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Porous Asphalt Innovation: Evaluation of Marshall Characteristics of Porous Asphalt with Marble Waste as an Additive

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Abstract: Transportation is crucial to Indonesia's development, with highways being the main element. Road damage is often caused by low-quality materials, loads, and weather. The modification of asphalt mixtures with additives can improve their stability. Porous asphalt, which is effective in terms of drainage and strength, can improve the road safety. In Tulungagung, marble waste can be used in asphalt mixtures, thereby reducing waste and cost. This study evaluates the use of marble waste in asphalt mixtures, particularly the characteristics of the porous asphalt Marshall. The method used was The Australian Asphalt Pavement Association (AAPA) Marshall with stability parameters, Flow, Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), Cantabro Loss (CL), and Asphalt Flow Down (AFD), with variations in asphalt content of 4.5, 5, 5.5, and 6%. After obtaining the OAC, the test specimens were made with marble fragments and marble powder contents of 15, 25, and 35%. The results showed that the OAC was 5% with Marshall characteristics, namely stability of 1,037 kg, flow of 3.33 mm, Marshall quotient of 311 kg/mm, VIM of 24.96%, and VMA of 27.84%wasmarble frMarshallat a content of 25% Marshall characteristics are stability 509 kg, flow 3.00 mm, Marshall quotient 200 kg/mm, VIM 19.00%, and VMA 50.00%. and marble powder at 15 % content is stability 805 kg, flow 3.00 mm, Marshall quotient 279 kg/mm, VIM 27.00% and VMA 40.00%. All parameters meet the specifications except VIM, which does not meet the specifications because the addition of marble powder reduces voids in the porous asphalt. The AFD value decreases with an increasing percentage of marble fragments and marble powder, affecting the separation of asphalt in the mixture and the permeability value.

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1. Introduction

Highways, such as land transportation, play an important role in supporting development in developing countries, such as Indonesia. Transportation plays an important role in maintaining connectivity between regions [1]. However, roads are often damaged by excessive loads and weather. Low-quality materials are a cause of road damage [2]. Road pavement construction can be classified into flexible, rigid, and composite pavements [3]. Porous asphalt is a new paving method currently being developed for highway construction [4]. Porous asphalt is modified to prevent brittleness, reduce cracking, and increase stability, thereby producing a layer of large cavities on the road surface. The presence of these cavities can reduce the characteristic value of porous asphalt mixtures [5]. The large void content and large pores can function as drainage in the mixture [6].

Porous asphalt pavement is an effective road-surface-coating technique because it allows water to percolate into the top layer through vertical and horizontal flow [7]. Tulungagung is known for its marbling industry. In Besole Village, Campurdarat District, Tulungagung, East Java, approximately 150 industries have focused on the use of marble for various decorative products [8]. Marble waste is produced from the processing of marble into furniture or crafts, where the stone is cut, split, and smoothed, producing waste in the form of powder, chunks, or liquid [9]. Marble waste is a residue from the marble industry. The process of making marble from mined marble produces fragments during sawing. This residue was in the form of gravel, sand, and powder [10]. Marble can be used as a material for industrial factory crafts; however, waste from industrial factory crafts is not utilized properly because it is no longer used. The use of waste fragments and powders is expected to improve the performance of porous asphalt pavement. Previous research was the basis of this study. The Marshall method has been used to identify the density, stability, VIM, and VMA in porous asphalt mixtures [11]. The Marshall quotient is the result of dividing the stability by flow. The Marshall quotient provides the flexibility of the mixture [12]. Because coarse aggregate and Portland Cement are non-renewable, this study evaluated the influence and optimal levels of marble waste and powder as alternative asphalt mixture materials.

2. Method

The research was conducted using an experimental method with the location of the research to be carried out in the laboratory of the Faculty of Engineering, Tribhuwana University, Tunggadewi Malang, East Java. In this method, a research flow diagram is explained, which is a parameter in the research method, so that there is harmony between the methods used in this research to produce a series that is in accordance with the research flow diagram. This study used testing consisting of aggregate testing, such as asphalt, sand, gravel, marble waste, and marble powder. Further testing was carried out, including testing the characteristics of porous asphalt with the addition of marble waste and marble powder, and Marshall characteristic testing to determine the optimum asphalt content of OAC for porous asphalt mixtures.

