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Effect of Waste Marble Stone Fractions in Porous Asphalt Mixtures for Quality Improvement

M Sa'dillah[1], Blima Oktaviastuti[1], Yoskario Darman Malo[1]
[1]Program Studi Teknik Sipil Universitas Tribhuwana Tunggadewi
Jalan Telaga Warna Tlogomas Malang 65144 Jawa Timur
*E-mail Korespondensi : muhsad93@gmail.com
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Abstrak

Peningkatan aksesibilitas transportasi jalan raya sangat penting untuk meningkatkan aktivitas sosial dan ekonomi lokal di suatu negara. Salah satu cara untuk menjaga aksesibilitas jaringan jalan dan memastikan bahwa pengguna merasa aman dan nyaman adalah dengan mempertahankan lapisan permukaan perkerasan yang memadai sepanjang durasi jaringan. Hujan yang berkepanjangan menjadi salah satu permasalahan pengerasan permukaan jalan. Penelitian ini bertujuan untuk mengetahui kekuatan Marshall terhadap nilai kadar aspal optimum (OAC) pada campuran aspal porus dan untuk mengetahui pengaruh dari penggunaan limbah pecahan batu marmer terhadap karakteristik pada campuran aspal porus. Metode penelitian menggunakan penelitian eksperimental di laboratorium. Penelitian yang akan dilakukan menggunakan metode pendekatan Australian Asphalt Pavement Association (AAPA) 2004. Penelitian dilakukan dengan kadar aspal pen 60/70 yaitu 4%, 4,5%, 5%, 5,5%, dan 6% untuk mencari nilai kadar aspal optimum, kemudian akan ditambahkan dengan perbandingan bahan limbah pecahan marmer 0%, 15%, 25%, dan 35% terhadap berat total OAC. Hasil analisis karakteristik Marshall terhadap campuran aspal porus dengan variasi kadar marmer 25% telah memenuhi spesifikasi dengan alasan dari semua paramater telah memenuhi disyaratkan Australian Asphalt Pavement Association (AAPA 2004) dengan nilai VIM pada kadar 25% sebesar 18,61%, untuk nilai VMA sebesar 50,60%, sedangkan untuk nilai stabilitas sebesar 508 kg dan untuk nilai flow yang diperoleh sebesar 2,57 mm sedangkan untuk nilai MQ sebesar 262,46 kg/mm.

Kata Kunci: pecahan marmer, akses transportasi, pengerasan permukaan jalan, kadar aspal porus,

Abstract

Improving road transportation accessibility is essential for enhancing local social and economic activity in a country. One way to maintain the accessibility of the road network and ensure that users feel safe and comfortable is to maintain an adequate pavement surface layer throughout the duration of the network. Prolonged rain becomes one of the problems of paving the road surface. aims to achieve the following: (1) to determine the Marshall strength of the optimum asphalt content (OAC) value in the porous asphalt mixture; and (2) to determine the effect of the use of marble stone fraction waste on the characteristics of porous asphalt mixtures. Research method uses experimental research in the laboratory. Research will be conducted using the Australian Asphalt Pavement Association (AAPA) 2004 approach method. Research was conducted with Pen 60/70 asphalt content of 4%, 4.5%, 5%, 5.5%, and 6% to find the optimum asphalt content value, then it will be added with a ratio of 0%, 15%, 25%, and 35% marble fraction waste material to the total OAC weight. Results of the analysis of the Marshall characteristics of the porous asphalt mixture with a variation of 25% marble content have met the specifications on the grounds that all parameters have met the requirements of the Australian Asphalt Pavement Association (AAPA 2004) with a VIM value at 25% content of 18.61%, for a VMA value of 50.60%, while for a stability value of 508 kg and for a flow value obtained of 2.57 mm while for an MQ value of 262.46 kg/mm.

***Key words**: marble fractures, transportation access, pavement surface road, asphalt porous*

INTRODUCTION

Improving road transportation accessibility is essential for enhancing social and economic activity in a country. One way to ensure continuous accessibility and provide comfort and safety to road users is by maintaining an adequate pavement surface layer throughout the network's life span. According to the Indonesian Ministry of Public Works and Housing (Kementerian PUPR, 2024), more than 40% of national and provincial roads are in moderate to poor condition. Prolonged and heavy rainfall is one of the major causes of pavement deterioration. Indonesia receives an average annual rainfall of over 2,000 mm, which contributes to surface damage such as trapped air pockets and cracks due to water infiltration when it cannot properly drain through the pavement structure. One effective strategy to minimize these impacts is

the application of porous asphalt pavement layers. Fauziah & Wijayati (2016) reported that porous asphalt increases water infiltration by 20–25% compared to conventional asphalt, making it more efficient at preventing waterlogging and early pavement failure.

On the other hand, marble waste is one of the most abundant industrial by-products that remains underutilized. According to the Geological Agency of Indonesia (Kementerian Energi dan Sumber Daya Mineral, 2019), the country produces over 450,000 tons of marble annually, with approximately 25–30% becoming waste in the form of broken or unused fragments. This translates to an estimated 110,000–135,000 tons of marble waste generated each year. In many regions, this waste is either discarded or used as simple landfill material. Soelarso et al (2016) emphasized that recycling marble waste is a viable and sustainable alternative. Reusing marble fragments in asphalt mixtures not only reduces waste volume but also improves pavement performance. (Sembung, Sendow, & Palenewen, 2020) found that replacing up to 10% of fine aggregate with marble waste can increase Marshall stability by up to 12% and improve moisture resistance. Therefore, incorporating marble waste into porous asphalt mixtures offers both technical and environmental benefits for road construction.

