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Scrap Rubber and Asphalt for Ballast Layer Improvement

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Abstract: The use of scrap rubber from waste motorcycle tire and asphalt materials is expected to improve the quality of the ballast structure. The objective of this paper is to analyze the characteristics of ballast mixture with additional scrap rubber (uniformed size 3/8" and graded size No.4, 3/8", 1/2", 3/4", 1") and asphalt materials through compressive strength test by Micro-Computer Universal Testing Machine (UTM). The samples are made in a ballast box with a size of 40 cm x 20 cm x 30 cm. The parameters of this research are the vertical deformation, the aggregate abrasion, and the elastic modulus of the ballast layer. It could be concluded that asphalt 2% able to improve the stiffness of the ballast layer so it could minimize the vertical deformation and increase the ability to retain the loads up to 28%. Moreover, the use of scrap rubber materials, especially with various sizes between No.4, 3/8", 1/2", 3/4", 1" combined with 2% asphalt could reduce the ballast abrasion up to 57%. However, the use of scrap rubber material could reduce the stiffness of the ballast layer which leads to a decrease in the elastic modulus ranging from 50% to 60%. While on the other hand, asphalt material could improve the stiffness of the ballast layer so that the elastic modulus could be increased up to 21%.

Keywords: Asphalt, ballast abrasion, deformation, elastic modulus, scrap rubber

1. Introduction

Most rail track in Indonesia still uses the conventional (ballasted) system where the track maintenance requires significant costs, and it has a shorter service life compared to the slab track system [1]. Moreover, conventional rail track is a system that has been widely used throughout the world, because of its advantages regarding lower construction costs compared to the slab track system.

The ballast layer is a granular structure on the rail track substructure consisting of various aggregate gradation sizes between 22 to 63 mm. Its utility is to deliver a compact foundation, accept the load from the sleeper which is then directed to the sub-ballast layer, provide adequate drainage, provide the desired level of elasticity, and reduce noises and vibrations levels [2], [3], [4]. However, in reality, the use of conventional track poses significant problems related to the stiffness and abrasion in ballast material which results in high maintenance costs and low structural durability. Poor material conditions can be used as a benchmark for maintenance work requirements and the application of train speed restrictions [5], [6].

Lakusi et al. [7] described that ballast bounding method is used to bind the ballast aggregate on each side of the material. This method aims to prevent material from abrasion. Excessive material abrasion will have an impact on the geometric changes of the railroad, poor durability in the ballast layer and the shortage of railroad services level. According to Setiawan [1], the type of structure that is owned by the slab track has the characteristics that are stronger than conventional rail tracks. However, the main difficulty is the very high construction cost, up to double when compared to the conventional railroad. Therefore, new ideas emerged regarding stabilization of ballast by using asphalt.

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The ballast stabilization is not only conducted to reduce deformation and increase stiffness. On the other hand, it is also to reduce abrasion and increase the ability to dampen the energy from the trainloads [2], [3], [8]-[11]. According to D'Angelo et al. [2], Giunta et al. [12], and Di Mino et al. [13], the use of bitumen material is now also used as a modification of the ballast and sub-ballast layer. Ballast modified with bitumen will increase the modulus value since the bitumen is used as a binding material between ballast particles [8], [14]. Ballast that has been mixed with asphalt will produce a more compact and rigid layer resulting in the better modulus [2] and can increase stiffness even at high temperatures [15].

The use of bitumen material as much as 2 to 3% as a ballast mixture has been tested by Alvarez et al. [16] using dynamic loads to analyze the characteristics of the ballast layer. Then the combination of bitumen is further analyzed related to the assessment of service life and maintenance costs. As a substitute for asphalt emulsion, the use of 60/70 penetration asphalt has a high substance value to be used as additional material in rail track. Next, D'Angelo et al. [8] conduct an evaluation to optimize the use of bitumen based on the resilient modulus value (Mr) and the index flowability in increasing the quality of the ballast layer. Research on the mixture of ballast material with bitumen and rubber by Lee et al. [15] concluded that these mixtures could reduce degradation and minimize vibration level.

Other materials in the form of rubber or elastic materials are also used in railroad stabilization because the components are intended to provide elastic properties vertically on the ballasted track and to increase ballast layer durability. The high durability of ballast layer can increase performance and reduce damage to the ballast layer due to the contact between aggregate could be minimized, thus reducing the maintenance cost on the ballast layer [12], [17]-[19]. However, excessive use of rubber material could reduce the value of ballast layer density [9].

Utilization of waste materials from un-used vehicle tires is also becoming a solution to reduce the use of natural ballast aggregates and to increase the durability of railroad structures [17]. Signes et al. [9] researched the characteristics of the ballast layer with a cyclic triaxial test to calculate the resilient modulus (Mr) from the mixture of ballast with the rubber material. Farhan et al. [18] confirmed that crumb rubber could increase durability, but in another side, it also can reduce the stiffness of the ballast. Meanwhile, according to Sanchez et al., the optimum percentage of crumb rubber for the ballast layer mixture is 10% due to the influence of the elastic properties of the crumb rubber. If it is too much used, it will reduce the stiffness of the ballast layer [3].

