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Application of 60/70 Grade Bitumen with Layer Variations on Ballast Structures

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Abstract— **The conventional track application dominates the Indonesian rail track type. The rail track deterioration due to the overloading train becomes a crucial issue since it leads to high maintenance costs. Damage to the rail track can reduce its service life and carrying capacity. This research utilized the 60/70 grade bitumen as a binding material and stabilization of ballast structure. The aim is to analyze the mechanical behavior of new-ballast and poor-ballast structures, with 4% of the 60/70 grade bitumen in one layer (ballast surface layer) and three layers. The specimen's weight, vertical deformation, elastic modulus, and ballast material abrasion have been analyzed using a UTM compressive strength test. The most obvious finding to appear from this research is that the new-ballast-based specimen, as for being free of mud and dust, was lighter in weight than the poor-ballast-based sample. Furthermore, the new-ballast and poor-ballast-based specimens added with 4% of the 60/70 grade bitumen had a lower vertical deformation than the baseline specimen. The position of 4% of the 60/70 grade bitumen on the ballast surface layer produced an optimum load distribution to the overall ballast layer. Also, the specimens consisting of new-ballast produced a higher elastic modulus compared to the specimens comprising poor-ballast. Lastly, the presence of the well-distributed asphalt on three layers of ballast structure could produce the minimum abrasion value due to the possibility that asphalt materials could protect ballast materials from abrasion.**

Keywords— **60/70 grade bitumen; ballast abrasion; elastic modulus; specimen's weight; vertical deformation**

I. INTRODUCTION

Indonesia's railroad transportation still uses a conventional (ballasted) track to link regions with both short and extended service routes. However, there are several problems with railroad transportation in Indonesia, namely, the inappropriate track structure with the minimum structural requirements, and its result in applying train speed restriction. Furthermore, train overload also becomes a crucial issue since it can affect the high maintenance costs due to rail track deterioration. Damage to the rail track can reduce both its service life and carrying capacity.

Each ballast and sub-ballast structure layer have a different stiffness depending on the material properties and mechanics [1]. The continuous dynamic load application could decrease the mechanical and geometric performance of the railroad ballast structure layer [2]. Some researchers around the world have been studied additive material to improve ballast structure quality.

Although its utilization needs to be studied further regarding its obtainability in the railway industry, an exclusive material called in-situ polyurethane polymer was applied [3] to enhance ballast structure performance. On the other side, the use of scrap rubber material [4]-[7] and asphalt [8]-[12] could also be the options for the use of additional materials on the ballast layer. The asphalt is one of the potential solutions that can be used to reduce damage and improve the ballast layer's performance [2]. Hot Mix Admixture (HMA) and Polyurethane Stabilized Ballast (PSB) also have been utilized by [13] for the stabilization of ballast layers and the enhancement of ballast structure by improving its bearing capacity.

The ballast aggregate mixed with bitumen produces lower abrasion of ballast material and minimizes vertical deformation and structural settlement of the ballast layer [2], [14]-[17]. Asphalt addition to the ballast layer can reduce the need for maintenance work [8]. Moreover, the mixture of asphalt and aggregate material will result in a more bound aggregate [15] and decrease the effect of dynamic loads, as shown by the presence of stiffness modulus improvement [12]. Some research on the application of scrap rubber as additional material in ballast structure has been conducted to improve ballast mechanical behavior. Rubber in the shape of crumb as a mixture of ballast material [7]. The possibility of deformation in the ballast layer could be increased, and the ballast layer stiffness could be reduced due to the excessive use of crumb rubber in the ballast layer. Ten percent was the optimum rubber content used as elastic material in the ballast layer [4]. Design of the ballast layer together with a mixture of scrap tire rubber was able to decrease vibration caused by dynamic loads received when the train was operated, and at the same time, could minimize the degradation of ballast material [4],[6],[8].

Rubber and ballast mixture characteristics are subject to obtain ballast modulus resilient [5]. Rubber has an elastic specification that can minimize the direct contact between materials it separated. However, rubber is vulnerable to temperature heating to be classified as thermoplastic material [18]. In the ballast structure, which is overlaid with rubber at the bottom section of the ballast layer, the deformation value could be reduced by around 35%-45% [19]. Rubber mixtures utilization on ballast layers could reduce long-term deformation and degradation. However, excessive utilization of elastic material affects reducing density values, the results of which directly affect the decreasing of elastic modulus and rail track stability [4], [5], [10], [20].

