

The Role Of Compaction and Scrap Rubber Size Against

by Ijciet Vol.9 No.13

Submission date: 04-Mar-2020 09:29AM (UTC+0700)

Submission ID: 1268835197

File name: IJCIET_09_13_131.pdf (871.98K)

Word count: 4592

Character count: 23865

14

International Journal of Civil Engineering and Technology (IJCIET)

Volume 9, Issue 13, December 2018, pp.1275–1286, Article ID: IJCIET_09_13_131

Available online at <http://www.iaeme.com/ijciyet/issues.asp?JType=IJCIET&VType=9&IType=13>

ISSN Print: 0976-6308 and ISSN Online: 0976-6316

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THE ROLE OF COMPACTION AND SCRAP RUBBER SIZE AGAINST THE PERFORMANCE OF BALLAST LAYER

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ABSTRACT

This research utilizes scrap rubber from waste motorcycle tires as a ballast layer mixture component. The objective of this study is to analyze the elastic modulus, material durability and vertical deformation of the ballast layer. In this research, a compressive strength test method was used with six samples. The most obvious finding to emerge from this study is that in the ballast layer with scrap rubber, an increase in compaction up to 100% is only able to increase the elastic modulus of ballast layers by 6%. However, it was also shown that the compaction works plays an important role in increasing ballast materials durability up to 38% and ballast layer ability to withstand the loads up to 70%. These findings also conclude that the various sized scrap rubber has an effective role in enhancing ballast durability.

Key words: Ballast durability, Compaction, Elastic Modulus, Scrap Rubber, Vertical Deformation.

Cite this Article: D. M. Setiawan and S. A. P. Rosyidi, The Role of Compaction and Scrap Rubber Size Against The Performance of Ballast Layer, *International Journal of Civil Engineering and Technology (IJCIET)* 9(13), 2018, pp. 1275–1286.
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1. INTRODUCTION

The primary function of the ballast layer is to provide a stable and uniform foundation and to reduce the loading effect to a level that can be accepted by the subgrade [1]. However, the performance of ballast layers needs to be improved in order to fulfill its function as a load distributor [2, 3]. Poor material conditions can be a benchmark for the needs of maintenance work and the application of train speed restrictions [4, 5]. One effort to overcome the speed limitation and to minimize the work of ballast layer maintenance is by the repairment of the ballast structure.

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Woodwart et al. [6] through their research have applied a special material called in-situ polyurethane polymer to improve the stability of ballast layers. However, the use of this material needs to be considered its availability in the railway industry.

Rubber is one of the essential materials in human life which can be seen from the use of goods by the community to carry out their activities such as sandals, shoes, rubber bands, and vehicle tires which are all made of rubber. However, the problem that cannot be avoided is waste material from un-used rubber which is difficult to recycle and the increasing number of scrap rubber which can have a negative impact on the environment.

In Indonesia, the utilization of scrap rubber from waste vehicle tires is still limited due to the lack of research on this matter. Besides, data on the number of scrap tires every year in Indonesia has never been reported in detail [7]. As one solution to this problem, the authors propose the idea of using scrap rubber as an additional material in the railroad ballast layer to improve the quality of ballast layer and to reduce the maintenance requirements of rail track. It can be seen that the application of scrap rubber on the highway pavement system could able to reduce the tendency of cracking and improve the performance of the pavement mixture [8]. Also, elastic material in the form of rubber has also been used in railway sleepers to reduce cracks by 80-100% by research conducted by Hameed et al. [9].

Therefore, the use of scrap rubber from motorized vehicle tires as added material in the ballast layer is also a solution to reduce the use of ballast material which its availability is feared to be scarce in the future. In addition, according to Sol-Sanchez et al. [10], Navaratnarajah et al. [11], Indraratna et al. [12, 13], and Nimbalkar et al. [14], the use of scrap rubber also serves to increase the durability of railroad structures because it can reduce material degradation in the long term. In addition, in previous studies, Sol-Sanchez et al. [15] said that the optimal rubber content used as elastic material in the ballast layer was 10%.

The purpose of this study was to determine the characteristics of ballast mixtures with and without scrap rubber and with the various number of manual compaction through a compressive strength test by analyzing the characteristics of elastic modulus, durability, and vertical deformation.

2. RESEARCH METHOD

The data needed in this test are the data of compressive strength test in the form of force, stress, strain, and change in the height of the sample. Before testing the sample, first of all, the physical testing is carried out on the ballast aggregate. Then the compressive strength test results were analyzed to compare the modulus of elasticity, ballast material abrasion (durability) and vertical deformation of each specimen. This research is divided into several stages, namely preparation and testing of materials, mixture planning and samples making, and compressive strength testing.