Along with their respective strengths and weaknesses, the use of scrap rubber from waste motorcycle tire and asphalt materials is expected to improve the quality of the ballast structure by increasing stiffness and minimizing material degradation so it could increase ballast layer service life and reduce the need for rail track maintenance. According to Asgharzadeh et al. [20], the use of asphalt and rubber mixture has a decisive role in carrying capacity and stability, and the main thing is to optimize vibration reduction on rail track structures. Thus, the combination of ballast with scrap rubber and asphalt could be used as a solution to increase the service life of the ballast layer and to reduce the expenditure for periodic maintenance of railroad structures in Indonesia.

The use of asphalt and scrap rubber as ballast modification needs to be analyzed regarding the level of stiffness. According to Wiyono et al. [21] and Sehonanda et al. [22], one of the stiffness parameters is the elastic modulus based on the linear slope of the axial stress-strain relationship curve in elastic deformation.

Modulus of elasticity (E) is a quantity that describes the level of elasticity of a material and is produced by a relationship between stress (σ) and strain (ε) [22]. In this research, the two parameters are obtained from the results of compressive testing using the Universal Testing Machine (UTM) machine. Some parameters resulting from the compressive strength testing are stress, strain, elongation and loads. The objective of this paper was to analyze the characteristics of the ballast mixture with additional scrap rubber and asphalt materials through compressive strength test. The parameters of this research were the vertical deformation, aggregate abrasion, and elastic modulus of the ballast layer.

2. Materials

2.1 Ballast

The ballast used in this study was obtained from Clereng, Kulon Progo, Special Region of Yogyakarta. The ballast that used was in clean condition, in other words, it is free from the mud content. The ballast was put in the oven for 24 hours until the condition is completely dry to fit the test plan that has been prepared. The form of ballast is presented in Fig. 1(a). The grain size of the ballast used is 2"- 3/4" based on the gradation requirements for ballast material that stated in the Peraturan Dinas No. 10 Tahun 1986 [23]. Moreover, this ballast material is classified into the class III in Indonesian Railways systems.

2.2 Scrap Rubber

This study uses scrap rubber from the outer tires of motorized vehicles. The scrap rubber then had been cut into two size groups that functioned as elastic materials. The first group is the scrap rubber which had been cut into a size of 3/8 ", or the scrap rubber was restrained by a 3/8" filter. Furthermore, the second group is the scrap rubber which had been cut into grain sizes between No.4, 3/8", 1/2", 3/4", and 1". This scrap rubber material was obtained from motor vehicle workshops located in Kasihan District, Bantul Regency, Special Region of Yogyakarta. The amount of scrap rubber material used in this research is as much as 10% of the total weight of each sample based on previous international studies. The display of the scrap rubber can be seen in Fig. 1(b).

(a) (b)

Fig. 1 - (a) Ballast materials; (b) Scrap rubber.

2.3 Bitumen

The asphalt used in this study is the asphalt type of 60/70 penetration in the form of solid asphalt which is then to be melted through heating. This asphalt material is obtained from asphalt storage located in Piyungan District, Bantul Regency, Special Region of Yogyakarta, Indonesia. Then, the asphalt was put in the oven for 4 hours, and heated to reach a temperature of 155° C. The asphalt was used as much as 2% of the total weight of the sample based on the results of previous international studies.

3. Experimental Design

3.1 Sample Design

This study uses six specimens or samples. Each sample mixed in a ballast box which has a different combination of materials. Ballast was used as the primary material, while asphalt and scrap rubber was utilized as the additional materials for ballast layer modifications. The samples are presented in Table 1 as follows.

Table 1 - Sample design

No.	Sample	Configuration
1	S.1	Ballast
2	S.2	Ballast + Scrap Rubber 3/8”
3	S.3	Ballast + Scrap Rubber No.4, 3/8", 1/2", 3/4", 1"
4	S.4	Ballast + Scrap Rubber 3/8”+ Bitumen 2%
5	S.5	Ballast + Scrap Rubber No.4, 3/8", 1/2", 3/4", 1" + Bitumen 2%
6	S.6	Ballast + Bitumen 2%

Before the compressive strength test is carried out, the first step taken in this research is to do the mixing process of the samples. The samples are made with a size of 40 cm x 20 cm x 30 cm in a ballast box (Fig. 2). 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. The mixing process is done directly in the box, and the samples were compacted every 1/3 layer from the height of the box with the number of blows as much as a 25 times/layer.

Sample 1 (S.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.

Sample 2 (S.2) and Sample 3 (S.3)
Ballast and 10% of scrap rubber (size 3/8" for Sample 2 and sizes No.4, 3/8", 1/2", 3/4", and 1" for Sample 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 per layer. The same thing is done for the next two layers.

Sample 4 (S.4) and Sample 5 (S.5)
The pouring of ballast and 10% of scrap rubber is done as the same as the preparation of Samples 2 and 3. However, after compaction, 2% of asphalt is poured over ballast and scrap rubber evenly, and so on until the ballast box is fulfilled.

Sample 6 (S.6)
Ballast is poured into the ballast box as in the Sample 1. Then, after the compaction, 2% asphalt is poured on it until evenly distributed. The same stage is used in the next layer.

(a) (b) (c)

Fig. 2 – (a) Ballast box, (b) Sample preparation, (c) Micro-Computer Universal Testing Machine.