Modification has been applied to the ballast layer using graded and uniformly-sized rubber pieces with manual compaction variations 25 and 50 times [21]. It concluded that the addition of rubber pieces could increase the ballast layer's durability by 38%. Besides, another study [22] added scrap rubber and 3% of the 60/70 grade bitumen material to optimize the ballast layer's quality. The addition of this type of bitumen could minimize the value of vertical deformation by 14% and reduce material abrasion by 80%. Furthermore, the addition of asphalt and graded rubber was effective in increasing material durability.

In another study, some researchers focused on using crumb rubber and scrap rubber as an elastic substance in the ballast structure. However, without a binding material, the crumb rubber usage would lead to some adverse effects, such as the reduction of ballast stiffness. Moreover, some researchers applied specific bitumen type as much as 2%-3% as a binding material in the ballast layer. However, much more research is needed regarding the utilization of the 60/70 grade bitumen in the rail track structure. This study emphasizes the use of 4% of the 60/70 grade bitumen (a higher percentage than the previous research) as a binding material in the ballast structure.

This research aims to analyze the new and poor-ballast mechanical behavior both with and without 4% of the 60/70 grade bitumen in one layer (ballast surface layer) and three layers, through a compressive strength test by analyzing the vertical deformation, specimen weight, ballast material abrasion, and elastic modulus. The new-ballast was utilized to model a new rail track behavior, while the poor-ballast was used to model an existing rail track structure that needs to be rehabilitated for further usage.

II. The Material and Method

A. Ballast Layer

Ballast layers are the main component in the conventional rail track structure. The ballast layer is located above the subgrade [23]. It functions as a load distributor from the sleeper to the sub-ballast layer with a more even distribution pattern. The ballast layer is composed of broken rocks measuring 20-60 mm, spread out and compacted above the subgrade surface and the sub-ballast layer. In this study, ballast material was tested regarding the physical and mechanical properties, which are referred to SNI (Indonesian National Standard) [24], [25], [26]. The specific gravities were 2.61, 2.68, and 2.80, respectively, for the dry, bulk, and apparent (≥2.6). The water absorption was 2.65% (≤3%). The result of the Los Angeles analysis was 19.26% (≤25%). Moreover, the mud content was only 0.2% (≤0.5%).

B. 60/70 Grade Bitumen

At room temperature (20-30 ºC), bitumen as a binder and cavity filler between aggregate materials has solid to semi-solid properties and becomes soft or liquid if heated (thermoplastic). At 25ºC, the bitumen molecule is stable, while at temperatures between 25ºC - 60ºC, it begins to soften, and it will freeze at temperatures below 25ºC. Before using bitumen as additional material in this study, the physical properties of the 60/70 grade bitumen were tested, which has displayed in Table 1.

TABLE I
THE 60/70 GRADE BITUMEN SPECIFICATIONS

Parameters	Results	Specifications	Standard
Penetration	66.7	60-70	[28]
Specific Gravity	1.01	≥1.0	[27]
Softening Point	53ºC	≥48	[29]
Oil Losses	0.13%	≤0.8	[30]
Ductility	112 cm	≥100	[31]

C. Vertical Deformation

Vertical deformation is the difference in the shape of an object because the force has given impacts the object vertically. In this research, the force comes from the compressive stress, and its calculation was based on the concrete compressive testing analysis [32], [33] to obtain the mechanical parameters of ballast structure such as stiffness.

D. Elastic Modulus

A stress and strain relationship were obtained by a UTM machine (Universal Testing Machine) to get the elastic modulus value from a compressive strength test and by equation 1 (one) as follows:

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

With:

E = Elastic modulus (MPa);
σ = Stress (kPa);
ε = Strain (%).

