noise and vibration.

2. Resistance to severe environmental conditions

Evaluation of USP with regard to water and frost resistance as well as the influence of high temperatures on the USP material is essential from the practical point of view. During the operating life the under sleeper pads are subject to various actions, such as water penetration, numerous freeze-thaw cycles and varying temperatures. Not taking into account these effects could lead to application of not resistant USP and, as a result, would cause the necessity to replace defective pads after a short time of service.

Resistance to severe environmental conditions should be checked in accordance with the rules given in the European Standard PN-EN 16730 [15]. For the purpose of this paper, three different USP were tested following the requirements of the mentioned standard:

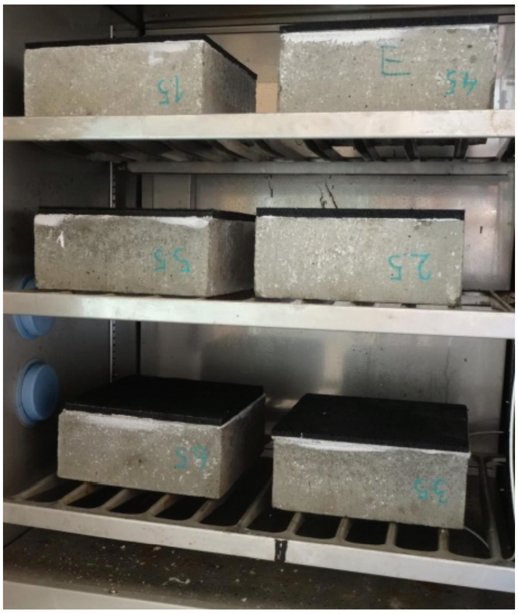
- 002 – a styrene-butadiene rubber-based pad (SBR) glued with a polyurethane glue, 9 mm thick;
- 006 – a polyurethane-based pad, 7 mm thick;
- 075 – a styrene-butadiene rubber-based pad (SBR), 10 mm thick;
- 095 – a polyurethane-based pad, 8 mm thick.

All tested USP samples had the same dimensions: 250 mm × 250 mm × thickness of USP, and they were mounted to the concrete block measuring 250 mm × 250 mm × 100 mm (Fig. 1a). Concrete blocks with the pads were immersed in water at room temperature (23±5°C – as recommended in appendix N of PN-EN 16730) for 24 h (Fig. 1b) and then placed in a climatic chamber for 7 cycles of 24 h for resistance testing (Fig. 2).

a)

b)

Fig. 1. Sample no. 002: a) attached to the concrete block; b) immersed in water for 24 h



a)

b)

Fig. 2. A series of USP samples in a climatic chamber: a) samples in a chamber; b) climatic chamber with tested samples

One of the parameters that defines mechanical properties of under sleeper pads is a bedding modulus. Static and dynamic bedding moduli determine effectiveness of damping the vibrations transmitted to the environment [13]. The values of static and dynamic bedding moduli can vary significantly: from ~0,08 N/mm^3 to ~0,45 N/mm^3 [14], depending on the type and inner structure of the material, thickness of the pad, load value for which the bedding modulus is defined and load frequency (for dynamic modulus). A low value of the bedding modulus of the under sleeper pad results in a significant shear deflection of the rail and the railway track.

The static bedding modulus indicates the rail deflection under the pressure of stationary rolling stock and has impact on the sheer deflection of the railway track. It is calculated as a ratio of the stress to the unit deflection of the rail, measured under a uniaxial load. The relationship between the static bedding modulus and the applied force is non-linear. Therefore, the static bedding modulus should be determined within different ranges of load values, depending on the type of application – the tests that are described in this paper concerned USP that can be used with concrete sleepers or bearers in Track Category no. 3 (TC3) according to PN-EN 16730 [15].

The dynamic bedding modulus characterizes the pad's work under the pressure of moving rolling stock and therefore, it determines limitation of the vibration transmission. The value of the dynamic bedding modulus is related not only to the loading force, as in the case of the static bedding modulus, but also to load frequencies.

The static and dynamic bedding moduli of under sleeper pads should be determined following the procedures described in PN-EN 16730 [15]. The samples described above were tested for both static and dynamic bedding moduli. The tests were conducted at the room temperature. The load was applied using a geometric ballast plate (GBP), which transmitted loads to the pads mounted to the top surface of the concrete blocks. The samples were supported by non-deformable smooth steel plates with a sanding disc (K240 grit on a rigid linen backing cloth). The sample loading (both static and dynamic) was applied by the INSTRON 8802 hydraulic fatigue testing system. The deflections were measured with the use of four displacement inductive sensors (WA-T type by HBM) together with HBM's Spider8 data acquisition and signal conditioning system and dedicated software – Catman AP.

