FINAL PROJECT

PERFOMANCE OF ASPHALT CONCRETE - WEARING COARSE MIXTURE WITH GLASS POWDER FILLER AGAINST BEKASI RIVER WATER SUBMERSION

Submitted to The Universitas Islam Indonesia Yogyakarta as A Fulfillment of the Requirements to Obtain Civil Engineering Bachelor Degree

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I hereby declare that the Final Project report I have submitted, as a requirement for the completion of the Bachelor's degree Program in Civil Engineering, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, is entirely the result of my own work. Any sections of the report that reference or cite the work of others have been properly acknowledged in accordance with the norms, standards, and ethical guidelines for academic writing. If it is subsequently discovered that any part or the entirety of this report is not my original work or contains elements of plagiarism, I am prepared to accept any sanctions deemed appropriate, including the revocation of the academic degree awarded, in accordance with prevailing laws and regulations.

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Declaring the statement,

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DEDICATION

"Wonder is the beginning of wisdom" – Socrates

This Final Project is wholeheartedly dedicated to my beloved parents, who have answered every question I've ever had—patiently, thoughtfully, and lovingly—from the time I was a curious child until now. You have given me access to every bit of knowledge I longed to understand, never limiting my curiosity, always encouraging me to explore the world and all its wonders. You taught me that there is never anything wrong with learning, even when we don't yet know the purpose of what we're learning. Your acceptance of me, in every version of myself—whether lost or thriving—is something I hold closest to my heart.

And to my cat, Achilles, thank you for always being there for me. Even in your quietness, and even when you act a little mean, you have been the purrfect companion through it all. You supported me emotionally through every high and low, listened silently to everything I needed to say, and even though you couldn't respond—your presence meant more than words ever could.

I love you, always.

PREFACE

Praise be to Allah SWT for His divine guidance and blessings, which have enabled the author to complete this Final Project, entitled *"Performance of Asphalt Concrete-Wearing Course Mixture with Glass Powder Filler Against Bekasi River Water Submersion."* This Final Project is submitted as a partial fulfillment of the academic requirements for the Civil Engineering Undergraduate Program, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta.

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The author sincerely hopes that this Final Project will provide valuable insights and contribute to further discourse and development in the field of Pavement Engineering. Despite its limitations, it is hoped that this work may serve as a foundation for future research.

Yogyakarta 22nd July 2025

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LIST OF ABBREVIATIONS

AASHTO	=	American Association of State Highway and Transportation Officials
AC	=	Asphalt Concrete
AC-BC	=	Asphalt Concrete – Binder Course
AC-WC	=	Asphalt Concrete – Wearing Course
ASTM	=	American Society for Testing and Materials
CL	=	Cantabro Loss
GP	=	Glass Powder
IRS	=	Index of Retained Strength
ITS	=	Indirect Tensile Strength
MQ	=	Marshall Quotient
MS	=	Marshall Standard
OAC	=	Optimum Asphalt Content
SMA	=	Stone Mastic Asphalt
SNI	=	*Standar Nasional Indonesia*
SSD	=	Saturated Surface Dry
TSR	=	Tensile Strength Ratio
VFWA	=	Void Filled with Asphalt
VITM	=	Void in Total Mixture
VMA	=	Void in Mineral Aggregate

LIST OF NOTATIONS

a	=	Percentage of asphalt by aggregate (%)
A	=	Weight of pycnometer with lid (gr)
A	=	Percentage of coarse aggregate (%)
b	=	Percentage of asphalt by mix (%)
B	=	Weight of pycnometer filled with water (gr)
B	=	Percentage of fine aggregate (%)
c	=	Weight of specimen before immersion (gr)
C	=	Weight of pycnometer filled with asphalt (gr)
d	=	Weight of the specimen in SSD condition (gr)
D	=	Diameter sample (cm)
D	=	Weight of pycnometer filled with water and asphalt (gr)
e	=	Weight in water (gr)
f	=	Volume (cm^3)
F1	=	Specific gravity of coarse aggregate
F2	=	Specific gravity of fine aggregate
g	=	Density value (gr/cm^3)
h	=	Theoretical maximum specific gravity mixture
K	=	constant
l	=	VMA value (%)
L	=	Percentage of weight loss (%)
m	=	VFWA value (%)
Mi	=	Weight after abrasion (gr)
Mo	=	Weight before abrasion (gr)
n	=	VITM value (%)
P	=	Peak load (kg)
Pb	=	Asphalt content (%)
q	=	Stability value (kg)
r	=	Flow value (mm)
S1	=	Average MS value after immersion for 30 minutes (kg)
S2	=	Average MS value after immersion for 24 hours (kg)

s	=	Specimen thickness correction factor
t	=	Thickness of sample (cm)
T_1	=	Average of ITS value without immersion (kg)
T_2	=	Average of ITS after 24 hours of immersion (kg)

ABSTRACT

Seasonal heavy rainfall and poor water management make flooding a persistent issue in Indonesia. A major inundation occurred in Bekasi City in early 2020 due to river overflow and industrial pollution. Moisture intrusion accelerates asphalt pavement damage by reducing stiffness and cohesion. This study investigates the effect of substituting conventional filler with recycled glass powder (GP), rich in SiO_2, on the strength, durability, and volumetric properties of AC-WC under flood-like conditions.

Asphalt specimens using 0%, 25%, 50%, 75%, and 100% GP were prepared following Bina Marga 2018 standards. The optimum asphalt content was determined using the Marshall method with a Pertamina Pen 60/70 binder. Specimens were then submerged in Bekasi River water for 0, 24, and 48 hours. Performance tests included MS, ITS, IRS, TSR, and CL.

Results showed that GP significantly influenced structural strength and volumetric characteristics. Up to 75% GP increased MS, MQ, and ITS while reducing flow. At 100%, all parameters declined. Submersion for 24–48 hours reduced MS, MQ, and ITS and increased flow. GP substitution also increased VFWA and density, while decreasing VITM and VMA, with 100% GP showing the poorest values. Submersion duration had minimal effect on volumetric values. Durability was affected as IRS and TSR declined with higher GP and longer submersion, indicating more susceptibility to moisture-induced damage. CL values remained low except at 100% GP, but increased over time, suggesting reduced resistance to degradation. The optimal substitution was 75% GP, but only effective up to 24 hours of water exposure.

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Keywords: Glass Powder, Filler, AC-WC, Mixture Performance

ABSTRAK

Curah hujan musiman yang tinggi dan manajemen air yang tidak memadai menjadikan banjir sebagai permasalahan kronis di Indonesia. Salah satu kejadian banjir besar terjadi di Kota Bekasi pada awal tahun 2020 akibat luapan Sungai Bekasi yang diperparah oleh pencemaran industri. Infiltrasi kelembaban mempercepat kerusakan perkerasan aspal dengan menurunkan kekakuan dan kohesi. Penelitian ini mengevaluasi pengaruh substitusi filler konvensional dengan serbuk kaca daur ulang (GP) *yang kaya kandungan* SiO_2 *terhadap kekuatan, durabilitas, dan karakteristik volumetrik campuran* AC-WC *dalam kondisi simulasi genangan banjir.*

Spesimen campuran aspal dengan kandungan GP *sebesar* 0%, 25%, 50%, 75%, *dan* 100% *disiapkan sesuai dengan* Spesifikasi Umum Bina Marga 2018. *Kadar aspal optimum ditentukan menggunakan metode Marshall dengan aspal penetrasi* Pertamina Pen 60/70. *Selanjutnya, spesimen direndam dalam air Sungai Bekasi selama* 0, 24, *dan* 48 *jam. Pengujian kinerja meliputi* MS, ITS, IRS, TSR, *dan* CL.

Hasil menunjukkan bahwa substitusi GP *secara signifikan memengaruhi kekuatan struktural dan karakteristik volumetrik. Hingga* 75% GP *meningkatkan stabilitas,* MQ, *dan* ITS *serta menurunkan nilai* flow. *Pada tingkat* 100% GP, *seluruh parameter mengalami penurunan. Perendaman selama* 24–48 *jam menyebabkan penurunan nilai stabilitas,* MQ, *dan* ITS *serta peningkatan nilai* flow. *Substitusi* GP *juga meningkatkan nilai* VFWA *dan* density, *namun menurunkan* VITM *dan* VMA, *dengan penurunan paling signifikan pada* 100% GP. *Durasi perendaman tidak berdampak signifikan terhadap parameter volumetrik. Durabilitas menurun ditunjukkan oleh penurunan nilai* IRS *dan* TSR *seiring peningkatan kadar* GP *dan waktu perendaman, yang mengindikasikan meningkatnya kerentanan terhadap kerusakan akibat kelembaban. Nilai* CL *tetap rendah kecuali pada* 100% GP, *namun meningkat dengan bertambahnya waktu perendaman, yang menandakan penurunan ketahanan terhadap degradasi. Tingkat substitusi optimum adalah* 75% GP, *namun hanya efektif hingga perendaman selama* 24 *jam.*

Kata kunci: *Serbuk Kaca*, Filler, AC-WC, *Performa Campuran*

CHAPTER I
INTRODUCTION

1.1 Background of The Study

Flooding represents a major problem in Indonesia, driven by seasonal heavy rainfall and deficient water-management systems. Between 2020 and 2025, the National Agency for Disaster Countermeasure (BNPB) recorded 8543 flood incidents across the country, highlighting the scale of the challenge. One particularly severe event occurred in early 2020 within the *Jabodetabek* area, where Bekasi City experienced inundation across 12 sub-districts and 51 villages, affecting 366.274 inhabitants with water depths reaching 3 m. Prolonged moderate to intense rainfall precipitated substantial economic losses, although comprehensive damage estimates remain scarce.

The primary cause of flooding in Bekasi City was the overflow of the Bekasi River, which receives flow from the Cikeas and Cileungsi rivers in Bogor Regency. Rojali & Elsari (2020) attribute this overflow to high upstream discharges combined with Bekasi's relatively low elevation, which together exceed the river's carrying capacity. Compounding the problem, in September 2023 industrial effluents from Bogor Regency pollute the Bekasi River, a crucial source for *Perumda Tirta Patriot Bekasi*, further degrading water quality. The Ministry of Environment and Forestry reported slight pollution at the Bogor 1 monitoring station for 23 days and moderate pollution at the Citeureup (Bogor 2) station for 21 days, citing heavy metals and organic waste among the principal contaminants.

Water infiltration adversely affects asphalt pavements by diminishing their structural integrity and service life. According to AASHTO (1993), moisture can reduce the stiffness modulus of dry asphalt by over 30% and decrease base- and subbase-layer rigidity by up to 50%. In asphalt-treated base (ATB) layers, elevated moisture levels increase erosion risk, particularly in cement or lime

stabilised materials, leading to further performance degradation. Sarkar & Elseifi (2023) observes that water promotes stripping, meaning the detachment of asphalt binder from aggregate surfaces, which manifests as rutting, raveling and cracking. Alam & Aggarwal (2020) note that this loss of adhesion accelerates pavement deterioration under traffic loading.

To counteract moisture damage, researchers have investigated incorporating waste materials into asphalt mixes. Kandhal (1992) classifies waste additives into industrial, domestic, and mining categories, with glass waste falling into the domestic category. Liu, et al. (2015) identified the high silica-dioxide (SiO_2) content in glass waste as beneficial for enhancing binder–aggregate adhesion. Redden & Neithalath (2014) explored alkali activation of glass powder as an eco-friendly binder, reporting a composition of 72,5% SiO_2, 9,7% CaO, 13,7% Na_2O, 0,4% Al_2O_3, 0,2% Fe_2O_3, 3,3% MgO, and 0,1% K_2O. Their findings indicated that NaOH-activated glass powder achieved greater compressive strengths than fly-ash binders at lower curing temperatures.

Empirical studies have demonstrated the promise of glass waste as an asphalt filler. Yuniarti, et al. (2019) reported that replacing 75% of conventional filler with glass waste increased Marshall stability by 15% and reduced Cantabro loss by 10%, thereby improving both stiffness and durability under water immersion. Simone, et al. (2017) found that glass-powder-enhanced dense-graded mixtures exhibited a 20% increase in rutting resistance, as determined through rheological and mechanical testing.

Building on these insights, the present study evaluates the use of glass waste powder as a filler substitute in asphalt concrete wearing course (AC-WC) mixtures to enhance moisture resistance in flood-prone areas such as Bekasi City. Five mixture designs containing 0%, 25%, 50%, 75%, and 100% glass waste by filler mass were prepared with aggregates conforming to Indonesian specifications and a 60/70 penetration-grade binder. Specimens were immersed in Bekasi River water for 0, 24, and 48 hours to simulate flood conditions. Performance was assessed via the Marshall Standard (MS), Indirect Tensile Strength (ITS), Index of Retained Strength (IRS), Tensile Strength Ratio (TSR), and Cantabro loss (CL).

The primary objective is to identify the optimal glass-waste proportion that maximizes stability, strength, and moisture resistance in AC-WC mixtures.

1.2 Problem Statements

The problem statements of the research are:

1. How does the effect of glass powder as filler substitute AC-WC layer on structural strength characteristic based on various submersion times of Bekasi River water?
2. How does the effect of glass powder as filler substitute AC-WC layer on volumetric characteristic based on various submersion times of Bekasi River water?
3. How does the effect of glass powder as filler substitute AC-WC layer on durability characteristic based on various submersion times of Bekasi River water?

1.3 Objective of The Study

The objectives of the study are as follows:

1. Identify the effect of glass powder as filler substitute AC-WC layer on structural strength characteristics based on the various submersion times of Bekasi River water.
2. Identify the effect of glass powder as filler substitute AC-WC layer on volumetric characteristics based on the various submersion times of Bekasi River water.
3. Identify the effect of glass powder as filler substitute AC-WC layer on durability characteristics based on the various submersion times of Bekasi River water.

1.4 Significance of The Study

Below here is the significance of the study, namely:

1. The study provides knowledge regarding filler substitution using glass powder, particularly in the AC-WC asphalt layer mixture relying upon various submersion times from Bekasi River water.

2. The study enables an understanding of the advantages of using glass powder as filler substitution in AC-WC asphalt layer mixture relying upon various submersion times from Bekasi River water.

1.5 Scope and Limitation of The Research

The research has certain limitation to conform expected goals, namely:

1. The regulations used are AASHTO and Spesifikasi Umum Bina Marga 2018 Revision 2.
2. The binding material used is Pertamina Pen 60/70 asphalt.
3. Coarse aggregate obtained from the Highway Laboratory of the Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia.
4. Fine aggregate obtained from the Highway Laboratory of the Civil Engineering Department, Faculty of Civil Engineering and Planning, Islamic University of Indonesia.
5. The filler material used is stone dust obtained from Clereng, Kulon Progo, Yogyakarta Special Region Province.
6. Glass powder filler substitute obtained from Pasuruan City, East Java Province.
7. The glass powder substitution variations used are 0%, 25%, 50%, 75%, and 100%.
8. The soaking used is river water obtained by taking water samples in the Bekasi River, Bekasi.
9. The influencing variable studied is soaking time, namely 0 hours, 24 hours and 48 hours.
10. Chemical properties and reaction test of Bekasi River water will be carried out at the Water Quality and Environment Laboratory of the Environment Engineering Department, Faculty of Civil Engineering and Planning, Islamic University of Indonesia.
11. The physical form of the glass powder filler was observed at the the Water Quality and Environment Laboratory of the Environment Engineering

Department, Faculty of Civil Engineering and Planning, Islamic University of Indonesia.

12. Structural strength was evaluated through Stability, Flow, MQ, and ITS. Volumetric properties included VITM, VMA, VFWA, and Density, while durability was assessed using IRS, TSR, and CL.
13. Testing was carried out at the Highway Laboratory of the Civil Engineering Department, Faculty of Civil Engineering and Planning, Islamic University of Indonesia.
14. This research did not test the mineral content contained in glass powder.

CHAPTER II
LITERATURE REVIEW

2.1 Utilization of Various Alternative Materials as Filler Substitutes in Asphalt Mixture

Based on the Spesifikasi Umum Bina Marga 2018 revision 2, there are two types of fillers commonly used, namely active chemical fillers such as portland cement, hydrated lime, and ammonium sulfate, and inactive chemical fillers such as limestone dust, fly ash, and stone dust. Fillers must contain fine particles that pass through the No.16 sieve and those that pass through the 0,075mm (No.200) sieve. The use of fillers can affect the characteristics of asphalt mixtures, particularly their elastic properties and sensitivity to water.

Research conducted by Osuolale, et al. (2023) evaluated the performance of asphalt mixtures using bamboo leaf ash and steel slag powder as filler substitutes. The samples were tested using Marshall testing, flow voids, ITS, TSR, fatigue test, resilient modulus, CL, skid resistance, and retain strength. The performance of asphalt mixtures containing steel slag powder showed improvements in Marshall stability, ITS, ravelling resistance, and resistance to bending deformation by 10%, 15%, 20%, and 25%, respectively. However, conventional fillers showed better performance in moisture resistance, fatigue resistance, and resilient modulus. The use of bamboo leaf ash and steel slag powder is more economical compared to conventional fillers, for the wearing and binder courses, bamboo leaf ash and steel slag powder are respectively 4,35%, 4,13%, and 3,17%, 3,03% cheaper per ton of produced asphalt concrete.

Zangooeinia, et al. (2023) investigated the enhancement of pavement engineering properties using calcium carbide residue as a filler in Stone Mastic Asphalt (SMA). The effects of the mixture were evaluated using Marshall stability, ITS, and TSR tests. The results showed that the highest values for MS,

MQ, and TSR were obtained with a composition of 80% calcium carbide residue and 20% stone dust, increasing by 45%, 35%, and 51%, respectively. The alkaline nature of calcium carbide residue forms strong bonds with acidic bitumen, resulting in asphalt that is 97% more resistant to damage compared to the control samples. This mixture was also found to be less sensitive to water damage compared to traditional SMA mixtures with stone dust fillers. The rough texture of calcium carbide residue affects the strength and moisture damage resistance of the asphalt mixture. Using calcium carbide as a filler in SMA mixtures can improve pavement engineering properties, reduce production costs and environmental issues, and develop sustainable asphalt mixtures.

Gedik, et al. (2021) investigated the use of fluorescent lamp waste in highway construction in AC-WC and AC-BC mixtures by testing Marshall characteristics, indirect tensile stiffness modulus, wheel track, indirect tensile fatigue, and dynamic creep tests. The results showed promising performance and cost-effectiveness of incorporating fluorescent lamp waste into low to medium traffic road surfaces, providing the pavement industry with a new resource option. In terms of rutting deformation, it should be noted that the use of fluorescent lamp waste should be limited to low to medium traffic volumes.

Chasanah & Sukmo (2019) examined the effect of talc powder as a filler substitute in AC-WC mixtures to determine its impact by testing Marshall parameters, ITS, and CL. The Marshall test results showed significant changes, with increased load bearing and fatigue resistance. The ITS value increased with higher proportions of talc powder filler up to a replacement level of 50%, after which the ITS value decreased with further increases in filler content. The cantabro value of AC-WC mixtures using talc powder as a filler decreased with higher percentages of talc powder filler replacement.

Tolab & Fauziah (2024) investigated the use of geothermal waste as a filler substitute in Stone Matrix Asphalt (SMA) mixtures. Their findings show that geothermal waste improves SMA performance by reducing void content and producing a denser, more stable mixture. Stability increased, enhancing resistance to traffic loads, while flow values decreased, resulting in a stiffer mixture.

Improved stone-on-stone contact strengthened the bond between aggregate and asphalt, increasing load-bearing capacity, deformation resistance, and reducing the risk of cracking. The hydrophobic and micro-porous nature of geothermal waste contributed to greater durability. Additionally, its use enhanced aggregate interlocking, improved mixture homogeneity, reduced aggregate segregation, increased viscosity, and strengthened resistance to plastic deformation and elevated temperatures.

2.2 Utilization of Glass Powder Waste as a Filler Substitute in Asphalt Mixture

In the study conducted by Ogundipe & Nnochiri (2020) on the evaluation of the use of glass waste in AC-BC asphalt mixtures concerning Marshall parameter characteristics, the Marshall test results indicated that stability values increased with the increase in glass powder filler percentage up to 18%. This demonstrates an enhancement in fatigue resistance for higher glass waste content. Additionally, the flow value increased with the addition of glass powder filler, indicating that resistance to permanent deformation did not improve. Overall, the use of glass waste in asphalt concrete is environmentally friendly and aids in sustainable glass waste management.

The research by Almira, et al. (2022) on the effect of using glass powder in HRS-WC mixtures on Marshall characteristics showed that a flow value of 3,7 mm met the requirements with 50% glass powder filler. Using 75% glass powder filler resulted in an MQ value of 369,124 kg/mm. However, the VIM and VFB values for the combinations of 25%, 50%, and 75% glass powder filler did not meet the specifications of Bina Marga 2018 revision 2, leading to the conclusion that glass powder cannot be considered a viable alternative to cement filler.

Glass waste has potential applications beyond its use as a filler material. In a study conducted by Fauziah & Wijayati (2016), glass waste was utilized as a substitute for fine aggregate in porous asphalt mixtures. The study concluded that replacing up to 30% of No. 8 fine aggregate with glass waste is effective in enhancing several key performance characteristics. Specifically, stability, MQ,

VITM, and VMA increased up to an optimum substitution level, after which these parameters declined. Meanwhile, flow, VFWA, and density initially decreased but subsequently increased beyond certain substitution thresholds. CL values exhibited minor fluctuations, indicating that the mixtures maintained good abrasion resistance up to the optimum substitution level, with a decrease in impact resistance beyond this point. Furthermore, Asphalt Flow Down (AFD) values decreased significantly as the proportion of glass substitution increased, suggesting improved homogeneity of the asphalt mixtures.

2.3 The Effect of Water Submersion on Asphalt Mixtures

In the study conducted by Mawarni & Fauziah (2019) on the effect of seawater immersion on the characteristics of porous asphalt with and without the addition of rubber tire waste, the parameters tested included Marshall Standard, IRS, ITS, asphalt flow down, permeability, and cantabro. The results showed that Pen 60/70 asphalt and rubber asphalt mixtures have sufficient ability to drain water. The Marshall test indicated a decrease in strength, flexibility, and stability of the porous asphalt mixtures with Pen 60/70 asphalt and rubber asphalt as the immersion time in seawater increased. The ITS test showed a reduction in tensile strength of the porous asphalt mixtures with Pen 60/70 asphalt and rubber asphalt due to seawater immersion. The cantabro test results showed increased damage with longer immersion times in seawater.

The research conducted by Liana, et al. (2023) on the effect of rainwater immersion in Samarinda on AC-WC asphalt through Marshall testing, with stability, flow, density, MQ, VIM, VMA, and VFWA parameters, concluded that specimens immersed in rainwater can affect the compressive strength of asphalt in Marshall testing. After 1 day of immersion, asphalt concrete showed an 8,15% decrease in stability, a 16,59% decrease in flow value, a 92,01% and 23,97% increase in VIM and VMA values, respectively, a 22,72% decrease in VFWA, and a 4,48% decrease in density, with MQ value increasing by 12,47%. After 3 days of immersion, stability value decreased by 4,70%, flow value increased by 17,96%,

VIM and VMA increased by 24,67% and 9,44%, respectively, VFWA decreased by 12,47%, density decreased by 2,19%, and MQ value decreased by 13,06%.

In a separate study, Fauziah & Handaka (2017) investigated the use of Starbit E-55 asphalt to mitigate performance degradation caused by rainwater immersion in SMA mixtures. The study involved laboratory testing focused on Marshall characteristics and immersion tests to assess the durability of mixtures utilizing two types of binders, Starbit E-55 and AC 60/70. The results demonstrated that both the stability and Marshall quotient values decreased, while the flow values increased with prolonged rainwater immersion. The mixture with Starbit E-55 binder retained 92,63% of its initial stability after 72 hours of immersion, outperforming the mixture with AC 60/70 binder, which retained only 89,23% of its initial stability. Although durability declined with extended immersion time, both mixtures maintained good water resistance after 72 hours, indicated by IRS values exceeding 75%. Overall, the SMA mixture incorporating Starbit E-55 exhibited superior resistance to water-induced damage compared to the mixture using AC 60/70 asphalt.

In the study conducted by Yandriano, et al. (2022) on the analysis of the quality degradation of AC-BC hot mix asphalt due to muddy water immersion, with Marshall parameters tested, it was shown that muddy water immersion can affect the Marshall characteristics of AC-BC hot mix specimens. The stability value decreased with immersion, the flow value decreased due to reduced stability, VIM increased, VFA decreased, VMA increased, and MQ value decreased as MQ is the ratio of stability to flow.

2.4 Comparison of Previous and Current Research

The comparison of previous and current research will be shown in the Table 2.1 on the next page.

Table 2.1 Comparison of the Previous and Current Research

No	Aspect	Zangooeinia, et al. (2023)	Osuolale, et al. (2023)	Ogundipe & Nnochiri (2020)	Almira, et al. (2022)	Yandriano, et al. (2022)	Lingga (2025)
1	Title	Improvement of Pavement Engineering Properties with Calcium Carbide Residue (CCR) as Filler in Stone Mastic Asphalt	Performance Evaluation of Bamboo Leaf Ash and Steel Slag Powder as Alternative Filler in Asphaltic Mixes	Evaluation of The Effects of Waste Glass in Asphalt Concrete Using the Marshall Test	The Effect of The Use of Glass Powder on The Characteristics of Mixed Marshall HRS-WC	Analysis of Quality Decrease of AC-BC Hot Mix on The Effect of Muddy Water Immersion	Perfomance of AC-WC Mixture with Glass Powder Filler Against Bekasi River Water Submersion
2	Type of Mixture	Stone Mastic Asphalt	AC-WC and AC-BC	AC-BC	Hot Rolled Sheet – WC	AC-BC	AC-WC
3	Filler Material	Calcium Carbide Residue (CCR)	Bamboo Leaf Ash (BLA) and Steel Slag Powder (SSP)	Glass Powder	Glass Powder	-	Glass Powder
4	Water Submersion	-	-	-	-	Flood Muddy Water	Bekasi River Water

Source: Zangooeinia, et al. (2023), Osuolale, et al. (2023), Ogundipe & Nnochiri (2020), Almira, et al. (2019), and Yandriano, et al. (2022)

Table 2.1 Comparison of the Previous and Current Research (continued)

No	Aspect	Zangooeinia, et al. (2023)	Osuolale, et al. (2023)	Ogundipe & Nnochiri (2020)	Almira, et al. (2022)	Yandriano, et al. (2022)	Lingga (2025)
5	Laboratory Test	Marshall Stability, ITS, and TSR	Stability, flow, voids, ITS, TSR, CL, fatigue, stiffness, skid, and durability.	Stability, Flow, VIM, VMA, and VFB	Stability, Density, VIM, VMA, VFA, Flow, and MQ	Stability, Flow, VIM, VMA, VFA, and MQ	MS, ITS, IRS, TSR, and CL
6	Results	CCR as an additive in Stone Mastic Asphalt enhances Marshall Stability by 45% with an 80% CCR + 20% RP mix, boosts ITS by 97% (saturated) and 40% (dry), and increases TSR by 51%, reducing moisture sensitivity and costs.	Asphalt mixes with SSP outperform BLA in stability, rutting, ravelling, and skid resistance. SSP also resists cracking and moisture, while quarry dust leads in fatigue life. Both SSP and BLA are cost-effective alternatives	Waste glass filler boosts stability up to 18% but stays below control. Flow suggests deformation risk. Higher density, lower air voids, and more filled voids indicate improved durability.	Glass powder (25–75%) in HRS-WC meets VMA, stability, some flow and MQ specs, but fails VIM and VFB. Unsuitable as full cement filler replacement.	AC-BC mix submerged in muddy water (2–8 days, 60°C) showed decreased stability, flow, VFA, and MQ, with rising VIM and VMA. Stability stayed above the 800 kg minimum.	AC-WC with glass powder meets standards at 0 hours. At 24–48 hours, higher doses reduce key values. Glass powder improves stiffness but lowers moisture resistance 75% is optimal.

Source: Zangooeinia, et al. (2023), Osuolale, et al. (2023), Ogundipe & Nnochiri (2020), Almira, et al. (2019), and Yandriano, et al. (2022)

CHAPTER III
THEORITICAL FRAMEWORK

3.1 Flexible Pavement Structure

Flexible pavement refers to pavement that uses asphalt as a binding material. The layers of the pavement function to bear and distribute traffic loads to the subgrade (Sukirman, 1993).

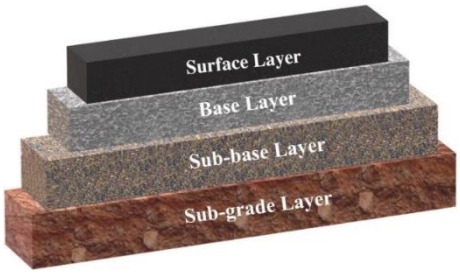

Figure 3.1 Flexible Pavement Layer

(Source: Noor & Rehman, 2022)

The distribution of loads through the contact area of the wheels is absorbed by each layer within the flexible pavement, which includes:

1. Subgrade Layer

According to Totomihardjo (1994), the subgrade is the compacted soil that serves as the foundational surface for the placement of pavement components. The purpose of subgrade compaction is to achieve a high level of stability against volumetric changes. Variations in moisture content significantly affect the strength of the subgrade, therefore, it is essential to maintain an optimal moisture content consistently throughout the design life. Soil compaction testing must comply with SNI 1742:2008, which specifies the standard for light compaction tests for soil component of the pavement structure designed to distribute wheel loads to the subgrade. This layer must possess sufficient strength, with a California Bearing Ratio (CBR) of 20% and a Plasticity Index (PI) ≤ 10%.

2. Subbase Layer

The subbase layer is the portion of the pavement situated between the base course and the subgrade. According to Sukirman (1993), this layer functions as:

a. Efficient use of materials. The subbase material is relatively inexpensive compared to the layers of pavement above it.
b. Drainage layer, to prevent groundwater from accumulating within the foundation.
c. Initial layer, to ensure smooth construction progress. This is particularly important in field conditions that require immediate covering of the subgrade to protect it from weather influences or when the subgrade has low bearing capacity to support heavy machinery.
d. A layer to prevent fine particles from the subgrade from rising into the base course.

3. Base Course Layer

The base course is the part of the pavement located between the surface course and the subbase (or directly on the subgrade if no subbase is used). The functions of the base course include:

a. A pavement layer that resists shear forces from wheel loads and distributes the load to the layers beneath.
b. A drainage layer for the subbase.
c. A cushion for the surface layer.

Generally, the materials used in the base course are strong, with a CBR > 50% and a PI < 4%. Natural materials such as crushed stone, crushed gravel, and soil stabilized with cement or lime can be used as the base course.

4. Surface Layer

The surface course is the uppermost part of the pavement. Its functions include:

a. A pavement layer that bears wheel loads, requiring high stability to withstand the wheel loads during its service life.
b. A waterproof layer to prevent rainwater from seeping into the underlying layers and weakening them.

c. A wearing course, which is the layer in direct contact with vehicle braking friction, making it susceptible to wear.
d. A layer that distributes loads to the underlying layers, ensuring they can be supported by layers with lower bearing capacity.

There are two types of surface courses commonly used in Indonesia:

a. Non-structural layers, which function as wearing courses and waterproof layers. Examples of this type of surface layer construction include single-coat asphalt surface dressing *(burtu)*, two-coat asphalt surface dressing *(burda)*, sandsheet asphalt layers *(latasir)*, asphalt surface dressing/chip seal *(buras)*, pure Buton thin asphalt layer *(lataskum)*, and Hot Rolled Sheet (HRS).
b. Structural layers, which function as layers that bear and distribute wheel loads. Examples of this type of surface layer construction include penetration macadam *(lapen)*, Buton asphalt aggregate layer *(laskutag)*, and asphalt concrete layer (AC).

