Performance of Aggregate in Relation to Polishing Resistance

Eti Sulandari[1*], Slamet Widodo[2], Siti Mayuni[3], Yoke Lestyowati[4], Falderika[5], Sutarno[6]
[1,2,3,4]Department of Civil Engineering, Tanjungpura University, Indonesia
[5]Department of Civil Engineering, Indonesian Computer University, Indonesia
[6]Asosiasi Tenaga Teknik Indonesia (ASTTI), Indonesia

Article Info

Article history:

Received, March 4, 2025
Accepted, April 1, 2025
Published, April 30, 2025

Keywords:

Aggregate, Polishing, PSV, BPT, BPN

ABSTRACT

More than 90% of aggregate is used in asphalt mixtures, meaning the type of rock used as aggregate must comply with permitted specifications. Igneous rocks, as one type of rock, are often used in road construction. Aggregates found in various sources indicate that they possess different characteristics. The resistance of aggregates to polishing demonstrates their ability to support better skid resistance. This study aims to determine the polishing resistance of aggregates by comparing two types of aggregates from different sources (aggregate-1 and aggregate-2). The testing method was conducted in a laboratory, referring to the 2018 Bina Marga and British standards. The equipment includes the polishing Stone Machine and the British Pendulum Tester (BPT).

The results showed that both aggregates are suitable for asphalt mixture materials. However, the polishing resistance test results for aggregate-2 (28 BPN) were higher than aggregate-1 (26.4 BPN) because the surface texture of aggregate-2 is coarser, with larger pores, making it rougher. Based on the polishing resistance test, aggregate-1 had longer resistance (65.35%) than aggregate-2 (61.74%) because aggregate-1 is harder than aggregate-2; this can also be observed from their property test results.

In conclusion, aggregates from different sources have distinct characteristics and polishing resistance.

Available online at http://dx.doi.org/10.62870/fondasi

Corresponding Author:

Eti Sulandari,
Department of Civil Engineering,
Tanjungpura University,
Jl. Prof. Dr. H. Hadari Nawawi, 78124, Indonesia.
Email: *etisulandari@civil.untan.ac.id

1. INTRODUCTION

In the field of road construction, two types of evaluations are recognized: structural evaluation and functional evaluation. Structural evaluation aims to assess the performance of asphalt mixtures by ensuring the pavement strength of the asphalt mixture does not suffer damage and provides comfort (service). Meanwhile, functional evaluation aims to provide safety for road users.

As an integral part of the transportation system, road infrastructure plays a pivotal role in fostering development across all regional areas. Therefore, it becomes imperative to consider the condition of road pavements to deliver service and ensure safety for road users. Numerous factors, such as material quality, proper asphalt mixture design, traffic volume, and temperature, influence the condition of pavements. According to [1], weather conditions and traffic loads are factors that must be considered when designing an asphalt mixture to enhance the bonding between materials in the asphalt mixture (aggregate and asphalt) and in the selection of aggregates for the asphalt mixture. The morphological features such as shape (form), roughness, and texture have a significant influence on the performance of asphalt mixtures [2].

The construction world, particularly in road construction, utilizes aggregates derived from rocks found across various regions worldwide, especially in Indonesia. Over 90% of the aggregates in asphalt mixtures are used, indicating that the type of rock used as aggregates must comply with permitted specifications. Igneous rocks, as one type of rock, can be explicitly used in road construction to create asphalt mixtures. Igneous rocks are formed from magma that cools and hardens, with or without crystallization, either below intrusive rocks (plutonic) or above the surface as extrusive rocks [3].

The process of rock formation depends on the influence of temperature, pressure, time, and changes in environmental conditions both within the Earth's crust and on its surface. Generally, rocks are classified into three types: igneous, metamorphic, and sedimentary [4]. It cannot be assumed that rocks with the same silica content will have the same mineralogy, as the crystallization process of rock magma is a complex interaction influenced by various parameters [4]. It is essential to study and understand the types of rocks used as aggregates in the construction industry, particularly for road construction. Moreover, alternative materials such as waste rock or by-products can also be used as aggregates [5]. Examples include steel slag [6],[7],[8],[9], slag fiber [10],[11], fly ash as a filler [12],[13],[14] and concrete waste as coarse aggregates [15],[16],[17],[18]. Aggregates with coarse surface textures tend to be more resistant to polishing, while aggregates with smooth surface textures are less resistant [19]. Polishing resistance reflects aggregates' ability to support better skid resistance.

