Ballast Assessment

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The role of scrap rubber size against the characteristics of ballast layer

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Abstract. This research utilizes scrap rubber from motorcycle tires as a ballast layer mixture component. A compression test method was used with three test samples: ballast (sample I), ballast with 10% uniform graded scrap rubber (sample II) and ballast with 10% continuous graded scrap rubber (sample III). This research aims to analyze the elastic modulus, durability and vertical deformation of the ballast layer. It can be concluded that the elastic modulus of sample I, II, and III was 14.28 MPa, 8.53 MPa, and 3.10 MPa, respectively. Moreover, the abrasion of sample I, II, and III was 162.1 gr (3.24%), 54.2 gr (1.08%), and 50.1 gr (1%). Furthermore, at the same number of vertical deformation (5 mm), the sample I was able to receive the most considerable load that is 1980.9 Kg, followed by sample II by 1252.2 Kg and sample III by 443.7 Kg.

Keywords: ballast durability, elastic modulus, rail track, scrap rubber, vertical deformation.

1. Introduction

The ballast layer functions to hold the sleepers construction and distribute the load from the sleeper to the subgrade. In recent years, conventional track structure is the most widely used railroad type because of its low construction cost compared to the slab track. However, the performance of ballast layers needs to be improved to fulfill its function as a load distributor in the rail track structure [1]. The poor ballast material conditions can be a benchmark for the needs of maintenance work and the application of train speed restrictions [2, 3]. One effort to avoid the speed limitation is by strengthening the ballast structure. The use of scrap rubber as an added component in the ballast layer is a proposed method in this study to reduce the use of aggregate material. With the addition of rubber, it is also expected to be able to decrease the friction between aggregates and to minimize the ballast wear. The previous study has reported that the utilization of scrap rubber from waste motorcycle tires is not only the solution that can reduce the aggregate use, but also serves to increase the durability of the railroad structure [4].

Sol-Sanchez et al., (2014) have found that the optimum rubber content used as elastic material in the ballast layer was 10% [5]. Also, Hameed et al., (2016) have identified that flexible mixture can also be used in sleepers to reduce cracks by 80-100% [6]. It is also known that the stiffness of the ballast layer is different for each layer. The greatest stiffness is in the bottom part of the ballast layer, and the flexible portion is found at the top of the ballast layer [7]. In another study, Navaratnarajah et

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al., (2017) have concluded that the use of rubber mixtures on ballast layers can reduce long-term degradation and deformation [8].

Most studies in rubber usage for rail track structure have only been carried out with crumb rubber and natural rubber. In this study, the author has used the scrap rubber from outer motorcycle tire with two different sizes as additional material in ballast layer. This study aimed to evaluate and validate the characteristics of modified ballast with scrap rubber mixtures through a compressive strength test by analyzing the elastic modulus, ballast material durability, and vertical deformation. Thus it can be seen the effect of adding scrap rubber from outer motorcycle tire on the ballast layer and the characteristics comparison between ballast with uniformly sized scrap rubber and ballast with graded-sized scrap rubber.

2. Research Method

2.1. Material Preparation and Testing

The ballast aggregates were obtained from Kulon Progo, while the scrap rubber was obtained from the outer tires of motor vehicles (Figure 1). At the stage of material testing, the aggregate physical properties were examined to identify the specifications of the material used. Regulations regarding testing aggregate specifications are based on the Indonesian National Standard [9, 10, 11, 12]. The physical tests performed on the ballast aggregate were the specific gravity and absorption tests, sieve analysis, mud content and abrasion with Los Angeles machines.

2.2. Mixture Planning and Sample Making

The specimens were made in the ballast box with a size of 40 cm x 30 cm x 20 cm. The test material prepared is a mixture of ballast and scrap rubber. The mixing process is accompanied by a manual compaction process with a pulverizer that has a load of 4.5 kg, a diameter of 6 cm and a falling height of 20 cm. Scrap rubber used in this study is divided into two (2) types. The first is scrap rubber with a uniform size of 3/8", while the second is scrap rubber with the graded size of 1", ½", ¾", and No.4, with the percentage of each type of scrap rubber is 10% from the total aggregate weight. The 10% of scrap rubber in the mixture is the optimum level of rubber utilization in this research based on the results of Sol-Sanchez et al. (2015) study [4]. After the aggregate material is known to meet the requirements, the specimens can be made according to the mix planned. There are three samples, which are sample I (ballast), sample II (ballast and 10% scrap rubber with a uniform size of 3/8"), and sample III (ballast with 10% scrap rubber with graded-size of 1", ½ ", ¾", and No.4) as shown in Table 1.