3.2 Construction Materials of Flexible Pavement

The materials that compose road pavement consist of coarse aggregate, fine aggregate, asphalt, and other additives according to the type of asphalt mix used. The following is a general description of the materials used in road pavement construction.

3.2.1 Aggregate

According to ASTM 1974, aggregate is defined as a material composed of solid minerals, either in large masses or as fragments. Aggregates are a core component of road pavement, as they constitute 75-85% of the total volume of pavement materials. Understanding the properties of aggregates, such as gradation, size, shape, porosity, surface characteristics, and strength, is crucial, however, the relative importance of these characteristics depends on the specific requirements of aggregate use. Aggregates can be classified into two types:

1. Coarse Aggregate

An aggregate is classified as coarse if its size is greater than 4,75 mm according to ASTM or greater than 2 mm according to AASHTO. The aggregate fraction used for mix design must be clean, hard, durable, and free from clay or other undesirable materials, and it must meet the specifications provided in Table 3.1 below.

Table 3.1 Requirement of Coarse Aggregate Used in Asphalt Concrete

Laboratory Test		Standard	Value
Aggregate Shape Stability in Solution	*Sodium sulfate*	SNI 3407:2008	Max 12%
	Magnesium sulfate		Max 18%
Abrasion Resistance Using the Los Angeles Machine	100 revs	SNI 2417:2008	Max 6%
	500 revs		Max 30%
Aggregate Adhesion to Asphalt		SNI 2439:2008	Min 95%
Crushed Particles in Coarse Aggregate		SNI 7619:2012	95/90*)
Flat and Elongated Particles (Ratio 1:5)		SNI T-01-2005	Max 10%
Material Passing Through the No. 200 Sieve		SNI ASTM C117:2012	Max 1%

Notes:

*) 95/90 indicates that 95% of the coarse aggregate has one or more fractured faces, and 90% of the coarse aggregate has two or more fractured faces.

Source: Spesifikasi Umum Bina Marga 2018

2. Fine Aggregate

Fine aggregate is defined as having a size of less than 4,75 mm according to ASTM or less than 2 mm and greater than 0,075 mm according to AASHTO. The material used as fine aggregate must be clean, hard, free from clay, and other undesirable substances, and must meet the specifications outlined in Table 3.2 below.

Table 3.2 Requirement of Fine Aggregate Used in Asphalt Concrete

Laboratory Test	Standard	Value
Sand Equivalent Value	SNI 03-4428-1997	Min 50%
Void Content Test without Compaction	SNI 03-6877-2002	Min 45
Clay Clumps and Easily Fractured Particles in Aggregate	SNI-03-4141-1996	Max 1%
Aggregate Passing Through the No. 200 Sieve	SNI ASTM C117:2012	Max 10%

Source: Spesifikasi Umum Bina Marga 2018

3.2.2 Filler

Filler is defined as the dust that passes through a No. 200 sieve and may include limestone dust, hydrated lime dust, magnesium lime dust, cement, fly ash, or other non-plastic materials. The filler material must be dry and free from clumps, and the sieving test must comply with SNI ASTM C136:2012, containing no less than 75% of material passing through the No. 200 sieve by weight. The use of filler can influence the characteristics of the mix. In asphalt concrete mixtures, filler functions as a filler between coarser aggregates. This results in increased stability due to the filler filling the air voids and the particles being bonded together through inter-particle friction.

3.2.3 Aggregate Gradation

Gradation refers to the arrangement of aggregate particles according to their size. The size of aggregate particles can be determined through sieve analysis, using a set of sieves arranged in a stack with the coarsest sieve on top and the finest sieve on the bottom. Aggregate gradation affects the amount of voids between particles, which in turn influences the stability and ease of the construction process. The gradation of aggregates for asphalt mixtures is expressed as a percentage by weight of the aggregate, and the filler material must comply with the limits specified in Table 3.3 below.

Table 3.3 Aggregate Gradation for Asphalt Concrete Mixture

Sieve Size		% Weight Passing Through Relative to Total Aggregate		
ASTM	(mm)	AC-WC	AC-BC	AC-Base
$1^1/_2$"	37,5			100
1"	25		100	90 – 100
$^3/_4$"	19	100	90 – 100	76 – 90
$^1/_2$"	12,5	90 – 100	75 – 90	60 – 78
$^3/_8$"	9,5	77 – 90	66 – 82	52 – 71
No. 4	4,75	53 – 69	46 – 64	35 – 54
No. 8	2,36	33 – 53	30 – 49	23 – 41
No.16	1,18	21 – 40	18 – 38	13 – 30
No. 30	0,600	14 – 30	12 – 28	10 – 22
No. 50	0,300	9 – 22	7 – 20	6 – 15
No. 100	0,150	6 – 15	5 – 13	4 – 10
No. 200	0,075	4 – 9	4 – 8	3 – 7

Source: Spesifikasi Umum Bina Marga 2018

3.2.4 Asphalt

Asphalt is defined as a cementitious material, typically black or dark brown in color, primarily composed of bitumen, which can be derived from natural sources or as a residue from petroleum refining. Asphalt is a thermoplastic material, when heated to a certain temperature, it melts and will solidify again as the temperature decreases (Sukirman, 2003). Asphalt used in road pavement functions as follows:

1. Binder, it provides a strong bond between the asphalt and aggregate or between different asphalt layers.
2. Filler, it fills the voids between aggregate particles and the pores within the aggregate itself.

Asphalt can be classified based on its penetration value. AASHTO divides asphalt into five groups, namely 40/50, 60/70, 85/100, 120/150, and 200/300

penetration grades. In this study, a penetration grade of 60/70 asphalt is used. This material must meet the specifications required by the Spesifikasi Umum Bina Marga 2018 Revision 2, as indicated in Table 3.4 below.

Table 3.4 Asphalt Requirement for AC Pen 60/70

No.	Laboratory Test		Standard	Requirements Value
1	Penetration at 25 ºC	(0,1 mm)	SNI 2456:2011	60 - 70
2	Kinematic Viscosity at 135 ºC	(cSt)*)	ASTM D2170-10	≥ 300
3	Softening Point	(°C)	SNI 2433:2011	≥ 48
4	Ductility at 25 ºC	(cm)	SNI 2432:2011	≥ 100
5	Flash Point	(°C)	SNI 2434:2011	≥ 232
6	Solubility in *Trichloroethylene*	(%)	AASHTO T44-14	≥ 99
7	Specific Gravity		SNI 2441:2011	≥ 1
8	Paraffin Wax Content	(%)	SNI 03-3639-2002	≤ 2

Notes:
*) Viscosity is also tested at temperatures of 100°C and 160°C for the 60/70 penetration grade to determine the applicable temperature for use.

Source: Spesifikasi Umum Bina Marga 2018

3.3 Asphalt Concrete – Wearing Course (AC-WC)

Asphalt concrete can be classified into three types based on the temperature during the mixing and compaction process:

1. Hot Mix Asphalt (HMA), this type of asphalt is mixed at temperatures around 140°C.
2. Warm Mix Asphalt (WMA), this type of asphalt is mixed at temperatures around 60°C.
3. Cold Mix Asphalt (CMA), this type of asphalt is mixed at ambient temperatures of approximately 25°C.

In Indonesia, there are various types of hot mix asphalt, differentiated by aggregate gradation and asphalt content. The selection of the type of asphalt concrete for a specific location depends on the preferred characteristics of the asphalt (Sukirman, 2003). One example is Asphalt Concrete (AC).

AC is generally used on roadways with heavy traffic and utilizes aggregates with continuous gradation. The key characteristic of this type of asphalt concrete is its stability. Based on its function, AC is divided into three mix types, AC-WC, AC-BC, and AC-Base. This study will focus on the hot mix asphalt AC-WC. The AC-WC mix is positioned at the top layer of the pavement, making it subject to direct contact with vehicle wheels and weather conditions. The nominal minimum thickness of this mix is 4 cm. Table 3.5 displays the specifications for Laston mix properties.

Table 3.5 Requirement of Asphalt Concrete Characteristics

Mixture Characteristics		Asphalt Concrete		
		AC-WC	AC-BC	AC-Base
Number of Impacts per Unit Area		75		112
Ratio of Particles Passing Through a 0.075 mm Sieve to Effective Asphalt Content	Min	0,6		
	Max	1,2		
Voids in Mix (%)	Min	3		
	Max	5		
Voids in Aggregate (VMA) (%)	Min	15	14	13
Asphalt Binder Content (%)	Min	65	65	65
Marshall Stability (kg)	Min	800		1800
Flow (mm)	Min	2		3
	Max	4		6
Residual Marshall Stability (%) after Immersion for 24 Hours at 60°C	Min	90		
Voids in Mix (%), at Refusal Density	Min	2		
Dynamic Stability, traction/mm	Min	2500		

Source: Spesifikasi Umum Bina Marga 2018

3.4 Waste Glass Powder

Various types of waste are generated from different sectors of society, including industrial manufacturing, services, waste processing, households, and mining. Typically, waste disposal methods include sending waste to landfills, incineration, or recycling into other products. However, issues such as limited landfill capacity, air pollution from incineration, and inadequate recycling practices can arise. Consequently, several countries have started to utilize certain types of waste in hot mix asphalt mixtures. One such type is glass waste, which is predominantly produced from households.

Glass powder waste represents an innovative, environmentally friendly, and multifunctional approach as a filler derived from industrial production residues. Based on their chemical composition, glass powders can be categorized into several distinct types.

a. Soda-lime glass powder

   Predominant type, composed of SiO_2, sodium oxides, calcium oxide, and alumina; sourced from recycled bottles, offering cost-efficiency and sustainability.

b. Borosilicate glass powder

   Exhibits high thermal resistance and low expansion, suited for heat-stable, chemically resistant applications (e.g., labware, cookware).

c. Leaded crystal glass powder

   Enhances luminosity and texture, usually used in artistic media, though limited in engineering due to toxicity and cost.

d. Aluminosilicate glass powder

   Features alkali resistance and elevated softening points, applicable in electronics and specialized contexts.

e. Potash-lime silicate glass

   Known as "crown" glass, with high softening temperature and devitrification resistance, premium option for niche architectural/optical uses, constrained by cost and specificity.

Simone, et al. (2017) investigated the chemical properties of glass powder, which are detailed in Table 3.6 below.

Table 3.6 Glass Powder Chemical Properties

Chemical Component	Content (%)
SiO_2	29,17
CaO	16,51
Al_2O_3	18,85
Fe_2O_3	6,97
MgO	2,60
Na_2O	10,72
K_2O	0,65
SO_3	0,87
$CaCO_3$	-
other	13,66

Source: Simone, et al. (2017)

According to the study by Simone, et al. (2017), although the silica (SiO_2) content is relatively low—despite silica being a primary component—this indicates that the glass material has not undergone specialized purification processes, thus making it a more cost-effective and environmentally friendly product.

3.5 Moisture Damage in Asphalt Mixture

Moisture is a key element in the deterioration of asphalt pavements, playing its role through two main mechanisms: loss of adhesion, typified by the breakdown of the interfacial bond between the asphalt binder and aggregate, and loss of cohesion, typified by the loss of internal strength within the asphalt mix. As indicated by Neupane & Wu (2025), the intrusion of moisture initiates a stripping phenomenon that destroys the structural integrity of the pavement. Such degradation is evidenced visibly through surface distresses, including rutting, cracking, and the formation of potholes, which undermine functionality and safety.

In HMA, such moisture damage is associated with an appreciable reduction in Indirect ITS and TSR, fundamental indicators of pavement performance and durability. The mechanisms behind this damage, detachment, displacement, spontaneous emulsification, pore pressure development, and hydraulic scouring,

attest to the intricate interaction between water, asphalt binder, and aggregate phase. The degree of such deterioration is contingent on several variables, ranging from the physical and chemical characteristics of the binder and aggregate to the air void content and distribution in the mix and ambient environmental conditions, all of which cumulatively determine the theoretical conceptualization of moisture's adverse impacts on asphalt pavements.

A study conducted by Hadi and Fauziah (2019) investigated the characteristics of Superpave mixtures using Starbit E-55 and Pen 60/70 binders under varying durations of brackish water submersion. The results indicated that, in general, as the submersion duration increased, the mixture’s performance declined while flow values increased. This deterioration was attributed to the weakening of the binder–aggregate bond caused by chemical compounds present in the brackish water.

Understanding the pavement’s resistance to submersion is crucial, as it provides insights into its durability under extreme environmental conditions and allows for better prediction of service life. Moreover, such studies can serve as a basis for evaluating alternative materials that may enhance pavement performance in harsh environmental settings.

3.6 Bekasi River Water

Fatmawati (2016) defines a river as a freshwater flow originating from its source on land and flowing into larger bodies of water such as seas, lakes, or larger rivers. River flow is derived from runoff, including precipitation runoff, glacial melt, runoff from tributaries, and groundwater runoff. Based on environmental conditions, Mulyanto (2007) classifies rivers into three regions: the river source, the river downstream, and the river mouth. The river source is situated in higher elevations, the river downstream is located in lower elevations, and the river mouth is the confluence of the river with other bodies of water, such as larger rivers, lakes, or seas.

Wijaya, et al. (2023) conducted a study on the Bekasi River Basin and reported that the area is prone to flooding. The primary cause of flooding in the Bekasi River Basin is the slope of the terrain, with much of the Bekasi River

Basin having flat surfaces. Another contributing factor is land use; several areas within the Bekasi River Basin are developed for buildings, including residential areas, businesses, and industries. The study indicates that 70.81% of the total area of the Bekasi River Basin is highly vulnerable to flooding. This flooding is exacerbated by the Bekasi River being the confluence point for two upstream rivers, namely the Cikeas River and the Cileungsi River from Bogor Regency. The volume of water from the Cikeas and Cileungsi Rivers exceeds the capacity of the Bekasi River to accommodate it (Rojali & Elsari, 2020).

In this study, water from the Bekasi River will be used as the submersion medium to test asphalt concrete mixtures with glass powder waste as a filler substitution.

3.7 River Water Test

Two key water quality parameters assessed in this study are turbidity and pH. Turbidity refers to the cloudiness or haziness of water caused by suspended solids, measured in Nephelometric Turbidity Units (NTU). The World Health Organization suggests that drinking water should ideally have turbidity below 5 NTU, though for pavement interaction, no strict standard exists; however, lower turbidity is preferable to minimize sediment deposition on pavement surfaces. High turbidity can exacerbate pavement damage by introducing abrasive particles that accelerate surface wear and clog porous asphalt, reducing permeability and increasing moisture retention, which further promotes stripping and material degradation. pH measures the acidity or alkalinity of water on a scale from 0 to 14, with a neutral pH of 7. For pavement applications, water with a pH range of 6.5–8.5 is generally considered non-corrosive, as extreme pH values can chemically react with asphalt binders. Acidic water ($pH < 6.5$) can weaken the binder-aggregate bond, accelerating adhesion loss, while highly alkaline water ($pH > 8.5$) may cause emulsification of the binder, reducing pavement cohesion.

Hu, et al. (2022) proved that all acid rain types reduce the water stability of asphalt pavements, worsen by the longer exposure of immersion. Primarily caused by the loss of bond strength between asphalt and aggregate. Meanwhile, Zhang, et al. (2024) stated that alkaline water degrades adhesion between asphalt and

aggregate. Alkaline ions can interfee with polar interactions, a component important to adhesion.

3.8 Marshall Standard Test Parameter

The Marshall test is employed to evaluate the performance of asphalt concrete, which can be identified through several parameters stability, flow, density, VITM, VMA, VFWA, and MQ. Stability and flow values are determined using the Marshall testing apparatus, while the other parameters are determined through specimen weighing and calculations. Below is an explanation of each parameter identified from the Marshall test.

3.8.1 Stability

Stability refers to the ability of road pavement to withstand traffic loads without undergoing deformations such as waves, ruts, or bleeding. Roads with high traffic volumes require a high stability value, whereas roads with low traffic volumes do not necessarily need a high stability value. The stability value increases with the asphalt content until it reaches a maximum, after which it declines. The relationship between stability value and asphalt content is illustrated in Figure 3.2, while the formula for calculating stability value is provided in Equation 3.1.

$$q = p \times s \quad (3.1)$$

description:

q = stability value

p = stability dial reading × equipment calibration factor

s = specimen thickness correction factor

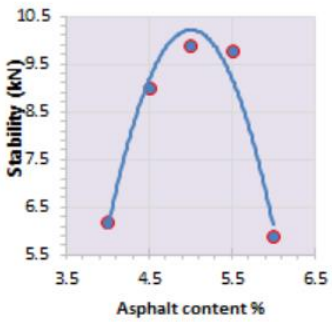

Figure 3.2 Relationship Between Stability and Asphalt Content

(Source: Al-Azawee & Qasim, 2018)

3.8.2 Flow

The stability and flow testing must adhere to the procedures outlined in *SNI-2489-1991* or AASHTO T245-90. The flow value can be measured after the reading is taken on the flowmeter, this parameter is used to measure the deformation due to loading. The flow value will continue to increase as the asphalt content increases, as the thicker asphalt coating reduces friction between the aggregates. The relationship between flow value and asphalt content is illustrated in Figure 3.3 below.

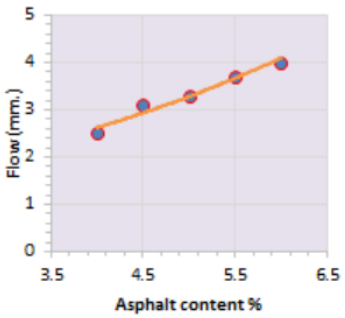

Figure 3.3 Relationship Between Flow and Asphalt Content

(Source: Al-Azawee & Qasim, 2018)

3.8.3 Density

The density value is measured to determine the bulk specific gravity of the compacted asphalt concrete following AASHTO T 166-88. The density graph is shown in Figure 3.4. This graph is similar to the stability curve, but the maximum value is reached at an asphalt content slightly higher than that required to achieve maximum stability. To calculate the density value, Equations 3.2 and 3.3 below can be used.

$$g = \frac{c}{f} \tag{3.2}$$

$$f = d - e \tag{3.3}$$

description:

g = density value (gr/cm^3)

c = weight of the specimen before submersion (gr)

d = weight of the specimen in a SSD condition (gr)

e = weight in water (gr)

f = volume (cm^3)

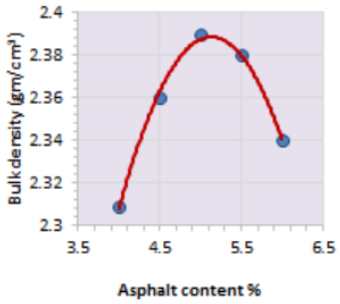

Figure 3.4 Relationship Between Density and Asphalt Content

(Source: Al-Azawee & Qasim, 2018)

3.8.4 VITM

VITM refers to the amount of voids between the aggregate particles that are coated with asphalt. VITM is necessary to allow for the displacement of aggregates due to additional compaction caused by traffic load repetition or to accommodate the softening of asphalt due to rising temperatures. Excessively high VITM will reduce the water resistance of the asphalt concrete, leading to increased oxidation of the asphalt, which can accelerate its aging and decrease the durability of the asphalt concrete. On the other hand, excessively low VITM may result in pavement bleeding when temperatures rise. The VITM curve, as shown in Figure 3.5, will continuously decrease as the asphalt content increases until it ultimately reaches a minimum value. The VITM value can be determined using Equations 3.4 and 3.5 below.

$$n = 100 - \left(100 - \frac{g}{h}\right) \tag{3.4}$$

$$h = 100 - \left[\frac{100}{\left(\frac{\%\ \text{Aggregate}}{\text{Spec.Gravity Aggregate}} + \frac{\%\ \text{Asphalt}}{\text{Spec.Gravity Asphalt}}\right)}\right] \tag{3.5}$$

description:

n = VITM value

g = density value (gr/cm^3)

h = theoretical maximum specific gravity of the mixture

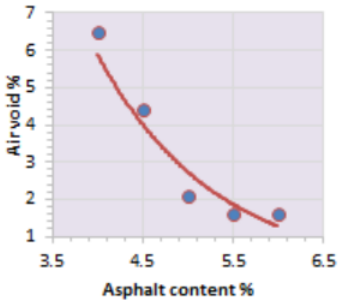

Figure 3.5 Relationship Between VITM and Asphalt Content

(Source: Al-Azawee & Qasim, 2018)

3.8.5 VMA

VMA refers to the volume of voids within the compacted asphalt concrete if the entire asphalt binder were to be removed. VMA does not include the voids within individual aggregate particles. The VMA value increases when the asphalt binder thickness increases or when the aggregate used has an open gradation. The VMA curve in the graph, as shown in Figure 3.6, will decrease until it reaches a minimum value and then increase again as the asphalt content increases. The VMA value can be calculated using Equations 3.6 and 3.7 below.

$$l = 100 - j \quad (3.6)$$

$$j = \left(\frac{(100-b)\ x\ g}{\text{Spec.Gravity Asphalt}}\right) \quad (3.7)$$

description:

l = VMA value (%)

b = percentage of asphalt by mix (%)

g = density value (gr/cm^3)

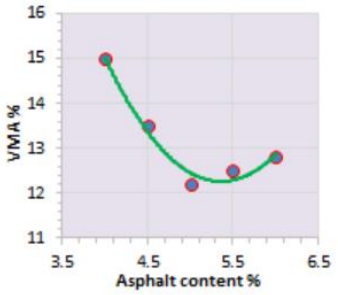

Figure 3. 6 Relationship Between VMA and Asphalt Content

(Source: Al-Azawee & Qasim, 2018)

3.8.6 VFWA

VFWA represents the volume of voids within the compacted asphalt concrete that is filled with asphalt or the volume of the asphalt film/coating. As the VFWA value increases, a greater amount of asphalt fills the voids, making the mixture more resistant to water and air infiltration. Conversely, a lower VFWA value indicates that the mixture is less resistant to water and air penetration, which can lead to quicker oxidation of the asphalt and reduced durability. The relationship between asphalt content and VFWA is illustrated in the graph shown in Figure 3.7. The VFWA value can be calculated using Equations 3.8 through 3.12 below.

1. Percentage of asphalt by mix

$$b = \left(\frac{a}{100+a} \times 100\right) \quad (3.8)$$

description:

a = percentage of asphalt by aggregate (%)

b = percentage of asphalt by mix (%)

2. Percentage of asphalt by aggregate

$$m = \left(100 \times \left(\frac{i}{j}\right)\right) \quad (3.9)$$

$$i = \frac{b \times g}{BJ\ Aspal} \quad (3.10)$$

$$l = 100 - j \quad (3.11)$$

$$j = \left(\frac{(100-b) \times g}{\text{Spec.Gravity Asphalt}}\right) \quad (3.12)$$

description:

m = VFWA value (%)

g = density value (gr/cm^3)

b = percentage of asphalt by mix (%)

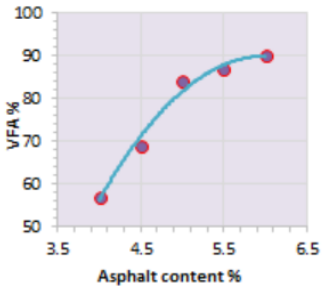

Figure 3.7 Relationship Between VFWA and Asphalt Content

(Source: Al-Azawee & Qasim, 2018)

3.8.7 MQ

The MQ is the ratio of stability to flow values. MQ serves as an indicator of the mixture's flexibility and its potential to resist cracking. The MQ value can be calculated using Equation 3.13 below.

$$MQ = \frac{q}{r} \tag{3.13}$$

description:

MQ = MQ value

q = stability value (kg)

r = flow value (mm)

3.9 ITS Test Parameter

ITS is a method used to determine the tensile strength of asphalt concrete mixtures. The parameters tested serve to assess the potential for cracking within the mixture. The ITS test is conducted similarly to the Marshall test but is modified using a concave plate with a width of 12,5 mm at the Marshall press point. The measurement of tensile strength is halted when the load gauge needle reverses direction or moves counterclockwise. The ITS value can be calculated using Equation 3.14 as follows.

$$ITS = \frac{2 \times P}{\pi \times D \times t} \tag{3.14}$$

description:

ITS = Indirect Tensile Strength (kg/cm^2)

P = peak load (kg)

D = diameter (cm)

t = thickness (cm)

3.10 TSR Test Parameter

TSR is obtained by comparing the tensile strength of a mixture that has been immersed in a water bath at 60°C for 24 hours with the tensile strength of the mixture without immersion, then multiplying by 100. Equation 3.15 is used to calculate the TSR value.

$$TSR = (T_2/T_1) \times 100 \quad (3.15)$$

description:

T_1 = average of ITS value without immersion (kg)

T_2 = average of ITS value after 24 hours of immersion (kg)

3.11 IRS Test Parameter

IRS aims to assess the changes in the characteristics of the asphalt mixture due to the influence of water, temperature, and weather conditions. IRS is calculated as the percentage of the stability value of the mixture after immersion for 30 minutes and 24 hours (S_2), compared to the stability of the non-immersed mixture (S_1). Equation 3.16 is used to calculate the IRS value.

$$IRS = \frac{S2}{S1} \times 100\% \quad (3.16)$$

description:

S_1 = average marshall stability value after immersion for 30 minutes

S_2 = average marshall stability value after immersion for 24 hours

3.12 CL Test Parameter

CL is used to evaluate the abrasion resistance or mass loss of porous asphalt mixtures or other asphalt mixtures that are not coated with fine aggregate. This

test uses the Los Angeles machine under the condition that both sides of the test specimen have been compacted, then the specimen is rotated 300 times. The weight loss after abrasion can be calculated using Equation 3.17 as follows.

$$L = \frac{Mo-Mi}{Mo} \times 100\% \quad (3.17)$$

description:

Mo = weight before abrasion (gr)

Mi = weight after abrasion (gr)

L = percentage of weight loss (%)

CHAPTER IV
RESEARCH METHOD

4.1 Research Method

The research method employed in this study is the experimental method. This method involves conducting a series of experiments to obtain data, which is then processed for comparison with the relevant requirements or specification standards. The specification standards and research procedures utilized in this study are based on the guidelines provided by the AASHTO and the Spesifikasi Umum Bina Marga 2018 Revision 2.

4.2 Sampling Method

The sampling method employed in this study is non-probability sampling, wherein the samples are not selected randomly. Specifically, purposive sampling is utilized, meaning the samples are chosen based on predetermined objectives established at the outset of the research. In this study, river water samples were collected from the Bekasi River, and the filler material used is waste glass powder, with the asphalt employed being Pertamina Pen 60/70.

4.3 Data Collection Method

Data collection in this study is categorized based on the type of data obtained during testing. Accordingly, the test specimens are grouped to obtain data including stability values, flow, density, VITM, VMA, VFWA, MQ, IRS, ITS, TSR and CL values.

4.4 Research Stages

This research was conducted in the Highway Laboratory, Department of Civil Engineering, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia. The research stages are as follows.

4.4.1 Material Preparation and Inspection

The material inspection in this research aims to determine the suitability of materials based on the applicable specifications. The specification values applied refer to the AASHTO and the Spesifikasi Umum Bina Marga 2018, Revision 2. The materials tested for the AC-WC mixture include aggregate, asphalt, and filler. Properties of the glass powder were not tested, as it was sourced from factory grinding. The tests conducted for the aggregate and asphalt are as follows.

1. Aggregate Laboratory Test
    a. Testing the specific gravity and water absorption of coarse aggregate (SNI 1969:2008)

       This testing is conducted to determine the bulk specific gravity, SSD specific gravity, apparent specific gravity, and absorption of coarse aggregates.
    b. Testing the specific gravity and water absorption of fine aggregate (SNI 1970:2008)

       This testing is conducted to determine the adhesion of asphalt to aggregate. Asphalt adhesion is measured as the percentage of the rock's surface area covered by asphalt relative to the total surface area.
    c. Testing the adhesion of aggregate to asphalt (SNI 03-2439-1991)

       This testing is conducted to determine the gradation of fine and coarse aggregates using a sieve analysis.
    d. Sieve analysis testing (AASHTO-27-74)

       This testing is conducted to determine the particle size distribution (gradation) of fine and coarse aggregates using a sieve analysis.
    e. Sand equivalent testing (SNI 3423:2008)

       This testing is conducted to determine the dust or clay content in fine aggregates or soil.
    f. Aggregate abrasion testing (SNI 2417:2008)

       This testing is conducted to assess the abrasion resistance of coarse aggregates using the Los Angeles machine. The abrasion is expressed as

the percentage of material that passes through a No. 12 sieve relative to the original weight.

2. Asphalt Laboratory Test

   a. Penetration testing of bitumen (SNI 06-2456-1991)

      This testing is conducted to determine the hardness or softness of bitumen (solid or semi-solid) by inserting a needle of a specific size, under a specific load and time, into the bitumen at a specified temperature.

   b. Softening point testing (SNI 06-2434-1991)

      This testing is conducted to determine the softening point of asphalt and tar, ranging from 30°C to 200°C. The softening point is the temperature at which steel balls of a specified weight press down on a layer of asphalt or tar contained within a ring of a specific size, causing the material to touch a base plate located beneath the ring due to a specific rate of heating.

   c. Ductility testing (SNI 06-2432-1991)

      This testing is conducted to assess the cohesion properties of asphalt by measuring the maximum elongation distance that can be achieved between two molds containing hardened bitumen before breaking at a temperature of 25°C and a specific pulling speed of 5 cm/min. Asphalt with higher ductility values can bind aggregate particles better but is more sensitive to temperature changes.

   d. Specific gravity testing of bitumen (SNI 06-2441-1991)

      This testing is conducted to determine the specific gravity of bitumen using a pycnometer. The specific gravity of bitumen is the ratio of the weight of the bitumen to the weight of distilled water of the same volume at a specified temperature.

   e. Flash and fire point testing (SNI 06-2433-1991)

      This testing is conducted to determine the flash point and fire point of all types of petroleum-based asphalt, except for fuel oil and other materials with an open cup flash point below 79°C. The flash point is the

temperature at which a brief flame appears at a point above the asphalt surface. The fire point is the temperature at which a flame persists for at least 5 seconds on the asphalt surface. This test helps determine the maximum heating temperature of asphalt to prevent combustion.

f. Solubility testing using CCl_4 (SNI 06-2438-1991)

This testing is conducted to determine the bitumen content that is soluble in carbon tetrachloride or carbon disulfide.

3. Filler Properties

Filler is a fine-grained material used to fill the voids between aggregate particles in asphalt mixtures. The filler must have very small particle sizes, capable of passing through a No. 200 sieve (with a sieve opening size of 0.074 mm). The quality of the filler must comply with the standards outlined in SNI 03-6723-2002 to ensure optimal performance of the asphalt mixture.

4.4.2 Equipment Preparation

The equipment used to support the research process was provided by the Highway Laboratory, Department of Civil Engineering, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia. The equipment utilized includes the following.

1. A set of aggregate testing apparatus, including a sieve analysis set, Los Angeles abrasion machine, sand equivalent test device, and a vibrator.
2. A set of asphalt testing apparatus, including devices for ductility, penetration, asphalt solubility, flash point, fire point, and softening point tests.
3. Test molds with a diameter of 10 cm and a height of 7,5 cm.
4. Marshall testing equipment, which includes:
   a. A testing ring with a capacity of 2500 kg and a precision of 12,5 kg.
   b. A curved breaking head.
   c. A pressure gauge with a precision of 0,0025 cm.
   d. A flow meter with a precision of 0,25 mm and its accessories.
5. A compactor weighing 4,536 kg with a drop height of 45,7 cm used for compacting test specimens.
6. An ejector used for removing test specimens from molds.

7. Weighing scales with a capacity of 2 kg and a precision of 0,1 gr and another with a capacity of 5 kg and a precision of 1 g, both equipped with hooks.
8. A water bath for soaking test specimens prior to testing, with a minimum temperature setting of 20°C.
9. An oven used to heat test specimens with a temperature control up to (200±3)°C.
10. ITS and TSR testing apparatus, which includes:
    a. A compressive load measurement device with a width of 0,5 inchi.
    b. A stability and flow gauge with a precision of 0,25 mm.
    c. Other supporting equipment for the research process, such as a stove, thermometer, spatula, pan, measuring glass, tray, plastic container, cloth, caliper, and other items.

