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Laboratory pull-off tests for bond strength of under sleeper pads (USP)

Abstract: In the present paper results of pull-off tests performed on several prototypical under sleeper pads (USP) attached to the concrete body are presented. The pads had been tested beforehand for resistance to severe environmental conditions. The USP are used in the ballasted track systems to reduce the material and acoustic vibration emitted to the railway track's surroundings (vibration and noise) and to reduce stress in the ballast – especially in the ballast layer directly under the sleeper. The presented values of tested bond strength of the USP were compared to the requirements used by foreign railway infrastructure managers.

Keywords: Under sleeper pads (USP); Material tests; Pull-off bond strength; Resistance to severe environmental conditions

Introduction

Under sleeper pads [2, 4, 5], hereinafter abbreviated to "USP" are primarily used in ballasted railway track system to reduce the dynamic interaction between train traffic and the ballast layer, which is transmitted from the wheels of vehicles through rails, couplings and rail supports (in ballast, usually in the form of concrete sleepers and in turnouts in the form of switch sleepers). The USP may fully cover the lower surface of the base/switch sleeper (Fig. **1**) or only occur in the rail zone (Fig. **2**). The term "base", as used hereafter, is understood conventionally as a concrete base or also as a concrete switch-sleeper, where the term "concrete" has a simplistic, general meaning including all types of concrete compression technologies used in such base (e.g. pre-tensioned prestressed concrete, cable-stressed concrete, etc.).

1. Under sleeper pad (USP) - complete coverage of the foundation surface

2. Under sleeper pad (USP) - partial coverage of the foundation surface

In a ballasted track system, USP sleepers shall perform the following functions:

- limit the adverse impact of railway traffic on the environment by reducing the level of impacts in the form of material and acoustic vibrations (vibrations and noise);
- reduce stresses in the sub-ballast layer by increasing the contact surface between the sub-base and the sub-ballast, thus increasing the service life of the surface structure.

USP are fixed to the bottom of the base and this can be done in two ways:

- during the production process of the base by placing an unsettled USP sleeper on its lower surface and then subjecting the sleeper to short vibrations, which will cause the adhesion layer of the sleeper (e.g. geosynthetics) to penetrate the still plastic concrete;
- on the finished base by sticking the pads with a fast hardening and bonding adhesive (e.g. epoxy). USP may be glued to the underside of the base during the production process of the sleepers (either at the factory or at the supplier's) or after they have been manufactured, but only after they have been transported to the construction site, which provides additional protection for the pads against possible mechanical damage during transport and handling.

In USP used in different countries, the arrangement and material and design solutions of the pad layers are different and do not result from mandatory requirements of European standards or other national regulations.

The solutions to be installed during the production process of concrete base typically consist of three layers, described as follows in the order from top to bottom at the final (operational) base position:

1. a bonding layer fixed in the concrete of the sub-base, which is usually a spatial element with indentations penetrating into the concrete of the sub-base e.g. made of plastic or geosynthetics;
2. a resilient layer which, from the point of view of the function of the USP, is its basic layer made of an elastomeric material giving the pad an adequate level of stiffness;
3. a protective layer made of geosynthetics which protects the elastomer against mechanical damage caused by sharp-edged gravel grains.

The solutions for fixing a ready-made primer with adhesive to the bottom differ from the three-layer system described above in that they do not contain an upper bonding layer fixed in the primer concrete.

The third, lowest layer protecting the basic elastic layer of the USP against mechanical gravel grain damage is usually made of geosynthetics.

However, it is not necessary for this layer to be present in the material samples covered by the pull-off bond strength tests described below, as it does not come into direct

contact with the concrete of the sleeper and therefore does not affect the adhesion of the USP to the underside of the base. For this reason, there was no protective layer in several of the samples tested.

Laboratory tests of pull-off bond strength

The USP, as an element permanently connected to the base, regardless of the assembly technology of the track stud, must have an adequate adhesion (pull off strength) so that the substructure does not separate from the rail support during transport to the installation site or during its long-term operation. In order to take into account the influence of adverse weather conditions (water, frost, low and high temperatures) on the adhesion of the sleeper pad to the base during its operation on a ballasted track, the samples were previously tested for resistance to weather conditions.

