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Performance assessment of glass powder as filler in AC-WC asphalt exposed to Bekasi River Water

Ardhya Alga Lingga[1], Muhamad Abdul Hadi[1*]
[1] Department of Civil Engineering, Universitas Islam Indonesia, Yogyakarta, Indonesia

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Corresponding Author:
Muhamad Abdul Hadi
muhamad.abdul.hadi@uii.ac.id

Abstract

Frequent flooding in Indonesia causes significant infrastructure damage, including deterioration of asphalt pavements. Bekasi City was selected as the study area due to its river system characteristics, which make the region highly susceptible to prolonged inundation. This study evaluates glass powder (GP) as an alternative filler in AC-WC mixtures and examines performance under simulated flooding. Five GP substitution levels (0%, 25%, 50%, 75%, and 100%) were tested and immersed in Bekasi River water for 0, 24, and 48 hours. Performance was assessed through Marshall Standard (MS), Indirect Tensile Strength (ITS), Index of Retained Strength (IRS), Tensile Strength (TSR), and Cantabro Loss (CL) testing. Results show that GP affects all performance parameters, with 75% substitution exhibiting the best behavior among modified mixtures. However, all GP mixtures showed lower stability and ITS compared to the control, and full substitution (100%) resulted in the greatest performance decline. Longer immersion further reduced stability, ITS, TSR, and IRS while increasing flow, indicating higher moisture susceptibility. CL decreased with GP addition except at 100% substitution or extended immersion, where mass loss increased. Overall, while 75% GP substitution showed the best relative performance and remained functional up to 24 hours of immersion, long-term soaking led to significant degradation. GP shows potential as a sustainable filler, but improvements are required for use in flood-prone areas.

Introduction

Flooding is a critical and recurring issue in Indonesia, occurring annually and exerting a significant impact on infrastructure. Over the past five years, a total of 8548 flood events have been recorded across various regions of the country, with West Java Province reporting the highest frequency, accounting for 11,69% of the national total. One of the major flood events occurred in the Greater Jakarta (Jabodetabek) area in early 2020, where Bekasi City suffered considerable losses. This was attributed to the lower topography of the Bekasi River, which receives upstream flow from two tributaries, Cikeas and Cileungsi River, originating from Bogor City. The river's limited capacity was insufficient to accommodate the excess volume of water, resulting in widespread inundation in several areas (Rojali & Elsari, 2020).

Water accumulation on pavement surfaces can reduce durability and shorten pavement service life. Prolonged exposure to moisture can lead to various forms of damage, including stripping, cracking, and the deterioration of structural integrity. Moisture accelerates the stripping process, which involves the detachment of asphalt from aggregate surfaces, eventually triggering surface failures such as rutting, raveling, and cracking (Sarkar & Elseifi, 2023). The loss of

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adhesion between asphalt and aggregate directly contributes to the accelerated degradation of pavements under repeated traffic loading (Alam & Aggarwal, 2020)

The use of filler materials in asphalt mixtures has been shown to significantly enhance pavement performance. Numerous previous studies have evaluated the effectiveness of conventional fillers, such as stone dust and limestone (Upoma, et al., 2024), both of which are widely used as standard materials for assessing asphalt mixture quality. Nevertheless, the application of waste materials as filler substitutes in asphalt mixtures remains limited in Indonesia. Several studies have explored the potential of alternative fillers in asphalt mixtures, including bamboo leaf ash, steel slag powder (Osuolale, et al. 2023), construction brick waste (Palinggi, 2020), volcanic ash (Sufanir, et al., 2020), talc powder (Chasanah & Sukmo, 2023), recycled plastic bottle waste (Widojoko & Purnamasari, 2012), fluorescent lamp waste (Gedik et al., 2021), and glass powder (Sucipto & Sari, 2021). Although research has examined the effects of using glass powder as a filler on the properties of AC-WC mixtures, no studies to date have specifically investigated the behavior of such mixtures under soaking conditions that simulate flood inundation. Therefore, this study aims to evaluate the effects of substituting conventional filler with glass powder on the structural strength and durability of AC-WC mixtures after immersion. The evaluation criteria include structural strength parameters assessed through Marshall and Indirect Tensile Strength (ITS) tests, as well as durability indicators under moisture exposure measured by the Index of Retained Strength (IRS), Tensile Strength Ratio (TSR), and Cantabro Loss (CL).