The next test uses the same tool, namely Marshall, the purpose of this Marshall test is to determine the value of Void in Mix (VIM), Void In Mineral Aggregate (VMA), Flow (Melting), Stability and Marshall Quotient (MQ). This study aims to determine the porous asphalt mixture that has been conceptualized using either material or additional materials of marble waste and marble powder. Data collection is a concept that supports the research methods. The research method that was used by researchers consisted of two methods that were carried out by the study:

1. The literature study aimed as a container and study of secondary data obtained from various items presented by previous research, which are the basis or reference for researchers conducting research. The secondary data collection consisted of literature studies, such as books, articles, scientific journals, and SNI standard data, so from some of the literature above as a review that is poured out by the researcher this time.
2. The examination and testing of samples in the laboratory were aimed at collecting the primary data. In the preparation of samples that were tested, it was necessary to ensure the suitability of the samples to be used for research, so that from the primary data that were used as an analysis method from the results of the research carried out.

The materials to be used as research materials include coarse aggregates (gravel), fine aggregates (sand), and penetration asphalt or asphalt. The materials used were aggregates, fillers, and marble waste in the form of marble fragments and marble powder obtained from Tulungagung, East Java. Aggregate was obtained from Malang Regency and Stoppale Tribhuwana University Tunggadewi with the addition of additional marble waste and marble powder. The planned content value with optimum asphalt contents (OAC) of 4.5, 5, 5.5, 6, and 6.5, as an additional porous asphalt pavement material to be analyzed in the laboratory. The testing of the characteristics of the asphalt includes penetration testing, softening point, flash point, and fire point. The researcher also recommends the standard to be used, which will be used as a National Standard concept that includes equipment preparation before the effective research process takes place in the context of time. The research steps included material preparation and examination of the aggregate to be used in the form of marble waste and marble powder with testing specifications (Australian Asphalt Pavement Association (AAPA), 2004). The asphalt used in this study had a penetration of 60/70, based on the 2010 Bina Marga specification revision 3. Table 4 shows the types of testing that must be performed to meet the specification standards. The manufacturing of the test objects was carried out after examining the asphalt properties, which included aggregate properties and gradation examination, taking into account the amount of material used against the total weight of the mixture. Mixing of test objects using the wet process method.