2.1. Preparation and Testing of Ballast Materials

The initial stage was carried out in the form of preparation of tools and materials. The ballast aggregate was obtained from KulonProgo, Special Region of Yogyakarta, while scrap rubber material was obtained from waste motorcycle tires (Figure 1). At the stage of material testing, the aggregate physical properties were tested to determine the specifications of the material. Regulations regarding testing of aggregates specifications are based on the Indonesian National Standard (SNI) [16, 17, 18,19]. Physical tests that carried out on the ballast aggregate include the specific gravity and absorption, sieve analysis, mud content analysis, and Los Angeles analysis. The grain size of the ballast used is 2"- 3/4" based on the gradation requirements for ballast material that is stated in PeraturanDinas No. 10 Tahun 1986 [20], PeraturanMenteriPerhubungan No. 60 Tahun 2012 [21], and Undang-Undang No. 23 Tahun

2007 [22]. Moreover, this ballast material is classified into class III in Indonesian Railways systems.

2.2. Mixture Planning and Sample Construction

The specimens were made in ballast box with a size of 40 cm x 20 cm x 30. The mixing process is accompanied by a compaction process manually with a pounder which has a load of 4.5 kg, a diameter of 6 cm and a falling height 20 cm, which is distinguished by the amount of compaction by the pounder which is 25 times and 50 times. The scrap rubber in this study is divided into two (2) types. The first is scrap rubber with a uniformly sized of 3/8", while the second is scrap rubber with graded sizes of 1", 1/2", 3/4", and No.4. The total percentage of scrap rubber in each specimen is 10% of the total aggregate weight, and that number is the optimum level of rubber obtained from the results of previous studies by Sol-Sanchez et al. [15].

Table 1 Samples design

Configuration	Sample
Ballast with 25 Compaction Times	S.1
Ballast with 50 Compaction Times	S.2
Ballast + Uniformly Sized Scrap Rubber 3/8" with 25 Compaction Times	S.3
Ballast + Uniformly Sized Scrap Rubber 3/8" with 50 Compaction Times	S.4
Ballast + Graded-Sized Scrap Rubber 1", 1/2", 3/4", and No.4 with 25 Compaction Times	S.5
Ballast + Graded-Sized Scrap Rubber 1", 1/2", 3/4", and No.4 with 50 Compaction Times	S.6

After the aggregate material is known to meet the requirements, then the samples can be made according to the planned mixture. The prepared samples are shown in Table 1. In each sample, the test material is inserted into the ballast box per 1/3 of the ballast box height. Then the layer is compacted with a pounder for all sides and the middle part of the layer with a load height of ± 20 cm, and then the same thing is done in the second and third layers until the box is filled entirely.

2.3. Compressive Strength Testing

At this stage, the compressive strength testing was done using the Micro-Computer Universal Testing Machine (UTM) with a load plate area of 30 cm x 15 cm (Figure 2). The results of this test are the value of force, stresses, strains, and the changes in the specimen's height. Furthermore, the relationship between stress and strain and the relationship between the loads and vertical deformation were analysed in this stage.



Figure 1 Ballast Aggregate and Scrap Rubber, and Compressive Strength Test Machine



Figure 2. Compressive Strength Test Machine

2.4. Elastic Modulus Analysis

The modulus of elasticity (E) is obtained based on the test data of compressive strength which is processed in the form of a stress-strain relationship curve with the trendline approach.

2.5. Vertical Deformation Analysis

The Examination of vertical deformation is obtained based on the number of changes in the height of the samples that occurs due to the vertical loading process is given by the Micro-Computer Universal Testing Machine. The vertical deformation value indicates the level of stiffness and the density of the ballast layer.

2.6. Ballast Material Abrasion Analysis

In this research, the analysis was carried out by calculating the amount of aggregate material that was degraded or broken after the compressive strength test was completed. The investigation is carried out by taking a 5000 gr of sample material and put it into the sieve tools with sizes 1" to No.4. Then the calculation of material abrasion is based on the material that was passing the filter $\frac{3}{4}$ ", or in other words, the ballast grain size is smaller than 25.4 mm. The abrasion of ballast is obtained based on material damage such as the aggregate fracture or wear due to compressive strength testing that leads to the reduction of ballast quality.

3. RESULT AND DISCUSSION

3.1. Ballast Aggregate Examination Result

In Table 2, the results of aggregate physical tests are shown, and it has met the specifications determined by the regulations applied in Indonesia.

Table 2 Ballast Aggregate Examination Result

No	Examination	Specification	Result	Unit
1	Specific Gravity-Bulk	≥ 2.60	2.62	-
2	Specific Gravity-Dry	≥ 2.60	2.65	-
3	Specific Gravity -Apparent	≥ 2.60	2.69	-
4	Absorption	≤ 3.00	0.98	%
5	Mud Content	≤ 0.50	1.89	%
6	Los Angeles	≤ 25.0	18.04	%

3.2. Elastic Modulus

The modulus of elasticity can be known by comparing the stress and strain values. Elastic modulus is the assessment of a material that is in an elastic condition resulting from the relationship between two axes, namely the Y axis that denotes the stress (σ) and the X-axis which presents the strain (ϵ).