For each tested sample three parameters were determined: C_{stat} – the static bedding modulus for the load range (0.01÷0.1) N/mm^2, C_{tend} – the static bedding modulus for the load range (0.01÷0.2) N/mm^2 and C_{dyn} – the dynamic bedding modulus at 5 Hz, which was obtained using the force control method. The values of these parameters are given in Tab. 1–4. Apart from the static and low frequency dynamic bedding moduli, variations of bedding moduli between before (be) and after (af) the climatic treatment were determined, using the following formula:

$$\Delta C_{\mathrm{i}} = \frac{C_{\mathrm{i,af}} - C_{\mathrm{i,be}}}{C_{\mathrm{i,be}}} \cdot 100\,[\%], \tag{1}$$

where: i={stat; tend; dyn}.

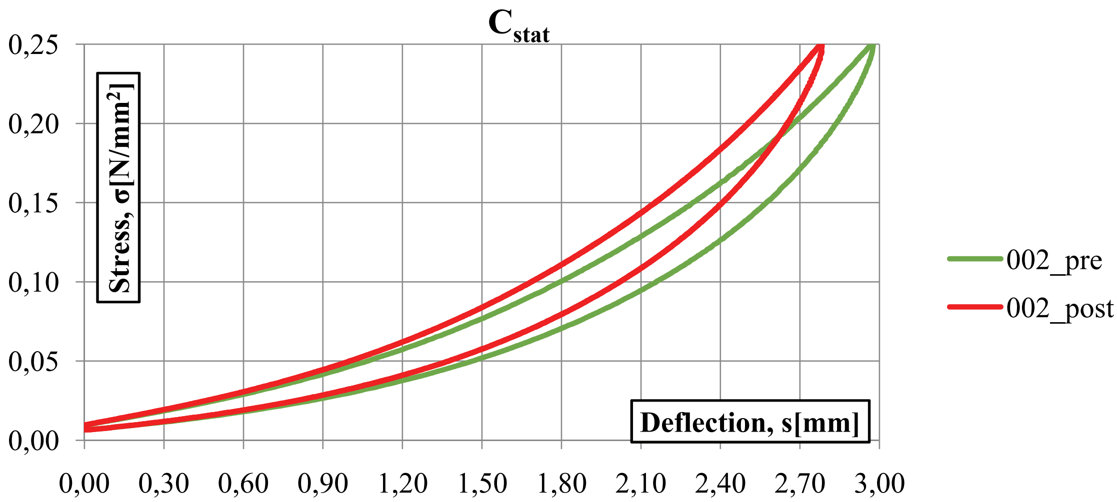
Moreover, for each sample diagrams of static and low frequency dynamic bedding moduli were prepared (Fig. 3–6). Each diagram contains two curves corresponding to: initial values (before submitting the samples to severe environmental conditions) – marked "_pre", and final values after the climatic treatment – marked "_post".

Analysis of the bedding moduli values and the curves makes it possible to indicate which of the tested samples have favourable and which unfavourable properties. As it turned out, a rubber-based sample no. 075 exhibits the best behaviour taking into account its resistance to severe environmental conditions. In the case of this sample it can be noticed that the curves after the climatic treatment are very close to the initial values, both for static and dynamic bedding moduli, which means that the sample had almost the same stiffness before and after the tests. Another rubber-based pad – sample no. 002 can also be considered as a rather good material, with the moduli variations not exceeding 10%. A polyurethane-based sample no. 006, on the other hand, has the worst properties out of four tested USP. In this case, submitting the pad to severe environmental conditions caused stiffening of the sample, which is an unfavourable effect for vibroacoustic isolators. The values of moduli variations for this sample exceed 50%, which is unacceptable taking into account the requirements described in the next section. Similarly, sample no. 095 cannot be recommended with the variations of bedding moduli reaching 40%.

