# [Jurnal Teknologi] Submission Acknowledgement "The Effect of Sea Water Immersion on Asphalt Concrete Modification Buton Asphalt (As-Buton)"

From: Editor-in-Chief (journal_utm@utm.my)

To: gito_98@yahoo.com

Date: Wednesday, 31 March 2021, 02:35 pm GMT+7

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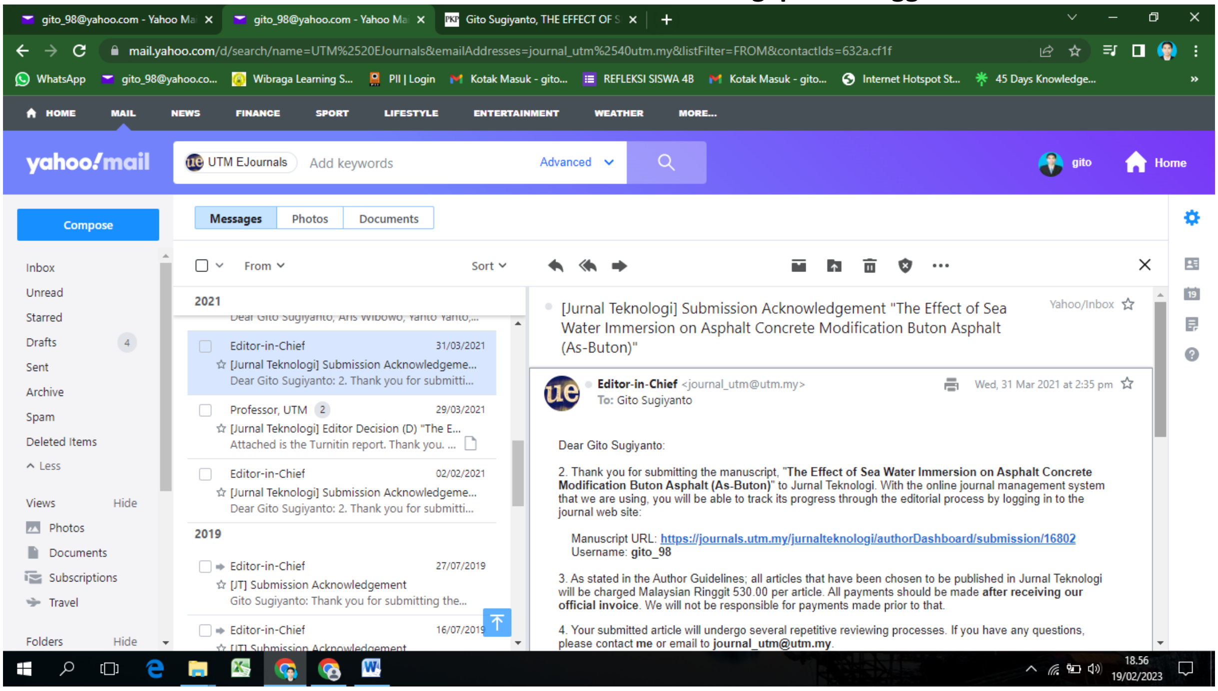