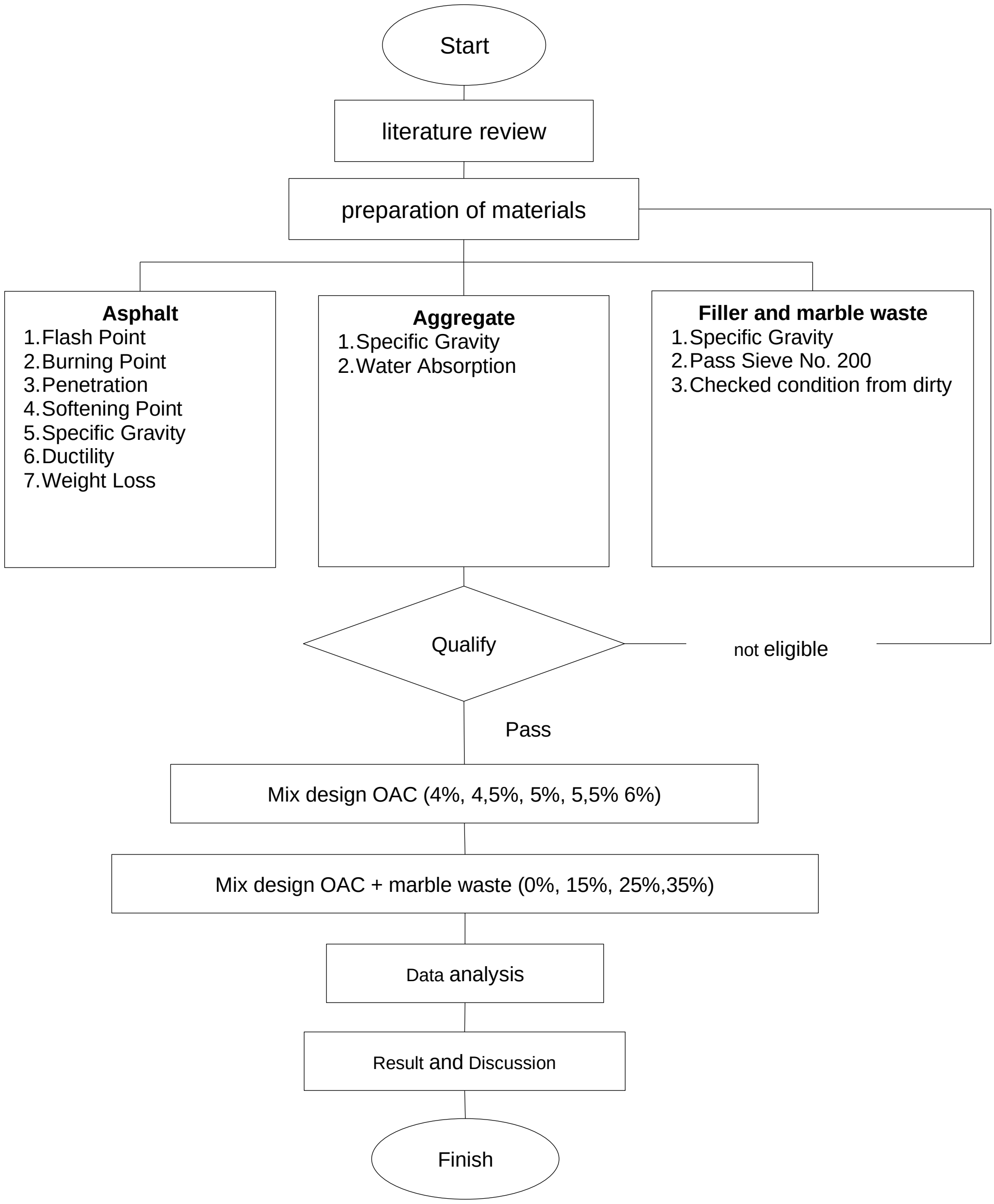

Figure 1. Flowchart

Table 1 . Porous Asphalt Mix Aggregate Gradation

Filter Number	Sieve Size (mm)	Specification	% Passed	% Retained	Weight (grams)
¾	19.0	100	100	0	0
½	13.2	85-100	90	10	120
3/8	9.5	45-70	58	32	384
No.4	4.75	10-25	17	41	492
No.8	2.36	7-15	11	6	72
No. 16	1.18	6-12	9	2	24
No. 30	0.60	5-10	7	2	24
No. 50	0.30	4-8	6	1	12
No. 100	0.15	3-7	5	1	12
No. 200	0.075	2-5	3	2	24
Pan	0.00	0	0	3	36
Total Weight					**1200**

3. Results and Discussion

3.1. Aggregate Testing

The results of the aggregate and marble waste tests are listed in Table 1. From this table, it can be concluded that the aggregate used satisfied the requirements.

Table 2. Aggregate Testing Recapitulation

Testing	Results	Standard	Specification	Information
		Coarse Aggregate		
Gradation Test	6.21	SNI 03-1968-1990	6.0-7.1	Complied
BJ Bulk	2.60	SNI 03-1968-2008	≥ 2.5	Complied
BJ SSD	2.55	SNI 03-1968-2008	≥ 2.5	Complied
BJ Semu	2.71	SNI 03-1968-2008	≥ 2.5	Complied
Absorption	0.04	SNI 03-1968-2008	≤ 3 %	Complied
Wear and tear	26.88	SNI 2417-2008	≤ 40 %	Complied
		Fine Aggregate		
Gradation Test	2.72	SNI 03-1968-1990	1.5-3.8	Complied
BJ Bulk	2.63	SNI 03-1970-2008	≥ 2.5	Complied
BJ SSD	2.52	SNI 03-1970-2008	≥ 2.5	Complied
BJ Semu	2.76	SNI 03-1970-2008	≥ 2.5	Complied
Absorption	0.06	SNI 03-1970-2008	≤ 3.0%	Complied
		Marble Waste		
Gradation Test	2.67	SNI 03-1968-1990	1.5-3.8	Complied
BJ Bulk	2.63	SNI 03-1970-2008	≥ 2.5	Complied
BJ SSD	2.51	SNI 03-1970-2008	≥ 2.5	Complied
BJ Semu	3.41	SNI 03-1970-2008	≥ 2.5	Complied
Absorption	0.18	SNI 03-1970-2008	≤ 3.0%	Complied

Based on the results of the analysis of the coarse and fine aggregate tests and marble waste, as shown in Table 1, it can be concluded that the results obtained met the requirements in accordance with the specified standards.