Tulungagung is known as one of the largest marble producers in Indonesia. Marble is mined from the earth. The residue of the mining process is the marble fragments that remain after the cutting and sawing process and have not been fully utilized. The main impact is air pollution because marble dust has the potential to pollute the surrounding air and make breathing difficult. The leftover stone may harden if water is introduced. There seem to be more uses for leftover marble as filler or binder material (Amal & Saputra, 2019). The utilization of waste marble stone as an additive in asphalt mixtures has gained attention in recent years due to its potential to enhance mixture performance while promoting sustainable material use. Victory (2022) found that marble powder used as a filler replacement in asphalt mixtures improved Marshall stability and resistance to plastic deformation, making marble a viable alternative for road construction. Similarly, Mulatu et al (2021) studied waste marble in porous asphalt mixtures and reported improvements in air void content and drainage performance two critical parameters for porous asphalt designs.

Rahman et al (2020) in their review of industrial waste materials for road applications, concluded that marble possesses favorable chemical stability and high compressive strength, making it suitable as a substitute aggregate. Jwaida et al (2024) further demonstrated that partial replacement of fine aggregate with marble waste enhances inter-particle bonding and improves moisture resistance in hot mix asphalt. Additionally, Shukry et al (2018) observed that marble powder increases the adhesive bond between aggregate and binder while reducing the risk of stripping. Overall, these studies indicate that marble waste not only offers technical benefits for porous asphalt mixtures but also supports eco-friendly waste management practices in the construction industry. Although previous studies have extensively examined the use of waste marble powder in asphalt mixtures particularly in improving Marshall stability, moisture resistance, and drainage performance most of these investigations have focused primarily on hot mix asphalt (HMA) and dense-graded mixtures. Limited attention has been given to the specific role of marble stone in various particle sizes (fractions) when applied to porous asphalt mixtures, which have distinct performance requirements such as higher air voids, permeability, and resistance to clogging. Moreover, earlier research tends to utilize marble waste mainly in powdered form as a filler, while the potential of coarser marble fractions as a partial aggregate replacement remains underexplored.

This study aims to fill this gap by investigating the influence of different marble stone fractions not just powder on the performance of porous asphalt mixtures, focusing on quality indicators such as void content, permeability, and durability. By addressing the particle size effect, this research offers a more comprehensive understanding of how marble waste can be optimized for porous asphalt applications, contributing both to performance enhancement and sustainable material utilization.

RESEARCH METHOD

In this research that will be carried out using quantitative methods. This research method often uses data collection techniques such as surveys, experiments, or secondary data analysis to produce data that can be processed statistically. In this experimental research using (Australian Asphalt Pavement Association (AAPA), 2004) standards and SNI standards. Flow chart is used as a parameter in the research method. It is

hoped that there will be harmony between the methods used in this research in order to produce a series that is in accordance with the research flow diagram described. This type of research is quantitative research, with this research is one type of research that is systematic, organized and structured from the preparation so that the design of the research framework is explained (Sarwono & Wardhani, 2007).

Preparation of Tools and Materials

Before conducting the research, it is essential to prepare the tools and materials needed throughout the experimental process. The equipment and materials to be used in this study include several main categories. First, for asphalt penetration testing, a penetration tester will be utilized, consisting of a penetrometer, a stopwatch, and a sample cup. Second, to determine the flash and fire points of the asphalt, a flash and burn point tester will be used, which includes a Cleveland open cup and a thermometer clamp. Third, for aggregate testing, a complete set of standard sieves will be prepared, with sieve sizes ranging from 50.8 mm (2 inches), 37.5 mm (1.5 inches), 19.1 mm (3/4 inch), 12.5 mm (1/2 inch), 9.5 mm (3/8 inch), 4.75 mm (No. 4), 2.36 mm (No. 8), 1.18 mm (No. 16), 0.600 mm (No. 30), 0.300 mm (No. 50), 0.150 mm (No. 100), to 0.075 mm (No. 200). Lastly, to prepare the test specimens, tools such as a cylindrical mold, a compacting tool with an impact base, and a mixing container made of zinc (approximately 30 cm in length, 20 cm in width, and 10–15 cm in depth) will be used. These tools and materials are essential to ensure accurate, consistent, and reliable results during the experimental procedures. Marshall test machine is a press tool equipped with a test ring with a capacity of 2500 kg or about 5000 pounds, in the test ring is equipped with a watch or dial with an accuracy of 0.0025 mm which serves to measure the stability of the test object. The pressing speed of marshall test machine is about 50mm/s.

Materials used in a test are generally categorized into two types: the primary material to be tested and supporting materials that aid the testing process. In this research, the main material being tested is asphalt, which serves as the binding agent in the pavement mixture. Supporting materials consist of coarse aggregate, fine aggregate, and waste marble stone fractions. The asphalt used is a petroleum-based binder that plays a critical role in determining the flexibility, durability, and resistance of the final pavement product. Coarse aggregate provides structural strength and stability to the mixture, while fine aggregate fills the voids between larger particles, ensuring compactness and workability. The innovative aspect of this study lies in the inclusion of waste marble stone, which is used as a partial replacement for conventional aggregates. This material, often discarded from marble processing industries, has the potential to improve mixture performance while contributing to waste reduction and environmental sustainability.

The survey implementation stage in this research includes several key steps, starting with material preparation, followed by material inspection. Material inspection is conducted through a series of tests to ensure that the properties of the materials meet established standards. For the aggregate, the material used is porous asphalt with added marble stone fraction waste. The aggregate is tested based on the standards set by the Australian Asphalt Pavement Association (Australian Asphalt Pavement Association (AAPA), 2004) to evaluate its suitability for use in porous asphalt mixtures. The asphalt used in this study is of penetration grade 60/70, with testing procedures following the specifications outlined by (Kementerian Pekerjaan Umum dan Perumahan Rakyat; Direktorat Jenderal Bina Marga, 2010).