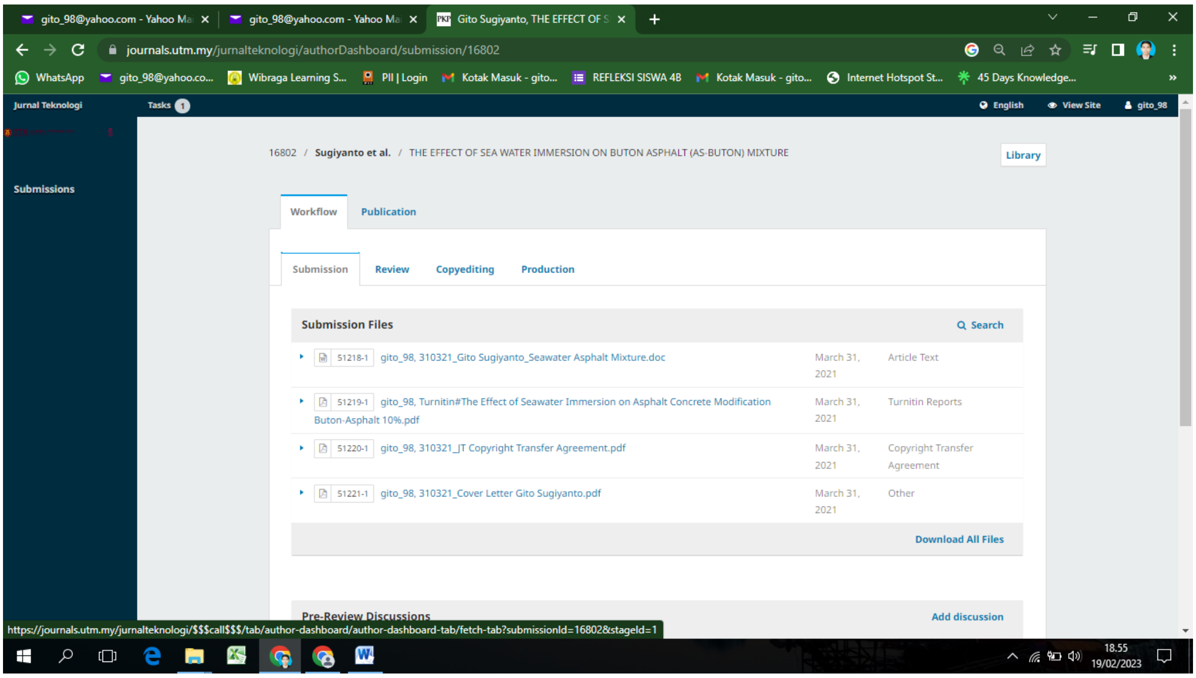


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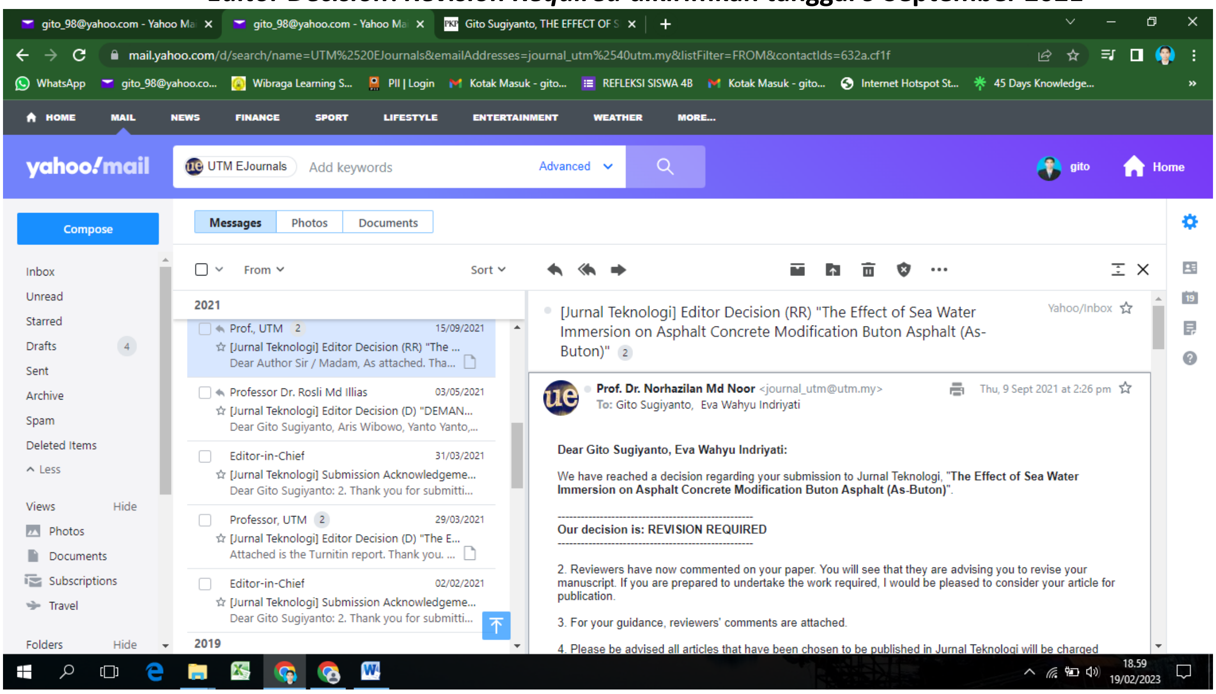

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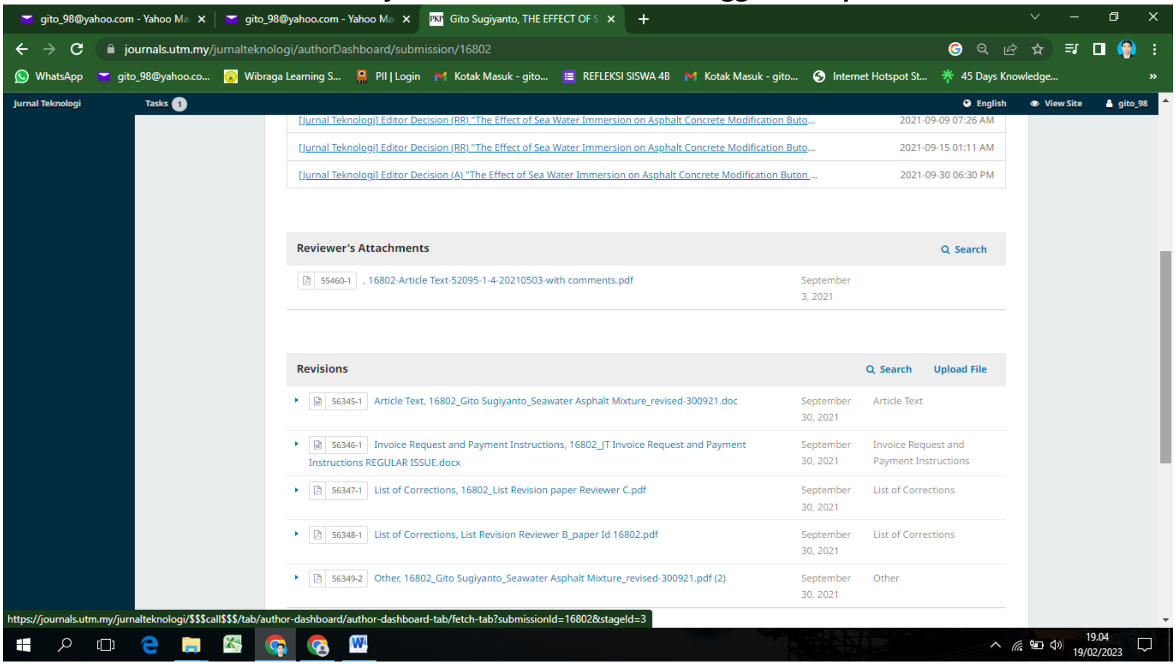


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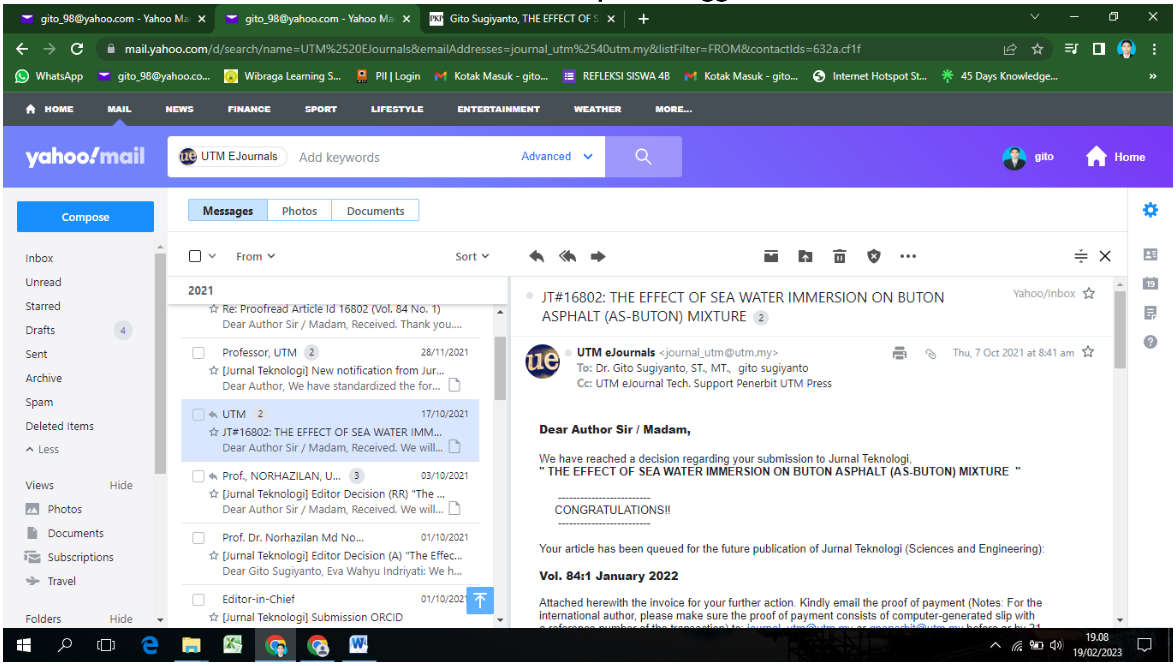