3.2 Compressive Strength Testing and Data Analysis

The compressive test has produced the data in the form of a force received by a sample per unit area. The compressive strength of the samples was tested so that it can be determined how much strength the sample has in holding the vertical load [24]. The testing of compressive strength was conducted by Micro-Computer Universal Testing Machine (UTM) (Fig. 2), with a loading plate of 30 cm x 15 cm as presented in Fig. 3. After knowing the characteristics of each sample, then the sample is placed on the UTM compressive strength testing machine to get four parameters which are force, stress, strain, and elongation. Based on these parameters, it could be obtained the value of vertical deformation, abrasion of ballast material, and elastic modulus.

Fig. 3 - compressive test process with UTM tools.

4. Results and Discussion

4.1 Physical Test of Ballast

Physical testing is done on ballast to determine the feasibility of its use as the main component in this study. The results of testing the physical properties of ballast material are summarized in Table 2.

Table 2 - Results of ballast physical test.

No	Variable	Value	Specification
1	Specific Gravity		
	a. Bulk	2.64	Min. 2.6
	b. Dry	2.67	Min. 2.6
	c. Apparent	2.71	Min. 2.6
2	Absorption	0.9%	Max. 3%
3	Los Angeles	17.5%	Max. 25%

Filter analysis tests are also conducted to determine the distribution of gradations. In this study, the size of the ballast ranges from 25 to 60 mm as determined in the Peraturan Menteri Perhubungan No. 60 Tahun 2012 [25].

4.2 Physical Test of Bitumen

Physical testing of bitumen in the preparation stage of the sample is carried out to determine the feasibility of asphalt of penetration 60/70 usage in this research. Based on the analysis, the bitumen has the specifications of Direktorat Jenderal Bina Marga as presented in Table 3 [26].

Table 3 - Results of bitumen physical test

No	Variable	Value	Specification
1	Specific Gravity	1.047	Min. 1.0
2	Penetration	63.9	60 - 70
3	Softening Point	49 ºC	$\geq$ 48
4	Ductility	147	Min. 100
5	Oil Losses	0.395%	Maks. 0.8

4.3 Mixture Characteristics

Each sample has different mixture characteristics due to the different types of constituent materials. Identification of the mixture characteristics is made to find out the volume of each material and volume of the cavity on a ballast box.

Table 4 - Mixture characteristics.

% Volume	S.1	S.2	S.3	S.4	S.5	S.6
Volume Weight (gr/cm^3)	1.41	1.39	1.39	1.48	1.47	1.54
Scrap Rubber (%)	-	12.2	12.2	12.9	12.9	-
Bitumen (%)	-	-	-	2.8	2.77	2.90
Ballast (%)	52.8	47.1	46.6	49.1	48.1	56.6
Cavity (%)	47.2	40.7	41.2	35.2	36.3	40.5

The more varied the size of the material mixed in the ballast layer especially scrap rubber, the smaller the volume of the cavity. This condition is due to the scrap rubber, and asphalt in the ballast box functioned to fill the small cavities between the ballasts. The volume weight and the material volume percentage in each sample are presented in Table 4.

4.4 Vertical Deformation

The vertical deformation is obtained based on the number of deformations that occurs due to the vertical loading process given to the samples. The deformation value indicates the level of layer stiffness and can be used as a parameter to determine the ballast layer thickness. Deformation is a change in the shape and the size of a sample after undergoing testing. From this definition, it can be intended as a change in the height of a sample after being given a load. In this study, the deformation value in each sample is obtained from a graph of the relationship between deformation (mm) and stress (kPa) which is interpreted as a change in the height of a sample on particular loads. The deformation values that occur in each sample are very different, due to the variation of mixture characteristics as shown in Fig. 4. The results of the comparison between the loads and vertical deformation of each sample are presented in Fig. 5.

Based on Fig. 4 and Fig. 5, it can be seen that Sample 2 (ballast modification that used scrap rubber with uniform size of 3/8") and Sample 3 (ballast modification that used scrap rubber with various size of No.4, 3/8", 1/2", 3/4", 1") has the greatest deformation value. In other words, they produce a vertical deformation of 5 mm by only 107 and 113 kPa loads, respectively. But when these two samples compared, it shows that Sample 3 which consists of ballast and scrap rubber with varying sizes between No.4, 3/8", 1/2", 3/4", 1" has a better resistance to the vertical deformation compared to Sample 2 which consists of ballast and scrap rubber with a uniform size of 3/8 ". This condition is because Sample 3 has a better density due to the size of the scrap rubber varies so that it can fill small cavities between the ballast materials.

A better condition compared to Samples 2 and 3 is shown by Sample 4 (ballast with scrap rubber of 3/8" and asphalt of 2%) and Sample 5 (ballast with scrap rubber of No.4, 3/8", 1/2", 3/4", 1" and asphalt 2%) where the addition of asphalt can increase the resistance to vertical deformation. In other words, Sample 4 experiences a 5 mm vertical deformation at a higher load of 144 and 179 kPa, respectively. The properties of scrap rubber materials can reduce the stiffness of the ballast layer. While on the other hand, the asphalt material can improve the stiffness of the ballast layer. Furthermore, it could be concluded that Sample 5 has better resistance to vertical deformation compared to Sample 4 because Sample 5 has a better material density due to the size variation of the scrap rubber that can fill small cavities between ballast and asphalt material.