In this study, the elastic modulus value is obtained using the trendline method assuming the sample is still elastic until the peak stress and strain is reached. In other words, the stress-strain curve is assumed to be in a linear elastic condition. The trendline method then used because there are only nine readings of stress and strain relationships and the maximum testing load is only 3,000 kg. This condition causes difficulties in determining the elastic and plastic area limits on the curve because there is the possibility of each sample still able to receive greater stress and the possibility of the stress-strain curve still able to increase.

The obtained elastic modulus from each sample shows different values due to the nature of the material from the mixture which also has different levels of elasticity. The use of the trendline method to determine the modulus of elasticity has been presented in Figure 3 to Figure 8 as follows.

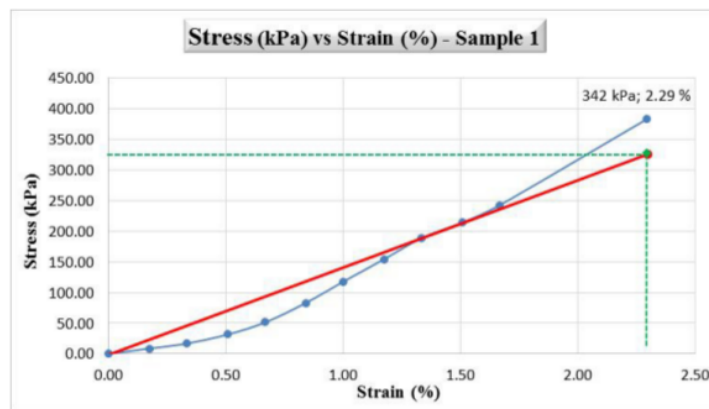


Figure 3. Stress (kPa) and Strain (%) of Sample 1 ¹⁷

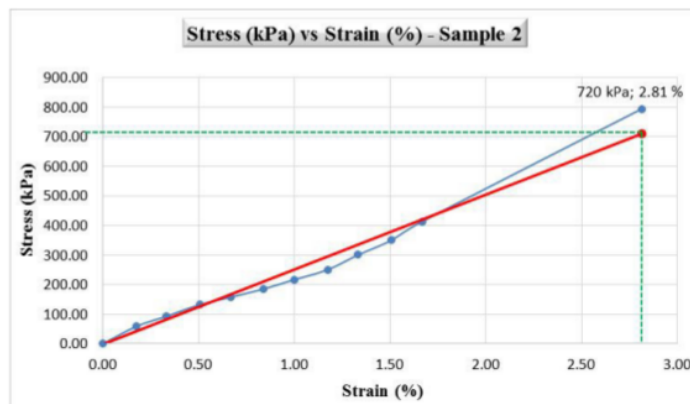


Figure 4. Stress (kPa) and Strain (%) of Sample 2

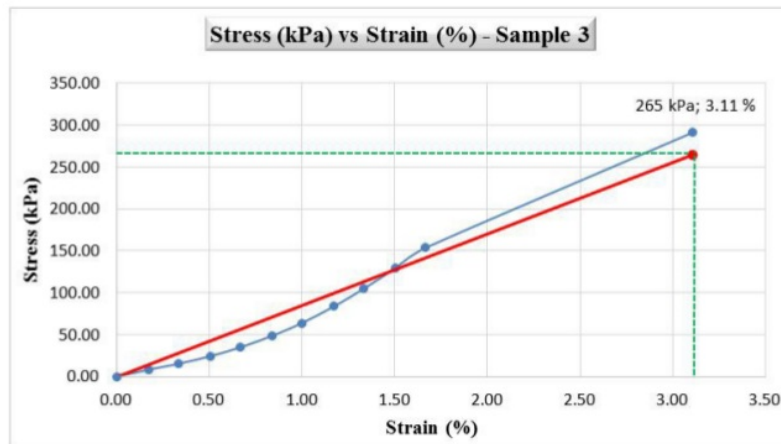


Figure 5. Stress (kPa) and Strain (%) of Sample 3

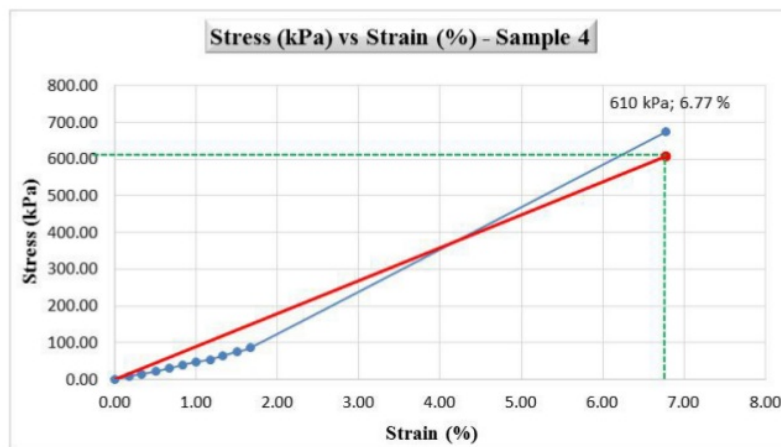


Figure 6. Stress (kPa) and Strain (%) of Sample 4

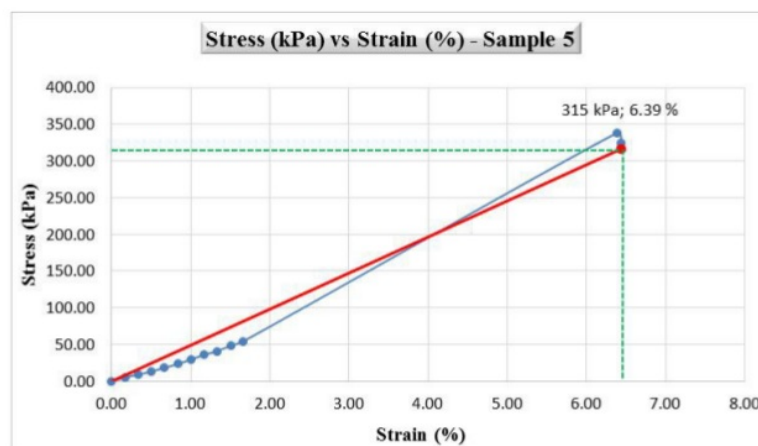


Figure 7. Stress (kPa) and Strain (%) of Sample 5

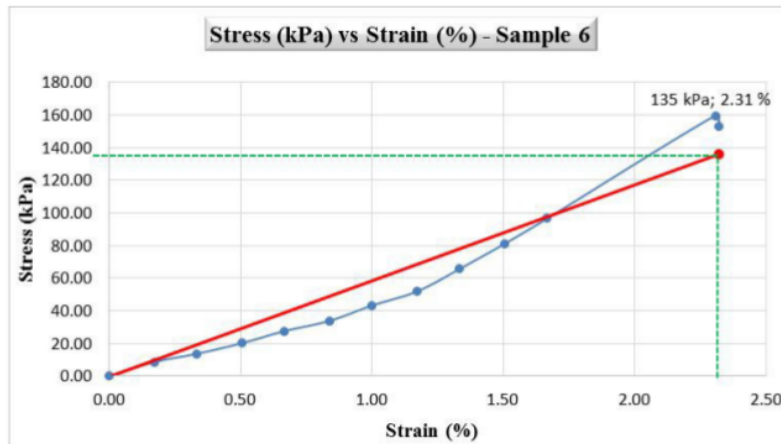


Figure 8. Stress (kPa) and Strain (%) of Sample 6