4.4.3 Mixture Design

The preparation of AC-WC graded test specimens is based on the Spesifikasi Umum Bina Marga 2018 Revision 2, as follows.

1. Determine the aggregate composition.
2. Establish the asphalt content variation in the mixture using Pb calculations.
3. Prepare the test specimens with 2 x 75 blows using a Marshall compactor.
4. Determine the Optimum Asphalt Content (OAC) based on the following parameters:
    a. VITM with a minimum requirement of 3% and a maximum of 5%
    b. VMA with a minimum requirement of 15%
    c. VFWA with a minimum requirement of 68%
    d. Marshall stability of the mixture with a minimum requirement of 800 kg
    e. Flow of the mixture with a minimum requirement of 2 mm and a maximum of 4 mm
    f. IRS with a minimum requirement of 90%

The aggregate gradation used in the AC-WC mixture can be seen in Table 4.1 below.

Table 4.1 Aggregate Gradation AC-WC Mixture

Sieve Size		Specification (%)		Total Percentage (%)	
ASTM	(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
No. 4	4,75	53	69	61	39
No. 8	2,36	33	53	43	57
No.16	1,18	21	40	30,5	69,5
No. 30	0,6	14	30	22	78
No. 50	0,3	9	22	15,5	84,5
No. 100	0,15	6	15	10,5	89,5
No. 200	0,075	4	9	6,5	93,5
Pan		0	0	0	100

Based on Table 4.1, a gradation graph of the AC-WC mixture is constructed, which can be seen in Figure 4.1 below.

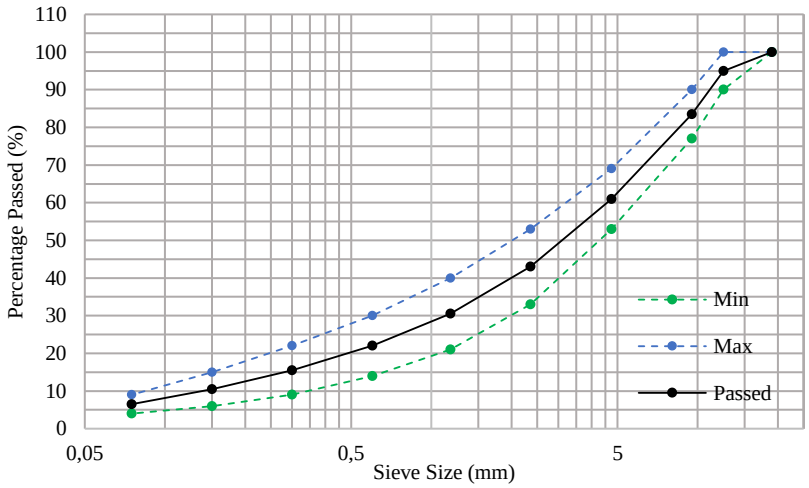

Figure 4.1 Gradation Graphic of AC-WC Mixture

The determination of the planned optimum asphalt content is calculated using Equation 4.1 as follows.

Pb = 0,035 (%CA)+0,045 (%FA)+0,18 (%Filler)+K (4.1)

description:

Pb = asphalt content

CA = percentage of aggregate retained on No. 4 sieve

FA = percentage of aggregate passing No. 4 sieve and retained on No. 200 sieve

Filler = percentage of aggregate passing No. 200 sieve

K = constant (1-2)

Based on Table 4.1, the values obtained are CA 39%, FA 54,5%, Filler 6,5%, dan K value using 1. Therefore, the planned optimum asphalt content can be calculated using Equation 4.1, yielding:

Pb = 0,035 (39) + 0,045 (54,5) + 0,18 (6,5) + 1 = 5,99%

the OAC variations used are 5%, 5,5%, 5,99%, 6,5%, 7% based on the total mixture weight of 1200 grams. Tables 4.2 through 4.6 detail the aggregate requirements for each asphalt content level.

Table 4.2 Aggregate Necessity of Asphalt Optimum Content 5%

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
3/4"	19	100,0	100,0	100,0	0,0	0,0	0,0
1/2"	12,5	90,0	100,0	95,0	5,0	57,0	57,0
3/8"	9,5	77,0	90,0	83,5	16,5	131,1	188,1
No. 4	4,75	53,0	69,0	61,0	39,0	256,5	444,6
No. 8	2,36	33,0	53,0	43,0	57,0	205,2	649,8
No.16	1,18	21,0	40,0	30,5	69,5	142,5	792,3
No. 30	0,6	14,0	30,0	22,0	78,0	96,9	889,2
No. 50	0,3	9,0	22,0	15,5	84,5	74,1	963,3
No. 100	0,15	6,0	15,0	10,5	89,5	57,0	1020,3
No. 200	0,075	4,0	9,0	6,5	93,5	45,6	1065,9
Pan		0	0	0	6,5	74,1	1065,9

Table 4.3 Aggregate Necessity of Asphalt Optimum Content 5,5%

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
3/4"	19	100,0	100,0	100,0	0,0	0,0	0,0
1/2"	12,5	90,0	100,0	95,0	5,0	56,7	56,7
3/8"	9,5	77,0	90,0	83,5	16,5	130,4	187,1
No. 4	4,75	53,0	69,0	61,0	39,0	255,2	442,3
No. 8	2,36	33,0	53,0	43,0	57,0	204,1	646,4
No.16	1,18	21,0	40,0	30,5	69,5	141,8	788,1
No. 30	0,6	14,0	30,0	22,0	78,0	96,4	884,5
No. 50	0,3	9,0	22,0	15,5	84,5	73,7	958,2
No. 100	0,15	6,0	15,0	10,5	89,5	56,7	1014,9
No. 200	0,075	4,0	9,0	6,5	93,5	45,4	1060,3
Pan		0	0	0	6,5	73,7	1060,3

Table 4.4 Aggregate Necessity of Asphalt Optimum Content 5,99%

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
3/4"	19	100,0	100,0	100,0	0,0	0,0	0,0
1/2"	12,5	90,0	100,0	95,0	5,0	56,4	56,4
3/8"	9,5	77,0	90,0	83,5	16,5	129,7	186,1
No. 4	4,75	53,0	69,0	61,0	39,0	253,8	440,0
No. 8	2,36	33,0	53,0	43,0	57,0	203,1	643,0
No.16	1,18	21,0	40,0	30,5	69,5	141,0	784,0
No. 30	0,6	14,0	30,0	22,0	78,0	95,9	879,9
No. 50	0,3	9,0	22,0	15,5	84,5	73,3	953,3
No. 100	0,15	6,0	15,0	10,5	89,5	56,4	1009,7
No. 200	0,075	4,0	9,0	6,5	93,5	45,1	1054,8
Pan		0	0	0	6,5	73,3	1054,8

Table 4.5 Aggregate Necessity of Asphalt Optimum Content 6,5%

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
3/4"	19	100,0	100,0	100,0	0,0	0,0	0,0
1/2"	12,5	90,0	100,0	95,0	5,0	56,1	56,1
3/8"	9,5	77,0	90,0	83,5	16,5	129,0	185,1

Table 4.5 Aggregate Necessity of Asphalt Optimum Content 6,5%

(continued)

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
No. 4	4,75	53,0	69,0	61,0	39,0	252,5	437,6
No. 8	2,36	33,0	53,0	43,0	57,0	202,0	639,5
No.16	1,18	21,0	40,0	30,5	69,5	140,3	779,8
No. 30	0,6	14,0	30,0	22,0	78,0	95,4	875,2
No. 50	0,3	9,0	22,0	15,5	84,5	72,9	948,1
No. 100	0,15	6,0	15,0	10,5	89,5	56,1	1004,2
No. 200	0,075	4,0	9,0	6,5	93,5	44,9	1049,1
Pan		0	0	0	6,5	72,9	1049,1

Table 4.6 Aggregate Necessity of Asphalt Optimum Content 7%

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
$^{3}/_{4}$"	19	100,0	100,0	100,0	0,0	0,0	0,0
$^{1}/_{2}$"	12,5	90,0	100,0	95,0	5,0	55,8	55,8
$^{3}/_{8}$"	9,5	77,0	90,0	83,5	16,5	128,3	184,1
No. 4	4,75	53,0	69,0	61,0	39,0	251,1	435,2
No. 8	2,36	33,0	53,0	43,0	57,0	200,9	636,1
No.16	1,18	21,0	40,0	30,5	69,5	139,5	775,6
No. 30	0,6	14,0	30,0	22,0	78,0	94,9	870,5
No. 50	0,3	9,0	22,0	15,5	84,5	72,5	943,0
No. 100	0,15	6,0	15,0	10,5	89,5	55,8	998,8
No. 200	0,075	4,0	9,0	6,5	93,5	44,6	1043,5
Pan		0	0	0	6,5	72,5	1043,5

The detailed number of test specimens used to determine the OAC can be seen in Table 4.7.

Table 4.7 Total Specimen Needed on Optimum Asphalt Content Test

Asphalt Type	Filler Variations				
	5%	5,5%	5,99%	6,5%	7%
Pertamina Pen 60/70	3	3	3	3	3
Total	15				

The number of test specimens for each test after obtaining the OAC value can be found in Tables 4.8 through 4.10.

Table 4.8 Total Specimen Needed for Each Test with 0 Hours Duration

Testing Type	Number of Sample Based on Submersion Duration (units)				
	0 Hour				
Filler	0%	25%	50%	75%	100%
Marshall	3	3	3	3	3
ITS	3	3	3	3	3
IRS	3	3	3	3	3
CL	3	3	3	3	3
Number	12	12	12	12	12
Total	60				

Table 4.9 Total Specimen Needed for Each Test with 24 Hours Duration

Testing Type	Number of Sample Based on Submersion Duration (units)				
	24 Hour				
Filler	0%	25%	50%	75%	100%
Marshall	3	3	3	3	3
ITS	3	3	3	3	3
IRS	3	3	3	3	3
CL	3	3	3	3	3
Number	12	12	12	12	12
Total	60				

Table 4.10 Total Specimen Needed for Each Test with 48 Hours Duration

Testing Type	Number of Sample Based on Submersion Duration (units)				
	48 Hour				
Filler	0%	25%	50%	75%	100%
Marshall	3	3	3	3	3
ITS	3	3	3	3	3
IRS	3	3	3	3	3
CL	3	3	3	3	3
Number	12	12	12	12	12
Total	60				

The aggregate requirements for the AC-WC mixture with optimum asphalt content for each percentage of substitute filler can be found in Tables 4.11 through 4.15 below.

Table 4.11 Aggregate Necessity with 0% Replacement Filler Content

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	Passed	Retained	Retained	Total
3/4"	19	100	100	100	0	0,00	0,00
1/2"	12,5	90	100	95	5	56,45	0,00
3/8"	9,5	77	90	83,5	16,5	129,84	129,84
No. 4	4,75	53	69	61	39	254,03	383,87
No. 8	2,36	33	53	43	57	203,22	587,09
No.16	1,18	21	40	30,5	69,5	141,13	728,22
No. 30	0,6	14	30	22	78	95,97	824,18
No. 50	0,3	9	22	15,5	84,5	73,39	897,57
No. 100	0,15	6	15	10,5	89,5	56,45	954,02
No. 200	0,075	4	9	6,5	93,5	45,16	999,18
Stone Dust Filler						73,04	1072,22
Glass Powder Filler						0,00	1072,22

Table 4.12 Aggregate Necessity with 25% Replacement Filler Content

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	ASTM	(mm)	Min	Max
3/4"	19	100	100	100	0	0,00	0,00
1/2"	12,5	90	100	95	5	56,45	0,00
3/8"	9,5	77	90	83,5	16,5	129,84	129,84
No. 4	4,75	53	69	61	39	254,03	383,87
No. 8	2,36	33	53	43	57	203,22	587,09
No.16	1,18	21	40	30,5	69,5	141,13	728,22
No. 30	0,6	14	30	22	78	95,97	824,18
No. 50	0,3	9	22	15,5	84,5	73,39	897,57
No. 100	0,15	6	15	10,5	89,5	56,45	954,02
No. 200	0,075	4	9	6,5	93,5	45,16	999,18
Stone Dust Filler						50,84	1050,02
Glass Powder Filler						16,95	1066,97

Table 4.13 Aggregate Necessity with 50% Replacement Filler Content

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	ASTM	(mm)	Min	Max
3/4"	19	100	100	100	0	0,00	0,00
1/2"	12,5	90	100	95	5	56,45	0,00
3/8"	9,5	77	90	83,5	16,5	129,84	129,84
No. 4	4,75	53	69	61	39	254,03	383,87
No. 8	2,36	33	53	43	57	203,22	587,09
No.16	1,18	21	40	30,5	69,5	141,13	728,22
No. 30	0,6	14	30	22	78	95,97	824,18
No. 50	0,3	9	22	15,5	84,5	73,39	897,57
No. 100	0,15	6	15	10,5	89,5	56,45	954,02
No. 200	0,075	4	9	6,5	93,5	45,16	999,18
Stone Dust Filler						36,52	1035,70
Glass Powder Filler						33,89	1069,59

Table 4.14 Aggregate Necessity with 75% Replacement Filler Content

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	ASTM	(mm)	Min	Max
3/4"	19	100	100	100	0	0,00	0,00
1/2"	12,5	90	100	95	5	56,45	0,00
3/8"	9,5	77	90	83,5	16,5	129,84	129,84
No. 4	4,75	53	69	61	39	254,03	383,87
No. 8	2,36	33	53	43	57	203,22	587,09
No.16	1,18	21	40	30,5	69,5	141,13	728,22
No. 30	0,6	14	30	22	78	95,97	824,18
No. 50	0,3	9	22	15,5	84,5	73,39	897,57
No. 100	0,15	6	15	10,5	89,5	56,45	954,02
No. 200	0,075	4	9	6,5	93,5	45,16	999,18
Stone Dust Filler						18,26	1017,44
Glass Powder Filler						50,84	1068,28

Table 4.15 Aggregate Necessity with 100% Replacement Filler Content

Sieve Size		Specification (%)		Total Percentage (%)		Retained Weight (gr)	
ASTM	(mm)	Min	Max	ASTM	(mm)	Min	Max
3/4"	19	100	100	100	0	0,00	0,00
1/2"	12,5	90	100	95	5	56,45	0,00
3/8"	9,5	77	90	83,5	16,5	129,84	129,84
No. 4	4,75	53	69	61	39	254,03	383,87
No. 8	2,36	33	53	43	57	203,22	587,09
No.16	1,18	21	40	30,5	69,5	141,13	728,22
No. 30	0,6	14	30	22	78	95,97	824,18
No. 50	0,3	9	22	15,5	84,5	73,39	897,57
No. 100	0,15	6	15	10,5	89,5	56,45	954,02
No. 200	0,075	4	9	6,5	93,5	45,16	999,18
Stone Dust Filler						0,00	999,18
Glass Powder Filler						67,78	1066,96

4.4.4 Specimen Submersion

The steps for soaking the test specimens in river water are as follows.

1. Ensure the test specimens are free from any adhering dirt or dust.
2. Measure the height of the test specimens at three different points, then calculate the average with an accuracy of up to 0,01 mm.
3. Weigh the test specimens to obtain their dry weight.
4. Submerge the test specimens in river water with varying soaking durations of 24 hours and 48 hours.

4.4.5 Marshall Testing

The steps for conducting the Marshall test are as follows.

1. Weigh the test specimen in water to determine its volume.
2. Dry the test specimen with a damp cloth until the surface is in a SSD condition.
3. Weigh the test specimen in its SSD condition.
4. Submerge the hot asphalt or tar test specimen in a water bath for 30 minutes at a temperature of 60 ± 1°C or heat it in an oven for 2 hours at a constant temperature of 60 ± 1°C, or 38 ± 1°C for tar test specimens.

5. Before testing, clean the guide rods and the inner surface of the test head. Lubricate the guide rods so that the upper test head can move freely. If desired, the test head can be soaked along with the test specimen at a temperature between 21°C and 38°C.
6. Remove the test specimen from the water bath or oven and place it in the lower segment of the test head. Attach the upper segment on top of the test specimen and place the entire assembly in the testing machine.
7. Set the flow meter dial to zero, while firmly holding the sleeve of the dial against the upper segment of the test head. Apply the sleeve of the flow meter to the upper segment of the test head during loading.
8. Before applying the load, raise the test head and specimen until they touch the base of the testing ring. Adjust the dial gauge reading to zero.
9. Apply the load to the test specimen at a constant rate of 50 mm per minute until the maximum load is reached, or until the load decreases as indicated by the dial gauge. Record the maximum load (stability) and simultaneously record the flow value from the flow meter.
10. Release the sleeve of the flow meter after the flow value is recorded. The time taken from when the specimen is removed from the water bath until the maximum load is reached should not exceed 30 seconds.

4.4.6 ITS Test

The steps for conducting the ITS test are as follows.

1. Place the test specimen, which has been removed from the river water immersion, onto the ITS testing apparatus for testing.
2. Record the dial readings obtained from the test results.
3. Analyze the data from the test results and prepare the discussion.

4.4.7 IRS Test

The steps for conducting the IRS test are as follows.

1. The test specimen is first immersed in river water for 24 hours at room temperature, allowing the water to fully penetrate the specimen.

2. After saturation, weigh the specimen while it is still submerged in water.
3. Carefully dry the surface of the specimen, then weigh it again in its SSD condition.
4. The specimen is then immersed in hot water at a temperature of 60°C for 24 hours.
5. Following the heating process, perform the Marshall test on the specimen according to the procedures outlined in subsection 4.4.5.
6. Analyze the data obtained from the Marshall test and prepare the discussion.

4.4.8 TSR Test

The steps for conducting the TSR test are as follows.

1. Record the thickness and diameter of each specimen.
2. Immerse the test specimens for the specified soaking duration. After soaking, transfer the specimens to a water bath maintained at 60°C for 24 hours.
3. Place the specimen in the Marshall testing apparatus and adjust the test head for ITS testing.
4. Record the dial reading based on the test results, then analyze the data from the test results and prepare the discussion.

4.4.9 CL Test

The steps for conducting the CL test are as follows.

1. Weight the test specimen to obtain it’s initial mass before abrasion (Mo).
2. Place the test specimen into the Los Angeles abrasion machine without steel balls.
3. Turn on the machine to rotate the specimen at a speed of 30-33 rpm for 300 revolutions.
4. After the rotation is complete, remove the test specimen from the machine and weight it again to determine the mass after the abrasion test (Mi).

4.5 Data Analysis

After conducting a series of tests, data analysis is performed to obtain the testing parameters.

4.5.1 Analysis of Marshall Characteristics Test

Based on the Marshall test, the following data are obtained.

1. Weight of the specimen before immersion (gram)
2. Weight of the specimen in water (gram)
3. Weight of the specimen in SSD condition (gram)
4. Thickness of the specimen
5. Stability dial reading (kg)
6. Flow dial reading (mm)

The Marshall characteristics can be calculated using the following formulas.

1. Asphalt specific weight

$$\text{Spec. gravity asphalt} = \frac{C-A}{(B-A)-(D-C)} \quad (4.2)$$

description:

A = weight of pycnometer with lid (g)

B = weight of pycnometer filled with water (g)

C = weight of pycnometer filled with asphalt (g)

D = weight of pycnometer filled with water and asphalt (g)

2. Aggregate specific weight

$$\text{Spec. gravity aggregate} = \frac{(A\ x\ F1)+(B\ x\ F2)}{100} \quad (4.2)$$

description:

A = percentage of coarse aggregate (%)

B = percentage of fine aggregate (%)

F1 = specific gravity of coarse aggregate

F2 = specific gravity of fine aggregate

3. The stability value is determined using Equation 3.1.
4. The flow value is read directly from the flow dial reading.
5. The density value can be calculated using Equations 3.2 and 3.3.
6. The VITM value can be calculated using Equations 3.4 and 3.5.
7. The VMA value can be calculated using Equations 3.6 and 3.7.
8. The VFWA value can be calculated using Equations 3.8 through 3.12.
9. The MQ value can be calculated using Equation 3.13.

4.5.2 Analysis of ITS Test

The ITS test value can be calculated using Equation 3.14.

4.5.3 Analysis of TSR Test

The TSR test value can be calculated using Equation 3.15.

4.5.4 Analysis of IRS Test

The IRS test value can be calculated using Equation 3.16.

4.5.5 Analysis of CL Test

The CL test value can be calculated using Equation 3.17.

4.6 Research Method Flowchart

The flowchart outlining the steps undertaken in this research is depicted in Figure 4.2.

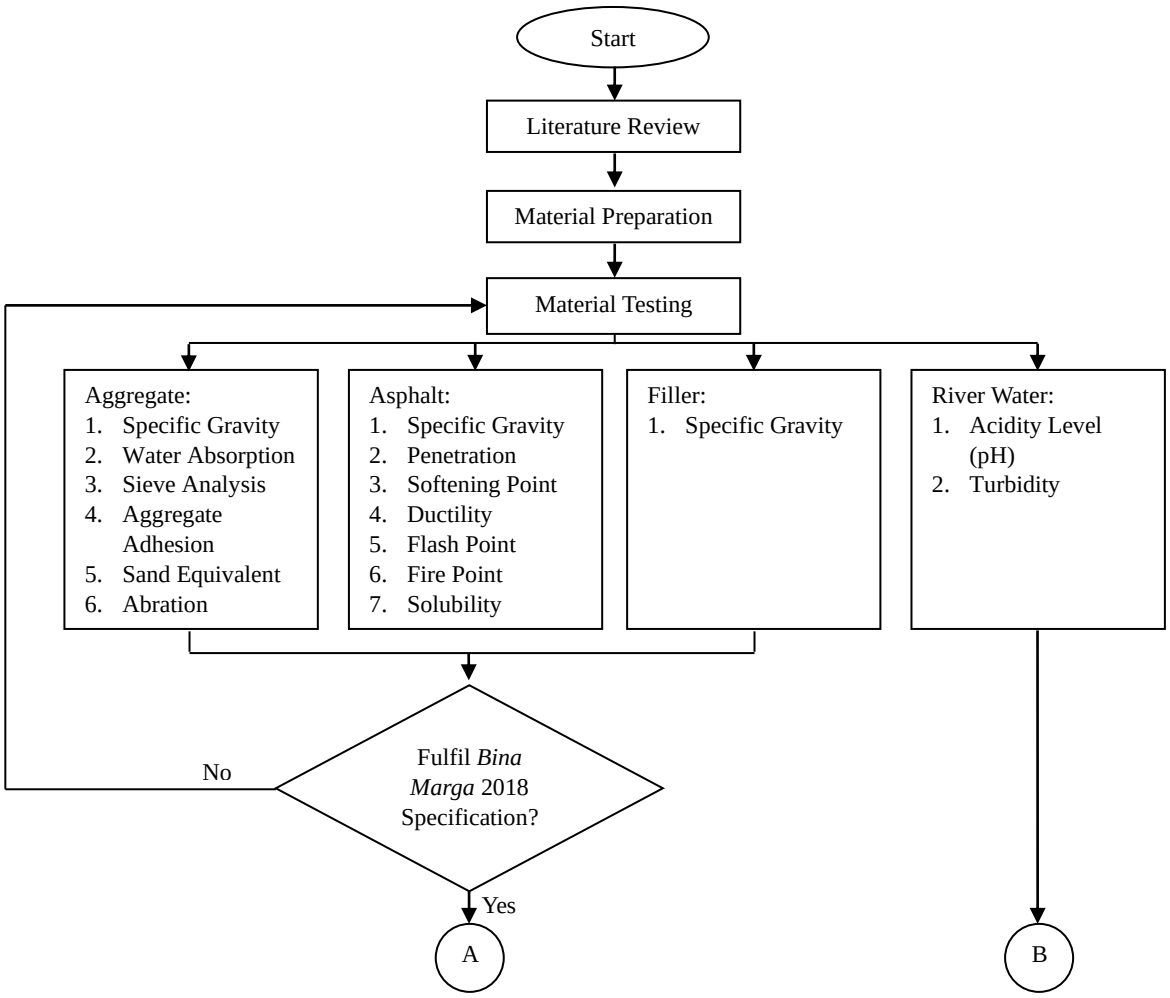

Figure 4.2 Research Flowchart

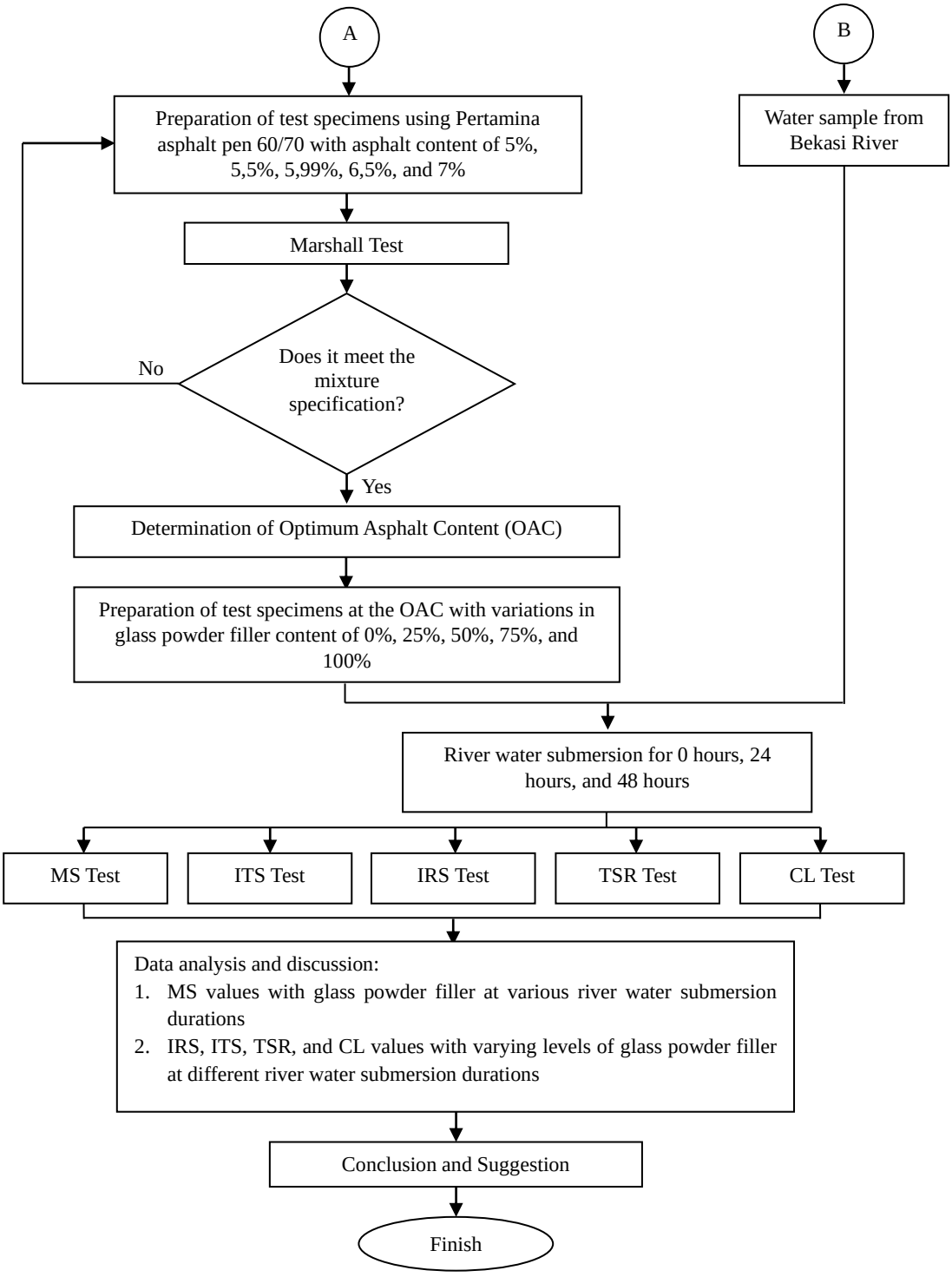

Figure 4.2 Research Flowchart (continued)

CHAPTER V
ANALYSIS AND DISCUSSION

5.1 Material and Mixture Test Results

The results of the laboratory tests on the AC-WC mixture are presented as follows.

5.1.1 Asphalt Characteristics Test Results

In this study, the asphalt characteristic tests were conducted using Pertamina Pen 60/70 asphalt as the test material for the mixture. The testing was carried out at the Highway Laboratory, Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia. The test results indicate that the obtained data meet the specifications and requirements based on the Bina Marga Specification 2018 Revision 2. A summary of the test results is presented in Table 5.1 below.

Table 5.1 Test Results of Pertamina Pen 60/70 Asphalt

No	Type of Test	Specification	Result	Remarks
1.	Specific gravity	≥ 1,0	1,040	Compliant
2.	Penetration (mm)	60-70	64	Compliant
3.	Ductility (cm)	≥ 100	134,5	Compliant
4.	Softening point (°C)	≥ 48	48,5	Compliant
5.	Flash point (°C)	≥ 232	308	Compliant
6.	Fire point (°C)	≥ 232	313	Compliant
7.	Solubility in TCE (%)	≥ 99	99,51	Compliant

5.1.2 Aggregate and Filler Characteristics Test Results

The aggregate characteristic tests include tests on coarse aggregate, fine aggregate, and glass powder filler. These tests were conducted at the Highway Laboratory, Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia. Based on the test results, all test parameters meet the specifications and requirements set forth in the Bina Marga

Specification 2018 Revision 2. A summary of the test results is presented in Table 5.2 below.

Table 5.2 Coarse Aggregate Test Results

No	Type of Test	Specification	Result	Remarks
1.	Specific gravity	≥ 2,5	2,57	Compliant
2.	Water absorption (%)	≤ 3	2,59	Compliant
3.	Aggregate adhesion to asphalt (%)	≥ 95	97	Compliant
4.	Aggregate abrasion using Los Angeles machine (%)	≤ 40	12,20	Compliant

Table 5.3 Fine Aggregate Test Results

No	Type of Test	Specification	Result	Remarks
1.	Specific gravity	≥ 2,5	2,65	Compliant
2.	Water absorption (%)	≤ 3	2,61	Compliant
3.	Sand equivalent (%)	≥ 50	71,62	Compliant

Table 5.4 Filler Test Results

No	Type of Test	Specification	Result	Remarks
1.	Specific gravity of stone dust		2,54	Compliant
2.	Specific gravity of glass powder		2,36	Compliant

5.1.3 River Water Test Result

Water sample testing was conducted by examining the turbidity and acidity level (pH) of the water. The water sample used was sourced from the Bekasi River and tested at the Environmental Quality Laboratory, Faculty of Civil Engineering and Planning, Islamic University of Indonesia. The test results are shown in Table 5.5 below.

Table 5.5 River Water Test Results

No	Parameter	Unit	Result	Test Method
			APS.006	
1.	Turbidity	NTU	3,62 ± 1,04	SNI 06-6989.25-2005
2.	pH	-	6,49 ± 0,24	SNI 6989.11-2019

5.1.4 Test Results of AC-WC Mixture to Determine the Optimum Asphalt Content

The purpose of this test is to identify the OAC in the AC-WC mixture using Pertamina Pen 60/70 asphalt. The OAC value is determined based on the results obtained from the Marshall characteristics, which include stability, flow, density,

MQ, VITM, VFWA, and VMA. A summary of the OAC test results is presented in Table 5.6 below.

Table 5.6 Test Results of Mixture 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
Specification	> 800	2-4	>250	3-5	>68	>15	>2

Based on the Marshall test results, the OAC can be determined through the graph presented in Figure 5.1 below.

