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# THE EFFECT OF THE USE OF GBFS AS A MEDIUM AGGREGATE SUBSTITUTION ON THE PERFORMANCE OF THE AC-WC ASPHALT MIXTURE

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**ABSTRACT**

The massive use of natural materials in major road infrastructure frequently disrupts the sustainability of the ecosystem in the environment. A solution for using other materials is needed to minimize the impact of using these natural materials. GBFS (Granulated Blast Furnace Slag) is waste from blast furnace combustion of iron and steel material in granular form, which characteristically can be used as a substitute for medium aggregate asphalt mixture material. The study was conducted by several testing, such as GBFS material testing, AC-WC asphalt mixture characteristic test using Absolute Density Method, and performance testing on AC-WC asphalt mixtures, based on its structural performance and dunctional performance with the percentage of GBFS as medium aggregate variation at 0%, 50%, 75%, and 100%. The study results show that the utilization of the percentage of GBFS as a medium aggregate substitution by 75% improves functional performance and structural performance of AC-WC asphalt mixture.

***Keyword:*** *GBFS, Asphalt Mixture, AC-WC, Medium Aggregate.*

## I. INTRODUCTION

The escalation in traffic growth along with increase in traffic growth causes the need for road infrastructure also increase. This also causes an increase in the need for material such as aggregates which are usually obtained from the environment. This activity grows massively which often can disrupt the environment sustainability.

Medium aggregate (screen) in the asphalt mixture is a type of coarse aggregate that functions as a gradation and size variation of aggregate with a size smaller than coarse aggregate, but larger than fine aggregate (sustained on a 4,80 mm sieve). The use of this type of coarse aggregate has a fairly large percentage in the AC-WC asphalt mixture.

Granulated Blast Furnace Slag or GBFS is waste from blast furnace combustion of iron and steel material in granular form, which is categorized as slag. In Indonesia, this waste is non-renewable waste which has actually started to be used in powder form named Ground Granulated Blast Furnace Slag or GGBFS. According to Government Regulation (PP) No. 101 of 2014 issued by the Minister of Environment and Forestry (No . P.10 MENLHK/S ETJEN/PLB.3/4/2020), GBFS is classified as waste that is hazardous to the environment, so if it is to be used in a construction, it must be processed first so that it does not harm the environment. Therefore, this material was rarely used in Indonesia.

**Figure 1.** GBFS material

## II. LITERATURE REVIEW

The use of slag-like materials in asphalt mixtures as a substitute for aggregate or filler has been implemented in several previous studies and has also been used in road infrastructure construction in several countries. According to Australian Slag Association in "*A Guide to the Use of Steel Furnace Slag in Asphalt and Thin Bituminous Surfacings* (1990)*"* explained that the use of slag in asphalt mixture has been used as filler and aggregate in Australian road construction.

Research on the use of GBFS material which is similar to slag in asphalt mixtures has been carried out several times. Hanin Mohd Rusli et.al (2012), based on research on the use of slag material in the AC-WC asphalt mixture explained, the use of slag material as a substitute for coarse aggregate increases stability, flow, and maintains the flexible properties of the asphalt mixture. Kavyashree L Magadi et. al (2014), namely research on the use of steel slag material as a substitute for coarse aggregate in the hot mix asphalt mixture. The research was conducted using a variation of coarse aggregate substitution with steel slag measuring 40 mm down, 20 mm down and 12.5 mm down. The result of this research is that asphalt mixture with steel slag substitution varied by 12.5 mm increases the mechanical properties and characteristics of the asphalt mixture.

Chris Maharaj et. al (2017), also stated that the use of slag material as coarse aggregate substitution with percentage limit at 15 % on asphaltic pavement (Steel Slag Asphalt) shows better characteristic result. The latest research on the use of various materials such as slag is then summarized by Hitesh Kumar and Sudhir Varma (2020). The results of the study explain that the use of various types of slag material has an influence on the mechanistic properties and performance of the asphalt mixture. Thus, for each type of slag material to be used in the asphalt mixture, the properties and chemical content must be tested.

