Vertical Deformation and Ballast Abrasion Characteristics

by Ijaseit Vol 8, No 6 (2018)

International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 6
ISSN: 2088-5334

Vertical Deformation and Ballast Abrasion Characteristics of Asphalt-Scrap Rubber Track Bed

Dian M Setiawan[#], and Sri Atmaja P. Rosyidi[#]

[#] *Department of Civil Engineering, Universitas Muhammadiyah Yogyakarta, Jl. Brawijaya, Bantul, 55183, Indonesia*
E-mail: diansetiawanm@ft.umy.ac.id, atmaja.sri@gmail.com

***Abstract*— Innovations in the field of railroad construction need to be improved, especially in the ballast layer which is an essential structure in conventional railways. The purpose of this study was to analyse the characteristics of vertical deformation and ballast material abrasion with 10% of scrap rubber in two types of sizes (uniform and graded) and with 3% of asphalt. This study uses a compressive test method with six types of samples modeled with ballast boxes measuring 400 x 300 x 200 mm. The test results present that the use of 10% scrap rubber can increase the vertical deformation value significantly to 84%. On the other hand, the use of 3% asphalt can minimize vertical deformation to only 14% because asphalt can increase the ballast layer stiffness. Furthermore, it can also be concluded that in general, the use of 10% scrap rubber and 3% asphalt can reduce the percentage of material abrasion up to 80%. Besides, it also can be known that the use of graded sized scrap rubber material is the most effective in increasing material durability. Scrap rubber and asphalt have the potential to be used together on ballast layers which are expected to be a solution of the problems related to the service-life and ballast maintenance work.**

***Keywords*— asphalt; ballast abrasion; scrap rubber; vertical deformation.**

I. Introduction

The main factor in rail track loading system is the ability of the rail track to distribute the load from the wheel to the sleeper and then spreads the load evenly to the ballast layer [1]. The better resilience of rail track structures can increase the speed of passing train and can reduce the costs needed for maintenance [2].

Furthermore, innovation in the field of rail track construction needs to be increased, especially in the ballast layer which is an important structure in conventional railways. One type of rail track structure with high durability performance is the slab track structure. However, the use of slab tracks requires very high development costs, which is two times greater than conventional railways. Therefore, a new idea emerged regarding modification of ballast layers with asphalt mixtures which are expected to produce the higher quality of railways compared to conventional railways but with lower costs compared to slab tracks [3], [4], [5], [6], [7], [8].

If the asphalt is mixed with aggregate material, then the asphalt will become a binding material between the ballast aggregates [9] so that it can increase the resistance of the ballast layer against the influence of dynamic loads [4]. Addition of asphalt material can also reduce vertical deformation in the ballast layer because it is influenced by the percentage and thickness of the asphalt layer [10], [11], [12]. Besides, D'Angelo et al. and D'Andrea et al. also stated that mixing ballast material with asphalt as a binding material can increase the material durability of ballast and reduce maintenance work so that it can reduce ballast maintenance costs [10], [5].

Also, scrap rubber as waste materials could be utilized for ballast structures mixtures [13], [14], [12], [15]. Based on the results of several previous studies, the use of excessive rubber (a large percentage) can reduce the stiffness and increase the instability of the rail track which is characterized by the high vertical deformation [16], [7], [17], [8], [14], [15]. Rubber also has properties that are not resistant to temperature heating because rubber is categorized as a thermoplastic material [18].

However, on the other hand, modification of ballast mixed with scrap rubber has good ability in minimizing damage to ballast material, because in the presence of scrap rubber, the movement that occurs in the ballast material becomes lesser or limited, thereby reducing friction between ballast [19].

Other studies also prove that the modification of ballast layers using 10% scrap rubber can reduce ballast degradation and can reduce vibrations caused by dynamic loads produced by the passing train [13], [5], [16], [14]. Furthermore, the use of scrap rubber spread on the bottom of ballast material can increase the vertical deformation by about 35% - 45%

[20]. Because in other studies only focused on the use of ballast with scrap rubber or ballast with asphalt, therefore this research aims to examine the effect of the application of 10% scrap rubber (with size of 3/8" and with graded size) and 3% asphalt against the vertical deformation, and material abrasion of ballast layer.

II. Material and Method

A. Materials

The quality of the rail track can be assessed from various aspects, one of which is the quality of the material used. The materials that meet the specifications could produce a safe and a comfort rail track [21].

1) Ballast: The ballast material used in this study obtained from Clereng District, Kulon Progo Regency, Special Region of Yogyakarta. The ballast material is classified into the class 2 ballast specifications [22]. Furthermore, the ballast was tested the specific gravity, water absorption, sludge content, wear and sieve analysis according to the Indonesian National Standardization Agency [23], [24], [25], [26]. The appearance of ballast material is presented in and Figure 1.