Furthermore, to identify the change in samples performance after the initial maximum loads, then each sample was tested twice, namely IA, IB, IIA, IIB, IIIA, and IIIB. Next, the mixture of ballast aggregate and scrap rubber is put into the ballast box per 1/3 the height of the mold, then the layer is compacted with a manual compactor 25 times for all sides, and the center of the layer with a falling height is approximately 20 cm. The same thing was done in the second and the third layers until the box is filled. In order to control the compaction, the compaction energy that produced by a manual compactor was transferred through a plate that covers the surface of the ballast layer.

Table 1. Specimens

No.	Configuration	Name
1.	Ballast	Sampel I (A and B)
2.	Ballast + 10% Scrap Rubber 3/8‖	Sampel II (A and B)
3.	Ballast + 10% Scrap Rubber 1‖, ½‖, ¾‖, dan No.4	Sampel III (A and B)

2.3. Compressive Strength Testing
At this stage, the sample was weighed then the compressive strength testing was conducted using a Micro-Computer Universal Testing Machine (UTM) tool with a load plate area measuring 30 cm x 15 cm (Figure 1). The results of this test are in the form of stress, strain, and elongation.

Figure 1. Ballast Aggregate, Scrap Rubber and Compressive Strength Testing Process with Universal Testing Machine

2.4. Elastic Modulus Examination
The elastic modulus (E) is obtained based on the compressive strength test data and is processed in the form of a stress-strain relationship curve with the trend-line approach.

2.5. Vertical Deformation Examination
Examination of vertical deformation is conducted based on the change of sample height that occurs due to the vertical loading process is given by the UTM Machine. The deformation value shows the level of stiffness and density of the ballast layer.

2.6. Aggregate Abrasion Examination
The method to find out the abrasion value of aggregate material in the mixture is based on the wear that occurs due to the compressive strength test process and by comparing the amount of deteriorating aggregate material after the compressive strength test process. The comparison is made by taking 5000 gr of ballast material from the total mixture weight before and after the compressive strength test of each mixture type. Furthermore, the ballast materials from each sample were compared using sieve analysis with the size of 1 inch to No.4. The value of material abrasion is obtained from the percentage of aggregate that has the grain size smaller than 25.4 mm. In another word, the material was able to pass the sieve with the size of a ¾ inch.

3. Result and Discussion

3.1. Ballast Aggregate Checking Result
In Table 2, the results of aggregate physical tests are shown. It can be concluded that the ballast met the specifications determined by the Indonesian National Standard (SNI).

Table 2. Aggregate Examination Results

No	Examination	Specification	Result	Unit
1.	Specific Gravity	≥ 2.6	2.63	-
	a. Bulk	≥ 2.6	2.66	-
	b. Dry	≥ 2.6	2.70	-
	c. Apparent	≤ 3.0	0.95	%
2.	Water Absorption	≤ 0.5	1.88	%
3.	Mud Content	≤ 25.0	17.66	%

3.2. Mixture Characteristics

Each sample has a different mixture characteristic that occurs because of the variety of constituent materials. Identifying the characteristics of the mixture was done to determine the volume of the material and the cavity that fills a ballast box — the more varied the size of scrap rubber mixed in the ballast modification, the smaller the volume of the cavity. This result is caused by the use of scrap rubber which serves to fill the cavities. The amount of cavities in each sample is presented in Table 3.

Table 3. Mixture Characteristics

Parameter	S.I	S.II	S.III
Volume Weight (gr/cm^3)	1.60	1.46	1.43
Scrap Rubber Volume Percentage	-	13.3%	14.5%
Ballast Volume Percentage	62.4%	49.5%	56.2%
Pore Volume Percentage	37.6%	37.2%	29.3%
Total	100%	100%	100%

