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Research paper

Laboratory tests of pull-off strength of chosen USPs attached to concrete sleepers

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Abstract: Resilient under sleeper pads (USPs) are vibration isolators used in the ballasted track structure to improve the dynamic performance of the track, reduce vibrations and protect the ballast layer. Being permanently connected with the rail supports (sleepers or turnout bearers), the pads must exhibit a proper value of the pull-off strength, which ensures that they do not separate from the supports while being transported to the construction site or during many years of exploitation. This study focuses on the experimental determination of the pull-off strength of USPs attached to full scale prestressed concrete sleepers. Three variants are tested: two pads equipped with different anchor layers attached to the sleepers in the production plant and one pad glued to the sleeper in the laboratory. Some of the tested USPs are made of recycled styrene-butadiene rubber (SBR). An important part of the work is specification of the requirements for the pull-off strength of USPs, as well as the requirements for sleepers and turnout bearers equipped with resilient pads.

Keywords: ballasted track structure, pull-off strength, under sleeper pad, laboratory testing of USP, concrete sleepers

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1. Introduction

Vibration isolators, such as under sleeper pads (USPs) considered in this study, are elastic elements used in the ballasted track structures, mainly to reduce negative effects in the form of vibration and noise generated by the movement of railway vehicles. Their main function is to provide protection against noise and vibration, improve the track stability and protect the ballast layer [1, 2]. They are used, for example, when the ballast layer under the rail supports (sleepers or turnout bearers) is too small; in transition zones; when it is important to protect the track structure against fast degradation; in case of a need for protecting the built environment surrounding the track structure against vibration and structure-borne noise.

The most common materials used for the production of USPs are: polyurethane (PU) with closed or open pores, or rubber (blends of natural rubber and/or synthetic rubber, including recycled SBR from end-of-life tires) [3]. The pads are attached to the bottom part of the rail supports, either covering their whole surface, or only in active zones [4]. There are two methods of attaching the pad to the sleeper:

– during the production process of the prestressed concrete sleeper, by placing the pad on the lower surface of the unbound concrete of the sleeper, and then subjecting the sleeper to short vibrations, which cause penetration of the USP anchor layer into the still plastic concrete;
– on the ready sleeper, by gluing the pad with a fast curing adhesive, e.g. epoxy glue.

Resilient elements used in the ballasted track structures, such as USPs or UBMs, have been a subject of many studies, both numerical and experimental. However, most of the experimental research carried out on vibration isolators is based on small scale laboratory tests, using concrete blocks or parts of the sleepers instead of testing full rail supports. Although such tests are consistent with the standard requirements and provide precious information on the mechanical behaviour of tested elements, they do not cover the whole spectrum of the performance of vibration isolators in real structures. There are, however, several examples of large scale studies, which were performed either in laboratory or as field tests on real track structures.

Paixão et al. [5] carried out field measurements to analyse the response of the track to passing trains along the transition zone. They proved that USPs applied at transition zones are able to reduce the ballast degradation and influence vertical stiffness of the track. Similar results were obtained by Mottahed et al. [6] in the field tests on a transition zone to a railway bridge, where the ballasted track was equipped with USPs. Le Pen et al. [7] performed field measurements aimed at studying the behaviour of USPs at switches and crossings. Kaewunruen et al. [8] presented a field investigation into the vibration attenuation characteristic of USPs. The performed field trial was aimed at mitigating rail joint impacts in a heavy haul track under mixed traffic, by using resilient vibration isolators attached to concrete sleepers. Zakeri et al. [9] carried out a field investigation into the effect of USPs on the reduction of railway-induced ground-borne vibrations.

Omodaka et al. [10] caried out full scale laboratory tests on the ballasted track structure equipped with USPs and proved that the resilient sleepers have the effect of controlling subsidence of the track. Gräbe et al. [11] performed laboratory tests on full scale concrete sleepers with and without USPs, in order to study the effects of USPs on various aspects of the sleeper-ballast interaction, such as contact area, contact pressure, ballast settlement and ballast breakdown. Qu et al. [12] constructed a full scale section of the ballasted ladder track with two sleepers, which was used to obtain data for the validation of the numerical model of the track with USPs or UBMs. Abadi et al. [13] presented results of large scale cyclic loading tests carried out to study the performance improvement through the application of different sleeper types and modifications to the sleeper/ballast interface. They proved that the use of USPs can reduce maintenance requirements and whole-life costs for the track.