Fig. 1 Ballast

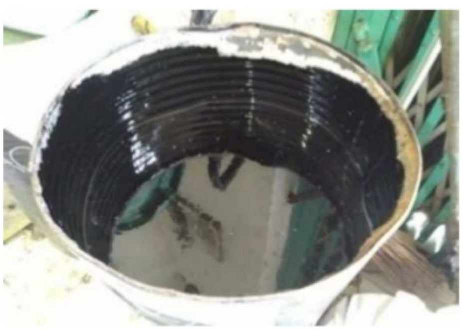


Fig. 2 Asphalt

2) Asphalt: This study uses 60/70 penetration asphalt which has been heated in the oven for 5 hours at a temperature of 155ºC and with a percentage of 3% of the total specimen weight. The use of 60/70 penetration asphalt has a substantial value that is high enough to be used as pavement materials [27]. Asphalt physical testing was conducted to analyse the specific gravity, asphalt penetration, ductility, oil losses, and asphalt softening point according to the Indonesian National Standardization Agency [28], [29], [30], [31], [32]. The asphalt display is shown in Figure 2.

3) Scrap Rubber: The scrap rubber used in this study was obtained from motorized vehicle tires that cut into two groups of sizes. The first is scrap rubber with a uniform size of 3/8 inch or equal to 9.52 mm. Second is scrap rubber with sizes of 1", ¾", ½", No. 4, and 3/8". The percentage of scrap rubber used is 10% based on the previous studies. The display of scrap rubber pieces can be seen in Figure 3.

Fig. 3 Scrap rubber

B. Compressive Strength Test Procedure

1) Specimen Design: This study uses six specimens which each specimen mixed in a ballast box 40 cm x 20 cm x 30 cm. Each specimen also has a different material mixture modification where ballast acts as the main materials and scrap rubber and asphalt act as additional materials. The specimens' configuration is presented in Table 1 and Figure 5.

TABLE I
SPECIMENS

Name	**Mixture**
Specimen 1 (S.1)	Ballast
Specimen 2 (S.2)	Ballast + Scrap Rubber 3/8"
Specimen 3 (S.3)	Ballast + Scrap Rubber No.4, 3/8", 1/2", 3/4", 1"
Specimen 4 (S.4)	Ballast + Bitumen 3%
Specimen 5 (S.5)	Ballast + Scrap Rubber 3/8" + Bitumen 3%
Specimen 6 (S.6)	Ballast + Scrap Rubber No.4, 3/8", 1/2", 3/4", 1" + Bitumen 3%

Before the compressive strength test is carried out, the first step taken in this research is to conduct the mixing process of the specimens. The specimens are made with a size of 40 cm x 20 cm x 30 cm in a ballast box. The mixing process is accompanied by a manual compaction process with a compactor that has a load of 4.5 kg, a diameter of 6 cm and a falling height of 20 cm (Figure 4). The mixing process is done directly in the box, and the specimens were compacted every 1/3 layer from the height of the box with the number of blows as much as a 50 times/layer.

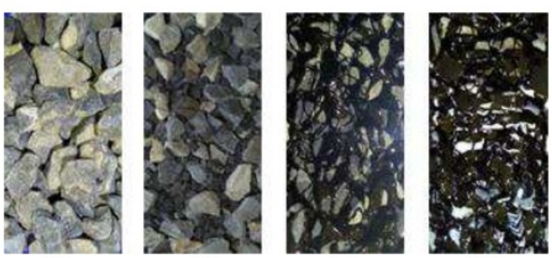
Fig. 4 Manual compactor

2) Specimen 1: Ballast is poured into a ballast box every 1/3 layer from the height of the box, then compacted with the manual compactor, and so on up to 3/3 part of the ballast box is fulfilled (Figure 5a).

3) Specimen 2 and 3: Ballast and 10% scrap rubber (size 3/8 " for specimens 2 and sizes No.4, 3/8", 1/2", 3/4", and 1 "for specimen 3) was poured into the ballast box every 1/3 layer from the height of the box evenly and then compacted with the manual compactor for each layer. The same thing is done for the next two layers (Figure 5b).

4) Specimen 4: Ballast is poured into the ballast box as in the specimens 1. However, after the compaction, 3% asphalt is poured on it until evenly distributed. The same stage is used for the next layer (Figure 5c).

5) Specimen 5 and 6: The pouring of ballast and 10% scrap rubber is done as the same as the preparation of specimen 2 and 3. However, after the compaction, 3% of asphalt is poured over ballast and scrap rubber evenly, and so on until the ballast box is fulfilled (Figure 5d).