3.2. Marble Waste Testing

3.2.1. XRF Test Results

The aim of this study was to identify the chemical elements present in marble waste, particularly oxides [7].

Table 3. XRF Test Results

Compound	*Conc Unit (%)*
Al2O3	1.5
SiO2	7.2
K2O	0.20
CaO	81.95
TiO2	0.37
V2O5	0.02
MnO	0.14
Fe2O3	4.98
CuO	0.047
SrO	0.31
MoO3	0.64
In2O3	2.3
BaO	0.08
Yb2O3	0.32

Based on the XRF test results presented in the table and image above, the chemical elements contained in the marble waste were Al203 (1.5%), SiO2 (7.2%), K2O (0.20%), CaO (81.95%), TiO2 (0.37%), V2O5 (0.02%), MnO (0.14%), Fe2O3 (4.98%), CuO (0.047%), SrO (0.31%), MoO3 (0.64%), In2O3 (2.3%), BaO (0.08%), and Yb2O3 (0.32%). This means that, from the results of the XRF test above, it can be concluded that the largest chemical element is CaO. Marble (CaCl) is metamorphic rock derived from limestone or dolomite (CaCO3). The influence of temperature and pressure produced by endogenous forces causes recrystallization in the rock to form various foliations and non-foliations [13].

3.3. Asphalt Testing

An asphalt penetration test of 60/70 was conducted at the Civil Engineering Laboratory of Tribhuwana Tunggadewi University, Malang, according to the 2010 Bina Marga specifications. The tests included asphalt density, penetration, specific gravity, flash point, fire point, softening point, and dactylitis.

Table 4. Asphalt Testing of Pen 60/70

Testing	**Standard**	**Results**	**Unit**	**Information**
1. Penetration	60-79	66	Mm	Complied
2. Specific Gravity	>1.0	1.034	gr/cm	Complied
3. Flash Point	>200	302	C°	Complied
4. Burn Point	>200	322	C°	Complied
5. Soft Point	48-58	55	C°	Complied
6. Dactylitis	>100	147.67	cm	Complied

3.4. Marshall OAC Testing

Marshall testing has been carried out to obtain results including flow, stability, VMA, VIM, Marshall Quotient. The results of the data analysis guided and required by *the* Australian Asphalt Pavement Association (AAPA 2004) showed that an asphalt content of 5% meets AAPA standards with appropriate VIM, while the levels of 4.5%, 5.5%, and 6% do not, because they require a curing time of 24 h. For VMA, asphalt levels of 4%, 5%, 6%, and 7% met the AAPA standards, and the stability test of AAPA 2004 showed that levels of 4%, 4.5%, 5%, and 6% met (> 500 kg), with the best stability at 5% (1037.27 kg).

3.5. Test the effect of adding marble powder to porous asphalt

The determination of the porous asphalt content with the AAPA 2004 standards using levels of 0%, 15%, 25%, and 35% aims to meet the Marshall specifications. The VIM, VMA, stability, flow, and MQ values were analyzed to determine the Optimum Asphalt Content (OAC), which was found to be 5%. The determination of the porous asphalt content based on the AAPA 2004 standards with planned levels of 0%, 15%, 25%, and 35% showed that the mixture design met the Marshall strength specifications. The Optimum Asphalt Content (OAC) was 5%.

a. VIM

VIM testing with variations in marble fragments in Figure 2 shows that only 25% content met the AAPA standards, namely VIM 19%, while other contents, namely 0%, 15%, and 35%, were not appropriate. A 25% content supports pavement durability, whereas a very high VIM can accelerate asphalt oxidation and aging [14]. VIM testing with marble powder contents of 0%, 15%, 25%, and 35% (Figure 3) did not meet the AAPA standards, with values of 43% -7%. The addition of marble powder made VIM outside the limits, while testing conducted in previous research showed that VIM still met the standards, even though it decreased with the addition of AAT [15]. This difference occurred because the characteristics of the additional materials did not change significantly and still met AAPA standards.