This study focuses on the laboratory pull-off tests performed on full sleepers with attached USPs. Three variants of samples are considered, differing in the type of the sleeper used, and the method of attaching the pad. Variants I and II relate to USPs attached to sleepers at the prefabrication plant, and variant III – in the laboratory, which reflects the process of bonding USPs to sleepers on the construction site. Only the pull-off tests carried out on the actual sleeper (due to its dimensions, e.g. 2.6 m length) are able to demonstrate whether the USP will be properly attached to the rail sleeper and will be able to perform its functions (e.g. vibration isolation or ballast protection) throughout the life of the railway track structure.

In the previous works, the authors of this paper studied fatigue strength [14], resistance to severe environmental conditions [15] and pull-off strength determined after the weather resistance tests [16] of USPs. Here, the main focus is put on the determination of pull-off strength in accordance with the procedure described in the European standard EN 1542 [17], using the test scheme from EN 16730 [18]. The main purpose of this study is to show that the same testing procedures and limit values of the pull-off strength can and should be applied to different products (e.g. from different manufacturers), regardless of the material (rubber or polyurethane). An important part of this work is specification of the requirements for the pull-off strength of USPs, as well as the requirements for sleepers and turnout bearers equipped with resilient pads.

2. Regulations and requirements

Due to the absence of regulations concerning the pull-off strength of USPs and the requirements for sleepers with USPs in Poland, requirements imposed by foreign railway infrastructure managers were considered. In particular, the authors took into account the regulations of the International Union of Railways UIC [19] and those of German [20], Italian [21], Belgian [22] and French [23] railway infrastructure managers. Based on the overview of the foreign requirements, the authors proposed preliminary recommendations for the Polish railways PKP PLK S.A.

Table 1 contains the requirements and authors' recommendations with regard to the pull-off strength of USPs attached to the rail supports. Table 2 gathers the requirements for sleepers or turnout bearers with USPs attached, according to the UIC recommendations [19].

Table 1. Required pull-off strength values of USPs (tested according to various procedures) based on the requirements of foreign railway infrastructure managers and preliminary authors' recommendation for the Polish railways PKP PLK S.A.

Property	UIC [19]*	Germany [20]	Italy [21]*	Belgium [22]	France [23]*	Authors' recommendation
Pull-off strength [N/mm^2]	min ≥ 0.4 mean ≥ 0.5	min ≥ 0.4 mean ≥ 0.5	min ≥ 0.4 mean ≥ 0.5	min ≥ 0.4	min ≥ 0.4 mean ≥ 0.55	min ≥ 0.4 mean ≥ 0.5

* testing procedure according to EN 16730 [18]

Table 2. Requirements for sleepers and turnout bearers with USPs attached, according to IRS 70713-1 [19]

Property	Tested feature	Requirement		
		USP type		
		soft	medium	stiff
Location of the USP relative to the rail support	Concrete edge of the sleeper (Fig. 1)	$e = 0$ or: $0 \leq e \leq 10$ mm	$e = 0 \div 20$ mm	
	Concrete sleeper step height (Fig. 1)	$s \geq 5$ mm	s – no requirements; it can be zero or take a small negative value	
	Flatness of the pad	Tolerance: ±2 mm (test in the direction perpendicular to the sleeper long axis, with a ruler of min. 300 mm)		

Recommendations of IRS 70713-1 [19] for sleepers or turnout sleepers with USPs impose requirements for the positioning of the pad in plan in relation to nominal dimensions and its positioning in relation to the height of the sleeper or turnout sleeper, as presented in Fig. 1.