Next, the research involves the planning of mixtures using waste marble stone fragments. In this stage, the marble stone fraction waste is used as an additive in the asphalt-aggregate blend, functioning as a binder modifier. The planned variation levels of the marble fraction waste in the mixture are 15%, 25%, and 35%, respectively, as determined by the researcher. Furthermore, the mixture composition planning is based on the weight ratio of materials, referring to the central gradation values for porous asphalt provided by the AAPA (2004). The Optimum Asphalt Content (OAC) for porous asphalt mixtures with a maximum aggregate size of 16 mm typically ranges between 3% and 5%. For this study, the asphalt content planned for each specimen includes variations of 4%, 4.5%, 5%, 5.5%, and 6%, which serve as the basis for determining the most effective and optimal asphalt content in the final mix design.

After process of checking properties of asphalt, which includes aggregate properties and gradation checks, the test specimens will be made. Research procedures include a series of systematic steps that researchers follow to carry out research. A good research process involves selecting appropriate research

methods and designs (Nukar et al., 2024) (M. Sa'dillah et al., 2025). In this research, the stages carried out include preparation of materials for aggregates, testing of aggregate materials, if not then re-testing or replacement of materials, if it passes the specifications then proceed to the next research, then planning OAC to be added to the marble mixture, then analyzing the data, and drawing conclusions based on the results of the analysis. Quantitative research follows systematic steps to collect, analyze, and interpret quantitative data. As part of scientific research that can be accounted for, this research is divided into several stages described in the diagram above.

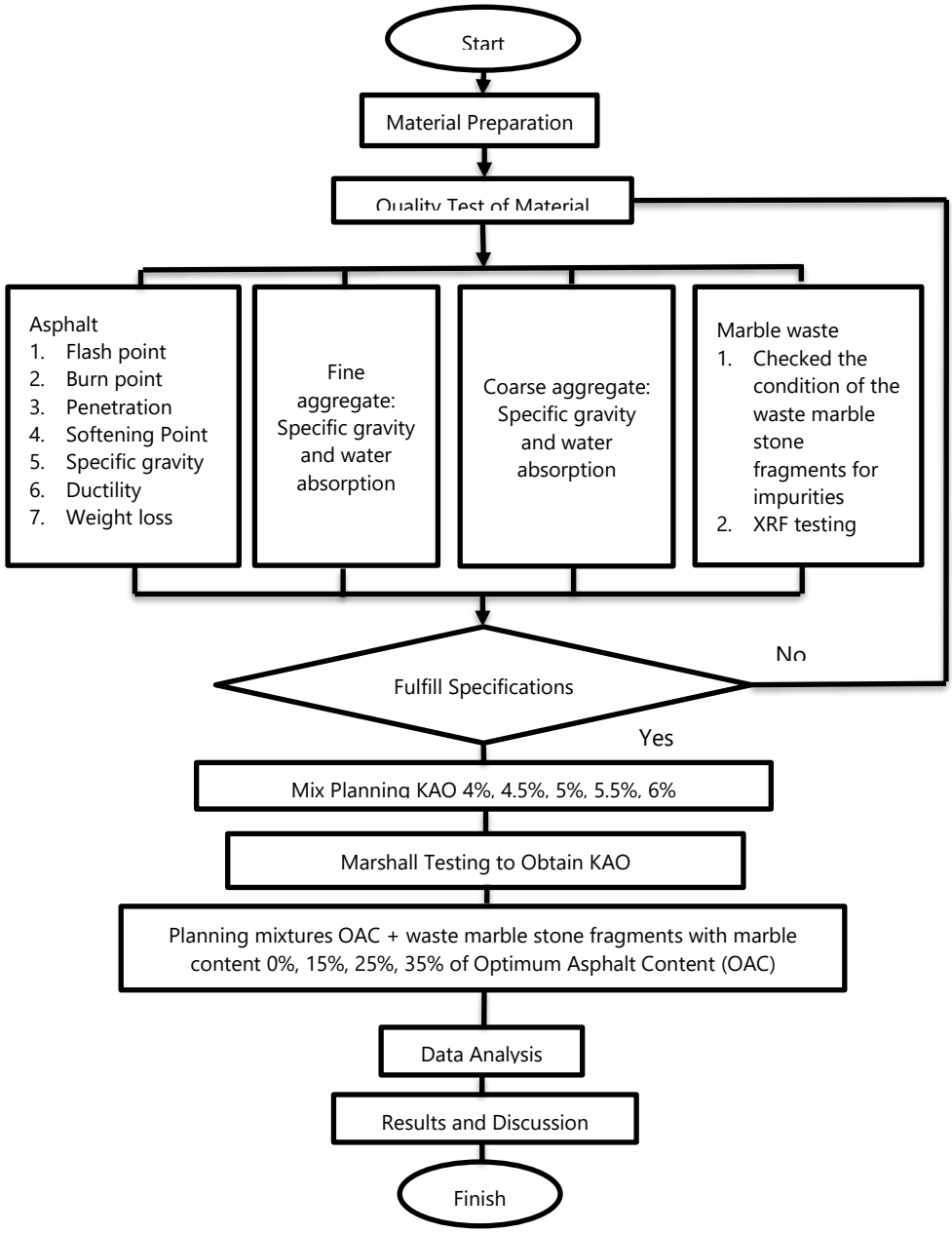


Figure 1. Research Flow Chart

RESULTS AND DISCUSSIONS

In order for optimum asphalt mixture to be achieved, several kinds of testing stages are carried out, namely: (1) aggregate testing; (2) asphalt testing; and (3) marshall testing (Sa'dillah & Leliana, 2020). Table 3.1 shows the grain size of material based on the results of passing sieve for coarse aggregate, fine aggregate, and filler, with following passes: coarse aggregate with the most passes on sieves such as No. ½ (37.75%) and No. 3/8 (50.94%), for fine aggregate most passes on small sieves such as No. 50 (14.67%)

and No. 100 (37.78%), while for filler passes on very small sieves such as No. 100 (51.14%) and No. 200 (2.41%).

