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RAILWAY NOISE REDUCTION BY THE APPLICATION OF CHFC MATERIAL ON THE RAIL

Summary. Traffic is the most widespread source of environmental noise. Railway noise has become increasingly common in urban areas in the past few decades. Therefore environmental requirements for railway operations regarding noise are becoming very strict and will become even tighter in future. In the present paper we present actual track-based field test performed on Slovenian Railways. The significant noise reduction (up to 30*dBA*) was achieved by the application of CHFC material on the rail using CL-E1 top anti noise system**.**

REDUKTION DES EISEBAHNLÄRMS DURCH DIE ANWENDUNG VON CHFC MATERIAL

Zusammenfassung. Der Verkehr ist die am weitesten verbreitete Quelle von Umgebungslärm. Eisenbahnlärm nahm in den letzten Jahrzehnten in städtischen Gebieten immer mehr zu. Aus diesem Grund wurden die Umweltanforderungen für den Bahnverkehr bezüglich des Lärms immer strenger und werden in der Zukunft noch höher. In der vorliegenden Arbeit stellen wir den tatsächlichen Track-basierten Feldversuch auf der Slowenischen Bahn dar. Die deutliche Lärmreduzierung (bis 30 dBA)wurde durch die Anwendung von CHFC-Material auf der Schiene mithilfe des Cl-E1 Antirauschsystems erreicht.

1. INTRODUCTION

Exposure to noise constitutes a health risk. There is sufficient scientific evidence for this claim. Exposure to noise can cause hearing loss, has an impact on high blood pressure and the effect on ischemic heart disease, disrupting sleep and reduce school performance. This implies that noise exposure can be a major public health problem in the twenty-first century [16]. The importance of this problem is evident by the fact that most of the effects of sound on health and quality of life were already known or at least hypothesized already in the 1960s. Later in the 1970s the research results were sufficiently reviewed to allow science based recommendations to be made to protect public health. If politicians had taken a more protective stance in the 1970s, a lot of harm would have been avoided [16].

Traffic is the most widespread source of environmental noise. In the past few decades road noise, has been the dominant noise source in many cities. However, as more and more railway lines are built to promote environmentally friendly modes of transport and deal with traffic congestion, railway noise has become increasingly common [2]. Because of the above mentioned facts, environmental requirements for railway operations regarding noise are becoming very strict and will become even tighter in future. Technical Specification for Interoperability (TSI) for high-speed trains in Europe, including the noise emission limits, is in force since December 2002. TSI on noise for conventional rail, according to a directive from 2001, [4] came in force in 2004 [8], but it was last amended in 2011 [7]. The limiting value for the pass-by noise emission of electric and diesel locomotives measured 7,5*m* from the centre of the track is stated to 85 dB.

Today almost all the countries within EU have railway noise reception limits for new and substantially upgraded lines, but some have limits also for existing lines [11]. To achieve the goals stated in legislation there are several strategies. Let us highlight some of them. Noise emission reduction of trains and wheel/track systems, noise emission reduction of railway line and noise cutback by sound barriers are most important strategies used worldwide. But there are many variations of them. In Switzerland for instance all rolling stock were improved, noise barriers were build an insulated windows installed in all cases in which thresholds were not attained by the first two measures [15]. The Taiwan authorities have taken a different approach [9]. Significant reduction of railway noise level has been achieved by planting tree belts near the railway. The effect was highly related to the form of the tree, density, height, length and width of the tree belt. In Hong Kong they used the special Viaduct design for minimization of direct and structured radiated train noise to build the West Rail extensions from Kowloon into the New Territories [5]. In Austria they have tested noise reduction technologies based on high-performance damping materials to reduce both rolling structure noise. The rail noise reduction system was found effective for reducing noise by 2 to 4 dB [12].

As we can see from the facts explained above, there are several technologies to reduce noise available. But the environmental impacts of different railway noise reduction technologies are different. In the Table 1 we can see the impacts listed.

In this paper we present actual track-based field test performed on Slovenian Railways. The field test was performed using CL-E1 top anti noise system, which represents a relatively simple and cost-effective solution. The results showed that relatively simple and cost-effective solutions could be as effective as much more expensive solutions, like for instance in the papers Dragan et al. [6] and Kramberger et al. [13] where the significant CO_2 reductions were achieved with no sophisticated technology used, but simple with optimization. In this innovative way, the significant noise reduction was achieved.