(a) (b) (c) (d)

Fig. 5 Specimens (a) ballast (specimen 1) (b) Ballast with scrap rubber (specimen 2 and 3) (c) Ballast with bitumen (specimen 4) (d) Ballast with scrap rubber and bitumen (specimen 5 and 6)

Fig. 6 Universal testing mechine-hung ta 9501

Fig. 7 Loading process

Compressive strength testing equipment used in this research was the Universal Testing Machine-Hung Ta 9501. This machine has a maximum compressive strength up to 45 kPa with dimensions of the loading plate is 300 x 150 mm. The main part of the vertical press test can be seen in Figure 6 as follows, while the condition of the specimen at the loading test is shown in Figure 7.

C. Data Analysis

Each specimen is placed on the UTM compressive strength testing machine which produces four parameters, namely, force, stress, strain, and elongation which are then processed in order to find the value of vertical deformation and abrasion percentage.

1) Vertical deformation testing process: The value of vertical deformation is obtained based on the number of changes in the height of the test object due to the vertical loading process. Vertical deformation values can also indicate the level of stiffness or flexibility of the specimen.

2) Aggregate abrasion testing process: To find out the percentage of aggregate abrasion, a sieve analysis method of size 1.5"- 3/4" was used to compare ballast material size before and after the loading test on the specimen. The comparison was made by taking ± 5000 grams of ballast material specimens from the total mixture weight. Material abrasion is calculated based on the percentage of ballast material that has the aggregate grain size smaller than 3/4".

III. Results and Discussion

A. Physical Properties of Ballast

Physical testing on ballast was conducted to determine the feasibility of ballast usage as the main materials in this study. The results of the ballast physical experiments are summarized in Table 2.

TABLE II
PHYSICAL PROPERTIES OF BALLAST

Parameters	Result
Bulk Specific Gravity, S_d	2,65
SSD Specific Gravity, S_s	2,67
Apparent Specific Gravity, S_a	2,70
Water Absorption, S_w (%)	0.8%
Mud Content (%)	1.8%
Los Angeles (%)	17.7%

Furthermore, based on the sieve analysis that has been done, it is known that the ballast material gradation distribution in this study is in accordance with the specifications of railroad class 2 in the Indonesian rail track system [22], [33].

B. Physical Properties of Scrap Rubber

In this study, three types of testing were carried out for scrap rubber namely specific gravity, water absorption, and sieve analysis. The results of scrap rubber physical testing are shown in Table 3.

TABLE III
PHYSICAL PROPERTIES OF SCRAP RUBBER

Parameters	Result
Bulk Specific Gravity, S_d	1.13
SSD Specific Gravity, S_s	1.15
Apparent Specific Gravity, S_a	1.15
Average Specific Gravity	1.14

C. Physical Properties of Asphalt

Physical testing of asphalt was carried out to determine the feasibility of 60/70 penetration asphalt usage as a binding material in the ballast layer. The results of the physical asphalt testing are presented in Table 4.

TABLE IV
PHYSICAL PROPERTIES OF ASPHALT

Parameters	Result
Unit Weight	1.03 gr/cm^3
Oil Lossess	0.402 %
Penetration	62 mm
Softening Point	52^{o}C
Ductility	147 mm

D. Cavity Volume

Identification of the specimen characteristics is carried out to determine the material volume, cavity volume and density of each specimen. The more varied the size of the material in the mixture of specimens, the lower the volume of the pore. This condition is caused by the presence of the scrap rubber and asphalt which is able to fill the cavities between the ballast aggregates. The cavity volume of each specimen is presented in Table 5.

TABLE V
CAVITY VOLUME

Specimen	Cavity Volume
S.1	47,75 %
S.2	41,23 %
S.3	41,23 %
S.4	34,36 %
S.5	29,23 %
S.6	30,33 %

E. Vertical Deformation

Vertical deformation is the change in the height of a specimen after experiencing loading or testing. In this test, the vertical deformation value in each specimen is obtained from a graph of the relationship between the loads and the height change of the specimens. In addition, the graph can also show the changes in the height of a specimen at specific stress. The vertical deformation values for each specimen are shown in Figure 8 and Table 6.

TABLE VI
VERTICAL DEFORMATION

Specimen	Maximum Stress (kPa)	Maximum Vertical Deformation (mm)	kPa/mm
S.1	196.6	5.72	34.4
S.2	77.27	9.12	8.5
S.3	77.27	9.12	8.5
S.4	176.29	5.56	31.7
S.5	121.97	6.04	20.2
S.6	104.8	5.2	20.2

From the results presented in Figure 8 and Table 6, it shows that the mixture of ballast and 10% scrap rubber (with uniform size on specimen 2 and with graded size on specimen 3) experienced the most significant vertical deformation which is 9.12 mm at a maximum stress of 77.27 kPa. In other words, these two specimen experiences stress approximately eight (8) kPa for each mm of vertical deformation. This condition is because the addition of scrap rubber material with a 10% percentage can increase the elastic properties of specimens 2 and 3.