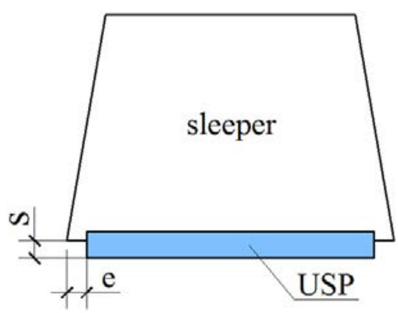

Fig. 1. Positioning the USP relative to the rail support in the horizontal and vertical plane. Symbols: e – concrete edge of the sleeper; s – concrete sleeper step height

Based on the regulations presented above, the authors proposed a series of requirements for the rail supports equipped with USPs, which are used in the Polish railways. The nominal dimensions of the USP should be adjusted to the dimensions of the sleeper or turnout bearer and cover the full bottom surface of the sleeper with an offset of 15 mm from the face and 10 mm from other edges of the sleeper (see red zones in Figs. 2 and 3), in order to protect the sleeper against mechanical damage during its transportation from the production plant to the construction site and during the construction works. The pad may consist of one or maximum two parts arranged closely next to each other. The positioning tolerance of the USP in plan relative to the nominal dimensions should equal ±3 mm. The requirements for the positioning of the pad in relation to the bottom of the sleeper or turnout bearer in vertical plane are shown in Fig. 4 and in Table 3. Moreover, according to the authors' opinion, technical conditions for the supply of sleepers or turnout bearers with USPs should impose specific requirements, which are gathered in Table 4.

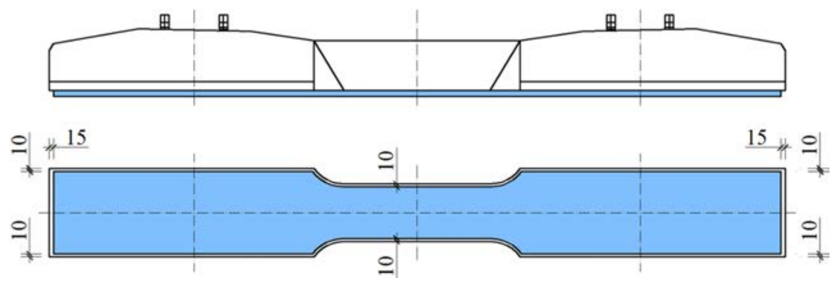

Fig. 2. Sleeper PS-83: side view and bottom view (blue colour – nominal dimensions of USP)

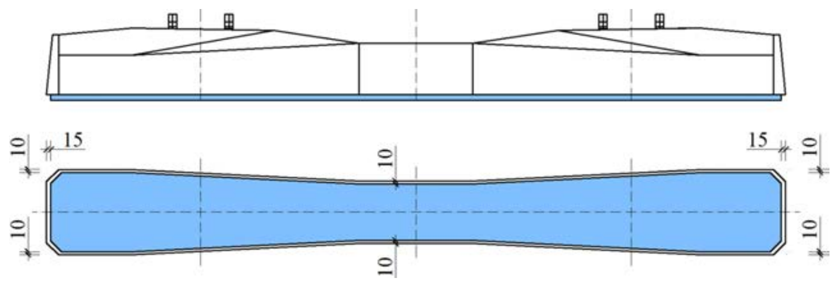

Fig. 3. Sleeper PS-93/PS-94: side view and bottom view (blue colour – nominal dimensions of USP)

Table 3. Requirements for the positioning of USP relative to the rail support in vertical plane – authors' recommendation for the Polish railways PKP PLK S.A.

Type of rail support	Requirement [mm]	Additional remarks
All types of sleepers and turnout bearers	$h_1 \geq h - 5$	USP cannot be embedded in the rail support at a depth bigger than 5 mm
	$h_2 \leq h + 20$	USP cannot stick out behind the bottom surface of the rail support by more than 20 mm

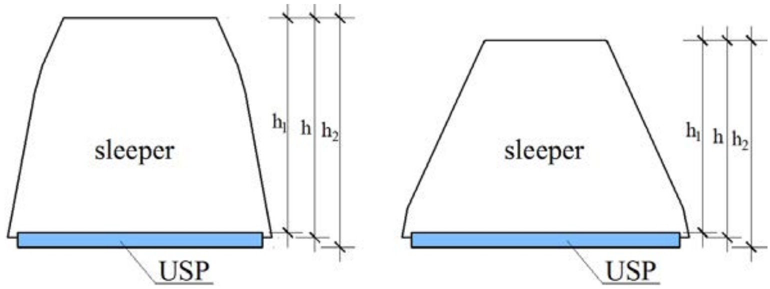

Fig. 4. Positioning of USP at the bottom of the rail support in vertical plane. Symbols: h – nominal height of the rail support; h_1 – net height of the rail support (without taking into account the part of the pad embedded inside); h_2 – total height of the rail support with USP

Table 4. Requirements for the sleepers and turnout bearers with USPs – authors' recommendation for the Polish railways PKP PLK S.A.