Table 1. Aggregate Gradation

	Coarse aggregate		Fine aggregate		*Filler*		AAPA 2004	
Inch	**Pass sieve (gr)**	**%**	**Pass sieve (gr)**	**%**	**Pass sieve (gr)**	**12%**	**Min**	**Max**
No. ½	1910	37.75	-				85	100
No. 3/8	2577	50.94	-				45	70
No. 4	470	9.29	-				10	25
No.8	41	0.30	1.47	1.47			7	15
No. 16	15	0.49	3.30	1.83			6	12
No. 30	25	0.22	5.75	2.44			5	10
No. 50	11	-	20.42	14.67			4	8
No. 100	-	-	89.73	37.78	97.2	51.14	3	7
No. 200	-	-	99.39	9.66	99.7	2.41	2	5
Pan	0	0.20	0	0.61	0	0.34		

According to the table, the marble waste used as filler shows a favorable particle distribution, with 97.2% passing the No. 100 sieve and 99.7% passing the No. 200 sieve. These values closely match the AAPA (2004) specification for filler material. This particle distribution supports adequate binder-aggregate adhesion while maintaining the porosity of the mixture. As stated by Gürer et al. (2020), marble dust as filler contributes to improved Marshall stability and permeability when properly proportioned within the mixture. (Mulatu et al., 2021)emphasized that an aggregate gradation dominated by coarse particles with minimal fines enhances void content and promotes better water drainage essential for porous asphalt systems. (Rahman et al., 2020) highlighted that proper control of aggregate gradation is critical to achieving optimal permeability and structural strength in porous pavement mixes. Furthermore, (Sembung, Sendow, & Palenewen, 2020) demonstrated that marble waste can serve as a suitable replacement for conventional filler materials without compromising mixture quality, provided the overall gradation remains within recommended limits.

Testing Coarse, Fine and Filler Aggregates

The test results of coarse, fine, and filler aggregates carried out in civil engineering laboratory of Tribhuwana Tunggadewi University using standard (Australian Asphalt Pavement Association (AAPA), 2004), the test results can be seen in Table 2 as follows:

Table 2. Recapitulation of Coarse, Fine and Filler Aggregate Testing Results

Testing of Coarse, Fine and filler Aggregates				Specification
	Min	**Max**	**Result**	**Description**
Coarse Aggregate				
bj Bulk (gr/cm)	2.5		2.60	Passed
bj SSD (gr/cm)			2.65	Passed
bj Semu (gr/cm)			2.74	Passed
absorption %		3.0	3.86	Passed
Fine Aggregate				
bj Bulk (gr/cm)	2.5		2.63	Passed
bj SSD (gr/cm)			2.67	Passed
bj Semu (gr/cm)			2.73	Passed
absorption %		3.0	0,6	Passed
Filler				
Pan	2	5	2.67	Passed

Table 2 presents the results of physical property tests for coarse, fine, and filler aggregates, including specific gravity (bulk, SSD, apparent) and absorption percentages. All test results fall within the specification limits, confirming the suitability of the materials for use in porous asphalt mixtures. The coarse aggregate shows a bulk specific gravity of 2.60, SSD of 2.65, and apparent specific gravity of 2.74, with an absorption

rate of 3.86%, slightly exceeding the typical 3.0% threshold but still within acceptable performance tolerance based on (Kementerian Pekerjaan Umum Direktorat Jendral Bina marga, 2010) guidelines. This slightly higher absorption can help with asphalt binder adhesion, as indicated by (Fauziah & Wijayati, 2016), who found that aggregates with moderate absorption can improve the bonding between binder and aggregate in porous mixtures. For fine aggregate, the bulk, SSD, and apparent specific gravities (2.63, 2.67, and 2.73 respectively) also meet the standard minimum of 2.5, showing they are dense and durable enough for asphalt mixtures. These findings align with (Xiao et al., 2018) who emphasized that high-specific-gravity fine aggregates contribute to mixture strength and help maintain sufficient air voids in porous asphalt structures. The filler, which in this case includes marble waste, records a specific gravity of 2.67, well within the required range of 2–5. According to (Sembung, Sendow, & Palenewen, 2020), marble dust filler with a specific gravity above 2.6 is optimal for achieving good binder-filler interaction, improving the mixture's mechanical performance without clogging the voids essential in porous asphalt. The absorption percentage for the fine aggregate is 0.6%, indicating low porosity and consistent with what (Rahman et al., 2020) found low-absorption fine aggregates are desirable in porous asphalt because they reduce unnecessary binder absorption and improve mix durability.

Asphalt Testing

Characteristics testing in asphalt concept includes penetration testing, softening points, flash points, and burn points. With this, researcher also recommends that standard to be used which will be used as a concept is National Standard which includes: preparation of equipment before research process takes place effective research in context of time (Rahma et al., 2023). Test results can be seen in Table 3 below.