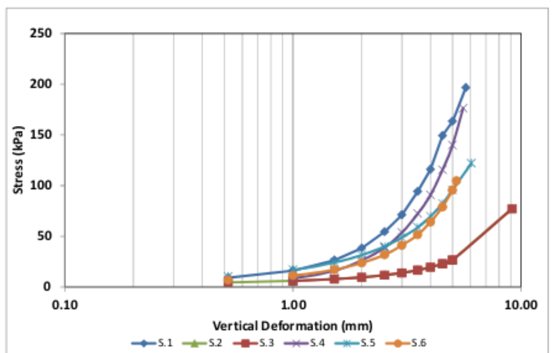


Fig. 8 The relationship between the loads and the change in specimen height

Also, specimens 5 and 6 show better results compared to the specimens 2 and 3, where specimens that added with 3% of asphalt and 10% scrap rubber (uniform size on specimen 5 and graded size on specimen 6) was able to receive higher stress which is 20.2 kPa for each mm of vertical deformation.

Furthermore, specimen 4 shows better results compared to the specimens 2, 3, 5, and 6, where the specimen consisting of ballast and 3% asphalt mixture experiences the stress of 31.7 kPa for each mm of vertical deformation. This condition is due to the presence of asphalt material which has a role as a binder between ballast materials so that it can increase the mixture's stiffness.

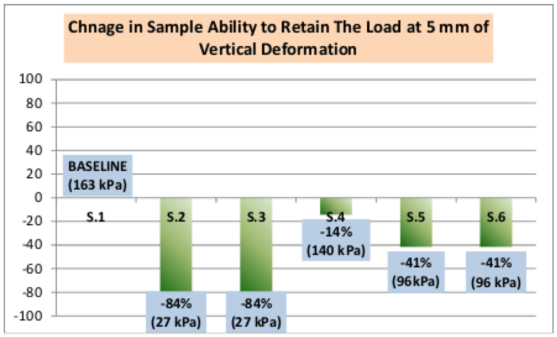


Fig. 9 The changes in loads that can be withheld at vertical deformation of 5 mm

Based on the data obtained, it can also be known the amount of load that can be received by the specimens at a vertical deformation of 5 mm. As shown in Figure 9, generally specimens 2, 3, 4, 5, and 6 have decreased in the amount of load that can be received at a vertical deformation of 5 mm.

First of all, when compared to specimen 1, then the specimens 2 and 3, namely modification of ballast material with 10% scrap rubber have experienced the decline in the value of the load that can be withheld at the vertical deformation of 5 mm by 84%. The addition of 10% of scrap rubber from the total weight greatly affects the properties of specimens 2 and 3 because the elastic material can fill each cavity on each side of the ballast.

Second, specimens 5 and 6 which are the modification of ballast material with 10% of scrap rubber and 3% of asphalt have a better performance compared to specimen 2 and 3. In these two specimens, the decline in the value of the load that can be received at the vertical deformation of 5 mm is only 41%. Finally, specimen 4 (ballast and asphalt 3 %) has experienced the smallest decline that is only 14%. The behavior of asphalt added to the ballast layer is intended as a binding material in the ballast layer.

F. Ballast Abrasion

The abrasion value of ballast material is obtained through a sieve analysis method by comparing the material conditions before and after testing. The material used for abrasion testing is ± 5 kg or equal to 5000 grams of the total test specimen. The 50 times of compaction cycles and the loading test on compressive strength tests result in material damage such as rupture and wear which affects the change in gradation distribution of the ballast material.

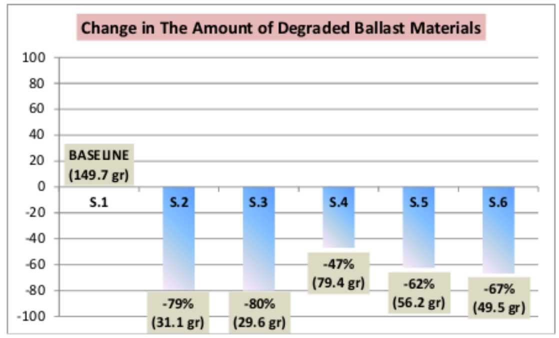


Fig. 10 The changes in degraded ballast material

Based on the data shown in Figure 10, the most considerable abrasion value occurs in specimen 1 (ballast only) which is 149.7 gr (baseline). However, the material abrasion value can be reduced by 47% (79.4 gr) if the mixture is added with 3% asphalt (specimen 4). Furthermore, a better abrasion percentage reduction value is shown by specimen 5 (ballast with 10% of uniform size scrap rubber and 3% asphalt) and specimen 6 (ballasts with 10% of graded size scrap rubber and 3% asphalt), which are reduced by 62% (56.2 gr) and 67% (49.5 gr), respectively.