The studies of pull-off bond strength described in the article were conducted for five selected prototype materials of USP - three materials based on SBR (*Styrene-Butadiene Rubber)* and two materials based on PU (*Polyurethane*) with the following markings and thicknesses:

- 002 - USP based on 12 mm thick SBR rubber granulate;
- 003 - USP based on 7 mm thick SBR rubber granulate;
- 004 - USP based on 9 mm thick SBR rubber granulate;
- 005 - USP based on 7 mm thick polyurethane;
- 008 - USP based on 10 mm thick polyurethane.

The pads No. 002, 003 and 004 based on SBR rubber granulate differ in production technology, thickness and density. No.
005 and 008 polyurethane based pads differ in thickness and density.

Preparation of samples for examination

Samples of USP were previously (before the test of pull-off bond strength) prepared for the test of resistance to weather conditions in the manner specified in PN-EN 16730 [7] and presented below:

- The USP was glued mechanically with adhesive to a concrete block (Fig. **4a**);
- after glue bonding (3-4 days), the samples were stored in water for 24 hours (fig. **3a**),
- after removing the sample from the water, it was placed in a climatic chamber (Fig. **3b**) and subjected to cyclic freezing and thawing (freezing to -15°C for 4 h, left at this temperature for 8 h, after which the temperature was increased to +40°C for 4 h, with a relative humidity of 80% and the sample remained in it for 8 h, the full cycle lasted 24 h, each time 7 full cycles were carried out), which was to simulate the atmospheric conditions in which the USP rootstock operates.

a) b)

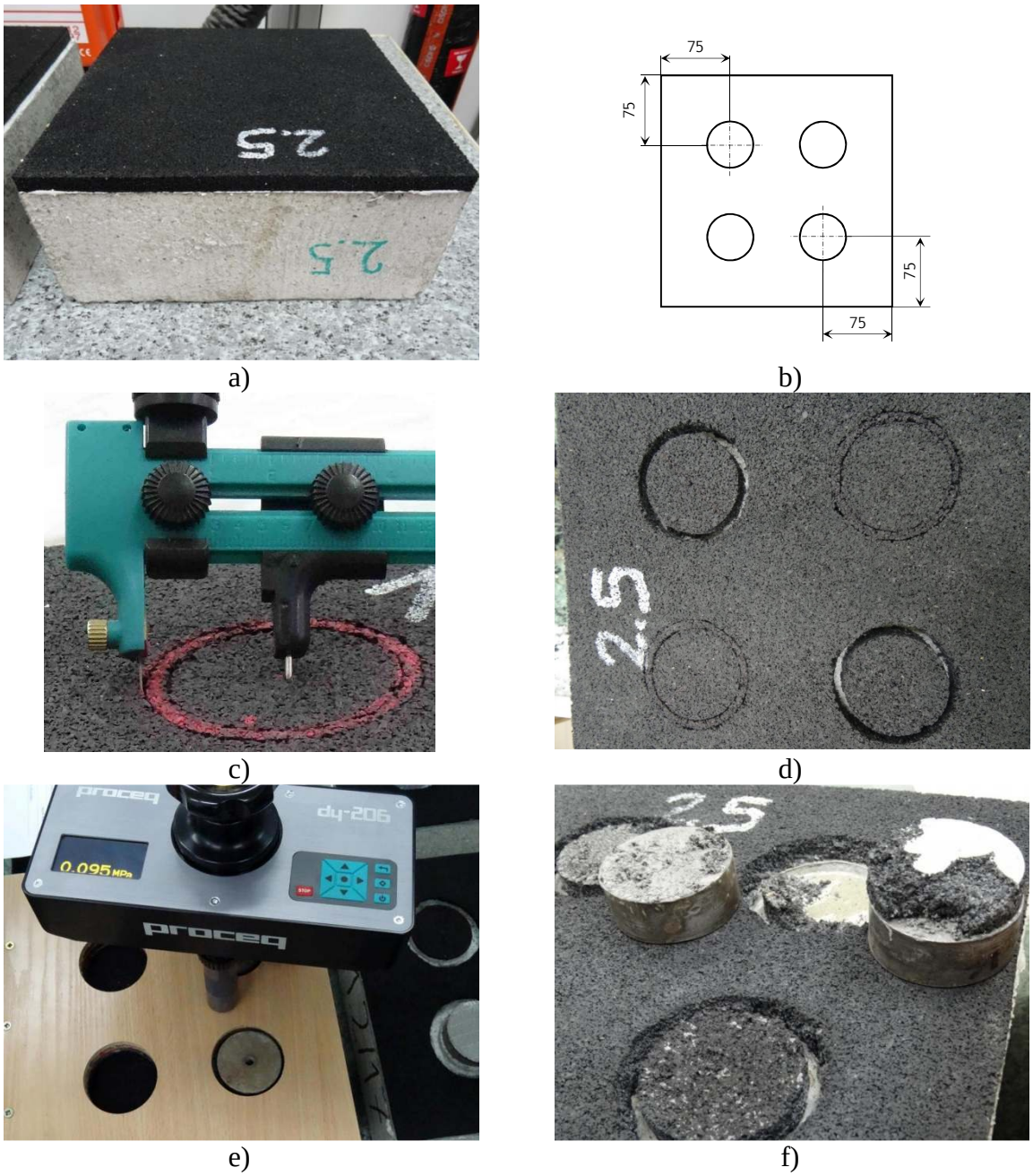
3. Samples of the USP glued mechanically to concrete cubes during the test of resistance to weather conditions: a) samples immersed in water for 24 hours; b) samples in a climatic chamber (Feutron KPK 400)