In Indonesia, the use of this waste material was not commonly used. Thus, based on a review of previous research, this study aims to introduce the effect of using GBFS materials in the outlook of referencing the use of waste in road infrastructure construction in Indonesia.

## III. METHODOLOGY

This study aims to determine the effect of using GBFS material as medium aggregate substitution on AC-WC asphalt mixture, in terms of its characteristics and performance. The samples used in this study was divided based on the percentage of GBFS contained in the AC-WC asphalt mixture as a medium aggregate substitution, namely 0%, 50%, 75%, and 100%. GBFS material that used in this study comes from PT. Cakra Tunggal Steel (**Figure 1**), with other materials, such as aggregate and asphalt Pertamina pen 60 obtained from Cagak, Subang, West Java. GBFS materials that will be used in this research were tested for its chemical characteristics using XFR method.

The research method applied is compiled into a research flow chart, which is detailed in **Figure 2**. In general, research on AC-WC asphalt mixture specimens using GBFS as a medium aggregate substitution consists of several tests as follows the characteristics test of the AC-WC asphalt mixture with absolute density method, as well as the performance of the AC-WC asphalt mixture test, which consisted of structural performance test and functional performance test of the asphalt mixture.

### 3.1. GBFS and Material Properties Test

Material testing is intended to determine the mechanical properties as well as the properties of the materials that make up the asphalt mixture such as aggregate and asphalt, which refers to the Spesifikasi Bina Marga Divisi 6 (2018). The GBFS material used in the study was also tested for its chemical content and properties to be able to analyze the suitability of using the material on the AC-WC asphalt mixture test object.

### 3.2. *AC-WC Asphalt Mixture Characteristic Test*

Characteristic test carried out in this study using the marshall test method. Asphalt mixture characteristic that are reviewed based on density, stability (kg), flow, VMA (%), VIM (%), VFB (%), marshall residual stability (%), and Optimum Bitument Content (OBC). The test results of each specimen were then analyzed and compared to determine the effect of the percentage of GBFS as medium aggregate substitution on the AC-WC asphalt mixture.

Later, the analysis result determine the GBFS percentage that can be used as the best percentage of GBFS variation as medium aggregate substitution, which will e used later in testing the performance of the AC-WC asphalt mixture. The test method carried out on each sample refers to the Spesifikasi Bina Marga Divisi 6 (2018).

### 3.3. *AC-WC Asphalt Mixture Structural Performance Test*

Structural performance testing aims to test the performance and durability of the AC-WC asphalt mixture in compensating traffic loads during its service life, which is reviewed structurally. Structural performance testing in this study used the Indirect Tensile Strength method to determine the value of the Resilience Modulus ($M_R$), which was tested using the Universal Material Testing Apparatus (UMATTA). $M_R$ is an indication of the value of the strength of the material in each layer of the pavement structure in resisting and compensating for repeated traffic loads that pass over it.

The MR value is obtained from the analysis results of the UMATTA tool during testing, referring to the recoverable strain parameters that occur vertically (recoverable strain #1) and horizontally (recoverable strain #2) on the test object when given a certain load and test temperature. In this study, the test temperature determination of 25ºC and 45ºC was used, which refers to the average road surface temperature or Mean Annual Pavement Temperature (MAPT) in Indonesia. The test object used is the test object with Optimum Bitumen Content (OBC), which was the results of the analysis of the characteristics of the asphalt mixture.

### 3.4. *AC-WC Asphalt Mixture Functional Performance Test*

Functional performance is the ability of the pavement structure to compensate for the traffic flow load and provide optimal function during the service life. In this case, the functionality of the AC-WC asphalt mixture is reviewed based on the function of the asphalt mixture as the main contact area on the pavement structure to vehicles passing on it. Functional performance testing carried out in this study consisted of Deformation Speed Testing using a Wheel Tracking Machine (WTM), Skid Resistance Testing, and Surface Texture Testing for AC-WC Asphalt Mixture with the Sand Patch Method.