Furthermore, the best decline in the percentage of abrasion is shown by specimen 2 (ballast with 10% scrap rubber in uniform size) and specimen 3 (ballasts with 10% scrap rubber in graded size), which are reduced by 79% (31.1 gr) and 80% (29.6 gr), respectively. Based on these results, it can be summarized that in overall, the use of scrap rubber and asphalt can minimize material abrasion significantly. Besides, it can also be seen that the utilisation of scrap rubber materials with varying sizes is more effective in increasing ballast material durability. Addition of scrap rubber material can protect ballast material from collisions and friction between aggregates thereby reducing aggregate abrasion values.

IV. CONCLUSIONS

According to the results of this study, it can be concluded that: the use of 10% scrap rubber material can increase the value of vertical deformation because it could enhance the elasticity of the ballast layer. On the other hand, the addition of 3% asphalt in the ballast mixture as a binder can improve the stiffness of the ballast layer. The use of 10% scrap rubber and 3% asphalt can reduce the value of material abrasion in the ballast layer significantly from 47% to 80%. The use of 10% scrap rubber and 3% asphalt has a positive role against ballast durability in rail track structures so that it has the potential to be used as a solution to increase service life and reduce rail track maintenance costs.

ACKNOWLEDGMENT

We would like to thank Lembaga Penelitian, Publikasi & Pengabdian Masyarakat Universitas Muhammadiyah Yogyakarta (LP3M UMY) for the Research Funds on the scheme of Multi Disiplin 2018.

REFERENCES

[1] S.A.P. Rosyidi, *Rekayasa Jalan Kereta Api*, Yogyakarta: Lembaga Penelitian, Publikasi dan Pengabdian Masyarakat (LP3M), 2015.

[2] D. M. Setiawan, "Pembatasan kecepatan maksimum dan kaitannya terhadap kapasitas lintas jalur kereta api muara enim – lahat sumatera selatan," in *Proc. Seminar Nasional Teknik Sipil Ke-IV 2016*, ISSN:2459-9727, p. 36-46.

[3] D. M. Setiawan, I. Muthohar, and G. Ghataora, "Conventional and unconventional railway track for railways on soft ground in indonesia (case study: rantau prapat - duri railways development)," in *Proc. The 16th International Symposium of Indonesia Inter University Transportation Studies Forum (FSTPT), Universitas Muhammadiyah Surakarta, 1-3 November 2013*, p. 610-620.

[4] G. D. Mino, M. D. Liberto, and C. Maggiore, "A dynamic model of ballasted rail track with bituminous sub-ballast layer," *Procedia - Social and Behavioral Sciences*, vol. 53, pp. 366 – 378, 2012.

[5] A. D'Andrea, G. Loprencipe, and E. Xhixha, "Vibration induced by rail traffic: evaluation of attenuation properties in a bituminous sub-ballast layer," *Procedia - Social and Behavioral Sciences*, vol. 53, pp. 245-255, 2012.

[6] S. H. Lee, J. W. Lee, D. W. Park, and H. V. Vo, "Evaluation of asphalt concrete mixture for railway track," *Construction and Building Materials*, vol. 73, pp. 13-18, 2014.

[7] G. D'Angelo, N. H. Thom, and D. L. Presti, "Optimisation of bitumen emulsion properties for ballast stabilization," *Materiales De Construcción*, vol. 67(327), pp. 124-133, 2017.

[8] S. Bressi, J. Santos, M. Giunta, L. Pistonesi, and D. L. Presti, "A comparative life-cycle assessment of asphalt mixture for railway sub-ballast containing alternative materials," *Resources, Conservation and Recycling*, vol. 137, pp. 76-88, 2018.

[9] F. M. Soto, and G.D. Mino, "Increased stability of rubber modified asphalt mixtures to swelling expansion and rebound effect during post compaction," *Transport and Vehicle Engineering*, 1307 – 6892, 2017.

[10] G. D'Angelo, N. H. Thom, and D. L. Presti, "Bitumen stabilized ballast: a potential solution for railway track bed," *Construction and Building Materials*, vol. 124, pp. 118-126, 2016.

[11] L. Pirozzolos, M. S. Sanchez, F. M, Navarro, G. M. Montes, and M. C. R. Gámez, "Evaluation of bituminous sub-ballast manufactured at low temperatures as an alternative for the construction of more sustainable railway structures," *Materiales De Construcción*, vol. 67, No 327, 2017.