Research methodology

The test of pull-off bond strength (on samples after the test of resistance to weather conditions) was conducted according to the "pull-off" method according to the procedure described in PN-EN 1542:2000 [6]. In accordance with this method, circles of 50 mm diameter were cut out of a sample of USP and then steel discs of 50 mm diameter were glued to them. For each sample of the pads, the adhesion was measured at four points, the location of which was determined in accordance with the guidelines contained in Annex N of the PN-EN 16730 standard [7] i.e. at a minimum distance of 50 mm from the edge of the sample and the next measuring point. The diagram of measurement points arrangement is shown in Fig. **4b**.

The result of the test was the value of tack adhesion expressed in N/mm^2. The measurements were taken with the *Proceq dy-206* apparatus (Fig. **4e**). According to Annex E of PN-EN 16730, the disc tear-off rate was constant and amounted to 0.01 N/mm2·s. After testing the material sample (Fig. **4f**), the type of damage was determined according to the following criteria:

- cohesive destruction in the layer of concrete blocks (concrete foundation) - type A;
- coherent destruction in the material layer (B, C, D, E, F, G, H) - type: B, C, D, E, F, G, H;
- adhesive damage between adjacent layers - e.g. type B/C.



4. Preparation of samples of USP for testing the pull-off bond strength carried out according to the "pull-off" method: a) a USP glued mechanically to the concrete block; b) the layout of the measurement points (compliant with the requirements formulated in the PN-EN 16730 [4] standard); c) making cuts in the USP material; d) sample prepared for gluing steel pull-off discs; e) performance of peel strength measurements using a "pull-off" apparatus (Proceq dy-206); f) the pad sample after the test - visible type of damage

Test results and limit values

The results of tearing-off adhesion tests are presented in Table **1** - **5**, while the graphs of adhesion changes during the test are shown in Fig. **5** - **9**.

Tab. 1. Pull-off bond strength values for material sample No. 002 - determined on the sample after weather resistance test

Sample designation	Disc designation	Adhesion, N/mm^2	Type of damage	Layers
002	1	0,45	C/D	0 - steel disc D - Poxipol glue C - USP B - StoPox SK100 glue A - concrete block
	2	0,55	B/A15%-C	
	3	0,46	C/D	
	4	0,48	C/D	
	The average value	**0,49**	**-**	
	standard deviation	0,05	-	

Type of destruction C/D (adhesive damage between the third and fourth layer) means that there was a break at the interface between the adhesive layer to which the steel disc was glued and the material of the elastic pad USP. Type of destruction B/A15% -C (adhesive damage between second and third layer 15%, and mainly cohesive in the third layer) means that there was a partial break at the interface of the adhesive layer, which was bonded concrete foundation, and concrete block 15%, and dominant cohesive rupture in the layer of elastomeric material USP.