Property	Tested feature	Proposed requirement
Location of the USP relative to the rail support	Location in plan in relation to the edge of the rail support	According to Figs. 2 and 3, tolerance: ±3 mm relative to the nominal dimensions
	Location in vertical plane in relation to the height of the rail support	According to Table 3 and Fig. 4
	Flatness of the pad	Tolerance: ±2 mm (test in the direction perpendicular to the sleeper long axis, with a ruler of min. 300 mm)
Pull-off strength		Minimum value ≥ 0.4 N/mm^2 Mean value ≥ 0.5 N/mm^2

3. Pull-off tests

3.1. Testing procedure

USPs are elements, which are permanently connected with the rail supports (sleepers or turnout bearers). Therefore, regardless of the assembly technology, they need to exhibit a proper value of the pull-off strength, which ensures that they do not separate from the rail supports while being transported to the construction site or during many years of exploitation. If the pad got detached from the sleeper (e.g. due to the action of water and frost), it could no longer fulfil its main function, which is the reduction of vibrations and protection of the ballast. The term used in this paper "pull-off strength" is consistent with the terminology of the standard EN 1542 [17], which describes the testing procedure.

The tests were carried out on a sleeper with USP in accordance with EN 16730 [18], using the procedure described in EN 1542 [17].The location and arrangement of measurement points is shown in Fig. 5, which is consistent with Annex E of EN 16730 [18]. The procedure assumes the following parameters: test temperature ≥ 5°C (the sample is placed at temperature 24 h before the test) for routine tests and (23 ± 5)°C for design approval tests; dry condition; diameter of the tear chip (test area): Ø (50 ± 1) mm; maximum loading speed: 0.01 N/mm^2·s applied with a metal stud adhesively bonded to the USP. The testing device used in the performed pull-off tests was Dyna Z16 from PROCEQ.

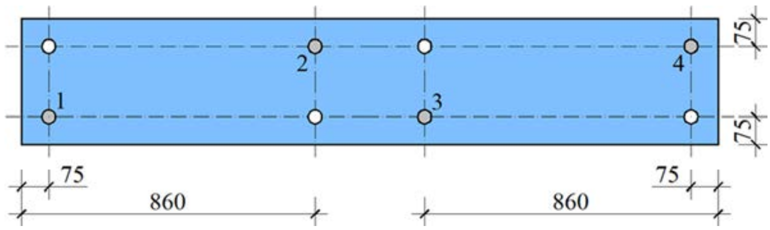

Fig. 5. Sleeper with marked location of four measurement points (1, 2, 3 and 4) for testing the pull-off strength (in accordance with EN 16730 [18])

3.2. Samples

Three variants of prestressed concrete sleepers with USPs attached were tested, variants I and II were prepared in two different sleepers prefabrication plants, variant III was prepared in the laboratory:

- variant I: sleeper PS-93 with PU-based USP (8 mm thick) attached with a plastic hook-and-loop-like anchor layer (5 mm thick);
- variant II: sleeper PS-94 with prototype SBR-based USP (9 mm thick) (Fig. 6) attached with a geotextile anchor layer (1 mm thick);
- variant III: sleeper PS-94 with prototype SBR-based USP (8 mm thick) (Fig. 7) attached with glue.

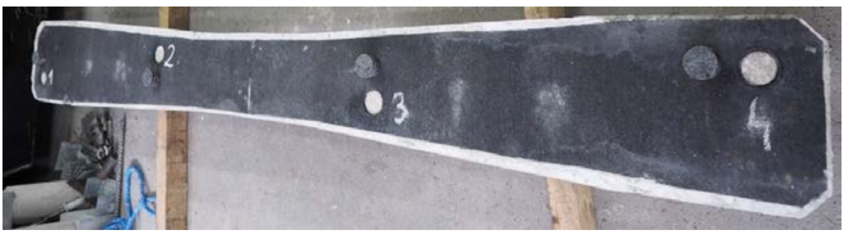

Fig. 6. Prestressed concrete sleeper PS-94 with attached prototype SBR-based USP (variant II) after the pull-off test, with marked location of four measurement points