Materials and Methods

This study employed an experimental method by conducting a series of laboratory tests to obtain data, which were then evaluated against relevant standards and specifications. All material characterization and testing procedures adhered to the guidelines set by AASHTO and Indonesian standard of Bina Marga 2018 Revision 2.

Materials

This study utilized a range of materials, including coarse aggregate, fine aggregate, filler, asphalt binder, and river water. The coarse and fine aggregates, as well as conventional stone dust filler, were sourced from a stone crusher in Clereng, Yogyakarta. Additionally, glass powder, used as an alternative filler, was produced from processed waste glass bottles collected in Pasuruan, East Java. The asphalt binder was Penetration Grade 60/70, manufactured by Pertamina. River water, simulating flood-induced submersion conditions, was collected from the Bekasi River. Physical properties of the aggregates, filler, and asphalt were assessed at the Highway Engineering Laboratory, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, while water quality analysis and observing microscopic magnification of GP filler was conducted at the Water Quality and Environmental Laboratory within the same faculty. No chemical analysis was performed on the glass powder in this study, however, its chemical composition, as reported by [15] comprises 29,17% SiO_2, 16,51% CaO, 18,85% Al_2O_3, 6,97% Fe_2O_3, 2,60% MgO, 10,72% Na_2O, 0,65% K_2O, 0,87% SO_3, and 13,66% other components, with no detectable $CaCO_3$. The high silica (SiO_2) and alkali (Na_2O, K_2O) content may influence the filler's interaction with moisture, potentially affecting asphalt mixture performance under submersion conditions.

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(a) Physical Form

(b) Under Microscopic Magnification

Figure 1. Glass Powder Filler

Methods

In the initial stage, physical property tests were conducted on the constituent materials, including asphalt, coarse aggregate, fine aggregate, and filler, as presented in Tables 2 to 4, following the procedures outlined in the Spesifikasi Umum Bina Marga 2018 Revision 2. Additionally, the quality of river water, specifically pH and turbidity was measured, as shown in Table 5. Subsequently, the AC-WC mixture gradation was designed based on the target gradation curve in Table 1. The optimum asphalt content (OAC) was determined through the Marshall test using various asphalt contents to obtain the highest stability and lowest flow values. Once the OAC was established, specimens were prepared by substituting glass powder filler at five levels, 0%, 25%, 50%, 75%, and 100% of the total filler weight.

Each substitution group was then subjected to immersion treatments in water at laboratory temperature (25 ± 2 °C) for 0, 24, and 48 hours. This treatment aimed to simulate flood-induced inundation conditions. Following immersion, the samples were tested using five methods namely Marshall, ITS, IRS, TSR, and CL. The test results were analyzed to evaluate the effect of glass powder filler substitution on the structural strength and durability of the AC-WC mixture after water exposure.

Table 1. AC-WC Mixture Gradation Plan

Sieve Size		Spec. (%)		Gradation Plan (%)	
Inches	mm	Min	Max	Passed	Retained
3/4"	19	100	100	100	0
1/2"	12,5	90	100	95	5
3/8”	9,5	77	90	83,5	16,5
4	4,75	53	69	61	39
8	2,36	33	53	43	57
16	1,18	21	40	30,5	69,5
30	0,6	14	30	22	78
50	0,3	9	22	15,5	84,5
100	0,15	6	15	10,5	89,5
200	0,075	4	9	6,5	93,5
Pan		0	0	0	100

Results

Result include material properties and determination of OAC.

Material Properties

Physical property testing was conducted on the asphalt, aggregate, and filler materials, with the results presented in Tables 2 to 4. Additionally, Table 5 provides the water quality test results from the Bekasi River, which was used in this study.