Tab. 2. Pull-off bond strength values for material sample No. 003 - determined on the sample after weather resistance test

Sample designation	Disc designation	Adhesion, N/mm^2	Type of damage	Layers
003	1	0,33	C/D	0 - steel disc F - Poxipol glue E - USP D - an adhesive layer bonding the adhesive layer to the USP C - bonding layer B - StoPox SK100 glue A - concrete block
	2	0,24	C/D	
	3	0,32	E/F	
	4	0,25	E/F	
	The average value	**0,29**	**-**	
	standard deviation	0,05	-	

The type of destruction C/D (adhesive damage between the third and fourth layer) means that there was a break at the interface between the adhesive layer to which the USP was glued, and the material of the USP backing layer. The type of damage E/F (adhesive damage between the fifth and sixth layer) means that there was a break at the interface between the adhesive layer to which the steel disc was glued and the material of the elastic USP.

Tab. 3. Pull-off bond strength values for material sample No. 003 - determined on the sample after weather resistance test

Sample designation	Disc designation	Adhesion, N/mm^2	Type of damage	Layers
004	1	0,45	E/F	0 - steel disc F - Poxipol glue E - USP D - an adhesive layer bonding the adhesive layer to the USP C - bonding layer B - StoPox SK100 glue A - concrete block
	2	0,41	E/F	
	3	0,45	E/F	
	4	0,34	E/F	
	average	**0,41**	**-**	
	standard deviation	0,05	-	

The type of damage E/F (adhesive damage between the fifth and sixth layer) means that there was a break at the interface between the adhesive layer to which the steel disc was glued and the material of the elastic USP.

Tab. 4. Pull-off bond strength values for material sample No. 005 - determined on the sample after weather resistance test

Sample designation	Disc designation	Adhesion, N/mm^2	Type of damage	Layers
005	1	0,14	C/B	0 - steel disc F - Poxipol glue *E - protective layer (only in samples 3 and 4)* D - mesh gluing the protective layer to the USP C - USP B - StoPox SK100 glue A - concrete block
	2	0,24	D/C	
	3	0*	E/D	
	4	0*	E/D	
	average	**0,19**	**-**	
	standard deviation	0,07	-	

*- adhesion below the minimum reading value of the "pull-off" device (less than 0.1 N / mm^2)