[23]. *Elastic Modulus*

Based on the results of the analysis, it is known that the addition of scrap rubber to the ballast mixture can reduce the stiffness of the ballast layer. As presented in Table 4, the highest modulus of elasticity is shown by sample I (ballast without scrap rubber) in the first test (A). Whereas, the modulus of elasticity of ballast mixture with the addition of scrap rubber in samples II and III has a value of elastic modulus that is smaller than sample I. Samples II and III have more elastic properties due to the existence of scrap rubber that able to decrease the stiffness of the ballast layer, thereby reducing the modulus of elasticity. Furthermore, it can be concluded that sample III, ballast with graded-sized scrap rubber, has a lower modulus of elasticity compared to sample II, ballast with uniformly sized scrap rubber. This result is due to the addition of scrap [20]e rubber with various sizes that can fill the cavities in the ballast layer in sample III. This result is also in[8]ine with the results of Farhan et al. (2015), Setiawan and Rosyidi (2018), Signes et al. (2016), and Sol-Sanchez et al. (2014) which show that the addition of elastic material can increase deformation and reduce stiffness [13, 14, 15, 5].

Table 4. Elastic Modulus

No	Sample	Stress (kPa)	Strain (%)	E (MPa)	Changes in E (%)
1	Sampel IA	328.39	2.30	14.28	-10.08%
2	Sampel IB	337.64	2.63	12.84	
3	Sampel IIA	266.24	3.12	8.53	-9.26%
4	Sampel IIB	131.55	1.70	7.74	
5	Sampel IIIA	52.01	1.68	3.10	-37.42%
6	Sampel IIIB	39.25	2.02	1.94	

To find out the change in samples stiffness after given the first maximum loads, then each sample was tested twice, namely A and B. It can be concluded that in the second test (B), each sample experienced a decrease in the level of stiffness because it had received the previous maximum load. As shown in Figure 2 and 3, the reduction in elastic modulus in the second test due to the first maximum loads that occurred in sample I was 10.08% (from A = 14.28 MPa to B = 12.84 MPa), sample II 9.26% (from A = 8.53 MPa to B = 7.74 MPa) and sample III 37.42% (from A = 3.10 MPa to B = 1.94 MPa).