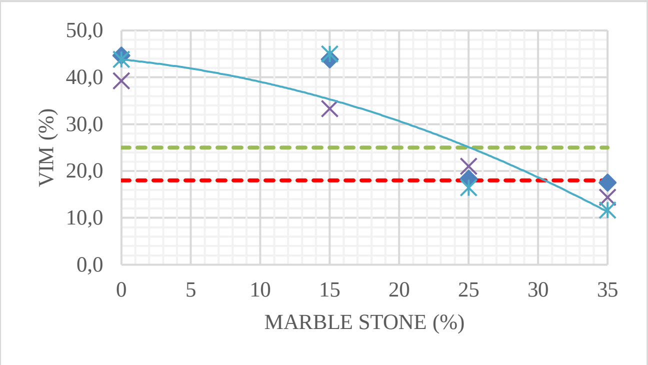

Figure 2. VIM Test Value with Variation of Marble Stone Fraction

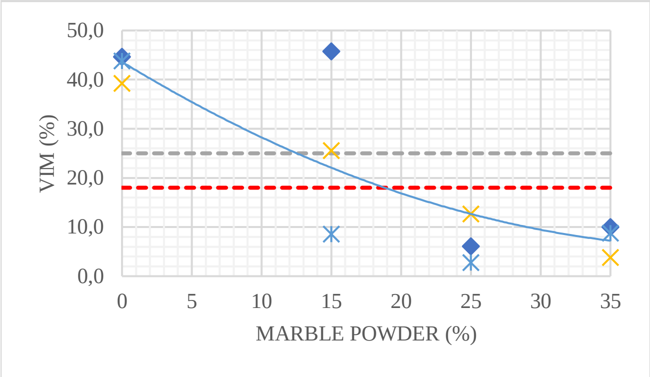

Figure 3. VIM Testing with Marble Powder Variations

b. VMA

VMA testing on Marshall with the addition of marble fragments with contents of 0, 15, 25, and 35% (Figure 4) met the AAPA requirements. The VMA value increases from 24% (0% marble) to 57% (35% marble), indicating a better mixture. The addition of gilsonite and asphalt reduces VMA by reducing the air space [16]. The VMA testing with marble powder in Figure 5 with contents of 0%, 15%, 25%, and 35% at an asphalt content of 5% met the AAPA standards, increasing from 24% to 56%. While the test conducted by previous research showed that VMA increased with Asbuton's LGA, but did not reach the minimum specification of 15% [17], the differences were due to the different characteristics of the additional materials.