Table 2. Asphalt Binder Properties Test

Parameters	Spec.	Result
Specific gravity	≥ 1,0	1,040
Penetration (mm)	60-70	64
Ductility (cm)	≥ 100	134,5
Softening point (°C)	≥ 48	48,5
Flash point (°C)	≥ 232	308
Fire point (°C)	≥ 232	313
Solubility in TCE (%)	≥ 99	99,51

Table 3. Aggregate Properties Test

Parameters	Spec.	Result
Coarse Aggregate		
Specific gravity	≥ 2,5	2,57
Water absorption (%)	≤ 3	2,59
Aggregate adhesion to asphalt (%)	≥ 95	97
Aggregate abrasion (%)	≤ 40	12,20
Fine Aggregate		
Specific gravity	≥ 2,5	2,65
Water absorption (%)	≤ 3	2,61
Sand equivalent (%)	≥ 50	71,62

Table 4. Filler Specific Gravity Test

Parameters	Result
Stone Dust	2,54
Glass Powder	2,36

Table 5. River Water Quality Test

Parameters	Unit	Result
		APS.006
Turbidity	NTU	3,62 ± 1,04
pH	-	6,49 ± 0,24

Determination of OAC

The determination of the OAC was based on the results of Marshall characteristics testing, which included stability, flow, density, MQ, VITM, VFWA, and VMA. All tests were performed in accordance with SNI 06-2489-1991. A summary of the Marshall test results used to determine the OAC is presented in Table 6.

Table 6. Marshall Test Results to Determine OAC

Asphalt Content (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)	VITM (%)	VFWA (%)	VMA (%)	Density (gr/cc)
5	1048,28	3,48	300,94	8,75	54,88	19,40	2,21
5,5	1107,53	3,55	312,27	6,33	65,37	18,26	2,26
6	1265,76	3,77	335,45	3,96	77,02	17,22	2,30
6,5	1116,40	3,83	291,23	3,35	81,08	17,71	2,30
7	1077,25	3,98	270,67	3,18	82,86	18,56	2,29
Spec	> 800	2-4	>250	3-5	>68	>15	>2

Based on these test results, the OAC was determined using the graphs shown in Figure 2. It was found that the optimum asphalt content used for the AC-WC mixture is 6,37%.

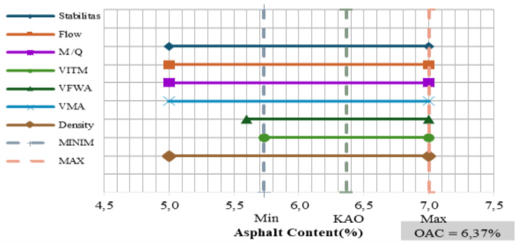


Figure 2. Graph of OAC Determination for the AC-WC Mixture

Following the determination of the OAC, the next stage involved preparing test specimens with glass powder filler substitution based on the identified OAC. These specimens were then submerged in Bekasi River water to evaluate the effects on the asphalt mixture. The parameters tested included Marshall standard, ITS, IRS, TSR, and CL. A summary of the test results is provided in Table 7 and Table 8.

Table 7. Marshall and Volumetric Properties on AC-WC Mixture

Filler Content (%)	**Stability (kg)**	**Flow (mm)**	**MQ (kg/mm)**	**VITM (%)**	**VFWA (%)**	**VMA (%)**	**Density (gr/cc)**
0 Hour of Immersion							
0	1363,22	3,26	420,81	3,69	79,28	17,73	2,29
25	1284,87	3,09	423,09	4,15	77,15	18,11	2,28
50	1329,42	2,81	476,26	3,83	78,54	17,83	2,29
75	1351,55	2,70	504,48	3,76	78,90	17,76	2,28
100	1240,00	3,46	359,96	4,39	76,07	18,28	2,27
24 Hour of Immersion							
0	1154,10	3,76	308,89	3,65	79,39	17,70	2,29
25	1061,13	3,59	306,20	4,07	77,44	18,05	2,28
50	1097,45	3,31	339,52	3,88	78,36	17,87	2,28
75	1148,37	3,14	368,58	3,74	78,94	17,73	2,29
100	1022,68	3,84	265,63	4,44	75,89	18,32	2,27