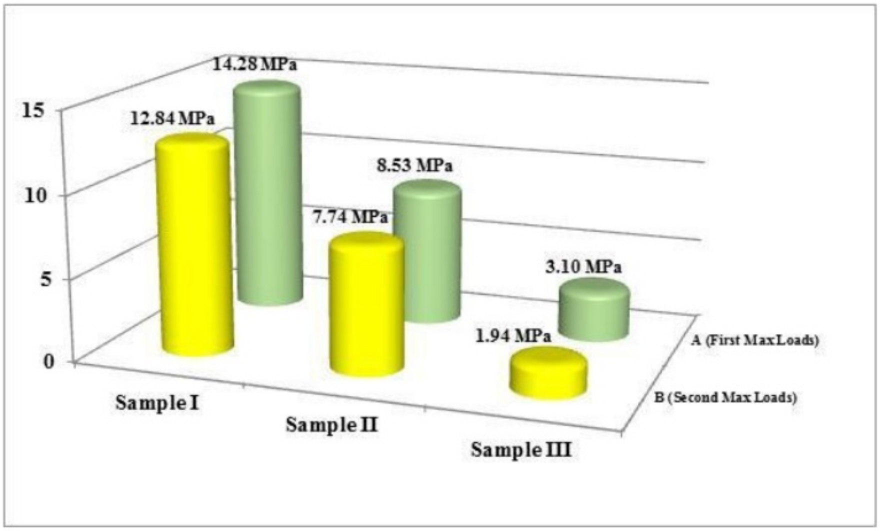

Figure 2. Elastic Modulus in the First and Second Max Loads

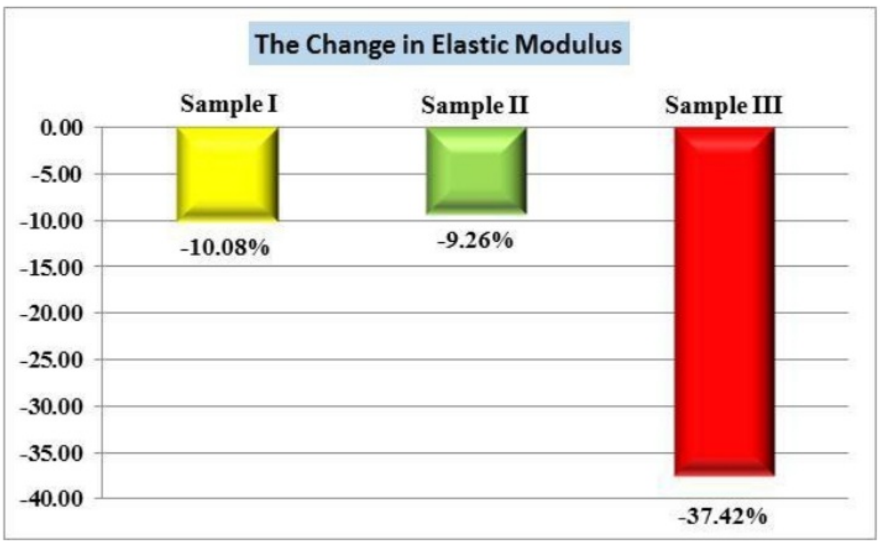

Figure 3. The Change in Elastic Modulus

3.4. Ballast Material Durability

Based on the following Figure 4 to 6, the results of sieve analysis tests in sample II were obtained after the testing which shows the changes in aggregate size distribution patterns. This result is due to the loads given during compaction using manual compactor and also the compressive testing process using UTM tools. The most significant changes in aggregate size distribution patterns occurred in sample 1.