E. Ballast Material Abrasion

The abrasion value is the ratio between the damaged ballast material weights to the specimen weight, and it was tested by comparing the distribution of aggregate material using gradation analysis before and after tested by the UTM machine. The calculation of material deterioration was based on the weight of the damaged material that could pass the filter sized of ¾" after conducting the compressive strength test. The ballast material abrasion percentage was affected by some aspects in each sample, such as preparation, compaction, and compressive strength test process. Figure 1 shows the ballast abrasion test process.

Fig. 1 The ballast aggregate abrasion test process

F. Research Stages

The study stages began with ballast and bitumen materials, followed by material mixing, material compaction, material compressive strength testing, and analysis of the testing results. Table 2 displays the specimen configuration in this research.

TABLE II
SPECIMEN'S CONFIGURATION

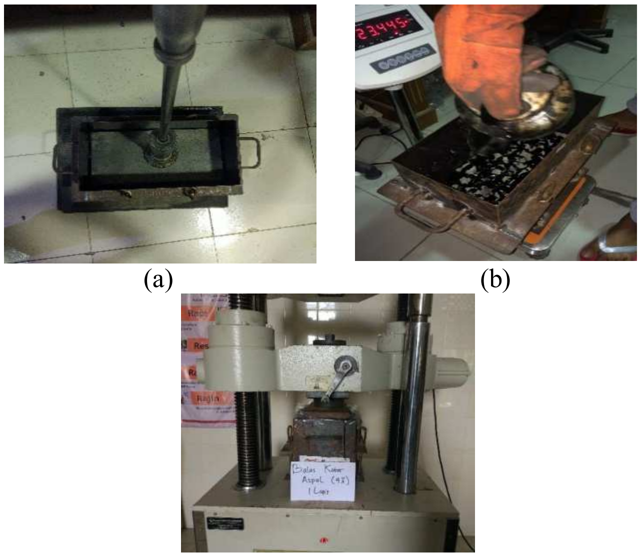
Specimen	Manual Compaction	Bitumen Content (%)	Code
New-Ballast	50 Times/Layer	-	NB
Poor-Ballast	50 Times/Layer	-	PB
New-Ballast + 4% Bitumen in 1 Layer	50 Times/Layer	4%	NB1
Poor-Ballast + 4% Bitumen in 1 layer	50 Times/Layer	4%	PB1
New-Ballast + 4% Bitumen in 3 Layers	50 Times/Layer	4%	NB3
Poor-Ballast + 4% Bitumen in 3 Layers	50 Times/Layer	4%	PB3

G. Sample Design and Preparation

The bitumen material and ballast aggregate preparation in this study were referred to Service Regulation No. 10 of 1986, Indonesian National Standard (SNI), and Minister of Transportation Regulation No. 60 of 2012 [34], [35]. After all the materials were prepared, then a ballast box with 400 x 200 x 300 mm was set up.

H. Bitumen Pouring and Material Compaction

The compaction of specimens was conducted 50 times for each layer (every 10 cm) using a manual compactor. The pounder had a rectangular flat surface with the same size as the ballast surface layer dimension (400 mm x 200 mm), weighing 4.5 kg and a free fall height of 45.7 cm. The compaction process, bitumen pouring process, and compressive strength test machine are displayed in Fig. 2.



(a) (b) (c)

Fig. 2 Specimen compaction process (a), bitumen pouring process (b), and compressive strength test (c)

Moreover, the bitumen pouring was carried out in 2 different conditions. In specimen NB1 (new-ballast with 4% of the 60/70 grade bitumen only on the surface of ballast layer) and PB1 (poor-ballast with 4% the 60/70 grade bitumen only on the surface of ballast layer), ballast material was prepared inside the ballast box in three sequences of the layer with the compaction process for each layer. Each layer had a 10 cm of thickness so that in the end, the total ballast layer thickness was 30 cm, and each layer was compacted 50 times by the manual compactor (Fig. 2a). Finally, the bitumen was poured once all layers have been compacted and reached 30 cm of thickness. In other words, the 60/70 grade bitumen was only poured on the ballast surface layer.

In specimen NB3 (new-ballast with 4% the 60/70 grade bitumen divided into three layers) and PB3 (poor-ballast with 4% the 60/70 grade bitumen in three layers), ballast material was also prepared in the ballast box in three sequences of the layer with the compaction process for each layer. Each layer also had a 10 cm of thickness, so in the end, the total ballast layer thickness was 30 cm, and each layer was compacted by the manual compactor 50 times. However, the bitumen was poured into the top of each layer (10 cm) after the compaction process was completed. Therefore, each layer had been poured with 1.33% of bitumen. The process of bitumen pouring is displayed in Fig. 2(b).