2. TOP-OF-RAIL SQUEAL AND FLANGING NOISE

Top-of-rail squeal and flanging noise are associated with curves on the railways. On sharp curves (R < 500*m*) rolling noise is associated generally with tangent track. A large proportion of the squeal noise originating from the top of the rail is associated with stick-slip lateral motion at contact between the wheel tread and rail head [10]. However, the curve squeal originates from the unstable response of a wheel objected to large creep forces in the region of contact, which excite the wheel's axial (and radial) mates and thus the noise generated is strongly tonal in nature in the frequency range 250 Hz to 10 kHz. Flanging noise is the high frequency, broadband or multi-tonal noise which is common on tight curves. The flange contact generates a different form of squeal noise, referred to as flange squeal, which has a considerably higher fundamental frequency and is often intermittent in nature. The lateral creep on the top of the rail is the major culprit in generating the squeal noise, though flange rubbing and longitudinal slip are also contributing factors to the overall noise radiated while negotiating a curved track [10].

Table 1

Environmental impact of different railway noise reduction technology

	At the source - Lubrication device	Between source and inhabitant - Barriers	Near the inhabitant - windows
Environmental impact			
Reduction of wear out	yes	no	no
Noise reduction	Yes, in our case up to 30 dB(A)	Yes, usually 5-15 dB(A) depends on height[4]	Yes, if windows are closed. 10-30 dB(A)[4]
Amount of ultrafine particles made by friction	yes/no depends which type of lubricant is used	no	no
Less frequent maintenance of rails/wheels	yes	no	no
Energy savings for railway	yes	no	no
Loss of view	no	yes	no
Toxic material used	no	no	no

Lubrication of the contact between the active rail gauge corner and the wheel flange is intended to reduce noise and wheel and rail degradation significantly and, thus, wear. The amount of applied lubricant is one important factor in controlling wear, but poor adhesion during braking is a safety issue as it extends braking distance [14]. Lubricant type and the addition of solid lubricants are also influencing factors. The lubricant type and effects from solid lubricants were examined in several independent tests [3]; [4]; [18]; [17]; [1]; [20]. These tests basically aimed to find out if different types of grease and the added quantity of solid lubricants affected retention and spread ability. In Reiff [17] the wheel forces of a former locomotive were measured, showing that molybdenum disulfide (MoS_2) gave the best effect on retention while graphite greases did not reveal any clear evidence about spread ability or retention. MoS_2 gave low wear rates in a twin-disc test in Clayton [4], while graphite added to lubricants did not indicate any opportunities according to wear. Abbasi with coworkers [1] reported that the number of ultrafine particles decrease when biodegradable rail grease or oil-based friction modifier was used. In contrast, the concentration of ultrafine particles increased drastically when water based lubricant was used.

3. COMPOSITE HEAVY FLUID COMPOUND MATERIAL AND CL-E1 TOP ANTI NOISE APPLICATION SYSTEM

However, the focus of this study was on testing a completely new developed Composite Heavy Fluid Compound material (CHFC). CHFC is special long-lasting, temperature-proof and environmentally friendly composite material. It contains more than 40% of solid particles and is capable of taking over extremely high pressure loads. The characteristics of CHFC material are shown in Table 2. The material can be applied directly on source of noise, the rail. For this purpose CL-E1 top anti noise application system for rails in curves was developed (see the Fig. 1) as a part of revolutionary Wear Out and Noise Reduction On Source **(**WONROS**)** technology. The main part of the system are patented and verified dosing borings (ϕ = 4 *mm*) made into the rail head. They enable expanding of the material CHFC onto the precisely defined point on the rail head.

Table 2

The characteristics of CHFC material

Characteristic	Value
Appearance	Paste
Color	Gray
Odor	Mild
Solubility in water	Negligible
Hazardous reactive properties	None
Consistency – NLGI (DIN 51818, ASTM-D 217)	2
Worked penetration (ISO 2137)	$295 mm/10$
Density (at $20^\circ C$) (ISO 12185)	$1.3 g/cm^3$
Viscosity (at $40^\circ C$) (ISO 3104)	$26.5 mm^2/s$
Viscosity index	136
Flash point	$> 300^\circ C$
Ignition temperature	$> 350^\circ C$
Thermal decomposition	$> 370^\circ C$
Drop point (ISO 2176)	Not applicable
Separation of base oil ($40^\circ C$, 7 days) (DIN 51817)	2.1
Behavior of the product in the presence of water (DIN 51807-1-40)	< 1
Anti-corrosion properties (DIN 51802, ASTM D6138)	Non-corrosive

CHFC material, when applied to the rail, reduce the wear out and noise significantly, especially the high frequency squealing noise, but its friction characteristics would not change the braking properties. The main technical problems with wayside lubricators have been highlighted as blocked applicator openings, leaking holes and poor choice of lubricant. However, with appropriate device, such is CL-E1 top device, and CHFC material all those problems are solved.