The deformation speed test was reviewed based on the elasticity ability of the AC-WC asphalt mixture against vehicle load repetitions, with a certain test temperature. The Wheel Tracking Machine (WTM) directly illustrates the vehicle load (such as a vehicle wheel) with a certain number of passes to test the deformation that may occur in the AC-WC asphalt mixture.

The test temperatures applied in this study were 45ºC and 60ºC, with a mixture of OBC test objects as a result of characteristic test analysis. Parameters that are reviewed from the test results include the depth of deformation that occurs in the test object, referring to the ratio and depth of the rutting and the rate of deformation (mm/min).

The slip resistance test in this study refers to the Standar Nasional Indonesia (SNI) 4427:2008. The slip resistance test was carried out to analyze the roughness of the AC-WC asphalt mixture. The roughness value affects the friction force generated between the road surface and the rider's tires, which will affect the functional quality and comfort of the rider on a road segment. The slip resistance of the AC-WC asphalt mixture was tested using British Pendulum Tools (BPT), with the test results interpreted as British Pendulum Number (BPN). The test object used for the slip resistance test is the same as that used in the deformation velocity test. The test results were then analyzed by comparing the effect of using GBFS as a substitute for medium aggregate in the AC-WC asphalt mixture with the normal AC-WC asphalt mixture (GBFS MA 0%) on the slip resistance of the AC-WC asphalt mixture.