Furthermore, the best resistance to vertical deformation is shown by Sample 6 (ballast with asphalt of 2%). Sample 6 can withstand the loads up to 483 kPa to experience a vertical deformation of 5 mm or 28% greater than Sample 1 (ballast only). The behavior of asphalt that added to the ballast layer is intended as a binding material. Previous research conducted by D'Angelo et al also showed that the emulsion properties on asphalt could increase the resistance to vertical deformation on the ballast layer [8].

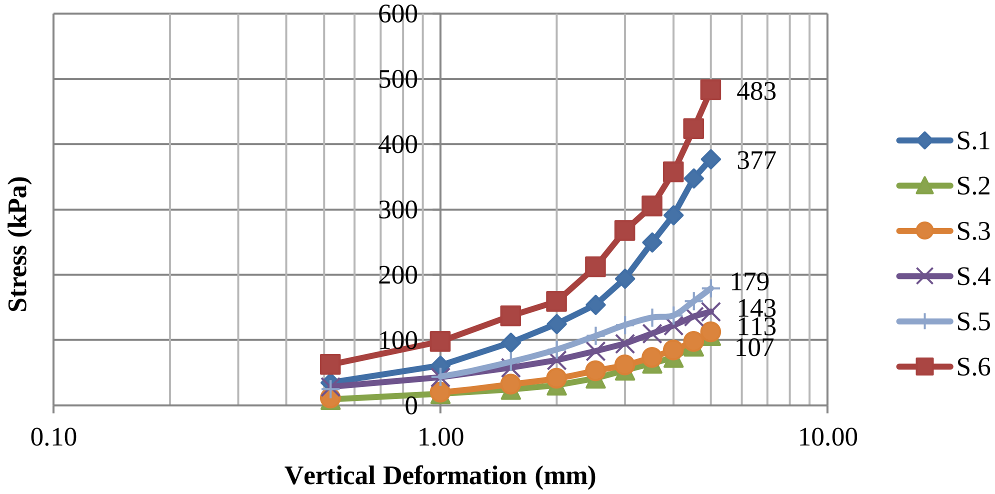

Fig. 4 - Vertical deformation (mm) and stress (kPa).

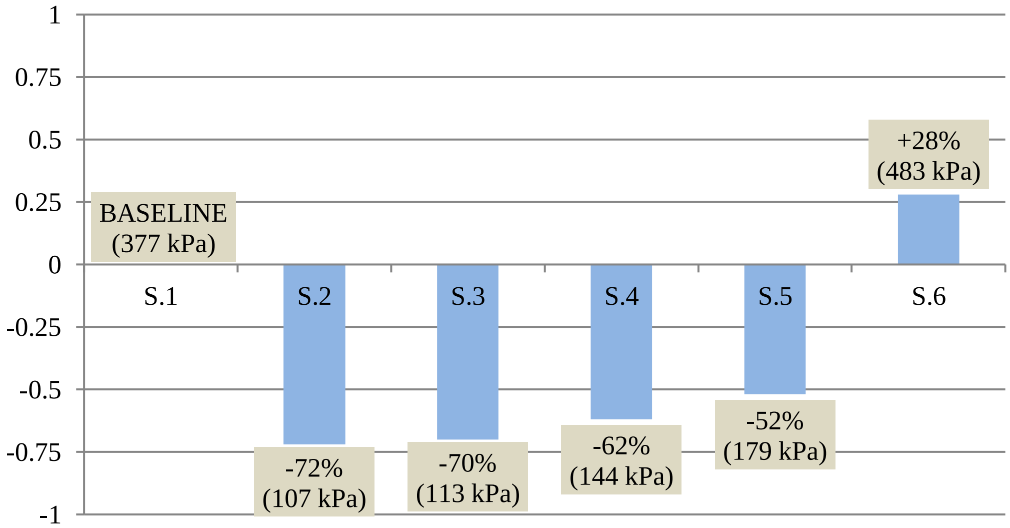

Fig. 5 - Decrease and increase in sample ability to retain the load at 5 mm of vertical deformation.

4.5 Materials Abrasion

Abrasion on the ballast layer occurs due to several processes, starting from the preparation process until the testing stage that can lead to the changes in the distribution of ballast gradations in each sample. The abrasion of aggregate material 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. Each sample produces varying levels of material abrasion as shown in Fig. 6.

Based on the analysis that has been carried out, it could be concluded that Sample 1 (ballast only) produces the largest abrasion value which reaches 37 grams or 0.74% due to the occurrence of direct contact between aggregates when given a load. However, the analysis shows a reduction of material degradation along with the use of scrap rubber and asphalt. The deterioration of ballast materials such as fracture and wear on the ballast mixture could reduce significantly by the utilization of scrap rubber and asphalt compared to the ballast without elastic materials.

Based on Fig. 6 and Fig. 7, it can also be concluded that Sample 2 (ballast with scrap rubber 3/8") and Sample 4 (ballast with scrap rubber 3/8" and asphalt 2%) produces a lower abrasion value than the Sample 1 which are 22.2 gr (0.45%) and 19.6 gr (0.37%), respectively. In another word, the scrap rubber with uniform size and asphalt usage in Samples 2 and 4 have able to decrease the abrasion values by 40% and 47% lower than the abrasion value in Sample 1.

