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The Performance Modeling of Modified Asbuton and Polyethylene Terephthalate (PET) Mixture Using Response Surface Methodology (RSM)

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Abstract: We often use the plastics daily, containing of polyethylene plastic polymers which recently can be utilized as additional material for road pavements. Several studies have attempted to find the optimum proportion of an asphalt mixture using modified Asbuton which is local bitumen abundantly deposited in Buton Island Indonesia, added with plastic waste. The optimum proportion of the asphalt mixture is influenced by many factors, such as the interactions of the material component in the asphalt mixture. To obtain the optimum proportion based a single factor, many studies employ statistical methods. This study aims to determine the optimum proportion for the asphalt mixture of the modified Asbuton with PET plastic waste by using a Response Surface Methodology (RSM). The employed RSM is the Expert Version 12 design (Stat-Ease, Inc., Minneapolis, MN, USA, 2020), in which the statistical modeling based on Box Behnken Design (BBD) and three factorial levels. The results obtained in this study show that the RSM optimization could achieve the asphalt mixtures characteristics including the stability, Marshall Quotient (MQ), Void in MIX (VIM), Void Mineral Aggregate (VMA) and density, in the level of satisfying the specification requirements of Ministry of Public Works of Indonesia. The optimum stability is at 2002.72 kg, fulfilled the minimum density of 800 kg. For the MQ, the optimal point of MQ is 500.68 kg/mm, satisfied the minimum the MQ standard minimum of 250 kg/mm. In addition, the optimal VIM is at 3.40%, satisfying the VIM specifications in the range of 3–5%. The optimal VMA response is at 21.65%, which is also satisfied the VMA specification, 15%.

Keywords: response surface methodology (RSM); PET plastic waste; modified asbuton

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1. Introduction

Pavement surface layer must have the ability to be a wearing layer and have good performance during its service life. The increase of traffic congestion has caused damage in pavement surface layer so that it cannot reach the expected service life. The repetition of traffic loads resulting from traffic density causes the accumulation of permanent deformation in the asphalt concrete mixture and decreases its service life [1,2]. One way to solve the problem is by using additives in the asphalt mixture. One of the additives is plastic waste, which contains polymer and found as plastomeric in the nature [3,4]. Several studies have suggested that PET plastic waste as an added material can improve the asphalt mixture performances [5–9].

In Indonesia, particularly in the island of Buton, the province of Southeast Sulawesi, natural deposit of asphalt or rock asphalt, namely Asbuton (Natural Asphalt Buton) can be found with abundant quantity. Asbuton is a naturally categorized as hydrocarbon material [10–13]. Asbuton bitumen content varies from 10% to 40%, and the rest is a mineral. The Asbuton deposit is quite large, around 600 million tons [14]. Moreover, the Asbuton deposit is estimated to be equivalent to 24 million petroleum asphalt [15–17]. It has been established in some previous studies that the combination of PET plastic waste and Asbuton can increase the asphalt mixture's stiffness, particularly the Marshall characteristics. They can improve several essential aspects of the asphalt mixture [18–20].

However, the optimum proportion of Asbuton and PET plastic waste for the asphalt mixture remains unclear. In general, experimental method was undertaken to evaluate a factor's effect in one experiment, associated with several variations and several experiments. In research terms, this is called a single factor experiment. The experimental method's weakness is that the conclusions obtained are only related to the experimental factors and are limited to 1 to 2 variables. Meanwhile, in reality, the quality of a product under study is influenced not only by one factor but also by several factors such as the level of modified Asbuton and the level of plastic waste. The proportions of these ingredients have interactions with one another, which significantly affect the quality of the Asphalt concrete-wearing course (AC-WC) mixture produced [21,22].

The method of quantifying the optimum proportion of PET plastic waste and the modified Asbuton in the asphalt mixture of AC-WC is still insufficient. Therefore, this study aims to investigate that optimum proportion of the modified Asbuton and PET plastic waste by using statistical techniques of Response Surface Methodology (RSM). This statistical method can take the contribution of two or more factors in an experiment into account and estimate the interactions and relationships between the experimental factors [23–26].

2. Materials and Methods

2.1. Physical Properties of Aggregate

Tables 1–3 show the result of laboratory tests, i.e., the characteristics of fine aggregate (stone ash), coarse aggregate characteristics and characteristics of the filler. The coarse aggregate, stone ash and filler are required to fulfil the road material's specification according to the 2018 Bina Marga (Indonesian Ministry of Public Works) General Specifications requirement.

Table 1. Physical properties of stone ash.

No.	Properties	Results	Specification		Unit
			Min	Max	
1	Water Absorption	2.79		3.0	%
2	Bulk Specific Gravity	2.45	2.5		
	SSD Specific Gravity	2.52	2.5		
	Apparent Specific Gravity	2.63	2.5		
3	Sand Equivalent	89.66	50		%

Table 2. Physical properties of coarse aggregate.