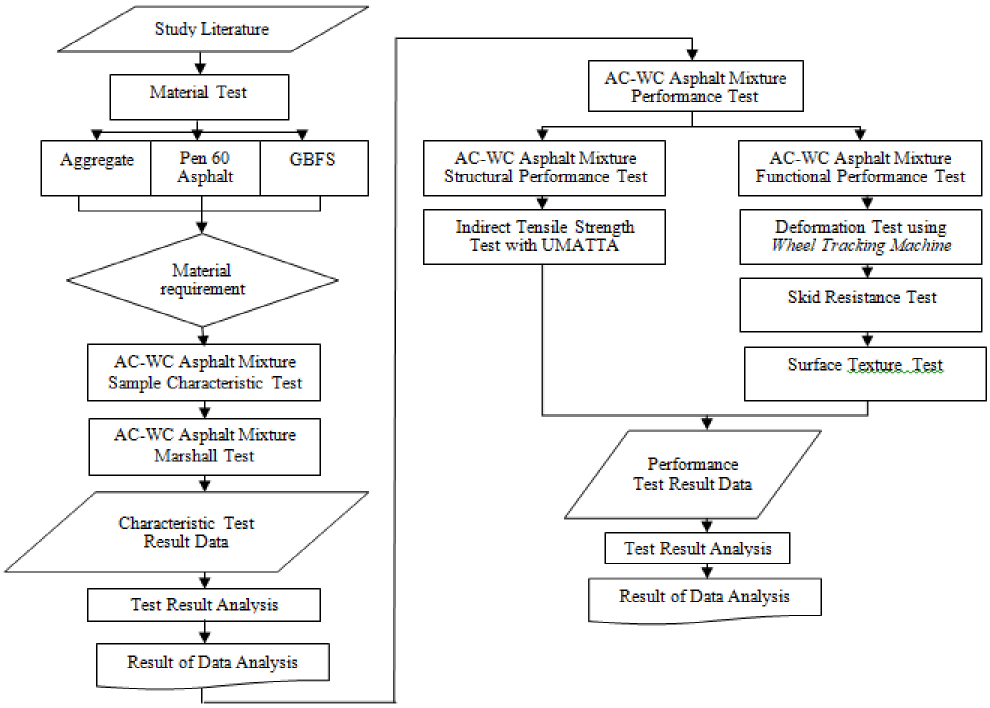


**Figure 2.** Study Method

Surface texture of the AC-WC asphalt mixture, then carried out using the Sand Patch Method, which is intended to determine the depth of texture in an asphalt mixture. Testing refers to the Road Research Laboratory (1969). The results of the next test are interpreted in the form of Mean Texture Depth (MTD), which is analyzed by comparing the effect of using GBFS as a medium aggregate substitution on the AC-WC asphalt mixture with the normal AC-WC asphalt mixture (GBFS MA 0%) on the surface texture depth. AC-WC asphalt mixture.

## IV. RESULT AND DISCUSSION

The The test results on the characteristics of the GBFS material, the characteristics of the AC-WC asphalt mixture, the functional performance of the AC-WC asphalt mixture, as well as the results of the structural performance testing of the AC-WC asphalt mixture that have been carried out in the study are listed in **Table 4.1** to **Table 4.5** below.

### 4.1. GBFS Material Chemical Content and Characteristic Test Result

The test results of the GBFS material chemical content in **Table 1** shows several lists of chemical content. Although there are many variations in chemical content that may affect the reaction in the asphalt mixture, according to Liu Wenhan, Li Hui, Zhu Huimei, and Xu Pinjing (2019), the chemical content that dominates the slag-like material does not have an effect on the chemical reaction in the asphalt mixture, in addition to slightly increasing the brittleness.

Therefore, the chemical content of the GBFS material used in this study is dominated by chemical content such as Iron (Fe) at 27,6%, Calcium (Ca) at 34,1%, Magnesium (Mg) at 13,3%, and Silica (Si) at 11,5%, relatively no effect on the AC-WC asphalt mixture. Based on the results of testing the chemical content of the GBFS material with the XRF method listed in Table 1, the chemical content of sulfur (S) is 0.,88%. Based on the Indonesian National Standard (SNI) Pd T 04-2005 B, slag or slag-like material can be used in asphalt mixtures with a maximum Sulfur (S) content of 2.5%. In other words, the tested GBFS material can be used. In **Table 2**, the results of testing the GBFS material properties have met the requirements of SNI Pd T 04-2005 B, which can be used further in the manufacture of asphalt mixture test specimens.

**Table 1.** GBFS Chemical Content Test Result

| Parameter | Test Result | Test Method |
|---|---|---|
| 1. Magnesium (Mg) (%) | 13.3 | XRF |
| 2. Aluminium (Al) (%) | 4.80 | |
| 3. Silica (Si) (%) | 11.5 | |
| 4. Phosphor (P) (%) | 0.173 | |
| 5. Sulfur (S) (%) | 0.688 | |
| 6. Chloride (Cl) (%) | 0.230 | |
| 7. Potassium (K) (%) | 0.292 | |
| 8. Calsium (Ca) (%) | 34.1 | |
| 9. Titanium (Ti) (%) | 0.478 | |
| 10. Chromium (Cr) (%) | 0.447 | |
| 11. Manganese (Mn) (%) | 2.81 | |
| 12. Ferro (Fe) (%) | 27.6 | |
| 13. Cuprum (Cu) (%) | 0.0998 | |
| 14. Zinc (Zn) (%) | 3.08 | |
| 15. Strontium (Sr) (%) | 0.131 | |
| 16. Zirconium (Zr) (%) | 0.0356 | |
| 17. Lead (Pb) (%) | 0.153 | |

**Table 2.** GBFS Properties Test Results

| No | Parameter | Test Methods | Requirement | Results | Explanation |
|---|---|---|---|---|---|
| 1. | Specific Gravity | SNI 03-1970-2008 | Min 2,5 | 2,77 | **Occupied** |
| 2. | Absorpsion | SNI 03-1970-2008 | Max 3% | 2,1% | **Occupied** |
| 3. | Abration (500 cycle) | SNI 03-2417-2008 | Max 40% | 29,6% | **Occupied** |
| 4. | Adhesion To Bitument | SNI 03-2439-2011 | Min 95% | 97% | **Occupied** |
| 5. | Organic Lumps | SNI 03-4141-1996 | Max 1% | 0,5% | **Occupied** |
| 6. | Material *Soundness* (Natrium Sulfat) | SNI 3407-2008 | Max 12% | 2,9% | **Occupied** |