The choice of the materials used for USPs was based on the function that they should fulfil, namely the reduction of vibration and structure borne noise, which implies the application of a soft type pad (i.e. produced from elastomeric materials). In some countries, EVA (ethylene-vinyl acetate) material is still used, but EVA-based pads are stiff – they are

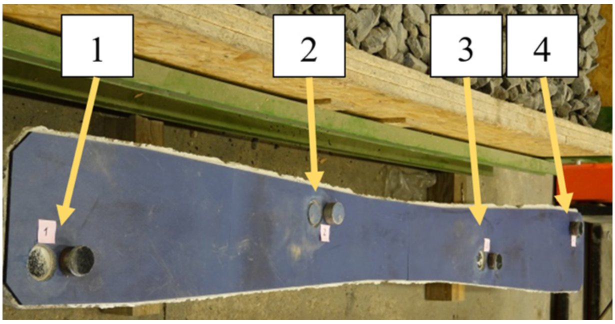

Fig. 7. Prestressed concrete sleeper PS-94 with glued prototype SBR-based USP with a blue protective layer (variant III) before the pull-off test, with marked location of four measurement points

used for the protective function (e.g. reducing the degradation of the ballast layer). The authors attempt to present different variants of USPs in order to show that the same test procedures and limit values can and should be applied to different products (e.g. from different manufacturers), regardless of the material (rubber or polyurethane).

It should also be noted that despite the unification of prestressed concrete sleeper solutions in accordance with the requirements of WTWiO PKP PLK S.A. [24], even the same types of sleepers (e.g. PS-94) may differ – which results, for example, from the use of locally available aggregate by a given sleeper prefabrication plant. Hence, conclusions for a given sleeper type from sleeper plant A cannot be applied to a sleeper of the same type from sleeper plant B. Presented research results and recommendations for the use of USPs should enable different USP solutions to be used and supplied to different manufacturers in the future. Therefore, the authors did not focus on one selected material solution or attachment method, but considered various solutions.

It is worth noticing that two out of three tested USPs were based on SBR produced from recycled end-of-life tires. The authors believe that vibration isolators based on recycled elastomers have a great potential in the construction of sustainable and environmentally friendly railway structures [25, 26]. The use of shredded rubber from recycled tires as a component of track superstructures may be one of the most effective ways of managing rubber waste.

3.3. Results

3.3.1. Variant I

During the tests of geometry of the sleeper with USP attached, examples of inaccuracies in the production technology were observed, i.e. a proper assembly that should ensure the symmetry of the USP location relative to the sleeper, a constant distance from the pad's edge to the sleeper's edge, and a full bond between the sleeper and the USP in all zones. These examples relate to improper installation of the pads at the production stage. The USP was attached to the bottom surface of the sleeper in an asymmetric manner – the distance between the edge of the pad and the edge of the sleeper varied from 10 mm to 25 mm (Fig. 8). Moreover, there were zones where the USP was not fully bonded with the sleeper – mainly in the central part of the sleeper (Fig. 9a) and at the pad's edges (Fig. 9b).

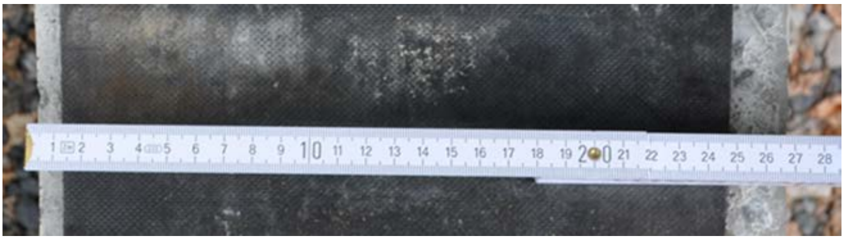

Fig. 8. Tests of dimensions of the sleeper with PU-based USP – identified varied distance between the pad's edge and the sleeper's edge

(a) (b)

Fig. 9. The zone with no bond between the PU-based USP and the sleeper: (a) in the central part of the sleeper; (b) at the edge of the pad

Results of the laboratory pull-off test performed on the PU-based USP attached to the concrete sleeper PS-93 are presented in Table 5, and the sample after the test, with visible failure type, is shown in Fig. 10.