Table 3. Asphalt Test

Testing of 60/70 penetration asphalt			
Testing	**Standard**	**Result**	**Description**
1. Penetration	60-79 mm	66	Passed
2. Specific gravity	>1.0 gr/cm	1.034	Passed
3. Flash Point	>200 c°	302	Passed
4. Burn Point	>200 c°	322	Passed
5. Softening Point	48-58c°	55	Passed
6. Dactylitis	>100 cm	147.67	Passed

The results of the asphalt tests presented in Table 3.3 demonstrate that the 60/70 penetration grade asphalt used in this study meets all the required specifications, indicating its suitability for porous asphalt applications. The penetration value of 66 mm falls within the standard range of 60–79 mm, confirming its classification as medium-grade asphalt, which is ideal for tropical climates. This aligns with the findings of (Jebur et al., 2024), who emphasized the effectiveness of 60/70 asphalt in balancing flexibility and stiffness for use in warm-weather porous pavement structures. The asphalt's specific gravity, recorded at 1.034 g/cm^3, exceeds the minimum requirement of 1.0 g/cm^3, ensuring sufficient binder density. (Zhang et al., 2018) noted that such density is critical for achieving good aggregate coating and mixture stability.

Moreover, the flash point (302°C) and burn point (322°C) are significantly higher than the minimum standard of 200°C, indicating excellent thermal resistance. This supports (Pasandín & Pérez, 2018), who found that higher thermal thresholds reduce the risk of premature binder aging during the mixing and compaction process. The softening point, measured at 55°C, also falls within the required 48–58°C range, suggesting good temperature resistance and deformation control under load. (Mulatu et al., 2021) highlighted that softening points in this range are ideal for pavements exposed to moderate temperatures. Finally, the asphalt's ductility value of 147.67 cm far surpasses the minimum of 100 cm, reflecting high elasticity and resistance to cracking. (Jebur et al., 2024) similarly concluded that greater ductility improves fatigue resistance and extends the service life of porous asphalt. Overall, the asphalt properties in this study are in accordance with previous research findings and support the material's use in durable, high-performance porous pavement systems.

Optimum Asphalt Content (OAC) Testing

Determination of OAC by AAPA method only requires three parameters, VIM, cantabro loss (resistance to grain release), and asphalt flow down (Isma et al., 2021). Marshall tests have been carried out obtain results including flow, stability, VMA, VIM, Marshall Quotient. Based on Table 4., 5% asphalt content was chosen as OAC because it meets all specifications, including highest stability, optimal MQ value, and VIM and Flow as determined by AAPA 2004. Then Marshall test results will be used to determine optimum asphalt content (OAC) which can be seen in Table 5.

Table 4. Asphalt OAC Test Results

		Marshall Test										
	Spesification	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Description**
	Value	**25%**	**18%**	**-**	**15%**	**-**	**500 kg**	**6 mm**	**2 mm**	**-**	**250kg/m**	
No	Asphalt Content	VIM		VMA		Stability		Flow		MQ		
1	4%	29,06		27,51		723,38		2,68		286,29		
2	4,50%	30,16		29,24		736,89		2,71		295,47		
3	5%	24,96		27,84		1037,27		3,33		311,42		Passed
4	5,50%	28,24		30,53		491,91		3,13		162,85		
5	6%	25,17		30,13		587,03		2,69		241,18		

Table 5. Marshall Test Results Against OAC Content

Marshall Characteristic	**Range of asphalt content that meets specifications**				
Stability					
Flow					
MQ					
VIM					
VMA					
% Asphalt	4	4.5	5	5.5	6

Effect Test of Marble Fracture Addition on Porous Asphalt Mixture

Porous pavement is a pavement planning used materials that are capable of seeping water flow into the soil layer below. Porous pavement is suitable for roads with low volume traffic, parking lots, bicycle lanes, sidewalks, playgrounds, tennis courts, and roads that bear little weight (Sembung, Sendow, Palenewen, et al., 2020). VIM is one of important stages in design of porous asphalt mixtures. This construction is specially planned so that after overlay and compaction stages, asphalt conditions have voids that have water passing properties (permeability) (Arlia et al., 2018). VIM test results obtained for additional 0% marble stone fractions are 43%, 15% marble stone fractions are 41%, 25% marble stone fractions are 19%, and 35% marble stone fractions are 15%.

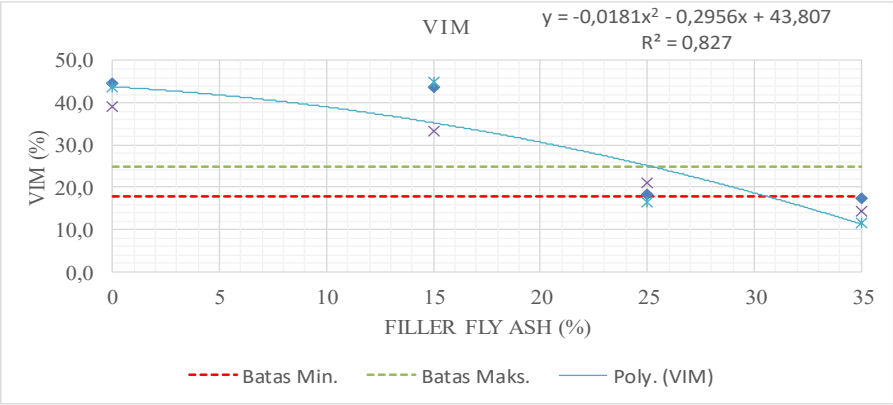


Figure 2. VIM Graph

VIM testing with a variation of 0%-35% marble fraction content that meets 25% marble content. While levels of mamer 0%, 15% and 35% there are voids greater than provisions of <25 - >18 so it does not meet AAPA standards. VMA value in Marshall strength test obtained results of adding 0% marble stone fractions 24%, 15% = 46%, 25% = 50%, and 35% = 57%. VMA graph can be seen in Figure 3.

