Research Inventy: International Journal of Engineering and Science
Vol.16, Issue 11 (November 2026), PP 31-35
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

The Effect of Aggregate Sampling Distance on The Tensile Strength of AC-WC Asphalt Concrete Wearing Course Mixtures

Kasmini Ibrahim[1], Syamsul Arifin[2], Arief Setiawan[3]
[1] *Postgraduate Student, Department of Civil Engineering, Tadulako University*
[2] *Civil Engineering Study Program, Faculty of Engineering, Tadulako University*
[3] *Civil Engineering Study Program, Faculty of Engineering, Tadulako University*

ABSTRACT
The use of aggregates from the Labuan River, Donggala Regency, Central Sulawesi, as road pavement materials needs to be supported by research into their characteristics and their ability to maintain the performance of asphalt mixtures. The distance of material extraction from the river mouth may indicate differences in material characteristics at each sampling point due to transportation, abrasion, and sedimentation processes, which may affect the tensile strength of AC-WC (Asphalt Concrete-Wearing Course) mixtures. Testing was conducted using aggregates collected from five sampling points located 100 m, 200 m, 300 m, 400 m, and 500 m from the Labuan River mouth, with 60/70 penetration-grade asphalt. The mixture characteristics were determined through the Marshall test, while tensile strength was evaluated using the Indirect Tensile Strength (ITS) test. The results show that the tensile strength of the AC-WC mixture tends to increase as the aggregate sampling distance increases. The ITS values among locations differed only slightly, ranging from 0.066 to 0.069 kg/mm². XRF results indicate that the chemical composition of the aggregates was relatively homogeneous and dominated by SiO_2, at 58.422%–59.421%, providing supporting information on the material characteristics. Overall, variations in aggregate sampling distance from the river mouth indicate relatively small differences in the ability of AC-WC mixtures to withstand indirect tensile stress.

Keywords: *AC-WC, Labuan River Aggregate, Tensile Strength, XRF*

Date Of Submission: 10-10-2026 Date Of Acceptance: 22-11-2026

I. INTRODUCTION

Infrastructure development, particularly in the land transportation sector, continues to increase significantly in line with population growth and expanding economic activities in various regions of Indonesia. In infrastructure construction, the availability of construction materials is a key factor, particularly aggregate materials such as sand and gravel, which are used in concrete mixtures, asphalt mixtures, and road pavement construction.

The tensile strength of asphalt concrete is an important mechanistic parameter in road pavement design. It describes the mixture's response to tensile stress under applied loading. This parameter is expressed in psi (pounds per square inch) or MPa. The modulus is used in deflection analysis (FWD), overlay thickness design, stress-strain calculations, and mechanistic simulations of pavement-layer behavior (Sukirman, Silvia, 2016, Hot Mix Asphalt Concrete).

In addition to conventional mechanical properties, understanding the geochemistry of local andesite through X-Ray Fluorescence (XRF) testing is necessary to identify dominant compounds such as silica (SiO_2), which is hydrophilic. The geochemical characteristics of rocks can be determined from their chemical composition, including the concentrations of oxides and elements present in rock samples (Oggier et al., 2023). This experimental study aims to identify aggregate characteristics at several sampling distances from the river mouth and to examine their effects on the tensile strength of AC-WC mixtures, with reference to the 2025 General Specifications for Road and Bridge Works.

II. RESEARCH METHODOLOGY

A quantitative approach was used to process laboratory test data in order to produce objective and measurable analyses. Materials were collected directly from the submerged riverbed flow of the Labuan River at five sampling points, each separated by 100 m from the river mouth: Point 1 (100 m), Point 2 (200 m), Point 3 (300 m), Point 4 (400 m), and Point 5 (500 m). The binder used was 60/70 penetration-grade asphalt.

Aggregate physical-property testing referred to the 2025 General Specifications for Road and Bridge Pavement and the BSI standards. The tests included the flakiness and elongation indices, Los Angeles abrasion, specific gravity, and water absorption.

The AC-WC mix design used planned asphalt content variations of 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%, with mechanical compaction of 75 blows per side to simulate heavy traffic. The Optimum Asphalt Content (OAC) for the aggregate from each location was determined from Marshall volumetric-property graphs. After the OAC values had been obtained, new specimens were prepared for evaluation using the Indirect Tensile Strength (ITS) test.

III. RESULTS AND DISCUSSION

3.1 Test Results of Materials Used in the AC-WC Mixture

Aggregate testing was conducted to determine whether the materials complied with the 2025 General Specifications for Road and Bridge Construction for use in AC-WC mixtures. The tests covered the flakiness and elongation indices, specific gravity, absorption, Los Angeles abrasion, and sieve analysis.