No.	Properties	Results.	Specifications		Unit
			Min	Max	
1	Water absorption				
	Coarse aggregate 5–10 mm	2.07		3.0	%
	Coarse aggregate 1–2 cm	2.08		3.0	%
2	Density				
	Coarse aggregate 0.5–1 cm				
	Bulk Specific Gravity	2.62	2.5		
	SSD Specific Gravity	2.67	2.5		
	Apparent Specific Gravity	2.77	2.5		
	Coarse aggregate 1–2 cm				
	Bulk Specific Gravity	2.62	2.5		
	SSD Specific Gravity	2.68	2.5		
	Specific Gravity	2.77	2.5		

Table 2. *Cont.*

No.	Properties	Results.	Specifications		Unit
			Min	Max	
3	Artificial Flake Index				
	Coarse aggregate 0.5–1 cm	20.10		25	%
	Coarse aggregate 1–2 cm	9.38		25	%
4	Abrasion				
	Coarse aggregate 0.5–1 cm	25.72		40	%
	Coarse aggregate 1–2 cm	24.36		40	%

Table 3. Physical properties of filler.

No.	Properties	Results	Specification		Unit
			Min	Max	
1	Water Absorption	2.28		3.0	%
2	Bulk Specific Gravity	2.60	2.5		
	SSD Specific Gravity	2.65	2.5		
	Apparent Specific Gravity	2.76	2.5		
3	Sand Equivalent	69.57	50		%

2.2. Characteristics of Asbuton Modification

Table 4 shows the testing results of the modified Asbuton, which is the asphalt extracted from Buton's bitumen asphalt granular and added with petroleum bitumen. The results describe the modified Asbuton's characteristics. It can be seen that the modified Asbuton used in this study qualified the specifications required by the 2018 General Specifications of Bina Marga.

Table 4. Physical Properties of Asbuton Modification.

No.	Test	Results	Specification	
			Min	Max
1	Penetration before weight loss (mm)	78.6	60	79
2	Flabby point (°C)	52	48	58
3	Ductility at 25 °C, 5 cm/min (cm)	114	100	
4	Flash point (°C)	280	200	
5	Specific gravity	1.12	1	
6	Weight loss (%)	0.3		0.8
7	Penetration after weight loss (mm)	86	54	

2.3. Characteristics of PET Plastic Waste

The plastic bottle used is a type of PET (Polyethylene Terephthalate), one of the polyethylene types, namely polymer consisting of long chains of monomers ethylene (IUPAC: ethene). The structure of molecularethene C_2H_4 is–CH_2–CH_2–n. Two CH_2 united by double bonds, Polyethylene is formed through a process polymerization of ethene. Figure 1 shows a thin surface polyethylene.

Figure 1. Thin surface Polyethylene.

PET type plastic is a brown type plastic made from petroleum. Its mechanical properties are strong, slightly translucent, high flexibility and the surface is somewhat greasy. At a temperature of 60 °C, PET is very resistant to chemical compounds, with a specific gravity of 0.91–0.94 gr/cm^3. PET is also a type of low-density polyethylene produced by free radical polymerization at high temperature (200 °C) and high pressure, it can be melted at temperature of 260 °C.

2.4. Marshall Stability

The testing method for the asphalt mixture is Marshall equipment test refers to SNI 06-2489-1991. The quotient of stability and flow magnitude is an indicator of potential flexibility of the asphalt mixture to cracking, and the quotient is called as Marshall Quotient.

2.5. Response Surface Methodology (RSM)

Experimental asphalt mixture design utilized in this study is Box-Behnken Design (BBD) in which RSM is used to optimize the mixture design. The BBD is designed to form a combination of two techniques with incomplete block design by adding the center points or center runs to the plan. The center run (NC) is an experiment with the center point at (0, 0, . . . , 0), and there are at least three center runs for various sums of the factor k. If there are three factors, then the BBD design amounts to 12 plus a center run as in the equation matrix two and can be described in Figure 2.

$$D = \begin{bmatrix} -1 & -1 & 0 \\ -1 & 1 & 0 \\ 1 & -1 & 0 \\ 1 & 1 & 0 \\ -1 & 0 & -1 \\ -1 & 0 & 1 \\ 1 & 0 & -1 \\ 1 & 0 & 1 \\ 0 & -1 & -1 \\ 0 & -1 & 1 \\ 0 & 1 & -1 \\ 0 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix} \tag{1}$$

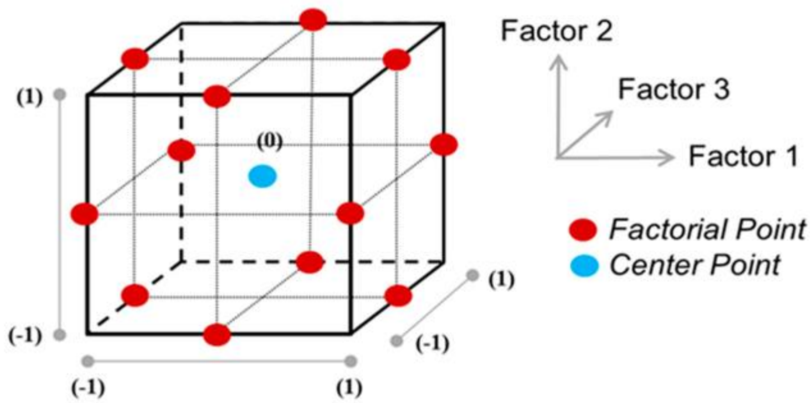


Figure 2. Box-Behnken Design.