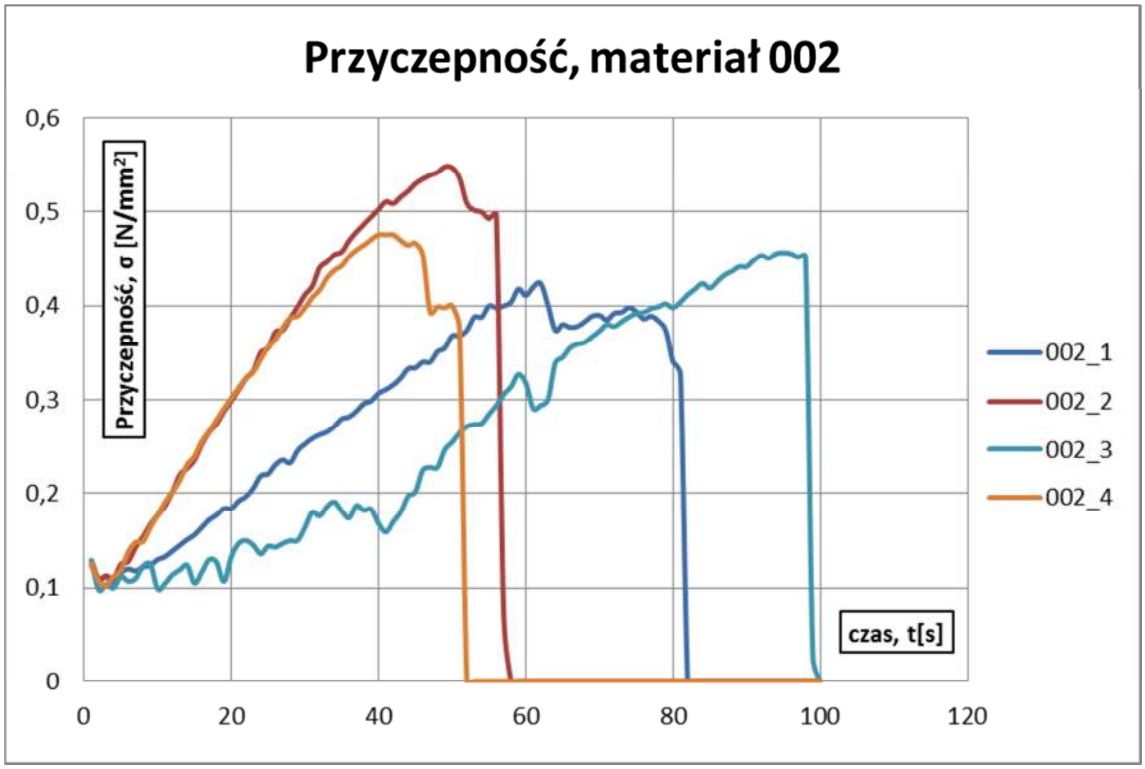
The type of C/B destruction (adhesive damage between the second and third layers) means that there was a break at the interface between the adhesive layer to which the concrete block was covered and the elastic USP pad material. In this test, the protective material was removed mechanically before gluing the steel disc. D/C destruction type (adhesive damage between the third and fourth layer) means that there was a break at the interface of the adhesive layer with a protective layer, and the material of the elastic USP pad. In this test, the protective material was removed mechanically before gluing the steel disc. Type of destruction E/D (adhesive damage between the third and fourth layers) means that there was a break at the interface between the adhesive net layer of the protective layer and the material of the protective layer

Tab. 5. Pull-off bond strength values for material sample No. 008 - determined on the sample after weather resistance test

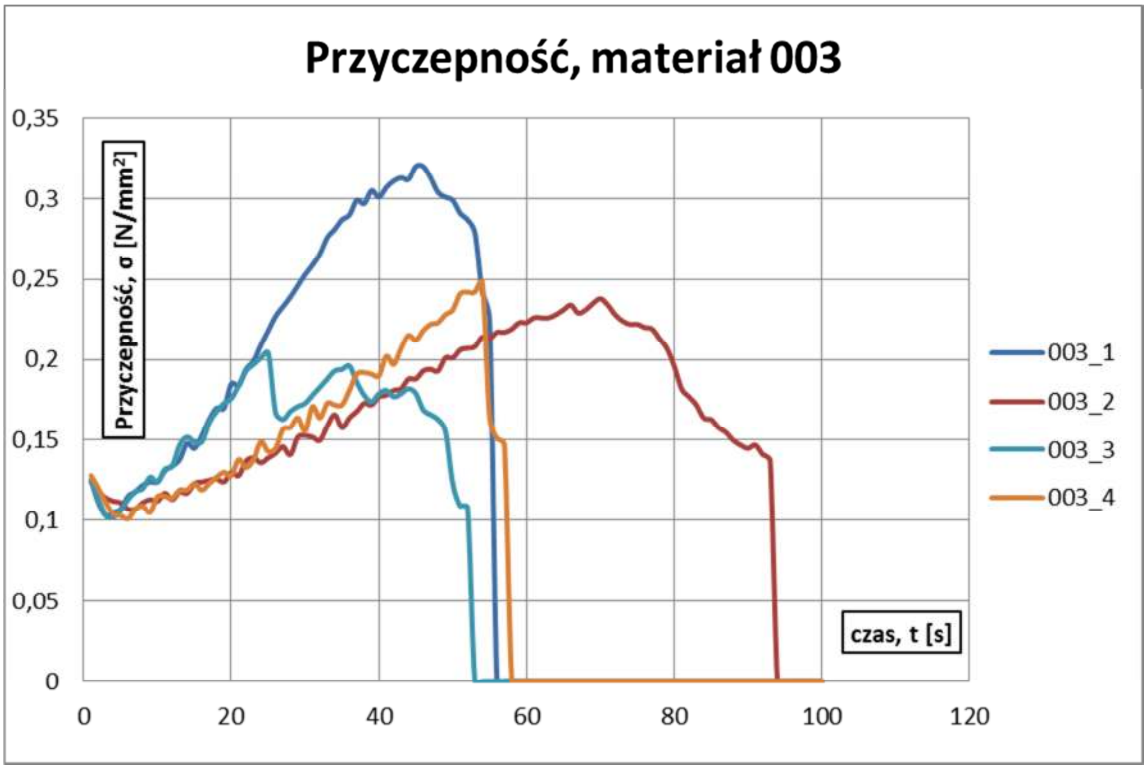
Sample designation	Disc designation	Adhesion, N/mm^2	Type of damage	Layers
008	1	0,40	B/C	0 - steel disc F - Poxipol glue *E - protective layer (only in samples 3 and 4)* D - mesh gluing the protective layer to the USP C - USP B - StoPox SK100 glue A - concrete block
	2	0,37	B/C	
	3	0*	C/D	
	4	0*	C/D	
	average	**0,39**	**-**	
	standard deviation	0,02	-	