As presented in Table 3 and Figure 4, the highest modulus of elasticity is shown by sample 2 (ballast without scrap rubber and with 50 compaction times), which is equal to 25.62 MPa, or increases by 72% compared to sample 1 as the baseline. Furthermore, when compared with sample 1 (as the baseline) and sample 2, it is known that the modulus of elasticity shows a decrease along with the use of scrap rubber. As shown in Figure 9, the most significant reduction in the modulus of elasticity is found in sample 5 (ballast with graded-sized scrap rubber and with 25 compaction times) and sample 6 (ballast with graded-sized scrap rubber and with 50 compaction times), with a value of 67% (4.93 MPa) and 61% (5.84 MPa) respectively. This result is due to the addition of scrap rubber with various sizes that can fill the cavities in the ballast layer that able to reduce the stiffness of the ballast mixture, thus reducing the modulus of elasticity. This result is also in line with the results of the study conducted by Setiawan et al. [23], Sol-Sanchez et al. [15], and Signes et al. [24] which shows that the addition of elastic material can reduce the stiffness of the back layer.

Table 3 Elastic Modulus

Sample Name	Stress (kPa)	Strain (%)	Elastic Modulus (MPa)
S.1	342	2.29	14.93
S.2	720	2.81	25.62
S.3	265	3.11	8.52
S.4	610	6.77	9.01
S.5	315	6.39	4.93
S.6	135	2.31	5.84

Besides, the results of the research in Table 3 and Figure 9 also show that, in the same mixed configuration, the elastic modulus value on the sample with 50 compaction times is higher than the sample with 25 compaction times. So that can be concluded, the good and the proper compaction is an essential factor to increase the stiffness of the ballast layer.