Table 7. Marshall and Volumetric Properties on AC-WC Mixture (continued)

Filler Content (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)	VITM (%)	VFWA (%)	VMA (%)	Density (gr/cc)
48 Hour of Immersion							
0	956,55	4,06	236,67	3,69	79,22	17,74	2,29
25	916,73	3,96	236,84	4,09	77,39	18,06	2,28
50	952,07	3,72	256,77	3,82	78,72	17,82	2,29
75	982,15	3,62	271,72	3,77	78,85	17,76	2,28
100	883,87	4,26	215,29	4,26	76,61	18,16	2,27
Specification	> 800	2-4	>250	3-5	>68	>15	>2

Table 8. Moisture Susceptibility, Cracking Resistance, and Durability of AC-WC Mixture

Filler Content (%)	ITS (kPa)	IRS (%)	TSR (%)	CL (%)
0 Hour of Immersion				
0	140,60	96,82	96,35	2,75
25	130,80	96,22	94,77	3,47
50	137,47	95,93	92,23	3,11
75	138,47	95,31	91,11	2,94
100	122,37	93,95	84,65	3,65
24 Hour of Immersion				
0	128,00	94,70	93,71	3,08
25	118,92	93,40	91,15	3,84
50	125,52	92,59	88,86	3,50
75	127,47	91,47	87,05	3,37
100	107,15	89,45	80,85	4,12
48 Hour of Immersion				
0	121,82	91,65	89,86	3,51
25	111,99	90,59	87,58	4,23
50	118,60	89,44	85,66	4,03
75	120,95	88,82	82,48	3,88
100	97,35	86,99	77,73	5,00
Specification	-	> 90	> 80	< 20

Discussion

Discussion of research results consists of Marshall Standard Characteristics, Indirect Tensile Strength (ITS), Index of Retained Strength (IRS), Tensile Strength Ratio (TSR), and Cantabro Loss (CL).

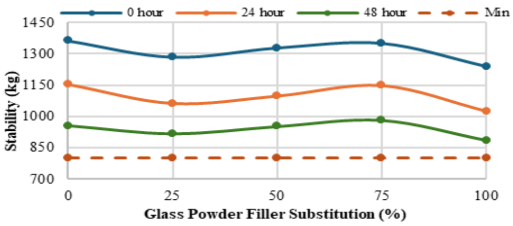
Marshall Standard Characteristics

Table 7 shows that VITM increases at 25% GP substitution, decreases through 75%, and rises sharply at 100%. This pattern indicates that glass powder influences void structure, where improved particle packing reduces voids up to the 75% substitution level, while void expansion occurs at 25% due to filler imbalance and at 100% due to reduced binder–aggregate adhesion. These findings are consistent with Kifile et al. (2024), Kalampokis et al. (2023), and Tang et al. (2015), who reported that glass powder improves compaction up to an optimum content before cohesion and overall mixture structure deteriorate.

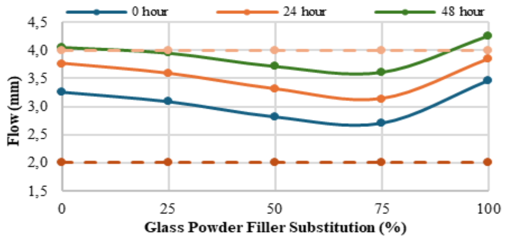
VMA values exhibit a corresponding pattern to VITM, decreasing from 25% to 75% substitution as the glass powder progressively occupies voids between aggregate particles, resulting in a denser mix. As supported by Choudhary et al. (2021), higher glass powder content generally contributes to more effective void filling, thereby lowering VMA.

For VFWA, the results show an increasing trend up to 75% substitution, suggesting improved binder distribution and void filling efficiency when glass powder is incorporated at moderate levels. However, beyond 75%, VFWA declines sharply, indicating that excessive glass powder disrupts binder cohesion and reduces the effectiveness of asphalt in occupying voids. This supports the argument that optimal substitution exists where particle geometry improves mix performance before excess filler undermines binder–aggregate bonding.