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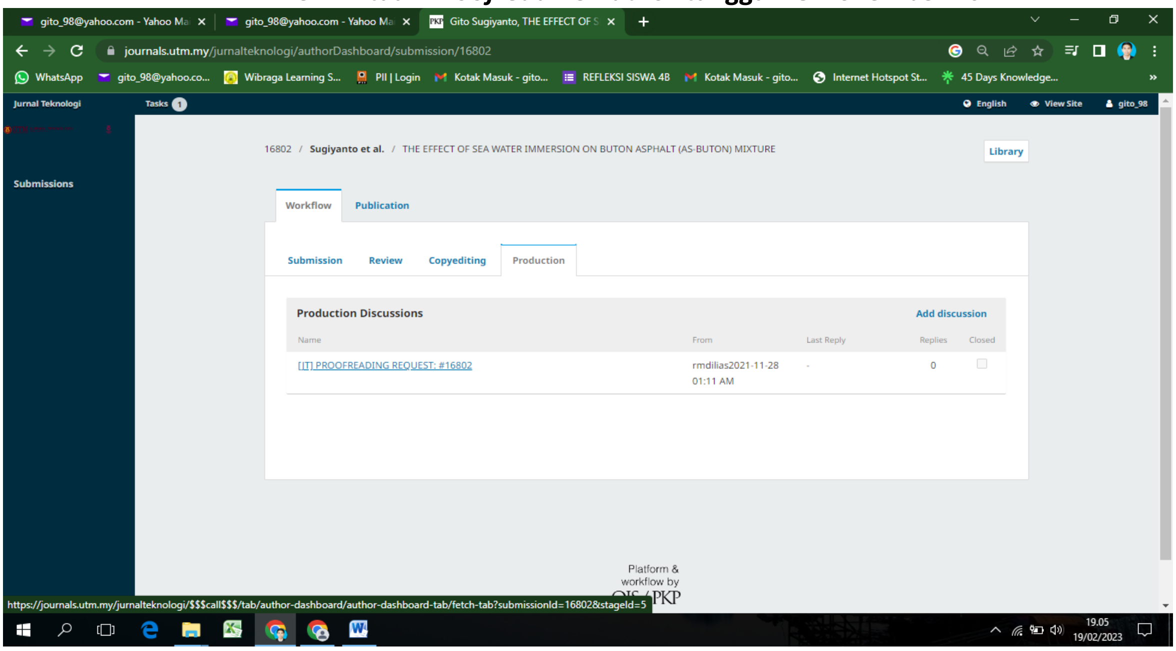


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From: Prof. Dr. Norhazilan Md Noor (journal_utm@utm.my)

To: gito_98@yahoo.com; indriyati.eva@gmail.com

Date: Thursday, 9 September 2021 at 02:26 pm GMT+7

**Dear Gito Sugiyanto, Eva Wahyu Indriyati:**

We have reached a decision regarding your submission to Jurnal Teknologi, "**The Effect of Sea Water Immersion on Asphalt Concrete Modification Buton Asphalt (As-Buton)**".

--------------------------------------------------
**Our decision is: REVISION REQUIRED**
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2. Reviewers have now commented on your paper. You will see that they are advising you to revise your manuscript. If you are prepared to undertake the work required, I would be pleased to consider your article for publication.

3. For your guidance, reviewers' comments are attached.

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b) **List of CORRECTIONS DONE;**
and
c) Filled document "**JT Invoice Request and Payment Instructions REGULAR ISSUE**" to enable us prepare a formal invoice for payment purpose.

We look forward for your favourable reply. Thank you.

Yours sincerely;

**Prof. Dr. Norhazilan Md Noor<br/>Universiti Teknologi Malaysia, Malaysia<br/>norhazilan@utm.my**

**Prof. Dr. Norhazilan Md Noor**
Editor, Jurnal Teknologi
Universiti Teknologi Malaysia, Malaysia
norhazilan@utm.my

------------------------------------------------------
Reviewer B:
Recommendation: Revisions Required

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Referee's comments

The paper has a novelty but its structure is not well organized and need to enhance more. The main test of the paper is only Marshall Stability and novelty of the work is the effect of As-buton to asphalt binder/mixture in the coastal road conditions.
- In the abstract section, it is recommended to take out the last sentence about future works. Hence, include specific comments in line with the results of the current study.
- In the introduction section, it is not mentioned to the why there is a need to evaluate asphalt binder performance with As-buton modifier. It is better to touch on this issue more than general literature

review about the asphalt mixture performance.
- Please include PI calculation results of the samples to the related tables (for all of the samples).
- Final paragraph of the discussion section is not related to the research purposes and is beside the point.

A. EvaluationsPlease evaluate the paper according to the following criteria. Check the item if you agree to the statement:

- The topic is important and relevant for publication
- The work presented in the manuscript is original
- The manuscript uses sufficient references
- The manuscript uses appropriate language and styles
- The title of the manuscript is appropriate
- The abstract adequately summarizes the content of the manuscript
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B. Suggestions to the author(s)What can the author(s) do to improve the quality of this paper?