In the case of samples no. 002 and 075 the curves of dynamic characteristics, determined after one to two weeks after the tests, are only slightly shifted (up to ~0.1 mm) relatively to the initial curves (Fig. 3 and 5), which proves their durable elasticity. Sample no. 075 is least prone to the effects of severe environmental conditions. The shifts of curves obtained for samples no. 006 and 095 (Fig. 4 and 6) are significant (up to ~0.3 mm), which points to the loss of their elastic properties caused by the negative influence of severe environmental conditions (water, frost, low and high temperatures).

Table 1. Values of bedding moduli and their variations for sample no. 002

Parameter	Bedding modulus [N/mm^3]		
	002_pre	002_post	ΣΔ [%]
C_{stat} (0.01–0.10)	0.056	0.059	5.4
C_{tend} (0.01–0.20)	0.078	0.083	6.4
C_{dyn05}	0.068	0.072	5.9



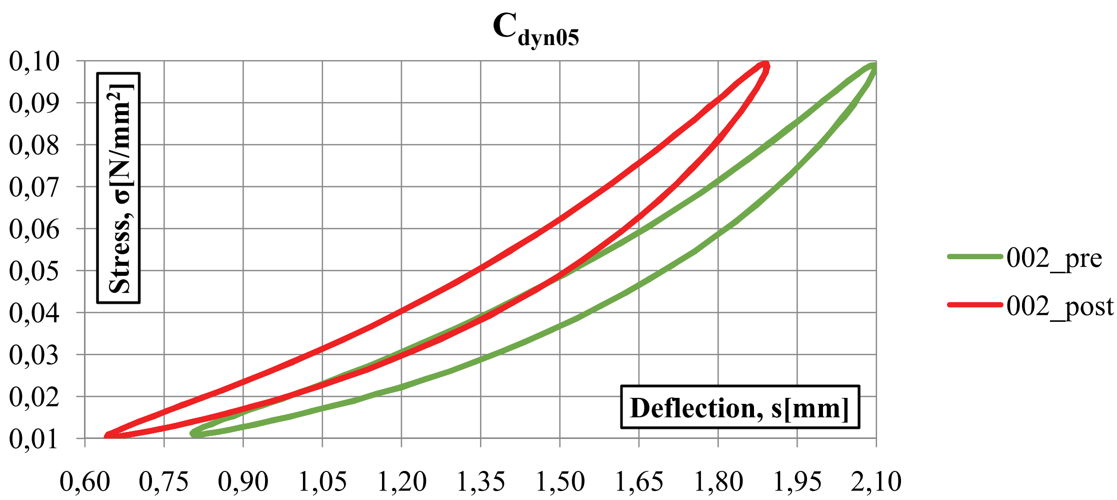
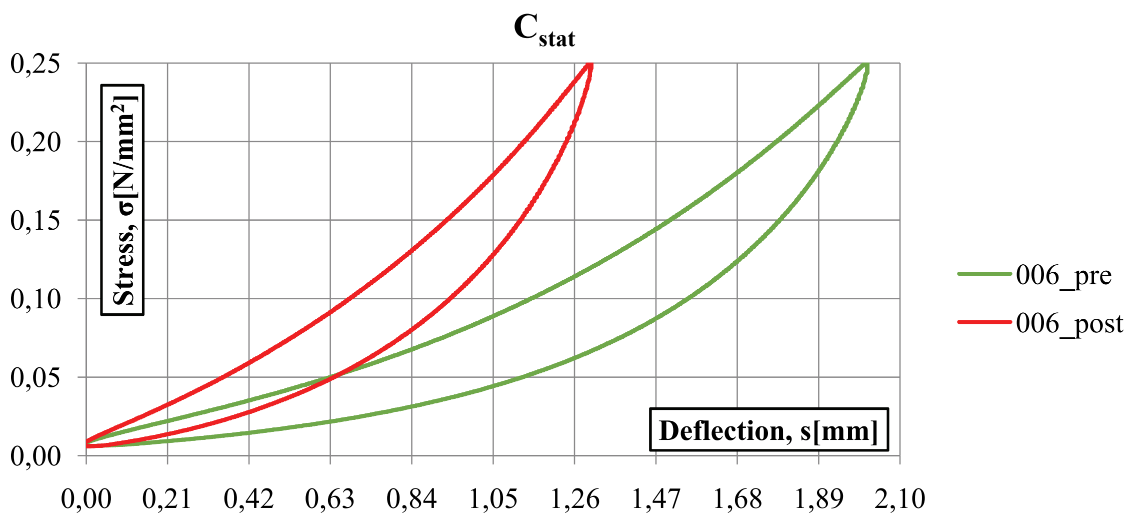