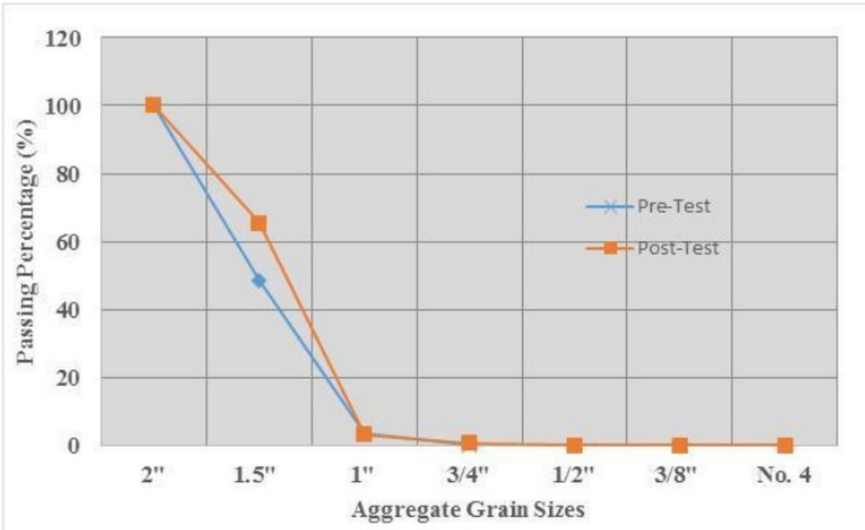

Figure 4. The Change in Aggregate Gradation on Sample I

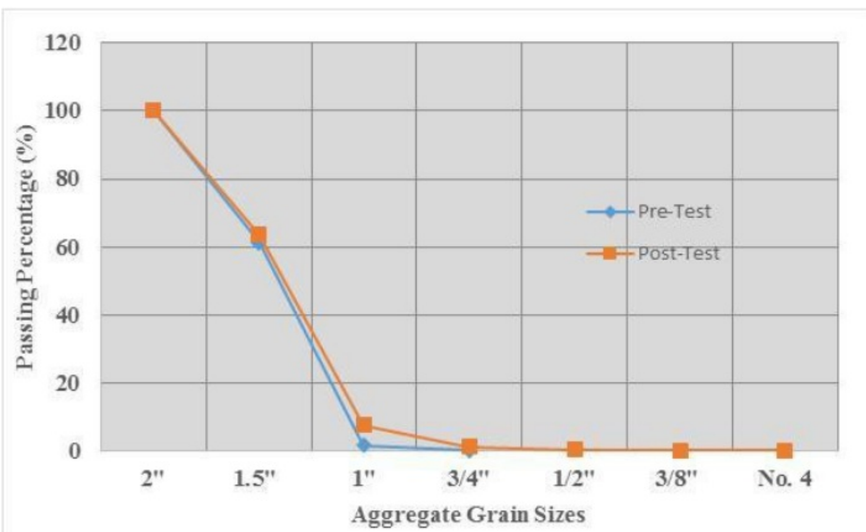

Figure 5. The Change in Aggregate Gradation on Sample II

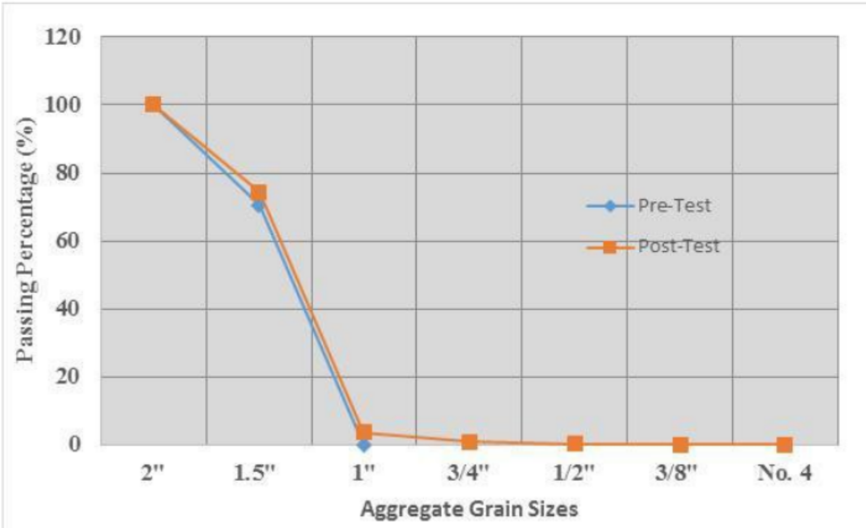

Figure 6. The Change in Aggregate Gradation on Sample III

The deterioration of ballast can be seen from the change in aggregate grain size that becomes smaller and able to pass the filter ¾", or in other words, the size of the ballast aggregate becomes smaller than 25.4 mm. Each sample has a different abrasion value depending on the modification of the mixture. The lower percentage of abrasion in the sample indicates that the sample has a higher degree of durability due to reduced friction or direct contact between the aggregates by the presence of the scrap rubber in the ballast layer. The scrap rubber can fill the cavity or pore in the mixture of the samples so that the modification of scrap rubber in the ballast layer can reduce the level of ballast material deterioration.

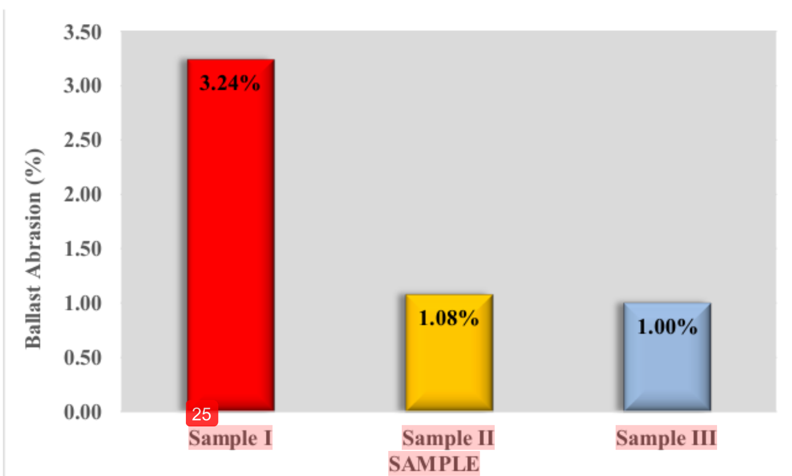

Figure 7. Weight and Percentage of Ballast Abrasion

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Based on the information obtained in Figure 7, the highest aggregate abrasion percentage was found in sample I (ballast without scrap rubber) by 3.24% (162.1 grams) while the least was found in sample III (ballast with modified scrap rubber with graded-sized) by 1% (50.1 grams). Although sample II and sample III both used the scrap rubber, however, there were differences in results between these two samples. The abrasion value of sample III was lower than that of sample II due to the presence of graded-sized scrap rubber in the sample III which had a variety of rubber sizes so that it could fill the cavity in the ballast layer better and more evenly.

The addition of scrap rubber on the ballast layer can reduce the damage of ballast material. This is also in line with the research of D’Angelo et al. (2016), D’Angelo et al. (2017), Indraratna et al. (2014), Indraratna et al. (2017), Nimbalkar et al. (2012), and Setiawan and Rosyidi (2018) which state that the elastic materials in the ballast can minimize the movement of the ballast material and reduce the friction between aggregate so that material durability increases and material degradation decreases [16, 17, 18, 19, 20, 14].