**Table 3.** AC-WC Characteristic Test Result

| No. | Characteristic Parameter | Asphalt Mixture Sample | | | | Requirement | |
|---|---|---|---|---|---|---|---|
| | | AC-WC GBFS 0% | AC-WC GBFS 50% | AC-WC GBFS 75% | AC-WC GBFS 100% | Min | Max |
| 1. | Optimum Bitument Content, (%) | 5,875 | 5,875 | 5,875 | 6,25 | - | - |
| 2. | Density, (ton/m$^3$) | 2,369 | 2,369 | 2,369 | 2,369 | - | - |
| 3. | VMA (%) | 15,8 | 15,8 | 15,8 | 15,8 | 15 | - |
| 4. | VIM-Marshall (%) | 3,60 | 3,73 | 3,73 | 3,20 | 3 | **5** |
| | VIM-PRD (%) | 2,25 | 2,36 | 2,36 | 1,80 | 2 | - |
| 5. | VFB (%) | 76,50 | 75,70 | 75,70 | 79,78 | 65 | - |
| 6. | Stability, (kg) | 1152 | 1158 | 1158 | 1104 | 800 | - |
| 7. | Flow, (mm) | 3,68 | 3,63 | 3,63 | 3,96 | 2 | 4 |
| 8. | Refusal Stability (%) | 91,3 | 93,8 | 93,9 | 87,0 | 90 | - |

**Table 4.** AC-WC Structural Performance Test Results

| Parameter | Testing Temperature | | | |
|---|---|---|---|---|
| | **25ºC** | | **45ºC** | |
| | AC-WC GBFS 0% | AC-WC GBFS 50% | AC-WC GBFS 75% | AC-WC GBFS 100% |
| Modulus resilien (Mpa) | 1700,5 | 1741 | 176 | 185 |
| Total Recoverable Horizontal Deformation | 11,955 | 12,43 | 74,675 | 65,88 |
| *Peek Loading Force* (N) | 1979 | 2024 | 1286 | 1316,5 |
| *Recoverable Deformation* (Horizontal) #1 | 4,585 | 6,255 | 38,13 | 41,11 |
| *Recoverable Deformation* Horizontal #2 | 7,27 | 6,175 | 35,65 | 34,77 |
| *Seatling Force* (N) | 198,5 | 198 | 128,5 | 131 |

**Table 5.** AC-WC Functional Performance Test Results

| No | Tests | Parameter | GBFS Percentage in AC-WC Asphalt Mixture (%) | |
|---|---|---|---|---|
| | | | **GBFS 0%** | **GBFS 75%** |
| **1.** | Deformation Test using *Wheel Tracking Machine* Test | Deformation | 0,083 (45ºC) | 0,011 (45ºC) |
| | | (mm/minute) | 0,053 (60ºC) | 0,034 (60ºC) |
| | | Dinamic Stability | 5040, 0 (45ºC) | 3818,2 (45ºC) |
| | | (rate/minute) | 787,5 (60ºC) | 1247,5 (60ºC) |
| **2.** | Skid Resistance Test | *BPN* Value | 66,4 | 66,2 |
| **3.** | Surface Texture Test | *Mean Texture Depth* (in 10 times test) | 1,103 | 1,106 |

### 4.2. AC-WC Asphalt Mixture Characteristic Test Result

The test result of asphalt mixture characteristics are listed in **Table 3**. Based on the test results, it was found that the use of GBFS material as a substitute for medium aggregate with a percentage of 75% has characteristics in the form of mechanistic properties that are superior to other variations of test objects, which increase stability (1158 kg) and residual stability (93,9%), at the. Optimum Bitumen Content (OBC) which is relatively the same as the variation of other test objects (5,875%). Meanwhile, the use of GBFS as a substitute for medium aggregate by 100% increases the need for OBC, and reduces the residual stability value to 87%. This shows that substitution of medium aggregate overall with GBFS material is not recommended because it does not meet the requirements of the General Specifications of Highways Division 6 2018 (residual stability value of at least 90%).

