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Factorial Experimental Analysis of Buton Natural Asphalt with Crumb Rubber in Asphalt Concrete Wearing Course (AC-WC)

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Abstract Buton natural asphalt with crumb rubber (BNA-R) represents an innovative approach to enhancing the performance characteristics of asphalt mixtures. However, previous studies have primarily focused on incorporating BNA-R at a single, optimum dosage level. This study explores the impact of varied dosages of Buton natural asphalt with crumb rubber (BNA-R) on asphalt mixture performance using the factorial design analysis. The factorial design method is a statistical method to test the influence of several factors with different levels. With this method, all possible combinations of each level from the elements can be analyzed for their effects on the asphalt mixture without lethal or freeze other factors. Based on the analysis of two-level full-factorial designed experiments revealed on the Marshall test, it's shown that: the bitumen content has a significant correlation with the flow, MQ, VIM and VFA, while BNA-R has a substantial relationship with stability, flow, VIM and VFA. Results show enhanced stability, increased Marshall Quotient (MQ), and improved workability with lowered production temperatures. While the correlation between asphalt levels and BNA-R content is not significant for mechanical properties, such as stability, flow, MQ, voids in mineral aggregate (VMA), and VFA, the presence of BNA-R alone exhibits influential relationships with these parameters and BNA-R alone influences these parameters. The results from the study suggest that the optimal combination identified is 5.6% asphalt with 20% BNA-R, 5.7% asphalt with 25% BNA-R, and 5.8% asphalt with 30% BNA-R.

Keywords AC-WC, BNA-R, Marshall Test, Factorial Experimental Design

1. Introduction

Flexible pavements employ asphalt as the aggregate-binding material [1,2]. Asphalt exhibits cohesive, adhesive, and thermoplastic properties [3], rendering it susceptible to heat and age changes [4]. Asphalt can be modified by adding materials (additives) to improve the quality of flexible pavements [5,6,7]. One of the additive materials used to replace oil asphalt is Buton Natural Asphalt (BNA), a representative product derived from rock asphalt on the Island of Buton in southeast Sulawesi [8,9], Indonesia as shown in Figure 1. It is characterized by high asphalt and nitrogen content. Furthermore, BNA is resiniferous and non-waxy [10,11,12] and can be further improved by incorporating Crumb Rubber [13].

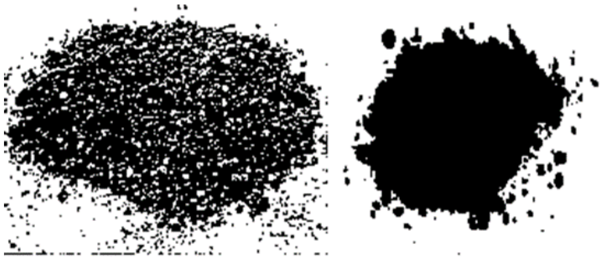

Figure 1. Buton Natural Asphalt (left) and BNA R (right)

Prior research indicates that the addition of Buton natural asphalt with crumb rubber (BNA-R) affects the properties of the asphalt mixture, increasing the stability and Marshall Quotient (MQ) while concurrently decreasing the value of melting plastic (flow). However, previous studies have only identified the influence of incorporating BNA-R at a solitary asphalt level, namely, the optimum dosage [14,15]. The optimal combination of BNA-R and asphalt remains unexplored; whether it aligns with the optimum level remains uncertain.

This study seeks to address these gaps by employing the factorial design method, allowing us to investigate the impact of various asphalt levels in conjunction with BNA-R content. By doing so, we aim to broaden our understanding of the potential benefits of this additive in asphalt mixtures. Furthermore, we intend to elucidate how this novel approach differs from previous research, emphasizing our contributions to the field.

This study investigated the effect of adding BNA-R into asphalt mixtures across various asphalt levels using the factorial design method, a statistical method used to test the influence of multiple factors at different levels. This method can be used to analyze all conceivable combinations of each factor level to ascertain their effect on the properties of the asphalt mixture without lethal or freezing other factors [16,17]. Hence, the influence of the two factors can be analyzed simultaneously namely, asphalt level and the BNA-R level on the properties of the asphalt mixture without lethal or freezing factors.

2. Theoretical Review

Asphalt, primarily composed of bitumen, is an adhesive material characterized by cohesive, adhesive, and thermoplastic properties. The asphalt content within a mixture affects the characteristics of the road pavement. Inadequate asphalt content renders pavements fragile, while excessive levels yield instability.