Furthermore, the results of the research in Table 3 and Figure 9 also indicate that on the same amount of compaction, samples with graded-sized scrap rubber have a lower modulus of elasticity compared to samples with uniformly sized scrap rubber. This result is in line with the results of previous studies conducted by Setiawan et al. [23], which states that a scrap

rubber with graded size can fill the cavity between ballast with better and more evenly so that it can increase the flexibility of the back layer.

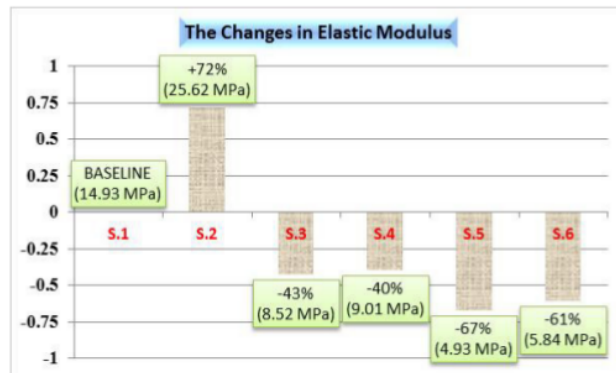


Figure 9. The Changes in Elastic Modulus

3.3. Ballast Material Abrasion (Durability)

Percentage of ballast that experienced abrasion can be analyzed based on the changes in aggregate grain size that become smaller and able to pass the sieve with the size of $\frac{3}{4}$ ". In another word, the ballast grain size becomes smaller than 25.4 mm. As shown in Figure 10 and Figure 11, the highest percentage of the ballast material abrasion is shown by sample 1 as a baseline (ballast without scrap rubber with 25 compaction times), which is 3.24% (162.1 gr). Furthermore, when compared with sample 1 (as the baseline) and sample 2, it is known that the percentage of ballast material abrasion shows a decrease along with the use of scrap rubber. The most significant reduction on the percentage of the ballast material abrasion is shown by sample 4 (ballast with uniformly sized scrap rubber and with 50 compaction times) and sample 6 (ballast with graded-sized scrap rubber and with 50 compaction times), with a decrease of 77% (36.5 gr) and 78% (36.2 gr) respectively. The lower percentage of ballast material abrasion on the sample indicates that the sample has a higher level of durability so it can minimize the occurrence of rupture and wear on ballast aggregates due to a reduction in friction or direct contact between aggregates. Scrap rubber can fill the cavity or pore in the mixture of the samples so that the modification of ballast with scrap rubber can reduce the level of ballast damage.

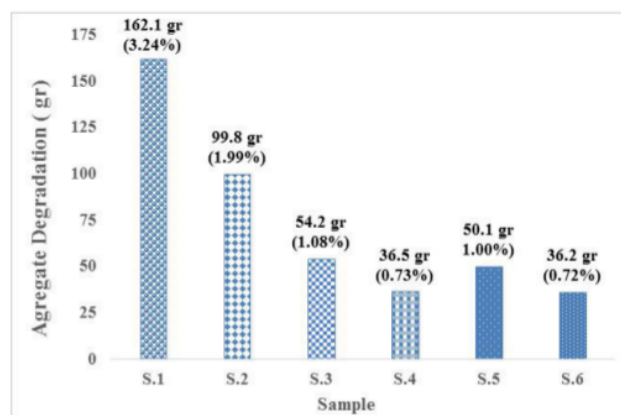


Figure 10. Percentage and Weight of Degraded Ballast Material

Also, the results of the research in Figure 10 and Figure 11 also show that on the same mixture configuration, the percentage of ballast material abrasion on the sample with 50 compaction times is lower than the sample with 25 compaction times. So that it can be concluded that the good and the proper compaction is one of the crucial factors to minimize material abrasion.

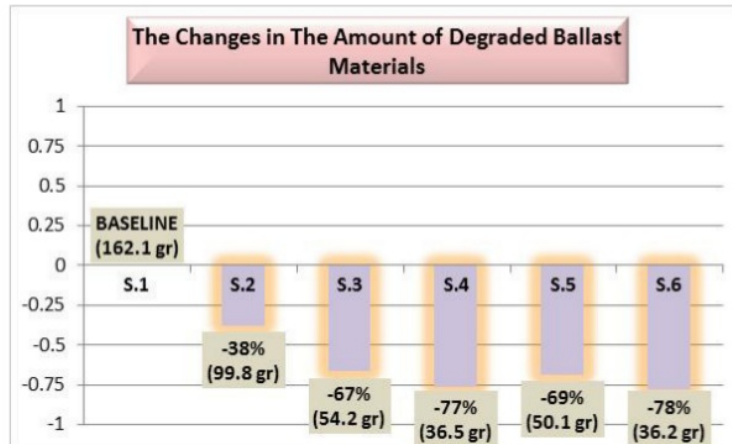


Figure 11. The Changes in the Amount of Ballast Materials Abrasion

Furthermore, the results of the research in Figure 10 and Figure 11 also present that on the same number of compaction, samples with graded-sized scrap rubber produce a lower ballast material abrasion percentage compared to samples with uniformly sized scrap rubber. This result is in line with the results of previous studies conducted by Setiawan et al. [23] and Sol-Sanchez et al. [15] which states that graded-sized scrap rubber can fill the cavity between ballast with better and more evenly so that it can reduce friction between ballast aggregates.