The simplest way to differentiate aggregate characteristics is through visual analysis, such as distinguishing aggregates by their differing colour, indicating that variations in the mineralogy and structure of the rock, which affects the physical properties of the aggregates and the chemical composition contained within them [20],[21]. Almost all aggregates used in road construction contain a high level of silica (SiO_2) compared to other chemical elements (XRF tests, X-ray Fluorescence). That indicates that silica (SiO_2) is a crucial mineral [22], indicating that aggregates are stiff and robust. However, high silica content can also negatively impact the adhesion between aggregates and asphalt [23],[24]. Softer aggregates tend to wear out more quickly than harder aggregates [25].The hardness and strength of aggregates can be determined through aggregate testing based on the Bina Marga 2018 Revision 2 Specifications [26]. Do complex aggregates have high polishing resistance, and what is the surface texture condition of such aggregates? How do aggregate characteristics relate to polishing resistance? This study aims to determine the polishing resistance of aggregates by comparing the characteristics of aggregates from different sources.

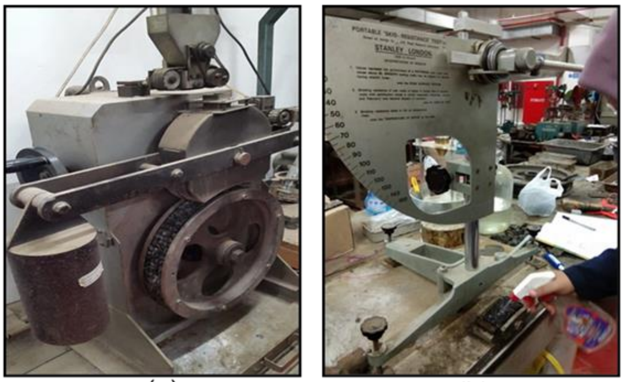
2. MATERIALS AND METHODS

2.1 Materials

The aggregate materials used in this study were obtained from two sources, namely Karawang (aggregate-1) and Cimahi (aggregate-2).

2.2 Polishing Test Equipment

The polishing stone machine and British Pendulum Tester (BPT) are the two tools used to test the polishing resistance of aggregates. They are illustrated in Figure 1.



(a) (b)

Figure 1. Polishing stone equipment (a) Polishing Stone Machine (b) BPT

2.3 Research Stages

In this research design, there are four stages, where each stage represents a series of research activities conducted in the laboratory. These stages are as follows:

1) Stage 1: Identification of Aggregate Sources
   Identification of aggregate sources from different locations.
2) Stage 2: Basic Aggregate Testing
   It aims to determine the quality of aggregates that meet the 2018 Bina Marga specifications[26].
   - Specific Gravity and Absorption Test: To determine the specific gravity and absorption of the aggregates.
   - Durability Test: To assess the resistance of aggregates to magnesium sulfate solution.
   - Mechanical Testing: To determine the resistance of aggregates to treatments such as abrasion, impact, and crushing tests.
3) Stage 3: Polishing Test
   This test is conducted to determine the polishing resistance of aggregates. The surface texture of the aggregates affects the roughness value expressed by the Polishing Stone Value (PSV). Coarse aggregate surfaces will have higher PSV values compared to smooth aggregate surfaces. For this test, samples are shaped into plates according to moulds, and the aggregates are placed on the plates with resin as a base. The test is conducted for 6 hours, with readings taken every hour using the British Pendulum Tester (BPT)[27].
4) Stage 4: Analysis of Test Results
   In this stage, the test results are analyzed by observing the relationship between basic testing and polishing tests to reach conclusions from this research.

3. RESULTS AND DISCUSSION

3.1 Results of Aggregate Characteristic Testing

Aggregates are the most significant contributing material in both flexible and rigid pavements. Thus, the quality of aggregates plays a significant role in creating asphalt/concrete mixtures to produce better pavement mixtures. Aggregate characteristic testing, as a basic aggregate test, refers to the Bina Marga 2018 revision 2 standard. The aggregate tests conducted include:

3.1.1 Aggregate Color

One of the physical properties of aggregates is color, although the color of minerals is not the main characteristic used to distinguish one mineral from another. However, with its distinctive color, it can be used to identify the presence of certain elements within the aggregate. Therefore, the easiest way to identify the type of aggregate is through its color. Colour differences indicate variations in the chemical elements contained within them. Figure 3 presents changes in aggregate colour.


(a) (b)

Figure 3. Aggregate Colour (a) Aggregate – 1 (b) Aggregate-2

3.1.2 Testing of Specific Gravity and Aggregate Absorption

The specific gravity of aggregates is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water at a specified temperature [28]. The specific gravity measured includes Bulk Specific Gravity, SSD Specific Gravity (Saturated Surface-Dry Specific Gravity), and Apparent Specific Gravity.