Increased asphalt content was found to increase the fatigue life and reduce the stiffness. Alternative models for predicting the fatigue life and initial stiffness using asphalt content, air void content, voids filled with bitumen, and volume concentrations of asphalt and aggregate have been evaluated [18,19].

Aggregates are solid mineral particles typically manifesting large granules or fragments and are pivotal for road pavement structures. Aggregate characteristics primarily determine road pavement capacity, with each asphalt mixture type designed for road pavements adhering to specific aggregate gradation. Aggregate size distribution affects the stiffness of the asphalt mixture [20]. Aggregates can be divided into three types based on their sizes.

- Coarse aggregates are characterized by their wear resistance, durability, cleanliness, and absence of loam.
- Fine aggregate contributes to the mixture stability, mitigates permanent deformation, and fosters strong binding among the aggregates, creating voids within the coarse aggregate.
- Fillers, serving as filling material in asphalt, occupy the voids between fine and coarse aggregates. They increase the asphalt viscosity and reduce its sensitivity to the mixture temperature.

Buton natural asphalt (BNA) denotes a modified asphalt derived from mixing Buton asphalt with AC 60/70 asphalt. BNA-R, a composite of 60% semi-extracted Buton asphalt and 40% crumb rubber, impacts asphalt strength owing to its high durability and flexibility. Rubber asphalt has demonstrated increased durability, resistance to wear, greater resilience against cracking and ageing, and an enhanced optimum asphalt level [11]. As an asphalt modification product, BNA-R offers several advantages, including water resistance, rigidity modulus, softening point, cracking resistance, ease of application, economical, and durability [15].

In an asphalt concrete wearing course (ACWC) mixture, the aggregate gradation adheres to defined limits encompassing upper and lower limits, each exerting different impacts on the characteristics of the ACWC mixture [21]. The aggregate mixture falls within the specified range when it lies below the gradation line. This condition produces a dominant mixture of coarse aggregates, fine aggregates, and fillers (see Fig. 2).

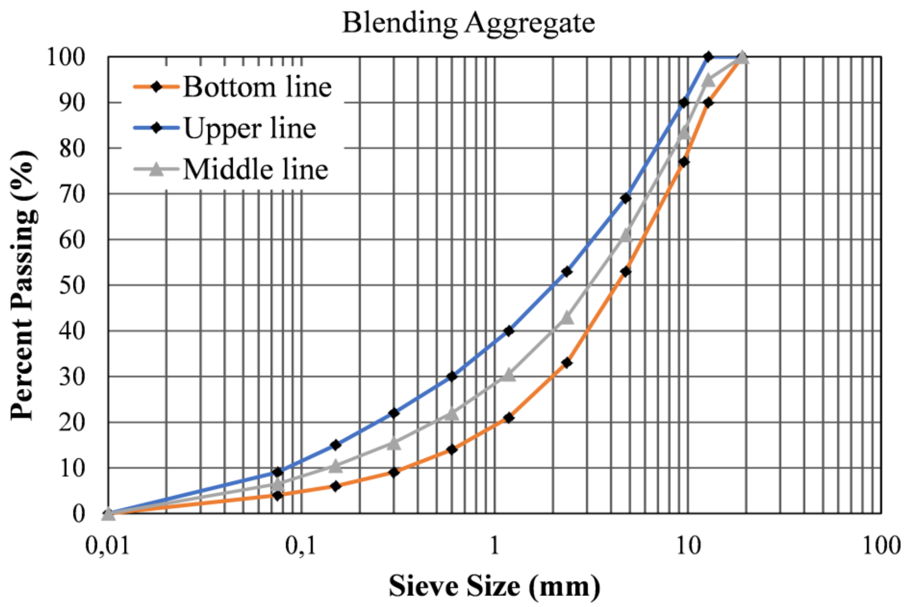

Figure 2. Aggregate composition on AC-WC mixture.

Asphalt concrete and mixtures comprise coarse aggregates, fine aggregates, and fillers with asphalt-binding materials. The asphalt mixtures were characterized using the Marshall test, which assessed key properties, including stability, melting (flow), Marshall Quotient (MQ), void in mix (VIM), void in mineral aggregates (VMA), and void filled with asphalt (VFA) [22, 23].

Factorial design is a statistical method employed to test the influence of several factors at different levels. It can show the effect of the interaction between variables and estimate the variable effects across varying levels while considering other factors [16,17]. The 3^2-factorial design was implemented, encompassing two factors, each with three levels. The experiment, conducted without replications, required nine treatment combinations.