Fig. 3. Static and dynamic bedding modulus at 5 Hz for sample no. 002: values before and after climatic treatment

Table 2. Values of bedding moduli and their variations for sample no. 006

Parameter	Bedding modulus [N/mm^3]		
	006_pre	006_post	ΣΔ [%]
C_{stat} (0.01–0.10)	0.082	0.138	68.3
C_{tend} (0.01–0.20)	0.112	0.174	55.4
C_{dyn05}	0.102	0.179	75.5



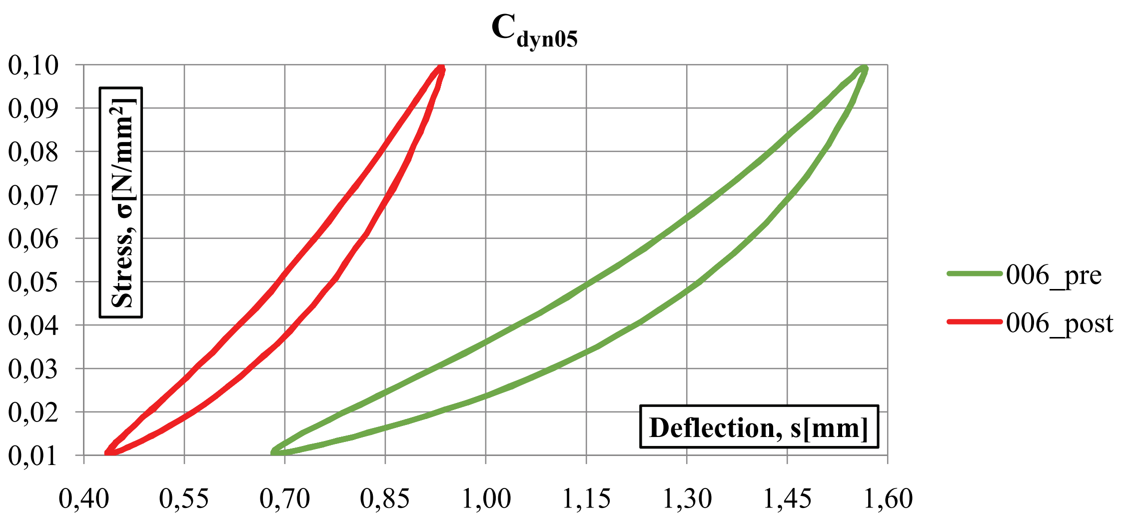
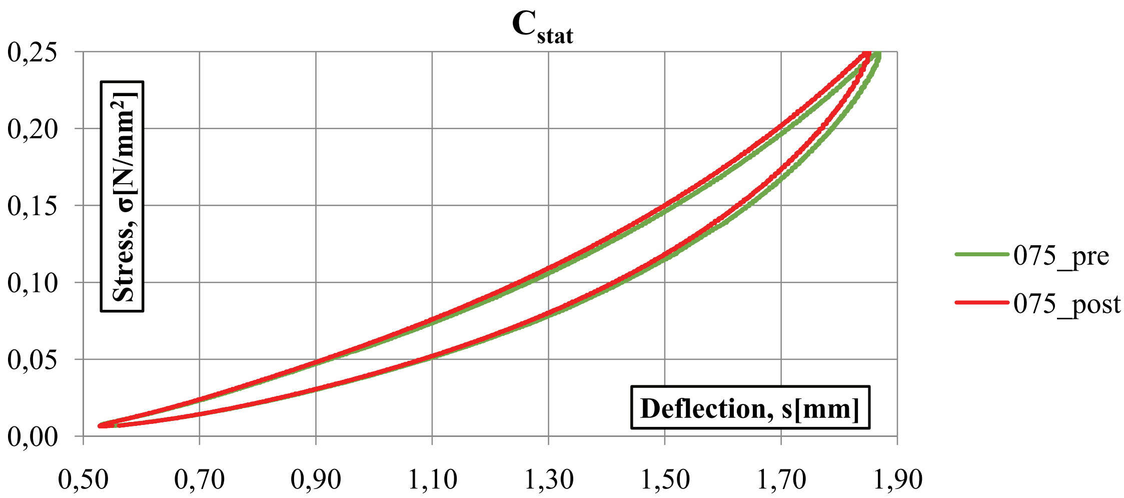