*- Adhesion below the minimum reading value of the "pull-off" device (below 0,1 N/mm^2)

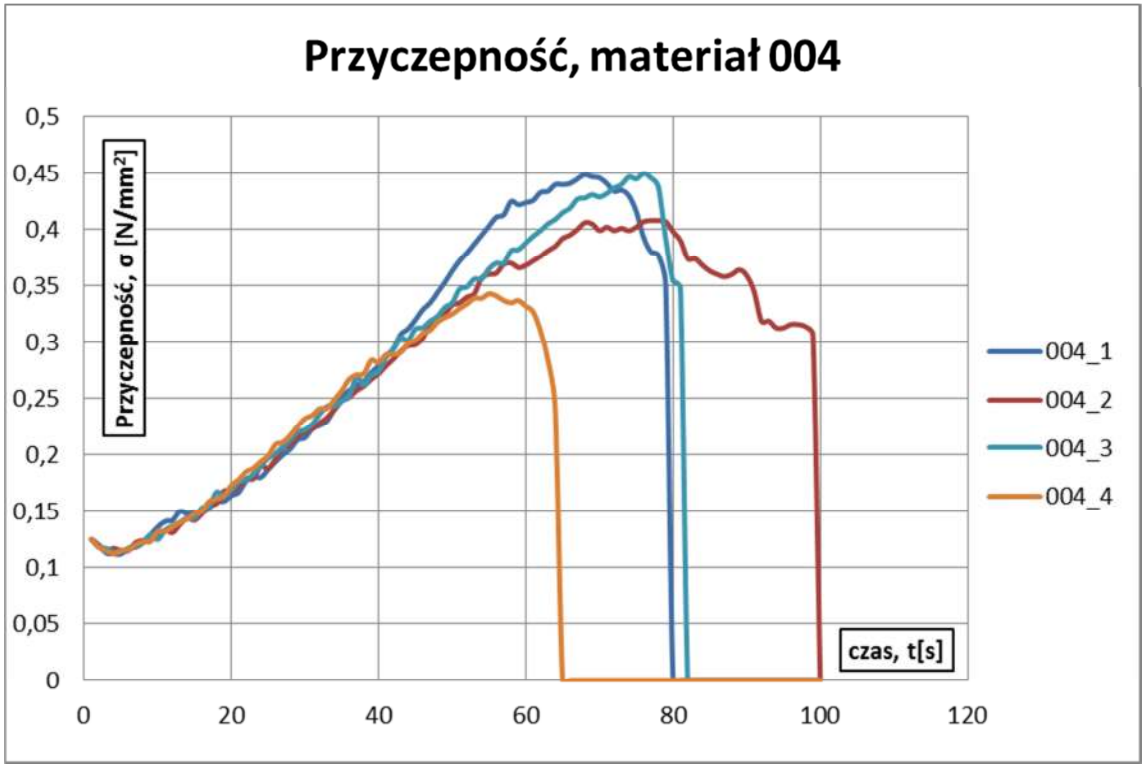
Type of destruction B/C (adhesive damage between the second and third layer) means that there was a break at the interface between the adhesive layer to which the concrete block was covered and the material of the elastic USP. In this test, the protective material was removed mechanically before gluing the steel disc. The type of C/D destruction (adhesive damage between the third and fourth layer) means that there was a break at the interface between the adhesive layer and the elastic pad material USP.