Table 5. Results of the pull-off test on USP attached to the concrete sleeper (variant I)

Measurement point	Pull-off strength s [N/mm^2]	Failure type*
1	0.42	A/B
2	0.23	A/B
3	0.23	A/B
4	0.32	A/B

*failure type A/B means that an adhesive failure occurred between the plastic hook-and-loop-like layer, which is a part of the USP, and the concrete surface of the sleeper

Fig. 10. Failure between the plastic hook-and-loop-like anchor layer and the concrete surface of the sleeper (failure type A/B)

3.3.2. Variant II

Results of the laboratory pull-off test performed on the prototype SBR-based USP attached to the concrete sleeper PS-94 are presented in Table 6, and the sample after the test, with visible failure type, is shown in Fig. 11.

Fig. 11. Failure between the geotextile anchor layer and the elastomer material of the pad (failure type B/C)

Table 6. Results of the pull-off test on USP attached to the concrete sleeper (variant II)

Measurement point	Pull-off strength s [N/mm^2]	Failure type*
1	0.28	B/C
2	0.28	B/C
3	0.37	B/C
4	0.42	B/C

*failure type B/C means that an adhesive failure occurred between the geotextile layer, which is a part of the USP, and the elastomer material of the pad

3.3.3. Variant III

Results of the laboratory pull-off test performed on the prototype SBR-based USP glued to the concrete sleeper PS-94 are presented in Table 7 and in Fig. 12, and the sample after the test, with visible failure types, is shown in Fig. 13.

Table 7. Results of the pull-off test on USP glued to the concrete sleeper (Variant III)

Measurement point	Pull-off strength s [N/mm^2]	Failure type*
1	1.15	B/C35%-C65%
2	0.97	D
3	0.59	B/C20%-C80%
4	0.86	B/C10%-C90%

*failure type B/C-C means that partially, an adhesive failure occurred between the glue layer and the elastomer material of the pad, and partially, a cohesive failure occurred in the elastomer layer; failure type D means that a cohesive failure occurred in the protective layer of the USP

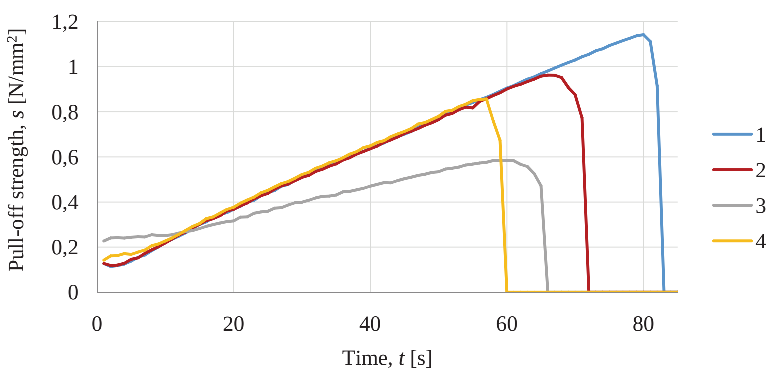

Fig. 12. Results of the pull-off test (variant III)

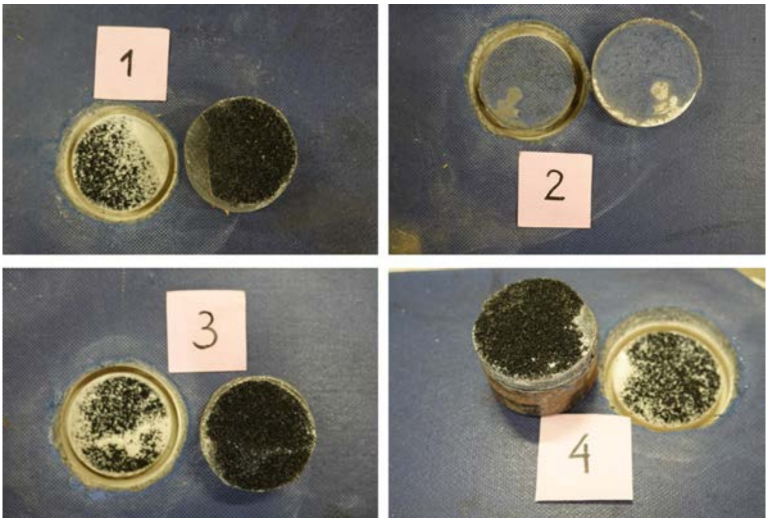

Fig. 13. Failures observed in variant III: discs 1, 3 and 4 – failure type B/C-C; disc 2 – failure type D