I. Compressive Strength Test

The compressive strength test using the Universal Testing Machine (UTM) with a load of 4000 kg (as shown in Fig.2c) was conducted by performing two consecutive times of compressive strength tests, which then was processed to obtain the value of vertical deformation and modulus of elasticity.

III. RESULTS AND DISCUSSION

A. Sample Weight

According to the test results, it can be concluded that each specimen had different weight characteristics. Figure 3 shows the weight of each sample in this research.

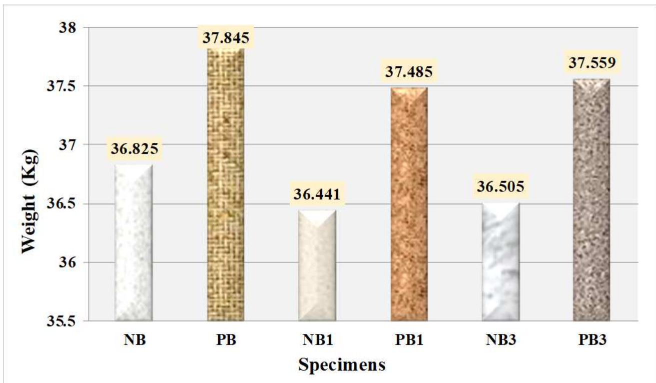


Fig. 3 The weight of specimens

As shown in Fig. 3, the new-ballast-based sample was comparatively lighter in weight than the poor-ballast-based sample, both with and without the addition of 4% of the 60/70 grade bitumen. It was due to the new-ballast that had been through the washing and drying processes. Therefore, because containing sludge content, the poor-ballast was heavier than the new-ballast. The NB specimen (new-ballast) weighed 36.825 kg, while the PB specimen (poor-ballast) weighed 37.854 kg. Besides, the NB1 specimen weighed 36,441 kg, while the PB1 specimen weighed 37.485 kg. Furthermore, the NB3 specimen weighed 36.505 kg, while the PB3 specimen weighed 37.559 kg.

B. Vertical Deformation

The values of vertical deformation from the 1st and the 2nd testing stages and the percentage change in deformation value are shown in Fig. 4 to Fig. 8.

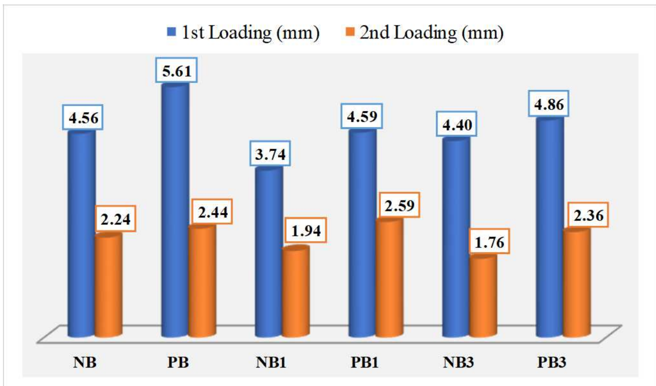


Fig. 4 Vertical deformation value in first loading and second loading

Fig. 4 presents the vertical deformation value due to the 1st and the 2nd loadings. A specimen's higher density level caused the vertical deformation reduction in the 2nd test in each sample. It was due to the first loading causing the stiffness of the model also increased. In conclusion, poor-ballast (PB, PB1, and PB3) specimens produced a higher vertical deformation than the specimens consisting of new-ballast (NB, NB1, and NB3) because the sludge contained in poor-ballast could diminish the ballast material interlocking ability. Furthermore, it was also found that the new-ballast and poor-ballast specimens that had been added with 4% of the 60/70 grade bitumen (NB1, NB3, PB1, and PB3) had a lower vertical deformation compared to the baseline specimens (NB and PB). In other words, the 60/70 grade bitumen as a binding material was capable of improving the new-ballast and the poor-ballast layer performance since it increases ballast structural stiffness.