- In the abstract section, it is recommended to take out the last sentence about future works. Hence, include specific comments in line with the results of the current study.
- In the introduction section, it is not mentioned to the why there is a need to evaluate asphalt binder performance with As-buton modifier. It is better to touch on this issue more than general literature review about the asphalt mixture performance.
- Please include PI calculation results of the samples to the related tables (for all of the samples).
- Final paragraph of the discussion section is not related to the research purposes and is beside the point.

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Reviewer C:
Recommendation: Revisions Required

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Referee's commentsA. EvaluationsPlease evaluate the paper according to the following criteria. Check the item if you agree to the statement:

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- The work presented in the manuscript is original
- The manuscript uses sufficient references
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B. Suggestions to the author(s)What can the author(s) do to improve the quality of this paper?

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# THE EFFECT OF SEA WATER IMMERSION ON ASPHALT CONCRETE MODIFICATION BUTON ASPHALT (AS-BUTON)

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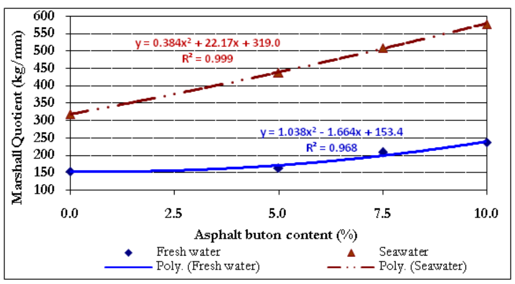
## Graphical abstract




## Abstract

One of the causes of flexible pavement damage is being submerged in water with a high acidity, such as sea water. To overcome this condition, a study on the use of Buton asphalt as a mixture of modified asphalt (as-buton) was conducted. The advantages of Buton asphalt are that it has higher adhesion and more resistant to temperature changes. As-buton modification by mixing Lawele Buton Asphalt Southeast Sulawesi, Indonesia with oil asphalt pen 60/70. This study focuses on determining the effect of the addition of Buton asphalt to the modified asphalt mixture and the effect of sea water immersion on asphalt concrete modification Buton asphalt (as-Buton) based on the Marshall characteristic test. The percentage of Buton asphalt used is 0%, 5%, 7.5%, and 10%. The immersion was carried out in two conditions, namely fresh water immersion and sea water immersion for 24 hours at a temperature of 30°C. The result of this study show that the addition of Buton asphalt increase the value of stability, void in mixture, Marshall quotient, and void in mineral aggregate, but reduce the value of flow, void filled with asphalt, and density. The increase of stability value in sea water immersion due to the addition of buton asphalt was higher than that in fresh water. The stability value of the 10% modified as-buton mixture in fresh water immersion increased by 169.338 kg (14.61%) and in sea water immersion increased by 1261.669 kg (55.65%). The flow value in fresh water immersion decreased by 1.9 mm (25.33%) while in sea water immersion decreased by 1 mm (14.08%). For the next research, variations in the addition of Buton asphalt will be carried out to obtain the optimum buton asphalt content. In addition, variations in the duration and immersion temperature of the modified asphalt mixture will also be carried out.

*Keywords*: Marshall characteristics, asbuton, asphalt concrete wearing course, sea water immersion, asphalt mixture.

## Abstrak

Salah satu penyebab kerusakan perkerasan lentur adalah terendam air dengan tingkat keasaman yang tinggi, seperti air laut. Untuk mengatasi kondisi ini maka dilakukan kajian tentang penggunaan Aspal Buton sebagai campuran aspal modifikasi aspal buton (as-buton). Kelebihan aspal Buton yaitu memiliki daya lekat lebih tinggi dan lebih tahan terhadap perubahan temperatur. Modifikasi as-buton dibuat dengan mencampurkan Aspal Buton Lawele, Sulawesi Tenggara, Indonesia dengan aspal minyak pen 60/70. Penelitian ini fokus pada identifikasi dampak penambahan aspal Buton pada campuran aspal modifikasi dan dampak perendaman air laut berdasarkan hasil uji karakteristik marshall. Persentase penambahan aspal buton yang digunakan yaitu 0%, 5%, 7,5% dan 10%. Perendaman dilakukan pada dua kondisi yaitu rendaman air biasa dan rendaman air laut selama 24 jam pada suhu 30°C. Hasil dari studi adalah penambahan kadar aspal Buton meningkatkan nilai stabilitas, rongga udara, *marshall quotient*, dan rongga agregat tetapi menurunkan nilai flow, rongga terisi aspal, dan kepadatan (*density*). Kenaikan nilai stabilitas pada rendaman air laut akibat penambahan aspal Buton lebih tinggi dibandingkan dengan rendaman pada air biasa. Nilai stabilitas campuran as-buton modifikasi 10% pada rendaman air biasa naik sebesar 169,338 kg (14,61%) dan pada rendaman air laut naik 1261,669 kg (55,65%). Nilai flow pada perendaman air biasa turun sebesar 1,90 mm (25,33%) sedangkan pada perendaman air laut turun 1 mm (14,08%). Untuk riset selanjutnya akan dilakukan variasi penambahan aspal Buton untuk mendapatkan kadar nilai aspal buton optimum. Selain itu juga akan dilakukan variasi terhadap durasi dan suhu perendaman campuran aspal modifikasi.

*Kata kunci*: *Karakteristik marshall, asbuton, laston lapis aus, rendaman air laut, campuran aspal*



## 1.0 INTRODUCTION

One type of road pavement construction is flexible pavement, namely pavement using asphalt as a binding material. Flexible pavement consists of pavement layers that carry and spread traffic loads to the subgrade. Flexible pavement is a composite material consisting of aggregate, asphalt mastic, air void, and filler. It is considered the primary paving type of road, taxiway, and runway, due to their good riding quality, fast construction speed, low noise, excellent durability, and stability [1], recyclability, and easy maintenance [2], [3]. In last decades, Indonesia intended to improve infrastructure by increasing highway network and building the asphalt pavement almost 329,926 km [4]. The Chinese government increasing highway network 130,000 km [5], more than 90% of that is flexible pavement [6]. In the United State of America, flexible pavements represent 95% of total pavement [7].