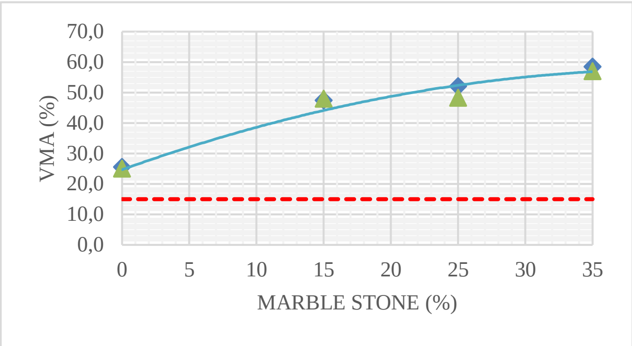

Figure 4. VMA Testing with Variations of Marble Stone Fractions

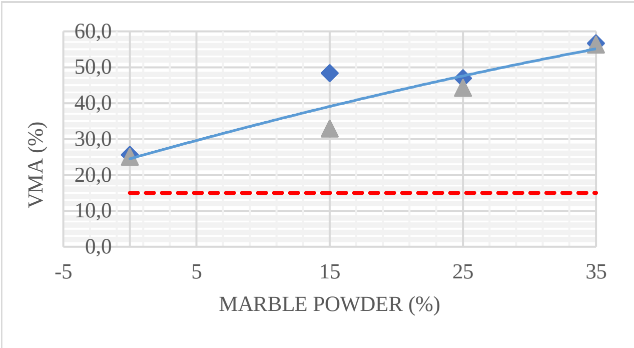

Figure 5. VMA Testing with Marble Powder Variations

c. Stability

Stability testing with 0%-25% marble fragments in Figure 6 met the standard, while 35% did not, owing to the quality of the pounding. In a test conducted by previous research, it was shown that the stability of 4%-6% asphalt exceeded the minimum AAPA limit (500 kg), with an average of 563.3-650 kg [17]. The difference in the results was caused by variations in the additional materials, asphalt content, and pounding methods. Stability testing with 0%, 15%, 25%, and 35% marble powder in Figure 7 met the AAPA specifications, with the highest value of 1183 kg, namely 0%, and the lowest of 805 kg, namely 15%. In a test conducted by previous research, the highest stability was recorded at 1011 kg at an asphalt content of 7%, meeting the Bina Marga specifications, while the lowest value was recorded at an asphalt content of 5% [18]. The difference in the results between these studies was caused by several factors, such as the type of additional material used.

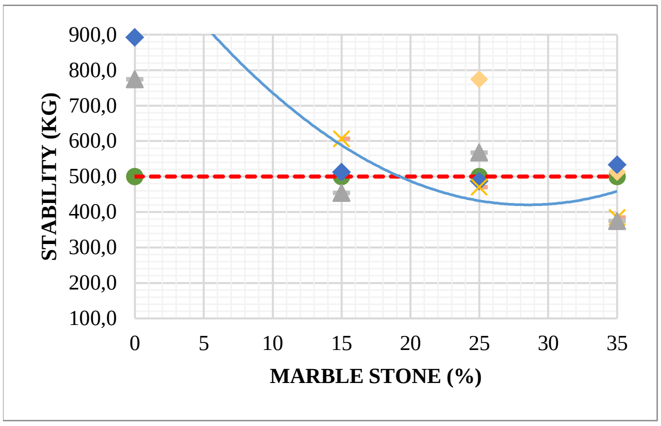

Figure 6. Stability Testing with Variations in Marble Stone Fractions

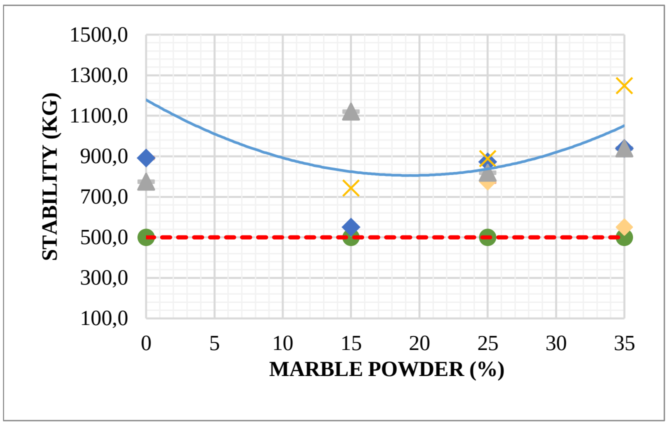

Figure 7. Stability Testing with Variations in Marble Powder

d. Flow

The Flow values of the porous asphalt mixture with marble fragments, namely 0%, 15%, 25%, and 35% in Figure 8, met the AAPA 2004 specifications, indicating the stability of the flexible pavement. The test conducted by previous research showed that the flow value fluctuated with asphalt content [17] owing to different additives, where marble fragments increased stability, while LGA and BGA affected elasticity and load spreading power. Flow testing with variations in marble powder in Figure 9 shows that only 0% content met the AAPA specifications of 4 mm, whereas 15%, 25%, and 35% content did not meet the flow value *of* 2-3 mm. Meanwhile, in a previous study, it was found that the flow *value* increased with a used tire rubber powder content of 0.025 % -0.075 % and decreased at levels above 0.075 % [19].