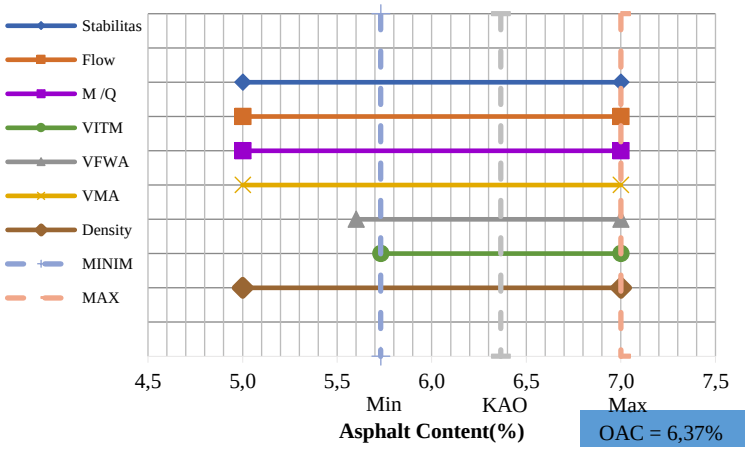

Figure 5.1 Determination of OAC for the AC-WC Mixture with Pertamina Pen 60/70 Asphalt

Based on Figure 5.1 above, the optimum asphalt content used for the AC-WC mixture with Pertamina Pen 60/70 asphalt is 6,37%.

5.1.5 Test Results of the AC-WC Mixture with the Optimum Asphalt Content

After determining the OAC, the next stage involved preparing samples with glass powder filler substitution, which were soaked in river water to observe its effect on the mixture's performance. The characteristics of the glass powder must be analyzed, as its physical properties—such as specific gravity and particle shape—affect the performance of the mixture. Based on the test results, the glass powder had a specific gravity of 2,361 g/cm³, which is lower than that of stone dust at 2,544 g/cm³. Figure 5.2 presents the glass powder particles under a 40x microscopic magnification, illustrating their texture and surface shape.

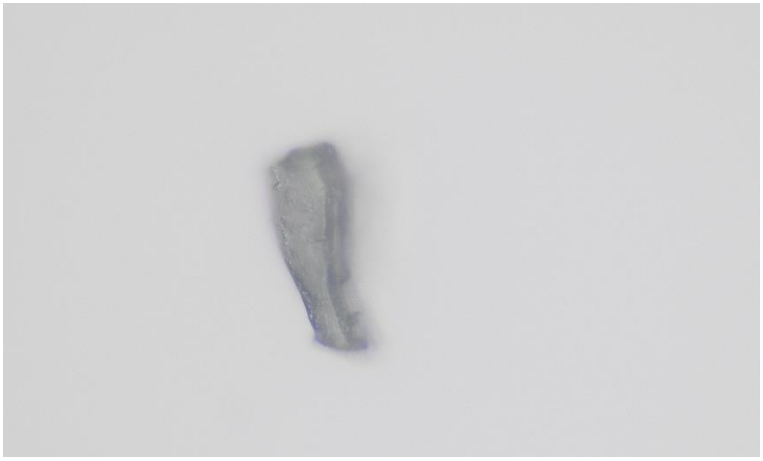

Figure 5.2 Glass Powder Particles Under 40X Microscopic Magnification

The AC-WC mixture at the OAC with filler substitution was soaked for 0 hours, 24 hours, and 48 hours. Subsequently, the mixture was subjected to Marshall tests, as well as IRS, ITS, TSR, and CL tests. The results of these tests are summarized in Tables 5.7 through 5.11.

Table 5.7 Summary of Marshall Test Results with OAC

Soaking Duration	Filler Content (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)	VITM (%)	VMA (%)	VFWA (%)	Density (gr/cc)
0 Hour	0	1363,22	3,26	420,81	3,69	17,73	79,28	2,29
	25	1284,87	3,09	423,09	4,15	18,11	77,15	2,28
	50	1329,42	2,81	476,26	3,83	17,83	78,54	2,29
	75	1351,55	2,70	504,48	3,76	17,76	78,90	2,28
	100	1240,00	3,46	359,96	4,39	18,28	76,07	2,27
Specification		> 800	2-4	3-5	>15	>250	>68	>2

Table 5.7 Summary of Marshall Test Results with OAC (continued)

Soaking Duration	Filler Content (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)	VITM (%)	VMA (%)	VFWA (%)	Density (gr/cc)
24 Hour	0	1154,10	3,76	308,89	3,65	17,70	79,39	2,29
	25	1061,13	3,59	306,20	4,07	18,05	77,44	2,28
	50	1097,45	3,31	339,52	3,88	17,87	78,36	2,28
	75	1148,37	3,14	368,58	3,74	17,73	78,94	2,29
	100	1022,68	3,84	265,63	4,44	18,32	75,89	2,27
48 Hour	0	956,55	4,06	236,67	3,69	17,74	79,22	2,29
	25	916,73	3,96	236,84	4,09	18,06	77,39	2,28
	50	952,07	3,72	256,77	3,82	17,82	78,72	2,29
	75	982,15	3,62	271,72	3,77	17,76	78,85	2,28
	100	883,87	4,26	215,29	4,26	18,16	76,61	2,27
Specification		> 800	2-4	3-5	>15	>250	>68	>2

Table 5.8 Summary of IRS Test Results with OAC

Soaking Duration	Filler Substitution Rate (%)	IRS (%)
0 Hour	0	96,82
	25	96,22
	50	95,93
	75	95,31
	100	93,95
24 Hour	0	94,70
	25	93,40
	50	92,59
	75	91,47
	100	89,45
48 Hour	0	91,65
	25	90,59
	50	89,44
	75	88,82
	100	86,99

Table 5.9 Summary of ITS Test Results with OAC

Soaking Duration	Filler Substitution Rate (%)	ITS (kPa)
0 Hour	0	140,60
	25	130,80
	50	137,47
	75	138,47
	100	122,37
24 Hour	0	128,00
	25	118,92

Table 5.9 Summary of ITS Test Results with OAC (continued)

Soaking Duration	Filler Substitution Rate (%)	ITS (kPa)
24 Hour	50	125,52
	75	127,47
	100	107,15
48 Hour	0	121,82
	25	111,99
	50	118,60
	75	120,95
	100	97,35

Table 5.10 Summary of TSR Test Results with OAC

Soaking Duration	Filler Substitution Rate (%)	TSR (%)
0 Hour	0	96,35
	25	94,77
	50	92,23
	75	91,11
	100	84,65
24 Hour	0	93,71
	25	91,15
	50	88,86
	75	87,05
	100	80,85
48 Hour	0	89,86
	25	87,58
	50	85,66
	75	82,48
	100	77,73

Table 5.11 Summary of Cantabro Loss Test Results with OAC

Soaking Duration	Filler Substitution Rate (%)	CL (%)
0 Hour	0	2,75
	25	3,47
	50	3,11
	75	2,94
	100	3,65
24 Hour	0	3,08
	25	3,84
	50	3,50
	75	3,37
	100	4,12
48 Hour	0	3,51
	25	4,23
	50	4,03
	75	3,88
	100	5,00

5.2 Discussion

The discussion of the results from material and mixture characteristic testing is presented as follows.

5.2.1 Asphalt Characteristic Test Results

The discussion on the asphalt characteristic test results is described below.

1. Asphalt Specific Gravity

   The specific gravity of asphalt is the ratio between the mass of asphalt and the mass of distilled water at the same volume and temperature. Based on the test results, the specific gravity of Pertamina Pen 60/70 asphalt is 1,040. This value indicates that the test result meets the Bina Marga 2018 Revision 2 specification, which requires a minimum value of 1,00.

2. Asphalt Penetration

   This test aims to measure the hardness of bitumen by the depth of penetration of a needle under specified conditions. The penetration value of Pertamina Pen 60/70 asphalt is 64, indicating compliance with the Bina Marga 2018 Revision 2 specification range of 60–70 mm.

3. Asphalt Ductility

   This test is conducted to evaluate the cohesive properties of asphalt by measuring the maximum elongation of the bitumen before breaking. The ductility result of Pertamina Pen 60/70 asphalt is 134,5 cm, which satisfies the Bina Marga 2018 Revision 2 requirement of greater than 100 cm.

4. Flash Point and Fire Point of Asphalt

   This test determines the maximum heating temperature of asphalt before combustion occurs, by observing the temperature at which the asphalt ignites and sustains a flame for at least 5 seconds. The flash point and fire point of Pertamina Pen 60/70 asphalt are 308°C and 313°C, respectively, both of which comply with the Bina Marga 2018 Revision 2 specification of $\geq$ 232°C.

5. Softening Point of Asphalt

   This test aims to determine the temperature at which asphalt begins to soften. The softening point of Pertamina Pen 60/70 asphalt is recorded at 48,5°C, in accordance with the Bina Marga 2018 Revision 2 specification of ≥ 48°C.

6. Solubility in *Trichloroethylene* (TCE)

   This test is conducted to identify the presence of mineral impurities in asphalt by dissolving it in carbon tetrachloride. A high solubility percentage indicates a low presence of impurities that could hinder the bond between asphalt and aggregate. The solubility of Pertamina Pen 60/70 asphalt in TCE is 99,51%, which meets the Bina Marga 2018 Revision 2 requirement of ≥99%.

5.2.2 Coarse Aggregate Characteristic Test Results

The discussion of the coarse aggregate characteristic test results is as follows.

1. Aggregate Specific Gravity

   Specific gravity is the ratio between the dry weight of aggregate and the weight of distilled water occupying the same volume at a specified temperature. The specific gravity value influences the amount of voids within the aggregate. A higher specific gravity indicates fewer voids, which reduces asphalt demand. The test results show that the specific gravity of Clereng coarse aggregate is 2,57, which meets the Bina Marga 2018 Revision 2 specification of greater than 2,5.

2. Water Absorption of Aggregate

   Water absorption refers to the percentage of water absorbed into the aggregate’s pores relative to its dry weight. Aggregates with smaller pores generally have lower water absorption, thereby requiring less asphalt, and vice versa. According to the test results, the water absorption of Clereng coarse aggregate is 2,59%, which complies with the maximum allowable value of 3% as specified in Bina Marga 2018 Revision 2.

3. Aggregate Adhesion to Asphalt

This test aims to measure the percentage of the aggregate surface area that is coated with asphalt. The better the adhesion between aggregate and asphalt, the more stable and resistant the asphalt mixture is to stripping. The results show that the adhesion of aggregate to Pertamina Pen 60/70 asphalt is 97%, which satisfies the Bina Marga 2018 Revision 2 specification of greater than 95%.

4. Los Angeles Abrasion Test

This test evaluates the resistance of coarse aggregate to impact and abrasion by using the Los Angeles abrasion machine. The abrasion value is determined by comparing the weight of aggregate passing through sieve No. 12 after testing to the initial sample weight. Based on the results, the abrasion value obtained is 12,20%, which is well within the Bina Marga 2018 Revision 2 requirement of less than 40%.

5.2.3 Fine Aggregate Characteristic Test Results

The discussion of the fine aggregate characteristic test results is as follows.

1. Specific Gravity of Aggregate

The specific gravity of fine aggregate is defined as the ratio of the aggregate’s mass to the mass of water at the same volume and temperature, as regulated in SNI 1970:2008. The test results indicate that the specific gravity of Clereng fine aggregate is 2,65, which complies with Bina Marga Specification 2018 Revision 2, which requires a value greater than 2,5.

2. Water Absorption of Aggregate

Water absorption refers to the aggregate's ability to absorb water through its pores, typically expressed as a percentage. Aggregates with larger pores tend to require more asphalt compared to those with smaller pores. The water absorption value of Clereng fine aggregate was found to be 2,61%, meeting the Bina Marga Specification 2018 Revision 2 requirement of less than 3%.

3. Sand Equivalent

   This test aims to determine the amount of dust, silt, or other clay-like materials mixed with the fine aggregate. Fine aggregates free from such impurities can improve the bonding between asphalt and aggregate. The test results showed a sand equivalent value of 71,62%, which fulfills the Bina Marga Specification 2018 Revision 2 requirement of greater than 50%.

5.2.4 Filler Characteristics Test Results

This study utilized two types of fillers: stone dust and a substitute filler in the form of glass powder. The following is a discussion of the filler characteristics test results.

1. Specific Gravity of Stone Dust

   Specific gravity is defined as the ratio of the dry weight of the filler to the weight of water at the same volume and a given temperature. This value influences the pore volume, a higher specific gravity generally indicates smaller pores within the filler particles, and vice versa. The test result for the specific gravity of stone dust was 2,544.

2. Specific Gravity of Glass Powder

   Specific gravity is the ratio between the weight of the material and the weight of water at the same volume and temperature. The specific gravity of the glass powder was found to be 2,361.

This test is essential to determine the volumetric comparison between stone dust and glass powder to ensure equivalent volume usage. Since the specific gravity of glass powder is lower than that of stone dust, for the same volume, glass powder occupies a greater volume than stone dust.

5.2.5 River Water Quality Test Results

Surface water samples were collected from the Bekasi River, located in the city of Bekasi, West Java Province. The samples were analyzed at the Environmental Quality Laboratory, Faculty of Civil Engineering and Planning, Islamic University of Indonesia. The parameters tested included turbidity and pH level. The results are discussed as follows.

1. Turbidity

   Turbidity testing measures the extent to which water becomes cloudy due to the presence of fine suspended particles, with the aim of assessing water clarity and visual quality. Higher turbidity values indicate a higher concentration of particulate matter, which may negatively affect asphalt mixture performance. The turbidity of the Bekasi River water sample was recorded at 3,62 NTU.

2. pH Level

   The pH test determines the acidity level of a solution using a pH meter. A higher pH value indicates a more alkaline solution, whereas a lower value indicates a more acidic solution. The pH scale ranges from 0 to 14, with a neutral pH of 7. The pH value of the Bekasi River water sample was found to be 6,49.

5.2.6 Effect of Asphalt Content on the Mixture for Determining OAC

The determination of OAC in the AC-WC mixture was based on several parameters, including stability, flow, MQ, VITM, VMA, VFWA, and density. The analysis of Marshall test results served as the basis for identifying the OAC, as outlined in the following discussion.

1. Analysis of the Influence of Stability on Determining OAC

   Stability refers to the pavement’s ability to withstand traffic loads without undergoing permanent deformation, such as rutting, shoving, or asphalt bleeding. This parameter is critical for preventing early pavement failures that may compromise safety. By optimizing asphalt content, the mixture can be designed to be both strong and flexible, allowing it to resist traffic loads over time. The stability values of the AC-WC mixture are illustrated in Figure 5.3.

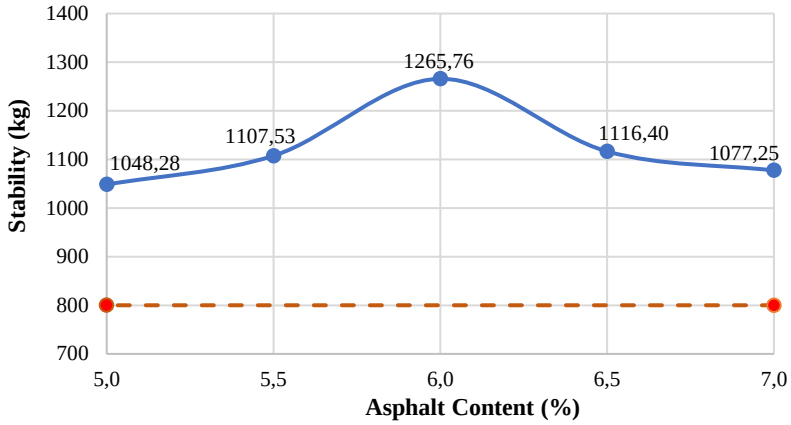

Figure 5.3 Graph of the Effect of Asphalt Content on Stability

As shown in Figure 5.3, the stability of the mixture increases with rising asphalt content, reaching a peak at 6%, after which it begins to decline. This increase is attributed to enhanced internal cohesion due to the uniform formation of an asphalt film on the aggregate surface. However, beyond the optimum asphalt content, an excessively thick asphalt film leads to a lubrication effect that weakens inter-particle bonding, thereby reducing stability. Nevertheless, the stability values across asphalt contents ranging from 5% to 7% still meet the minimum requirement of 800 kg, as stipulated in the Spesifikasi Umum Bina Marga 2018 Revision 2.

2. Analysis of the Influence of Flow Value on Determining OAC

The flow parameter in the Marshall test measures the deformation of the asphalt mixture under maximum load, serving as an indicator of the mixture's flexibility. This parameter ensures that the pavement can endure traffic loads and environmental effects without excessive deformation. The flow values of the AC-WC mixture are shown in Figure 5.4.

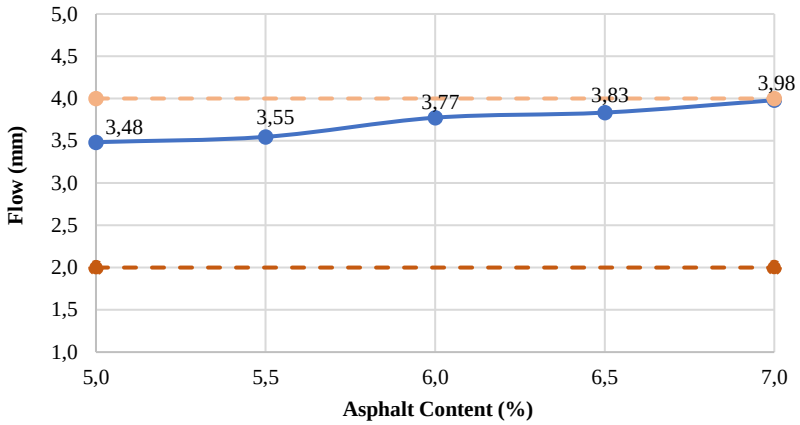

Figure 5.4 Graph of the Effect of Asphalt Content on Flow

As illustrated in Figure 5.4, the flow value increases with higher asphalt content. This is attributed to the thickening of the asphalt film coating the aggregate, which increases the mixture's plasticity. A more plastic mixture tends to deform more easily under traffic loads. According to the Spesifikasi Umum Bina Marga 2018 Revision 2, the acceptable flow range for AC-WC mixtures is 2–4 mm. Accordingly, the flow values at asphalt contents of 5% to 7% remain within the specified limits.

3. Analysis of the Influence of MQ on Determining OAC

The MQ is the ratio between the stability and flow values obtained from the Marshall test. It is used to determine the optimum asphalt content and evaluate the mixture's performance under loading. The MQ values are presented in Figure 5.5.

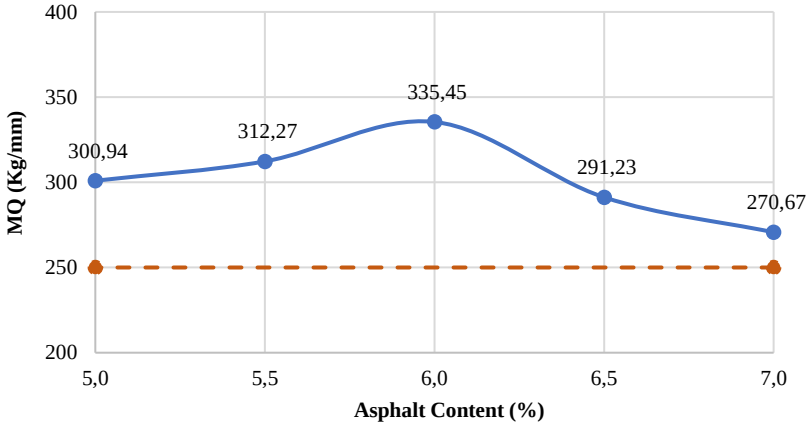

Figure 5.5 Graph of the Effect of Asphalt Content on MQ

As shown in Figure 5.5, the MQ increases with asphalt content up to a peak at 6%, after which it decreases. The initial increase results from the asphalt binder filling the voids between aggregate particles, thereby enhancing internal cohesion between asphalt and aggregate. This results in a stiffer mixture with reduced plastic deformation. However, beyond the optimum content, the excess asphalt acts as a lubricant between aggregate particles, weakening internal bonding and increasing plasticity, thus lowering the MQ. Nevertheless, all MQ values within the asphalt content range of 5%–7% exceed the minimum threshold of 250 kg/mm, as specified in Bina Marga 2018 Revision 2.

4. Analysis of the Influence of VITM on Determining OAC

VITM refer to the percentage of air voids within the compacted asphalt mixture, representing the mixture's density and its resistance to deformation. The VITM values of the AC-WC mixture are displayed in Figure 5.6.

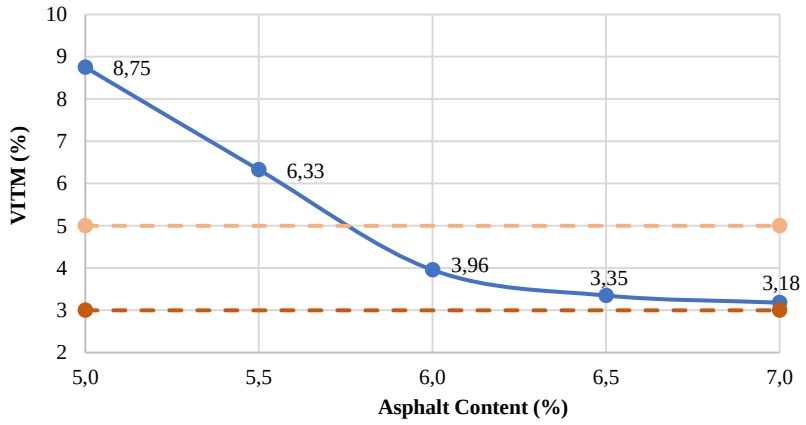

Figure 5.6 Graph of the Effect of Asphalt Content on VITM

Figure 5.6 shows that VITM values decrease with increasing asphalt content, due to air voids being progressively filled by asphalt. However, the VITM values at 5% and 5,5% asphalt content fall outside the specified limits outlined in Bina Marga 2018 Revision 2, which requires VITM values to be between 3% and 5%.

5. Analysis of the Influence of VMA on Determining OAC

VMA represent the percentage of volume consisting of both air voids and asphalt-filled voids between the mineral aggregate particles. VMA values are shown in Figure 5.7.

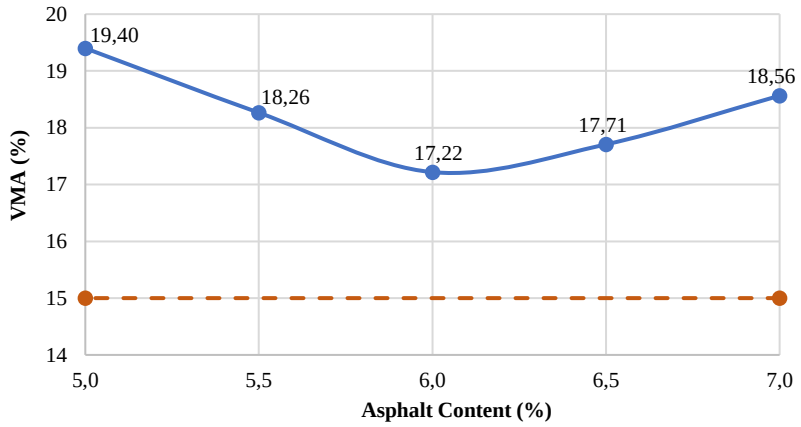

Figure 5.7 Graph of the Effect of Asphalt Content on VMA

As seen in Figure 5.7, VMA values decrease with increasing asphalt content up to a minimum at 6%, then begin to rise again at higher contents. The initial decrease is due to the asphalt filling the voids between aggregate particles, reducing the empty space. Conversely, the increase at higher asphalt contents is caused by thicker asphalt films forming on aggregate surfaces, increasing the spacing between particles. Despite these fluctuations, all VMA values from 5% to 7% asphalt content remain above the minimum requirement of 15%, as stated in the Bina Marga 2018 Revision 2.

6. Analysis of the Influence of VFWA on Determining OAC

VFWA is the percentage of voids within the mixture that are filled with asphalt. VFWA generally increases as asphalt content increases, since more air voids are occupied by asphalt, as shown in Figure 5.8.

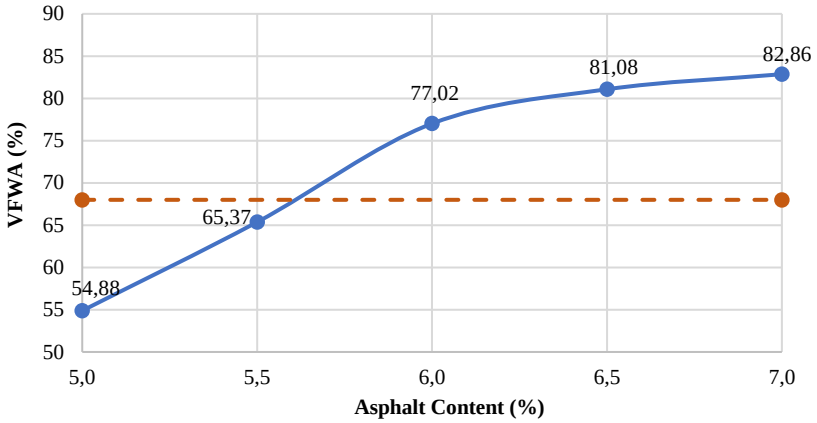

Figure 5.8 Graph of the Effect of Asphalt Content on VFWA

Figure 5.8 demonstrates that VFWA values rise in tandem with increasing asphalt content, due to the progressive filling of air voids. However, VFWA values at 5% and 5,5% asphalt content do not meet the minimum specification of 68%, as required by Bina Marga 2018 Revision 2.

7. Analysis of the Influence of Density on Determining OAC

Density is used to assess the compactness and structural integrity of the mixture. A mixture with higher density generally exhibits better resistance to traffic loads. The density values of the AC-WC mixture are presented in Figure 5.9.

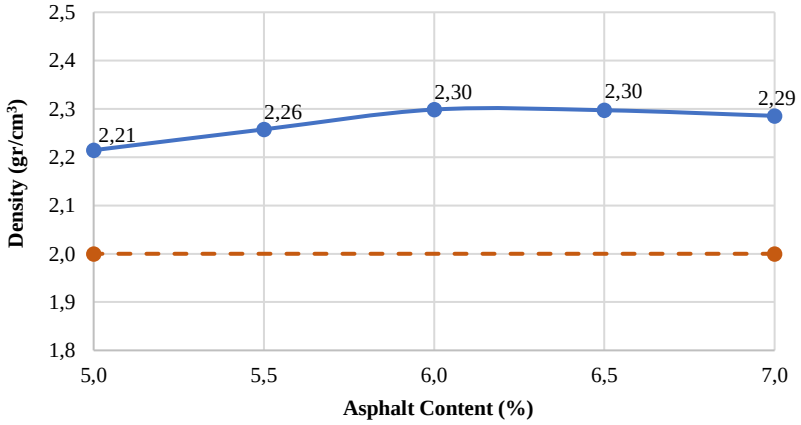

Figure 5.9 Graph of the Effect of Asphalt Content on Density

Figure 5.9 shows that density increases with asphalt content up to 6–6,5%, then decreases at 7%. The increase is due to the asphalt filling the voids

between aggregates, resulting in a denser mixture. The subsequent decrease is attributed to excess asphalt acting as a lubricant, reducing the packing efficiency between aggregates. Nonetheless, all density values within the asphalt content range of 5%–7% comply with the minimum requirement of 2 g/cm³, in accordance with Bina Marga 2018 Revision 2.

5.2.7 Marshall Characteristics at the OAC of Mixtures with Glass Powder (GP) Filler Substitution

Based on the Marshall test results, the OAC of the AC-WC mixture using Pertamina Pen 60/70 asphalt was determined to be 6,37%. The mixture was subsequently tested after subemersion in river water for 24 and 48 hours, with the unsoaked mixture serving as a control. The results revealed changes in performance characteristics due to the submersion treatment, as discussed in the following sections.

1. Analysis of the Effect of River Water Submersion on the Stability of AC-WC Mixtures with Glass Powder Substitution

The stability test results for AC-WC mixtures incorporating GP filler under various river water submersion durations are presented in Figure 5.10.

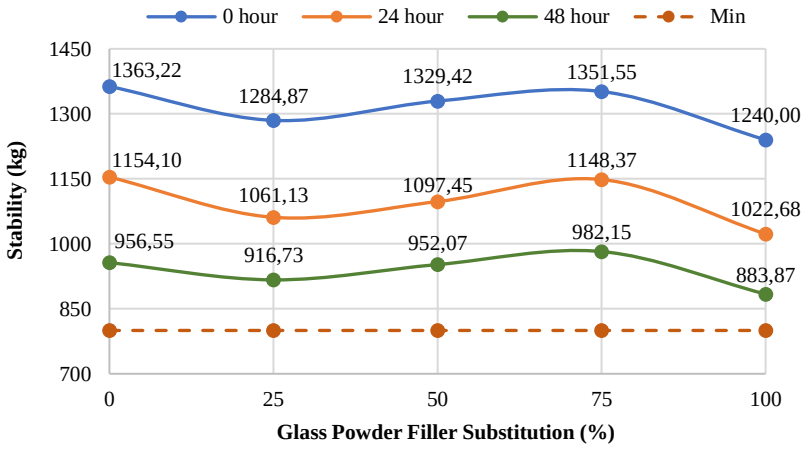

Figure 5.10 Graph of the Relationship Between GP Filler Content and Stability Under Different Submersion Durations

As shown in Figure 5.10, the addition of glass powder as filler in the AC-WC mixture led to a decrease in stability at 25% substitution, followed by an increase up to 75%, and then a sharp decline at 100% substitution. Generally, mixtures with stone dust filler exhibit higher stability compared to those with glass powder, which is attributed to the lower specific gravity of glass powder, resulting in a less compact mixture. Although higher GP content can increase stability through void filling and the angular shape of its particles, which strengthens the bond between filler and binder, the reduction in stability at 25% is due to suboptimal interaction between the two filler types. The sharp decline at 100% substitution is caused by the smooth surface of glass powder, which reduces adhesion to the asphalt binder, thereby increasing voids and reducing mixture density. This finding aligns with Ogundipe & Nnochiri (2020), who stated that glass powder filler does not significantly engage in chemical reactions, resulting in lower stability than conventional fillers, with stability increasing to a peak before dropping drastically at higher substitution levels.

Figure 5.10 also indicates that increasing submersion duration leads to decreased stability. This decline is due to the weakening of the asphalt–aggregate bond caused by the penetration of slightly acidic river water into aggregate pores. Furthermore, suspended particles in turbid water may trap water in the voids, exacerbating this effect. These results are consistent with the findings of Fauziah & Handaka (2017), who reported that longer submersion periods reduce stability due to disrupted adhesion caused by acidic rainwater.

2. Analysis of the Effect of River Water Submersion on the Flow of AC-WC Mixtures with Glass Powder Substitution

   Flow test results for AC-WC mixtures containing GP filler under varying river water submersion durations are shown in Figure 5.11.

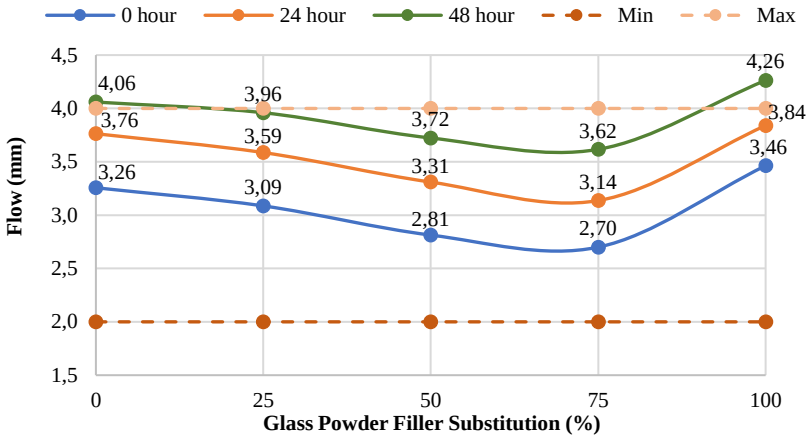

Figure 5.11 Graph of the Relationship Between GP Filler Substitution and Flow Under Different Submersion Durations

Figure 5.11 shows a decrease in flow values up to 75% GP substitution, followed by a sharp increase at 100%. The initial decrease is attributed to increased void filling by glass powder and the contribution of angular particles, which enhance structural stiffness. Conversely, at 100% substitution, the smooth surface of the glass powder reduces adhesion with the asphalt, increasing voids and leading to a more plastic mixture that is more prone to deformation. These findings are in agreement with Hasan, et al. (2025), who reported a reduction in flow due to increased density and interlocking of particles.