The experimental mixture design was carried out using Response Surface Methodology (RSM) based on the Box-Behnken Design (BBD). The quadratic model and each variable vary on three levels. Design Expert Version 12 (Stat-Ease, Inc., Minneapolis, MN, USA) was used for regression analysis of experimental data and to plot response surfaces. The second stage uses the second-order quadratic polynomial equation to evaluate each independent variable's main effect and interaction on the response as given by Equation (2).

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i<j}^{n} \beta_{ij} X_i X_j + \sum_{j=1}^{n} \beta_{jj} X_j^2 \quad (2)$$

In Equation (2), Y represents the experimental response, i and j are linear and quadratic coefficients, respectively, β is the regression coefficient, n is the number of variables studied in the experiment, and X_i is a factor (independent variable). In this experiment, the independent variables (factor X) studied were X_1: the PET ratio to Asbuton, X_2: mixing temperature and X_3: mixing time, respectively. The response (Y) is characteristic of Marshall.

3. Results and Discussion

3.1. AC-WC Combined Aggregate Gradation

Figure 3 shows that the combined aggregate design or combined aggregate gradation made is within the standard specification according to the 2018 General Specifications of Bina Marga and has met the requirements for surface coating, so that the mixture design can be categorized as optimal mixture design.

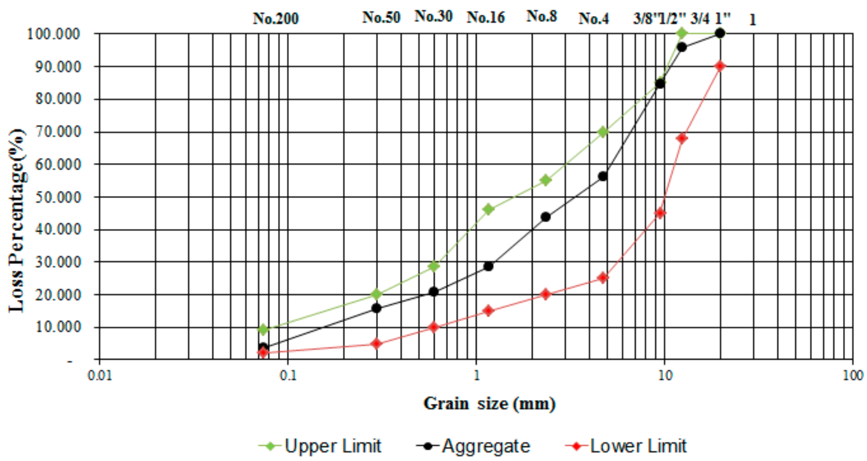


Figure 3. Combined aggregate gradation.

3.2. Mixture Design Results Based on RSM (Response Surface Methodology)

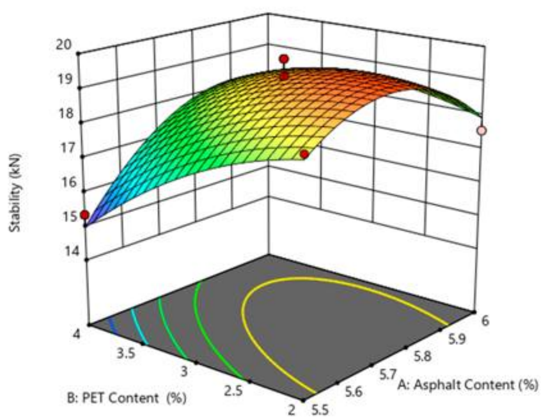
Table 5 shows the mixture design of asphalt mixture using Box Behnken Design (BBD) in the laboratory. In the fulfillment of the assumptions of Equation (2), we involved the five response variables in continuing at the modeling stage for optimization using the method Response Surface Methodology (RSM). This method is used to obtain the AC-WC asphalt mixture's optimization results using PET plastic waste and modified Asbuton based on Marshall characteristics (stability, MQ, VIM, VMA and density).

Table 5. Mixture design of asphalt mixture using BBD.