Fig. 4. Static and dynamic bedding modulus at 5 Hz for sample no. 006: values before and after climatic treatment

Table 3. Values of bedding moduli and their variations for sample no. 075

Parameter	Bedding modulus [N/mm^3]		
	075_pre	075_post	ΣΔ [%]
C_{stat} (0.01–0.10)	0.127	0.131	3.1
C_{tend} (0.01–0.20)	0.165	0.167	1.2
C_{dyn05}	0.165	0.170	3.0



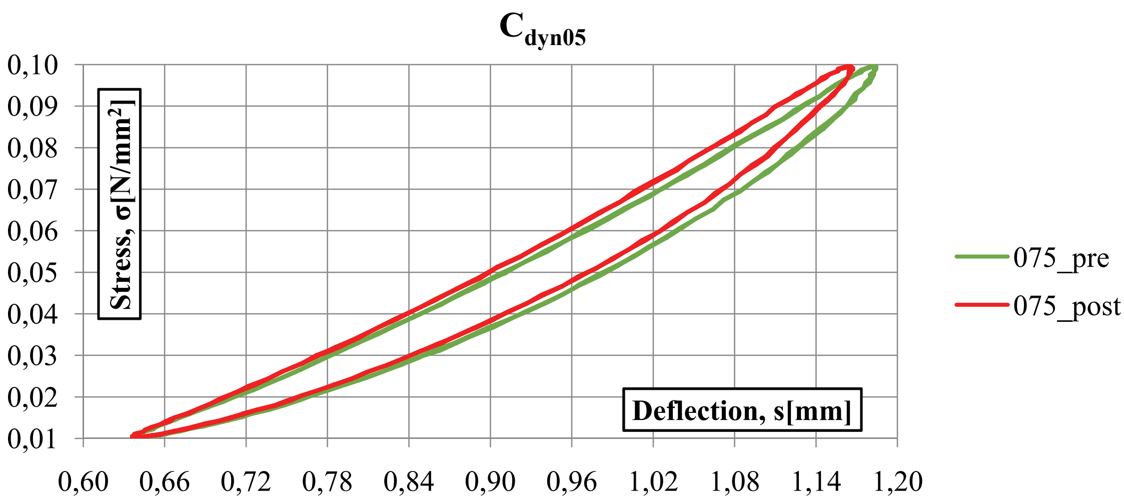
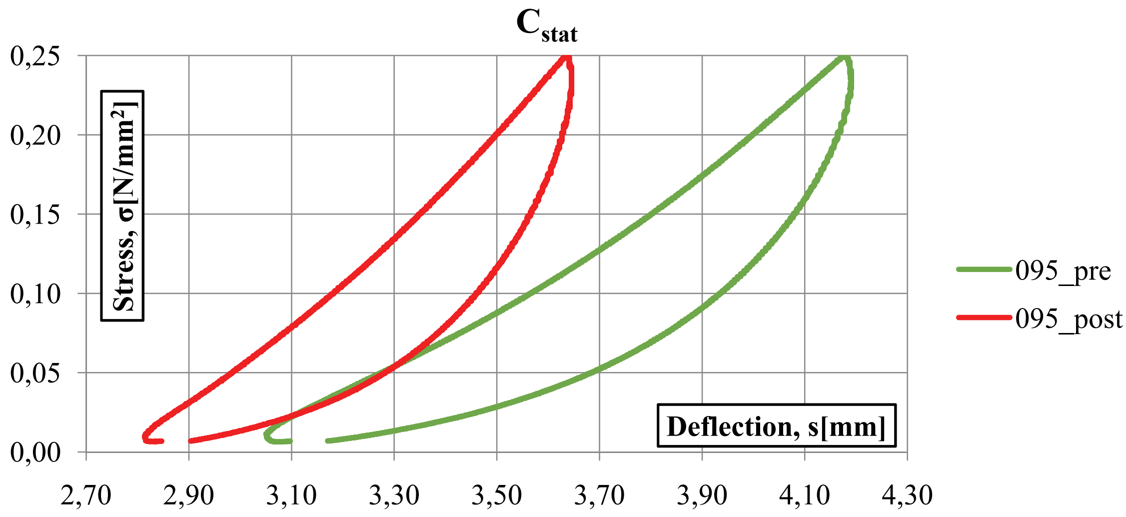


Fig. 5. Static and dynamic bedding modulus at 5 Hz for sample no. 075: values before and after climatic treatment