4. Discussion and conclusions

This study focused on the experimental determination of pull-off strength of USPs attached to prestressed concrete sleepers. Results of the laboratory tests performed on three variants of the sleeper with attached USP were presented. Variant I (sleeper PS-93 with PU USP attached with a plastic hook-and-loop-like layer) and variant II (sleeper PS-94 with prototype SBR-based USP attached with a geotextile layer) were prepared in the sleepers prefabrication plant, variant III (sleeper PS-94 with prototype SBR-based USP attached with glue) was prepared in the laboratory (the sleeper was prefabricated in the production plant, but the USP was glued in the laboratory). The tests were carried out according to the procedure described in EN 1542 [17] and the location of the measurements points was adopted in accordance with EN 16730 [18].

Moreover, the authors proposed preliminary recommendations for the Polish railways PKP PLK S.A., which are based on the regulations of foreign railway infrastructure managers, particularly the ones imposed by the International Union of Railways UIC [19]. The following limiting values of pull-off strength were proposed: minimum value ≥ 0.4 N/mm^2 and mean value ≥ 0.5 N/mm^2.

None of the variants (I and II), which were prepared in the prefabrication plant, achieved the pull-off strength values recommended by the UIC [19] (Tables 1 and 2) and by the authors (Tables 1 and 4), which – combined with the observed large deviations in the positioning of the USP in relation to the edge of the sleeper and the zones with no adhesion of the pad to the sleeper surface – leads to the conclusion that the required precision in the production has not been achieved in the analysed cases. Such a precision is necessary to ensure the durability of the connection between the pad and the rail support. However, it should be highlighted that a negative pull-off strength test result does not necessarily mean that the particular pad is not suitable for future use, but only that the bonding must be improved until the required pull-off strength values are achieved.

Apart from the pull-off strength values, the authors also analysed types of failures that occurred in the tests. In variant I, failure type A/B was observed, which is an adhesive failure between the plastic hook-and-loop-like layer, which is a part of the USP, and the concrete surface of the sleeper. In variant II, failure type B/C was identified, which means that an adhesive failure occurred between the geotextile layer, which is a part of the USP, and the elastomer material of the pad. In variant III, two types of failures were observed: B/C-C and D. Failure type B/C-C indicates partially an adhesive failure between the glue layer and the elastomer material of the pad, and partially, a cohesive failure in the elastomer layer. Failure type D means that a cohesive failure occurred in the protective layer of the pad.

In the authors' opinion, direct application of anchor layer solutions from other countries in Poland (e.g. the PU-based USP solution used in variant I and described in detail in [16]) does not provide the proper value of pull-off strength, because it should be modified taking into account, for example, the mutual proportion of dimensions between the spatial mesh of the plastic hook-and-loop-like layer and the ballast grains used for the production of sleepers in Poland (in accordance with the requirements of PKP PLK S.A. regarding prestressed concrete sleepers and turnout bearers [24]).

The tests presented in this study must be repeated for each specific case: for a specific USP, a specific fastening method and a specific type of sleeper from a specific prefabrication plant. Such tests should be carried out both as type tests (at the certification stage for prestressed concrete sleepers with USPs) and at the factory production control stage (for a randomly selected number of sleepers with USPs from the entire manufactured batch). The parameters in Table 4 are those that should be verified by the manufacturer in the prefabrication plant at the factory production control stage. Research on the development of a solution for the anchor layer of USP with concrete sleepers, suitable for Polish conditions, should be continued – cooperating with the producers of both USPs and concrete sleepers.

In this paper, USPs attached to prestressed concrete sleepers with a length of 2.6 m were investigated. Significantly greater problems in ensuring the required pull-off strength (both in the case of prefabrication and on-site installation) may arise when USPs are mounted to prestressed concrete turnout bearers, the length of which may be longer than the length of the sleepers – e.g. SP06a and SP-93 with lengths of up to 4.9 m. Tests of the pull-off strength of USPs attached to prestressed concrete turnout bearers will be a further part of the research work carried out by the authors of this study.