No	A: Asphalt Content (%)	B: PET Content (%)	C: Mixing Time (Minutes)	R1: Stability (kN)	R2: Flow (mm)	R3: MQ (kN/mm)	R4: VIM (%)	R5: VMA (%)	R6: VFB (%)	R7: Density
1	5.50	2.00	25.00	18.58	4.00	4.64	2.97	20.73	90.27	2296.00
2	5.50	4.00	25.00	15.35	4.00	3.84	1.77	20.68	90.70	2276.00
3	6.00	2.00	25.00	17.56	4.00	4.39	3.24	22.87	88.64	2278.00
4	6.00	4.00	25.00	17.83	4.00	4.46	5.00	20.37	90.93	2248.00
5	5.50	3.00	20.00	16.58	4.00	4.14	2.92	20.92	92.09	2203.00
6	5.50	3.00	30.00	16.97	4.00	4.24	2.78	20.86	90.72	2355.00
7	6.00	3.00	20.00	18.27	4.00	4.57	3.70	20.70	89.79	2196.00
8	6.00	3.00	30.00	18.82	4.00	4.70	5.25	20.48	84.27	2398.00
9	5.75	2.00	20.00	18.90	4.00	4.72	3.21	21.87	89.43	2234.00
10	5.75	2.00	30.00	19.76	4.00	4.94	2.98	21.78	89.23	2397.00
11	5.75	4.00	20.00	17.26	4.00	4.31	2.36	21.83	91.47	2264.00
12	5.75	4.00	30.00	17.53	4.00	4.38	2.57	20.98	87.49	2378.00
13	5.75	3.00	25.00	18.45	4.00	4.61	3.37	21.93	87.98	2263.00
14	5.75	3.00	25.00	19.75	4.00	4.94	3.95	22.35	85.78	2231.00
15	5.75	3.0	25.00	19.25	4.00	4.81	3.87	21.15	90.85	2316.00

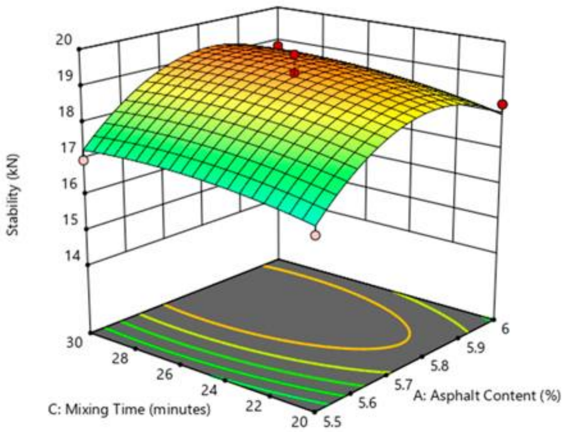
The step of determining the optimum points simultaneously with RSM is through in 2 ways: manual experimentation on 15 combinations of the three parameters and by calculation using the RSM program. The first step is to determine which parameters are representing as X1, X2 and X3. Usually, in RSM, time and temperature are chosen as X1 and X2. Simultaneously, other parameters are expressed as X3 because, in this system, X1 also described as is the ratio of PET to Asbuton, the mixing temperature is X2 and X3 is the mixing time. Based on the RSM results, Figures 4–8 present the equations for predicting Marshall characteristics.

a. Surface Stability Response Plots

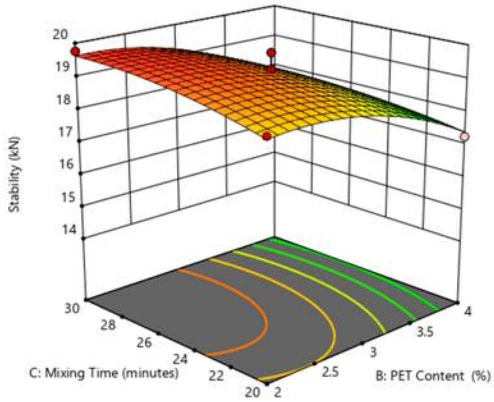


(**a**) Effect of asphalt content (A) and PET content (B).

Figure 4. *Cont.*



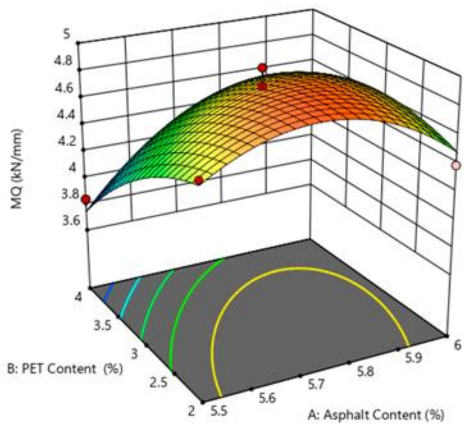
(**b**) Effect of asphalt content (A) and mixing time (C).



(**c**) Effect of PET content (B) and mixing time (C).