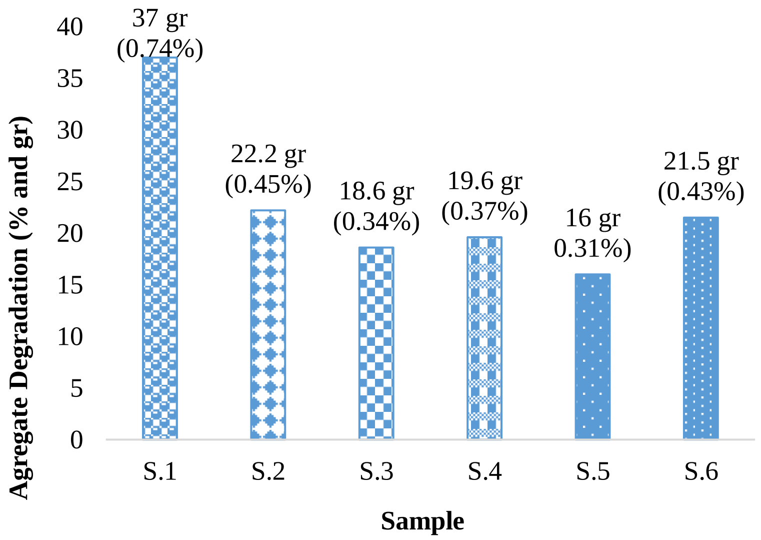

Fig. 6 - Material abrasion.

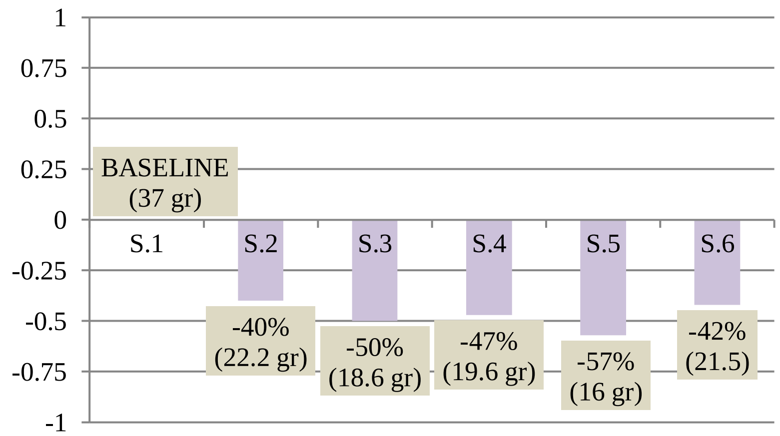

Fig. 7 - Decrease and increase in the amount of degraded ballast materials.

A better situation than Samples 1, 2 and 4 is shown by Sample 3 (ballast and scrap rubber with varies size No.4, 3/8", 1/2", 3/4", 1") and Sample 5 (ballast with scrap rubber with varies size No.4, 3/8", 1/2", 3/4", 1", and asphalt 2%) which results in the lowest abrasion value of 18.6 gr (0.34%) and 16 gr (0.31%), respectively. In another word, the scrap rubber with graded size and asphalt usage in Samples 3 and 5 have able to decrease the abrasion values by 50% and 57% lower than the abrasion value in Sample 1. Samples 3 and 5 have better density levels because of the presence of asphalt and the varied size of scrap rubber so that they can fill small cavities in between the ballast material to minimize collisions between aggregates when given a load. Moreover, scrap rubber as elastic properties and asphalt as binding materials could increase the durability of ballast aggregate.

4.6 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). The concept of an elastic modulus is shown in Eq. (1).

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where, E = Elastic Modulus (N), σ = Stress (MPa) and ε = Strain (mm)

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 3000 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 is presented in Fig. 8 to Fig. 13. Meanwhile, the results of the elastic modulus values are shown in Fig. 14.

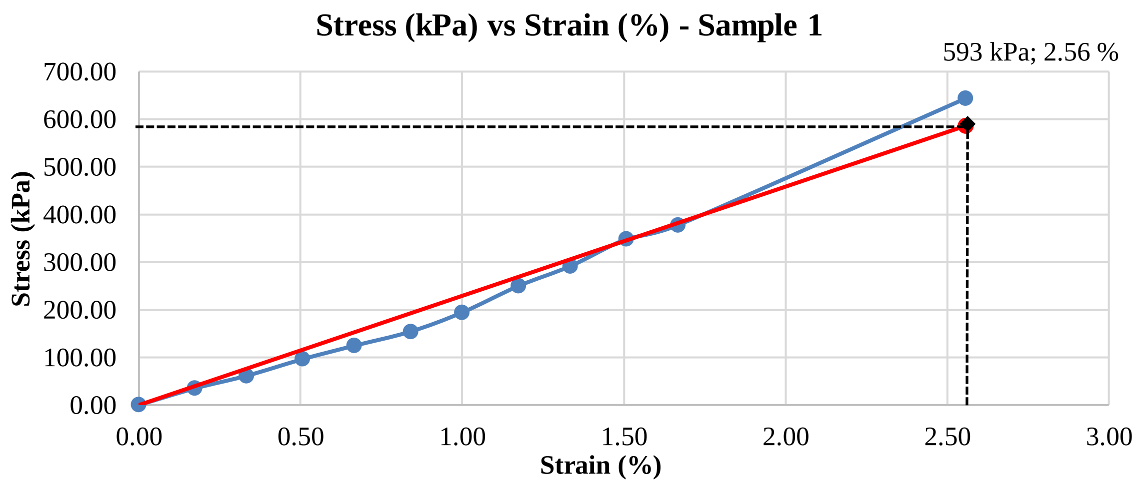

Fig. 8 - Stress (kPa) and Strain (%) of S.1.