Asphalt surface layer plays a fundamental role in flexible pavement structure, withstand varying traffic loads and constantly changing environmental conditions. However, under the effects of repeated vehicle loading flexible pavements are susceptible to thermal cracking, low temperatures, and freeze-thaw cycles [8]. High concentration of salt spray in the environment deteriorates asphalt mixtures durability [9]. Chen and Xu investigate the fibers in reinforcing effects and mechanisms for stabilizing and reinforcing asphalt binder. Fibers improve asphalt binder's resistance to rutting, flow, and dynamic shear modulus [10].

Many factors cause damage to flexible pavements. Asphalt pavements degradation is an inevitable phenomenon due to combined effects of high traffic loads or overloading, low speed vehicles [11], [12], and harsh environmental conditions. Environmental conditions include unstable subgrade conditions, temperature, weather, and water. Water is the main destroyer of road pavement. Especially water that has a high level of acidity such as sea water can affect the bond between asphalt and aggregate which accelerates oxidation, causing premature damage to the road surface layer. The influence of climate change causes natural phenomena such as tides, winds, waves, and ocean currents, which have a significant effect in parts of Indonesia, in coastal areas. The phenomenon of rising sea water causes tidal flooding so that roads near coastal areas are prone to experiencing sea water inundation either for a short time or for a long time. Sea water immersion will damage flexible pavement. Feng *et al* in 2010 stated that salt has a significant effect on the asphalt binders performance on low temperature [13]. Asphalt concrete performance in sulfate solution is more severe than in water. The brucite fiber in the mixture has an excellent effect on enhancement, stability, and reinforcement [14]. The interaction level between filler and bitumen is highly dependent on the polymer modification type [15]. Asphalt porous concrete mix had better aggregates interlocking, homogeneous void structure [16], improved adhesion properties, and higher number of asphalt fibrils with longer lengths relative to the neat asphalt [17]. The road pavement surface damage factor is one of the causes of traffic accidents [18]. It is necessary to seek efforts to repair road damage.

Tahmoorian and Samali using recycled construction aggregate in asphalt mixtures. Mixtures containing recycled construction aggregate have better workability, deformation resistance and compaction in comparison with basalt [19]. The previous study, Sugiyanto in 2017 identify the asphalt concrete characteristic produced from scrapped tire rubber. Scrapped tire rubber can improve resistance to permanent deformation due to ruts, provide better resistance in high temperatures [20], and resistance to water [21]. Liu *et al*. added the steel wool [22] and Do *et al*. using recycled waste lime in asphalt concrete mixture. Recycled waste lime improves stiffness, permanent deformation characteristics, and fatigue endurance of asphalt concrete [23]. Bowers *et al*. in 2014 investigate the reclaimed asphalt pavement blending efficiency through gel permeation chromatography. Blending occur throughout all layers of the asphalt mixture [24]. As mentioned by Ge *et al.* in 2017 penetration and asphalts ductility decreased and softening point of asphalts increased after modified with Sasobit and Polyphosphoric acid [25]. The other study, addition of nanoclay and carbon microfiber improve mixture's moisture susceptibility performance [26]. Polyester fibers improve properties of asphalt mixture [27]. The pulling rate and asphalt film thickness have an equivalent relation. As mentioned by Huang *et al*. in 2016, binder bond strength test could be applied to reflect mixture resistance in modified asphalt mixtures [28].

One effort that can be tried to reduce the damage to flexible pavements due to sea water immersion is the addition of buton asphalt into a modified mixture. The Buton Asphalt (As-buton) is natural rock asphalt in Lawele, South Buton Island, Southeast Sulawesi, Indonesia. As-buton consists of 20-35% high quality bitumen and 65-80% limestone filler. The total deposit is estimated at 650 million tonnes [29]. The advantages of Buton Asphalt are that it has higher adhesion and more resistant to temperature changes so that it is expected to increase stability to water. The aim of this research is to identify the effect of sea water immersion on asphalt concrete modification buton asphalt (as-buton). Experimental investigation based on characteristics of Marshall conducted to determine the efffect of sea water on the modification asphalt containing as-buton. The novelty of this research is that the composition of the modified as-buton asphalt mixture was produced and the effect of the buton asphalt mixture in sea water immersion was based on Marshall characteristic test results.

The organization of the remaining parts of the article is divided in four sections as follows. In section 1, the introduction provides background, aims of this research, the literature review with a discussion of previous studies related the effect of salt in flexible pavement. Additionally, section 2 the method involves materials, number of samples, data collection, standard of experimental testing in the laboratory. In section 3 provides result and discussion, coarse and fine aggregate testing results, asphalt testing results, asphalt concrete mixture, Marshall test, optimum asphalt content, and effect of sea water immersion. Finally, in section 4 contains the conclusion about the obtained results and future research.

## 2.0 METHODOLOGY

### 2.1 Asphalt Mixture and Gradation of Aggregate

In this research, a layer of asphalt concrete type namely AC-WC or Asphalt Concrete-Wearing Course with maximum aggregate size is 19 mm. The aggregate gradations limit specification by Ministry of Public Work Republic of Indonesia: *Bina Marga* 2010 (Revision 3) as stated in **Table 1** [30].

**Table 1** Specification of aggregate gradation limits for AC-WC Mixture [30]

| Size of sieve (mm) | Sieve number | Percentage passing of sieve (%) Lower limit | Upper limit |
|---|---|---|---|
| 19.1 | ¾ inch | - | 100 |
| 12.7 | ½ inch | 90 | 100 |
| 9.52 | 3/8 inch | 77 | 90 |
| 4.76 | No. 4 | 53 | 69 |
| 2.38 | No. 8 | 33 | 53 |
| 1,18 | No. 16 | 21 | 40 |
| 0.59 | No. 30 | 14 | 30 |
| 0.279 | No. 50 | 9 | 22 |
| 0.149 | No. 100 | 6 | 15 |
| 0.074 | No. 200 | 4 | 9 |

### 2.2 Material

Materials in this research consists of coarse and fine aggregate, filler using stone ash, asphalt Buton, asphalt with the penetration grade 60-70 from PERTAMINA, Indonesia and sea water. Asphalt buton from deposits on Lawele, South Buton Island, Southeast Sulawesi. Sea water used in this research is taken from *Teluk Penyu* Beach, in Cilacap District, Central Java, Indonesia.