The specific gravity test aims to determine whether the specific gravity meets the specifications of the Bina Marga 2018 revision 2, which requires a minimum specific gravity of 2.5 for aggregates used in pavement mixtures.

In addition to specific gravity, absorption is also measured, representing the porosity of the aggregates that can absorb water or asphalt. The results of the specific gravity and absorption tests are presented in Table 1. The level of absorption can affect the amount of asphalt absorbed into the aggregate. Therefore, Bina Marga limits the maximum aggregate absorption to 3%, except for SMA-type asphalt mixtures, where the maximum is 2%. High absorption indicates that the aggregate surface texture tends to be rough due to larger pores; however, aggregates with larger pores tend to wear out more quickly compared to aggregates with smaller pores.

Table 1. Testing of Specific Gravity and Absorption of Aggregate

No	Testing	Method	Value	Result	
				Aggregate-1	Aggregate-2
1	SG Bulk	SNI 1969: 2016	SG Min. 2,5	2,62	2,52
2	SG SSD			2,68	2,65
3	SG Apparent			2,77	2,89
4	Absorption		Max. 3%	1,79	2,97

The average specific gravity of the aggregates is above 2.5, with absorption values of 1,79 (aggregate-1) and 2.97 (aggregate-2), indicating that the aggregates meet the specifications and are suitable for use as materials in asphalt mixtures.

3.1.3 Durability Testing

Durability refers to the resistance of aggregates to Magnesium Sulfate ($MgSO_4$) solution, commonly known as the Soundness test. This testing process is conducted over five days, following the specifications of SNI 3407:2008, with a maximum allowable limit of 18%. This test aims to assess the resistance of aggregates to weathering or freeze-thaw cycles, simulated through repeated immersion in a magnesium sulfate ($MgSO_4$) solution. It provides an indication of the aggregate's ability to withstand extreme environmental conditions, such as wet-dry or freeze-thaw cycles, which can cause damage to pavement structures. In each cycle, the aggregates are immersed in a magnesium sulfate solution for a specified period (typically up to 24 hours), followed by oven drying. During immersion, the salt solution penetrates the pores of the aggregates, and upon drying, salt crystals form within the pores, creating internal pressures that may cause the aggregates to fracture. The greater the damage observed after a number of cycles, the lower the aggregate's resistance to weathering. The results of the aggregate testing are shown in Table 2.

Table 2. Durability Test of Aggregate on $MgSO_4$ Solution

Description	Index	Result			
		Aggregate-1		Aggregate-2	
		(1)	(2)	(1)	(2)
Sample weight, gram	A	300,40	300,30	300,60	300,90
Sample weight after soaking, gram	B	290,20	295,70	285,20	290,70
Soundness (%)	(A-B)/A	3,40	1,53	5,12	3,39
Average Soundness (%)		2,46		4,26	

The test results indicate that both aggregate-1 and aggregate-2 have resistance to $MgSO_4$ solution, as they remain within the allowable limit of 18%. Changes in form due to the $MgSO_4$ solution are shown in Figure 4.

(1a) before (1b) after (2a) before (2b) after

Figure 4. Changes in aggregate form due to MgSO4 solution (1a),(1b) Aggregate-1 and (2a),(2b) Aggregate-2

As shown in Figure 4, the changes in aggregate shape caused by the $MgSO_4$ solution were minimal, indicating that both aggregates have resistance to weathering. The critical aspects of the weathering test are:

1) Simulation of Weathering Due to Weather
   This test uses a magnesium sulfate solution to simulate the effects of weathering or weather-induced degradation on aggregates. The aggregates are soaked in the solution for a specific period and then dried. This cycle is repeated several times to simulate harsh environmental conditions.
2) Measuring Aggregate Resistance to Freeze-Thaw Cycles
   Magnesium sulfate salts crystallize within the aggregate pores during the drying process, creating pressure similar to the natural freeze-thaw cycles in the environment.

3) Identifying Long-Lasting Aggregates
The test results show the extent to which aggregates break down or experience degradation after the weathering cycle. More durable and stable aggregates exhibit minimal damage or weight loss after testing.

3.1.4 Results of Aggregate Mechanical Testing

Mechanical testing is intended to evaluate aggregates using manual or electrically operated equipment. The tests include abrasion, impact, and crushing, each of which involves different testing procedures.