CL-E1 top anti noise system with patented boreholes offers reasonable noise reduction despite extremely low consumption of CHFC material. The whole system can be installed also in the middle of the curve and underground. CL-E1 provides also reduction of rails and wheel life cycle cost. CL-E1 reduces environmental pollution with metal filings. Our measurement showed reduction from 2218 *kg* to 779 *kg* per year on the curve with radius $r = 400\ m$ and length $l = 60\ m$.

Fig. 1. Dosing borings of CL-E1 top anti noise system
Bild 1. Bohrungen des CL-E1 Anti-Lärm-Systems

3.1. CL-E1 TOP ANTI NOISE APPLICATION SYSTEM

CL-E1 system has many advantages; some of them are already pointed out in paragraph 3. However beside this, with using CL-E1 device:

- the reduction of LCC is high,
- the rail and wheel lifetime is increased and the intervals for grinding are significant prolonged,
- the system reduces corrugation (sinus line) of rails
- maintains low roughness level,
- keeps the rail and the wheel smoother,
- reduce brake screech,
- high percentage of metal particles in the material prevents the rail erosion, GCC and RCF,
- consumption of driving power on serviced segments is reduced,
- system operates at all extreme weather conditions,
- system has ability of supplying both rails with one device,
- the dosing of material can be with borings or with blades,
- the detecting of the wheel is contactless,
- the device detect the driving direction, therefore the applying of material is only in desired direction (consumption of material is lower),
- own source of power, provided by solar panels or net voltage
- removal of the device is not necessary when maintenance vehicle is passing over,
- etc.

However, according to Slovenian Railways by using the CL-E1 device very good results had been achieved in terms of lubricating and also in terms of maintenance since the maintenance cost are insignificant. Beside this the usage of CHFC material is controlled and rational and the quality of device meets all requirements.

4. MEASURMENTS AND RESULTS

Measurement of noise reduction was performed on the railway line from Ljubljana to Pivka where it makes a long sharp turn and therefore the direction change by approximately 180_. Two measurements point were created. First one, MM1 was located on the beginning and second one, MM2 at the end of the curve (see the Figure 2). The radius of the curve at this part of the track is r = 298 m.

The detector was mounted 7 m away from the center of the track at MM1 and 8 m at MM2 at hight 2 and 4 meter from the ground level. Railway line runs through the village Dražica on this section. This is the reason why we have chosen that spot for installation of the sensors. The measurements were carried out in the normal daily traffic in August and September 2012. We used modular sound detectors B&K 2250 and 2270.

Fig. 2. Measurements points
Bild 2. Messpunkte

After several measurements we gained the following results. In the Table 3 we see the average sound levels measured at two measurement points MM1 and MM2. We have average values for passenger and freight trains without and with usage of CL-E1 top anti noise system in [*dB*]. In the last two columns we see the average sound level reductions for passenger and freight trains respectively.

Table 3

The average sound levels at two measurement points MM1 and MM2 for passenger and freight trains without and with usage of CL-E1 top anti noise system in [*dB*]