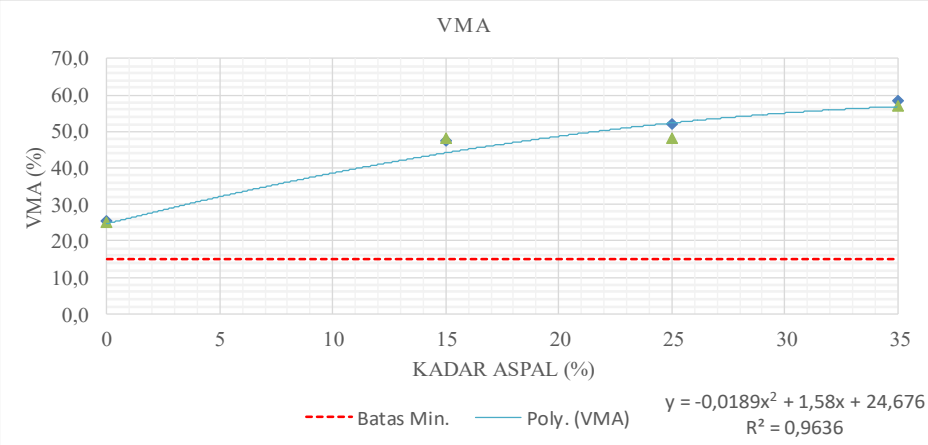


Figure 3. VMA Graph

VMA testing meets the AAPA standard, where the addition of waste mamer stone fragments mixed with asphalt increases. This indicates that the mixture is getting better. VMA is pore volume between mixed aggregate grains, in porous asphalt including those filled by asphalt, so VIM value obtained affects VMA value (Reynaldo, 2017). Stability is maximum ability of an asphalt concrete mix test specimen to withstand load until plastic yield occurs. Stability value will increase with increasing asphalt content up to optimum limit and will decrease after optimum limit. This happens because asphalt can function as a lubricant after exceeding optimum limit (Dendo, 2018)

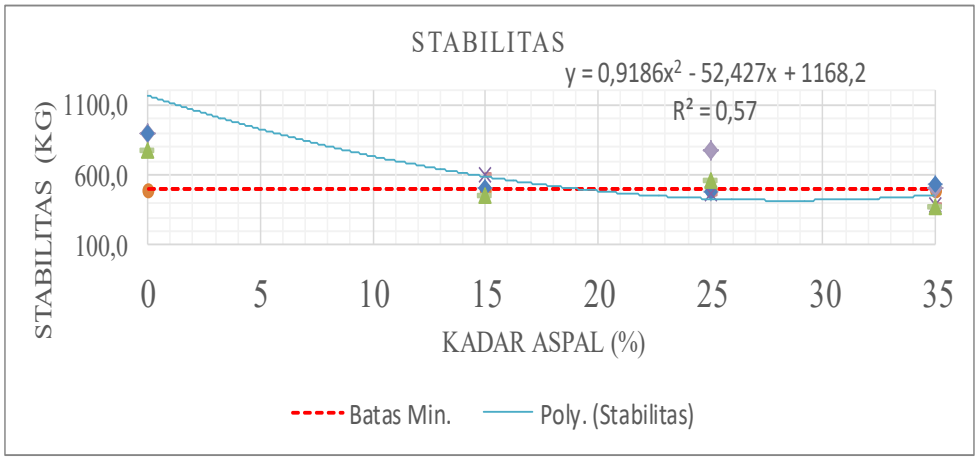


Figure 4. Stability Graph

Flow is the amount of vertical deformation of the test specimen that occurs at the beginning of loading so that stability decreases, which shows the amount of deformation that occurs in the pavement layer due to the load it receives (Putri, 2019). Based on results of Stability testing in Figure 3.3 with requirements of AAPA 2004 obtained stability of marble mixture 0%=1182kg, 15%=524kg, 25%=508kg, 35%=431 kg. So stability testing with addition of marble shard waste with 0%-25% variation is eligible, while for 35% variation is not eligible. This can occur due to pounding of test objects that are evenly sized.

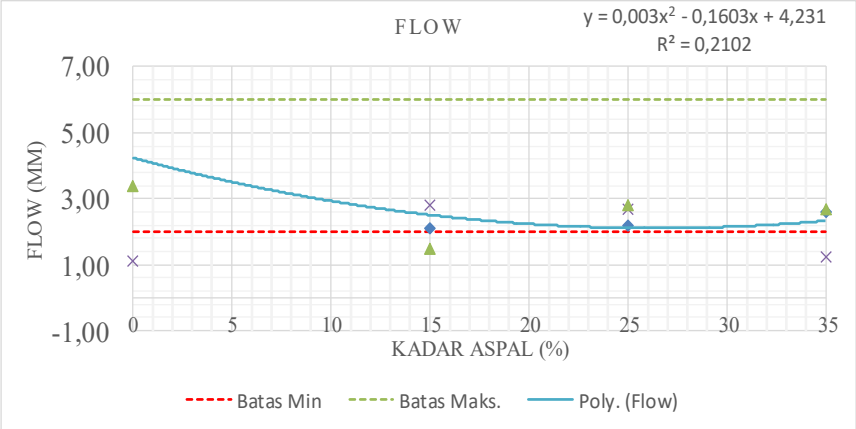


Figure 5. Flow Graph

Based on Figure 5, flow value obtained results of the asphalt mixture content that passes is at a percentage of 0% of 4 mm, and content that does not pass at a percentage of 15% of 2 mm, 25% of 2 mm, and 35% of 2 mm. This behavior aligns with the findings of (Rahman et al., 2020), who observed that increasing asphalt content beyond an optimum level can lead to excess binder, thereby increasing the flexibility (flow) but potentially compromising structural integrity. Similarly, (Jebur et al., 2024)emphasized that the optimal flow value is essential in porous asphalt to maintain performance under traffic load without rutting or cracking. In the context of using marble waste as an additive, research by (Mulatu et al., 2021) supports that waste fillers tend to affect the viscoelastic properties of asphalt, influencing both stiffness and flow behavior. Therefore, this study confirms previous findings while adding the dimension of marble stone waste as a contributing factor to flow stability in porous asphalt mixtures.