Table 4. Values of bedding moduli and their variations for sample no. 095

Parameter	Bedding modulus [N/mm^3]		
	095_pre	095_post	ΣΔ [%]
C_{stat} (0.01–0.10)	0.175	0.245	40.0
C_{tend} (0.01–0.20)	0.201	0.278	38.3
C_{dyn05}	0.370	0.443	19.7



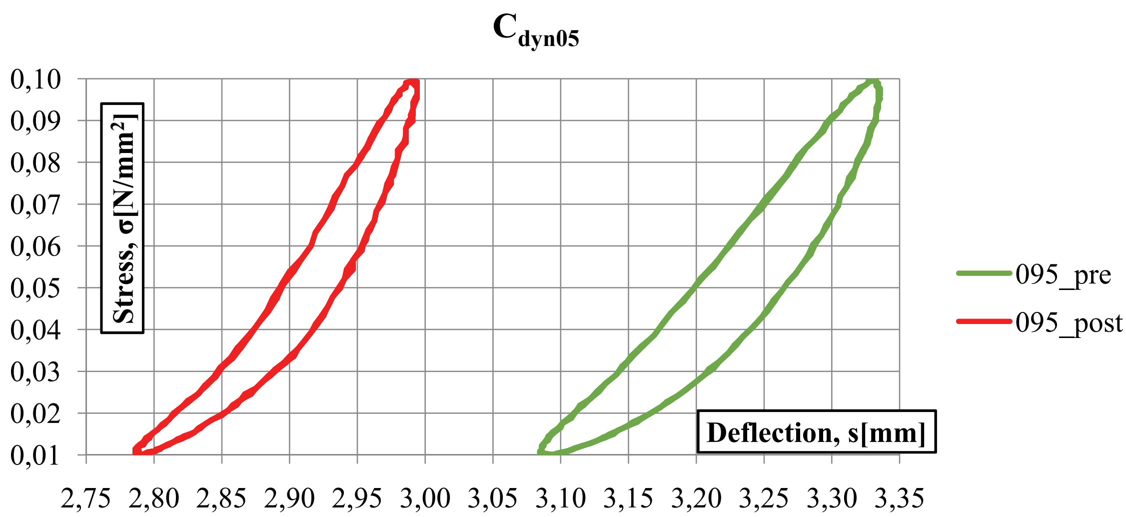


Fig. 6. Static and dynamic bedding modulus at 5 Hz for sample no. 095: values before and after climatic treatment

3. Regulations and requirements

In the absence of regulations concerning the durability of under sleeper pads with regard to severe environmental conditions in Poland, the requirements imposed by foreign railway infrastructure managers were taken into account: the Italian Infrastructure Manager RFI, the French Infrastructure Manager SNCF and the Worldwide Railway Organization UIC. Moreover, the preliminary authors' recommendations for the Polish railways PKP PLK S.A. were formulated. The most important requirements from the point of view of the durability and resistance to severe environmental conditions are presented in Tab. 5.

Table 5. Required parameters of USP (tested according to various procedures) after the tests of resistance to severe environmental conditions, based on the requirements of foreign railway infrastructure managers and preliminary authors' recommendation for the Polish railways PKP PLK S.A.

Properties		UIC [14]	Italy [16]	France [17]	Authors' recommendation
Resistance to severe environmental conditions	Appearance	no damage	no damage	no damage	no damage
	ΔC_{stat}	–	–	≤ 15%	≤ 15%
	ΔC_{dyn}(5 Hz)	≤ 15%	≤ 15%	≤ 15%	≤ 15%

In the light of the above regulations it can be noticed that two out of four tested USP samples fulfil the requirements concerning the variations of the dynamic bedding moduli: sample no. 002 and 075. In the case of samples no. 006 and 095, the said variations exceed the limiting values.

4. Discussion and conclusions

In the present paper static and dynamic characteristics of various under sleeper pads (USP), subjected to severe environmental conditions, are discussed. Such elastic elements should provide protection against vibration, preserve the ballast under the tracks and improve track stability.

For the purpose of this paper four different USP samples were put to testing: two rubber-based pads and two polyurethane-based pads. For each sample three parameters were determined: a static bedding modulus at the load range (0.01÷0.1) N/mm^2, a static bedding modulus at the load range (0.01÷0.2) N/mm^2 and a dynamic bedding modulus at 5 Hz. The samples were glued to concrete blocks and immersed in water at room temperature for 24 h and then placed in a climatic chamber for resistance testing.