### 2.3 Methods

The test methods and standards for coarse and fine aggregate and asphalt followed the Indonesian specification or Standard National of Indonesia (SNI). The conducted tests are water absorption, specific gravity, abrasion, adhesive of aggregate and asphalt. Standards used namely SNI 1969-2008 [31] for bulk specific gravity and water absorption test, SNI 2417-2008 [32] for abrasion test, SNI 06-2456-2011 [33] for penetration test of asphalt, SNI 2441-2011 [34] for specific gravity of asphalt test, SNI 2432-2011 [35] for ductility asphalt test, SNI 2433-2011 [36] for flash and fire point of asphalt test, SNI 2434-2011 [37] for softening point of bitumen test, and SNI 7729-2011 [38] for viscosity asphalt test. Asphalt content range from 4.5 to 6.5% based on the study by Sugiyanto *et al*. in 2015 [39]. To determine the optimum asphalt content, the AC-WC mixture was varied from 4.5 to 6.5% at 0.5% interval. The specimens were immersed in fresh water and sea water up to 24 hours at a temperature of 30°C.

Total samples in this study are 39 units, 15 samples for Marshall Test characteristic to get the optimum asphalt content value from AC-WC mixture, 12 samples of modification buton asphalt (as-buton) fir fresh water immersion test, and 12 samples of modification buton asphalt (as-buton) for sea water immersion test. The number of samples of each asphalt contents is 3 samples. Details of the mixture type and number of samples of AC-WC mixture for Marshall Test characteristic are shown in **Table 2**. Details of the number of samples of modification as-buton fresh water and sea water immersion are shown in **Table 3**.

**Table 2** Number of samples of AC-WC mixture for Marshall test

| Mixture type | Asphalt content (%) | The number of samples |
|---|---|---|
| AC-WC | 4.5 | 3 |
| AC-WC | 5.0 | 3 |
| AC-WC | 5.5 | 3 |
| AC-WC | 6.0 | 3 |
| AC-WC | 6.5 | 3 |
| | Total | 15 |

**Table 3** Number of samples of modification buton asphalt (as-buton) fresh water immersion and sea water immersion

| Asphalt Buton content (%) | The number of samples | |
|---|---|---|
| | Fresh water immersion | Sea water immersion |
| 0 | 3 | 3 |
| 5 | 3 | 3 |
| 7.5 | 3 | 3 |
| 10 | 3 | 3 |
| Total | 12 | 12 |

## 3.0 RESULTS AND DISCUSSION

### 3.1 Aggregate Test Results

The aggregate physical properties and characteristics of coarse aggregate, fine aggregate, and filler are determine based on the aggregate tests. The physical properties test results of coarse aggregate includes specific gravity, water absorption, and abrasion test as shown in **Table 4**. The physical properties of fine aggregate and filler can be seen in **Table 5**.

**Table 4** Physical properties of coarse aggregate

| Tests (unit) | Result | Specification | Standard |
|---|---|---|---|
| Bulk specific gravity (gr/cc) | 2.57 | Min. 2.50 | SNI 1969-2008 |
| SSD specific gravity (gr/cc) | 2.58 | Min. 2.50 | SNI 1969-2008 |
| Effective specific gravity (gr/cc) | 2.58 | Min. 2.50 | SNI 1969-2008 |
| Water absorption (%) | 0.28 | Max. 3% | SNI 1969-2008 |
| Abrasion test with Los Angeles machine 100 rotations (%) | 4 | Max. 6% | SNI 2417-2008 |
| Abrasion test with Los Angeles machine 500 rotations (%) | 11 | Max. 30% | SNI 2417-2008 |

**Table 5** Physical properties of fine aggregate and filler

| Tests (unit) | Result | Specification | Standard |
|---|---|---|---|
| Bulk specific gravity of fine aggregate (gr/cc) | 2.56 | Min. 2.50 | SNI 1969-2008 |
| SSD specific gravity of fine aggregate (gr/cc) | 2.57 | Min. 2.50 | SNI 1969-2008 |
| Effective specific gravity of fine aggregate (gr/cc) | 2.57 | Min. 2.50 | SNI 1969-2008 |
| Water absorption (%) | 0.42 | Max. 3% | SNI 1969-2008 |
| Filler specific gravity (gr/cc) | 2.56 | Min. 2.50 | SNI 1969-2008 |

Based on **Table 4**, the physical properties test results of coarse aggregate are bulk specific gravity is 2.57 (min. specification 2.50), water absorption 0.28% (max. specification 3%), the abrasion with Los Angeles Machine 100 rotation for asphalt mixture 4% (maximum specification 6%), and the abrasion with Los Angeles Machine 500 rotation for as-buton modification mixture 11% (maximum specification 30%). It means that coarse aggregate: crushed stone is comply with required specification standard and can be used as a coarse aggregate in asphalt concrete mixture and as-buton modification mixture. Based on **Table 5,** the result of physical properties of fine aggregate are water absorption is 0.42% (maximum specification 3%), the bulk specific gravity is 2.56 (minimum specification 2.50). The specific gravity of stone ash as filler in the asphalt mixture is 2.56 (minimum specification 2.5). The results of aggregate gradation examination obtained the percentage of coarse aggregate, namely aggregate grains which have a larger grain size than sieve no. 4 (4.76 mm) of 39%. Fine aggregate which has a finer grain size than sieve no. 4 (4.76 mm) of 54.5% and filler is 6.5%.

### 3.2 Asphalt Test Results

Asphalt with the penetration grade 60-70 from PERTAMINA, Indonesia was used in this research. Asphalt test includes penetration of asphalt, softening point, ductility, specific gravity, flash and fire point, and viscosity. The asphalt test results can be seen in **Table 6**. The asphalt buton modification test results with 5%, 7.5% and 10% as-buton can be seen in **Table 7**.