Figure 5.11 also indicates that prolonged submersion contributes to increased flow values. This increase suggests that the mixture's structure weakens due to interaction with water, making it more susceptible to deformation under loading. This observation is consistent with the reduction in stability shown in Figure 5.10, which also declines with longer submersion durations. According to the Bina Marga 2018 Revision 2 Specifications, the acceptable flow range for AC-WC mixtures is 2–4 mm. Therefore, at 0% and 100% GP substitution, the flow values after 48 hours of submersin do not meet the specified criteria.

3. Analysis of the Effect of River Water Submersion on the MQ Value of Mixtures with Glass Powder Substitution

The results of the MQ test on AC-WC mixtures containing GP filler under varying durations of river water submersion are presented in Figure 5.12.

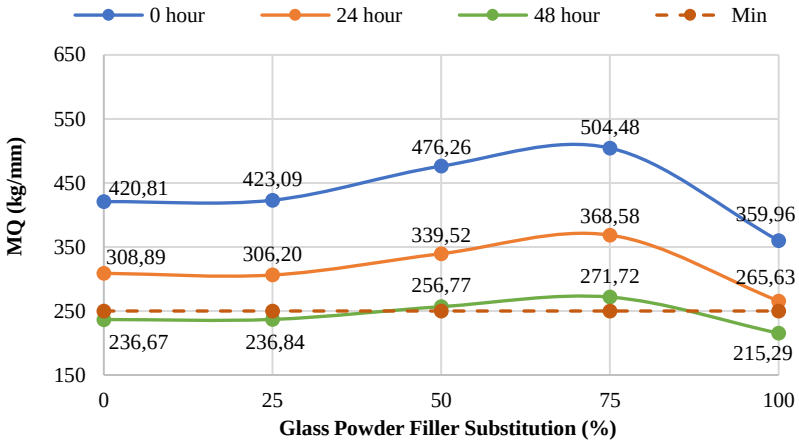

Figure 5.12 Graph of the Relationship Between GP Filler Substitution and MQ Value Under Different Submersion Durations

As shown in Figure 5.12, the MQ value increased and peaked at 75% GP filler substitution, followed by a significant decline at 100%. This increase indicates improved stiffness and resistance of the mixture to permanent deformation. The maximum value at 75% is attributed to relatively high stability, supported by effective void filling by the filler and low flow values, resulting in a stiff and stable structure. In contrast, at 0% substitution, although the mixture achieved the highest stability, the high flow value indicates a tendency for the mixture to be more plastic. The sharp decrease in MQ at 100% substitution is caused by weak internal bonding in the mixture, due to reduced adhesion between the GP filler and asphalt binder, which leads to increased voids and lower compaction, making the mixture more prone to deformation. These findings are consistent with Hasan, et al. (2025), who noted that while glass powder increases mixture stiffness by reducing voids, excessive amounts can reduce the mixture's flexibility under load.

Figure 5.12 also shows that MQ values decrease with increasing submersion durations, indicating reduced mixture stiffness due to the influence of river water. The most significant reduction occurred at 100% GP substitution compared to the control sample (0% filler, 0 hours), with decreases of 16.91% at 0 hours, 58,42% at 24 hours, and 95,47% at 48 hours. According to the Bina Marga 2018 Revision 2 Specifications, the minimum required MQ value for AC-WC mixtures is 250 kg/mm. Accordingly, mixtures with 0%, 25%, and 100% filler substitution failed to meet this minimum criterion after 48 hours of submersion.

4. Analysis of the Effect of Glass Powder Filler Content on VITM

The VITM test results for AC-WC mixtures with GP filler substitution are presented in Figure 5.13.

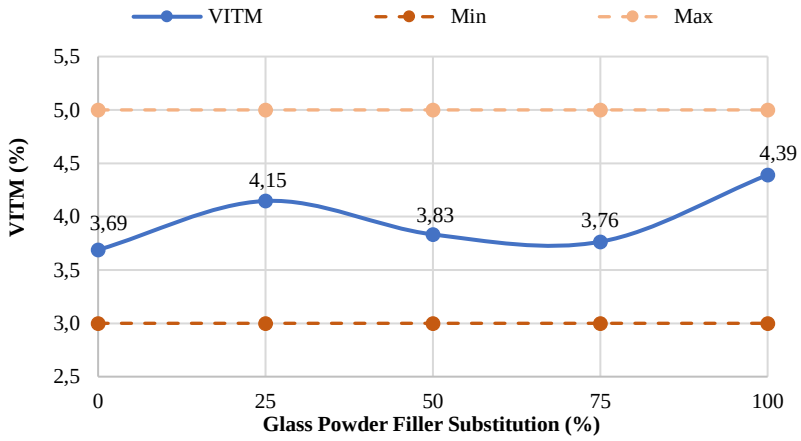

Figure 5.13 Graph of the Relationship Between GP Filler Substitution and VITM

According to Figure 5.13, VITM values increased at 25% GP filler substitution, decreased up to 75%, and then rose significantly again at 100%. The initial increase at 25% is attributed to an imbalance in the proportion of stone dust and glass powder, resulting in a less compact mixture. The decrease in VITM up to 75% is due to the more effective void-filling capacity of glass powder, which enhances mixture compaction. However, at 100% substitution, VITM increased again due to the smooth

surface of the glass powder, which reduces adhesion to asphalt and hinders the formation of a dense structure. High VITM values increase the likelihood of water infiltration, which can accelerate bond degradation and reduce pavement service life.

These findings align with Kifile, et al. (2024), who observed that increasing glass powder content generally reduces VITM due to improved compaction efficiency and particle packing. However, at higher substitution levels, the use of glass powder alone is less effective at forming strong bonds with asphalt, resulting in a rebound in VITM.

5. Analysis of the Effect of Glass Powder Filler Content on VMA

The VMA test results for AC-WC mixtures incorporating GP filler substitution are presented in Figure 5.14.

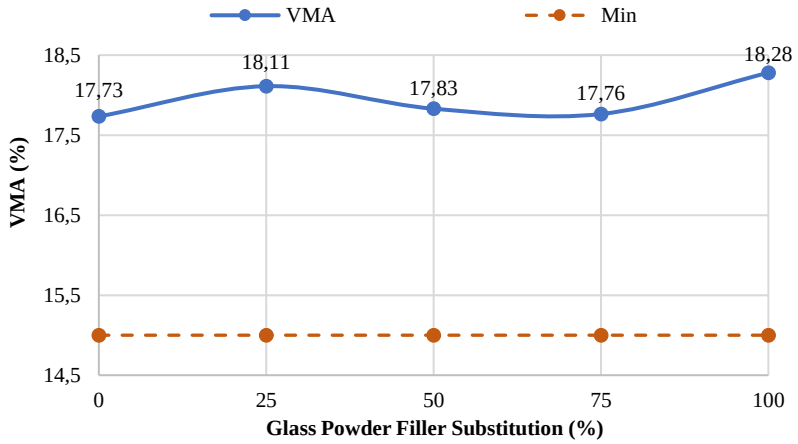

Figure 5.14 Graph of the Relationship Between GP Filler Substitution and VMA

Figure 5.14 provides an analysis of how GP filler substitution influences the volumetric properties of asphalt mixtures. The increase in VMA from 17,73% at 0% substitution to 18,11% at 25% is attributed to initial disruption in aggregate compaction due to the lower specific gravity and distinct particle characteristics of glass powder compared to conventional stone dust filler. Subsequently, VMA decreases to 17,76% at 75%

substitution, reflecting enhanced compaction and optimal interaction between filler and binder, which is consistent with higher mixture density and maximum stability. However, the VMA rises again to 18,28% at 100% substitution, indicating that excessive glass powder reduces the workability of the mixture, leading to increased voids and potential performance degradation.

This trend aligns with Choudary, et al. (2021), who found that VMA decreased with increasing glass powder content up to 8,5%, primarily due to the filler occupying more of the voids between aggregates. The observed VMA behavior also mirrors the changes in air void content within the mixture.

6. Analysis of the Effect of Glass Powder Filler Content on VFWA

The VFWA test results for AC-WC mixtures incorporating GP filler substitution are shown in Figure 5.15.

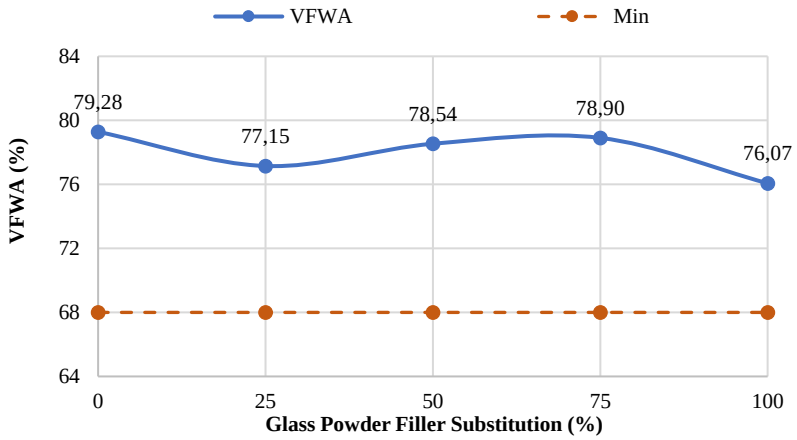

Figure 5.15 Graph of the Relationship Between GP Filler Substitution and VFWA

As shown in Figure 5.15, the VFWA graph illustrates the influence of GP filler substitution on asphalt mixture properties. VFWA initially decreases at 25% substitution, indicating early disruption in aggregate compaction. It then increases up to 75% substitution, reflecting a more uniform asphalt distribution, before declining again at 100% due to excessive GP content.

This pattern is consistent with the trends observed in VMA and VITM, where at 75% substitution the mixture shows the lowest VMA (17,76%) and moderate VITM (3,77%), indicating optimal asphalt filling. Conversely, at 100% substitution, the increase in both VMA (18,28%) and VITM (4,39%) contributes to a reduction in VFWA, suggesting diminished mixture integrity. Therefore, a 75% GP substitution is considered the most optimal.

These findings are consistent with Kifile, et al. (2024), who observed that VFWA increased with glass waste content up to 7%, then declined at 10% due to increased air voids that reduced the proportion of voids that could be filled with asphalt.

7. Analysis of The Effect of Glass Powder Filler Content on Density

The density test results for AC-WC mixtures incorporating GP filler substitution are shown in Figure 5.16.

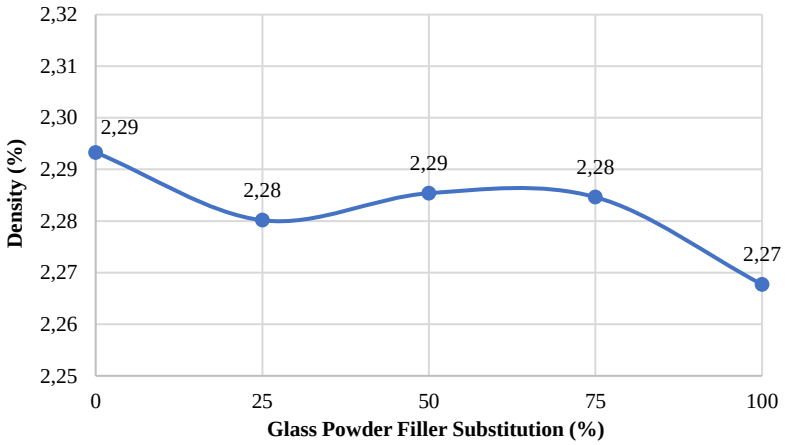

Figure 5.16 Graph of The Relationship Between GP Filler Substitution and Density

According to Figure 5.16, mixtures containing GP filler exhibited lower density compared to those with stone dust filler. This is due to the lower specific gravity of glass powder, which results in a less compact mixture owing to its more porous nature. At 25% substitution, density decreases due to suboptimal interaction between the two filler types. However, density increases up to 75% as the filler effectively reduces voids and enhances mixture compaction. At 100% substitution, the bonding capacity of the filler

with asphalt decreases, leading to an increase in voids and a subsequent drop in mixture density.

This trend is consistent with the findings of Ogundipe & Nnochiri (2020), who reported that mixture density increases with higher proportions of glass waste up to a peak point, but then declines once the glass content exceeds that threshold. The reduction is attributed to the formation of a tender mix, which hampers proper placement and compaction.

5.2.8 IRS Test Characteristics of OAC Mixtures with GP Filler Substitution

IRS test is used to assess the loss of cohesion due to moisture in compacted asphalt mixtures. This test serves as an indicator of moisture resistance. The IRS value is calculated by comparing the stability of unconditioned samples (0,5 hours immersion) with conditioned samples (24 hours immersion). Figures 5.17, 5.18, and 5.19 sequentially present comparisons of stability between unconditioned and conditioned samples at immersion durations of 0, 24, and 48 hours, respectively.

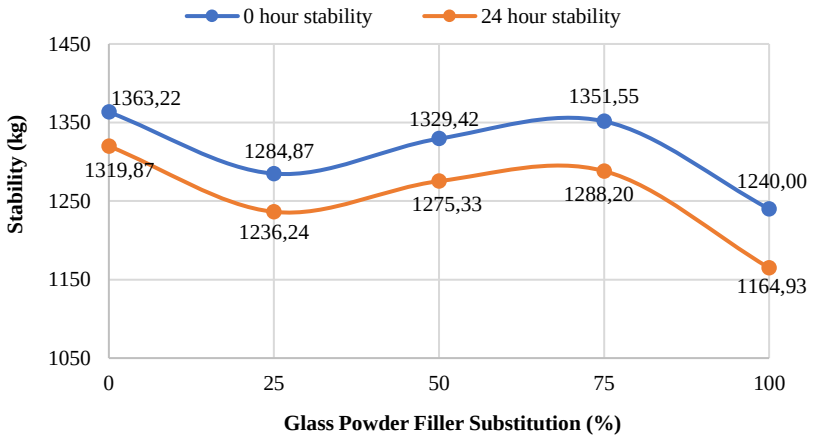

Figure 5.17 Graph of the Relationship Between Immersion and Stability at 0 Hours

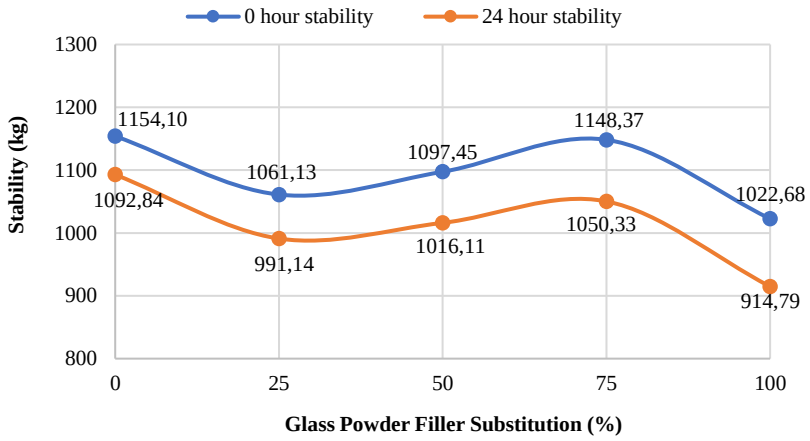

Figure 5.18 Graph of the Relationship Between Immersion and Stability at 24 Hours

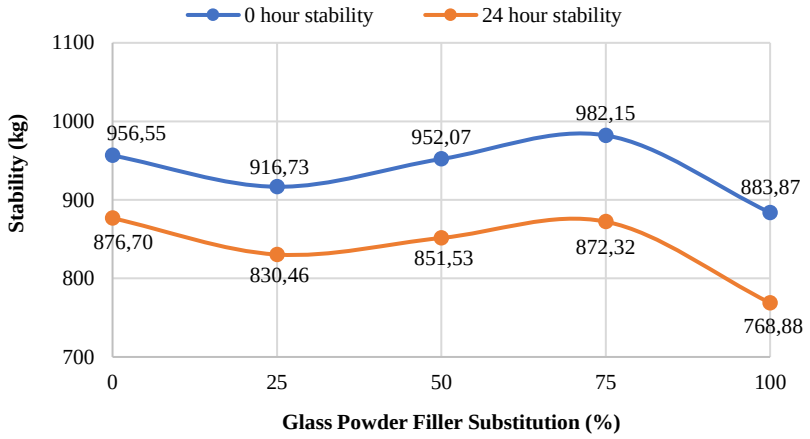

Figure 5.19 Graph of the Relationship Between Immersion and Stability at 48 Hours

Based on the figures above, it can be concluded that, in general, the stability of conditioned samples is lower than that of unconditioned samples. This is attributed to the weakening of the asphalt–aggregate bond due to water penetrating the voids within the mixture. The graph illustrating IRS values based on varying levels of GP filler substitution is shown in Figure 5.20.

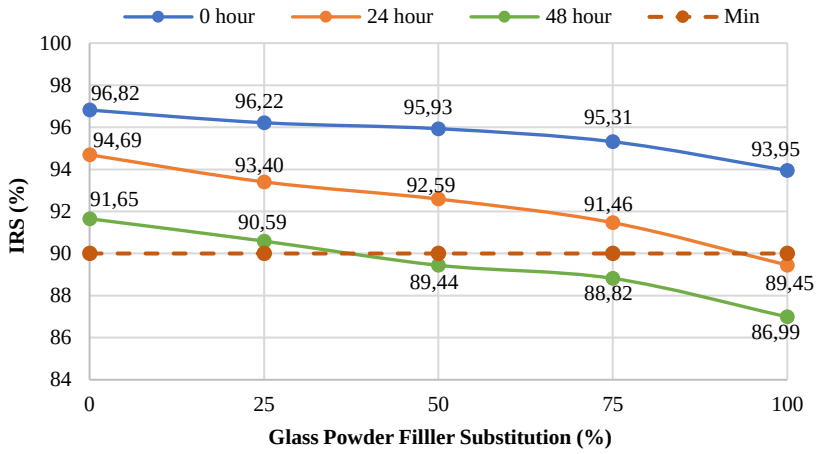

Figure 5.20 Graph of the Effect of GP as Filler Substitution on IRS

Based on the results presented in Figure 5.20, it can be concluded that the use of GP filler has a detrimental effect on the performance of the asphalt mixture. This is demonstrated by a decreasing IRS value as the proportion of GP filler substitution increases. The reduction is due to the smooth surface texture of GP filler, which fails to form a strong adhesive bond between the asphalt and aggregates, thereby decreasing mixture cohesion. Furthermore, the high silica content dominant in GP filler also contributes to the weakening of bonding strength. These findings are consistent with Choudary, et al. (2018), who reported that asphalt mixtures containing GP filler generally exhibit lower moisture resistance compared to those using other types of filler, primarily due to the high silica content in glass powder.

The graph in Figure 5.20 also indicates a decline in IRS values as submersion time in river water increases. This is because longer submersion durations allow more water to infiltrate the voids within the mixture and aggregates, which in turn causes the asphalt to detach from the aggregate surface. Consequently, the asphalt–aggregate bond deteriorates, leading to reduced structural strength of the mixture. Additionally, the slightly acidic nature of river water accelerates this degradation, especially when combined with suspended particulates in the murky water that may become trapped within the mixture's voids, exacerbating the condition. These results are in line with the findings of

Fauziah & Handaka (2017), who noted that IRS values decreased with prolonged submersion, with more significant reductions observed in mixtures using conventional Pen 60/70 asphalt.

According to the Bina Marga 2018 Revision 2 Specifications, the minimum IRS requirement is >90%. Therefore, the IRS values for mixtures with 100% GP substitution at 24-hour submersion, and mixtures with 50%, 75%, and 100% GP substitution at 48-hour submersion, do not meet the specification.

5.2.9 ITS Test Characteristics of OAC Mixtures with GP Filler Substitution

ITS is a key parameter used to evaluate how well an asphalt mixture can resist cracking. The ITS value reflects the tensile strength of the mixture, how strongly it can resist forces that may induce cracking, whether due to repeated traffic loading or temperature variations. A higher ITS value generally indicates better resistance to cracking. Therefore, ITS can serve as an indicator to estimate the potential for pavement cracking and to assess the overall quality of the asphalt mixture. The ITS test results reflecting the influence of GP filler substitution are presented in Figure 5.21.

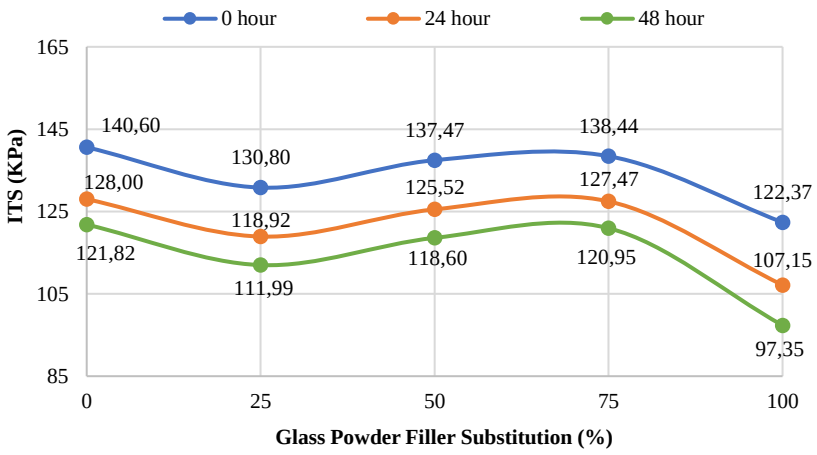

Figure 5.21 Graph of the Effect of GP as Filler Substitution on ITS

According to Figure 5.21, the ITS value decreases at 25% GP substitution, increases to an optimum at 75%, then drops significantly at 100%. The initial

decrease is attributed to the disruption of the previously stable structure formed with stone dust filler. The increase in ITS up to 75% is due to a denser and more balanced filler composition, which enhances tensile strength. The significant decline at 100% substitution is caused by the complete replacement of filler with fine-textured GP, which weakens interparticle bonding. These findings are consistent with Yuniarti, et al. (2019), who reported that 75% substitution produced the optimal tensile strength.

Figure 5.21 also shows that increased submersion duration in river water results in a decline in ITS values. This decrease is due to the weakening of the adhesive bond between asphalt and aggregates, leading to reduced tensile strength of the mixture. This observation aligns with the findings of Mataram, et al. (2021), who reported that ITS values in AC-WC mixtures tend to decline with prolonged submersion times.

5.2.10 TSR Test Characteristics of OAC Mixtures with GP Filler Substitution

TSR value is obtained by comparing the ITS of samples soaked for 24 hours in a water bath with that of unsoaked samples. The graph showing the TSR values influenced by GP filler substitution is presented in Figure 5.22.

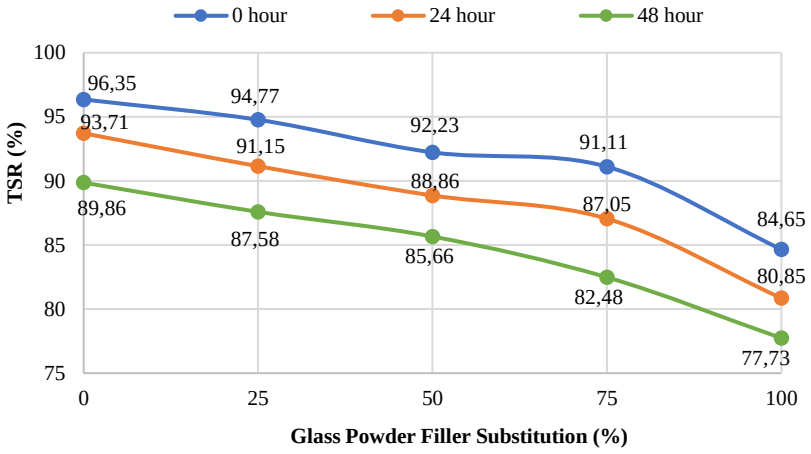

Figure 5.22 Graph of the Effect of GP as Filler Substitution on TSR

In general, Figure 5.22 shows that the TSR values of mixtures without GP substitution are higher than those with GP substitution. This indicates that the use

of glass powder tends to reduce the moisture resistance of the mixture, due to its lower affinity for water. At full substitution, TSR values drop significantly, as the smooth surface of GP fails to form a strong adhesive bond with the asphalt, thus weakening the aggregate–asphalt adhesion. This finding is consistent with Choudary, et al. (2021), who reported that GP filler demonstrates poor moisture resistance performance.

Additionally, an increase in submersion duration also leads to a reduction in TSR values across all substitution levels, indicating that prolonged water exposure further deteriorates the tensile durability of the mixture. These results are in line with Siburian, et al. (2022), who observed a declining TSR trend with increased soaking time.

5.2.11 CL Test Characteristics of OAC Mixtures with GP Filler Substitution

CL test is conducted to evaluate the abrasion resistance of asphalt mixtures by rotating the specimens within a Los Angeles abrasion machine. This test serves as a parameter to assess the durability of the mixture under traffic loading. The graph presenting the CL values as affected by GP filler substitution is shown in Figure 5.23.

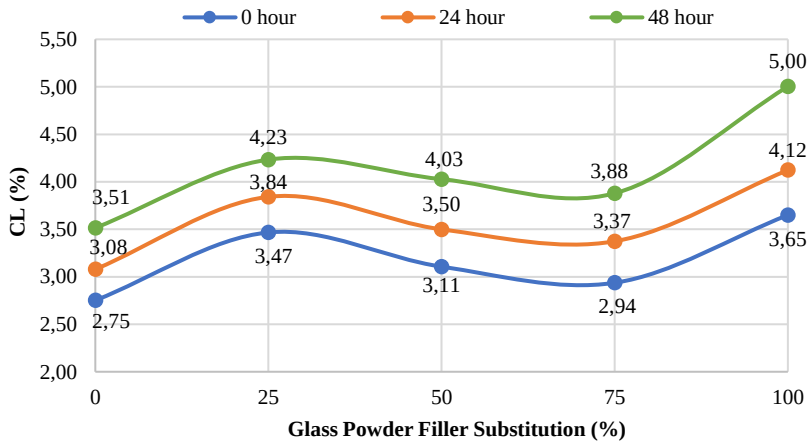

Figure 5. 23 Graph of the Effect of GP as Filler Substitution on CL

Based on the test results displayed in Figure 5.23, the CL value increases at 25% GP substitution, decreases to a minimum at 75%, and then rises sharply at

100%. The initial increase at 25% is attributed to the suboptimal proportion between glass powder and stone dust filler, which disrupts the stability achieved at 0% substitution. The decrease in CL value up to 75% indicates that the mixture becomes denser and more resistant to abrasion, as the voids between aggregates are more effectively filled by the glass powder. However, at 100% substitution, the sharp increase in CL reflects the weakened asphalt–aggregate bond due to the fine surface texture of the glass powder, which fails to establish a strong bond with the asphalt, resulting in greater mass loss due to abrasion.

Additionally, CL values tend to increase with longer submersion durations. This is caused by the weakening of adhesion between asphalt and aggregate due to water penetration into the mixture's pores during prolonged soaking. This process softens the asphalt and facilitates the dislodgement of aggregate particles. As a result, the longer the submersion duration, the greater the potential mass loss in the mixture, as reflected in higher CL values. These findings are consistent with Yuniarti, et al. (2019), who noted that the optimum substitution level for CL performance occurs at 75%, before performance degradation sets in due to excessive moisture exposure.

5.3 Summary of Test Results on Mixtures Using Glass Powder Filler

The summary of test results on AC-WC mixtures with glass powder filler substitution across various submersion durations is presented in Table 5.12 below.

Table 5.12 Summary of Test Results for Mixtures Using GP Filler with Varying Soaking Durations

Test Parameter	Submersion Time	Specs.	Filler Subsitution (%)					Description
			0	25	50	75	100	
Marshall Stability	0 hour	>800 (kg)	✓	✓	✓	✓	✓	The results of the Marshall Stability test consistently met the specification of >800 kg across all levels of filler substitution and submersion durations. This indicates that the stability of the material was not adversely affected by either the degree of filler substitution or the soaking duration.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	
Flow	0 hour	2-4 (mm)	✓	✓	✓	✓	✓	The Flow values met the specification range of 2–4 mm at all levels of filler substitution for 0 and 24 hours of submersion. However, at 48 hours of submersion, the Flow values did not meet the specification at 0% and 100% substitution levels, while the 25%, 50%, and 75% substitutions remained within the acceptable range. This suggests a sensitivity to extreme filler contents under prolonged submersion.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		×	✓	✓	✓	×	
MQ	0 hour	>250 (kg/mm)	✓	✓	✓	✓	✓	MQ values met the specifications at all substitution levels during 0 and 24 hours of submersion. At 48 hours, however, MQ values fell below the specification at 0%, 25%, and 100% substitution, while 50% and 75% substitutions remained compliant. This indicates that moderate filler contents are more effective in maintaining mixture stability under extended submersion.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		×	×	✓	✓	×	
VITM	0 hour	3-5 (%)	✓	✓	✓	✓	✓	The VITM values consistently fell within the specified range of 3–5% across all levels of filler substitution and submersion durations, indicating that neither filler substitution nor soaking time negatively affected the air void content within the mixture.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	
VMA	0 hour	>15 (%)	✓	✓	✓	✓	✓	VMA values consistently satisfied specification requirements at all filler substitution levels and submersion durations. This demonstrates that the aggregate structure was able to maintain adequate void space regardless of the filler content or duration of submersion.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	
VFWA	0 hour	>68 (%)	✓	✓	✓	✓	✓	The VFWA values remained above the specified minimum across all levels of filler substitution and submersion durations. This indicates that asphalt effectively filled the voids within the mixture, maintaining performance consistency regardless of filler substitution levels or submersion conditions.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	

Table 5.12 Summary of Test Results for Mixtures Using GP Filler with Varying Soaking Durations (continued)

Test Parameter	Submersion Time	Specs.	Filler Subsitution (%)					Description
			0	25	50	75	100	
Density	0 hour	>2	✓	✓	✓	✓	✓	The mixture density remained above the specified value of 2,0 for all filler substitution levels and soaking durations. This consistency suggests that neither the filler substitution nor submersion significantly affected the material's ability to achieve the required density.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	
IRS	0 hour	≥90 (%)	✓	✓	✓	✓	✓	IRS values met the specifications at all levels of filler substitution under 0-hour submersion. At 24 hours, failure occurred only at 100% substitution, and at 48 hours, failure was observed at 50%, 75%, and 100% substitution levels. This indicates a decrease in cohesive strength due to high filler content under prolonged submersion conditions.
	24 hour		✓	✓	✓	✓	×	
	48 hour		✓	✓	×	×	×	
ITS	0 hour	No Specs	✓	✓	✓	✓	✓	ITS was measured and reported across all filler substitution levels and submersion durations, without a defined threshold value in the specifications. Therefore, the test was successfully conducted under all conditions, although no minimum requirement was established. Notably, the 75% substitution level yielded the optimal ITS values across all submersion durations.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	
TSR	0 hour	>80 (kPa)	✓	✓	✓	✓	✓	TSR values met the specification at all filler substitution levels for 0 and 24 hours of immersion. At 48 hours, TSR values failed only at 100% substitution, while 0%, 25%, 50%, and 75% substitutions remained compliant. This indicates that high levels of filler substitution can reduce tensile strength under extended immersion conditions.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	×	
CL	0 hour	<20 (%)	✓	✓	✓	✓	✓	The cantabro loss values consistently remained below the 20% specification across all levels of filler substitution and submersion durations. This indicates that the material's durability and resistance to particle loss were not adversely affected by variations in filler content or prolonged submersion.
	24 hour		✓	✓	✓	✓	✓	
	48 hour		✓	✓	✓	✓	✓	

CHAPTER VI
CONCLUSIONS AND SUGGESTIONS

6.1 Conclusions

Based on the research findings and analysis of the characteristics of AC-WC mixtures with glass powder filler substitution and varying submersion durations in river water, the following conclusions can be drawn.

