# MARSHALL TEST CHARACTERISTICS OF AC-BC MIXTURE TO DETERMINATION OF OPTIMUM ASPHALT CONTENT AND MARSHALL IMMERSION INDEX USING PORTLAND COMPOSITE CEMENT AS FILLER

Parea R. Rangan[1] and M. Tumpu[2]
[1]Department of Civil Engineering, University of Christian Indonesia, Toraja, Indonesia
[2]Department of Civil Engineering, Fajar University, Makassar, Indonesia
E-Mail: pareausanrangan68@gmail.com

## ABSTRACT

Currently, the construction of road transportation facilities in Indonesia for pavement was still dominated by the used of asphalt. The most widely used type of asphalt for road pavement was asphalt derived from petroleum distillation, which was then known as petroleum bitumen. Today there were many power plants that use coal as fuel. The by-product of burning coal was fly ash, which is classified as a pollutant material. Marshall characteristic test is one of the tests carried out to test the strength and void characteristics produced by asphalt mixtures, including asphalt concrete binder course (AC-BC) mixtures. Marshall characteristics can also be used to determine the optimum asphalt content and Marshall immersion index of asphalt mixtures. This study aims to determine the optimum asphalt content and Marshall immersion index of the AC-BC mixture using portland composite cement as filler. The gradation of the AC-BC mixture as were 50.00% of coarse aggregate, 45.15% of fine aggregate and 5.85% of filler. AC-BC mixture were produced using petroleum bitumen of 60/70 grade penetration at variations in asphalt content of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0% by estimated asphalt content. The results showed that the optimum asphalt content of the AC-BC mixture was 5.5% with Void in Mix (VIM) value of 4.35%, Void Filled Bitumen (VFB) of 71.84%, Void in Mineral Aggregate (VMA) of 14.84%, stability of 812.04 kg, flow of 3.17 mm and Marshall Quetiont of 255.81kg/mm, respectively. The value of residual strength (immersion index) for 24 hours from the results of the Marshall Immersion test was 96.21% for AC-BC mixture.

**Keywords:** marshall test characteristics, AC-BC mixture, optimum asphalt content, marshall immersion index, PCC.

## 1. INTRODUCTION

Transportation facilities and infrastructure are very important components in supporting the accessibility of development, with the presence of durable and adequate road materials that will speed up the development process; asphalt is an adhesive material for road pavements which is an important component in the construction of new roads and rehabilitation of existing roads [1-4].

In Indonesia, to reducing of fly ash waste, a number of cement factories mixing of fly ash and waste containing pozzolans with portland cement clinker to produce Composite Portland Cement (SNI 15-7064-2004) with the aim of reduced energy consumption and reduced the use of non-renewable natural resources [5,6]. Portland Composite Cement can be categorized as CEM II according to the European standard EN 197-1:2000, in Indonesia it was only produced in 2005, but in Europe the market share of cement for the CEM II category has been more than 50%, larger than Type 1 Portland Cement which is only around 35% [7, 8].

The problem faced by the government regarding road construction at this time was that the design age was not achieved, so that further research was needed on the quality of asphalt pavement, the research that can be done included using portland composite cement as a filler on asphalt pavement, the reason for using Portland composite cement as a filler because environmentally friendly and recyclable materials, reduced noise and alternative solutions in reducing existing fly ash waste [9].

Stress conditions that occured due to wheel loads on the pavement layer can be tested in the laboratory but with many factors that can be simplified. In actual or in-situ conditions, the load can be applied in three dimensions. A number of tested have been simplified to test certain aspects in-situ behavior. The tested were divided into three groups. The first group of tested was the basic triaxial repeated load test, the unconfined static uniaxial creep compression test, the repeated load indirect tensile test, the dynamic stiffness and fatigue test. The second group of tested was a simulation test in the laboratory (simulative): Wheel-tracking test and the third test group is empirical testing with Marshall test [10-13].

In the implementation of road construction, it will not be separated from the influence of field conditions which sometimes make it impossible or have difficulty carried out work implementation procedures in accordance with specifications or implementation guidelines [14, 15]. For example, for compaction of hot asphalt mixtures on incline areas it often fails and the asphalt mixture rolls or the asphalt surface layer is uneven or bleeding. In addition to incline compaction areas will also experience difficulties on the outskirts of the road body where there are cliffs or road bodies resulting from soil piles. This is due to the risk of overturning the compactor so the compaction results are less than optimal [16-18].