1) Abrasion Testing

Abrasion testing uses the Los Angeles machine to determine the aggregate's resistance to impact from steel balls. The number of steel balls used depends on the type of abrasion test selected. This study used type A, involving sizes #3/4, #1/2, #3/8, and #4, each weighing approximately 2,500 grams. The results of the abrasion test are presented in Table 3. A high abrasion value indicates that the aggregate easily breaks when it rubs against other aggregates during the mixing process or when subjected to loads during compaction. The ease with which the aggregate breaks also lead to a shift in the gradation toward finer particles. According to the specifications, aggregate abrasion must not exceed 40%. In this study, the abrasion values obtained were 15.62% (aggregate-1) and 19.48% (aggregate-2).

Table 3. Abration Test Result

Description	Result			
	Aggregate-1		Aggregate-2	
	(1)	(2)	(1)	(2)
Total weight (A), gram	5.000,35	5.000,15	5003,6	5001,3
Weight retained on the sieve # 12, gram (B)	4.206,40	4.232,10	4045,40	4010,1
(A) – (B), gram	793,95	768,05	958,20	991,20
Wear = (A-B)/A x 100%	15,88	15,36	19,15	19,82
Average wear (%)	15,62		19,48	

The results indicate that aggregates from the two sources are suitable for use as aggregates in asphalt mixtures, as the abrasion values for both aggregates fall within the specifications of Bina Marga 2018 Revision 2, which requires values below 40%. Changes in aggregate shape from the abrasion test are presented in Figure 5.

(1a) before (1b) after (2a) before (2b) after

Figure 5. Abrasion Test (1a)-(1b) Aggregate-1, (2a)-(2b) Aggregate-2

2) Impact Testing

The impact test aims to determine the resistance or strength of aggregates to impact or collision loads, ensuring that the aggregates can withstand sudden traffic loads without damage. The impact test in the laboratory involves applying a one-directional impact load. The test results are shown in Table 4.
The results indicate that aggregates from the two sources are suitable for use in asphalt mixtures. The impact values for both aggregates meet the specifications of Bina Marga 2018 Revision 2, which requires values below 30%.

3) Crushing Test

The crushing test aims to evaluate the strength or resistance of aggregates to compressive loads. In construction, particularly in concrete and road pavements, aggregates must have high resistance to pressure to ensure that the built structure is solid and durable. The crushing test in the laboratory is conducted by applying pressure to the aggregates for 15 minutes. The test results can be seen in Table 5.

Table 4. Hasil Impact Testing on Aggregate

Description	Index	Result			
		Aggreagte-1		Aggreagte-2	
		(1)	(2)	(1)	(2)
Container weight, gram	W1	2467,1	2471,9	2570,9	2467
Container weight + Test specimen (after compaction), gram	W2	2919,2	2986,3	3062,2	2962,9
Initial sample weight, gram	A’ = W2 -W1	452,1	514,2	491,3	495,5
After impact and sieving, gram					
Weight of the test specimen passing through the sieve #8	B	44,9	55,8	57,9	62,7
Weight of the test specimen retained on the sieve #8	C	407,2	456	432,8	431,2
Total, gram	A = B + C	452,1	513,8	490,7	493,9
Aggregate Impact Value, AIV (%)	ACV = (B/A)	9,93	10,86	11,8	12,7
Average AIV (%)		10,4		12,2	

Table 5. Results of Aggregate Crushing Test

Description	Index	Result			
		Aggreagte-1		Aggreagte-2	
		(1)	(2)	(1)	(2)
Container weight + base, gram	W1	1697,7	1697,7	1697,8	1697,8
Container weight + base + test specimen (after compaction), gram	W2	2049,7	2067,7	2007,1	1998,1
Initial sample weight, gram	A’ = W2 -W1	352	370	309,3	300,3
After impact and sieving, gram					
Weight of the test specimen passing through the sieve #8	B	38,9	46,1	65,4	56,8
Weight of the test specimen retained on the sieve #8	C	313,1	332,9	244,3	239,2
Total, gram	A = B + C	352	379	309,7	296
Aggregate Crushing Value, ACV (%)	ACV = (B/A)	11,051	12,164	21,117	19,189
Average ACV (%)		11,61		20,15	

The results indicate that aggregates from the two sources are suitable for use as aggregates in asphalt mixtures, as the crushing values for both aggregates fall within the Bina Marga 2018 Revision 2 specifications, which require values below 30%.