1. The addition of GP as a filler substitute influenced the structural strength characteristics of the AC-WC mixture, resulting in increased stability, MQ, and ITS up to 75%, along with a reduction in flow. However, at a 100% substitution level, all performance parameters experienced a significant decline. Moreover, longer submersion durations in river water led to decreases in stability, MQ, ITS, and an increase in flow.
2. AC-WC mixtures incorporating GP filler substitution affect the volumetric characteristic, showing an increased in VFWA and density, meanwhile the VITM and VMA is decreased. At 100% substitution all performance were declining. Additionally, the increased submersion duration did not affect significantly to these parameters.
3. The AC-WC mixture with GP filler substitution also contribute the changes of durability characteristics. For moisture parameters such as IRS and TSR, it's exhibited a consistent decline with increasing filler content and submersion times, indicating the mixture more prone to stripping. Meanwhile for CL value, it's generally showed a reduction except at 100% substitution, where CL increased. Increased soaking durations also led to higher CL values, indicating reduced resistance to moisture-induced degradation.

6.2 Suggestions

Referring to the findings on the use of GP filler substitution in AC-WC mixtures under submersion in Bekasi River water, the researcher proposes the following suggestions for future studies.

1. Further research should investigate the chemical properties and compound composition of the GP filler and river water to better understand their specific effects on the AC-WC mixture.
2. Glass powder is not yet an alternative solution to flood prone areas, it may require further research by using other additives or filler materials.
3. For field implementation, compaction can be carried out using the gyratory method.
4. The use of glass powder as a filler substitute in asphalt mixtures shows potential as a sustainable and environmentally friendly pavement alternative, particularly suitable for flood-prone areas.
5. The optimal GP filler substitution level was found to be 75%, based on the performance indicators. However, this optimal performance was only sustained up to an submersion duration of 24 hours. Beyond that, the mixture's performance declined significantly when exposed to water

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APPENDIX

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Appendix 1 Specific Gravity Test of Asphalt Pen 60/70

SPECIFIC GRAVITY OF ASPHALT

REFERENCE : SNI 2441 - 2011

1 Material Source : Pertamina
2 Material Type : Pertamina Asphalt Pen 60/70
3 Test Conducted in : 2025

No.	Test Description	Sample	
		1	2
1	Weight of empty pycnometer (gr)	23,89	23,45
2	Weight of pycnometer + distilled water (gr)	46,32	46,56
3	Weight of distilled water (2 - 1) (gr)	22,43	23,11
4	Weight of pycnometer + asphalt (gr)	25,85	25,4
5	Weight of asphalt (4 - 1) (gr)	1,96	1,95
6	Weight of pycnometer + asphalt + distilled water (gr)	46,42	46,61
7	Weight of distilled water (6 - 4) (gr)	20,57	21,21
8	Volume of asphalt (3 - 7) (gr)	1,86	1,9
9	Specific gravity of asphalt = Weight / Volume (5/8)	1,05	1,026
10	Average specific gravity of asphalt	1,040	

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Appendix 2 Asphalt Penetration Test Pen 60/70

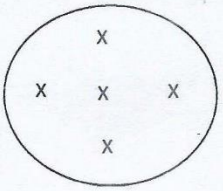
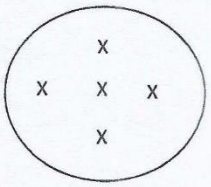
ASPHALT PENETRATION TEST

REFERENCE; AASHTO T 49-68, ASTM D 5-71

1 Material Source : Pertamina
2 Material Type : Pertamina Asphalt Pen 60/70
3 Test Conducted in : 2025

No	Test Sequence	Temperature Meas.	Time Meas.	Remarks
1	**Heating of speciment**			
	Start of heating	27 ^{o}C	10.00 WIB	
	End of heating	140 ^{o}C	10.30 WIB	
2	**Left at room temperature**			
	Start	140 ^{o}C	10.30 WIB	
	End	27 ^{o}C	13.00 WIB	
3	**Testing**			
	Start	25 ^{o}C	13.00 WIB	
	End	25 ^{o}C	13.30 WIB	

OBSERVATION RESULTS

No	Specimen		Test Sketch		Remarks
	I (mm)	II (mm)	Sample 1	Sample 2	
1	65	64			
2	65	62			
3	63	64			
4	64	63			
5	65	65			
Avg.	64,4	63,6			
Avg.	64				

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Appendix 3 Flash Point and Fire Point Test of Asphalt Pen 60/70

FLASH POINT AND FIRE POINT TEST

REFERENCE; AASHTO T 48-74, ASTM D 92-52

1 Material Source : Pertamina
2 Material Type : Pertamina Asphalt Pen 60/70
3 Test Conducted in : 2025

No	Test Sequence	Temperature Meas.	Time Meas.	Remarks
1	**Heating of speciment**			
	Start of heating	27 ^{o}C	08.20 WIB	
	End of heating	140 ^{o}C	08.35 WIB	
2	**Left at room temperature**			
	Start	140 ^{o}C	08.35 WIB	
	End	27 ^{o}C	09.40 WIB	
3	**Testing**			
	Start	27 ^{o}C	09.40 WIB	
	End	313 ^{o}C	10.20 WIB	

OBSERVATION RESULTS

No	Description	Flash Point	Fire Point	Remarks
1	Sample 1	308 ^{o}C	313 ^{o}C	
2	Sample 2			
3	Average	308 ^{o}C	313 ^{o}C	

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Appendix 4 Softening Point Test of Asphalt Pen 60/70

SOFTENING POINT TEST ASPHALT

REFERENCE : SNI 2434 - 2011

1 Material Source : Pertamina
2 Material Type : Pertamina Asphalt Pen 60/70
3 Test Conducted in : 2025

No	Test Sequence	Temperature Meas.	Time Meas.	Remarks
1	**Heating of speciment**			
	Start of heating	27 ^{o}C	08.20 WIB	
	End of heating	140 ^{o}C	08.35 WIB	
2	**Left at room temperature**			
	Start	140 ^{o}C	08.35 WIB	
	End	27 ^{o}C	09.40 WIB	
3	**Testing**			
	Start	5 ^{o}C	13.15 WIB	
	End	48 ^{o}C	13.30 WIB	

OBSERVATION RESULTS

No.	Observed Temperature	Heating Time (Seconds)		Softening Point (^{o}C)	
		Sample I	Sample II	I	II
1	5 ^{o}C	0 second	0 second		
2	10 ^{o}C	137 second	137 second		
3	15 ^{o}C	112 second	112 second		
4	20 ^{o}C	101 second	101 second		
5	25 ^{o}C	107 second	107 second		
6	30 ^{o}C	115 second	115 second		
7	35 ^{o}C	124 second	124 second		
8	40 ^{o}C	128 second	128 second		
9	45 ^{o}C	135 second	137 second	48^{o}C	49^{o}C
10	50 ^{o}C				

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Appendix 5 Ductility Test of Asphalt Pen 60/70

DUCTILITY TEST (RESIDUE)

REFERENCE : AASHTO : T - 51 -74 ; ASTM D - 113 - 69

1 Sample Source : Pertamina
2 Sample Type : Pertamina Asphalt Pen 60/70
3 Date of Test : 2025

Test Preparation

No	Test Step	Description	Duration	Temperature
1	Specimen preparation	Asphalt heated	15 minutes	heating temp. ±135°C
2	Specimen cooling	Left at room temperature	60 minutes	room temp. ±28°C
3	Specimen soaking	Soaked in water at 25°C	60 minutes	water bath temp. ±25°C
4	Testing	Ductility tested at 25°C, speed 5 cm/min	20 minutes	equipment temp. ±25°C

Test Results

No	Specimen	Test Result	Remarks
1	Sample 1	137 cm	Not Broken
2	Sample 2	132 cm	Not Broken
4	Rata-rata	134,5 cm	

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Appendix 6 Solubility Asphalt in *TCE*

SOLUBILITY TEST OF ASPHALT IN CCl_4 / TCE

REFERENCE : AASHTO T - 44 - 70 ; ASTM D - 165 - 42

1 Material Source : Pertamina
2 Material Type : Pertamina Asphalt Pen 60/70
3 Test Conducted ir : 2025

Test Preparation

No	Test Step	Description	Reading	
			Time	Temperature
1	Preparation	Start	14.00 WIB	28 °C
		End	14.10 WIB	28 °C
2	Weighing	Start	14.10 WIB	28 °C
3	Dissolving	Start	14.15 WIB	28 °C
4	Filtering	Start	14.20 WIB	28 °C
		End	14.25 WIB	28 °C
5	Oven Drying	Start	14.30 WIB	130 °C
6	Final Weighing	Start	14.30 WIB	28 °C

Test Results

No	Description	Specimen		Remarks
		1	2	
1	Weight of empty Erlenmeyer flask	54,400 gr	65,970 gr	
2	Weight of flask + asphalt	56,420 gr	68,010 gr	
3	Weight of asphalt (2 - 1)	2,020 gr	2,040 gr	
4	Weight of clean filter paper	0,580 gr	0,590 gr	
5	Weight of filter paper + mineral	0,590 gr	0,600 gr	
6	Weight of mineral (5 - 4)	0,010 gr	0,010 gr	
7	Mineral content (6/3x100%)	0,495 %	0,490 %	
8	Soluble asphalt (100% - 7)	99,505 %	99,510 %	
9	Average soluble asphalt(%)	99,507 %		

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Appendix 7 Specific Gravity Test of Coarse Aggregate

SPECIFIC GRAVITY TEST OF COARSE AGGREGATE

REFERENCE : SNI 03-1969-2008

1 Material Source : Clereng, Kulonprogo
2 Material Type : Coarse Aggregate
3 Test Conducted in : 2025

No.	Description	Specimen		Average
		1	2	
1	Weight of SSD specimen (BJ) gr	1611,62	1612,23	1611,93
2	Weight in water (BA) gr	1000,41	1000,80	1000,61
3	Oven-dry weight (BK) gr	1574,21	1568,25	1571,23
4	Spec. Gravity (Bulk) = $\frac{BK}{(BJ - BA}$	2,576	2,565	2,570
5	Spec. Gravity (SSD) = $\frac{BJ}{(BJ - BA}$	2,637	2,637	2,637
6	Spec. Gravity (Apparent) = $\frac{BK}{(BK - BA)}$	2,743	2,764	2,754
7	Water Absoprtion = $\frac{(BJ - BK)}{BK} \times 100\%$	2,376	2,804	2,590
8	Effective Specific Gravity = (G bulk + G apparent)/2	2,660	2,664	2,662

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Appendix 8 Aggregate Adhesion to Asphalt Test

AGGREGATE ADHESION TO ASPHALT TEST

1 Material Source : Clereng, Kulonprogo
2 Material Type : Coarse Aggregate
3 Test Conducted in : 2025

Test Preparation

No	Test Step	Temperature	Time	Remarks
1	**Heating the specimen**			
	Start	25^{O}C	08.00 WIB	
	End	150^{O}C	08.15 WIB	
2	**Cooling at room temperature**			
	Start	150^{O}C	08.15 WIB	
	End	25^{O}C	09.45 WIB	
3	**Soaking the specimen**			
	Start	25^{O}C	09.45 WIB	
	End	25^{O}C	10.15 WIB	

Test Results

No	Specimen	Test Result	Remarks
1	Sample 1	98%	
2	Sample 2	97%	
	Average	98%	

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Appendix 9 Coarse Aggregate Abrasion Test Using the Los Angeles Machine

ABRASION TEST OF COARSE AGGREGATE

AASHTO T 96 - 77 ; SNI 2417 : 2008

1 Material Source : Clereng, Kulonprogo
2 Material Type : Coarse Aggregate
3 Test Conducted in : 2025

No	Gradation Type		B		Remarks
	Sieve		Specimen (gram)		
	Passing	Retained	1	2	
1	72.2 mm (3")	63.5 mm (2.5")			
2	63.5 mm (2.5")	50.8 mm (2")			
3	50.8 mm (2")	37.5 mm (1.5")			
4	37.5 mm (1.5")	25.4 mm (1")			
5	25.4 mm (1")	19.0 mm (3/4")			
6	19.0 mm (3/4")	12.5 mm (0.5")	2502,50		
7	12.5 mm (0.5")	09.5 mm (3/8")	2500,00		
8	09.5 mm (3/8")	06.3 mm (1/4")			
9	06.3 mm (1/4")	04.75 mm (4")			
10	04.75 mm (No.4)	02.36 mm (No.8)			
11	TOTAL SAMPLE WEIGHT (A)		5002,50	5002,50	
12	RETAINED ON SIEVE NO 12(B)		4788,50	3995,50	
13	ABRASION 100x $=\frac{(A-B)}{A}\times 100\%$		4,278	20,130	
17	Average Abrasion Loss (%)		12,20		

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Appendix 10 Specific Gravity Test of Fine Aggregate

SPECIFIC GRAVITY TEST OF FINE AGGREGATE

REFERENCE : SNI 1970 - 2008

1 Material Source : Clereng, Kulonprogo
2 Material Type : Fine Aggregate
3 Test Conducted in : 2025

No.	Description	Specimen		Average
		1	2	
1	Weight of SSD specimen (BJ) gr	500,01	500,04	
2	Weight of Pycnometer + Water (B) gr	647,04	681,31	
3	Weight of Pycnometer + Water + Sample (BT) gr	963,04	998,84	
4	Oven-Dry Weight of Sample (BK)	482,82	487,01	
5	Spec. Gravity (Bulk) = $\frac{BK}{(B+500)-BT}$	2,624	2,669	2,647
6	Spec. Gravity (SSD) = $\frac{500}{(B+500)-BT}$	2,717	2,740	2,729
7	Spec. Gravity (Apparent) = $\frac{BK}{(B+BK)-BT}$	2,894	2,874	2,884
8	Water Absorption = $\frac{(500-BK)}{BK} \times 100\%$	3,558	2,667	3,113
9	Effective Specific Gravity = (G bulk + G apparent)/2	2,559	2,771	2,665

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Appendix 11 Sand Equivalent Test

SAND EQUIVALENT TEST

REFERENCE : SNI 3423-2008

1 Material Source : Clereng, Kulonprogo
2 Material Type : Fine Aggregate
3 Test Conducted in : 2025

No.	Description		Specimen 1	Specimen 2	Average
1	Preparation and soaking of specimens in $CaCl_2$ solution (±10.1 minutes)	Start	13.39	13.39	
		End	13.39	13.39	
2	Sedimentation time (after shaking specimen 90 times and adding $CaCl_2$ solution)	Start	13.44	13.44	
		End	13.59	13.59	
4	Clay reading (inches)		3,90	4,50	4,20
5	Sand reading (inches)		2,90	3,10	3,00
6	$Sand\ Eqiuvalent = \frac{Sand\ Reading}{Clay\ Reading} \times 100\ \%$		74,36	68,89	71,62
7	Clay Content = 100 - SE		25,64	31,11	28,38

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Appendix 12 Specific Gravity of Stone Dust Filler

SPECIFIC GRAVITY TEST OF STONE DUST FILLER

REFERENCE : SNI 2441-2011

1 Material Source : Clereng
2 Material Type : Stone Dust Filler
3 Test Conducted in : 2025

No.	Description	Specimen		Average
		1	2	
1	Weight of empty pycnometer gr	23,80	23,80	23,80
2	Weight of pycnometer + water gr	46,43	46,94	46,69
3	Weight of water (2-1) gr	22,63	23,14	22,89
4	Weight of pycnometer + filler gr	33,80	33,80	33,80
5	Weight of filler (4-1) gr	10,000	10,000	10,00
6	Weight of pycnometer + filler + water gr	53,120	52,100	52,61
7	Weight of water (6-4) gr	19,320	18,300	18,81
8	Volume of filler (3-7) gr	3,310	4,840	4,08
9	Specific gravity of filler = weight/vol (5/8)	3,021	2,066	2,544

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Appendix 13 Specific Gravity of Stone Dust Filler

SPECIFIC GRAVITY TEST OF GLASS POWDER FILLER

REFERENCE : SNI 2441-2011

1 Material Source : Pasuruan
2 Material Type : Glass Powder Filler
3 Test Conducted in : 2025

No.	Description	Specimen		Average
		1	2	
1	Weight of empty pycnometer gr	24,26	23,79	24,03
2	Weight of pycnometer + water gr	46,81	46,49	46,65
3	Weight of water (2-1) gr	22,55	22,70	22,63
4	Weight of pycnometer + filler gr	30,60	30,27	30,44
5	Weight of filler (4-1) gr	6,340	6,480	6,41
6	Weight of pycnometer + filler + water gr	50,470	50,220	50,35
7	Weight of water (6-4) gr	19,870	19,950	19,91
8	Volume of filler (3-7) gr	2,680	2,750	2,72
9	Specific gravity of filler = weight/vol (5/8)	2,366	2,356	2,361

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Appendix 14 Marshall Test Results

MARSHALL TEST RESULTS TO DETERMINE OPTIMUM ASPHALT CONTENT (OAC) USING ASPHALT PEN 60/70

Date of Testing: November 2024
Mixture Type: AC-WC

Sample	t (cm)	a (%)	b (%)	c (gram)	d (gram)	e (gram)	f (gram)	g	h	i	j	k	l VMA (%)	n VITM (%)	o	p	Thickness Corr.	q Stab. (kg)	r *Flow* (mm)
5%	67,93	5,26	5,00	1170,36	1178,29	650,15	528,14	2,216	2,427	10,653	80,657	8,689	19,34	8,69	92	1318,40	0,8993	1185,57	3,44
5%	65,18	5,26	5,00	1169,29	1174,99	650,75	524,24	2,230	2,427	10,723	81,183	8,094	18,82	8,09	73	1046,12	0,9585	1002,71	3,82
5%	69,02	5,26	5,00	1179,93	1188,48	651,40	537,08	2,197	2,427	10,562	79,963	9,475	20,04	9,48	75	1074,78	0,8900	956,56	3,19
								2,214					**19,40**	**8,75**				**1048,28**	**3,48**
5,5%	68,09	5,82	5,50	1184,18	1194,51	667,85	526,66	2,248	2,410	11,891	81,408	6,701	18,59	6,70	85	1218,09	0,8954	1090,61	3,10
5,5%	68,57	5,82	5,50	1181,76	1189,70	662,05	527,65	2,240	2,410	11,844	81,089	7,067	18,91	7,07	99	1418,71	0,8900	1262,65	4,58
5,5%	68,47	5,82	5,50	1189,60	1198,74	673,63	525,11	2,265	2,410	11,980	82,022	5,998	17,98	6,00	76	1089,11	0,8900	969,31	2,96
								2,251					**18,49**	**6,59**				**1107,53**	**3,55**
6%	64,76	6,38	6,00	1191,20	1199,20	680,56	518,64	2,297	2,393	13,250	82,717	4,033	17,28	4,03	88	1261,08	0,9684	1221,26	4,02
6%	65,42	6,38	6,00	1183,50	1190,95	679,92	511,03	2,316	2,393	13,361	83,406	3,233	16,59	3,23	101	1447,37	0,9540	1380,79	3,50
6%	63,78	6,38	6,00	1180,38	1188,08	677,76	510,32	2,313	2,393	13,344	83,302	3,354	16,70	3,35	84	1203,76	0,9929	1195,24	3,80
								2,309					**16,86**	**3,54**				**1265,76**	**3,77**
6,5%	65,91	6,95	6,50	1178,03	1187,49	676,33	511,16	2,305	2,377	14,403	82,558	3,039	17,44	3,04	80	1146,43	0,945	1083,25	4,28
6,5%	68,25	6,95	6,50	1189,93	1199,92	678,04	521,88	2,280	2,377	14,250	81,679	4,071	18,32	4,07	60	859,83	0,891	766,25	4,12
6,5%	65,10	6,95	6,50	1182,18	1190,78	679,42	511,36	2,312	2,377	14,448	82,816	2,735	17,18	2,74	109	1562,02	0,960	1499,69	3,1
								2,299					**17,65**	**3,28**				**1116,40**	**3,83**
7%	69,13	7,53	7,00	1177,18	1191,88	668,23	523,65	2,248	2,361	15,130	80,100	4,770	19,90	4,77	57	816,83	0,8900	726,98	4,30
7%	66,31	7,53	7,00	1189,10	1197,22	678,16	519,06	2,291	2,361	15,419	81,627	2,955	18,37	2,95	80	1146,43	0,9374	1074,65	3,90
7%	65,61	7,53	7,00	1192,28	1196,36	681,92	514,44	2,318	2,361	15,599	82,580	1,821	17,42	1,82	105	1504,69	0,9504	1430,12	3,84
								2,286					**18,56**	**3,18**				**1077,25**	**4,01**

Approved by
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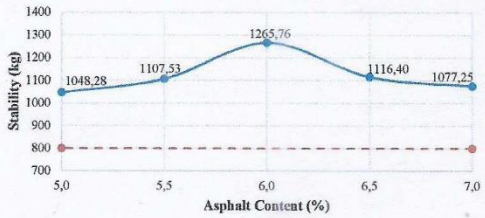
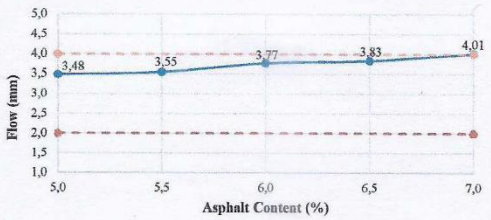
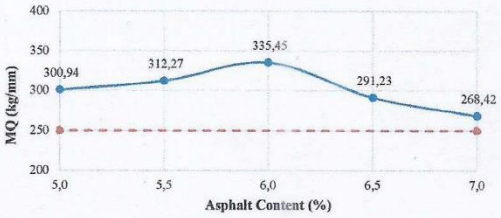
Appendix 15 Recapitulation of OAC Calculation

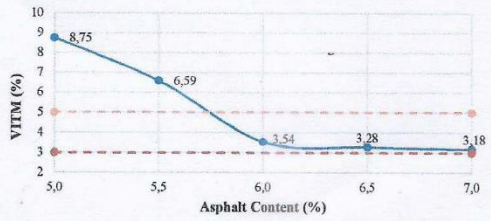
RECAPITULATION OF OPTIMUM ASPHALT CONTENT (OAC) CALCULATION

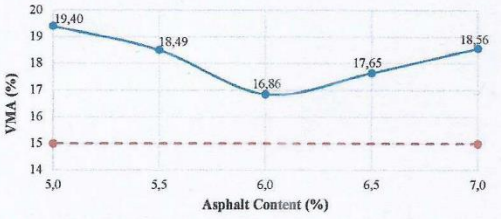
No.	Asphalt Content (%)	Marshall Stability (kg)	Flow (mm)	MQ (kg/mm)	VITM (%)	VMA (%)	VFWA (%)	Density (gr/cc)
1	5	1048,28	3,48	300,94	8,75	19,40	54,88	2,21
2	5,5	1107,53	3,55	312,27	6,59	18,49	64,37	2,25
3	6	1265,76	3,77	335,45	3,54	16,86	79,00	2,31
4	6,5	1116,40	3,83	291,23	3,28	17,65	81,41	2,30
5	7	1077,25	4,01	268,42	3,18	18,56	82,86	2,29
Specification		>800	2 - 4	>250	3 - 5	>15	>68	>2

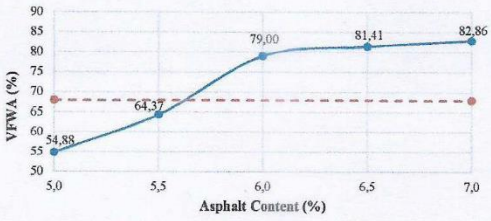


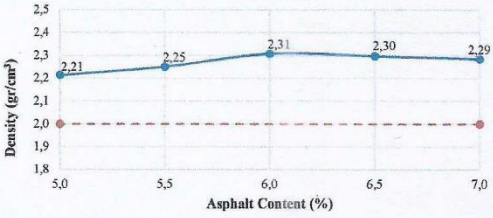


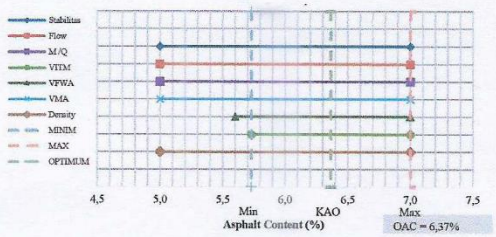












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Appendix 16 Marshall Test Results with Substitution of Glass Powder Filler (0 Hour)

MARSHALL TEST RESULTS WITH SUBSTITUTION OF GLASS POWDER FILLER
0 Hours of Immersion

Date of Testing: February 2025
Mixture Type: AC-WC

Substitution (%)	t (cm)	a (%)	b (%)	c (gram)	d (gram)	e (gram)	f (gram)	g	h	i	j	k	l VMA (%)	m VFWA (%)	n VITM (%)	o	p	Thickness Corr.	q Stab. (kg)	r *Flow* (mm)	MQ *(kg/mm)*
0	66,08	6,80	6,37	1201,74	1206,29	686,49	519,80	2,312	2,381	14,160	82,935	2,905	17,07	82,977	2,91	103	1476,03	0,9417	1389,96	3,17	438,47
0	63,71	6,80	6,37	1204,67	1208,89	679,91	528,98	2,277	2,381	13,948	81,694	4,357	18,31	76,196	4,36	101	1447,37	0,9947	1439,65	3,11	462,91
0	64,85	6,80	6,37	1203,55	1207,81	682,37	525,44	2,291	2,381	14,029	82,168	3,803	17,83	78,675	3,80	91	1304,07	0,9663	1260,06	3,49	361,05
								2,293					**17,73**	**79,28**	**3,69**				**1363,22**	**3,26**	**420,81**
25	64,59	6,80	6,37	1201,52	1205,42	677,05	528,37	2,274	2,379	13,928	81,668	4,405	18,33	75,974	4,40	96	1375,72	0,9727	1338,12	3,45	387,86
25	66,01	6,80	6,37	1181,63	1187,15	672,34	514,81	2,295	2,379	14,058	82,431	3,511	17,57	80,017	3,51	97	1390,05	0,9429	1310,73	3,35	391,26
25	65,31	6,80	6,37	1196,78	1200,59	673,64	526,95	2,271	2,379	13,910	81,565	4,525	18,44	75,454	4,53	88	1261,08	0,9561	1205,75	2,46	490,14
								2,280					**18,11**	**77,15**	**4,15**				**1284,87**	**3,09**	**423,09**
50	64,21	6,80	6,37	1202,68	1207,30	678,25	529,05	2,273	2,376	13,923	81,735	4,342	18,27	76,227	4,34	110	1576,35	0,9823	1548,37	2,70	573,47
50	66,07	6,80	6,37	1204,64	1210,12	685,50	524,62	2,296	2,376	14,064	82,559	3,377	17,44	80,636	3,38	92	1318,40	0,9358	1233,69	3,11	396,69
50	65,86	6,80	6,37	1202,94	1207,58	681,51	526,07	2,287	2,376	14,005	82,215	3,780	17,78	78,749	3,78	89	1275,41	0,9458	1206,22	2,63	458,64
								2,285					**17,83**	**78,54**	**3,83**				**1329,42**	**2,81**	**476,26**
75	69,58	6,80	6,37	1192,02	1211,54	688,25	523,29	2,278	2,374	13,952	81,995	4,053	18,00	77,489	4,05	112	1605,01	0,890	1428,46	2,60	549,41
75	64,33	6,80	6,37	1193,62	1210,31	684,44	525,87	2,270	2,374	13,902	81,702	4,396	18,30	75,977	4,40	98	1404,38	0,979	1375,12	2,54	541,39
75	65,69	6,80	6,37	1206,83	1218,93	695,73	523,20	2,307	2,374	14,128	83,028	2,844	16,97	83,242	2,84	92	1318,40	0,949	1251,08	2,96	422,66
								2,285					**17,76**	**78,90**	**3,76**				**1351,55**	**2,70**	**504,48**
100	65,82	6,80	6,37	1208,90	1215,36	686,50	528,86	2,286	2,372	14,000	82,374	3,625	17,63	79,432	3,63	99	1418,71	0,9466	1342,90	4,02	334,05
100	65,72	6,80	6,37	1196,24	1207,30	680,19	527,11	2,269	2,372	13,900	81,782	4,318	18,22	76,299	4,32	93	1332,73	0,9484	1263,93	3,23	391,31
100	65,15	6,80	6,37	1206,81	1219,63	682,75	536,88	2,248	2,372	13,767	81,004	5,229	19,00	72,474	5,23	81	1160,76	0,9590	1113,17	3,14	354,51
								2,268					**18,28**	**76,07**	**4,39**				**1240,00**	**3,46**	**359,96**

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Appendix 17 Marshall Test Results with Substitution of Glass Powder Filler (24 Hour)

MARSHALL TEST RESULTS WITH SUBSTITUTION OF GLASS POWDER FILLER
24 Hours of Immersion

Date of Testing March 2025
Mixture Type AC-WC

Substitution (%)	t (cm)	a (%)	b (%)	c (gram)	d (gram)	e (gram)	f (gram)	g	h	i	j	k	l VMA (%)	m VFWA (%)	n VITM (%)	o	p	Thickness Corr.	q Stab. (kg)	r *Flow* (mm)	MQ *(kg/mm)*
0	66,13	6,80	6,37	1197,68	1206,33	685,78	520,55	2,301	2,381	14,092	82,536	3,372	17,46	80,689	3,37	89	1275,41	0,9406	1199,68	3,73	321,63
0	66,98	6,80	6,37	1189,15	1199,93	682,03	517,90	2,296	2,381	14,063	82,367	3,570	17,63	79,755	3,57	87	1246,75	0,9229	1150,64	3,42	336,45
0	66,44	6,80	6,37	1200,24	1207,63	682,48	525,15	2,286	2,381	13,998	81,988	4,014	18,01	77,715	4,01	83	1189,42	0,9349	1111,96	4,14	268,59
								2,294					**17,70**	**79,39**	**3,65**				**1154,10**	**3,76**	**308,89**
25	67,92	6,80	6,37	1205,09	1216,43	687,92	528,51	2,280	2,379	13,965	81,889	4,146	18,11	77,109	4,15	70	1003,13	0,8994	902,23	4,34	207,89
25	66,33	6,80	6,37	1201,69	1209,88	682,89	526,99	2,280	2,379	13,966	81,893	4,141	18,11	77,132	4,14	87	1246,75	0,9370	1168,20	3,30	354,00
25	66,92	6,80	6,37	1198,52	1208,14	683,71	524,43	2,285	2,379	13,997	82,076	3,927	17,92	78,092	3,93	84	1203,76	0,9246	1112,97	3,12	356,72
								2,282					**18,05**	**77,44**	**4,07**				**1061,13**	**3,59**	**306,20**
50	68,70	6,80	6,37	1199,25	1213,37	684,66	528,71	2,268	2,376	13,893	81,554	4,554	18,45	75,314	4,55	85	1218,09	0,8900	1084,10	3,12	347,47
50	66,79	6,80	6,37	1194,98	1205,92	684,07	521,85	2,290	2,376	14,025	82,332	3,643	17,67	79,380	3,64	75	1074,78	0,9278	997,13	3,89	256,33
50	67,94	6,80	6,37	1195,41	1208,75	687,86	520,89	2,295	2,376	14,056	82,513	3,431	17,49	80,380	3,43	94	1347,06	0,8991	1211,12	2,92	414,77
								2,284					**17,87**	**78,36**	**3,88**				**1097,45**	**3,31**	**339,52**
75	66,21	6,80	6,37	1198,44	1207,28	684,14	523,14	2,291	2,374	14,031	82,460	3,509	17,54	79,996	3,51	87	1246,75	0,939	1171,01	2,86	409,44
75	69,40	6,80	6,37	1198,06	1208,02	683,36	524,66	2,283	2,374	13,986	82,195	3,819	17,80	78,552	3,82	94	1347,06	0,890	1198,88	3,17	378,20
75	66,28	6,80	6,37	1201,83	1211,32	684,67	526,65	2,282	2,374	13,977	82,143	3,881	17,86	78,269	3,88	80	1146,43	0,938	1075,21	3,38	318,11
								2,285					**17,73**	**78,94**	**3,74**				**1148,37**	**3,14**	**368,58**
100	64,65	6,80	6,37	1195,67	1199,45	677,15	522,30	2,289	2,372	14,021	82,496	3,483	17,50	80,103	3,48	81	1160,76	0,9712	1127,30	3,85	292,80
100	69,38	6,80	6,37	1197,37	1207,69	678,65	529,04	2,263	2,372	13,862	81,561	4,577	18,44	75,178	4,58	65	931,48	0,8900	829,01	3,70	224,06
100	66,45	6,80	6,37	1199,62	1205,58	671,77	533,81	2,247	2,372	13,764	80,984	5,252	19,02	72,382	5,25	83	1189,42	0,9347	1111,74	3,97	280,04
								2,267					**18,32**	**75,89**	**4,44**				**1022,68**	**3,84**	**265,63**