[12] M. S. Sanchez, N. H. Thom, F. M. Navarro, C. R. Gamez, and G. D. Airey, "A study into the use of crumb rubber in railway ballast," *Construction and Building Materials*, vol. 75, pp. 19-24, 2015.

[13] S. M. Asgharzadeh, J. Sadeghi, P. Peivast, and M. Pedram, "Fatigue properties of crum rubber asphalt mixtures used in railways," *Construction and Building Materials*, vol. 184, pp. 248-257, 2018.

[14] M. S. Sánchez, F. M. Navarro, and C. R. Gamez, "The use of deconstructed tires as elastic elements in railway tracks," *Materials*, vol. 7, pp. 5903-5919, 2014.

[15] C. H. Signes, P. M. Hernandez, J. G. Roca, M. E. G. del la Torre, and R. I. Franco, "An evaluation of the resilient modulus and permanent deformation of unbound mixtures of granular materials and rubber particles from scrap tyres to be used in subballast layers," *Transportation Research Procedia*, vol. 18, pp. 384 – 391, 2016.

[16] A. H. Farhan, A. R. Dawson, N. H. Thom, S. Adam, and M. J. Smith, "Flexural characteristics of rubberized cement-stabilized crushed aggregate for pavement structure," *Materials and Design*, vol. 88, pp. 897-905, 2015.

[17] T. Abadi, L. L. Pen, A. Zervous, and W. Powrie, "A review and evaluation of ballast settlement models using result form the southampton railway testing facility (srtf)," *Procedia Engineering*, vol. 143, pp. 999-1006, 2016.

[18] A. S. Hameed, and A. P. Shashikala, "Suitability of rubber concrete for railway sleepers," *Perspectives in Science*, vol. 8, pp. 32-35, 2016.

[19] B. Indraratna, N. T. Ngo, and C. Rujikiatkamjorn, "Improved performance of ballasted rail tracks using plastics and rubber inclusions," *Procedia Engineering*, vol. 189, pp. 207-214, 2017.

[20] S.K. Navaratnarajah, and B. Indraratna, "Use of rubber mats to improve the deformation and loading," *Geotechnical and Geoenvironmental Engineering*, 1943-5606, 2017.

[21] D. M. Setiawan, and S. A. P. Rosyidi, "Track Quality Index As Track Quality Assessment Indicator," in *Proc. Symposium XIX FSTPT, Universitas Islam Indonesia*, 2016.

[22] *Peraturan Menteri Perhubungan No. 60 Tahun tentang Persyaratan Teknis Jalur Kereta Api*, Ministry of Transportation, Jakarta, 2012.

[23] *Cara Uji Berat Jenis dan Penyerapan Agregat Kasar*, Badan Standardisasi Nasional (BSN), SNI 1969:2008, Jakarta, 2008.

[24] *Metode Pengujian Gumpalan Lempung dan Butir-Butir Mudah Pecah Dalam Agregat*, Badan Standardisasi Nasional (BSN), SNI 03-4142-1996, Jakarta, 1996.

[25] *Cara Uji Keausan Agregat dengan Mesin Abrasi Los Angles*, Badan Standardisasi Nasional (BSN), SNI 2417:2008, Jakarta, 2008.

[26] *Metode Uji Untuk Analisis Saringan Agregat Halus dan Agregat Kasar*, Badan Standardisasi Nasional (BSN), SNI ASTM C136-2012, Jakarta, 2012.

[27] A. E. Alvarez, L. V. Espinosa, S. Caro, E. J. Rueda, J. P. Aguiar, and L. G. Loria, "Differences in asphalt binder variability quantified through traditional and advanced laboratory testing," *Construction and Building Materials*, vol. 176, pp. 500-508, 2018.

[28] *Cara Uji Berat Jenis Aspal Keras*, Badan Standardisasi Nasional (BSN), SNI 2441:2011, Jakarta, 2011.

[29] *Cara Uji Penetrasi Aspal*, Badan Standardisasi Nasional (BSN), SNI 2432:2011, Jakarta, 2011.

[30] *Metode Pengujian Daktilitas Bahan – Bahan Aspal*, Badan Standardisasi Nasional (BSN), SNI 06:2432:1991, Jakarta, 1991.

[31] *Metode Pengujian Berat Minyak dan Aspal*, Badan Standardisasi Nasional (BSN), SNI 06:2440:1991, Jakarta, 1991.

[32] *Cara Uji Titik Lembek Aspal dengan Alat Cincin dan Bola (Ring And Ball)*, Badan Standardisasi Nasional (BSN), SNI 2434:2011, Jakarta, 2011.