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Badania laboratoryjne przyczepności przez odrywanie wybranych podkładek USP przymocowanych do betonowych podkładów

Słowa kluczowe: podkładka podpodkładowa, podsypkowa nawierzchnia torowa, przyczepność przez odrywanie, badania laboratoryjne USP, strunobetonowe podkłady

Streszczenie:

Podkładki podpodkładowe (z ang. USPs – *under sleeper pads*) to elementy sprężyste stosowane w konstrukcjach podsypkowych nawierzchni kolejowej w celu poprawy pracy nawierzchni torowej pod obciążeniami dynamicznymi, zmniejszenia drgań oraz ochrony podsypki przed przyśpieszoną degradacją. Jako elementy trwale połączone z podkładami lub podrozjazdnicami, podkładki USP muszą posiadać odpowiednią wytrzymałość na odrywanie (przyczepność przez odrywanie), aby nie oddzieliły się od podpory szynowej podczas transportu na plac budowy lub w trakcie wieloletniej eksploatacji.

W artykule przedstawiono wyniki badań laboratoryjnych przyczepności przez odrywanie przeprowadzonych na podkładkach USP zamocowanych do podkładów strunobetonowych. Rozpatrywano trzy warianty próbek, różniące się typem zastosowanego podkładu oraz sposobem mocowania podkładki:

– wariant I: podkład typu PS-93 z podkładką USP ze zintegrowaną warstwą sczepną przypominającą rzepy z tworzywa sztucznego (próbka wykonana w zakładzie prefabrykacji);
– wariant II: podkład typu PS-94 z podkładką USP ze zintegrowaną warstwą sczepną w postaci geowłókniny (próbka wykonana w zakładzie prefabrykacji);
– wariant III: podkład typu PS-94 z podkładką USP przymocowaną za pomocą kleju (podkład wykonany w zakładzie prefabrykacji, podkładka USP przyklejona w laboratorium).

Ponadto autorzy zaproponowali wstępne rekomendacje dla polskich kolei zarządzanych przez spółkę PKP PLK S.A., które odnoszą się do wymagań zagranicznych zarządców infrastruktury kolejowej – w szczególności regulacji Międzynarodowego Związku Kolejowego UIC oraz przepisów obowiązujących we Włoszech i Francji, opierających się na normowej procedurze EN 16730. Zaproponowano następujące graniczne wartości przyczepności przez odrywanie: wartość minimalna $\geq 0,4$ N/mm^2 i wartość średnia $\geq 0,5$ N/mm^2.

Porównując wyniki badań laboratoryjnych przedstawione w niniejszym artykule z proponowanymi granicznymi wartościami przyczepności przez odrywanie określonymi dla USP stwierdzono, że żaden z wariantów przygotowanych w zakładzie prefabrykacji podkładów (I i II), nie osiągnął wartości wytrzymałości na odrywanie zalecanych przez UIC oraz przez autorów, co w połączeniu z obserwowanymi dużymi odchyleniami w położeniu USP względem krawędzi podkładu oraz strefami braku przyczepności podkładki do powierzchni podkładu – prowadzi do wniosku, że w analizowanych przypadkach nie osiągnięto wymaganej dokładności wykonania, a taka precyzja jest konieczna dla zapewnienia trwałości połączenia podkładki z podporą szynową. Wariant III dotyczący podkładu wykonanego w zakładzie prefabrykacji i podkładki USP przyklejonej za pomocą kleju w laboratorium osiągnął wartości wytrzymałości na odrywanie zalecane przez UIC oraz przez autorów niniejszego artykułu.

Ponadto, zdaniem autorów, bezpośrednie zastosowanie w Polsce rozwiązań warstwy sczepnej z innych krajów nie zapewnia odpowiedniej wartości wytrzymałości na odrywanie. Należy ją zmodyfikować, uwzględniając np. wzajemną proporcję wymiarów pomiędzy siatką przestrzenną z rzepów z tworzywa sztucznego oraz ziarnami kruszywa stosowanego do produkcji podkładów w Polsce (zgodnie z wymaganiami WTWiO PKP PLK S.A. dotyczącymi podkładów i podrozjazdnic strunobetonowych). Należy kontynuować badania nad opracowaniem rozwiązania warstwy sczepnej USP, odpowiedniego dla warunków polskich – we współpracy z producentami zarówno podkładek USP, jak i podpór szynowych (podkładów i podrozjazdnic).

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