Marshall characteristic test is one of the tests carried out to test the strength and void characteristics produced by asphalt mixtures, including asphalt concrete binder course (AC-BC) mixtures. Marshall Characteristics can also be used to determine the optimum asphalt content and Marshall immersion index of asphalt mixtures. This study aims to determine the optimum asphalt content and Marshall Immersion index of the AC-BC mixture using portland composite cement as filler.

## 2. MATERIAL AND METHOD

### 2.1 Experimental Program Test

As scientific research, research must be carried out in a clear and orderly systematic or work order. The implementation of this research was divided into the following stages:

**1. Stage 1**

Stage I was the preparatory stage. At this stage all the materials and equipment that will be used in the research are prepared in advance so that the research to be carried out can run smoothly.

**2. Stage 2**

Stage II was the stage of testing the characteristics of the material. At this stage, research was carried out on coarse aggregate and fine aggregate. This is done to determine the physical properties and characteristics of the material to be used, as well as to determine whether the aggregate meets the requirements or not. The results of this test will be used as planning data.

**3. Stage 3**

Stage III was the stage of making the test object. At this stage an analysis of the design of the AC-BC mixture was carried out, after obtaining the proportion of the material to be used in the asphalt mixture, the test object was made followed by testing. After getting the results of the asphalt mixture, if it does not meet the specifications, we return to planning the asphalt mixture then repeat the procedure for maked test specimens and Marshall testing, and if it meets the specifications, the results of asphalt concrete testing will be obtained to calculated the void of asphalt mixture, there are VIM (Void in Mix), VMA (Void in Mineral Aggregate) and VFB (Void Filled Bitumen).

**4. Stage 4**

Stage IV was the data analysis stage. At this stage the data obtained from the test results were analyzed to obtain the value of the Marshall characteristics of the AC-BC mixture, then by determined the optimum asphalt content and the Marshall immersion value of the AC-BC mixture.

**5. Stage 5**

Stage V was the stage of drawing concluding remarks. At this stage, the AC-BC mixed data that had been analyzed in the previous stage was then made concluding remarks and suggestion related to the research objectives.

### 2.2 Physical Characteristics of Aggregate Testing Method

Aggregate is a hard and rigid material used as a mixed material in the form of various types of granules or fractions including aggregate ash (dust). Aggregate in the pavement mixture was generally the main component which contains 90-95% aggregate by weight percentage (%) or 75-85% aggregate based on percentage (%) volume. Thus, aggregate was the main material that also supported the load received by the pavement where asphalt binder was used which was strongly influenced by the quality of the aggregate. Physical characteristics of aggregate testing method is shown in Table-1.

**Table-1.** Physical characteristics of aggregate testing method.

| No | Testing type | Testing method |
|---|---|---|
| 1 | Bulk specific gravity | SNI 1969 : 2016 |
| 2 | Saturated surface dry specific gravity | SNI 1969 : 2016 |
| 3 | Apparent specific gravity | SNI 1969 : 2016 |
| 4 | Water absorption | SNI 1969 : 2016 |
| 5 | Abrasion with los Angeles machine | SNI 2417 : 2008 |
| 6 | Impact test | SNI 03-4426-1997 |
| 7 | Sludge content | SNI 03-4428-1997 |
| 8 | Flatness index | ASTM D-4791 :10 |
| | Elongation index | |
| | Flatness and elongation index | |

### 2.3 Physical Characteristics of Petroleum Bitumen Testing Method

Testing the characteristics of petroleum bitumen was carried out to determine the suitability of petroleum bitumen used as a binder in asphalt mixtures. Table-2 shows the method of testing the characteristics of petroleum bitumen based on the Indonesian National Standard (SNI).