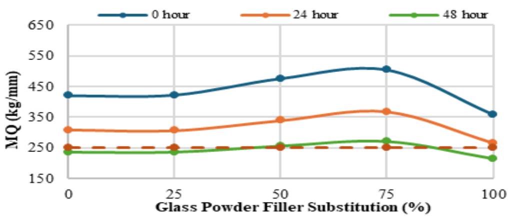
Density results further support these observations, showing a general upward trend with increasing substitution. However, variations remain below 0.5%, indicating no statistically significant change across the substitution levels. Minor reductions observed at 25% and 100% substitution correspond to increases in void content and reduced adhesion efficiency, especially when glass powder is used in full replacement. This behavior aligns with Ogundipe & Nnochiri (2020), who concluded that asphalt mixture density increases with glass powder substitution up to an optimum level, after which additional glass powder adversely impacts cohesion and mix stability.



(a) Stability



(b) Flow



(c) MQ

Figure 3. Marshall Standard Test Results with GP Substitution

Figure 3.a shows that the use of glass powder filler affects the stability of the AC-WC mixture, where stability decreases at 25% substitution, reaches its highest point at 75%, and declines sharply at 100%. Despite these fluctuations, all mixtures containing glass powder still demonstrate lower stability compared to the control mixture. This pattern indicates that while partial substitution may temporarily optimize particle packing and improve performance, glass powder generally results in lower stability than stone dust due to its lower specific gravity, which produces a less dense mixture. Up to 75% substitution, the angular shape of the glass particles appears to enhance void filling and binder cohesion, contributing to the observed peak stability. However, at 25% substitution, the interaction between filler and binder is not yet optimal, resulting in reduced stability. At 100% substitution, the smooth surface texture of the glass powder weakens asphalt adhesion and increases voids, leading to a significant decline in stability. In Figure 3.a also shows that longer submersion in acidic Bekasi River water reduces stability as water infiltration and turbid particles weaken asphalt-aggregate bonds. This aligns with Kabo, et al., (2021) noted that the presence of moisture can reduce the stability value.

Figure 3.b shows flow values in AC-WC mixtures decreasing with GP substitution up to 75%, then rising sharply at 100%. Reduced flow up to 75% stems from void filling and angular GP particles enhancing stiffness. At 100%, smooth GP surfaces weaken asphalt adhesion, increasing voids and plasticity. This aligns with Hasan, et al., (2025), noting lower flow with improved density. Extended immersion in Bekasi River water increases flow, indicating structural weakening and deformation susceptibility, mirroring stability declines. This aligns with Susilowati, et al., (2019), which noted that the longer the immersion duration, the lower the durability of the pavement. Per Bina Marga 2018 Revision 2, flow values at 0% and 100% GP after 48 hours exceed the 2–4 mm range, failing specifications.

Figure 3.c shows MQ in AC-WC mixtures peaking at 75% GP substitution, reflecting enhanced stiffness due to high stability and low flow from effective void filling. At 100%, MQ drops sharply as smooth GP surfaces weaken asphalt adhesion, increasing voids. At 0%, high stability is offset by high flow, indicating plasticity.

Indirect Tensile Strength (ITS)

ITS is a critical measure of an asphalt mixture's resistance to cracking caused by repeated traffic loads or temperature fluctuations. Higher ITS values indicate greater cracking resistance and improved mixture quality. Figure 4 presents ITS test results, illustrating the impact of GP filler substitution on the tensile strength of AC-WC mixtures