3.2. Results of Aggregate Polishing Testing

The polishing test evaluates aggregates' resistance to polishing. Polishing resistance is a critical factor in the functional evaluation of asphalt pavement. Aggregates with larger pores tend to have higher resistance to roughness, which is tested using the British Pendulum Tester (BPT). The polishing test procedure has two stages: the preparation of test specimens and the testing process itself.

1) First Stage

The first stage involves preparing materials for the polishing test. Seven test specimens are created for each type of aggregate, as one wheel accommodates 14 test specimens. The procedure for creating polishing test specimens is presented in Figure 6. Specimen preparation involves arranging 14 test specimens on the polishing machine's large wheel in a circular configuration. The aggregate used was #3/8 in size, with the material thoroughly washed to remove any adhering dirt or dust. The aggregates were then randomly arranged (approximately 40 particles) on a mold coated with resin to serve as the aggregate base. Before conducting the polishing test, the specimens were washed again to ensure that no foreign substances, such as oil, remained from the preparation process.

2) Second Stage

The second stage tests the aggregate's resistance to polishing. This test serves as a simulation to evaluate the aggregates' ability to resist wheel friction above them. The simulation uses the Polishing Stone Machine and takes 6 hours to assess the aggregate's polishing resistance. During the process, emery and water are applied, with the first 3 hours using coarse emery and the next 3 hours using fine emery, both continuously rinsed with water.

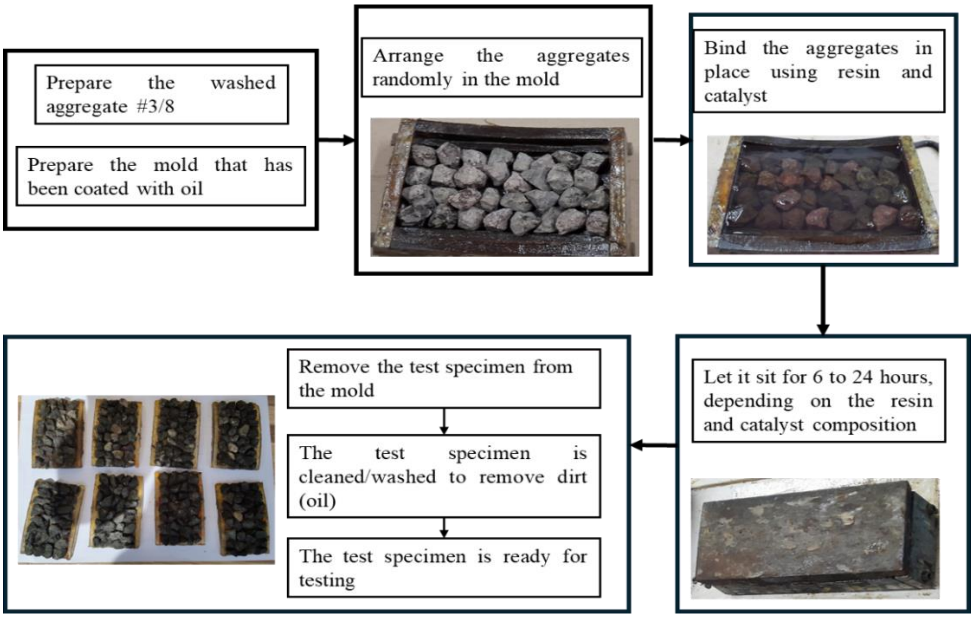


Figure 6. Test Specimen Preparation Process

In this study, polishing tests were conducted every hour using a British Pendulum Tester (BPT), and the device readings were taken 5 times. Subsequently, the test specimen was reattached to the Polishing equipment. The polishing test process is presented in Figure 7.

3.3. Analysis

Aggregates from two different sources show differences in their characteristics. Differences are evident from the results of specific gravity, absorption, and shape alteration tests caused by MgSO4 solution, impact, and crushing tests. Aggregate-1 qualitatively demonstrates better quality than Aggregate-2, meaning it has more excellent resistance to the applied treatments. However, Aggregate-2 also meets the quality requirements for aggregates as stipulated in the Bina Marga 2018 Revision 2 specifications.

The polishing test evaluates the resistance of aggregates to friction caused by the load of a moving wheel. The test is conducted hourly to determine the aggregate resistance to polishing for both aggregates. The results of the polishing test are presented in Figure 8.

Figure 8 shows that aggregate characteristics affect aggregate resistance to polishing. Regarding quality and strength, Aggregate-1 is superior to Aggregate-2, as demonstrated in the aggregate property tests.