The results of the performed analyses show that the rubber-based pad no. 075 exhibits the most favourable behaviour from the point of view of its resistance to severe environmental conditions. In the case of this sample it can be noticed that the curves obtained in the tests after climatic treatment are very close to the initial values, both for static and dynamic bedding moduli, which means that the sample had almost the same stiffness before and after the tests. A polyurethane-based pad – sample no. 006, on the other hand, has the worst properties – the climatic tests caused stiffening of this sample, which is an unfavourable effect as far as the resilient vibroacoustic isolators are concerned.
Two out of four tested USP samples fulfil the requirements concerning the variations of the dynamic bedding moduli: sample no. 002 and 075, which are rubber-based pads. In the case of samples no. 006 and 095 (polyurethane-based pads), the said variations exceed the limiting values. The obtained results lead to the conclusion that the rubber-based pads are less prone to the negative effects of severe environmental conditions than the polyurethane-based elements.

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Badania laboratoryjne odporności na warunki atmosferyczne prototypowych podkładek podpodkładowych USP stosowanych w podsypkowych konstrukcjach dróg szynowych

Słowa kluczowe: podkładki podpodkładowe USP, tłumienie drgań, odporność na warunki atmosferyczne

Streszczenie:

W niniejszej pracy skupiono się na analizie odporności na warunki atmosferyczne kilku prototypowych podkładek podpodkładowych (z ang. USP). Biorąc pod uwagę warunki klimatyczne panujące w Polsce, konieczna jest ocena podkładek USP pod kątem odporności na wpływ wody lub mrozu, a także wysokich temperatur. W pracy przedstawiono wyniki badań przeprowadzonych na czterech wybranych podkładkach podpodkładowych. Badania laboratoryjne zostały wykonane zgodnie z procedurami opisanymi w normie PN-EN 16730. Betonowe bloki z podkładkami USP zanurzano w wodzie w temperaturze pokojowej na 24 godziny, a następnie umieszczano w komorze klimatycznej. Uzyskane wyniki pokazują, że niekorzystne warunki atmosferyczne mają istotny wpływ na parametry statyczne i dynamiczne USP, co z kolei wpływa na efektywność tłumienia wibracji i halsu wtórnego. Przeprowadzone analizy pozwoliły autorom na wskazanie najbardziej odpornych na niekorzystne warunki atmosferyczne podkładek, które zostaną poddane dalszym badaniom.

Na potrzeby niniejszej pracy przebadano cztery różne próbki USP: dwie podkładki na bazie granulatu gumowego (próbki nr 002 i 075) i dwie na bazie poliuretanu (próbki nr 006 i 095). Dla każdej z próbek wyznaczono trzy parametry: statyczny moduł sztywności dla obciążeń z zakresu (0.01÷0.1) N/mm^2, statyczny moduł sztywności dla obciążeń z zakresu (0.01÷0.2) N/mm^2, a także dynamiczny moduł sztywności dla 5 Hz.

Wyniki przeprowadzonych analiz pokazują, że podkładka nr 075 na bazie granulatu gumowego wykazuje najbardziej korzystne właściwości z punktu widzenia odporności na warunki atmosferyczne. W przypadku tej próbki można zauważyć, że krzywe statycznych i dynamicznych charakterystyk sprężystych otrzymane po badaniu w komorze klimatycznej leżą bardzo blisko pierwotnych krzywych (przed badaniem), zarówno dla statycznego jak i dynamicznego modułu sztywności. Oznacza to, że sztywność próbki przed i po badaniu jest praktycznie taka sama. Z kolei próbka 006 na bazie poliuretanu wykazuje najmniej korzystne właściwości – testy w komorze klimatycznej spowodowały usztywnienie próbki, co jest niekorzystnym efektem w przypadku elementów wibroizolacyjnych.

Dwie z czterech badanych próbek USP spełniają wymagania dotyczące zmienności dynamicznych modułów sztywności: próbki nr 002 i 075, czyli podkładki gumowe. W przypadku próbek nr 006 i 095 (podkładki poliuretanowe), wspomniane zmienności modułów przekraczają dopuszczalne wartości. Uzyskane wyniki prowadzą do wniosku, że podkładki USP na bazie granulatu gumowego są mniej podatne na niekorzystne działanie warunków atmosferycznych niż podkładki na bazie poliuretanu.

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