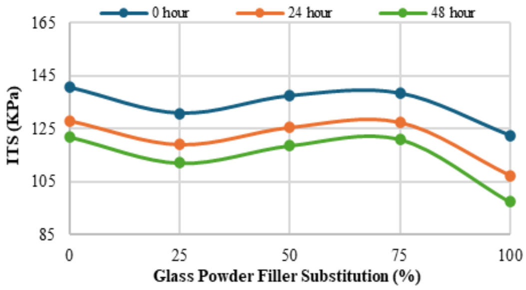


Figure 4. ITS Test Results with GP Substitution

Figure 4 shows that although ITS values fluctuate with varying GP substitution levels—with a decrease at 25%, a peak at 75%, and a sharp reduction at 100% all mixtures containing glass powder still exhibit lower ITS than the control mix, as confirmed in Table 8. The initial reduction at 25% substitution is likely due to disruption of the established filler structure formed by stone dust, resulting in reduced cohesion. The relative increase observed at 75% substitution suggests an improved particle arrangement and more balanced filler interaction, which temporarily enhances tensile resistance. However, at 100% substitution, the smooth and fine-textured nature of glass powder weakens particle interlock and asphalt adhesion, resulting in a significant decrease in ITS. These findings agree with Suarez et al. (2014) and Yuniarti et al. (2019), who reported that ITS values increase up to an optimum GP content before declining beyond that threshold.

The results further indicate that prolonged immersion in Bekasi River water leads to progressive reductions in ITS, reflecting moisture-induced damage and weakened asphalt–aggregate bonding. This trend is consistent with Mataram et al. (2021), who observed reduced ITS in AC-WC mixtures with extended immersion exposure.

Index of Retained Strength (IRS)

The IRS test evaluates cohesion loss in compacted asphalt mixtures due to moisture, serving as a key indicator of moisture resistance. Figure 5 illustrates IRS results, highlighting the effect of GP filler substitution on the tensile strength of AC-WC mixtures.

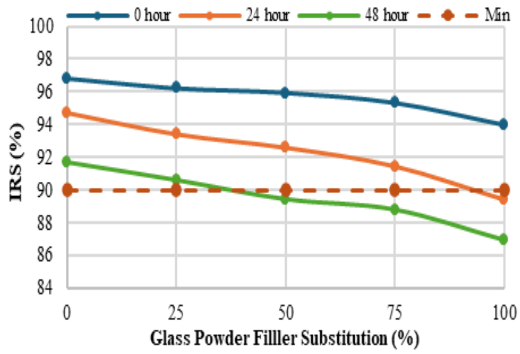


Figure 5. IRS Test with GP Substitution

From IRS value, it is demonstrated that conditioned asphalt AC-WC mixtures exhibit lower stability than unconditioned samples, primarily due to water infiltration weakening asphalt-aggregate bonds. The IRS decreases with increasing GP filler substitution, as shown in Figure 6, indicating reduced mixture performance. This decline results from the smooth surface of GP, which impairs adhesion between asphalt and aggregates, and its high silica content, which further diminishes bonding strength.

As shown in Figure 5, extended immersion in slightly acidic Bekasi River water further reduces IRS values, as prolonged exposure allows greater water penetration into mixture voids, detaching asphalt from aggregates and degrading structural integrity. Suspended particulates in turbid water exacerbate this by trapping moisture within voids. This corroborates Khaled, et al., (2024) who observed significant IRS reductions with longer immersion, particularly in mixtures with glass powder substitution. In Bina Marga 2018 Revision 2 Specifications, requiring a minimum IRS of 90%, mixtures with 100% GP substitution at 24 hours and 50%, 75%, and 100% at 48 hours fail to meet this standard.

Tensile Strength Ratio (TSR)

The TSR is determined by comparing the ITS of AC-WC samples submerged in a water bath for 24 hours to that of unsoaked samples, serving as an indicator of moisture resistance. Figure 6 presents the TSR values, illustrating the influence of GP filler substitution on the moisture susceptibility of the mixtures.