[33] *Peraturan Dinas No. 10 Tahun 1986 tentang Peraturan Perencanaan Konstruksi Jalan Rel*. Ministry of Transportation, Jakarta, 1986..

Vertical Deformation and Ballast Abrasion Characteristics

ORIGINALITY REPORT

17%	%	17%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Dian M. Setiawan. "Utilization of 60/70 penetration grade asphalt on ballast structures with the variation of percentage and the number of pouring layers", Journal of the Mechanical Behavior of Materials, 2019 Publication	2%
2	M. Sol-Sánchez, G. D'Angelo. "Review of the design and maintenance technologies used to decelerate the deterioration of ballasted railway tracks", Construction and Building Materials, 2017 Publication	1%
3	Yuantian Sun, Guichen Li, Junfei Zhang, Deyu Qian. "Prediction of the Strength of Rubberized Concrete by an Evolved Random Forest Model", Advances in Civil Engineering, 2019 Publication	1%
4	Tao Xin, Yu Ding, Pengsong Wang, Liang Gao. "Application of rubber mats in transition zone between two different slab tracks in high-speed railway", Construction and Building Materials,	1%

2020
Publication

5 Carlos Hidalgo Signes, Pablo Martínez Fernández, Julio Garzón-Roca, María Elvira Garrido de la Torre, Ricardo Insa Franco. "An Evaluation of the Resilient Modulus and Permanent Deformation of Unbound Mixtures of Granular Materials and Rubber Particles from Scrap Tyres to be Used in Subballast Layers", Transportation Research Procedia, 2016
Publication
1%

6 Li Zhihui, Zhuo Rui, Zhao Yonghua, Cao Qian, Qin Weijun. "Discriminating wavenumbers selection of ATR-FTIR spectra for identifying graded asphalt", Construction and Building Materials, 2019
Publication
1%

7 Seong-Hyeok Lee, Dae-Wook Park, Hai Viet Vo, Samer Dessouky. "Asphalt Mixture for the First Asphalt Concrete Directly Fastened Track in Korea", Advances in Materials Science and Engineering, 2015
Publication
1%

8 Tri H. M. Le, Dae-Wook Park, Jin-Yong Park, Tam M. Phan. "Evaluation of the Effect of Fly Ash and Slag on the Properties of Cement Asphalt Mortar", Advances in Materials Science
1%

and Engineering, 2019
Publication

9 Teguh Kurniawan, Zulkifli Lubis. "ALTERNATIF PENGGUNAAN SERAT ECENG GONDOK PADA CAMPURAN STONE MATRIX ASPHALT GRADASI HALUS MENINGKATKAN STABILITAS CAMPURAN ASPAL PANAS", UKaRsT, 2019 1%
Publication

10 Zhao Guotang, She Wei, Yang Guotao, Pan Li, Cai Degou, Jiang Jinyang, Hu Hao. "Mechanism of cement on the performance of cement stabilized aggregate for high speed railway roadbed", Construction and Building Materials, 2017 1%
Publication

11 T. Marolt Čebašek, A.F. Esen, P.K. Woodward, O. Laghrouche, D.P. Connolly. "Full scale laboratory testing of ballast and concrete slab tracks under phased cyclic loading", Transportation Geotechnics, 2018 1%
Publication

12 Huairong Zhou, Qingchun Yang, Shun Zhu, Ying Song, Dawei Zhang. "Life cycle comparison of greenhouse gas emissions and water consumption for coal and oil shale to liquid fuels", Resources, Conservation and Recycling, 1%

2019

Publication

13 Subandi, Santi Yatnikasari, Mukhripah Damaiyanti, Rafidah Azzahra, Vebrian. "Effect of Additional Fiberglass Fiber on Concrete Performance", Annales de Chimie - Science des Matériaux, 2019

Publication

1%

14 E Ngii, W Mustika, A S Sukri, R Balaka, R Sriyani, L Welendo. " The effect of clamshells partial substitution of coarse aggregates on the mechanical properties of shellfish concrete ( ) ", IOP Conference Series: Earth and Environmental Science, 2020

Publication

1%

15 Li, Qiushi, Haibo Ding, Ali Rahman, and Dongpo He. "Evaluation of Basic Oxygen Furnace (BOF) material into slag-based asphalt concrete to be used in railway substructure", Construction and Building Materials, 2016.