The polishing test indicates that Aggregate-2 (28 BPN) scores higher compared to Aggregate-1 (26.4 BPN) because the surface texture of Aggregate 2 is coarser, with larger pores making it rougher. However, based on the resistance of aggregates to polishing, Aggregate-1 is more durable (65.35%) against wear than Aggregate-2 (61.74%) due to its harder texture. The results of the property tests support this finding.

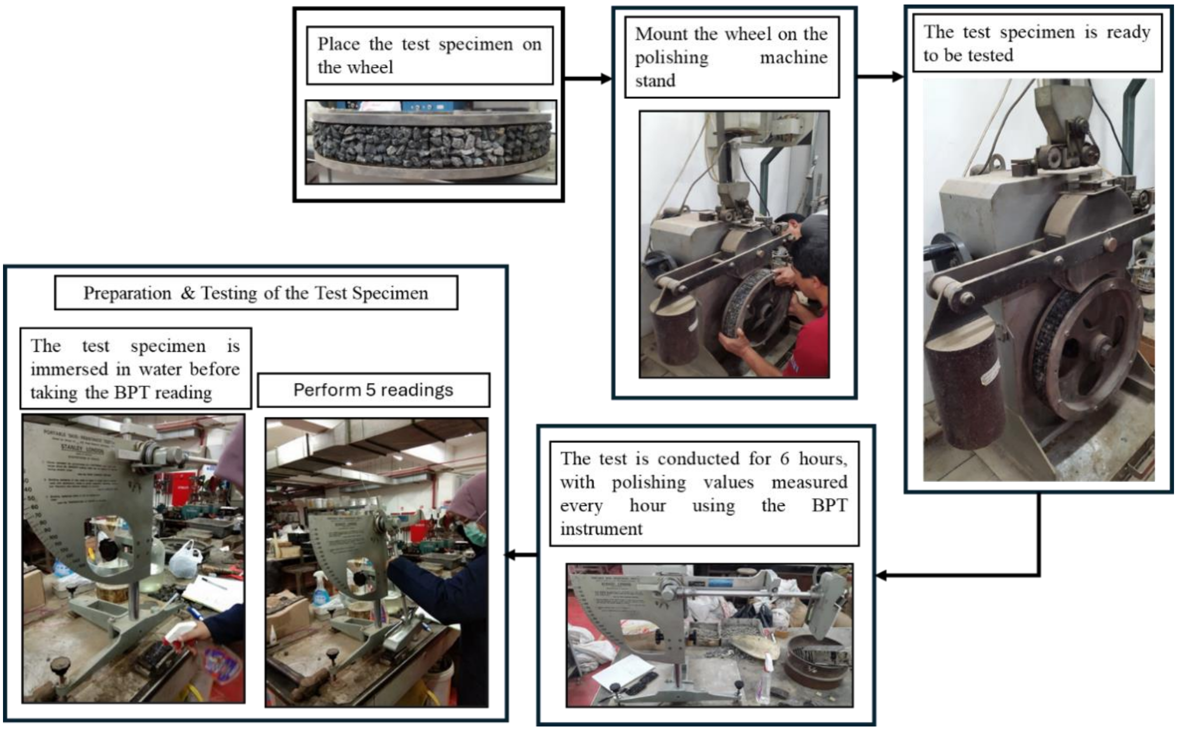


Figure 7. Polishing Test Process on Test Specimens

High abrasion levels are associated with low PSV (polishing stone value), but the resistance of such aggregates lasts quite a while against surface wear or polishing. As shown in Figure 4.3, the slope of the Aggregate-2 graph is steeper compared to Aggregate-1, where the resistance of Aggregate-2 (61.74%)

is lower than that of Aggregate-1 (65.35%) due to polishing. Although both aggregates are suitable for use as materials in asphalt mixtures, they exhibit different characteristics. In terms of hardness, Aggregate-1 is harder than Aggregate-2. However, the surface texture of Aggregate 2 is coarser because of its larger pores, resulting in higher roughness values.

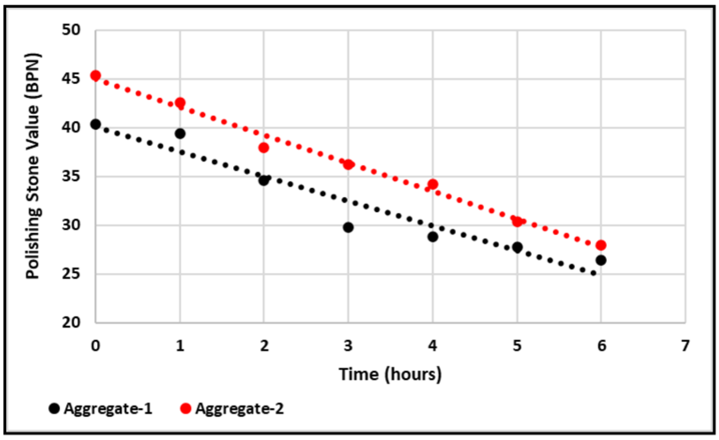


Figure 8. Relationship Between Polishing Test and Duration of Polishing

4. CONCLUSION

The results of testing and analysis in this study can be summarized as follows:

1) Aggregates originating from different sources have distinct characteristics.
2) Both aggregates used in this study are suitable for use as materials in asphalt mixtures.
3) In terms of aggregate hardness, Aggregate-1 is superior to Aggregate 2 due to its higher hardness, as evidenced by the property testing results. The abrasion resistance is below 40% (Aggregate-1 approximately 15.62%, Aggregate-2 approximately 19.82%), impact resistance is less than 30% (Aggregate-1 approximately 11.3%, Aggregate-2 approximately 12.2%), and crushing resistance is less than 30% (Aggregate-1 approximately 11.607%, Aggregate-2 approximately 20.152%).
4) The polishing test shows that Aggregate-2 (28 BPN) has a higher value compared to Aggregate-1 (26.4 BPN) because the surface texture of Aggregate 2 is coarser, with larger pores making it rougher. However, regarding aggregate resistance to polishing, Aggregate-1 is more durable (65.35%) than Aggregate-2 (61.74%) because Aggregate-1 is harder than Aggregate-2. The property test results support this result.
5) The polishing test was conducted using a Polishing Stone Machine, a polishing test on aggregate surface texture.

ACKNOWLEDGMENT

We would like to express our deepest gratitude to Allah SWT, our beloved family, and all those who have helped and supported the implementation of this research. We hope that the results of this research can be beneficial in the development of knowledge, particularly in the understanding of aggregate materials in asphalt mixtures. We also wish to thank the team at *Jurnal Fondasi: Jurnal Teknik Sipil Untirta* for their assistance in the journal submission process, approving the publication of this research, and making it a valuable reference in the field of civil engineering, especially in the field of transportation.

REFERENCES

[1] S. Anastasio, A. Patricia, P. Fortes, and I. Hoff, "Effect of Aggregate Petrology On The Durability of Asphalt Pavements," *Construction Building Materials*, vol. 146, pp. 652–657, 2017.

[2] F. Gong, Y. Liu, Z. You, and X. Zhou, "Characterization and evaluation of morphological features for aggregate in asphalt mixture : A review," *Construction Building Materials*, vol. 273, p. 121989, 2021.

[3] D. Noor, "*Pengantar Geologi"*, 2nd ed. Bogor: Pakuan University Press, 2012.

[4] J. P. Rafferty, "*Rocks"*, First. New York: Britannica Educational Publishing, 2012.

[5] M. Yilmaz, B. V. Kök, and N. Kulog, "Effects of Using Asphaltite As Filler on Mechanical Properties of Hot Mix Asphalt," *Construction Building Materials* , vol. 25, pp. 4279–4286, 2011.

[6] R. T. Bethary, "Analisis Kinerja Mekanistik Campuran Beraspal Lapis Pengikat (AC-BC) Menggunakan Bahan Pengganti Agregat Steel Slag Dan Reclaimed Asphalt Pavement (RAP)," ITB, 2020.

[7] G. Bosurgi, C. Celauro, O. Pellegrino, A. Ruggeri, and G. Sollazzo, "Mechanical and Environmental Performance Comparisons of Improved Asphalt Pavement Wearing Courses with High Quality Aggregates , Steel Slags , and Polymeric Compound," *Construction Building Materials*, vol. 382, no. April, p. 131252, 2023.

[8] J. Liu *et al.*, "Towards The Sustainable Utilization of Steel Slag in Asphalt Pavements : A Case Study of Moisture Resistance and Life Cycle Assessment," *Case Studies Construction Materials*, vol. 18, 2023.

[9] V. Kunaev, B. Bazarov, I. Tavshanov, and A. Kadyrov, "Evaluation of The Effect of Enrichment of Slag Aggregate for Pavement Subbase by Grains Density on Its Physical and Mechanical Characteristics," *Results in Engineering*, vol. 18, p. 101181, 2023.

[10] M. Fei, Q. Cai, W. Wu, X. Yan, and H. Zhao, "Surface Modified Slag Fiber Reinforced Asphalt Mixture : Enhancement of Pavement Performance and Field Validation," *Case Studies Construction Materials*, vol. 22, p. e04505, 2025.