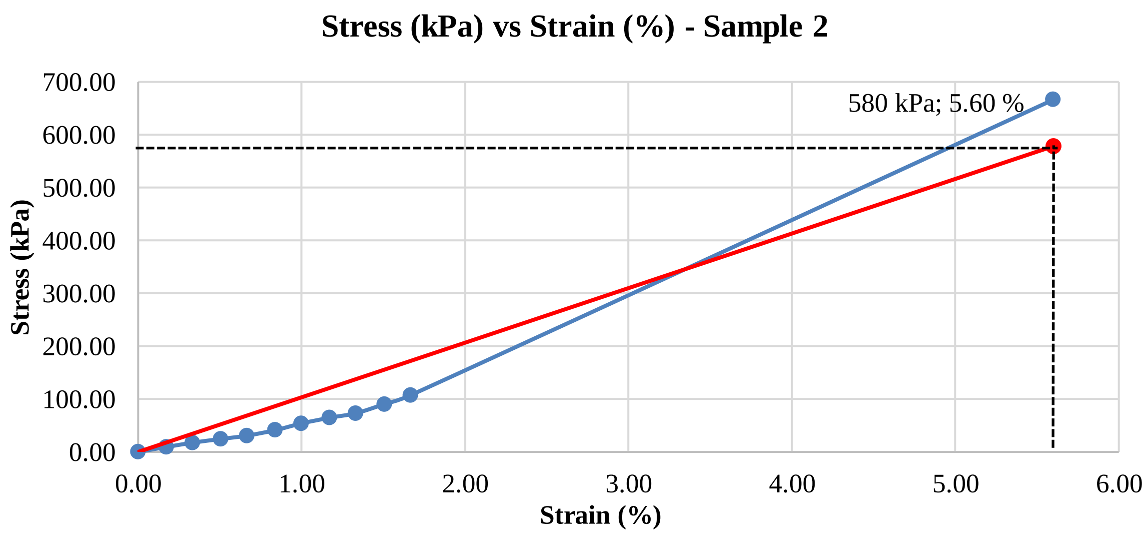

Fig. 9 - Stress (kPa) and Strain (%) of S.2.

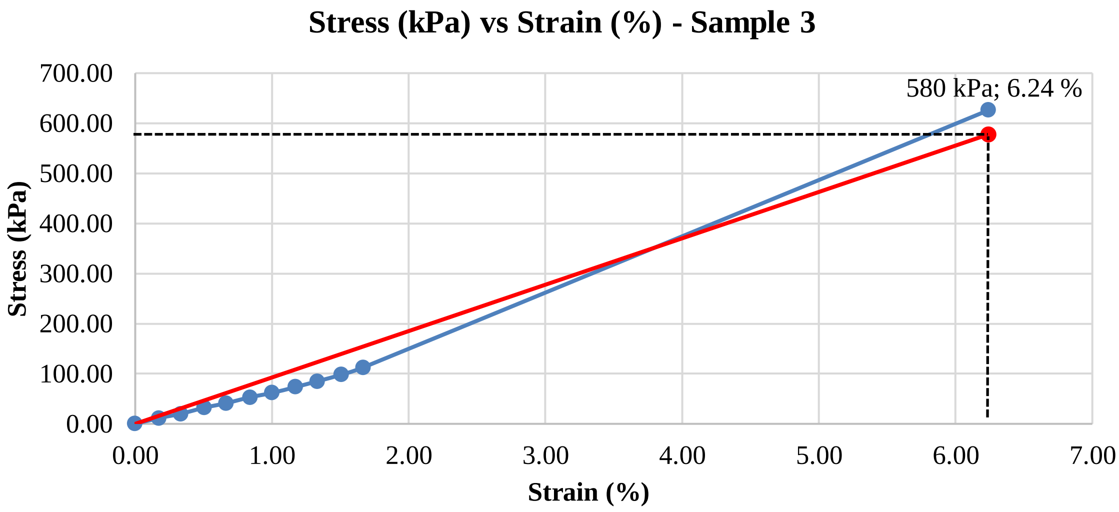

Fig. 10 - Stress (kPa) and Strain (%) of S.3.