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**Table-2.** Physical characteristics of petroleum bitumem testing method.

| No | Testing type | Testing method |
|---|---|---|
| 1 | Penetration, 25°C; 100 grams; 5 seconds; 0.1 mm | SNI 06-2456-1991 |
| 2 | Softening Point, (°c); | SNI 06-2434-1991 |
| 3 | Flash Point, (°c); | SNI 06-2433-1991 |
| 4 | Ductility, 25°C | SNI 06-2432-1991 |
| 5 | Specific gravity | SNI 06-2441-1991 |
| 6 | Solubility in Trichlor Ethylen, % weight | RSNI M-04-2004 |
| 7 | Weight loss, % weight | SNI 06-2440-1991 |
| 8 | Penetration after weight loss, % original | SNI 06-2456-1991 |
| 9 | Ductility after weight loss, cm | SNI 06-2432-1991 |

**2.4 Combined Aggregate Using BinaMarga Requirement, Indonesia**

The composition design of AC-BC mixture used was hot mix asphalt consisted of aggregate components which were the largest component in the mixture. The composition of the AC-BC mixture was used to determine the right amount of asphalt usage so that it can produce a good composition.

The composition of the mixture was based on the gradation of the selected aggregate mixture, namely the ideal gradation or used the middle value of the gradation range. The composition of the mixture was divided into three fractions, namely coarse aggregate fraction, fine aggregate fraction and filler fraction. Where the size of the fraction was based on the general specifications of BinaMarga in 2018 as shown in Table-3.

**Table-3.** Planned mix composition design by BinaMarga Requirement, Indonesia.

| Sieve number | Sieve size (mm) | % Weight pass by total aggregate in mixture | |
|---|---|---|---|
| | | Asphalt concrete(AC) | |
| | | Coarse gradation | |
| | | BC | Mixture gradation (BC) |
| 1½ | 37.50 | | |
| 1 | 25.00 | 100 | 100 |
| ¾ | 19.00 | 90 - 100 | 95 |
| ½ | 12.50 | 75 - 90 | 82.5 |
| 3/8 | 9.50 | 66 - 82 | 74 |
| No. 4 | 4.75 | 46 - 64 | 55 |
| No. 8 | 2.36 | 30 - 49 | 39.5 |
| No. 16 | 1.18 | 18 - 38 | 28 |
| No. 30 | 0.60 | 12 - 28 | 20 |
| No. 50 | 0.30 | 7 - 20 | 13.5 |
| No. 100 | 0.15 | 5 - 13 | 9 |
| No. 200 | 0.075 | 4 - 8 | 6 |

After all the required materials have passed the test, the next step was the number of test objects and the preparation of the mixed materials accorded to the mix design obtained.

**2.5 Determination of Optimum Asphalt Content**

The test object that has passed the conventional Marshall test was then calculated to determine the Optimum Asphalt Content. The data that has been obtained was processed based on Marshall Method, so that the resulted of stability, flow, density, and compacted aggregate density will be obtained. The optimum asphalt content was obtained from the highest average value of the graph of the stability relationship, the density of the compacted mixture with the asphalt content. Practical asphalt content in asphalt concrete mixtures was asphalt content that meets all the characteristics Marshall. Figure-1 shows the conventional Marshall test equipment.

**Figure-1.** Conventional Marshall test equipment.

However, to cope with fluctuations (increased or decreased) in the actual asphalt content in the asphalt mixture production process, it is necessary to determine the Optimum Asphalt Content, namely asphalt content with stability, flow, VIM, VMA, VFB and MQ that meet the BinaMarga requirement, Indonesia. According to the function from the type of intermediate layer mixture, the asphalt content with high stability and low flow was chosen as the Optimum Asphalt Content.

### 2.6 Marshall Test Immersion of AC-BC Mixture

Marshall Immersion test referred to SNI 06-2489-1991 [19]. This test aims to determine the ability of the mixture to immersed time, temperature, and water. The testing procedure was the same as the standard Marshall test procedure for hot mix mixtures, only the difference lied in the immersion time, namely in Marshall Immersion the immersion time was 24 hours at a temperature of 60°C. The result of this test was the stability ratio. This ratio compared the stability of Marshall specimens after immersion in a temperature of 60°C in a water bath for 24 hours to the stability of Marshall specimens by immersion for 30 minutes which is commonly called the Immersion Index (IP) or Residual Strength Index (IKS).

$$IP=\frac{Marshall\ stability\ Immersion}{Marshall\ stability\ standard} \quad (1)$$

$$IKS=\frac{S_2}{S_1}\times 100 \quad (2)$$

Where:

S1 = the average value of Marshall stability after immersion forT1 minute (kg)

S2 = the average value of Marshall stability after immersion for T2 minute (kg).