3.4. Vertical Deformation

Vertical deformation values were obtained from the graph of the relationship between the loads and the changes in the height of the specimens. Based on Figure 12 below, it can be seen the difference in the height of a sample at a particular load.

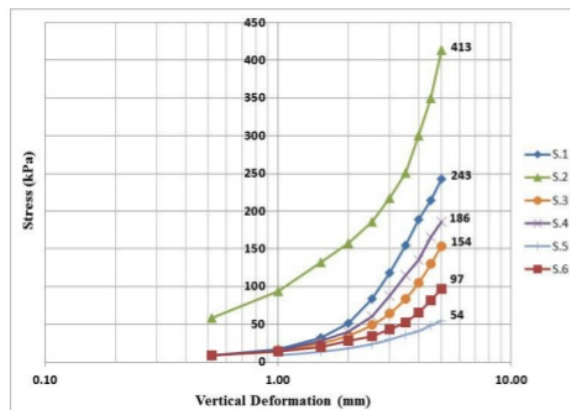


Figure 12. Vertical deformation (mm) and stress (kPa)

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As presented in Figure 12 and Figure 13, at the same vertical deformation value (5 mm), the highest loads received is shown by sample 2 (ballast without scrap rubber with 50 compaction times), which is 413 kPa. In other words, there is an increase of 70% compared to sample 1 as the baseline. Furthermore, when compared with sample 1 (as the baseline) and sample 2, it is known that there is a decrease on the loads needed to achieve a 5 mm of vertical deformation along with the use of scrap rubber. The most significant reduction in the loads required to produce a 5 mm of vertical deformation is shown by sample 5 (ballast with graded-sized scrap rubber and with 25 compaction times) and sample 6 (ballast with graded-sized scrap rubber and with 50 compaction times), with a value of 78% (54 kPa) and 60% (97 kPa) respectively. Elastic material in the form of scrap rubber added to the ballast mixture can improve the elastic properties of the ballast layer. So that on the ballast with the scrap rubber (sample 3, 4, 5 and 6), the loads needed to achieve the same vertical deformation value, for example, 5 mm, is much lower compared to the ballast without the scrap rubber (sample 1 and 2). The elastic properties possessed by scrap rubber cause the significant changes in the height of the ballast layer when given the load as shown by samples 3, 4, 5 and 6. This result is in line with the results of the study conducted by Setiawan et al. [23] and Signes et al. [24], which states that the use of scrap rubber can increase permanent deformation in the ballast and sub-ballast layers.

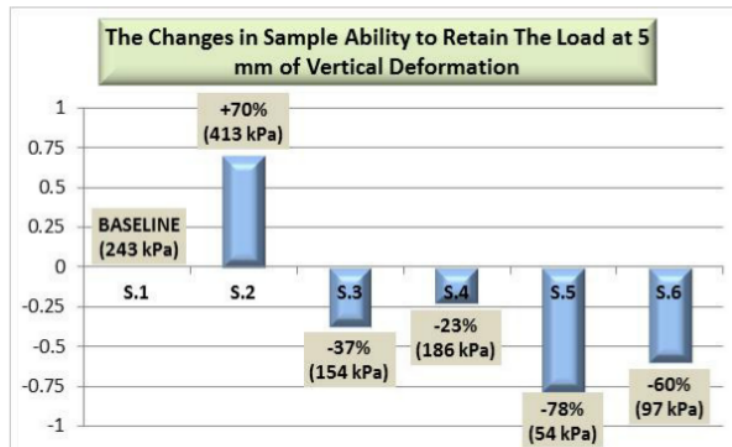


Figure 13. The changes in sample capability to retain the load at 5 mm of vertical deformation

In addition, the results of the research in Figure 12 and Figure 13 also show that on the same mixture configuration, the loads needed to achieve a 5 mm vertical deformation on the sample with 50 compaction times is higher than the sample with 25 compaction times. So that it can be concluded that the good and proper compaction is an essential factor to minimize vertical deformation and increase the stiffness of the ballast layer.

Furthermore, the results of the research in Figure 12 and Figure 13 also indicate that on the same number of compaction, samples with graded-sized scrap rubber require lower loads to achieve a 5 mm vertical deformation when compared to samples with uniformly sized scrap rubber. This result is in line with the results of previous studies conducted by Setiawan et al. [23], which states that a graded-sized scrap rubber can fill the cavity between ballast with better and more evenly so that it can reduce the stiffness of the ballast layer.