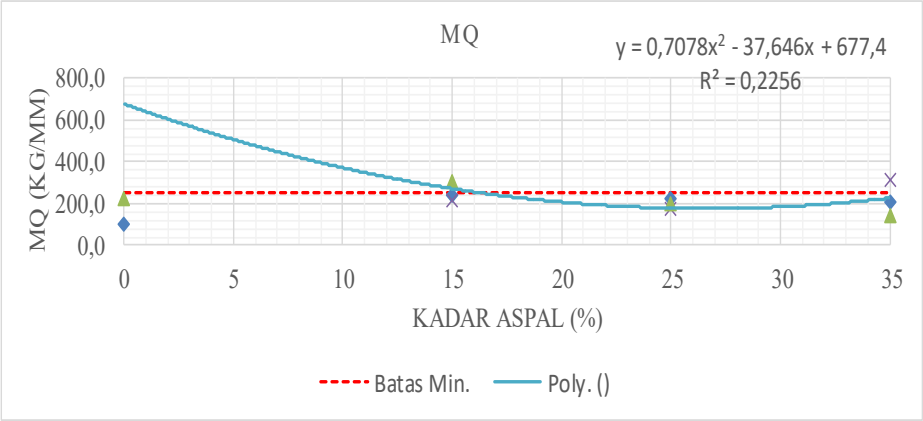


Figure 6. MQ Graph

Marshall Quotient is the quotient of the stability value with the flow value which is a form of mixture stiffness, the greater the MQ value, the mixture will be easily destroyed or cracked because it is hard, but the smaller the MQ value, the mixture will be too flexible or unstable (Anam & Pratikto, 2018). Marshall Quotient values were obtained from the average percentage levels of 0%=681kg/mm, 15%=254kg/mm, 25%=199kg/mm, and 35%=219kg/mm. The test results have met AAPA standard. This trend aligns with prior research (Mohd Shukry et al., 2018), who reported that an increase in asphalt binder typically reduces MQ due to a softening effect, especially when excessive binder fills the voids, diminishing structural stiffness. Similarly, (Zhang et al., 2018) highlighted that the incorporation of non-traditional fillers, such as marble dust, could moderate the reduction in stiffness, helping the mix maintain MQ values above specification limits. Additionally, (Xiao et al., 2018) found that optimal MQ values in porous asphalt mixtures are crucial for balancing strength and flexibility, particularly in high-load environments. Based on results of

the test stages that have been carried out, Marshall test results can be continued to determine the optimum asphalt content (OAC). OAC results can be seen in Table 6 below.

Table 6. Marshall Test Results for the Optimum Mixture Rate of Marble Fragments

Marshall Characteristics	**Range of Mixture Grades that Meet Specifications**			
Stability				
Flow				
MQ				
VIM				
VMA				
% marble waste	0	15	25	35

This finding aligns with contemporary studies on the use of marble-based fillers in asphalt mixtures. (Pasandín & Pérez, 2018) found that while 25% marble content produced the highest Marshall stability and stiffness, it did not translate into improved durability measured by strength loss indicators and in fact showed greater susceptibility to breakdown compared to mixtures without marble waste. Likewise, (Mulatu et al., 2021) reported that replacing conventional mineral filler with low percentages (around 3–5%) of marble dust enhanced stability and maintained acceptable flow values, whereas higher proportions could diminish mechanical performance. This supports the current study's outcome, which shows that a 25% marble content, though mechanically robust, exceeds acceptable Cantabro loss limits, whereas 15% and 35% contents remain within specification, striking a more sustainable balance between mixture stiffness, durability, and void structure.

Contrabro Loss (CL) Test

Cantabro Loss testing aims to determine percentage of the mixture's ability to release grains using a Los Angeles abrasion machine for 300 rounds (Rahmawati & Hidayat, 2021). Cantabro Loss testing is conducted to determine weight loss after Loss Angeles testing without using steel balls with 5% asphalt content variation of each test specimen with a total of 3 test specimens.

Table 7. Contrabro Loss Test Effect of Marble Stone Fracture Mixture

No	**Description**	**Unit**	**Sample**		
			1	**2**	**3**
1	Weight of Test Item Before Cantabro Loss (A)	gram	1037.9	1259.7	1367.3
2	Weight of Test Item After Cantabro Loss (B)	gram	758.1	428.9	938.9
3	CL = A-B/A x 100%	%	26.96	65.95	31.13
4	Maximum Value	%	35	35	35

Figure 7, is a graph of the Cantabro Loss test results in terms of the average results of each test specimen with 5% asphalt content which will draw a line to determine and show the test results. Cantabro Loss test results obtained a mixture of marble stone fragments and marble powder with a percentage of 15% = 26.96%, 25% = 65.95%, and 35% = 31.33%. So the results of the Cantabro Loss test concluded that the specimen with a percentage of 25% marble content did not meet the requirements of AAPA 2004, while for specimens with 15% and 35% marble content met the requirements of AAPA 2004. The figure indicates that Sample 2 experiences the highest Cantabro loss, exceeding 60%, while Samples 1 and 3 remain below the generally accepted durability limit (red dashed line) of 30–40% This trend aligns with the findings of (Zhang et al., 2018), who noted that the addition of excessive fine fillers can weaken aggregate bonding, leading to increased particle loss. Furthermore, (Pasandín & Pérez, 2018) concluded that incorporating marble waste in porous asphalt mixtures improves mechanical performance but may reduce durability if the percentage is not optimized.