### 4.3. AC-WC Asphalt Mixture Structural Performance Test Result

The results of the structural performance test on the variation of the percentage of GBFS utilization as a substitute for the medium aggregate using the Indirect Tensile Strength method with the UMATTA tool are listed in **Table 4**. The test results show that there is an increase in the $M_R$ value in the AC-WC GBFS asphalt mixture 75% at a test temperature of 25°C by 2,32%, and 4,86% at the test temperature of 45°C. This shows that the use of GBFS as a substitute for medium aggregate by 75% can increase the durability of the AC-WC asphalt mixture layer in compensating for the repetition of vehicle loads during its service life. Based on the value of the horizontal return strain (recoverable strain #1), there was an increase of 15,06% at 25°C, and 3,3% at 45°C, which indicates that the use of GBFS as a medium aggregate substitution can increase the resistance to horizontal deformation in the mixture. paved.

The results of the test on recoverable strain #2 showed a decrease of 15,06% at 25°C, and 3,3% at 45°C. This is also due to the original nature of the GBFS material, which is like cement, causing the AC-WC asphalt mixture to become more rigid (brittle). The stiffer AC-WC asphalt mixture results in a decrease in the resistance of the asphalt mixture to vertical deformation. The results of the analysis of the structural performance test are then compiled in the form of a barchart, which is shown in **Figure 3** below.

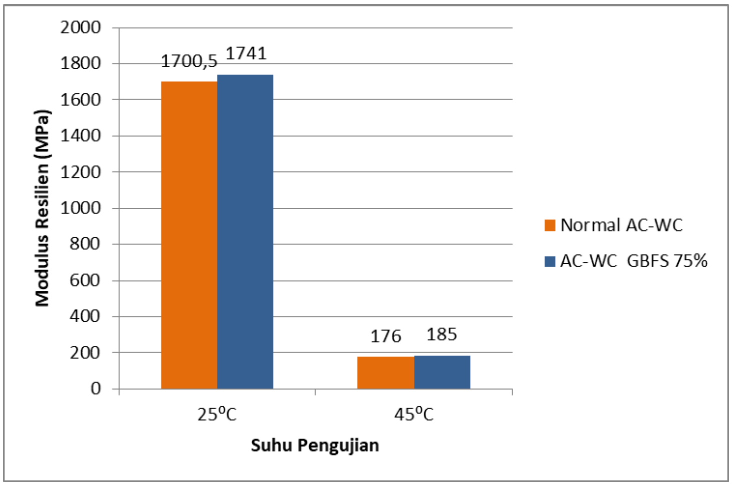


**Figure 3.** $M_R$ Value of AC-WC Asphalt Mixture Test Result

### 4.4. AC-WC Asphalt Mixture Functional Performance Test Result

The functional performance test of the AC-WC asphalt mixture then used OBC asphalt mixture with GBFS percentage as a substitute for medium aggregate which was superior in terms of characteristics (AC-WC GBFS 75%). Based on the data from the functional performance test results in **Table 5**. AC-WC with the percentage of GBFS as an aggregate substitution with a percentage of 75% increased the functional performance of the asphalt mixture. The results of the deformation speed test show that there is a decrease in deformation that occurs at a temperature of 45°C by 86,74% and 60°C by 35,84% when compared to the normal AC-WC asphalt mixture (GBFS 0%). This shows that the use of GBFS in the AC-WC asphalt mixture can increase the resistance to deformation. This can happen because GBFS has a low level of abrasion and is more resistant to heat, so it can better prevent deformation due to repetitive traffic loads. As for the dynamic stability at 45°C, there was a decrease of 24,24% in AC-WC GBFS 75% when compared to the normal AC-WC asphalt mixture, but increased at the test temperature of 60°C by 36,87%. This is due to the nature of the GBFS material which is like cement, causing the AC-WC asphalt mixture to be more brittle than the normal AC-WC asphalt mixture. The results of the deformation speed test are then recapitulated in the form of a graph shown in **Figure 4** below.