3. The Research Method

This study was conducted at the Structure and Materials Laboratory of the Department of Civil Engineering, Engineering Faculty, University of Indonesia, in Depok, Indonesia. The investigation commenced with mixing asphalt and BNA-R. The mixing process involved heating the asphalt at a temperature of 170 ˚C. BNA-R was gradually introduced into the heated asphalt while ensuring minimal volume fluctuations caused by the form generated during its addition. The mixing process was performed for approximately 30 min or until a thorough homogenous mixture was achieved [24].

Subsequently, assessments were conducted to ascertain the aggregate characteristics and properties of the asphalt and BNA-R-modified asphalt. The specific weights of the aggregate and modified asphalt were used in the calculation to determine the properties of the mixture.

The next phase involved developing test specimens encompassing asphalt mixture, BNA-R, and aggregate. They were printed in tubes with a diameter of ±10 cm. The temperature of the mixture of BNA-R modified asphalt and aggregate was maintained at 140 ˚C. The temperature of the mixing should be maintained between 100–140 ˚C. Once the aggregate and asphalt achieved a uniform distribution, the mixture was moulded and compacted using a compactor. The test specimens were then extracted from the mould using an extruder. Subsequently, the dimensions of the text specimens, including diameter, height, weight, saturation weight, and surface dry weight.

Prior to conducting the Marshall test, the specimens were soaked for 30 min at an extreme temperature of 60 ˚C. The results of the dial reading during the Marshall test showed the stability, flow, and MQ scores of the asphalt mixture. The aggregate specific weight, BNA-R-modified asphalt specific weight, and dimensions of the test specimens were used to calculate the VIM, VMA, and VFA of the asphalt mixture (see Table 1).

Table 1. Asphalt and BNA-R Combination

Asphalt Content	BNA-R Content		
	20% (b1)	25% (b2)	30% (b3)
5% (a1)	a1b1	a1b2	a1b3
5.5% (a2)	a2b1	a2b2	a2b3
6% (a3)	a3b1	a3b2	a3b3

These scores were analyzed using the factorial design method.

Observations of the responses from two factorial experiments, with each factor spanning three levels, can be expressed using the following model:

$$yijk = \mu + \tau i + \beta j + (\tau\beta) + \varepsilon ijk \qquad (1)$$

$$i = 1,2,3$$
$$j = 1,2,3$$
$$k = 1,2,3\ldots r$$

where:

yijk = observation value (response) derived from the BNA-R mixture on asphalt, with level i representing asphalt content factor and level j representing BNA-R content factor in modified asphalt for the kth replication.

μ = general average effect.

Ti = average effect of level i asphalt content factor.

βj = average effect of j factor level of BNA-R content in modified asphalt.

(τβ)ij = the average interaction effect of level i asphalt content factor and level j factor of BNA-R content in modified asphalt.

εijk = random error effect.

The variables in this study encompassed two free variables (asphalt content and BNA-R content) and bound variables (properties of the asphalt mixture, such as stability, flow, MQ, VIM, VMA, and VFA). The asphalt and BNA-R levels were analyzed for each property of the asphalt mixture. The factorial design method, an analytical method used in this study, was used to calculate.

- The total treatment value.
- The degrees of freedom of treatment.
- The sum of the squares of the factors.
- The degrees of freedom of the factors.
- The middle square.
- The F-count value.
- The significance value.

The following procedure was undertaken to interpret the results:

- Set the significance, α = 0,05
- Compare α with the obtained significance (sig.).

If (sig.) < α, then the correlation is significant. If (sig.) > α, the correlation is less significant.

4. Result and Discussion

The results of the Marshall test are summarized in Table 2, showing that adding 5% BNA-R to the asphalt content yielded an unfavourable mixture, as evidenced by VIM and VFA; the level of asphalt content is significantly small to cover the aggregate.

Conversely, when BNA-R levels exceeded 25%, subsequent t reduction in stability was observed. This pattern underscores the influence of BNA-R in enhancing the stability up to a BNA-R content equivalent to 25% of the asphalt content. Therefore, adding BNA-R above this threshold, i.e., >25%, is not recommended as shown in Fig. 3.