	MM1				MM2					
	Pass.		Freight		Pass.		Freight		Pass.	Freight
Fq[Hz]	Initial	CL-E1	Initial	CL-E1	Initial	CL-E1	Initial	CL-E1	Av. reduction	
12.5	9.69	9.72	22.96	15.95	16.84	5.73	17.78	16.32	5.52	4.10
16	14.86	14.55	32.22	18.08	19.62	3.19	25.97	14.38	8.37	12.89
20	23.97	23.32	34.11	29.07	25.48	8.65	33.68	22.11	8.74	8.31
25	35.19	28.44	40.18	28.08	25.14	23.24	36.53	22.01	4.33	13.31
31,5	35.17	36.17	50.57	37.67	33.59	22.94	40.68	32.35	4.83	10.62
40	38.19	38.62	46.87	38.23	39.43	30.43	45.58	34.63	4.29	9.80
50	38.88	36.76	43.79	38.71	39.74	38.81	55.13	40.84	1.53	9.71
63	40.29	39.53	43.79	42.39	41.81	41.74	51.41	43.43	0.41	4.69
80	45.13	45.47	46.81	44.02	47.56	44.94	49.21	52.84	1.14	3.21
100	47.17	44.89	49.40	49.58	48.23	47.75	52.16	53.97	1.37	1.00
125	52.90	52.45	61.53	57.24	53.65	46.26	54.33	53.52	3.92	2.55
160	59.16	56.47	63.12	63.67	57.82	50.60	58.10	59.48	4.96	0.97
200	61.30	57.53	66.77	68.16	64.56	58.42	68.78	67.39	4.96	1.39
250	86.54	66.12	71.94	74.54	71.87	65.45	73.08	72.69	4.42	1.50
315	73.83	66.71	75.66	80.04	72.07	68.55	76.45	75.81	5.32	2.51
400	72.57	67.41	81.16	81.44	76.60	70.18	80.08	77.94	5.79	1.21
500	73.19	70.40	84.95	85.39	80.23	70.54	82.40	80.12	6.24	1.36
630	72.00	67.08	86.18	85.44	82.00	69.91	83.52	81.24	8.51	1.51

800	71.31	68.46	87.94	85.96	82.06	73.36	86.99	86.82	5.78	1.08
1000	70?.82	68.49	87.40	85.27	80.14	72.53	84.83	84.84	4.97	1.07
1250	70.10	66.70	85.79	81.60	77.53	70.34	82.60	81.19	5.29	2.80
1600	86.58	65.97	85.61	81.07	74.99	65.43	82.14	77.84	6.08	4.42
2000	69.96	65.47	83.28	78.38	73.88	63.85	77.77	76.15	7.26	3.26
2500	71.49	63.84	88.90	78.94	69.24	61.56	84.23	75.67	7.66	9.26
3150	71.72	62.93	107.09	76.99	67.43	59.38	103.30	74.10	8.42	29.65
4000	72.63	64.95	92.57	73.79	67.13	59.40	87.54	71.16	7.88	17.58
5000	71.60	61.47	79.61	70.84	64.71	55.90	74.20	67.63	9.47	7.67
6300	72.38	58.41	86.06	67.47	62.69	53.88	80.37	64.63	11.39	17.17
8000	72.91	54.99	75.29	63.12	60.41	49.03	68.51	59.55	14.65	10.57
10000	68.45	52.06	75.25	58.59	57.11	45.53	66.83	56.41	13.99	13.58
12500	65.54	47.60	66.32	54.84	53.28	40.37	59.08	53.08	15.43	8.74
16000	61.29	40.69	58.05	47.64	47.78	33.13	52.03	45.67	17.63	8.39
20000	55.67	33.20	50.30	39.82	40.86	24.64	43.31	36.86	19.35	8.47
A	84.04	78.30	107.48	93.46	88.75	80.13	103.72	91.68	7.18	13.03
C	87.31	83.38	106.12	95.78	91.21	83.64	102.55	93.47	5.75	9.71

When we present the average sound level reductions graphically (see the Figure 3, where dotted line means freight trains and black line means passenger trains) we see that sound level reductions are higher at higher frequences. Higher reductions were achieved with freight trains which is obvious, because the nominal level of noise is much higher with freight trains than with passenger trains. At low frequences (12.5 *Hz* to 50 *Hz*) the average reductions are up to 14 *dBA*. At frequencies between 50 *Hz* to 2000 *Hz* reductions are lower but at frequences between 2000*Hz* and 5000*Hz* the reductions reach their peak, which is up to 30 *dBA*. With passenger trains the reduction reach their peak at 20000 *Hz*.