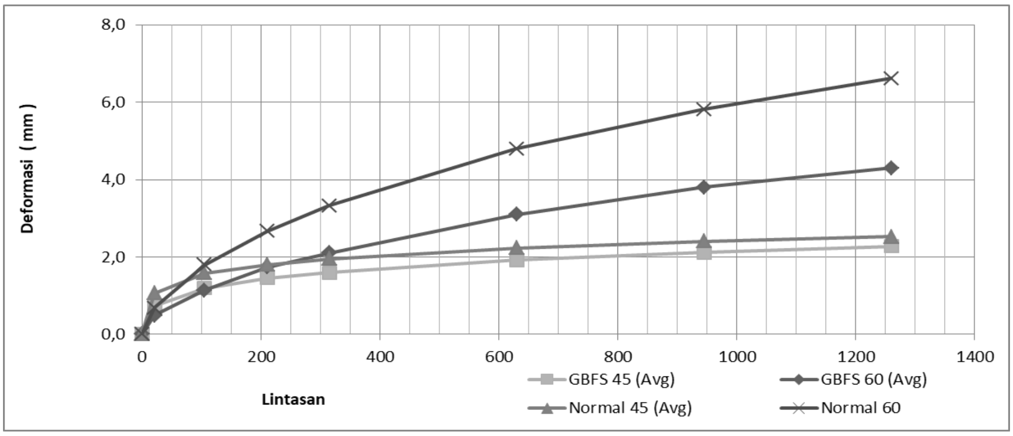


**Figure 4.** AC-WC Asphalt Mixture Deformation Test Result Recapitulation on Graphic

## V. CONCLUSION AND RECOMENDATION

The conclusion to the test result in the research that has been carried out are obtained:

- The GBFS material used in this study has chemical properties and properties that meet the AC-WC asphalt mixture standard for road infrastructure construction. Utilization of GBFS material in AC-WC asphalt mixture as a medium aggregate substitution with a percentage of 75% produces good AC-WC asphalt mixture characteristics, in terms of mechanistic properties in the form of increasing stability, as well as residual stability value so that the resulting asphalt mixture is more resistant to water.
- In terms of a review of the results of structural performance testing, the use of GBFS with a percentage of 75% as a substitute for medium aggregate in the AC-WC asphalt mixture can increase the $M_R$ value of the asphalt mixture, as well as the resistance to horizontal deformation, so that the resulting AC-WC asphalt mixture can compensate and withstand repetitive loads. caused by traffic.
- Furthermore, in terms of functional performance, it was found that the use of GBFS as a substitute for medium aggregate in the AC-WC asphalt mixture can increase the asphalt's ability to withstand the rate of deformation of the asphalt mixture and has good slip resistance and surface texture and meets the standards.
- The results of various tests and analyzes that have been carried out in research show that the use of GBFS can be a reference in the utilization of non-renewable waste materials in AC-WC asphalt mixtures for road infrastructure construction, as well as a reference in improving the quality of AC-WC asphalt mixtures in Indonesia in future.

Based on this research, it is recommended that further research in the form of:

- Further testing is needed on the effect of using different types of asphalt in asphalt mixtures with the use of GBFS as a substitute for medium aggregate in its effect on increasing mechanistic properties, structural performance, and functional performance of AC-WC asphalt mixtures.

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