4. CONCLUSION

Based on the research that has been done, it can be concluded that:

- ¹ the ballast layer without scrap rubber, an increase in compaction works up to 100% will increase the modulus of elasticity of the ballast layer up to 72%. Whereas in the ballast layer both with uniformly sized scrap rubber and with graded-sized scrap rubber, an increase in compaction work up to 100% is only able to increase the modulus of elasticity of ballast layers by 3% and 6% respectively.
- In the ballast layer without scrap rubber, an increase in compaction works up to 100% will increase the ballast materials durability up to 38%. Whereas in the ballast layer both with uniformly sized scrap rubber and with graded-sized scrap rubber, an increase in compaction works up to 100% is only able to increase the durability of the ballast material by approximately 10%.
- In ballast layers without scrap rubber, an increase in compaction works up to 100% will increase the ability of the ballast layer to withstand the loads up to 70%. Whereas in the ballast layer both with uniformly sized scrap rubber and with graded-sized scrap rubber, an increase in compaction works up to 100% can only increase the ability of the ballast layer to withstand the loads up to 14% and 18%, respectively.
- When the compaction process with manual pounding is carried out, the ballast materials in the sample with scrap rubber tend to bounce off each other so that the sample does not have sufficient and proper density and stiffness.
- The ²³ addition of scrap rubber can reduce the stiffness of the ballast layer which is characterized by a decrease in elastic modulus and an increase in vertical deformation. But on the other hand, the use of scrap rubber can minimize damage to the ballast material significantly, since the presence of scrap rubber can reduce the possibility of collision and friction between aggregates so that the material durability could be increased and material degradation could be decreased.

5. ACKNOWLEDGEMENTS

The authors would like to thank Lembaga Penelitian, Publikasi & Pengabdian Masyarakat Universitas Muhammadiyah Yogyakarta (LP3M UMY) for the Research Funds in the scheme of Multi-Discipline 2018. The authors also would like to thank Robby Rahman and Nikmatusholihah for their contribution to this research.

REFERENCES

- [1] ⁸ Angelo, G., Thom, N., and Presti, D. L. Bitumen Stabilized Ballast: A Potential Solution for Railway Track-Bed. *Construction and Building Materials*, 124, 2016, pp. 118-126.
- [2] Setiawan, D. M., Muthohar, I. and Ghataora, G. Conventional and Unconventional Railway for Rail Ways on Soft Ground in Indonesia (Case Study: Rantau Prapat-Duri Railways Development). *Proceeding of The 16th FSTPT International Symposium, Universitas Muhammadiyah Surakarta, Indonesia, 2013*, pp. 610-620.
- [3] ¹⁵ Zakeri, J. A., and Mosayebi, S. A. Study of Ballast Layer Stiffness in Railway Tracks. *Gradevinar*, 68(4), 2016, pp. 311-318.
- [4] Setiawan, D. M. Pembatasan Kecepatan Maksimum dan Kaitannya Terhadap Kapasitas Lintas Jalur Kereta Api Muara Enim-Lahat Sumatera Selatan. *Prosiding Seminar Nasional Teknik Sipil ke-VI, Universitas Muhammadiyah Surakarta, Indonesia, 2016*, pp. 36-46. ISSN: 2459-9727.
- [5] ¹¹ Setiawan, D. M. and Rosyidi, S. A. P. Track Quality Index as Track Quality Assessment Indicator. *Proceedings of the 19th International Symposium of FSTPT, Islamic University of Indonesia, Yogyakarta, 2016*, Ch. 2, pp. 197-207, ISBN: 979-95721-2-19.