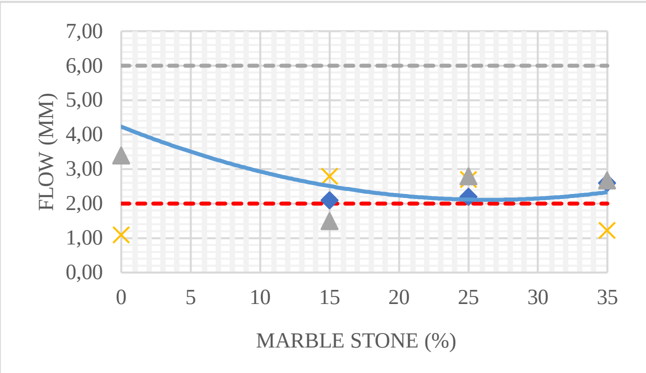

Figure 8. Flow Testing with Variations of Marble Stone Fractions

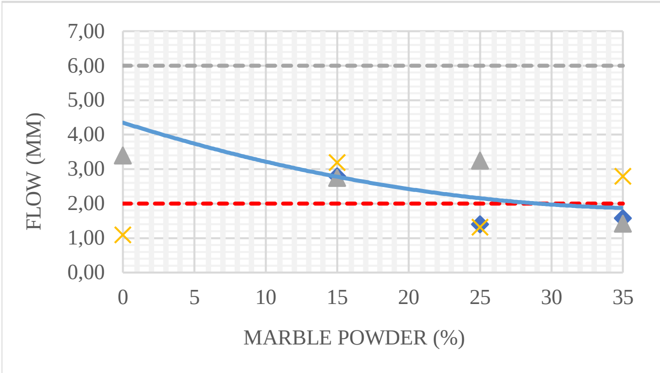

Figure 9. Flow Testing with Marble Powder Variations

e. MQ

Marshall Quotient (MQ) testing with marble fragments with content of 0%, 15%, 25%, 35% in Figure 10 meets the AAPA 2004 standard with a value of 199-681 kg/mm. The test conducted in previous research showed that MQ increases with asphalt content but decreases at a content of 6%. MQ is too low makes the mixture plastic, while MQ is too high makes it brittle [20]. The differences in the results were influenced by the material and asphalt contents. Marshall Quotient testing with 0%, 15%, 25%, 35% marble powder in Figure 11 meets the AAPA 2004 specifications, with an average value of 279-681 kg/mm. The test conducted in previous research showed a decrease in MQ along with an increase in LGA asbuton content [17]. This difference is caused by the characteristics of different materials.

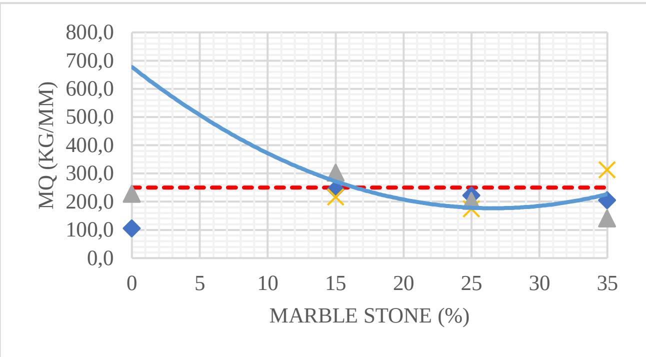

Figure 10. MQ Testing with Variations of Marble Stone Fractions

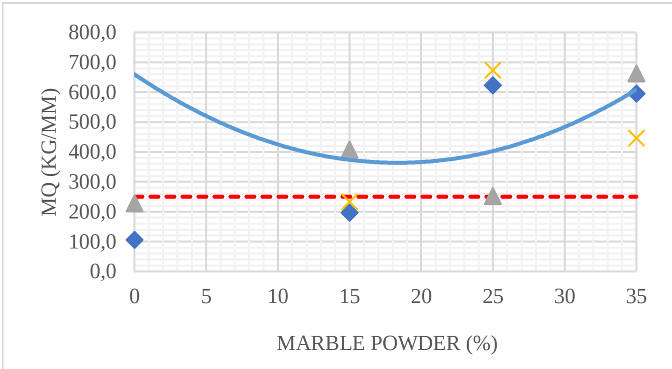

Figure 11. MQ Testing with Marble Powder Variations

3.6. CL (Contrabro Loss) Test Effect of Marble Stone Fragments and Marble Powder Mixture

The results of the Cantabro Loss test with an asphalt content of 5 % %showed CL values of 61.80%, 15%, 9.21%, or 25%, and 0.98% or 35%. Only 25% and 35% content met the AAPA 2004 specifications, while 15% content did not meet due to a decrease in asphalt content. The higher the marble content, the more the asphalt content needs to be increased to reduce the CL value, owing to the better mixture binding.

