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

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***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.

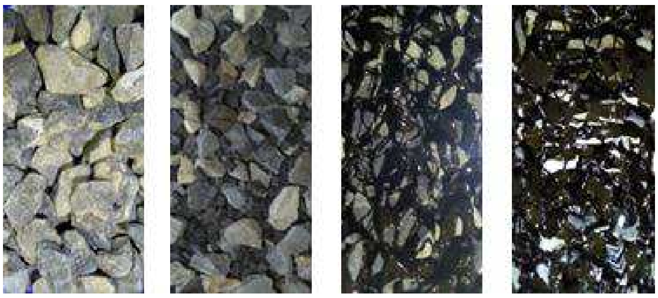
Fig. 4 Manual compactor

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^oC
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.

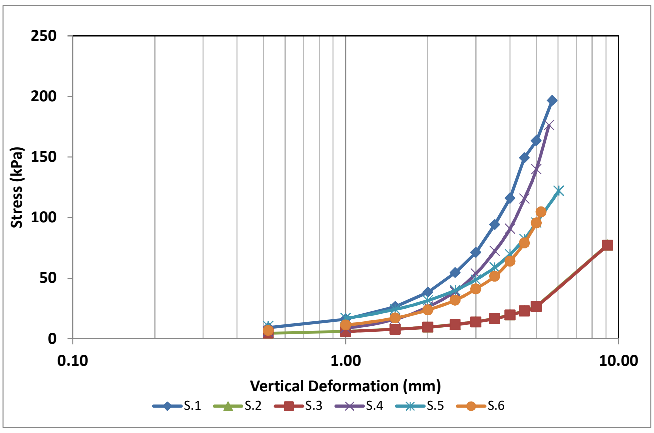


Fig. 8 The relationship between the loads and the change in specimen height

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.

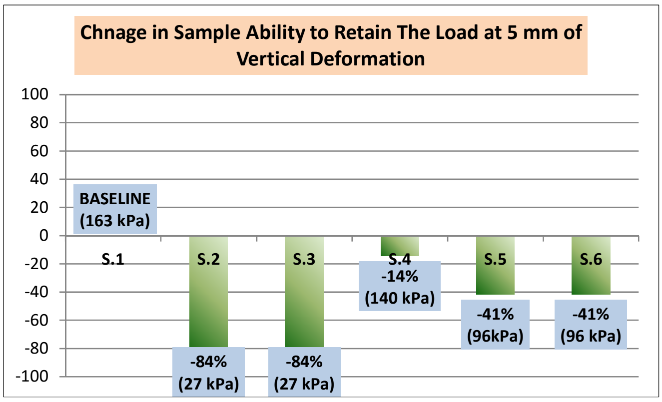


Fig. 9 The changes in loads that can be withheld at vertical deformation of 5 mm

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.

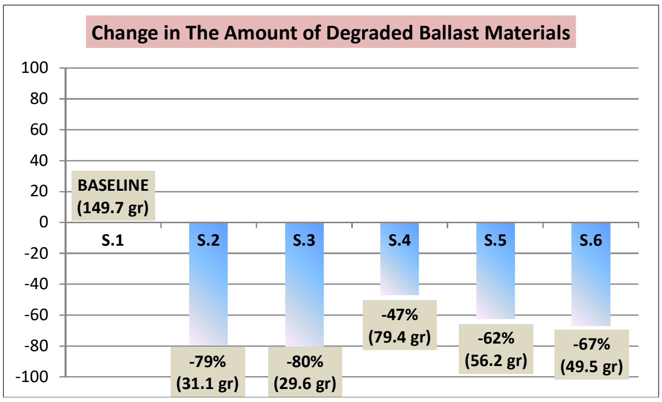


Fig. 10 The changes in degraded ballast material

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.

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