**Table 6** Asphalt test results

| Tests (unit) | Result | Specification | Standard |
|---|---|---|---|
| Penetration (dmm) | 63.6 | 60-70 | SNI 06-2456-2011 |
| Softening point (°C) | 54 | ≥ 48 | SNI 2434-2011 |
| Flash point (°C) | 282 | Min. 200 | SNI 2433-2011 |
| Fire point (°C) | 333 | - | SNI 2433-2011 |
| Ductility (cm) | 124.5 | Min. 100 | SNI 2432-2011 |
| Specific gravity (gr/cc) | 1.046 | ≥ 1.00 | SNI 2441-2011 |
| Viscosity (cSt) | | - | SNI 7729-2011 |
| Mixture temp. (°C) | 153 | | |
| Compaction temp. (°C) | 143.5 | | |

Based on **Table 6**, the penetration test in temperature 25$^0$C is 63.6 dmm (specification 60-70 dmm). The softening point of asphalt based on ring and ball test method is 54°C (min. spec. 48°C). Based on the penetration value and softening point of asphalt can be analyzed the penetration index. Flash and fire points of asphalt using Cleveland open cup method [36]. The value of flash point is 282°C (min. specification 200°C) and fire point of asphalt is 333°C. The ductility of asphalt is 124.5 cm (specification ≥ 100 cm). The specific gravity value of asphalt is 1.046 (spec. minimum 1.00). Asphalt with the penetration grade 60-70 from PERTAMINA is comply with the required specification *Bina Marga* 2010 (Revision 3) and can be used as bitumen in AC-WC mixture.

**Table 7** As-buton modification test results

| Tests (unit) | Asphalt buton content (%) | | | Speci-fication |
|---|---|---|---|---|
| | 5 | 7.5 | 10 | |
| Penetration (dmm) | 53 | 52 | 51.5 | Min. 50 |
| Softening point (°C) | 54.4 | 54.7 | 55 | ≥ 53 |
| Ductility (cm) | 104.5 | 102.5 | 100 | Min. 100 |
| Specific gravity (gr/cc) | 1.060 | 1.078 | 1.097 | ≥ 1.00 |

Based on **Table 7**, the penetration value for as-buton modification 5% is 53 dmm, as-buton modification 7.5% is 52 dmm, and 51.5 dmm for as-buton modification 10% (specification min. 50 dmm). The softening point of asphalt based on the ring and ball test method is 54.4 °C for 5% as-buton, 54.7 °C for 7.5% as-buton, and 55°C (spec. min. 53°C). The specific gravity of as-buton modification 5% is 1.060, 7.5% is 1.078, and 1.097 for as-buton 10% (spec. min. 1.0). As-buton modification is complying with the required specification Ministry of Public Works *Bina Marga* 2010 (Revision 3) [30].

3.3 Marshall Test Result

Marshall tests characteristic for the AC-WC or Asphalt Concrete-Wearing Course mixture with asphalt content range from 4.5 to 6.5%. Seven characteristics of Marshall Test namely Void in Mixture (VIM in % volume), Void in Mineral Aggregate (VMA in % volume), Voids Filled with Asphalt (VFA in % VMA), flow in mm, stability in kg, Marshall Quotient (MQ) in kg/mm and density in gr/cc. Specification for Marshall test based on specification *Bina Marga* 2010 (Rev. 3) [30]. Marshall Test results for AC-WC mixture for seven characteristics can be seen in **Figure 1**.

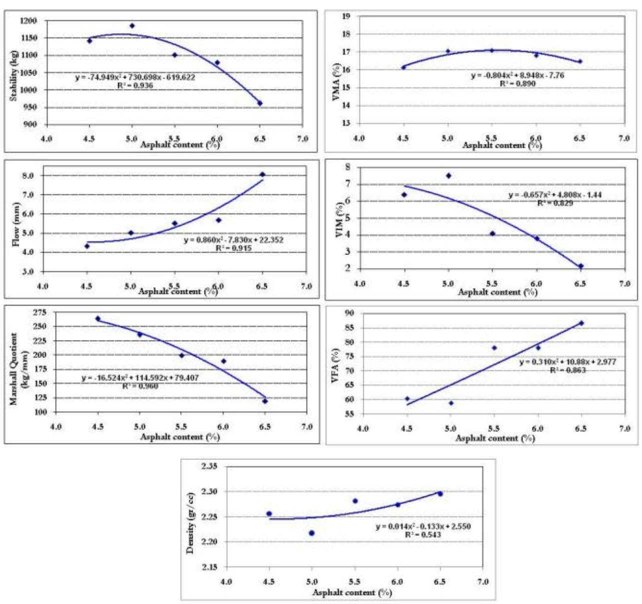



**Figure 1** Marshall Test analysis results for AC-WC mixture

As depicted in **Figure 1**, the results of Marshall tests characteristic show that the stability value of asphalt mixture will increase with the addition of mixed asphalt content and decrease if added asphalt content exceeds the optimum asphalt content value. Based on the specification from Minister of Public Works: *Bina Marga* 2010 (Rev. 3), the minimum requirement value for stability of AC-WC mixture is 800 kg [30], so that the AC mixtures with asphalt content from 4.5 to 6.5% is complying with the specification standard. The second parameter flow value shows the amount of reduction in the mixture of test objects due to the load to the limit of collapse. The flow result test of AC-WC mixture is increasing with the addition of asphalt content. For the asphalt content value from 4.5 to 6.5%, the flow value of asphalt mixture is 4.33-8.07 mm (≥ 3 mm), so that the asphalt mixture is complying with the required specification standard for the asphalt content from 4.5 to 6.5%. The third parameter Marshall Quotient (MQ) values for AC-WC mixture is 119.14 to 263.92 kg/mm (min. 250 kg/mm) [30]. The MQ values for AC-WC mixture is complying with the required specification for asphalt content from 4.5 to 4.75%. VMA shows the percentage of the number of air voids in the aggregate that can be filled with asphalt. The greater of the air voids between the aggregate grains, the greater the value of the air voids in the mixture. The VMA value for asphalt content of 4.5-6.5% obtained a value of 16.122 to 17.077%, it has complied with the requirements of the Highways specification is 14%. The VFA value shows the amount of cavity in the mixture filled with asphalt. The VFA value from test results obtained from 58.849 to 86.585%. The minimum requirement for a VFA value is 63%.