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Appendix 18 Marshall Test Results with Substitution of Glass Powder Filler (48 Hour)

MARSHALL TEST RESULTS WITH SUBSTITUTION OF GLASS POWDER FILLER
48 Hours of Immersion

Date of Testing: March 2025
Mixture Type: AC-WC

Substitution (%)	t (cm)	a (%)	b (%)	c (gram)	d (gram)	e (gram)	f (gram)	g	h	i	j	k	l VMA (%)	m VFWA (%)	n VITM (%)	o	p	Thickness Corr.	q Stab. (kg)	r *Flow* (mm)	MQ *(kg/mm)*
0	63,69	6,80	6,37	1197,05	1204,09	685,05	519,04	2,306	2,381	14,125	82,732	3,142	17,27	81,802	3,14	71	1017,46	0,9953	1012,63	4,40	230,14
0	68,27	6,80	6,37	1189,13	1200,45	679,37	521,08	2,282	2,381	13,977	81,863	4,160	18,14	77,064	4,16	76	1089,11	0,8907	970,10	4,27	227,19
0	66,29	6,80	6,37	1195,38	1202,27	680,54	521,73	2,291	2,381	14,033	82,191	3,776	17,81	78,797	3,78	66	945,81	0,9378	886,93	3,51	252,69
								2,293					**17,74**	**79,22**	**3,69**				**956,55**	**4,06**	**236,67**
25	67,44	6,80	6,37	1190,81	1204,25	685,44	518,81	2,295	2,379	14,058	82,431	3,511	17,57	80,017	3,51	77	1103,44	0,9114	1005,70	3,93	255,90
25	67,46	6,80	6,37	1197,98	1210,82	685,41	525,41	2,280	2,379	13,965	81,886	4,149	18,11	77,094	4,15	69	988,80	0,9109	900,71	4,78	188,43
25	67,10	6,80	6,37	1202,74	1214,84	684,77	530,07	2,269	2,379	13,897	81,488	4,614	18,51	75,073	4,61	64	917,15	0,9200	843,78	3,17	266,18
								2,281					**18,06**	**77,39**	**4,09**				**916,73**	**3,96**	**236,84**
50	66,77	6,80	6,37	1197,76	1208,57	690,93	517,64	2,314	2,376	14,172	83,194	2,634	16,81	84,329	2,63	74	1060,45	0,9282	984,28	3,48	282,84
50	66,12	6,80	6,37	1200,89	1211,62	681,81	529,81	2,267	2,376	13,883	81,496	4,622	18,50	75,024	4,62	72	1031,79	0,9408	970,72	4,07	238,51
50	66,24	6,80	6,37	1204,07	1213,56	684,62	528,94	2,276	2,376	13,942	81,846	4,212	18,15	76,800	4,21	67	960,14	0,9386	901,21	3,62	248,95
								2,286					**17,82**	**78,72**	**3,82**				**952,07**	**3,72**	**256,77**
75	66,60	6,80	6,37	1201,06	1209,62	679,93	529,69	2,267	2,374	13,888	81,619	4,493	18,38	75,554	4,49	81	1160,76	0,932	1081,69	3,90	277,36
75	68,31	6,80	6,37	1203,27	1217,07	691,12	525,95	2,288	2,374	14,012	82,350	3,637	17,65	79,392	3,64	70	1003,13	0,890	892,79	3,58	249,38
75	67,24	6,80	6,37	1198,45	1203,11	681,78	521,33	2,299	2,374	14,080	82,747	3,173	17,25	81,610	3,17	74	1060,45	0,917	971,99	3,37	288,42
								2,285					**17,76**	**78,85**	**3,77**				**982,15**	**3,62**	**271,72**
100	68,33	6,80	6,37	1191,99	1205,90	679,25	526,65	2,263	2,372	13,862	81,563	4,574	18,44	75,188	4,57	71	1017,46	0,8900	905,54	5,12	176,86
100	65,32	6,80	6,37	1193,10	1201,90	675,01	526,89	2,264	2,372	13,869	81,602	4,529	18,40	75,383	4,53	66	945,81	0,9559	904,13	4,56	198,27
100	67,18	6,80	6,37	1199,83	1204,73	679,64	525,09	2,285	2,372	13,995	82,343	3,661	17,66	79,263	3,66	64	917,15	0,9180	841,94	3,11	270,72
								2,271					**18,16**	**76,61**	**4,26**				**883,87**	**4,26**	**215,29**

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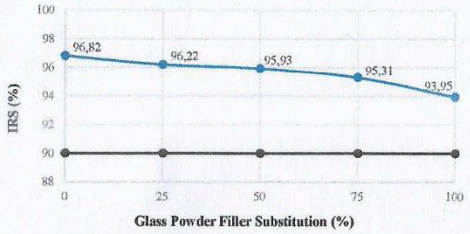
Appendix 19 IRS Test Results and Recapitulation (0 Hour)

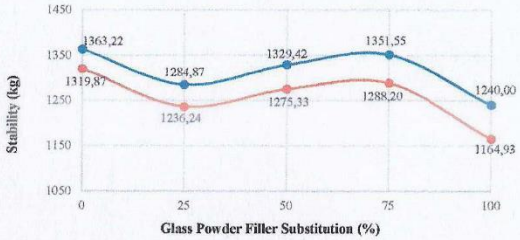
IRS TEST RESULTS
0 Hours of Immersion

Filler Substitution		Sample Thickness (mm)				Corr.	Stability Dial Gauuge			Stability (kg)			Thickness Correction			
													Sample Thickness		Correction	
		1	2	3	Average		Meas	Calibration	Adjust	Initial	Avg.	Min.	MIN	MAX	MIN	MAX
0%	1	64,90	65,60	64,80	65,10	0,96	98	31,56	3093,35	1347,02	1319,87	800	63,5	65,1	1	0,96
	2	62,50	63,00	63,70	63,07	1,01	92	31,56	2903,96	1331,51			61,9	63,5	1,04	1
	3	63,80	64,50	62,90	63,73	0,99	90	31,56	2840,83	1281,08			63,5	65,1	1	0,96
25%	1	64,70	64,50	64,90	64,70	0,97	92	31,56	2903,96	1277,72	1191,30	800	63,5	65,1	1	0,96
	2	64,30	65,80	64,20	64,77	0,96	88	31,56	2777,70	1206,21			63,5	54	1	1,32
	3	64,80	63,40	62,90	63,70	0,90	85	31,56	2683,01	1089,99			52,4	54	1,39	1,32
50%	1	66,00	66,50	65,60	66,03	0,94	92	31,56	2903,96	1241,50	1228,58	800	65,1	66,7	0,96	0,93
	2	63,60	63,70	64,40	63,90	0,89	95	31,56	2998,66	1206,32			52,4	54	1,39	1,32
	3	64,20	63,10	65,30	64,20	0,98	88	31,56	2777,70	1237,92			63,5	65,1	1	0,96
75%	1	65,10	64,90	64,70	64,90	0,97	98	31,56	3093,35	1354,03	1288,20	800	63,5	65,1	1	0,96
	2	64,80	64,70	64,40	64,63	0,97	91	31,56	2872,40	1266,00			63,5	65,1	1	0,96
	3	64,60	65,00	63,70	64,43	0,98	89	31,56	2809,27	1244,55			63,5	65,1	1	0,96
100%	1	64,60	65,20	65,60	65,13	0,96	88	31,56	2777,70	1208,78	1164,93	800	65,1	66,7	0,96	0,93
	2	66,30	66,20	65,80	66,10	0,94	83	31,56	2619,88	1118,56			65,1	66,7	0,96	0,93
	3	65,80	66,10	65,30	65,73	0,95	86	31,56	2714,57	1167,45			65,1	66,7	0,96	0,93

RECAPITULATION OF IRS TEST

Filler Substitution (%)	OAC (%)	Stability 0 Hour	Stability 24 Hour	IRS
0	6,37	1363,22	1319,87	96,82
25		1284,87	1236,24	96,22
50		1329,42	1275,33	95,93
75		1351,55	1288,20	95,31
100		1240,00	1164,93	93,95





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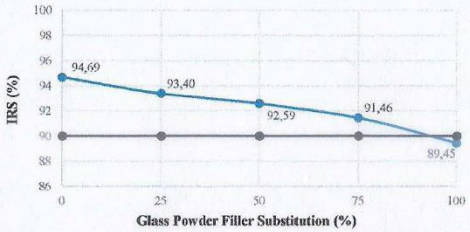
Appendix 20 IRS Test Results and Recapitulation (24 Hour)

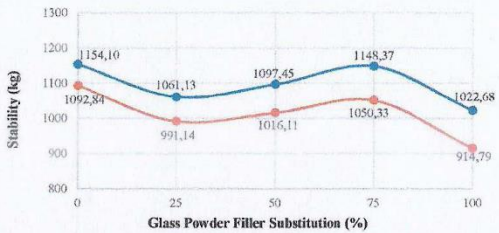
IRS TEST RESULTS
24 Hours of Immersion

Filler Substitution		Sample Thickness (mm)				Corr.	Stability Dial Gauuge			Stability (kg)			Thickness Correction			
													Sample Thickness		Correction	
		1	2	3	Average		Meas	Calibration	Adjust	Initial	Avg.	Min.	MIN	MAX	MIN	MAX
0%	1	64,60	63,90	65,00	64,50	0,98	77	31,56	2430,49	1074,91	1092,84	800	63,5	65,1	1	0,96
	2	65,80	64,80	66,40	65,67	0,95	79	31,56	2493,62	1073,84			65,1	66,7	0,96	0,93
	3	64,20	65,00	64,40	64,53	0,97	81	31,56	2556,75	1129,78			63,5	65,1	1	0,96
25%	1	66,10	65,00	65,50	65,53	0,95	72	31,56	2272,67	981,27	991,14	800	65,1	66,7	0,96	0,93
	2	65,90	65,00	65,80	65,57	0,95	78	31,56	2462,05	1062,34			65,1	66,7	0,96	0,93
	3	65,20	64,90	66,00	65,37	0,96	68	31,56	2146,41	929,80			65,1	66,7	0,96	0,93
50%	1	66,60	66,90	65,70	66,40	0,94	76	31,56	2398,92	1018,10	1016,11	800	65,1	66,7	0,96	0,93
	2	64,20	65,30	65,90	65,13	0,96	69	31,56	2177,97	947,79			65,1	66,7	0,96	0,93
	3	65,40	66,70	65,60	65,90	0,95	80	31,56	2525,18	1082,43			65,1	66,7	0,96	0,93
75%	1	63,00	62,80	63,30	63,03	1,01	73	31,56	2304,23	1057,39	1050,33	800	61,9	63,5	1,04	1
	2	66,20	64,40	65,80	65,47	0,95	74	31,56	2335,80	1009,85			65,1	66,7	0,96	0,93
	3	64,80	65,00	65,80	65,20	0,96	79	31,56	2493,62	1083,74			65,1	66,7	0,96	0,93
100%	1	65,10	65,60	64,90	65,20	0,96	67	31,56	2114,84	919,12	914,79	800	65,1	66,7	0,96	0,93
	2	65,70	64,40	62,60	64,23	0,98	63	31,56	1988,58	885,48			63,5	65,1	1	0,96
	3	65,20	66,00	65,50	65,57	0,95	69	31,56	2177,97	939,77			65,1	66,7	0,96	0,93

RECAPITULATION OF IRS TEST

Filler Substitution (%)	OAC (%)	Stability 0 Hour	Stability 24 Hour	IRS
0	6,37	1154,10	1092,84	94,69
25		1061,13	991,14	93,40
50		1097,45	1016,11	92,59
75		1148,37	1050,33	91,46
100		1022,68	914,79	89,45





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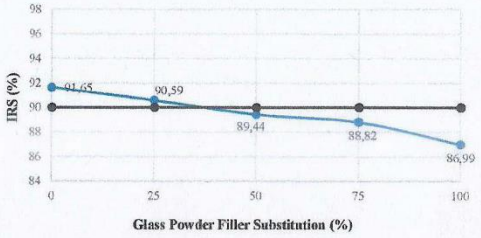
Appendix 21 IRS Test Results and Recapitulation (48 Hour)

IRS TEST RESULTS
48 Hours of Immersion

Filler Substitution		Sample Thickness (mm)				Corr.	Stability Dial Gauuge			Stability (kg)			Thickness Correction			
													Sample Thickness		Correction	
		1	2	3	Average		Meas	Calibration	Adjust	Initial	Avg.	Min.	MIN	MAX	MIN	MAX
0%	1	64,60	65,30	65,40	65,10	0,96	67	31,56	2114,84	920,92	876,70	800	63,5	65,1	1	0,96
	2	64,20	63,60	64,20	64,00	0,99	62	31,56	1957,02	876,61			63,5	65,1	1	0,96
	3	65,10	64,50	64,60	64,73	0,97	60	31,56	1893,89	832,58			63,5	65,1	1	0,96
25%	1	67,50	64,70	64,00	65,40	0,95	68	31,56	2146,41	929,19	830,46	800	65,1	66,7	0,96	0,93
	2	65,40	65,30	61,30	64,00	0,99	59	31,56	1862,32	834,19			63,5	65,1	1	0,96
	3	64,70	65,40	65,30	65,13	0,96	53	31,56	1672,93	728,02			65,1	66,7	0,96	0,93
50%	1	66,00	65,10	66,40	65,83	0,95	58	31,56	1830,76	785,80	851,53	800	65,1	66,7	0,96	0,93
	2	64,70	65,60	65,10	65,13	0,96	70	31,56	2209,54	961,53			65,1	66,7	0,96	0,93
	3	65,00	65,40	65,60	65,33	0,96	59	31,56	1862,32	807,26			65,1	66,7	0,96	0,93
75%	1	65,50	65,60	66,10	65,73	0,95	56	31,56	1767,63	760,20	872,32	800	65,1	66,7	0,96	0,93
	2	65,40	66,10	66,30	65,93	0,94	68	31,56	2146,41	919,45			65,1	66,7	0,96	0,93
	3	65,40	66,00	65,70	65,70	0,95	69	31,56	2177,97	937,30			65,1	66,7	0,96	0,93
100%	1	64,80	65,30	64,40	64,83	0,97	62	31,56	1957,02	858,11	768,88	800	63,5	65,1	1	0,96
	2	66,70	67,80	68,30	67,60	0,91	56	31,56	1767,63	727,63			66,7	68,3	0,93	0,89
	3	65,80	65,10	66,00	65,63	0,95	53	31,56	1672,93	720,90			65,1	66,7	0,96	0,93

RECAPITULATION OF IRS TEST

Filler Substitution (%)	OAC (%)	Stability 0 Hour	Stability 24 Hour	IRS
0	6,37	956,55	876,70	91,65
25		916,73	830,46	90,59
50		952,07	851,53	89,44
75		982,15	872,32	88,82
100		883,87	768,88	86,99



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Appendix 22 ITS Test Results (0 Hour)

ITS TEST RESULTS
0 Hour of Immersion

Asphalt Optimum Content	Filler Substitution (%)		Sample Thickness (mm)				Corr.	Sample Diameter (Inch)				Stability Dial Gauge			Stability (kg)			Thickness Correction				ITS 0 Hour kPa		
																		Sample Thickness		Correction				
			1	2	3	Avg		1	2	3	Avg	Meas	Calibration	Adjust	Initial	Avg	Min	MIN	MAX	MIN	MAX	Initial	Avg	Min
6,37%	0%	1	64,20	63,50	63,10	63,60	1,00	4,05	4,07	4,03	4,05	9	14,33	128,97	128,65	148,40	800	63,5	65,1	1	0,96	122,76	140,60	800
		2	65,90	66,50	67,10	66,50	0,93	3,98	3,97	3,97	3,97	10	14,33	143,30	133,81			65,1	66,7	0,96	0,93	124,47		
		3	63,90	64,60	64,30	64,27	0,98	3,99	4,02	4,00	4,00	13	14,33	186,30	182,72			63,5	65,1	1	0,96	174,56		
	25%	1	63,60	65,10	65,30	64,67	0,97	4,00	4,01	4,02	4,01	13	14,33	186,30	180,86	139,94	800	63,5	65,1	1	0,96	171,43	130,80	800
		2	66,40	66,90	68,30	67,20	0,92	3,98	3,97	3,97	3,97	10	14,33	143,30	131,48			66,7	68,3	0,93	0,89	121,03		
		3	66,30	65,80	66,80	66,30	0,94	3,98	3,99	3,99	3,99	8	14,33	114,64	107,48			65,1	66,7	0,96	0,93	99,95		
	50%	1	65,70	66,10	66,30	66,03	0,94	4,00	4,00	3,99	4,00	8	14,33	114,64	108,05	148,05	800	65,1	66,7	0,96	0,93	100,63	137,47	800
		2	67,10	66,50	65,40	66,33	0,94	3,97	4,00	3,99	3,99	12	14,33	171,97	161,11			65,1	66,7	0,96	0,93	149,74		
		3	65,30	66,50	66,80	66,20	0,94	4,02	4,01	4,00	4,01	13	14,33	186,30	175,00			65,1	66,7	0,96	0,93	162,03		
	75%	1	64,40	64,40	63,70	64,17	0,98	4,04	4,04	4,04	4,04	12	14,33	171,97	169,10	147,72	800	63,5	65,1	1	0,96	160,33	138,44	800
		2	66,30	66,30	65,50	66,03	0,94	3,98	4,20	4,00	4,06	9	14,33	128,97	121,56			65,1	66,7	0,96	0,93	111,45		
		3	64,50	65,10	64,80	64,80	0,97	4,00	4,03	4,06	4,03	11	14,33	157,63	152,51			63,5	65,1	1	0,96	143,55		
	100%	1	66,80	66,40	65,20	66,13	0,94	3,96	4,02	3,99	3,99	11	14,33	157,63	148,28	129,39	800	65,1	66,7	0,96	0,93	138,12	122,37	800
		2	62,00	62,50	66,00	63,50	1,00	4,02	4,05	4,03	4,03	11	14,33	157,63	157,63			63,5	65,1	1	0,96	151,28		
		3	65,30	64,70	65,80	65,27	0,96	3,95	4,01	4,00	3,99	6	14,33	85,98	82,27			65,1	66,7	0,96	0,93	77,72		

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Appendix 23 ITS Test Results (24 Hour)

ITS TEST RESULTS
24 Hour of Immersion

Asphalt Optimum Content	Filler Substitution (%)		Sample Thickness (mm)				Corr.	Sample Diameter (Inch)				Stability Dial Gauge			Stability (kg)			Thickness Correction				ITS 0 Hour kPa		
																		Sample Thickness		Correction				
			1	2	3	Avg		1	2	3	Avg	Meas	Calibration	Adjust	Initial	Avg	Min	MIN	MAX	MIN	MAX	Initial	Avg	Min
6,37%	0%	1	63,76	64,55	65,74	64,68	0,97	4,05	4,07	4,06	4,06	10	14,33	143,30	139,06			63,5	65,1	1	0,96	130,20		
		2	66,36	65,22	65,93	65,84	0,95	3,99	3,99	3,98	3,98	8	14,33	114,64	108,47	136,76	800	65,1	66,7	0,96	0,93	101,66	128,00	800
		3	65,45	66,21	65,83	65,83	0,95	3,99	4,02	3,97	3,99	12	14,33	171,97	162,73			65,1	66,7	0,96	0,93	152,15		
	25%	1	68,69	67,80	67,23	67,91	0,90	3,96	3,98	3,94	3,96	10	14,33	143,30	128,95			66,7	68,3	0,93	0,89	117,87		
		2	68,06	68,03	67,33	67,81	0,90	3,92	3,99	3,98	3,96	8	14,33	114,64	103,45	128,02	800	66,7	68,3	0,93	0,89	94,68	118,92	800
		3	64,65	65,37	65,02	65,01	0,96	3,96	3,99	3,98	3,98	11	14,33	157,63	151,67			63,5	65,1	1	0,96	144,19		
	50%	1	67,59	66,20	66,35	66,71	0,93	3,98	3,98	3,99	3,98	9	14,33	128,97	119,90			66,7	68,3	0,93	0,89	110,96		
		2	69,56	68,22	67,08	68,29	0,89	3,97	3,98	3,97	3,97	12	14,33	171,97	153,11	136,12	800	66,7	68,3	0,93	0,89	138,70	125,52	800
		3	66,21	65,73	65,84	65,93	0,94	3,99	3,97	3,97	3,98	10	14,33	143,30	135,35			65,1	66,7	0,96	0,93	126,90		
	75%	1	67,88	66,77	67,66	67,44	0,91	3,96	3,98	3,96	3,97	10	14,33	143,30	130,63			66,7	68,3	0,93	0,89	119,94		
		2	67,41	68,42	67,46	67,76	0,90	3,98	3,97	3,97	3,97	8	14,33	114,64	103,57	137,45	800	66,7	68,3	0,93	0,89	94,56	127,47	800
		3	65,36	64,98	65,57	65,30	0,96	4,01	3,99	3,98	3,99	13	14,33	186,30	178,13			65,1	66,7	0,96	0,93	167,90		
	100%	1	68,07	67,73	67,08	67,63	0,91	3,97	3,98	3,98	3,98	8	14,33	114,64	103,96			66,7	68,3	0,93	0,89	95,01		
		2	64,24	63,92	64,84	64,33	0,98	4,07	4,06	4,07	4,07	9	14,33	128,97	126,29	114,34	800	63,5	65,1	1	0,96	118,68	107,15	800
		3	64,35	63,90	64,21	64,15	0,98	4,02	4,01	4,00	4,01	8	14,33	114,64	112,77			63,5	65,1	1	0,96	107,75		

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Appendix 24 ITS Test Results (48 Hour)

ITS TEST RESULTS
48 Hour of Immersion

Asphalt Optimum Content	Filler Substitution (%)		Sample Thickness (mm)				Corr.	Sample Diameter (Inch)				Stability Dial Gauge			Stability (kg)			Thickness Correction				ITS 0 Hour kPa		
																		Sample Thickness		Correction				
			1	2	3	Avg		1	2	3	Avg	Meas	Calibration	Adjust	Initial	Avg	Min	MIN	MAX	MIN	MAX	Initial	Avg	Min
6,37%	0%	1	66,60	66,10	65,40	66,03	0,94	3,98	4,00	3,99	3,99	11	14,33	157,63	148,57	128,77	800	65,1	66,7	0,96	0,93	138,60	121,82	800
		2	64,80	63,90	64,00	64,23	0,98	3,99	4,00	4,00	4,00	10	14,33	143,30	140,68			63,5	65,1	1	0,96	134,69		
		3	65,20	64,70	64,50	64,80	0,97	4,00	3,98	4,00	3,99	7	14,33	100,31	97,05			63,5	65,1	1	0,96	92,19		
	25%	1	66,50	66,40	66,40	66,43	0,94	4,00	3,98	3,99	3,99	8	14,33	114,64	107,19	118,58	800	65,1	66,7	0,96	0,93	99,40	111,99	800
		2	64,90	64,80	65,40	65,03	0,96	3,97	3,97	3,98	3,97	11	14,33	157,63	151,59			63,5	65,1	1	0,96	144,20		
		3	65,00	64,80	64,70	64,83	0,97	3,96	3,97	4,01	3,98	7	14,33	100,31	96,97			63,5	65,1	1	0,96	92,37		
	50%	1	66,80	66,60	66,70	66,70	0,93	4,00	4,00	4,00	4,00	7	14,33	100,31	93,29	127,35	800	65,1	66,7	0,96	0,93	85,95	118,60	800
		2	64,80	65,80	64,40	65,00	0,96	4,03	4,03	4,02	4,03	11	14,33	157,63	151,72			63,5	65,1	1	0,96	142,48		
		3	65,70	64,90	65,30	65,30	0,96	4,06	4,04	4,05	4,05	10	14,33	143,30	137,03			65,1	66,7	0,96	0,93	127,36		
	75%	1	64,80	65,00	65,40	65,07	0,96	3,97	4,00	3,96	3,98	12	14,33	171,97	165,23	127,73	800	63,5	65,1	1	0,96	156,96	120,95	800
		2	66,30	66,20	67,40	66,63	0,93	3,97	3,98	3,97	3,97	8	14,33	114,64	106,76			65,1	66,7	0,96	0,93	99,11		
		3	64,60	64,10	65,40	64,70	0,97	3,94	3,98	3,95	3,96	8	14,33	114,64	111,20			63,5	65,1	1	0,96	106,77		
	100%	1	65,80	66,30	66,50	66,20	0,94	3,98	3,98	3,98	3,98	9	14,33	128,97	121,15	104,42	800	65,1	66,7	0,96	0,93	113,02	97,35	800
		2	65,10	65,70	64,50	65,10	0,96	4,06	4,06	4,05	4,06	8	14,33	114,64	110,06			63,5	65,1	1	0,96	102,43		
		3	64,90	65,50	65,80	65,40	0,95	4,02	4,03	4,03	4,03	6	14,33	85,98	82,06			65,1	66,7	0,96	0,93	76,59		

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Appendix 25 TSR Test Results (0 Hour)

TSR TEST RESULTS
0 Hour of Immersion

Asphalt Optimum Content	Filler Substitution (%)		Sample Thickness (mm)				Corr.	Sample Diameter (Inch)				Stability Dial Gauge			Stability (kg)			Thickness Correction				ITS 0 Hour kPa		
			1	2	3	Avg		1	2	3	Avg	Meas	Calibration	Adjust	Initial	Avg	Min	Sample Thickness MIN	Sample Thickness MAX	Correction MIN	Correction MAX	Initial	Avg	Min
6,37%	0%	1	63,50	63,30	64,20	63,67	1,00	4,06	4,04	4,04	4,05	11	14,33	157,63	156,98	141,80	800	63,5	65,1	1	0,96	149,75	135,47	800
		2	62,60	62,90	64,10	63,20	1,01	4,05	4,04	4,04	4,04	10	14,33	143,30	144,38			61,9	63,5	1,04	1	138,88		
		3	65,10	65,20	64,80	65,03	0,96	3,99	3,98	3,97	3,98	9	14,33	128,97	124,03			63,5	65,1	1	0,96	117,78		
	25%	1	63,30	64,70	65,30	64,43	0,98	4,06	4,04	4,02	4,04	10	14,33	143,30	139,96	130,99	800	63,5	65,1	1	0,96	132,27	123,96	800
		2	63,70	63,50	64,00	63,73	0,99	4,03	4,02	4,04	4,03	11	14,33	157,63	156,72			63,5	65,1	1	0,96	149,98		
		3	64,80	65,20	65,30	65,10	0,96	4,05	4,06	4,06	4,06	7	14,33	100,31	96,30			65,1	66,7	0,96	0,93	89,63		
	50%	1	65,70	62,70	64,80	64,40	0,98	4,04	4,06	4,03	4,05	10	14,33	143,30	140,08	133,62	800	63,5	65,1	1	0,96	132,16	126,78	800
		2	67,00	65,50	66,00	66,17	0,94	3,97	3,97	3,98	3,98	10	14,33	143,30	134,71			65,1	66,7	0,96	0,93	125,85		
		3	64,50	64,70	64,00	64,40	0,98	3,92	3,93	3,95	3,93	9	14,33	128,97	126,07			63,5	65,1	1	0,96	122,33		
	75%	1	65,80	64,10	65,00	64,97	0,96	4,00	3,99	3,97	3,99	10	14,33	143,30	138,05	133,03	800	63,5	65,1	1	0,96	131,01	126,13	800
		2	65,50	66,10	65,90	65,83	0,95	3,98	3,99	3,99	3,99	9	14,33	128,97	122,04			65,1	66,7	0,96	0,93	114,25		
		3	64,30	64,10	65,70	64,70	0,97	3,99	3,96	3,95	3,97	10	14,33	143,30	139,01			63,5	65,1	1	0,96	133,13		
	100%	1	66,70	66,50	65,30	66,17	0,94	4,00	4,02	4,00	4,01	10	14,33	143,30	134,71	110,23	800	65,1	66,7	0,96	0,93	124,91	103,59	800
		2	65,30	65,00	64,80	65,03	0,96	4,04	4,03	3,98	4,02	6	14,33	85,98	82,69			63,5	65,1	1	0,96	77,83		
		3	64,00	64,10	63,80	63,97	0,99	4,02	4,03	4,04	4,03	8	14,33	114,64	113,31			63,5	65,1	1	0,96	108,03		

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Appendix 26 ITS Test Results (24 Hour)

ITS TEST RESULTS
24 Hour of Immersion

Asphalt Optimum Content	Filler Substitution (%)		Sample Thickness (mm)				Corr.	Sample Diameter (Inch)				Stability Dial Gauge			Stability (kg)			Thickness Correction				ITS 0 Hour kPa		
																		Sample Thickness		Correction				
			1	2	3	Avg		1	2	3	Avg	Meas	Calibration	Adjust	Initial	Avg	Min	MIN	MAX	MIN	MAX	Initial	Avg	Min
6,37%	0%	1	63,76	64,55	65,74	64,68	0,97	4,05	4,07	4,06	4,06	10	14,33	143,30	139,06			63,5	65,1	1	0,96	130,20		
		2	66,36	65,22	65,93	65,84	0,95	3,99	3,99	3,98	3,98	8	14,33	114,64	108,47	136,76	800	65,1	66,7	0,96	0,93	101,66	128,00	800
		3	65,45	66,21	65,83	65,83	0,95	3,99	4,02	3,97	3,99	12	14,33	171,97	162,73			65,1	66,7	0,96	0,93	152,15		
	25%	1	68,69	67,80	67,23	67,91	0,90	3,96	3,98	3,94	3,96	10	14,33	143,30	128,95			66,7	68,3	0,93	0,89	117,87		
		2	68,06	68,03	67,33	67,81	0,90	3,92	3,99	3,98	3,96	8	14,33	114,64	103,45	128,02	800	66,7	68,3	0,93	0,89	94,68	118,92	800
		3	64,65	65,37	65,02	65,01	0,96	3,96	3,99	3,98	3,98	11	14,33	157,63	151,67			63,5	65,1	1	0,96	144,19		
	50%	1	67,59	66,20	66,35	66,71	0,93	3,98	3,98	3,99	3,98	9	14,33	128,97	119,90			66,7	68,3	0,93	0,89	110,96		
		2	69,56	68,22	67,08	68,29	0,89	3,97	3,98	3,97	3,97	12	14,33	171,97	153,11	136,12	800	66,7	68,3	0,93	0,89	138,70	125,52	800
		3	66,21	65,73	65,84	65,93	0,94	3,99	3,97	3,97	3,98	10	14,33	143,30	135,35			65,1	66,7	0,96	0,93	126,90		
	75%	1	67,88	66,77	67,66	67,44	0,91	3,96	3,98	3,96	3,97	10	14,33	143,30	130,63			66,7	68,3	0,93	0,89	119,94		
		2	67,41	68,42	67,46	67,76	0,90	3,98	3,97	3,97	3,97	8	14,33	114,64	103,57	137,45	800	66,7	68,3	0,93	0,89	94,56	127,47	800
		3	65,36	64,98	65,57	65,30	0,96	4,01	3,99	3,98	3,99	13	14,33	186,30	178,13			65,1	66,7	0,96	0,93	167,90		
	100%	1	68,07	67,73	67,08	67,63	0,91	3,97	3,98	3,98	3,98	8	14,33	114,64	103,96			66,7	68,3	0,93	0,89	95,01		
		2	64,24	63,92	64,84	64,33	0,98	4,07	4,06	4,07	4,07	9	14,33	128,97	126,29	114,34	800	63,5	65,1	1	0,96	118,68	107,15	800
		3	64,35	63,90	64,21	64,15	0,98	4,02	4,01	4,00	4,01	8	14,33	114,64	112,77			63,5	65,1	1	0,96	107,75		