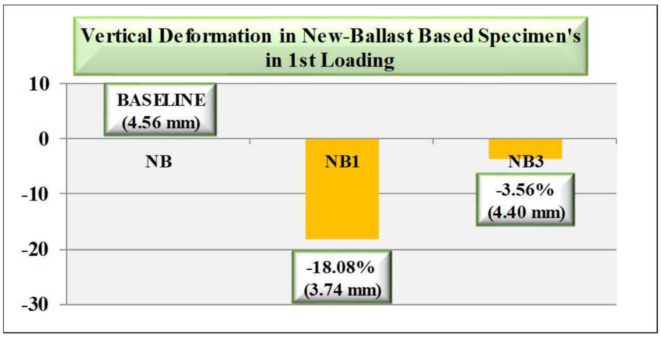


Fig. 5 Vertical deformation in new-ballast based samples due to first loading

According to Fig. 5 above, in terms of new-ballast based structure, the NB1 specimen produced the lowest vertical deformation (3.74 mm), or 18.08% lower than the NB specimen (4.56 mm), followed by NB3 specimen (4.40 mm), or 3.56% lower than the NB specimen (4.56 mm). Moreover, according to Fig. 6 below, regarding the poor-ballast based structure, the PB1 specimen produced the lowest vertical deformation (4.59 mm), or 18.23% lower than the PB specimen (5.61 mm), followed by PB3 specimen (4.86 mm), or 13.37% lower than the PB specimen (5.61 mm).

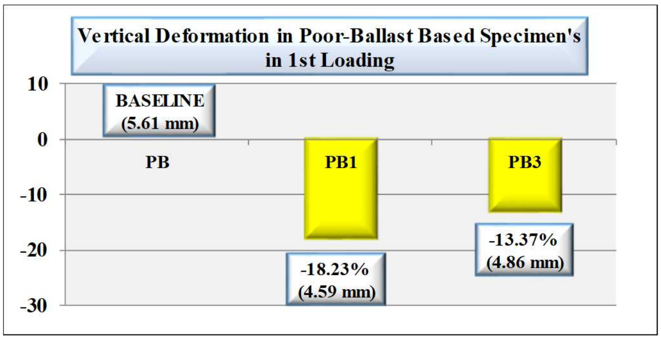


Fig. 6 Vertical deformation in poor-ballast based specimens due to first loading

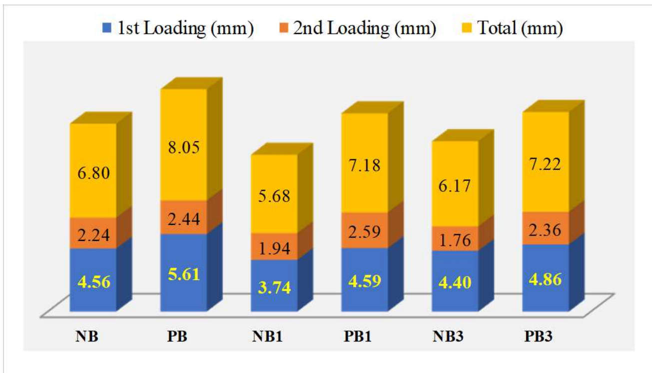


Fig. 7 Total of vertical deformation value

Furthermore, Fig. 7 above shows a total of vertical deformation in the specimens after experiencing two consecutive times of compressive strength tests. Concerning the new-ballast based structure, the NB1 specimen produced the lowest total of vertical deformation (5.68 mm), followed by NB3 and NB, which produced a higher total of vertical deformation, 6.17 mm, and 6.80 mm, respectively. Moreover, in terms of poor-ballast-based structure, the PB1 specimen produced the lowest total of vertical deformation (7.18 mm), followed by the PB3 specimen producing a higher total of vertical deformation (7.22 mm). In contrast, the PB specimen had a value of 8.05 mm, which was the highest number among the six specimens.