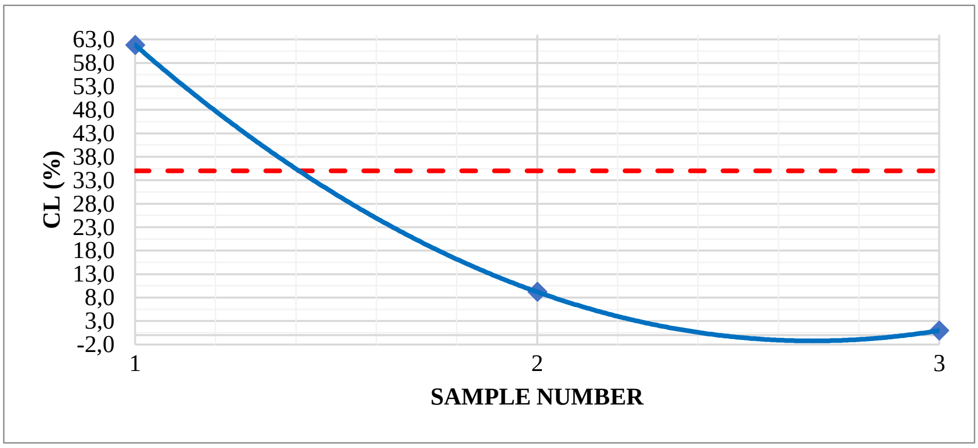

Figure 12. Contrabro Loss Test Results of the Effect of a Mixture of Marble Stone Fragments and Marble Powder

3.7. AFD (Asphalt Flow Down) Test Effect of Marble Crushed Stone and Marble Powder Mixture

The AFD value decreased as the percentages of marble powder and marble fragments increased. This caused the level of asphalt separation in the mixture to decrease. Therefore, this test meets the requirements of AAPA 2004.

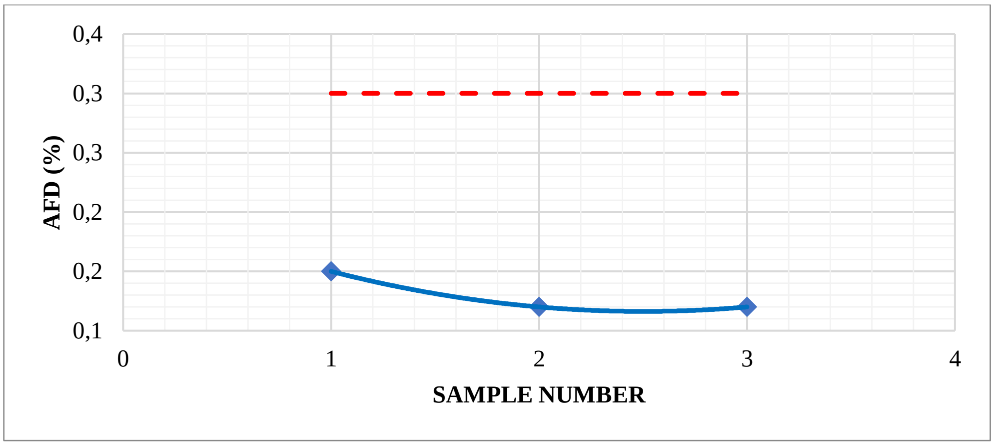

Figure 13. Asphalt Flow Down Test Results: Effect of Marble Crushed Stone and Marble Powder Mixture

4. Conclusion

The optimum asphalt content (OAC) that met the specifications in a porous asphalt mixture without additional crushed stone waste and marble powder is 5% with marshall characteristics, namely stability of 1,037 kg, flow of 3.33 mm, marshall quotient of 311 kg/mm, VIM of 24.96%, and VMA of 27.84%. The optimum mixture content that meets the specifications in a porous asphalt mixture with additional crushed marble waste is 25% with Marshall characteristics, namely stability of 509 kg, flow of 3.00 mm, marshall quotient of 200 kg/mm, VIM of 19.00%, and VMA of 50.00%. While with the addition of marble powder waste is 15% with marshall characteristics, namely stability of 805 kg, flow of 3.00 mm, marshall quotient of 279 kg/mm, VIM of 27.00% and VMA of 40.00%. The addition of 25% marble waste fragments and 15% marble powder, according to the AAPA 2004 standards, improves the Marshall characteristics, making this waste effective for improving the performance of porous asphalt mixtures and utilizing marble waste. It is expected that further research will use marble content ≤ 20% with a content range of 2–3% to obtain more detailed results.

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