IKS = Residual Strength Index (%)

## 3. RESULTS AND DISCUSSIONS

### 3.1 Physical properties of Aggregate

Table-4, Table-5 and Table-6 shows the physical properties of coarse aggregate, fine aggregate and filler (Portland Composite Cement). Coarse aggregate and fine aggregate in this research were taken from Mata Alloriver. Coarse aggregate in this research is classified as igneous rock with a hardness level above 95%. Filler in this research was taken from one of the manufacturers of Portland Composite Cement in Indonesia.

**Table-4.** Physical properties of coarse aggregate.

| No | Testing type | Testing results |
|---|---|---|
| 1 | Bulk specific gravity | 2.58 |
| 2 | Saturated surface dry specific gravity | 2.63 |
| 3 | Apparent specific gravity | 2.70 |
| 4 | Water absorption | 1.72 |
| 5 | Abrasion with los Angeles machine | 13.66 |
| 6 | Impact test | 16.60 |
| 7 | Sludge content | 0.65 |
| 8 | Flatness index | 4.64 |
| | Elongation index | 7.79 |
| | Flatness and elongation index | 4.95 |

**Table-5.** Physical properties of fine aggregate.

| No | Testing type | Testing results |
|---|---|---|
| 1 | Bulk specific gravity | 2.66 |
| 2 | Saturated surface dry specific gravity | 2.69 |
| 3 | Apparent specific gravity | 2.75 |
| 4 | Water absorption | 1.21 |
| 5 | Sludge content | 3.30 |

The results of testing the specific gravity of the Portland composite cement as filler in accordance with the test method based on ASTM C136: 2012 [20] was 3.09. From the results of testing in Table-4 and Table-5 the characteristics of the Mata Allo River coarse aggregate and fine aggregate, all test results meet the specifications for coarse aggregate required based on BinaMarga standards, Indonesia.

### 3.2 Physical Properties of Petroleum Bitumen Grade 60/70

Petroleum bitumen grade 60/70 using in this research and the physical properties of petroleum bitumen grade 60/70 as follows in Table-6.

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**Table-6.** Physical properties of petroleum bitumen.

| No | Testing type | Testing results |
|---|---|---|
| 1 | Ductility | 129.33 cm |
| 2 | Specific gravity | 1.03 |
| 3 | Flash point | 290°C |
| 4 | Burning point | 300°C |
| 5 | Softening point | 50.75°C |
| 6 | Weight loss | 0.175% |

### 3.3 Combined Aggregate Gradation

The results of the combined aggregate gradation analysis for the AC-BC mixture which were shown in percent of the combined aggregate pass to the tolerance limits were shown in Figure-2. The gradation of the AC-BC mixture as were 50.00% of coarse aggregate, 45.15% of fine aggregate and 5.85% of filler. From the combined aggregate gradation analysis for the AC-BC mixture above, all meet the combined aggregate gradation specifications to the tolerance limits based on the BinaMarga, requirement 2018.

### 3.4 Optimum Asphalt Content

The optimum asphalt content was the amount of asphalt used in the mixture in order to achieved the requirements for VIM, VFB, VMA, stability, flow value. Determination of the optimum asphalt content from the results of the Marshall characteristics test for the AC-BC mixture at an asphalt content of 5.5% as follows in Figure-3.

Based on Figure-3 it can be seen that:

a) The VIM value meets the requirements for asphalt content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0%.
b) The VFB value meets the requirements for asphalt content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0%
c) The VMA value meets the requirements for asphalt content of 4.9%, 5.5% and 6.0%.
d) Asphalt content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0%, meets the requirements for stability values.
e) Asphalt content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0%, meets the flow value requirements.
f) Asphalt content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0%, meets the requirements of the MQ value.
g) The optimum asphalt content value is 5.5% asphalt content, all meet the requirements of VIM, VFB, VMA, stability, flow.