3.5. Vertical Deformation

Vertical deformation values obtained based on the relationship between the loads and the change of samples height. Based on Figure 8 below, it can be seen that the height of a sample changes at a particular load. The test results show varying values. Ballast material without scrap rubber exhibits the highest stiffness. Based on the information obtained from Figure 8, at the same vertical deformation value of 5 mm, the sample I (ballast without scrap rubber) showed the highest level of stiffness because it was able to retain the loads with a value of 1980.9 Kg. Whereas sample III, ballast with additional graded-sized scrap rubber shows the lowest level of stiffness because it is only able to withstand the load of 443.7 Kg at 5 mm vertical deformation. Elastic material in the form of scrap rubber added to the ballast mixture causes an increase in the elastic characteristics of the mixture. Therefore, to achieve the same vertical deformation value, the load that can be retained by the ballast layer with scrap rubber mixture is smaller than the ballast without scrap rubber mixture. The elastic properties possessed by rubber cause a change in samples height when given the loads as in samples II and III. This statement is supported by the research of Setiawan and Rosyidi (2018) and Signes et al. (2016), where it is stated that the use of scrap rubber can increase permanent deformation in the ballast and sub-ballast layers [14, 15].

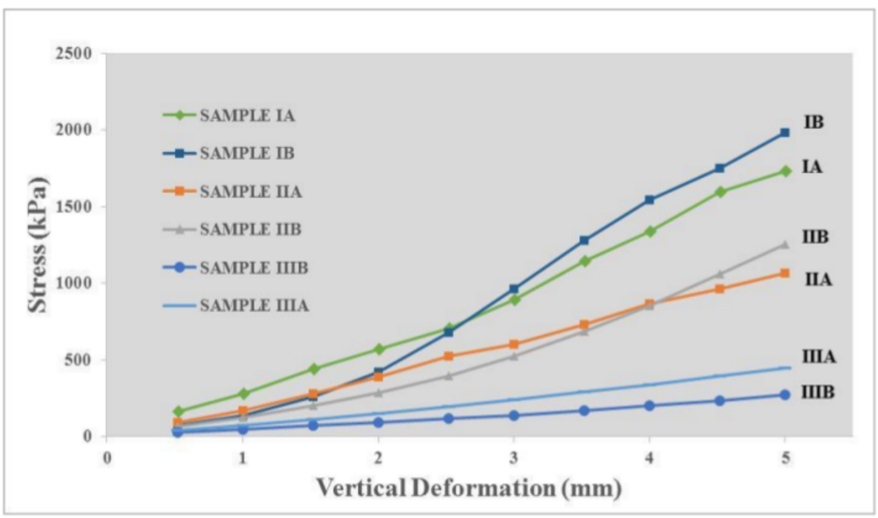

Figure 8. Vertical Deformation and Loads

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4. Conclusions

From the results of the research conducted, the following results are summarized:

a. Ballast without scrap rubber mixture has a higher value of elastic modulus compared to ballast with scrap rubber mixture.
b. The addition of scrap rubber with uniformly sized on the ballast layer could produce greater elastic modulus compared to the addition of scrap rubber with graded-sized.
c. The decreasing on samples modulus of elasticity due to previous loading in ballast without scrap rubber (sample I) is 12.69%, ballast with 10% uniformly sized scrap rubber (sample II) is 6.23%, and ballast with 10% graded-sized scrap rubber (sample III) is 40.20%.
d. Ballast with scrap rubber mixture has a higher value of durability compared to ballast without scrap rubber mixture.
e. The addition of scrap rubber with graded-sized on ballast layer could produce higher ballast durability compared to the addition of scrap rubber with uniformly sized.
f. The ballast abrasion percentage in sample I is 3.24% (162.1 gram), sample II is 1.08% (54.2 grams), and sample III is 1% (50.1 grams).
g. At the same vertical deformation value of 5 mm, the sample I has the highest level of stiffness because it can withstand the loads up to a 1980.9 Kg. While sample III shows the lowest level of stiffness because it is only able to retain loads of 443.7 Kg.
h. Modification of the ballast layer by adding scrap rubber or elastic material can reduce the stiffness of the ballast layer which is characterized by a decrease in elastic modulus and an increase in the value of vertical deformation. But on the other hand, modification of ballast layers with scrap rubber can increase ballast durability because it can reduce the possibility of friction between aggregate particles so that it can reduce the ballast material damage.