Table 2. Test Result of Mixture Properties

Properties	Specimen								
	5%			5.5%			6%		
	20%	25%	30%	20%	25%	30%	20%	25%	30%
	I	II	III	IV	V	VI	VII	VIII	IX
Stability	1945	2241	1438	1968	2066	1608	1605	1667	1439
Flow	3,07	3,1	2,93	3,03	3,3	3,2	3,23	3,67	3,17
MQ	633,5	722,9	490,8	649,3	626	502,3	496,9	454,3	453,9
VIM	6.61	7.55	6.05	4.85	5.31	3.97	3.29	4.99	4.43
VMA	17.63	18.35	17.10	17.11	17.41	16.31	17.80	18.16	17.74
VFA	62.55	58.95	64.69	72.3	69.64	75.76	80.46	72.54	75.19

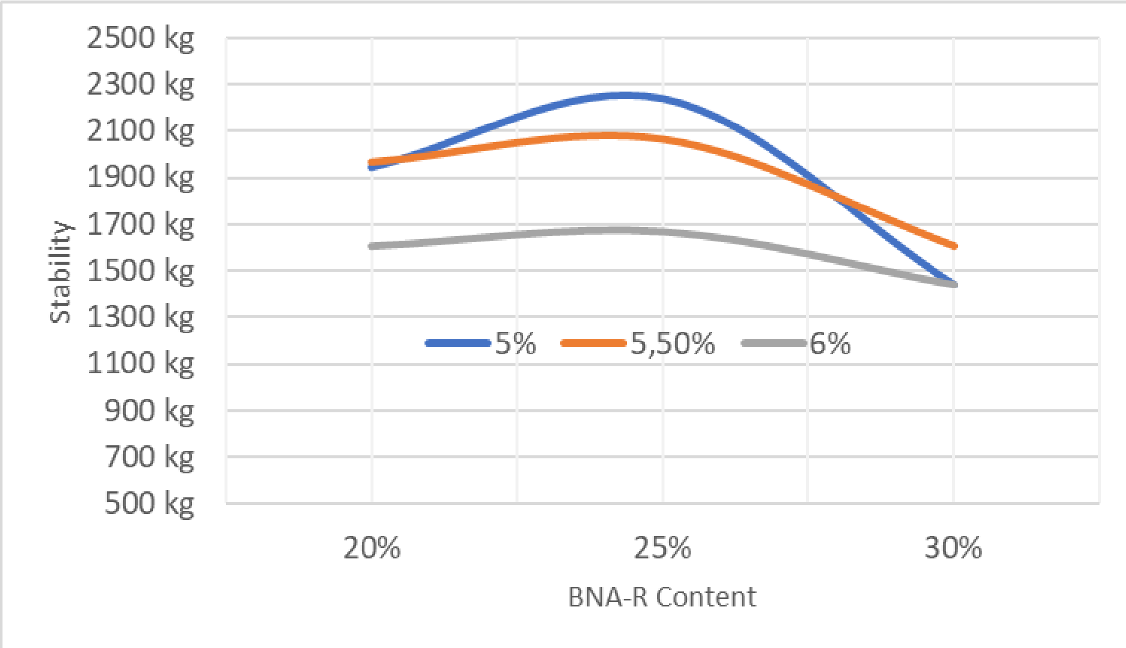

Figure 3. The Influence of BNA-R on Stability

Table 3. Results of the Factorial Design Test: Stability

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1392823.48[a]	8	174102.935	2.551	.047
Intercept	81846847.58	1	81846847.58	1199.442	.000
Asphalt Content	396858.215	2	198429.107	2.908	.080
BNAR Content	587117.055	2	293558.527	4.302	.030
Asphalt Content*BNAR Content	408848.213	4	102212.053	1.498	.245
Error	1228274.134	18	68237.452		
Total	84467945.20	27			
Corrected Model	2621097.617	26			

The results of the Marshall test were analyzed using a factorial design method to identify the effect of the interaction between the BNA-R and asphalt contents using statistical product and service solutions (SPSS). The following is the analysis results of the effect of BNA-R content at varying asphalt content on the properties of the asphalt mixture.

As shown in Table 3, the influence of asphalt content on stability yielded a significant score of 0.08, surpassing the score of $\alpha=0.05$. Consequently, the correlation between asphalt content and stability was less significant. The BNA-R content had a significant score of 0.03, indicating a significant correlation between BNA-R content and mixture stability. However, when examining the interaction effect between the asphalt and BNA-R content, the correlation between these variables with stability was less significant.