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Appendix 27 ITS Test Results (48 Hour)

ITS TEST RESULTS
48 Hour of Immersion

Asphalt Optimum Content	Filler Substitution (%)		Sample Thickness (mm)				Corr.	Sample Diameter (Inch)				Stability Dial Gauge			Stability (kg)			Thickness Correction				ITS 0 Hour kPa		
																		Sample Thickness		Correction				
			1	2	3	Avg		1	2	3	Avg	Meas	Calibration	Adjust	Initial	Avg	Min	MIN	MAX	MIN	MAX	Initial	Avg	Min
6,37%	0%	1	66,60	66,10	65,40	66,03	0,94	3,98	4,00	3,99	3,99	11	14,33	157,63	148,57	128,77	800	65,1	66,7	0,96	0,93	138,60	121,82	800
		2	64,80	63,90	64,00	64,23	0,98	3,99	4,00	4,00	4,00	10	14,33	143,30	140,68			63,5	65,1	1	0,96	134,69		
		3	65,20	64,70	64,50	64,80	0,97	4,00	3,98	4,00	3,99	7	14,33	100,31	97,05			63,5	65,1	1	0,96	92,19		
	25%	1	66,50	66,40	66,40	66,43	0,94	4,00	3,98	3,99	3,99	8	14,33	114,64	107,19	118,58	800	65,1	66,7	0,96	0,93	99,40	111,99	800
		2	64,90	64,80	65,40	65,03	0,96	3,97	3,97	3,98	3,97	11	14,33	157,63	151,59			63,5	65,1	1	0,96	144,20		
		3	65,00	64,80	64,70	64,83	0,97	3,96	3,97	4,01	3,98	7	14,33	100,31	96,97			63,5	65,1	1	0,96	92,37		
	50%	1	66,80	66,60	66,70	66,70	0,93	4,00	4,00	4,00	4,00	7	14,33	100,31	93,29	127,35	800	65,1	66,7	0,96	0,93	85,95	118,60	800
		2	64,80	65,80	64,40	65,00	0,96	4,03	4,03	4,02	4,03	11	14,33	157,63	151,72			63,5	65,1	1	0,96	142,48		
		3	65,70	64,90	65,30	65,30	0,96	4,06	4,04	4,05	4,05	10	14,33	143,30	137,03			65,1	66,7	0,96	0,93	127,36		
	75%	1	64,80	65,00	65,40	65,07	0,96	3,97	4,00	3,96	3,98	12	14,33	171,97	165,23	127,73	800	63,5	65,1	1	0,96	156,96	120,95	800
		2	66,30	66,20	67,40	66,63	0,93	3,97	3,98	3,97	3,97	8	14,33	114,64	106,76			65,1	66,7	0,96	0,93	99,11		
		3	64,60	64,10	65,40	64,70	0,97	3,94	3,98	3,95	3,96	8	14,33	114,64	111,20			63,5	65,1	1	0,96	106,77		
	100%	1	65,80	66,30	66,50	66,20	0,94	3,98	3,98	3,98	3,98	9	14,33	128,97	121,15	104,42	800	65,1	66,7	0,96	0,93	113,02	97,35	800
		2	65,10	65,70	64,50	65,10	0,96	4,06	4,06	4,05	4,06	8	14,33	114,64	110,06			63,5	65,1	1	0,96	102,43		
		3	64,90	65,50	65,80	65,40	0,95	4,02	4,03	4,03	4,03	6	14,33	85,98	82,06			65,1	66,7	0,96	0,93	76,59		

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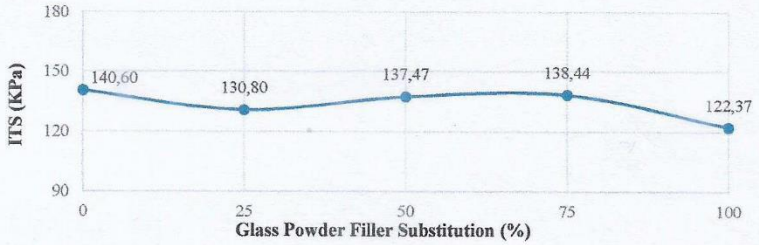
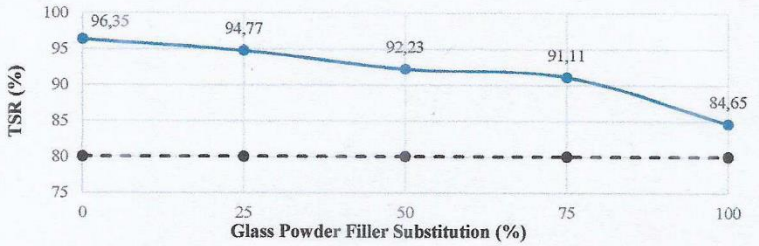
Appendix 28 Recapitulation of ITS & TSR Test Results (0 Hour)

RECAPITULATION OF ITS & TSR TEST
0 Hour of Immersion

Filler Substitution (%)	OAC (%)	ITS	ITS 24 Hour	TSR (%)
0	6,37	140,601	135,471	96,351
25		130,804	123,962	94,769
50		137,470	126,782	92,226
75		138,440	126,130	91,108
100		122,372	103,592	84,653





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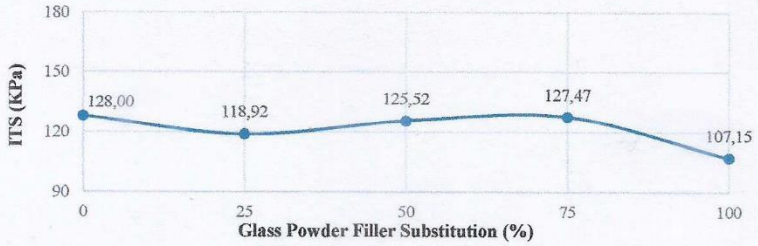
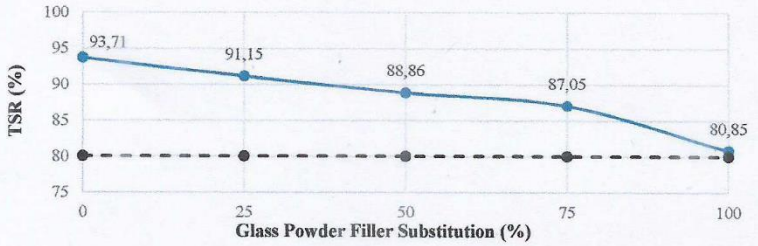
Appendix 29 Recapitulation of ITS & TSR Test Results (24 Hour)

RECAPITULATION OF ITS & TSR TEST
24 Hour of Immersion

Filler Substitution (%)	OAC (%)	ITS	ITS 24 Hour	TSR (%)
0	6,37	128,004	119,953	93,711
25		118,917	108,391	91,148
50		125,517	111,535	88,860
75		127,465	110,960	87,052
100		107,147	86,629	80,851





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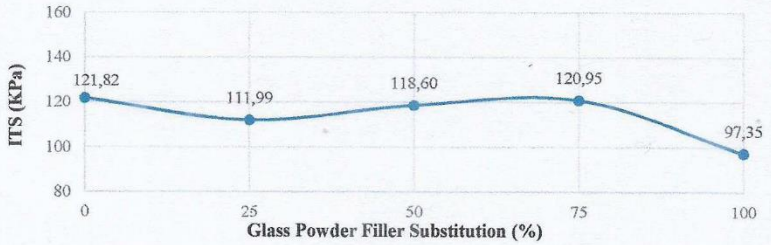
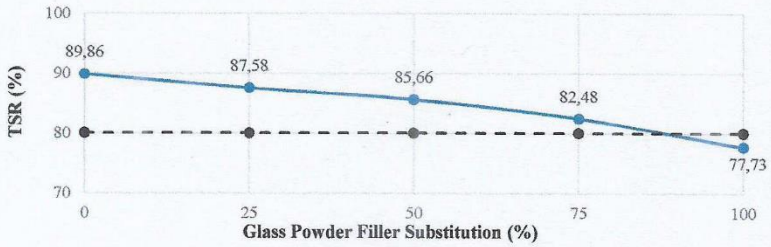
Appendix 30 Recapitulation of ITS & TSR Test Results (48 Hour)

RECAPITULATION OF ITS & TSR TEST
48 Hour of Immersion

Filler Substitution (%)	OAC (%)	ITS	ITS 24 Hour	TSR (%)
0	6,37	121,825	109,476	89,863
25		111,986	98,082	87,584
50		118,595	101,589	85,660
75		120,947	99,757	82,480
100		97,348	75,672	77,733





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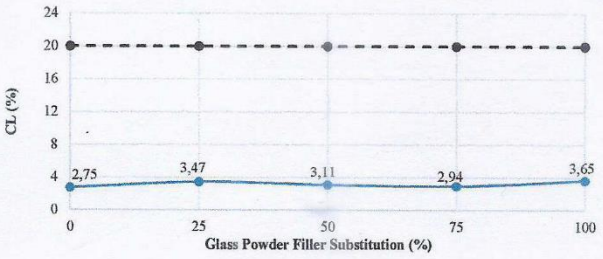
Appendix 31 Cantabro Loss Test Results and Recapitulation (0 Hour)

CANTABRO LOSS TEST RESULTS
0 Hour of Immersion

Filler Substitution	No.	Description	Sample		
			1	2	3
0%	1	Weight Before Abrasion	1199,17	1204,06	1199,23
	2	Weight After Abrasion	1159,11	1177,76	1166,49
	3	Weight Loss Percentage	3,34	2,18	2,73
	4	Average Specific Gravity of Filler		2,75	
25%	1	Weight Before Abrasion	1207,40	1206,19	1198,77
	2	Weight After Abrasion	1170,88	1157,48	1158,76
	3	Weight Loss Percentage	3,02	4,04	3,34
	4	Average Specific Gravity of Filler		3,47	
50%	1	Weight Before Abrasion	1198,33	1202,44	1199,28
	2	Weight After Abrasion	1142,89	1168,93	1176,42
	3	Weight Loss Percentage	4,63	2,79	1,91
	4	Average Specific Gravity of Filler		3,11	
75%	1	Weight Before Abrasion	1195,36	1201,60	1204,65
	2	Weight After Abrasion	1159,37	1169,21	1167,26
	3	Weight Loss Percentage	3,01	2,70	3,10
	4	Average Specific Gravity of Filler		2,94	
100%	1	Weight Before Abrasion	1202,10	1203,00	1203,56
	2	Weight After Abrasion	1162,52	1164,28	1150,15
	3	Weight Loss Percentage	3,29	3,22	4,44
	4	Average Specific Gravity of Filler		3,65	

RECAPITULATION OF CANTABRO LOSS TEST

Filler Substitution (%)	OAC (%)	CL (%)
0	6,37	2,75
25		3,47
50		3,11
75		2,94
100		3,65



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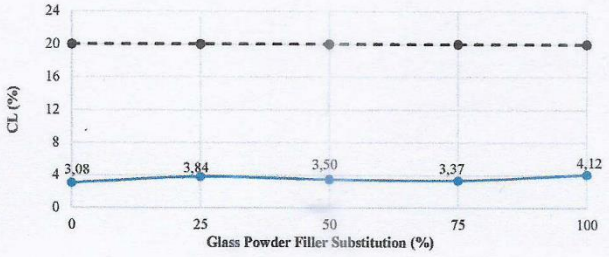
Appendix 32 Cantabro Loss Test Results and Recapitulation (24 Hour)

CANTABRO LOSS TEST RESULTS
24 Hour of Immersion

Filler Substitution	No.	Description	Sample		
			1	2	3
0%	1	Weight Before Abrasion	1201,11	1198,88	1190,17
	2	Weight After Abrasion	1168,04	1163,22	1148,41
	3	Weight Loss Percentage	2,75	2,97	3,51
	4	Average Specific Gravity of Filler		3,08	
25%	1	Weight Before Abrasion	1206,41	1202,57	1197,28
	2	Weight After Abrasion	1164,32	1159,16	1144,27
	3	Weight Loss Percentage	3,49	3,61	4,43
	4	Average Specific Gravity of Filler		3,84	
50%	1	Weight Before Abrasion	1196,92	1204,28	1201,31
	2	Weight After Abrasion	1140,02	1166,62	1169,88
	3	Weight Loss Percentage	4,75	3,13	2,62
	4	Average Specific Gravity of Filler		3,50	
75%	1	Weight Before Abrasion	1194,99	1192,67	1204,33
	2	Weight After Abrasion	1149,66	1162,58	1158,51
	3	Weight Loss Percentage	3,79	2,52	3,80
	4	Average Specific Gravity of Filler		3,37	
100%	1	Weight Before Abrasion	1207,41	1198,88	1202,13
	2	Weight After Abrasion	1153,05	1150,22	1156,36
	3	Weight Loss Percentage	4,50	4,06	3,81
	4	Average Specific Gravity of Filler		4,12	

RECAPITULATION OF CANTABRO LOSS TEST

Filler Substitution (%)	OAC (%)	CL (%)
0	6,37	3,08
25		3,84
50		3,50
75		3,37
100		4,12



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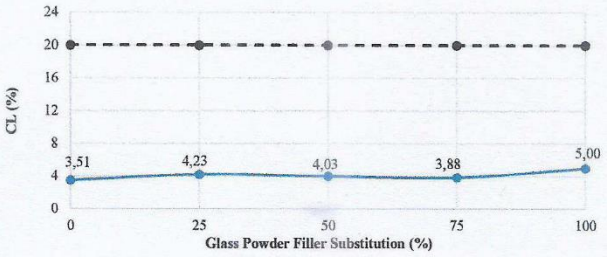
Appendix 33 Cantabro Loss Test Results and Recapitulation (48 Hour)

CANTABRO LOSS TEST RESULTS
48 Hour of Immersion

Filler Substitution	No.	Description	Sample		
			1	2	3
0%	1	Weight Before Abrasion	1202,52	1201,11	1199,72
	2	Weight After Abrasion	1142,30	1156,90	1177,46
	3	Weight Loss Percentage	5,01	3,68	1,86
	4	Average Specific Gravity of Filler		3,51	
25%	1	Weight Before Abrasion	1214,30	1207,21	1191,35
	2	Weight After Abrasion	1159,46	1157,10	1143,29
	3	Weight Loss Percentage	4,52	4,15	4,03
	4	Average Specific Gravity of Filler		4,23	
50%	1	Weight Before Abrasion	1203,50	1213,85	1200,34
	2	Weight After Abrasion	1153,67	1159,57	1158,68
	3	Weight Loss Percentage	4,14	4,47	3,47
	4	Average Specific Gravity of Filler		4,03	
75%	1	Weight Before Abrasion	1206,23	1198,26	1189,14
	2	Weight After Abrasion	1166,22	1147,83	1140,25
	3	Weight Loss Percentage	3,32	4,21	4,11
	4	Average Specific Gravity of Filler		3,88	
100%	1	Weight Before Abrasion	1204,38	1202,52	1200,08
	2	Weight After Abrasion	1120,70	1132,30	1173,41
	3	Weight Loss Percentage	6,95	5,84	2,22
	4	Average Specific Gravity of Filler		5,00	

RECAPITULATION OF CANTABRO LOSS TEST

Filler Substitution (%)	OAC (%)	CL (%)
0	6,37	3,51
25		4,23
50		4,03
75		3,88
100		5,00



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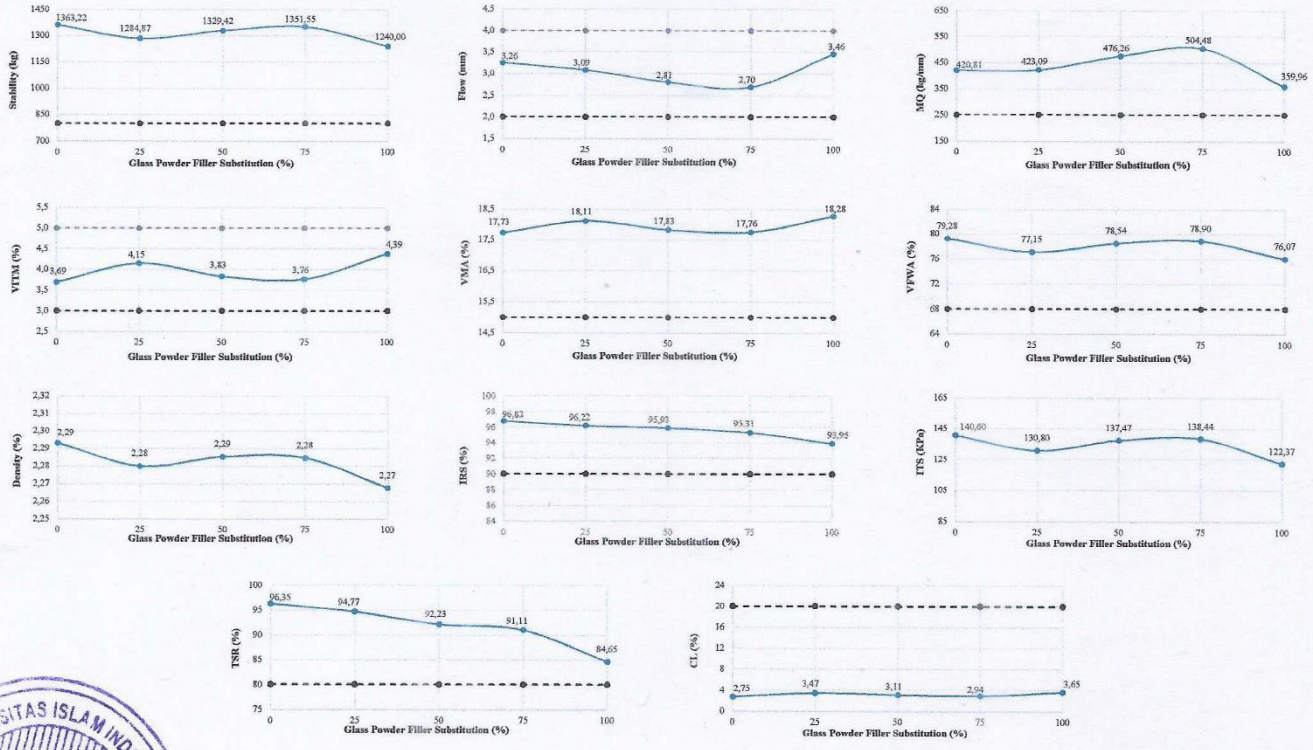
Appendix 34 Recapitulation of Test Results for Glass Powder Filler (0 Hour)

RECAPITULATION OF TEST RESULT AC-WC MIXTURE WITH GLASS POWDER FILLER
0 Hour of Immersion

AC-WC Specification	Filler Substitution (%)	Stability 0 Hour (kg)	Flow (mm)	MQ (%)	VITM (%)	VMA (%)	VFWA (kg)	Density (%)	IRS (%)	ITS (kPa)	TSR (%)	CL (%)
	0	1363,22	3,26	420,81	3,69	17,73	79,28	2,29	96,820	140,60	96,35	2,75
	25	1284,87	3,09	423,09	4,15	18,11	77,15	2,28	96,215	130,80	94,77	3,47
	50	1329,42	2,81	476,26	3,83	17,83	78,54	2,29	95,931	137,47	92,23	3,11
	75	1351,55	2,70	504,48	3,76	17,76	78,90	2,28	95,312	138,44	91,11	2,94
	100	1240,00	3,46	359,96	4,39	18,28	76,07	2,27	93,946	122,37	84,65	3,65
BINA MARGA 2018		**>800**	**2 - 4**	**>250**	**3 - 5**	**>15**	**>68**	**>2**	**>90**		**>80**	**<20**



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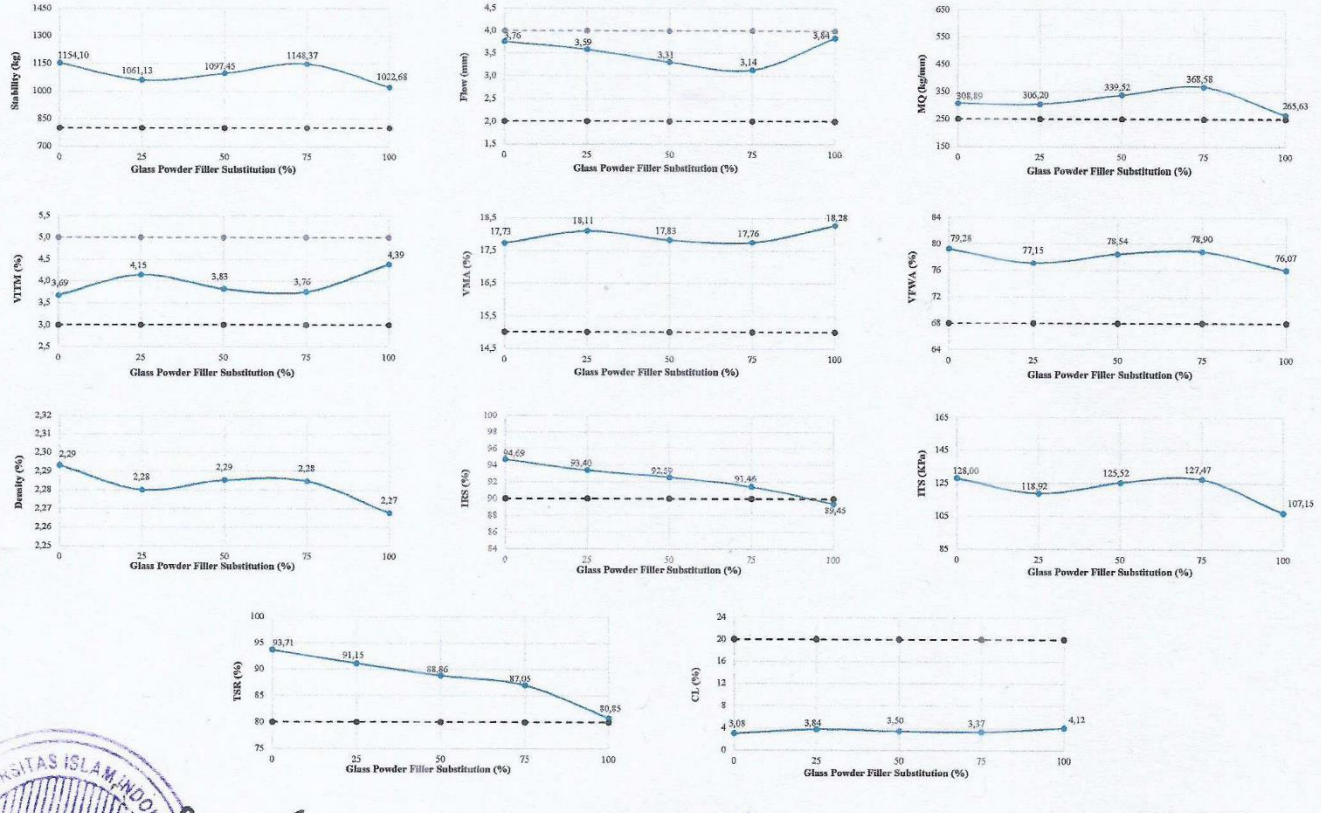
Appendix 35 Recapitulation of Test Results for Glass Powder Filler (24 Hour)

RECAPITULATION OF TEST RESULT AC-WC MIXTURE WITH GLASS POWDER FILLER
24 Hour of Immersion

AC-WC Specification	Filler Substitution (%)	Stability 0 Hour (kg)	Flow (mm)	MQ (%)	VITM (%)	VMA (%)	VFWA (kg)	Density (%)	IRS (%)	ITS (kPa)	TSR (%)	CL (%)
	0	1154,10	3,76	308,89	3,69	17,73	79,28	2,29	94,693	128,00	93,71	3,08
	25	1061,13	3,59	306,20	4,15	18,11	77,15	2,28	93,404	118,92	91,15	3,84
	50	1097,45	3,31	339,52	3,83	17,83	78,54	2,29	92,588	125,52	88,86	3,50
	75	1148,37	3,14	368,58	3,76	17,76	78,90	2,28	91,463	127,47	87,05	3,37
	100	1022,68	3,84	265,63	4,39	18,28	76,07	2,27	89,450	107,15	80,85	4,12
BINA MARGA 2018		**>800**	**2 - 4**	**>250**	**3 - 5**	**>15**	**>68**	**>2**	**>90**		**>80**	**<20**



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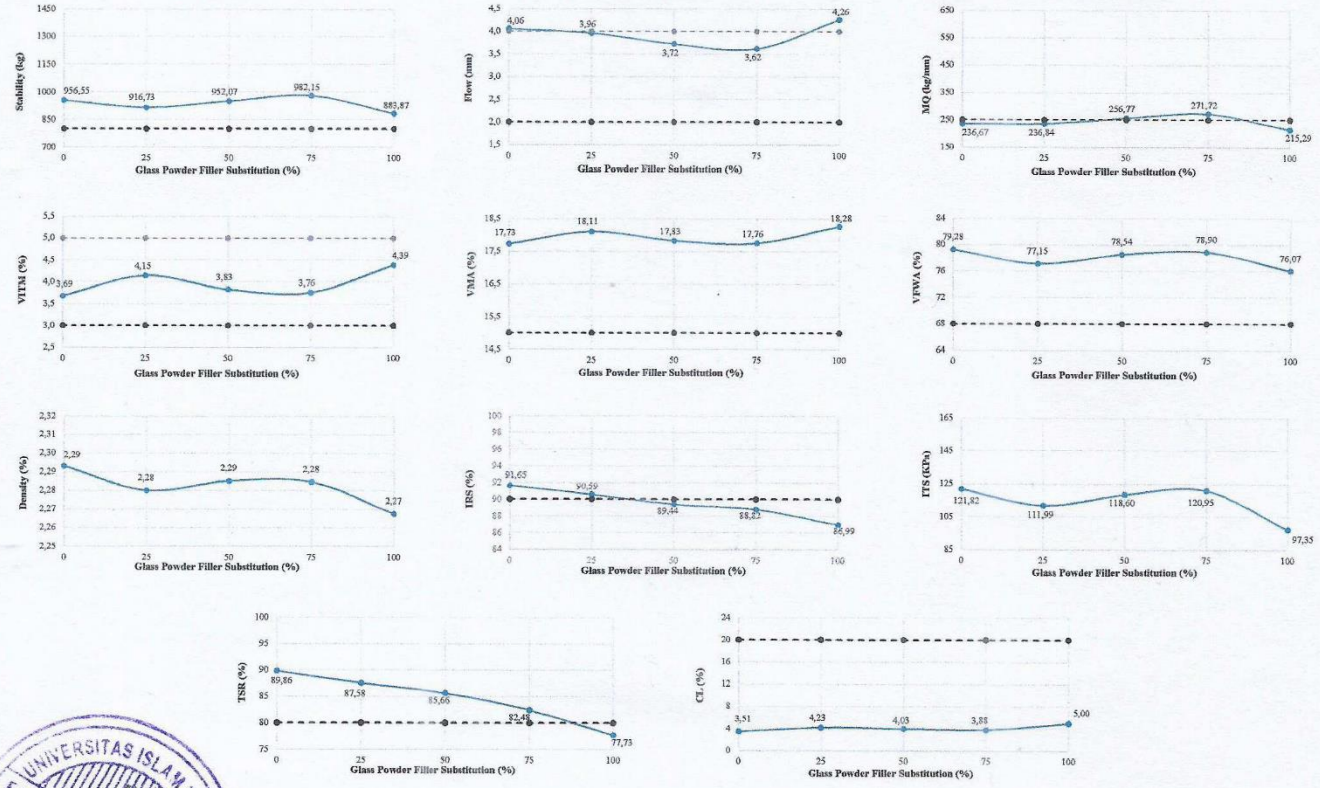
Appendix 36 Recapitulation of Test Results for Glass Powder Filler (48 Hour)

RECAPITULATION OF TEST RESULT AC-WC MIXTURE WITH GLASS POWDER FILLER
48 Hour of Immersion

AC-WC Specification	Filler Substitution (%)	Stability 0 Hour (kg)	Flow (mm)	MQ (%)	VITM (%)	VMA (%)	VFWA (kg)	Density (%)	IRS (%)	ITS (kPa)	TSR (%)	CL (%)
	0	956,55	4,06	236,67	3,69	17,73	79,28	2,29	91,652	121,82	89,86	3,51
	25	916,73	3,96	236,84	4,15	18,11	77,15	2,28	90,590	111,99	87,58	4,23
	50	952,07	3,72	256,77	3,83	17,83	78,54	2,29	89,440	118,60	85,66	4,03
	75	982,15	3,62	271,72	3,76	17,76	78,90	2,28	88,817	120,95	82,48	3,88
	100	883,87	4,26	215,29	4,39	18,28	76,07	2,27	86,990	97,35	77,73	5,00
BINA MARGA 2018		>800	2 - 4	>250	3 - 5	>15	>68	>2	>90		>80	<20



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Appendix 37 Bekasi River Water Quality Test Results

APS.011.476.02.25

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ID Pelanggan	:	-
Perusahaan / Instansi	:	Prodi Teknik Sipil FTSP UII
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Alamat	:	Jl. Kaliurang km 14,5, Ngemplak, Sleman, DI. Yogyakarta
Email	:	-
Jenis Order	:	☑ Pengujian ☐ Sampling & Pengujian
B. INFORMASI CONTOH UJI		
Kode Sampel	:	APS.006
Nama Sampel	:	Air Sungai
Jumlah Sampel	:	1
Parameter uji	:	Kekeruhan, pH
Pengambil Sampel	:	☐ Petugas Laboratorium ☑ Diambil sendiri
Tanggal Pengambilan Sampel	:	-
Tanggal Penerimaan Sampel	:	13 Januari 2025
Tanggal Pengujian	:	14 s.d. 31 Januari 2025
Lokasi	:	Air Sungai Bekasi
Kode & Koordinat Lokasi		
APS.006	:	E : - S : -

Laporan hasil uji ini dibuat secara obyektif dan independen yang hanya berlaku untuk contoh yang diuji. Dilarang menggandakan sebagian dan atau seutuhnya tanpa izin Manajer Laboratorium Kualitas Lingkungan.

Yogyakarta, 3 Februari 2025
Manajer Laboratorium

Fajri Mulya Iresha, S.T., M.T., Ph.D.

Hal. 1 dari 2

APS.011.476.02.25

HASIL PENGUJIAN

No.	Parameter	Satuan	HASIL UJI APS.006	Metode Uji
A.	**Parameter Fisik**			
1	Kekeruhan	NTU	3,62 ± 1,04	SNI 06-6989.25-2005
B.	**Parameter Kimiawi**			
2	pH	-	6,49 ± 0,24	SNI 6989.11-2019

Yogyakarta, 3 Februari 2025
Kepala Laboratorium

(Puji Lestari, S.Si., M.Sc., Ph.D.)