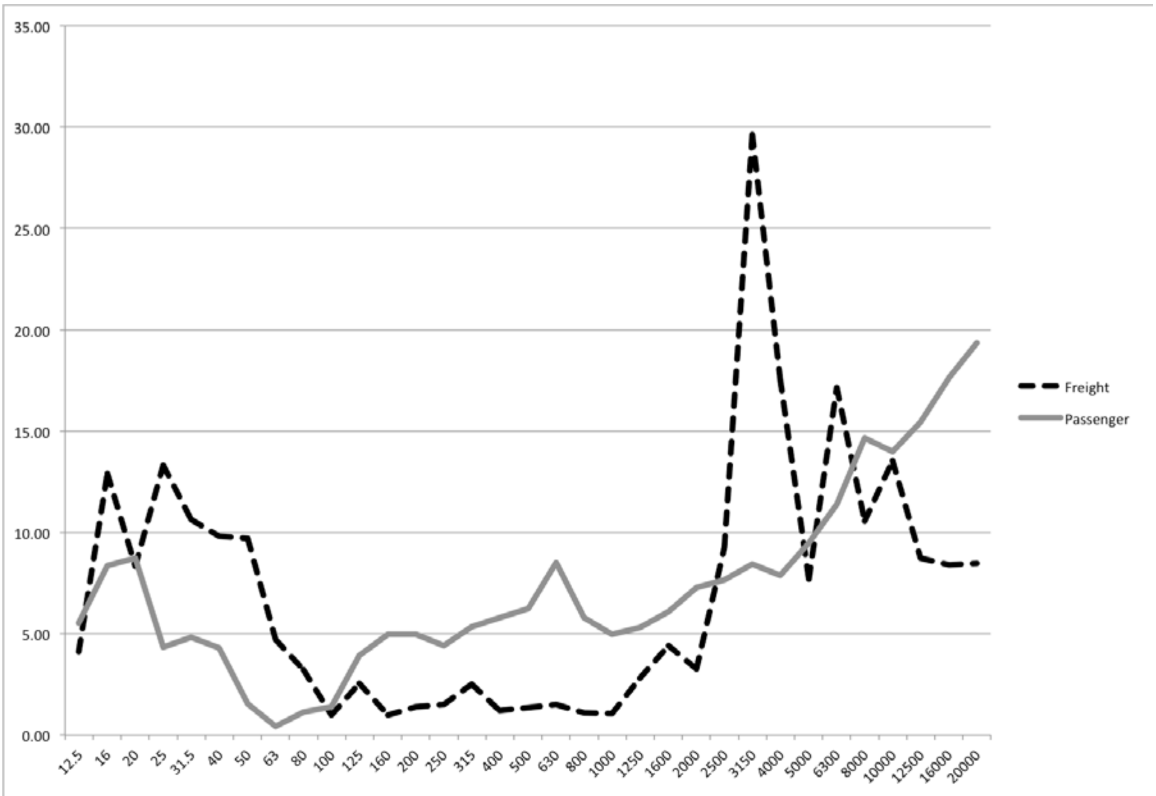

Fig. 3. Average reductions of noise level
Bild 3. Durchschnittliche Reduktion von Lärm

As we can see from above mentioned results application of CHFC material to the source of noise by use of innovative patented technology CL-E1 top anti noise system reduce the high frequency noise at most. The high frequency noise usually appears in sharp curves and shunting stations etc. which are mostly located near the populated areas. Therefore CL-E1 top anti noise system is appropriate for use in specified sections of rail lines. Relatively simple and easy to use technology in contrary to other expensive measures for noise level reductions almost all cases reduce the noise lower than 85 dB (see [7]).

5. DISCUSSIONS

Noise reduction can be achieved with several different approaches. Most of noise reduction technologies have to be designed before the construction of railways [5], or require major earthmoving works [9]. The solution described in the present paper is relatively simpler and less expensive than others. The apparatus is located right next to the railway line, also in the middle of the curve (see Fig. 4).

(a) CL-E1 top anti noise system
(a) CL- E1 des Anti-Lärm-Systems

(b) Dosing element of CL-E1 top anti noise system
(b) Element des CL-E1 des Anti-Lärm-Systems

Fig. 4. CL-E1 device detects the train (a) and apply CHFC material with use of dosing element (b) directly to the desired location in the optimal concentration

Bild 4. CL-E1 Vorrichtung nimmt den Zug wahr (a) und appliziert das CHFC-Material unter Verwendung des Dosierelements (b) direkt an der gewünschten Stelle in der optimalen Konzentration

The noise level reductions up to 30% are much higher than most of the solutions described in literature [12, 9] or much cheaper than the solution in [5]. In relation to 2 m high sound barrier where the screening effect of a 2 m high sound barrier is average 10 dB(A) but the cost extends up to 1 million EURO/km (see [19]).

According to the facts and results of the measurements listed in the paper, the innovative patented technology CL-E1 top anti noise system is worth considering in order to reduce railway noise. It can be concluded that the noise reduction is crucial to the welfare of the environment and human health and contribute significantly to the competitiveness of railway traffic.