Table 3.1. Flakiness Index and Elongation Index Test Results

Test type	Point 1	Point 2	Point 3	Point 4	Point 5	Specification
Flakiness, 3/4 in aggregate	7.26	8.15	7.22	8.48	9.68	Max. 25%
Elongation, 3/8 in aggregate	6.93	7.06	7.08	7.50	8.18	Max. 25%
Flakiness, 3/4 in aggregate	12.28	11.66	12.46	9.64	10.26	Max. 25%
Elongation, 3/8 in aggregate	18.86	19.97	19.71	22.52	22.18	Max. 25%

Based on the test data in Table 3.1, all flakiness and elongation values for the 3/4-in and 3/8-in aggregates meet the BSI specification because they are below the maximum limit of 25%. Aggregates with lower flakiness and elongation values tend to produce higher stability because their more proportionate particle shapes create stronger interlocking.

Table 3.2. Specific Gravity and Absorption Test Results for Coarse Aggregate

Test type	Point 1	Point 2	Point 3	Point 4	Point 5	Specification
Bulk specific gravity	2.634	2.646	2.651	2.661	2.652	Max. 3%*
SSD specific gravity	2.670	2.679	2.688	2.682	2.677	Max. 3%*
Apparent specific gravity	2.733	2.736	2.753	2.718	2.719	Max. 3%*
Absorption (%)	1.378	1.251	1.399	0.777	0.931	Max. 3%

Table 3.3. Specific Gravity and Absorption Test Results for Fine Aggregate

Test type	Point 1	Point 2	Point 3	Point 4	Point 5	Specification
Bulk specific gravity	2.604	2.627	2.606	2.595	2.607	Max. 3%*
SSD specific gravity	2.645	2.663	2.659	2.652	2.659	Max. 3%*
Apparent specific gravity	2.715	2.724	2.752	2.751	2.751	Max. 3%*
Absorption (%)	1.562	1.355	2.036	2.176	2.014	Max. 3%

Based on Tables 3.2 (coarse aggregate) and 3.3 (fine aggregate), all results generally comply with the 2025 General Specifications. The absorption values consistently remain below the maximum limit of 3%, ranging from 0.777% to 1.399% for coarse aggregate and from 1.355% to 2.176% for fine aggregate.

Table 3.4. Los Angeles Abrasion Test Results

Test type	Point 1	Point 2	Point 3	Point 4	Point 5	Specification
3/4-in aggregate	19.80	19.86	19.78	19.33	19.81	Max. 40%
3/8-in aggregate	21.20	21.24	20.89	21.02	21.19	Max. 40%

Based on Table 3.4, the abrasion values for the 3/4-in and 3/8-in aggregates at all sampling points range from 19.33% to 21.24%. These values are below the specification's maximum limit of 40%, indicating that the aggregates have good quality and resistance to friction and traffic loading.

The test results show that aggregates from all sampling-distance variations meet the requirements specified. Nevertheless, differences in aggregate absorption and abrasion values occur among the sampling locations. These differences indicate that aggregate sampling distance may affect the quality of the materials used in the mixture.

3.2 Asphalt Test Results

Table 3.5. Asphalt Test Results

Test type	Result	2025 General Specification requirement
Penetration (0.1 mm)	66.5	60/70
Softening point (°C)	48.25	Min. 48
Ductility (cm)	128.25	Min. 100
Specific gravity	1.078	Min. 1.0

Asphalt testing was conducted to determine the characteristics of the penetration-grade asphalt used as the binder in the AC-WC mixture. The tests included penetration, softening point, ductility, and specific gravity. The results show that all asphalt parameters remain within the required specification limits. The penetration value indicates a level of asphalt hardness suitable for flexible pavement, while the ductility value indicates the asphalt's ability to deform without cracking. Asphalt with suitable characteristics improves the bond between aggregate and asphalt, thereby enhancing the stability and durability of the AC-WC mixture.

3.3 X-Ray Fluorescence (XRF) Test Results

Testing of the mineral content of the aggregates was conducted to determine the composition of the elements or oxides making up the aggregate materials at each sampling point.

Table 3.6. XRF Test Results

Mineral content (%)	Point 1	Point 2	Point 3	Point 4	Point 5
SiO_2	58.422	59.002	58.794	59.421	58.406
CaO	3.583	3.445	3.445	3.609	3.454
Al_2O_3	18.262	17.488	18.343	18.220	18.427
Fe_2O_3	7.570	7.599	7.652	7.428	7.704
MgO	7.209	7.025	6.880	6.671	7.306
Na_2O	1.808	1.970	1.693	1.574	1.522
K_2O	1.860	1.835	1.870	1.790	1.795

X-Ray Fluorescence (XRF) testing was conducted to determine the chemical composition of aggregates from the five Labuan River sampling points. In this study, the SiO_2 content was combined with the Na_2O and K_2O contents using the Total Alkali-Silica (TAS) approach. The TAS diagram developed by Le Bas et al. (1986) is a chemical classification system for volcanic rocks that uses SiO_2 as the parameter on the horizontal axis and the sum of Na_2O and K_2O as the parameter on the vertical axis. The calculated SiO_2 and $Na_2O + K_2O$ values for each sampling point are presented in Table 3.7.