Table 4. Results of the Factorial Design Test: Flow

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.067[a]	8	.133	4.615	.003
Intercept	274.563	1	274.563	9504.115	.000
Asphalt Content	.469	2	.234	8.115	.003
BNAR Content	.376	2	.188	6.500	.008
Asphalt Content*BNAR Content	.222	4	.056	1.923	.150
Error	.520	18	.029		
Total	276.150	27			
Corrected Model	1.587	26			

Table 5. Results of the Factorial Design Test: Marshall Quotient

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	160993.134[a]	8	20124.142	3.571	.012
Intercept	8090622.503	1	8090622.503	1435.678	.000
Asphalt Content	90723.964	2	45361.982	8.049	.003
BNAR Content	28401.750	2	14200.875	2.520	.108
Asphalt Content*BNAR Content	41867.420	4	10466.855	1.857	.162
Error	101437.201	18	5635.400		
Total	8353052.838	27			
Corrected Model	262430.335	26			

Table 6. Results of the Factorial Design Test: VIM

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	39.884[a]	8	4.985	5.027	.002
Intercept	901.587	1	901.587	909.120	.000
Asphalt Content	29.202	2	14.601	14.723	.000
BNAR Content	7.011	2	3.505	3.535	.051
Asphalt Content*BNAR Content	3.672	4	.918	.926	.471
Error	17.851	18	.992		
Total	959.322	27			
Corrected Model	57.735	26			

The asphalt and BNA-R content exhibited a significant correlation with the flow, as indicated by a significance score of approximately 0 (zero) as shown in Table 4. Conversely, the correlation between these variables with the flow was less significant when assessing the interaction effect between asphalt content and BNA-R content.

The impact of asphalt content on stability displayed a significant correlation with MQ, as denoted by a significant score nearing 0 (zero). However, the influence of BNA-R content showed a less significant correlation with MQ as shown in table 5. Upon reviewing the interaction effect between the asphalt and BNA-R content, the correlation between the two variables and MQ was less significant.

Stability and MQ Improvement: The increased stability and Marshall Quotient (MQ) suggest that BNA-R enhances the mix's resistance to deformation. This could be due to the rubber particles in BNA-R improving the elasticity of the asphalt mixture.

Based on Table 6, the asphalt and BNA-R contents were significantly correlated with VIM, as indicated by a significance score of approximately 0 (zero). However, upon reviewing the interaction effect between the asphalt content and BNA-R content, we found that the correlation between the two variables with VIM was less significant.

Table 7. Results of the Factorial Design Test: VMA

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10.484[a]	8	1.311	1.705	.165
Intercept	7785.344	1	7785.344	10130.057	.000
Asphalt Content	3.034	2	1.517	1.974	.168
BNAR Content	4.752	2	2.376	3.092	.070
Asphalt Content*BNAR Content	2.698	4	.674	.878	.497
Error	13.834	18	.769		
Total	7809.662	27			
Corrected Model	24.318	26			

Table 8. Results of the Factorial Design Test: VFA

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1089.840[a]	8	136.230	7.815	.000
Intercept	118497.121	1	118497.121	6798.007	.000
Asphalt Content	890.385	2	445.193	25.540	.000
BNAR Content	135.506	2	67.753	3.887	.040
Asphalt Content*BNAR Content	63.949	4	15.987	.917	.475
Error	313.761	18	17.431		
Total	119900.722	27			
Corrected Model	1403.601	26			

The asphalt and BNA-R content exhibited no significant correlation with the VMA score, as indicated by a significance score exceeding 0.05. Specifically, the significance score for the correlation between asphalt content and VMA was 0.168, while the significance score for the correlation between BNA-R and VMA was 0.07 as shown in Table 7. Furthermore, the significance score for the correlation between the interaction of the two variables and VMA was less significant.

As shown in Table 8, both the asphalt and BNA-R contents were significantly correlated with VFA, with a significance score approaching 0 (zero). However, the correlation between the asphalt content and BNA-R content with VFA was less significant as shown in Table 8.

5. Conclusions

In this study, the full factorial design of the experiment was carried out to evaluate the effect of various factors such as bitumen content, BNA-R content, stability, flow, MQ, VIM, VMA, and VFA test temperature, and asphalt concrete wearing course (ACWC).

The asphalt content significantly correlated with the flow, Marshall Quotient, voids in the mixture, and VFA.

Moreover, BNA-R content was significantly correlated with stability, flow, VIM, and VFA.

The interaction between the asphalt content and BNA-R content was not significantly correlated with the properties of the asphalt mixture, i.e., stability, flow, MQ, VIM, VMA, and VFA.

The study identified the optimal combinations of asphalt content with BNA-R content as follows:

- 5.8% asphalt with 30% BNA-R
- 5.7% asphalt with 25% BNA-R
- 5.6% asphalt with 20% BNA-R

These combinations provide a balance between the beneficial effects of BNA-R and the practical considerations of asphalt mixture production and application.

The future potential research areas and problems that could be addressed are the performance tests that are required to be carried out to get a thorough understanding of the effect of BNA-R in ACWC.

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