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References

1. Abbasi, S. & Olofsson, U. & Zhu, Y. & Sellgren, U. Pin-on-disc study of the effects of railway friction modifiers on airborne wear particles from wheel-rail contacts. *Tribology International*. 2013. Vol. 60. P. 136-139.
2. Chan, T. & Lam, K. The effects of information bias and riding frequency on noise annoyance to a new railway extension in Hong Kong. *Transportation Research Part D.* 2008. Vol. 13. P. 334-339.
3. Clayton, P. & Danks, D. Laboratory evaluation of wheel/rail lubricants. *Proceedings of Symposium on Rail and Wheel Lubrication*. 1993.
4. Clayton, P. & Danks, D. & Steel, R. Laboratory assessment of lubricants for wheel/rail applications. *Lubrication Engineering.* 1989. Vol. 45. P. 501-506.
5. Crocket, A. & Pyke, J. Viaduct design for minimization of direct and structure-radiated train noise. *Journal of Sound and Vibration.* 2000. Vol. 231. P. 883-897.
6. Dragan, D. & Lipičnik, M. & Kramberger, T. Monte Carlo simulation-based approach to optimal bus stops allocation in the municipality of Laško. *Promet - Traffic – Transportation.* 2011. Vol. 23(4). P. 265-278.
7. European Commission. Commission decision concerning the technical specifications of interoperability relating to the subsystem 'rolling stock – noise' of the Trans-European conventional rail system. *Official Journal of the European Communities*. 4 April 2011.
8. European Parliament. Directive 2001/16/ec. *Official Journal of the European Communities.* 19 March 2001.
9. Fang, C. & Ling, D. Investigation of the noise reduction provided by tree belts. *Landscape and Urban Planning.* 2003. Vol. 63. P. 187-195.
10. Gerg, N. & Sharma, O. Noise emissions of transit trains at curvature due to track lubrication. *Indian Journal of Pure and Applied Physics*. 2010. Vol. 48. P. 881-885.
11. Kalivoda, M. & Danneskiold-Samsoe, U. & Krüger, F. & Barsikow, B. Eurailnoise: a study of European priorities and strategies for railwaynoise abatement. *Journal of Sound and Vibration.* 2003. Vol. 267. P. 387-396.
12. Koller, G. & Kalivoda, M. & Jaksch, M. & Muncke, M. & Oguchi, T. & Matsuda, Y. Noise and Vibration Mitigation for Railway Transportation Systems. *Notes on Numerical Fluid Mechanics and Multidisciplinary Design*. Springer. 2012. Vol. 118. P. 159-166.
13. Kramberger, T. & Dragan, D. & Prah, K. A heuristic approach to reduce carbon dioxide emissions. *Proceedings of the Institution of Civil Engineers - Transport*. 2013. DOI: 10.1680/tran.11.00053.
14. Lewis, R. & Olofsson, U. *Wheel–Rail Interface Handbook*. Wood head Publishing Limited: UK. 2009.
15. Oertli, J. The stairrs project, work package 1: a cost-effectiveness analysis of railway noise reduction on a European scale. *Journal of Sound and Vibration.* 2003. Vol. 267. P. 431-437.
16. Passchier-Wermeer, W. & Passchier, W. Noise exposure and public health. *Environ Health Perspect.* 2000. Vol. 108. P. 123-131.

17. Reiff, R. Rail/wheel lubrication studies at fast. *Lubrication engineering.* 1986. Vol. 42(6). P. 340-349.
18. Sato, M. & Sugino, K. & Tanikawa, K. & Lida, H. The nature of lubricants and their influence on the wear and fatigue behavior of rail. *Proceedings of Symposium on Rail and Wheel Lubrication*. 1993.
19. Schulte-Werning, B. & Beier, M. & Grütz, H.-P. Jäger, K.J. & Kock, G. & Onnich, J. & Strube, R. *Headed for the low-noise railway: The db noise reduction research programme*. Tech. rep, Deutsche Bahn AG, Forschungs- und Technologiezentrum. 2002.
20. Wang, W. & Zhang, H. & Wang, H. & Liu, Q. & Zhu, M. Study on the adhesion behavior of wheel/rail under oil, water and sanding conditions. *Wear*. 2011. Vol. 271. P. 2693-2698.

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