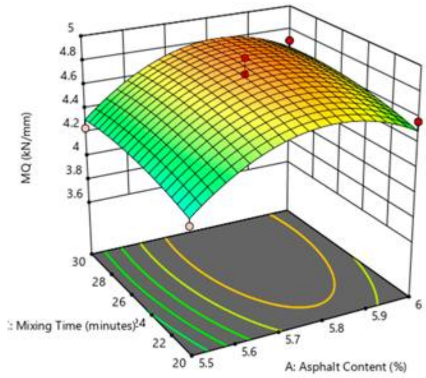
Figure 4. Contour and 3D surface response plots for stability.

b. Marshall Quetiont (MQ) Surface Response Plot

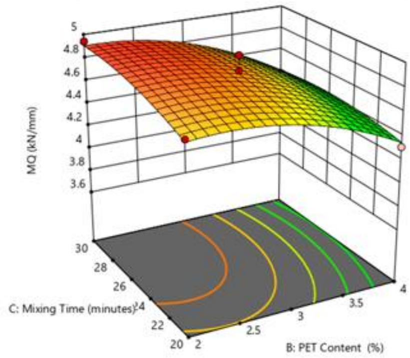


(**a**) Effect of asphalt content (A) and PET content (B).

Figure 5. *Cont.*



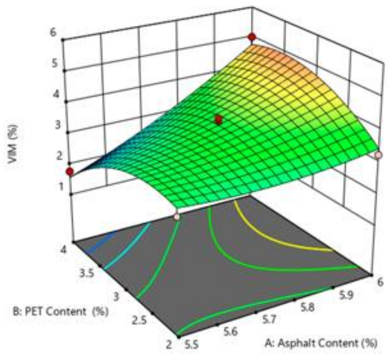
(**b**) Effect of asphalt content (A) and mixing time (C).



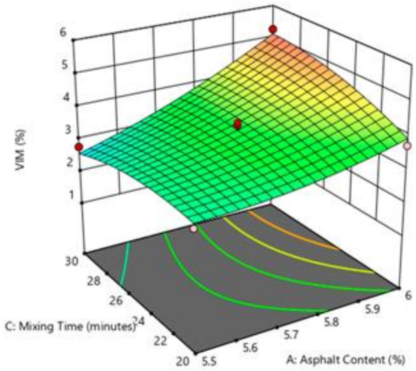
(**c**) Effect of PET content (B) and mixing time (C).

Figure 5. Contour and 3D surface response plots for MQ.

c. VIM Surface Response Plots

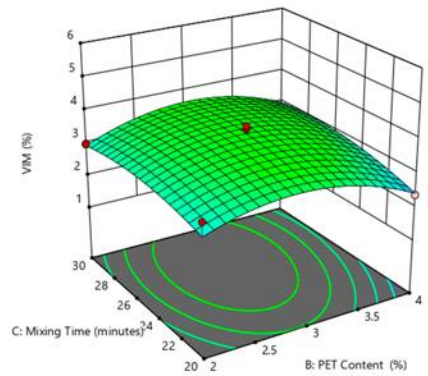


(**a**) Effect of asphalt content (A) and PET content (B).



(**b**) Effect of asphalt content (A) and mixing time (C).

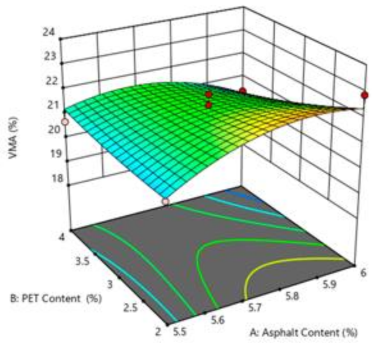
Figure 6. *Cont.*



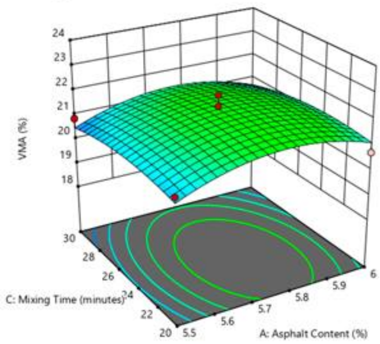
(**c**) Effect of PET content (B) and mixing time (C).

Figure 6. Contour and 3D surface response plots for VIM.

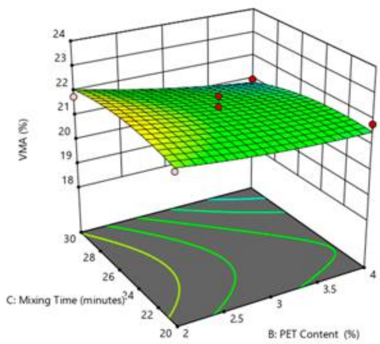
d. VMA Surface Response Plots



(**a**) Effect of asphalt content (A) and PET content (B).