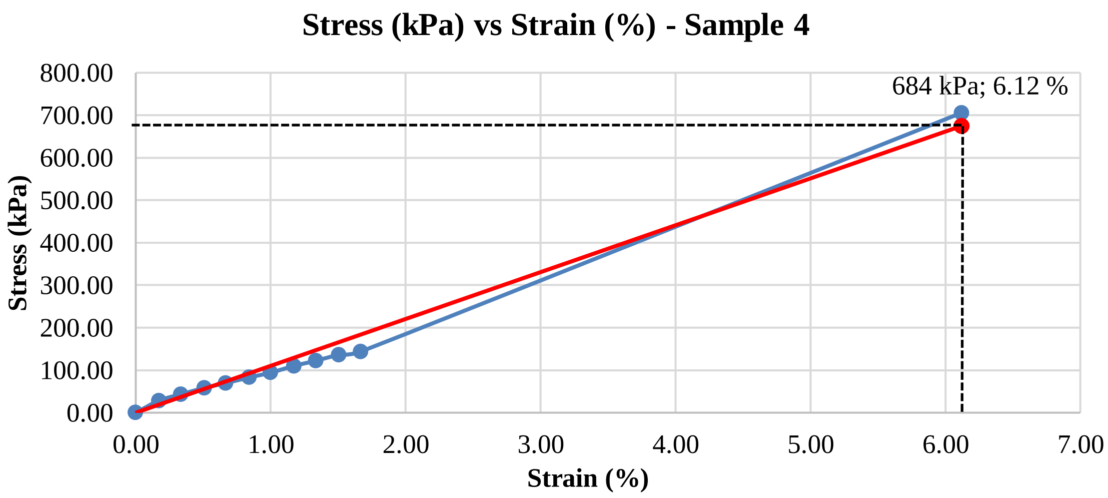

Fig. 11 - Stress (kPa) and Strain (%) of S.4.

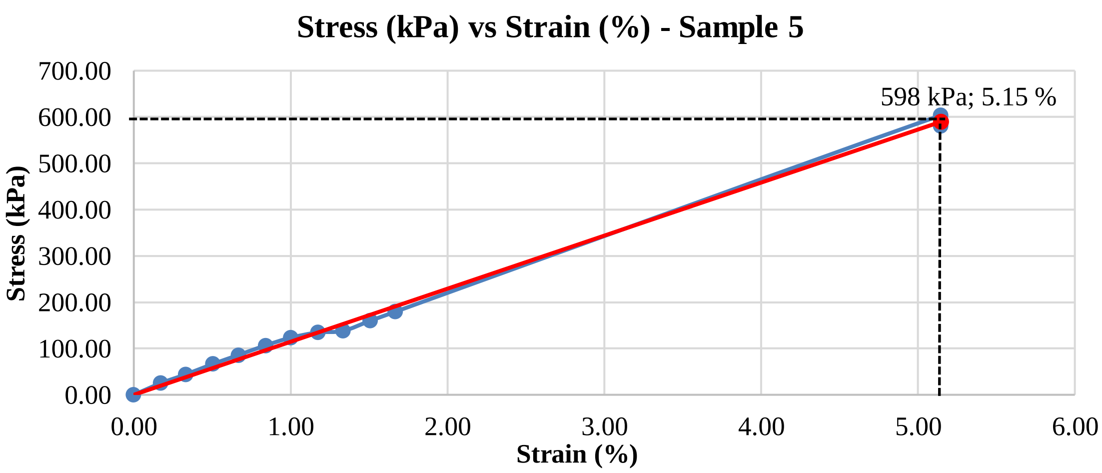

Fig. 12 - Stress (kPa) and Strain (%) of S.5.

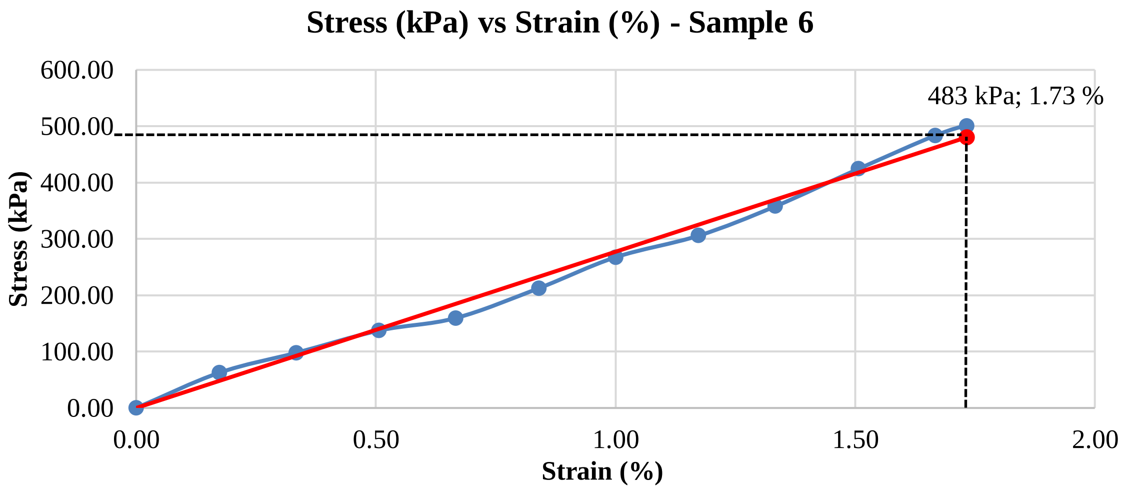

Fig. 13 - Stress (kPa) and Strain (%) of S.6.