[11] Y. Sun, L. Zheng, Y. Cheng, F. Chi, and K. Liu, "Research on Maintenance Equipment and Maintenance Technology of Steel Fiber Modified Asphalt Pavement With Microwave Heating," *Case Studies Construction Materials*, vol. 18, p. e01965, 2023.

[12] A. M. Yildiz K, "Improving Microwave Healing Characteristic of Asphalt Concrete by Using Fly Ash as A Filler," *Construction Building Materials*, vol. 262, 2020.

[13] E. Khankhaje, T. Kim, H. Jang, C. Kim, and J. Kim, "Properties of Pervious Concrete Incorporating Fly Ash as Partial Replacement of Cement : A Review," *Developments in The Built Environment*, vol. 14, no. February, p. 100130, 2023.

[14] E. Yaghoubi, B. Ghorbani, M. Saberian, R. Van Staden, M. Guerrieri, and S. Fragomeni, "Permanent Deformation Response of Demolition Wastes Stabilised with Bitumen Emulsion as Pavement Base / Subbase," *Transportation Geotechnics*, vol. 39, p. 100934, 2023.

[15] N. Imannurrohman and M. Amin, "Pemanfaatan Limbah Beton Sebagai Pengganti Agregat Kasar Pada Perkerasan Laston Asphalt Concrete – Wearing Coarse (AC-WC)," *Reviews in Civil Engineering*, vol. 04, pp. 6–14, 2020.

[16] E. A. M. Al-ghalibi and S. A. Mohamad, "Evaluate The Durability and Effect of Water Absorption of Recycled Aggregate Used in Pavement," *Materials Today : Proceedings*, vol. 42, pp. 2561–2565, 2021.

[17] J. G. B. Martınez, F. A. R. Lizcano, and H. A. R. Quintana, "Use of Recycled Concrete Aggregates in Asphalt Mixtures For Pavements : A Review," *Journal traffic Transportation. Engineering*, vol. 9, pp. 725–741, 2022.

[18] M. Akbas, B. Ozaslan, and R. Iyisan, "Utilization of recycled concrete aggregates for developing high-performance and durable flexible pavements," *Construction Building Materials*, vol. 407, no. September, p. 133479, 2023.

[19] E. Sulandari, B. S. Subagio, H. Rahman, and I. Maha, "Analysis of Aggregate Types with Micro-

texture and Macro-texture Charactristics of Asphalt Mixture in Indonesia," *Open Civil Engineering Journal*, pp. 1–9, 2023.
[20] S. Anastasio, A. Patricia, P. Fortes, E. Kuznetsova, and S. Willy, "Relevant Petrological Properties and Their Repercussions on the Final use of Aggregates," *Energy Procedia*, vol. 97, no. 1876, pp. 546–553, 2016.
[21] M. Kane and V. Edmondson, "Aggregates Mineralogical Composition Dataset to Estimate The Averaged Aggregate Hardness Parameter to Predict The Long-Term Skid Resistance of Pavements," *Data in Brief*, vol. 31, p. 105849, 2020.
[22] M. Akacem, M. Bouteldja, V. Cerezo, and A. Hachichi, "A Method to Use Local Low Performances Aggregates in Asphalt Pavements – An Algerian Case Study," *Construction Building Materials* vol. 125, pp. 290–298, 2016.
[23] A. R. Pasandín and I. Pérez, "The Influence of The Mineral Filler on The Adhesion Between Aggregates and Bitumen," *International Journal of Adhesion & Adhesives*, vol. 58, pp. 53–58, 2015.
[24] Y. Zhou *et al.*, "A Review on Adhesion Behavior of Chip Seal Pavement and Aggregate," *Journal of Traffic and Transportation Engineering*, vol. 11, no. 3, pp. 441–466, 2024.
[25] P. Cornu, M. Kane, M. Gennesseaux, C. Ropert, M. Do, and M. Duc, "Influence of Aggregate Minerals Hardness and Quartz Content on Long-Term Pavement Friction and Wear : An Experimental Analysis," *Wear*, p. 206030, 2025.
[26] Bina Marga, *Spesifikasi umum 2018 untuk Pekerjaan Konstruksi Jalan dan Jembatan (revisi 2)*. Indonesia, 2020.
[27] British Standard, "BS EN 1097-8 : 2020 : Tests for Mechanical and Physical Properties of Aggregates." 2020.
[28] S. Sukirman, *Beton Aspal Campuran Panas*, Edisi Ketiga. Institut Teknologi Nasional Bandung, 2016.