As shown in Fig. 8 below, the NB1 and PB1 specimens had the lowest difference value of vertical deformation between the first and second loadings. In the NB1 specimen, the percentage reduction of vertical deformation value was 48.15%. While in the PB1 specimen, it was 43.59%. It can be concluded that the position of 4% of the 60/70 grade bitumen in NB1 and PB1 (on ballast surface layer) became essential in retaining the load given by the compressive stress testing machine and in producing the preferable load distribution to the overall ballast structure. Therefore, it was reasonable that the NB1 and PB1 samples produced the lowest vertical deformation compared to other specimens. Also, according to the application method's simplicity, it was preferable to apply the 4% of the 60/70 grade bitumen only in 1 layer on the ballast surface layer.

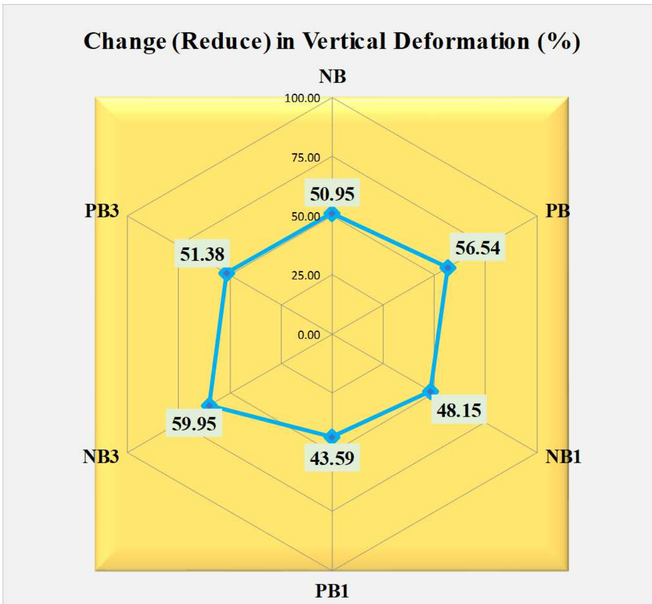


Fig. 8 Percentage of change in vertical deformation value

C. Elastic Modulus

The elastic modulus is the parameter to determine the stiffness of a material. Each specimen that had been tested by a compressive strength testing machine produced the stress and strain values. The modulus of elasticity for each sample is shown in Fig. 9.

The modulus of elasticity in this research resulted from the approach taken using a linear or trend-line curve. As shown in Fig. 9, the highest modulus of elasticity was found in the NB1, which was 72.76 MPa, and the lowest modulus of elasticity was found in the PB specimen, which was 43.80 MPa. In conclusion, the specimens consisting of poor-ballast produced the lower elastic modulus compared to the specimens consisting of new-ballast. Due to the sludge content in the poor-ballast, it could decrease the ballast material interlocking ability. The analysis also revealed that both new-ballast and poor-ballast specimens added with 4% of 60/70 grade bitumen (NB1, NB3, PB1, and PB3) had a higher elastic modulus compared to the baseline specimens (NB and PB). In other words, the 60/70 grade bitumen could improve new-ballast, and poor-ballast layer performance since the bitumen could increase the ballast structural stiffness.