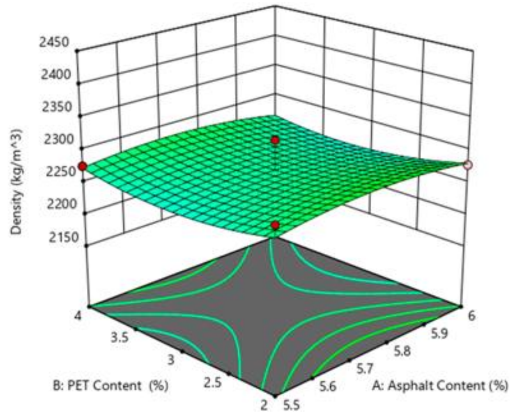
(**b**) Effect of asphalt content (A) and mixing time (C).



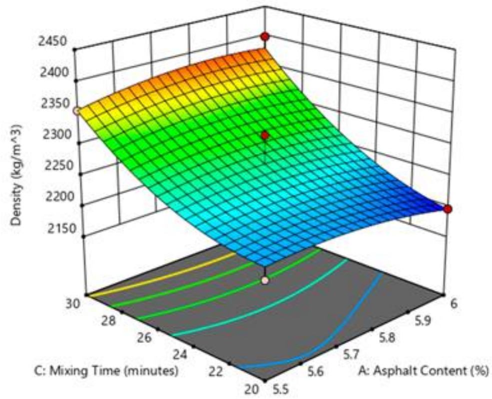
(**c**) Effect of PET content (B) and mixing time (C).

Figure 7. Contour and 3D surface response plots for VMA.

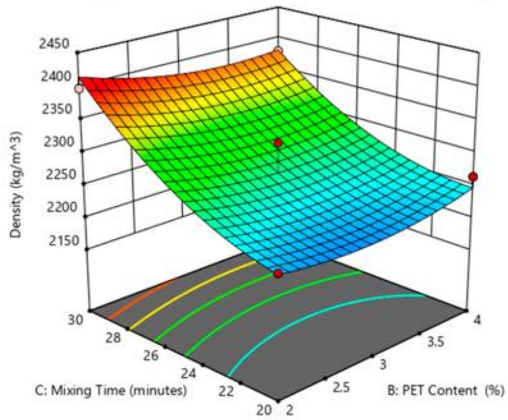
e. Density Surface Response Plots



(**a**) Effect of asphalt content (A) and PET content (B).



(**b**) Effect of asphalt content (A) and mixing time (C).



(**c**) Effect of PET content (B) and mixing time (C).

Figure 8. Contour and 3D surface response plot for density.

The ANOVA is shown in Table 6, and it can be seen that the order 2 which shows the order 2 model is suitable for this equation as evidenced by the f-value < f-table (19.16) for each variable. The f-table value with df lack of fit as df1 and df pure error as df 2 at alpha 0.05, the f-table is 19.16. If f-value > f-table then H_0 is stuck, where the assumption for lack of fit is that H_0 does not have a lack of fit and vice versa for H_1.

Table 6. ANOVA for predicting Marshall Stability based on RSM.

Variabel	Source	Sum of Squares	df	Mean Square	F-Value
Stability	Residual	1.51	5	0.3018	0.50
	Lack of Fit	0.65	3	0.2163	
	Pure Error	0.86	2	0.4300	
MQ	Residual	0.10	5	0.0193	0.50
	Lack of Fit	0.04	3	0.0138	
	Pure Error	0.05	2	0.0276	
VIM	Residual	0.88	5	0.1750	2.29
	Lack of Fit	0.68	3	0.2258	
	Pure Error	0.20	2	0.0988	
VMA	Residual	1.90	5	0.3799	1.04
	Lack of Fit	1.16	3	0.3860	
	Pure Error	0.74	2	0.3708	
Densitas	Residual	5732.75	5	1146.55	0.37
	Lack of Fit	2046.75	3	682.25	
	Pure Error	3686.00	2	1843.00	

The step of determining the optimum points simultaneously with RSM is carried out in two ways, namely by manual experimentation on 15 combinations of the three parameters and by calculation with the use of the RSM program. The first step to take is to determine which parameters are represented as X1, X2 and X3. In RSM, time and temperature are chosen as X1 and X2, while other parameters are expressed as X3 because in this system it is also expressed as X1 is the ratio of PET to Asbuton, the mixing temperature is X2 and X3 is the mixing time. Based on the RSM results, the equations for predicting Marshall characteristics are shown in Table 7.

Table 7. Equations for predicting Marshall Stability based on RSM.