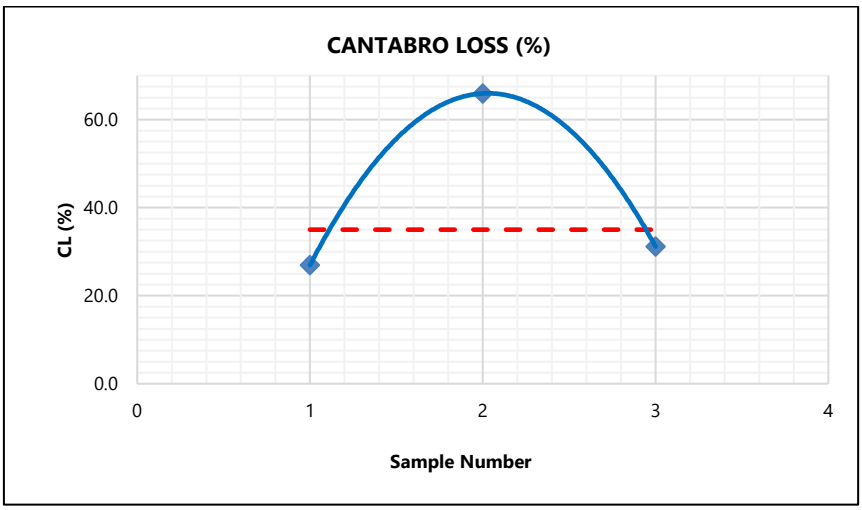


Figure 7. Cantabro Loss Graph (%)

Asphalt Flow Down (AFD) Test

AFD testing was carried out without using an aluminum container oven and heated to appropriate temperature and using time according to Australian Asphalt Pavement Association (AAPA 2004) specifications. AFD test results are listed in Table 8 below.

Table 8. Asphalt Flow Down (AFD) Testing

No	m1 gr	m2 gr	m3 gr	AFD %	AFD < 0,3 %	AFD %
1	310	310	1700	0.01%	**< 0,3 %**	0.25
2	300	300	1895	0.01%	**< 0,3 %**	0.25
3	300	300	1900	0.01%	**< 0,3 %**	0.19

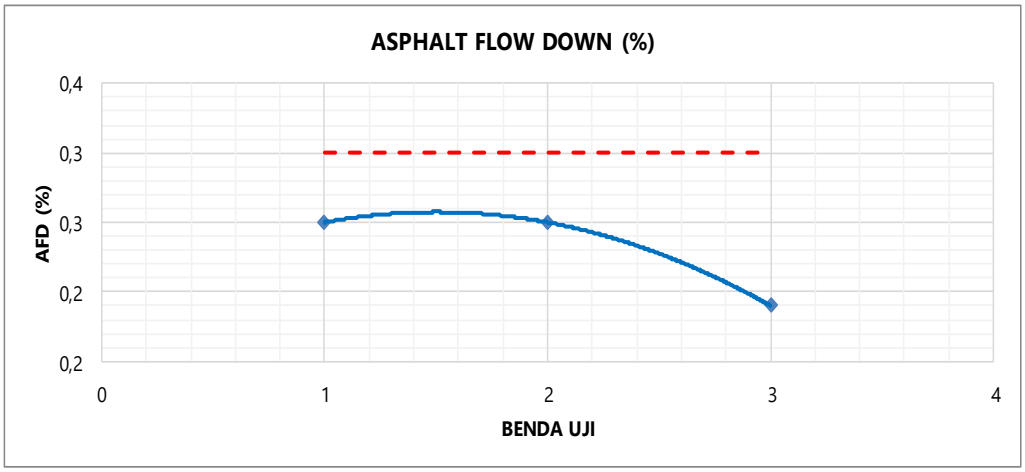


Figure 8. Asphalt Flow Down Graph (%)

Figure 8 shows that AFD value decreases as percentage of marble stone fractions increases. This causes level of asphalt separation in mixture to be smaller. So, it can be categorized that test results meet requirements of AAPA 2004 with a maximum limit of asphalt flow value of 0.3%. In accordance with research (Putri et al., 2020) that percentage of asphalt attached to the mixture will increase if the asphalt flow value is low. Recent research supports the observed behavior in this study. For instance, Bastari Alkām et al. (2019) found that adding 25% marble waste filler did not improve durability; in fact, the mixture exhibited higher strength loss compared to control specimens without marble waste based on residual strength and stability reduction indices. In the broader porous asphalt literature, (Zhang et al., 2018)and others have shown that

incorporation of modified binders such as polymer-modified or fiber-reinforced asphalts can reduce Cantabro loss by improving binder-aggregate adhesion and internal cohesion of the mixture.

CONCLUSIONS

Marshall test results for optimum asphalt content (OAC) for 5% asphalt content have results according to parameters of stability, flow, VIM, VMA, and MQ. Addition of marble fractions to the porous asphalt mixture (0%, 15%, 25%, 35%) affects characteristics of mixture. Mixtures with 25% percentage met AAPA requirements with parameters such as VIM and VMA, as well as increased strength and stability. In contrast, for the 35% percentage, the stability and flow results did not meet standards, this is likely due to less than optimal production and compaction process.

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