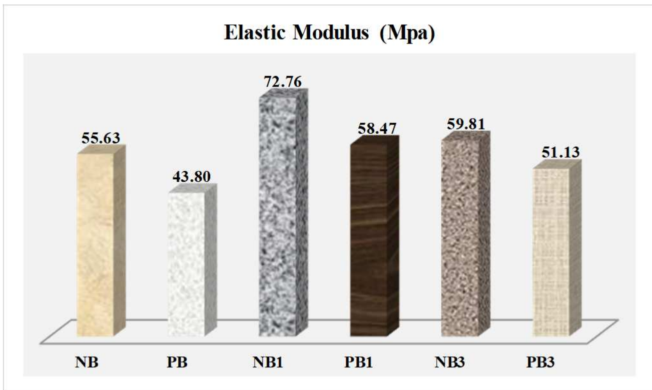


Fig. 9 Modulus of elasticity

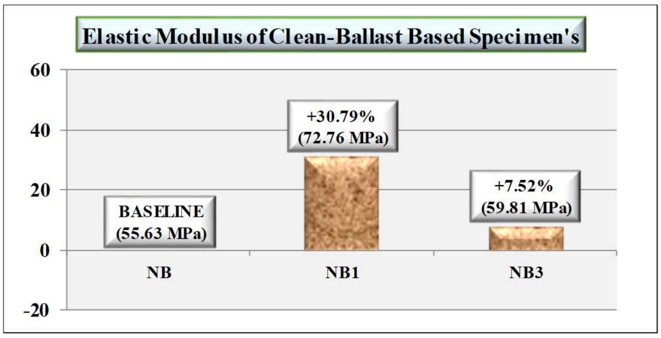


Fig. 10 Elastic modulus in new-ballast based specimen's

According to Fig. 10 above, in terms of new-ballast based structure, the NB1 specimen produced the highest elastic modulus (72.76 MPa), or 30.79% higher than the NB specimen (55.63 MPa), followed by NB3 specimen (59.81 MPa), or 7.52% higher than the NB specimen (55.63 MPa).

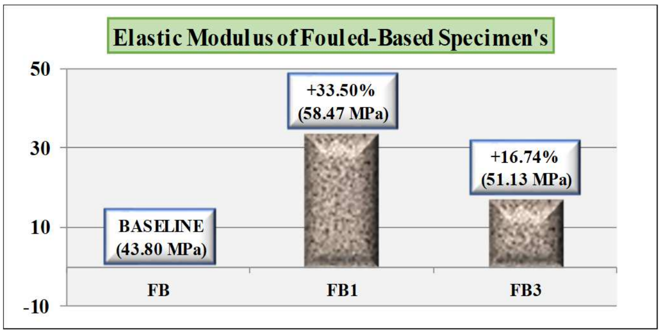


Fig. 11 Elastic modulus in poor-ballast based specimen's

Moreover, according to Fig. 11, concerning the poor-ballast based structure, the PB1 specimen produced the highest elastic modulus (58.47 MPa), or 33.50% higher than the NB specimen (43.80 MPa), followed by PB3 specimen (51.13 MPa), or 16.74% higher than the PB specimen (51.13 MPa).

D. Ballast Abrasion

According to Fig. 12, the two highest abrasion values were experienced by NB specimen (0.96%) and PB specimen (1.21%). Both specimens were without asphalt material. On the other side, the NB1 and PB1 specimens had a smaller abrasion value than the NB and PB specimens, 0.74% and 0.77%, respectively. Although the addition of asphalt could reduce these two specimens' abrasion value, the distribution of the 4% of bitumen was only on the ballast surface layer. Therefore, it was only able to protect some materials in the top layer of the ballast structure. While for NB3 and PB3, both specimens had the lowest abrasion value (0.50% and 0.46%, respectively) because ballast materials were protected from abrasion during the process of compaction and compressive testing by the presences of the well-distributed bitumen on three layers.

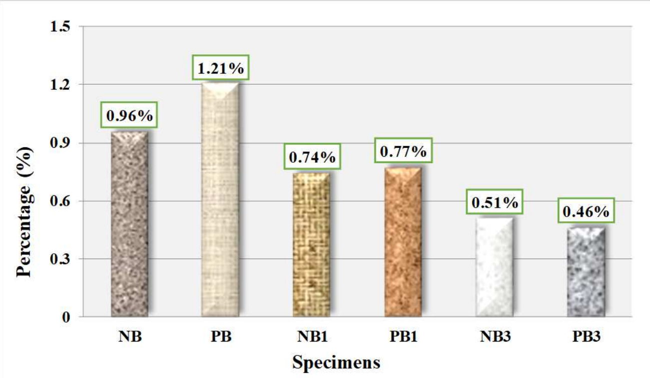


Fig. 12 Percentage of ballast material abrasion

IV. Conclusion

The new-ballast-based sample, both with and without the addition of 4% of the 60/70 grade bitumen, was relatively lighter in weight compared to the poor-ballast-based specimen due to the existence of the sludge content. Among all specimens, the minimum vertical deformation and the optimum load distribution were achieved by the specimen with 4% of the 60/70 grade bitumen on the ballast layer's surface. Being free of mud and dust, the specimens consisting of new-ballast produced a higher elastic modulus compared to the specimens consisting of poor-ballast. The presence of the well-distributed bitumen on three layers of ballast structure could produce the minimum abrasion value due to the possibility that ballast materials were protected from abrasion.

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