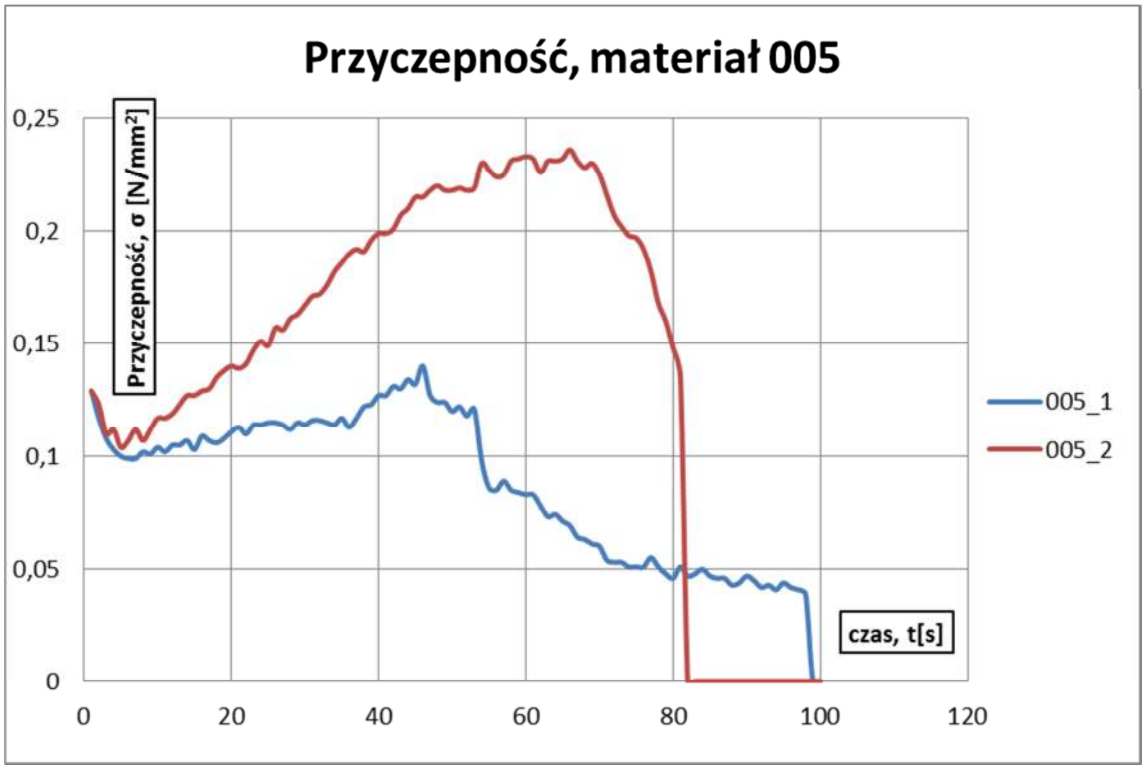
5. Pull-off bond strength for material sample No. 002 - determined on the sample after weathering test