No	Marshall Characteristics	The Equation for the Results of RSM	Adj. R^2
1	Stability	$19.15 + 0.63A - 0.85B + 0.26C + 0.88AB + 0.04AC - 0.15BC - 1.26A^2 - 0.56B^2 - 0.23C^2$	0.7975
2	MQ	$4.79 + 0.16A - 0.21B + 0.06C + 0.22AB + 0.0075AC - 0.04BC - 0.32A^2 - 0.14B^2 - 0.06C^2$	0.7921
3	VIM	$3.73 + 0.84A - 0.09B + 0.17C + 0.74AB + 0.42AC - 0.04BC - 0.32A^2 - 0.14B^2 - 0.06C^2$	0.7956
4	VMA	$3.73 + 0.84A - 0.09B + 0.17C + 0.74AB + 0.42AC - 0.04BC - 0.32A^2 - 0.14B^2 - 0.06C^2$	0.3241
5	Density	$2270 - 1.25A - 4.88B + 78.88C - 2.50AB + 12.50AC - 12.25BC - 12.87A^2 + 17.38B^2 + 30.87C^2$	0.7424

Note: The coefficients A, B, C refer to the linear response. AB, AC and BC are interactions between independent variables. A^2, B^2 and C^2 is a quadratic response involved in the process.

Based on the experimental design, the obtained VFB was in the range of 84.27–92.83%. However, this data can only reach order 1, as evidenced by the test's lack of fit in model 1, the decision to fail to reject H_0, which means that the model is suitable, or there is no lack of a fit model. This result leaves no increase to the 2nd order in this model. While in RSM, optimization will occur in order 2.

3.3. Optimization of PET Levels in Marshall Characteristics

Regarding the purpose of the study, Table 8 shows the optimizing results for PET content as much as possible in Marshall characteristics. It is shown that the optimal PET content used was at 3.84%, with a stationary point of 0.844. It is noted that the mixing time could not affect the stability and density of the asphalt mixture since the PET is not melted but crystalized in temperature of AC-WC mixture.

Table 8. Minimum PET content.

Response Variable	Optimal Response	Optimal A: Asphalt Content (%)	Optimal B: PET Content (%)	Optimal C: Mixing Time (Minutes)
Stability	19.64 kN	5.73	2.07	29.29
MQ	4.91 kN/mm	5.76	3.46	22.85
VIM	3.40%	5.56	2.49	23.07
VMA	21.65%	5.69	3.84	22.54
Density	2223.06 kg/m^3	5.40	2.67	18.89

4. Conclusions

The present study has observed the seven components of Marshall characteristics. There are two components that RSM cannot optimize, i.e., Flow and Void Filled Bitumen (VFB). Statistical tests cannot carry out the response flow because it does not have data diversity and the VFB response matches the 1st order model. This result may be due to the data range that is too small. Asphalt levels, PET plastic waste levels and mixing time have different optimum points for each response of the AC-WC mixture using modified Asbuton as the binder.

The RSM analysis results showed that optimum proportion of asphalt and PET contents in the AC-WC mixture could achieve the values of stability and MQ, VIM, VMA and density, meet with the technical specifications required by Indonesia Ministry of Public Works. The results also show that the PET content could enhance the VIM in the AC-WC mixtures, indicating the durability of the AC-WC mixtures against the water infiltration. The findings suggested the PET and the modified Asbuton for AC-WC asphalt mixtures would be potential for future application as environmentally friendly materials for asphalt pavement technology.

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References

1. Tayfur, S.; Ozen, H.; Aksoy, A. Investigation of Rutting Performance of Asphalt Mixtures Containing Polymer Modifiers. *Constr. Build. Mater.* **2005**, *21*, 328–337. [CrossRef]
2. Birgisson, B.; Montepara, A.; Romeo, E.; Roncella, R.; Napier, J.A.L.; Tebaldi, G. Determination and Prediction of Crack Patterns in Hot Mix Asphalt (HMA) Mixtures. *Constr. Build. Mater.* **2008**, 664–673. [CrossRef]
3. Ahmadinia, E.; Zargar, M.; Karim, M.R.; Abdelaziz, M.; Shafigh, P. Using waste plastic bottles as an additive for stone mastic asphalt. *Mater. Des.* **2011**, *32*, 4844–4849. [CrossRef]
4. Ahmadinia, E.; Zargar, M.; Karim, M.R.; Abdelaziz, M.; Ahmadinia, E. Performance evaluation of utilization of waste Polyethylene Terephthalate (PET) in stone mastic asphalt. *Constr. Build. Mater.* **2012**, *36*, 984–989. [CrossRef]
5. Musa, E.I.A.; Haron, H.E.F. Effect of the Low Density Polyethylene Carry Bags Waste on the Asphalt Mixture. *Int. J. Eng. Res. Sci. Technol.* **2014**, *3*, 86–93.
6. Rajput, P.S.; Yadav, R.K. Use of Plastic Waste in Bituminous Road Construction. *Int. J. Sci. Technol. Eng. (Ijste)* **2016**, *2*, 509–513.
7. Sojobi, A.O.; Nwobodo, S.E.; Aladegboye, O.J.; Pratico, F.G. Recycling of Polypthylene Terepthalate (PET) Plastic Bottle Wastes in Bituminous Asphaltic Concrete. *Cogent Eng.* **2016**. [CrossRef]