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- [6] Woodward, P. K., El Kacimi, A., Laghrouche, O., Medero, G., and Banimahd, M. Application of Polyurethane Geocomposites to Help Maintain Track Geometry for High Speed Ballasted Railway Tracks. *Journal of Zhejiang University Science*, **13**(11), 2012, pp. 836-849.
- [7] Satyarno, I. Penggunaan Serutan Karet Ban Bekas Untuk Campuran Beton. *Media Teknik*, **4**, 2006, pp. 45-51.
- [8] Farhan, A. H., Dawson, A. R., Thom, N. H., Adam, S., and Smith, M. J. Flexural Characteristics of Rubberized Cement-Stabilized Crushed Aggregate for Pavement Structure. *Materials and Design*, **88**, 2015, pp. 897-905.
- [9] Hameed, A. S., and Shashikala, A. P. Suitability of Rubber Concrete for Railway Sleepers. *Perspectives in Science*, **8**, 2016, pp. 32-35.
- [10] Sol-Sanchez, M. S., Thom, N. H., Navaro, F. M., Gomez, M. C. R., and Airey, G. D. A Study into The Use of Crumb Rubber in Railway Ballast. *Construction and Building Materials*, **75**, 2015, pp. 19-24.
- [11] Navaratnarajah, S. K. and Indraratna, B. Use of Rubber Mats to Improve The Deformation and Degradation Behavior of Rail Ballast Under Cyclic Loading. *Journal of Geotechnical and Geoenvironmental Engineering*, **143**(6), 2017, pp. 1943-5606.
- [12] Indraratna, B., Ngo, N. T., and Rujikiatkamjorn, C. Improved Performance of Ballasted Rail Tracks Using Plastics and Rubber Inclusions. Proceeding in Transportation Geotechnics and Geoecology, Saint Petersburg, Rusia, 2017, pp. 207-214.
- [13] Indraratna, B., Nimbalkar, S., Navaratnarajah, S. K., Rujikiatkamjorn, C., and Neville, T. Use of Shock Mats for Mitigating Degradation of Railroad Ballast. *Sri Lankan Geotechnical Journal - Special Issue on Ground Improvement*, **6**(1), 2014, pp. 32-41.
- [14] Nimbalkar, S., Indraratna, B., Dash, S. K., and Christie, D. Improved Performance of Railway Ballast Under Impact Loads Using Shock Mats. *Journal of Geotechnical and Geoenvironmental Engineering*, **138**(3), 2012, pp. 281-294.
- [15] Sol-Sanchez M. S., Navaro, F. M., and Gomez, M. C. R. The Use of Deconstructed Tires as Elastic Elements in Railway Tracks. *Materials*, **7**, 2014, pp. 5903-5919.
- [16] Badan Standardisasi Nasional. SNI 03-1968-1990 Metode Pengujian Tentang Analisis Saringan Agregat Halus dan Kasar. Badan Standardisasi Nasional, Jakarta, 1990.
- [17] Badan Standardisasi Nasional. SNI 03-4141-1996 Metode Pengujian Gumpalan Lempungan Butir-butir Mudah Pecah dalam Agregat. Badan Standardisasi Nasional, Jakarta, 1996.
- [18] Badan Standardisasi Nasional. SNI 1969-2008 Cara Uji Berat Jenis dan Penyerapan Agregat Kasar. Badan Standardisasi Nasional, Jakarta, 2008.
- [19] Badan Standardisasi Nasional. SNI 2417:2008 Cara Keausan Agregat dengan Mesin Abrasi Los Angeles. Badan Standardisasi Nasional, Jakarta, 2008.
- [20] Peraturan Dinas No. 10 Tahun 1986 tentang Peraturan Perencanaan Konstruksi Jalan Rel.
- [21] Peraturan Menteri Perhubungan No. 60 Tahun 2012 tentang Persyaratan Teknis Jalur Kereta Api.
- [22] Undang-Undang No. 23 tentang Perkeretaapian. Lembaran Negara RI Tahun 2007. Sekretariat Negara. Jakarta.
- [23] Setiawan, D. M., and Rosyidi, S. A. P. Vertical Deformation and Ballast Abrasion Characteristics of Asphalt-Scrap Rubber Track Bed. *International Journal on Advanced Science, Engineering and Information Technology*, **8**(6), 2018, pp. 2479-2484.
- [24] Signes, C., H., Hernandez, P. M., Roca, J. G., de la Torre, M. E., and Franco, R. I. An Evaluation of the Resilient Modulus and Permanent Deformation of Unbound Mixture of Granular Materials and Rubber Particles from Scrap Tyres to Be Used in Subballast Layers. *Transportation Research Procedia*, **18**, 2016, pp. 384-3.

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Publication

7 Chen, Qingsheng, Buddhima Indraratna, John Carter, and Sanjay Nimbalkar. "An Isotropic-Kinematic Hardening Model for Coarse Granular Soils Capturing Particle Breakage and Cyclic Loading under Triaxial Stress Space", Canadian Geotechnical Journal, 2015. **1%**

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A. Kravcov, O.L. Dudchenko, P. Svoboda, P.N. Ivanov, M.V. Sizikov, O.D. Belov, A.A. Gapeev. "Broadband ultrasonic pulse-echo method for estimation of local density of tungsten samples", Journal of Physics: Conference Series, 2019

Publication

15

Seyed-Ali Mosayebi, Morteza Esmaeili, Jabbar-Ali Zakeri. "Dynamic Train–Track Interactions and Stress Distribution Patterns in Ballasted Track Layers", Journal of Transportation Engineering, Part B: Pavements, 2020

Publication

16

Buddhima Indraratna. "1st Proctor Lecture of ISSMGE:", Transportation Geotechnics, 2016

Publication

17

Niranjan, Raja R., S. Junaid Kokan, R. Sathya Narayanan, S. Rajesh, V.M. Manickavasagam, and B. Vijaya Ramnath. "Fabrication and Testing of Abaca Fibre Reinforced Epoxy Composites for Automotive Applications", Advanced Materials Research, 2013.

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