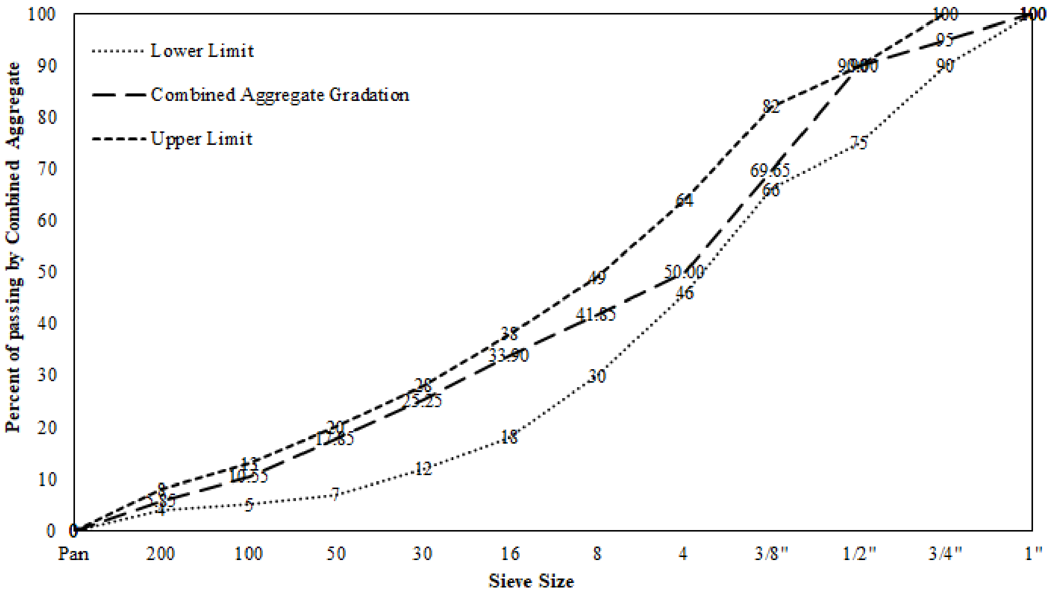


**Figure-2.** Combined aggregate gradation.

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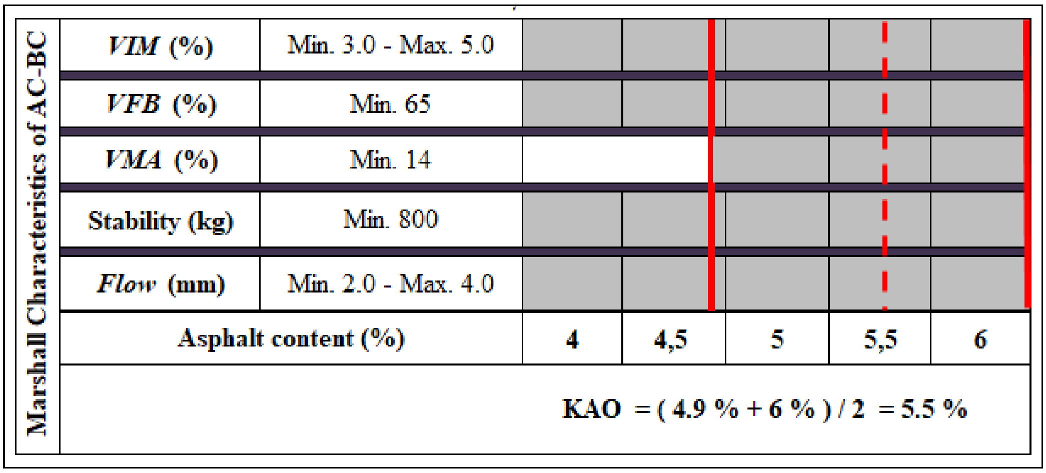


**Figure-3.** Optimum asphalt content.

In addition, based on the relationship between stability and the resulting flow, it can be seen that:

a) At 4% asphalt content, the voids in the mixture were quite small, so that there was less asphalt that fills the voids, and the aggregates were not interlocked so that when they receive heavy loads they are easily deformed, and stability decreases.

b) At 4.5% asphalt content the voids in the mixture were quite small, because in the mixture the fine aggregate fills the voids more so that the asphalt that fills the voids was less and the mixture does not lock each other well, so that when received the load it will deform and decreased stability.

c) At 5% asphalt content, the mixing of fine and coarse aggregates and fillers was more evenly distributed so that the voids in the mixture were reduced, so that the voids with asphalt were reduced and the mixture is stronger, so that when the load is received it was not easy to deform, and stability be normal

d) At the asphalt content of 5.5%, the voids that were filled with asphalt were reduced and the mixture was stronger, the stability becomes strong because the aggregates in the mixture were interlocked so that when they receive heavy loads they were not easily deformed.

e) At 6% asphalt content, the asphalt that fills the void was also less because the voids in the mixture were less. The aggregates in the mixture were interlocked so that when they received heavy loads they were not easily deformed.