8. Soltani, M.; Moghaddam, T.B.; Karim, M.R.; Baaj, H. Analysis of Fatigue Properties of Unmodified and Polyethylene Terephthalate Modified Asphalt Mixtures Using Response Surface Methodology. *Eng. Fail. Anal.* **2015**, *58*, 238–248. [CrossRef]
9. Gaus, A.; Tjaronge, M.W.; Ali, N.; Djamaluddin, R. Compressive Strength of Asphalt Concrete Binder Course (AC-BC) Mixture Using Buton Granular Asphalt (BGA). In Proceedings of the 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5), Surabaya, Indonesia, 15–18 September 2015; Volume 125, pp. 657–662.
10. Tjaronge, M.W.; Irmawaty, R. Influence of Water Immersion on Physical Properties of Porous Asphalt Containing Liquid Asbuton as Bituminous Asphalt Binder. In Proceedings of the 3rd International Conference and Sustainable Construction Material and Technologies-SCTM, Kyoto, Japan, 18–22 August 2003.
11. Tumpu, M.; Tjaronge, M.W.; Djamaluddin, A.R.; Amiruddin, A.A.; One, L. Effect of limestone and buton granular asphalt (BGA) on density of asphalt concrete wearing course (AC-WC) mixture. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012029. [CrossRef]
12. Tjaronge, M.W.M.; Djamaluddin, A.R. Prediction of long-term volumetric parameters of asphalt concrete binder course mixture using artificial aging test. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012058. [CrossRef]
13. Suryana, A. *Inventory on Solid Bitumen Sediment Using 'Outcrop Drilling' in Southern Buton Region, Buton Regency, Province Southeast Sulawesi, Colloquium on Result Activities of Mineral Resources Inventory*; Directorate Minerals: Bandung, Indonesian, 2003.
14. Mabui, D.S.; Tjaronge, M.W.; Adisasmita, S.A.; Pasra, M. Resistance to cohesion loss in cantabro test on specimens of porous asphalt containing modified asbuton. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012100. [CrossRef]
15. Iroth, M.W.; Tjaronge, M.W.; Pasra, M. Influence of short term oven aging on volumetric properties of asphalt concrete mixture containing modified Buton asphalt and limestone powder filler. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012072. [CrossRef]
16. Tjaronge, M.W.; Adisasmita, S.A.; Hustim, M. Analysis of stability of residue asphalt emulsion mixture containing Buton Granular Asphalt (BGA). *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012073. [CrossRef]
17. Mabui, D.S.; Tjaronge, M.W.; Adisasmita, S.A.; Pasra, M. Performance of porous asphalt containing modified Buton asphalt and plastic waste. *Int. J. Geomate* **2020**, *18*, 118–123. [CrossRef]
18. Ramli, M.I.; Pasra, M.; Amiruddin, A.A. The sustainable performance challenge of asphalt mixture using polypropylene due to environmental weather. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012075. [CrossRef]
19. Meraudje, A.; Ramli, M.I.; Pasra, M.; Amiruddin, A.A. The potential utilization of Polyethylene Terephthalate (PET) waste as fine aggregate replacement in asphalt mixture. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012036. [CrossRef]
20. Lapian, F.E.P.; Ramli, M.I.; Pasra, M.; Arsyad, A. Opportunity applying response surface methodology (RSM) for optimization of performing butonic asphalt mixture using plastic waste modifier: A preliminary study. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012032. [CrossRef]
21. Chávez-Valencia, L.E.; Manzano-Ramírez, A.; Alonso-Guzmán, E.; Contreras-García, M.E. Modeling of the performance of asphalt pavement using response surface methodology—The kinetics of the aging. *Build. Environ.* **2007**, *42*, 933–939. [CrossRef]
22. Ghasemi, I.; Karrabi, M.; Mohammadi, M.; Azizi, H. Evaluating the effect of processing conditions and organoclay content on the properties of styrene-butadiene rubber/organoclay nanocomposites by response surface methodology. *Express Polym. Lett.* **2010**, *4*, 62–70. [CrossRef]
23. Nassar, A.I.; Thom, N.; Parry, T. Optimizing the mix design of cold bitumen emulsion mixtures using response surface methodology. *Constr. Build. Mater.* **2016**, *104*, 216–229. [CrossRef]
24. Mogahaddam, T.B.; Soltani, M.; Karim, M.R.; Baaj, H. Optimization of asphalt and modifier contents for polyethylene terephthalate modified asphalt mixtures using response surface methodology. *Measurement* **2015**, *74*, 159–169. [CrossRef]
25. *General Specifications of Indonesia 2018 Indonesia Requirement*; Director General of Bina Marga, Public Work Ministry of Indonesia: Jakarta, Indonesia, 2018. (In Indonesian)
26. Standard National of Indonesia. *Standard Test Method of Asphalt Mix with Marshall Test*; SNI 06-2489-1991; Centre of Transportation of Research and Development Board of Public Work Ministry of Indonesia: Bandung, Indonesia, 1991. (In Indonesian)