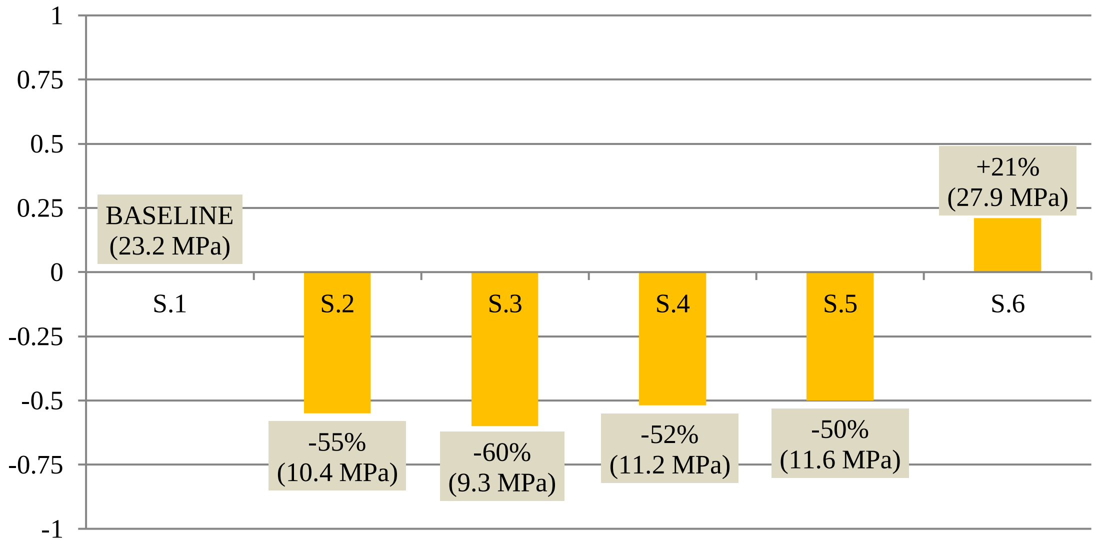

Fig. 14 - Decrease and increase in elastic modulus.

Based on the analysis in Fig. 14, it could be concluded that Sample 1 (ballast) has a modulus of elasticity of 23.3 MPa. Moreover, Sample 2 (ballast with scrap rubber with size of 3/8") and Sample 3 (ballast with scrap rubber with size of No.4, 3/8", 1/2", 3/4", 1") has the lowest modulus of elasticity, that is, only 10.4 MPa and 9.3 MPa, respectively. In another word, there is a reduction in elastic modulus on Samples 2 and 3 by 55% and 60% respectively compare to the elastic modulus value on Sample 1.

A better situation than Samples 2 and 3 is shown by Sample 4 (ballast with scrap rubber with a size of 3/8 "and asphalt 2%) and Sample 5 (ballast with scrap rubber with varies size No.4, 3/8", 1/2", 3/4", 1" and asphalt 2%) where the addition of scrap rubber and asphalt to the ballast layer could increase the modulus of elasticity to become 11.2 MPa and 11.6 MPa, respectively. However, these numbers still indicate a reduction in elastic modulus on Samples 4 and 5 by 52% and 50% respectively compare to the elastic modulus value on Sample 1.

In their research, Sanchez et al reviewed the stiffness modulus of ballast and rubber mixture. The results proved that the modulus could be decreased caused by scrap rubber that acts as an elastic aggregate which makes the sample more flexible [17]. Moreover, the application of manual compaction reveals the fact that the sample tends to be bounced, so it does not have the optimum compaction. This lack of compaction affects the decreasing of elastic modulus [9].

Furthermore, in this research, the highest elastic modulus is produced by Sample 6 (ballast with asphalt 2%) of 27.9 MPa or experiencing a significant increase in elastic modulus by 21% higher than Sample 1 (ballast). The asphalt material in Sample 6 is functioned as a binder between aggregates. Therefore Sample 6 becomes more rigid. The elastic modulus in Sample 6 confirms that asphalt has the ability to increase stiffness in the ballast layer.

5. Conclusions

Through the results and discussion, the following conclusions can be drawn about the scrap rubber and asphalt for ballast layer improvement:

- The use of scrap rubber material along with asphalt on the ballast layer can produce the lowest volume of the cavity compared to the sample that consists of ballast and scrap rubber only or a sample that consists of ballast only since the scrap rubber and asphalt can fill the small cavities between ballast materials.
- The use of scrap rubber material can reduce the level of stiffness of the ballast layer and increases the vertical deformation value. On the other hand, asphalt 2% can improve the stiffness of the ballast layer so it could minimize the vertical deformation and increase the ability to retain the loads up to 28%.
- Degradation of ballast material shows a reduction along with the use of scrap rubber and asphalt. The use of scrap rubber materials, especially with various sizes between No.4, 3/8", 1/2", 3/4", 1" combined with the use of asphalt 2% in the ballast layer can produce the lowest abrasion value compared to the sample that consisting ballast and scrap rubber or the sample that consisting ballast only. The reason is that the various sizes of the scrap rubber and the asphalt can fill the cavities among the ballast material so that it can minimize the occurrence of the rupture or wear on the ballast aggregate. The reduction in ballast degradation can reach up to 57%.
- The use of scrap rubber material can reduce the stiffness of the ballast layer which led to a decrease in the elastic modulus ranging from 50% to 60%. The decrease in elastic modulus value is caused by the scrap rubber which acts as an elastic aggregate and makes the sample more flexible. While on the other hand, asphalt material can improve the stiffness of the ballast layer so that the elastic modulus could be increased up to 21%.

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