Table 3.7. TAS Diagram Calculation Results

Sample	SiO_2 (%)	Na_2O (%)	K_2O (%)	$Na_2O + K_2O$ (%)
Point 1	58.422	1.808	1.860	3.668
Point 2	59.002	1.970	1.835	3.805
Point 3	58.794	1.693	1.870	3.563
Point 4	59.421	1.574	1.790	3.364
Point 5	58.406	1.522	1.795	3.317

Figure 3.1. Total Alkali-Silica (TAS) Diagram

The TAS diagram plot results show that points T1, T2, T3, T4, and T5 fall within the andesite field. The same classification field for T1 to T5 indicates that there is no change in the chemical characteristics represented by SiO_2 and $Na_2O + K_2O$ over the sampling-distance range of 100–500 m from the Labuan River mouth.

3.4 Marshall Mixture Characteristics and Determination of Optimum Asphalt Content (OAC)

The planned asphalt content was determined based on aggregate characteristics and the percentage of aggregate in the mixture. In this study, asphalt content was varied at 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%. Marshall testing of the AC-WC mixtures was conducted to determine mixture characteristics based on aggregate sampling-distance variations from Point 1 to Point 5. The analyzed parameters included stability, flow, VIM, VMA, VFB, and Marshall Quotient (MQ).

The optimum asphalt content was determined based on Marshall parameters that met the specifications. The resulting OAC represents a balance among mixture stability, flexibility, durability, and density, enabling optimal performance throughout the service life.

Based on the analysis of all Marshall parameters, different Optimum Asphalt Content (OAC) values were obtained for each sampling point. Point 1 had an OAC of 6.1%; Point 2, 6.05%; Point 3, 6.0%; Point 4, 6.03%; and Point 5, 6.02%.

3.5 Tensile Strength Test Results of the AC-WC Mixture

The Indirect Tensile Strength (ITS) test is a method used to measure the tensile force in an asphalt mixture. The ITS test was conducted to evaluate the ability of the asphalt mixture to withstand indirect tensile stress caused by traffic loading and to determine the mixture's resistance to cracking under indirect tensile loading. This test used a modified Marshall apparatus equipped with ITS loading heads at a test temperature of 25°C.

Table 3.8. Summary of Average Indirect Tensile Strength (ITS) Values

Sampling point	Average ITS (kg/mm²)	Description
Point 1	0.066	Initial ITS value
Point 2	0.067	Increase
Point 3	0.067	ITS value remains relatively constant
Point 4	0.068	Increase
Point 5	0.069	Increase; highest ITS value

Figure 3.2. Aggregate Sampling Distance and Mixture Tensile Strength (ITS)

Based on the graph, the increase in ITS values indicates that aggregates from locations farther from the river mouth produce AC-WC mixtures with a greater ability to withstand indirect tensile stress. However, the differences in ITS values among locations are relatively small, ranging from 0.066 to 0.069 kg/mm².

To test the data obtained from laboratory testing at each sampling point, statistical analysis was conducted using the Analysis of Variance (ANOVA) method to examine variation in the aggregate characteristics from the five sampling points.

Table 3.9. Single-Factor ANOVA Analysis Results

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	224898.9	4	224898.97	17.99191	0.002831	3.517655
Within groups	100000	8	12500			
Total	324898.9	9				

The Single-Factor ANOVA test was conducted to determine differences in Indirect Tensile Strength (ITS) values among the five distance variations. The ANOVA results produced a P-value of 0.002831, which is lower than the significance level of 0.05. Therefore, H_0 is rejected, indicating that there is a statistically significant difference among the mean values of the data groups tested.

IV. CONCLUSIONS

Based on the research into the effect of aggregate sampling distance on the tensile strength of Asphalt Concrete-Wearing Course (AC-WC) mixtures using aggregates from the Labuan River, the following conclusions can be drawn:

1. The characteristics of Labuan River aggregates collected at distances of 100–500 m from the river mouth show differences in several physical properties. Nevertheless, all aggregates meet the 2025 Bina Marga General Specifications for use in AC-WC mixtures based on specific gravity, absorption, Los Angeles abrasion, and gradation test results.
2. Aggregate sampling distance affects the tensile strength (Indirect Tensile Strength/ITS) of AC-WC mixtures. Differences in aggregate characteristics at each sampling location result in differences in the mixture's ability to withstand indirect tensile stress.
3. The increase in ITS values indicates that aggregates from locations farther from the river mouth produce AC-WC mixtures with a greater ability to withstand indirect tensile stress. However, the differences in ITS values among locations are relatively small, ranging from 0.066 to 0.069 kg/mm².
4. The relatively uniform mineral composition at each sampling point, dominated by SiO_2 (58.406%–59.421%), indicates that the aggregates have suitable characteristics as constituent materials for AC-WC mixtures.
5. Variations in aggregate sampling distance from the Labuan River mouth, based on the t-Test: Paired Two Sample for Means analysis, show a statistically significant difference in the mean Indirect Tensile Strength (ITS) values of AC-WC mixtures at the 5% significance level.

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