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References

[1] Setiawan D M, Muthohar I and Ghataora G 2013 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, 1-3 November 2013* 610-620.
[2] Setiawan, D M 2016 Pembatasan Kecepatan Maksimum dan Kaitannya Terhadap Kapasitas Lintas Jalur Kereta Api Muara Enim–Lahat Sumatera Selatan *Prosiding Seminar Nasional Teknik Sipil ke-VI 2016. Surakarta, 25 Mei 2016* 36-46. ISSN: 2459-9727.
[3] Setiawan, D M, and Rosyidi, S A P ―Track Quality Index as Track Quality Assessment Indicator‖ *Proceeding of The 19th International Symposium of Indonesian Inter-University Transportation Studies Forum (FSTPT), Universitas Islam Indonesia, Indonesia, October 2016.* Ch. 2, pp. 197-207, ISBN: 979-95721-2-19.
[4] Sol-Sanchez M, Thom N H, Navaro F M, Gomez M C R, and Airey G D 2015 A Study into The Use of Crumb Rubber in Railway *Ballast Construction and Building Materials* **75** 19 - 24.
[5] Sol-Sanchez M, Navaro F M, and Gomez M C R 2014 The Use of Deconstructed Tires as Elastic Elements in Railway Tracks *Materials* **7** 5903-5919.
[6] Hameed A S, and Shashikala A P 2016 Suitanability of Rubber Concrete for Railway Sleepers *Perspectives in Science* **8** 32-35.
[7] Zakeri J A, and Mosayebi S A 2016 Study of Ballast Layer Stiffness in Railway Tracks *Gradevinar* **68(4)** 311-318.

[8] Navaratnarajah S K and Indraratna B 2017 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)** 1943-5606.

[9] BSN 1990 *SNI 03-1968-1990 Metode Pengujian Tentang Analisis Saringan Agregat Halus dan Kasar* (Jakarta: Badan Standardisasi Nasional)

[10] BSN 1996 *SNI 03-4141-1996 Metode Pengujian Gumpalan Lempung dan Butir-butir Mudah Pecah dalam Agregat* (Jakarta: Badan Standardisasi Nasional)

[11] BSN 2008a *SNI 1969-2008 Cara Uji Berat Jenis dan Penyerapan Agregat Kasar* (Jakarta: Badan Standardisasi Nasional)

[12] BSN 2008b *SNI 2417:2008 Cara Keausan Agregat dengan Mesin Abrasi Los Angeles* (Jakarta: Badan Standardisasi Nasional)

[13] Farhan A H, Dawson A R, Thom N H, Adam S, and Smith M J 2015 Flexural Characteristics of Rubberized Cement-Stabilized Crushed Aggregate for Pavement Structure *Materials and Design* **88** 897-905.

[14] Setiawan, D M, and Rosyidi S A P 2018 Vertical Deformation and Ballast Abrasion Characteristics of Asphalt-Scrap Rubber Track Bed *International Journal on Advanced Science, Engineering and Information Technology* **8(6)** pp. 2479-2484.

[15] Signes C H, Hernandez P M, Roca J G, de la Torre M E, and Franco R I 2016 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 Subbalast Layers *Transportation Research Procedia* **18** 384 – 391.

[16] D'Angelo G, Thom N, and Presti D L 2016 Bitumen Stabilized Ballast: A Potential Solution for Railway Track-Bed *Construction and Building Materials* **124** 118-126.

[17] D'Angelo G, Thom N, and Presti D L 2017 Optimisation of Bitumen Emulsion Properties for Ballast *Materiales De Construction* **67** 124-133.

[18] Indraratna B, Nimbalkar S, Navaratnarajah S K, Rujikiatkamjorn C, and Neville T 2014 Use of Shock Mats for Mitigating Degradation of Railroad Ballast *Sri Lankan Geotechnical Journal - Special Issue on Ground Improvement* **6(1)** 32-41.

[19] Indraratna B, Ngo N T, and Rujikiatkamjorn C 2017 Improved Performance of Ballasted Rail Tracks Using Plastics and Rubber Inclusions *Proceeding in Transportation Geotechnics and Geoecology, Saint Petersburg, Rusia, 17-19 Mei 2017* 207-214.

[20] Nimbalkar S, Indraratna B, Dash S K, and Christie D 2012 Improved Performance of Railway Ballast Under Impact Loads Using Shock Mats *Journal of Geotechnical and Geoenvironmental Engineering* **138(3)** 281-294.

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