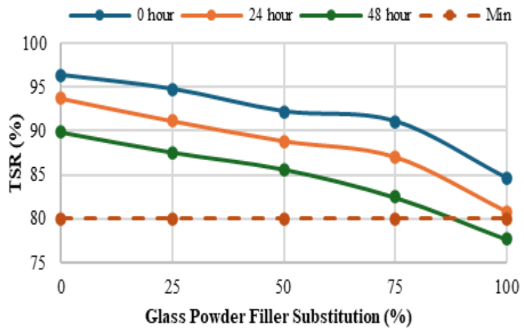


Figure 6. TSR Test with GP Substitution

Figure 6 indicates that TSR values for AC-WC mixtures without GP substitution surpass those with GP, suggesting reduced moisture resistance with GP use. The smooth GP surface impairs asphalt-aggregate adhesion, significantly lowering TSR at full substitution. This aligns with Choudhary, et al., (2021), who noted poor moisture resistance in GP-containing mixtures due to weak bonding. As shown in Figure 6, extended immersion in Bekasi River water further decreases TSR across all substitution levels, reflecting diminished tensile durability from prolonged water exposure.

Cantabro Loss (CL)

The CL test assesses the abrasion resistance of asphalt mixtures by rotating specimens in a Los Angeles abrasion machine, serving as an indicator of durability under traffic loading. Figure 7 illustrates CL values, highlighting the impact of GP filler substitution on asphalt mixture performance.

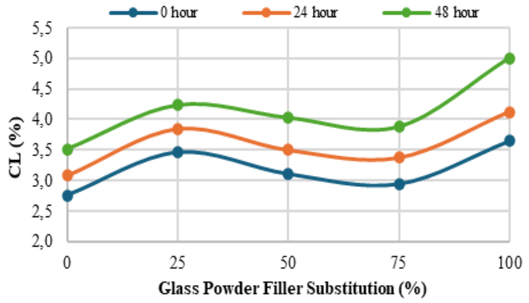


Figure 7. CL Test with GP Substitution

Figure 7 shows that, although the Cantabro Loss (CL) values fluctuate with the percentage of GP substitution—rising at 25%, reaching the lowest point at 75%, and increasing sharply at 100%—all GP-modified mixtures still exhibit higher CL compared with the control mixture, as confirmed in Table 9. This indicates that the use of GP generally reduces resistance to abrasion. The increase at 25% substitution may be attributed to an imbalance between GP and stone dust, which disrupts mixture stability and weakens aggregate interlock. The relative improvement observed at 75% suggests better void filling and denser packing, temporarily enhancing resistance against particle loss. However, at 100% substitution, the fine and smooth characteristics of GP reduce binder–aggregate adhesion, resulting in significant mass loss during abrasion.

Furthermore, Figure 7 shows that increasing immersion duration in Bekasi River water leads to progressively higher CL values. This trend reflects moisture-induced deterioration, where water penetration softens the asphalt binder and promotes aggregate stripping, ultimately increasing material disintegration. These results support findings by Yuniarti et al. (2019), who reported 75% as the optimum substitution level for minimizing CL, and

Harahap et al. (2023), who observed that prolonged moisture exposure accelerates surface degradation in AC-WC mixtures.

Conclusion

Based on the experimental findings, the following conclusions can be drawn regarding the effect of GP filler substitution and water immersion on the performance of AC-WC mixtures:

1. Glass powder (GP) substitution in AC-WC mixtures influenced performance across parameters, with 75% showing the most favorable behavior. However, all GP-modified mixtures demonstrated lower stability than the control, and full substitution (100%) resulted in clear performance deterioration. Immersion in river water further reduced stability and increased flow, indicating higher moisture susceptibility.

2. TSR and IRS consistently declined with higher GP content and longer soaking times, indicating increased susceptibility to moisture-induced stripping.

3. ITS values decreased for all mixtures containing GP compared with the control; however, within the GP-modified mixtures, ITS increased up to 75% substitution before declining sharply at 100%. Extended water immersion further reduced ITS, indicating increased vulnerability to moisture.

4. CL generally decreased with GP addition, except at 100 % replacement, where CL rose and increased with longer immersion, reflecting weakened resistance to moisture damage.

5. Among the GP-modified mixtures, the 75% substitution level showed the most favorable performance across the evaluated criteria; however, performance remained lower than the control mixture. This relative benefit was maintained only up to 24 hours of water exposure, after which significant deterioration was observed

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