Publication

1%

16 Song Liu, Xianhua Chen, Yuewei Ma, Jun Yang, Degou Cai, Guotao Yang. "Modelling and in-situ measurement of dynamic behavior of asphalt supporting layer in slab track system", Construction and Building Materials, 2019

Publication

1%

17	Vinay Hosahally Nanjegowda, Krishna Prapoorna Biligiri. "Recyclability of rubber in asphalt roadway systems: A review of applied research and advancement in technology", Resources, Conservation and Recycling, 2020 Publication	<1%
18	Arif Anwar, Yogi Arisandi. "INVENTARISASI JALAN REL NON OPERASI LINTAS YOGYAKARTA-MAGELANG-TEMANGGUNG IN ACTIVE RAILWAY INVENTORY FOR YOGYAKARTA-MAGELANG-TEMANGGUNG TRACK", Jurnal Penelitian Transportasi Darat, 2019 Publication	<1%
19	Mutia Hanifah, Alvanov Zpalanzani, Ruly Darmawan. "User Experience Design in Indonesia Mobile Learning Application", 2018 International Conference on Advances in Computing and Communication Engineering (ICACCE), 2018 Publication	<1%
20	"Advancement in the Design and Performance of Sustainable Asphalt Pavements", Springer Science and Business Media LLC, 2018 Publication	<1%
21	Xing-Wang Sheng, Wei-Qi Zheng, Zhi-Hui Zhu, Tian-Jing Luo, Yan-Huang Zheng. "Properties of	<1%

rubber under-ballast mat used as ballastless track isolation layer in high-speed railway", Construction and Building Materials, 2020
Publication

22	M. Sol-Sánchez, F. Moreno-Navarro, L. Saiz, M.C. Rubio-Gámez. "Recycling waste rubber particles for the maintenance of different states of railway tracks through a two-step stoneblowing process", Journal of Cleaner Production, 2019 Publication	<1%
23	Georgy Lazorenko, Anton Kasprzhitskii, Zelimkhan Khakiev, Victor Yavna. "Dynamic behavior and stability of soil foundation in heavy haul railway tracks: A review", Construction and Building Materials, 2019 Publication	<1%
24	Vytautas Motiejus Bubnelis, Benas Slepakovas, Laura Černiauskaitė, Henrikas Sivilevičius. "GELEŽINKELIO KELIO GEOMETRINIŲ PARAMETRŲ DINAMIKOS TYRIMAS TAIKANT KELIO KOKYBĖS INDEKSĄ / RAILWAYS GEOMETRICAL PARAMETERS DYNAMICS INVESTIGATION BY TRACK QUALITY INDEX", Mokslas - Lietuvos ateitis, 2018 Publication	<1%
25	Chamindi Jayasuriya, Buddhima Indraratna,	<1%

Trung Ngoc Ngo. "Experimental Study to Examine the Role of Under Sleeper Pads for Improved Performance of Ballast under Cyclic Loading", Transportation Geotechnics, 2019
Publication

26	Sri Atmaja P. Rosyidi. "Simultaneous in-situ Stiffness and Anomalies Measurement on Pavement Subgrade Using Tomography Surface Waves Technique", Procedia Engineering, 2015 Publication	<1 %
27	Subandi, Robby Cahyono, Chandra Kusuma, Muhammad Asnan. "Artificial Aggregate Lightweight Structural", Annales de Chimie - Science des Matériaux, 2019 Publication	<1 %
28	"Geotechnics for Transportation Infrastructure", Springer Science and Business Media LLC, 2019 Publication	<1 %
29	William S. Chen, Nevena Zivanovic, David van Dijk, Guy Wolf, Bernd Bodenmiller, Smita Krishnaswamy. "Uncovering axes of variation among single-cell cancer specimens", Nature Methods, 2020 Publication	<1 %
30	M. Esmaeili, P. Aela, A. Hosseini. "Experimental	

assessment of cyclic behavior of sand-fouled ballast mixed with tire derived aggregates", Soil Dynamics and Earthquake Engineering, 2017
Publication

<1%

31 G. Di Mino, M. Di Liberto, C. Maggiore, S. Noto. "A Dynamic Model of Ballasted Rail Track with Bituminous Sub-Ballast Layer", Procedia - Social and Behavioral Sciences, 2012
Publication

<1%

32 Rosolino Vaiana, Filippo G. Praticò, Teresa Iuele, Vincenzo Gallelli, Venant Minani. "Effect of Asphalt Mix Properties on Surface Texture: An Experimental Study", Applied Mechanics and Materials, 2013
Publication

<1%

33 Rosyidi, Sri Atmaja P.. "Use of Wavelet Analysis and Filtration on Impulse Response for SASW Measurement in PCC Slab of Pavement Structure", Contemporary Topics on Testing Modeling and Case Studies of Geomaterials Pavements and Tunnels, 2011.
Publication

<1%

34 Buddhima Indraratna, Qideng Sun, Ngoc Trung Ngo, Cholachat Rujikiatkamjorn. "Current research into ballasted rail tracks: model tests and their practical implications", Australian Journal of Structural Engineering, 2017
Publication

<1%