### 3.5 Marshall Immersion of AC-BC Mixture

Marshall Immersion was a test to see the durability (resistance to load and temperature effects) or the durability of a mixture, the result of this test was the stability ratio. This ratio was compared to the stability of the Marshall specimen after being immersed in the Marshall for 30 minutes which is commonly called the immersion index (IP) or residual strength index (IKS).

Table-7 shows the test results of Marshall Characteristics AC-BC mixture at $60^{0}$C in a water bath for 30 minutes and 24 hours on the stability of the test object in this research.

**Table-7.** Test results of Marshall Characteristics AC-BC mixture at $60^{0}$C in a water bath for 30 minutes and 24 hours.

| Asphalt content | Immersed time | VIM (%) | VFB (%) | VMA (%) | Stability y (kg) | Flow (mm) |
|---|---|---|---|---|---|---|
| 5.5% | 24 hours | 4.35 | 71.84 | 14.84 | 812.04 | 3,30 |
| | 30 minutes | 4.61 | 69.52 | 15.08 | 844.02 | 3.28 |

In the 30 minutes immersion condition, the VIM value = 4.61% while at the 24 hours immersion, the VIM value = 4.35%, this happens because the 24-hour immersion at a temperature of 60°C softens the asphalt more so that the asphalt easily fills the voids in the mixture and voids were reduced.

In the 30 minutes immersion condition, the VFB value = 69.52%, while in the 24 hours immersion, the VFB value = 71.84%. At 30 minutes of immersion, the VFB value was lower than 24 hours of immersion at 60 °C so that the void filled with asphalt was also higher.

In the 30 minutes immersion condition, the VMA = 15.08%, while in the 24 hours immersion, the VMA = 14.84%. This happens because the voids in the aggregate were reduced, because the asphalt was softer and can cause the voids in the aggregate to absorb more asphalt because the asphalt viscosity was reduced.

In the 30 minutes immersion condition, the stability value = 844.02 kg, while in the 24-hour immersion the stability value = 812.04 kg. Stability decreased because the mixture becomes softer because of water and high temperatures affected asphalt adhesion and asphalt hardness. Thus, the longer immersion conditions at high temperatures will soften and weaken the mixture as the ability to accept loads was lower and the stability value decreased.

In the 30 minutes immersion condition, the flow value = 3.28%, while in the 24 hours immersion, the flow value = 3.30%. In the 24 hours immersion condition, it was greater, so that the mixture underwent a greater change in shape.

The results of laboratory testing of AC-BC mixture at an optimum asphalt content of 5.5%, obtained the average stability test results for the standard Marshall 844.02 kg, and the average stability test results for the Marshall immersion test of 812.04 kg, the immersion index (IP) Marshall immersed AC-BC mixture, namely:

$$IP = \frac{Marshall\ stability\ Immersion}{Marshall\ stability\ standard}$$
$$= \frac{812.04}{844.02} x\ 100\%$$
$$= 96.21\%$$

Table-8 shows the value of the Marshall Immersion Index (IP) test results for AC-BC mixture.

**Table-8.** Marshall Immersion Index (IP).

| Asphalt content (%) | 5.5 |
|---|---|
| Stability Marshall Immersion (kg) | 812.4 |
| Stability Marshall Standard (kg) | 844.02 |
| Immersion Index (IP) (%) | 96.21 |
| Requirement (≥90%) | Fulfill |

The results of the Marshall immersed test obtained an immersed index of 96.21% for the AC-BC mixture with an asphalt content of 5.5%. This immersed index value had met the standards set by the BinaMarga, requirement which was 90%.

From the results of the Marshall immersion test of the AC-BC mixture, it was resistant to temperature and duration of water immersion which was supported by an immersed index value of 96.21% and had meet the standard BinaMarga, requirement, which was a minimum of 90%.

## 4. CONCLUSIONS

a) The optimum asphalt content of the AC-BC mixture was 5.5% with Void in Mix (VIM) value of 4.35%, Void Filled Bitumen (VFB) of 71.84%, Void in Mineral Aggregate (VMA) of 14.84%, stability of 812.04 kg, flow of 3.17 mm and Marshall Quetiont of 255.81kg/mm, respectively.
b) The value of residual strength (immersion index) for 24 hours from the results of the Marshall Immersion test was 96.21% for AC-BC mixture.

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