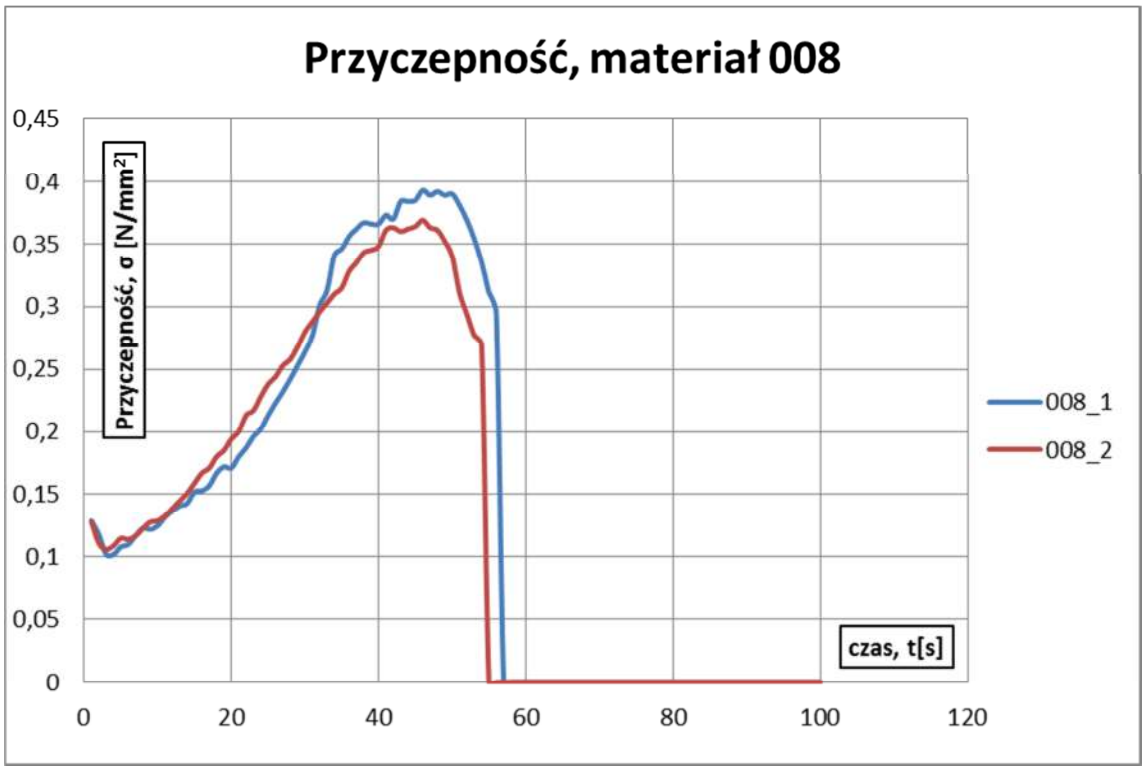
6. Pull-off bond strength for material sample No. 003 - determined on the sample after weathering test



7. Pull-off bond strength for material sample No. 004 - determined on the sample after weathering test



8. Pull-off bond strength for material sample No. 005 - determined on the sample after weathering test



9. Pull-off bond strength for material sample No. 008 - determined on the sample after weathering test

Due to the fact that the requirements for the use of USP on the PKP PLK network (including the requirements concerning the minimum value of adhesion by detachment determined on the samples after the weather resistance test) are not specified by the Polish regulations, it has been decided to refer to the limit values determined by the requirements of foreign railway infrastructure managers [1, 3, 8, 9]. These requirements are presented in Table **6**. On their basis, the authors proposed a **pull-off bond strength limit determined on the samples after the test of weather resistance of min. 0.4 N/mm^2.**

Relating the laboratory results to the proposed limit, only one of the five materials met the requirements, i.e. sample material No. 002. For the other four materials, further work to improve adhesion by detachment is recommended to reach a value of at least 0,4 N/mm^2 for each individual test.

Tab. 6. Required pull-off bond strength values after resistance test for weather conditions (for a single test) - based on the requirements of foreign railway infrastructure managers

Country/ Organisation	**Reference document**	**Required pull-off bond strength value determined on the sample after the weather resistance test (for single test), [N/mm^2], [N/mm^2].**
Germany	DBS 918 145-01 [1]	≥ 0,3
Italy	RFI TCAR SF AR 03 007 C [8]	≥ 0,4*
France	SNCF IG04013 [9]	≥ 0,6*
Union of UIC	IRS 70713-1 [3]	≥ 0,4*

*Test procedure according to EN 16730 [7]

Conclusions

The paper presents a tear-off adhesion test performed on specimens after weatherproofing for five prototype USP washers.

Of the five USP shim materials tested, only one showed adhesion above the limit proposed by the authors, based on the requirements of other European railway infrastructure managers. The remaining four materials showed unsatisfactory results and require further work on the adhesive and the material of the adhesive layer adjacent to the underside of the primer.

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Source materials

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