The determination of optimum asphalt content value for the AC-WC mixture based on Marshall test characteristics is shown in **Figure 2**. In AC-WC mixture, from seven characteristics of Marshall Test include: stability, flow, VMA, and density value are appropriate for the asphalt content from 4.5 to 6.5%. VIM value is appropriate for asphalt content from 5.34 to 6.235%, VFA appropriate for asphalt content from 4.848 to 6.5% and MQ for asphalt content 4.5 to 4.75%. The asphalt content that can satisfy six specifications of Marshall Test characteristic is from 5.34 to 6.235%. So the optimum asphalt content value of the AC-WC mixture is the median from 5.34 to 6.235% is 5.79% (indicated by the blue arrow in **Figure 2**).

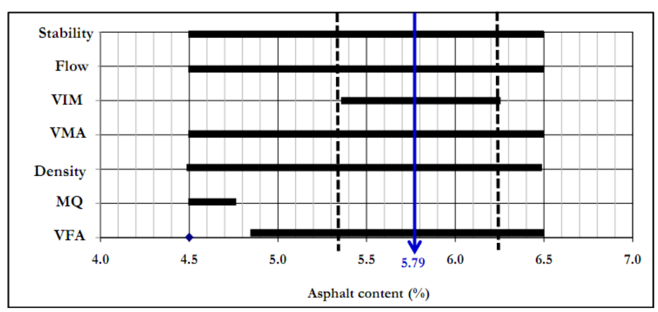



**Figure 2** Optimum asphalt content determination for the AC-WC mixture

The value of each Marshall Test analysis results for the AC-WC mixture with optimum asphalt content 5.79% is shown in **Table 8**. The specification of each parameter based on the Minister of Public Works: *Bina Marga* 2010 (Rev. 3).

**Table 8** Marshall Test analysis results for AC-WC with optimum asphalt content 5.79%

| Marshall Test | Result for 5.79% | Specification |
|---|---|---|
| Stability (kg) | 1098.52 | Min. 800 |
| Flow (mm) | 5.85 | Min. 3 |
| MQ (kg/mm) | 188.94 | Min. 250 |
| VMA (%) | 17.1 | Min. 14 |
| VIM (%) | 4.37 | 3-5.5 |
| VFA (%) | 76.36 | Min. 63 |
| Density (gr/cc) | 2.249 | - |

Based on **Table 8**, with optimum asphalt content value for AC-WC mixture is 5.79%, from seven characteristics Marshall test only Marshall Quotient (MQ) that doesn't comply with the Bina Marga specification. As for the other six parameters comply with the Bina Marga specifications. The void in mixture value of asphalt mixture must be maintain. Void in mixture value required for AC-WC mixture is between 3.5 to 5.5%. The asphalt mixture with void in mixture or VIM value range between 3 to 5.5% is not susceptible to flowing, melting, and plastic deformation. A very high of VFA value will cause bleeding. Based on the optimum asphalt content result, the next step is making the asphalt buton modification with the asphalt buton 5%, 7.5%, and 10%.

3.4 Marshall Immersion Test Result

The results of Marshall Immersion for AC-WC mixture (0% as-buton) and asphalt buton modifications 5% (as-buton 5%), as-buton 7.5%, and as-buton 10% are shown in **Table 9** that immersed in fresh water and **Table 10** for sea water immersion up to 24 hours at temperature of 30°C. Seven parameters of Marshall Test characteristics include stability, VIM or Void in Mixture, VMA or Void in Mineral Aggregate, VFA or Voids Filled with Asphalt, flow, Marshall Quotient (MQ), and density.

**Table 9** Marshal test characteristics of modification asphalt buton mixture in fresh water immersion

| Marshal test characteristics | Asphalt buton content (%) 0 | 5 | 7.5 | 10 | Speci-fication |
|---|---|---|---|---|---|
| Stability (kg) | 1159.01 | 1215.61 | 1250.12 | 1328.35 | Min.1000 |
| Flow (mm) | 7.5 | 7.4 | 6.0 | 5.6 | Min. 3 |
| MQ (kg/mm) | 154.535 | 164.271 | 208.354 | 237.206 | Min. 300 |
| VMA (%) | 14.675 | 15.690 | 15.825 | 15.914 | Min. 15 |
| VIM (%) | 1.50 | 2.90 | 3.20 | 3.60 | 3.5-5.5 |
| VFA (%) | 89.644 | 81.731 | 79.779 | 77.703 | Min. 65 |
| Density (gr/cc) | 2.330 | 2.303 | 2.299 | 2.297 | - |

**Table 10** Marshal test characteristics of modification asphalt buton mixture in sea water immersion

| Marshal test characteristics | Asphalt buton content (%) 0 | 5 | 7.5 | 10 | Speci-fication |
|---|---|---|---|---|---|
| Stability (kg) | 2267.24 | 2738.19 | 3155.24 | 3528.94 | Min.1000 |
| Flow (mm) | 7.10 | 6.25 | 6.20 | 6.10 | Min. 3 |
| MQ (kg/mm) | 319.329 | 438.111 | 508.909 | 578.514 | Min. 300 |
| VMA (%) | 14.993 | 15.099 | 15.366 | 15.632 | Min. 15 |
| VIM (%) | 1.90 | 2.20 | 2.60 | 3.20 | 3.5-5.5 |
| VFA (%) | 87.557 | 86.274 | 83.079 | 79.284 | Min. 65 |
| Density (gr/cc) | 2.322 | 2.319 | 2.312 | 2.304 | - |

3.5 Discussion

The adding buton asphalt effect to the modified asphalt mixture and effect of soaking the mixture in sea water can be explained as follows: as depicted in **Table 9** and **Table 10**, the results show that the asphalt mixture stability will increase with addition of Buton asphalt content. This occurs because the bitumen contained in grain buton asphalt mixes with asphalt with the penetration grade 60/70 in the asphalt mixture and causes the adhesion of the asphalt mixture to be better. The stability value of the modified asphalt buton mixture immersed in sea water is also greater than that immersed in fresh water. The increase in stability value due to the addition of buton asphalt as much as 10% in fresh water immersion reached 169.338 kg (increased by 14.61%) while the sea water immersion reached 1261.669 kg (increased by 55.65%). Relationship between stability with asphalt buton content in fresh water and sea water immersion is shown in **Figure 3**. The addition of asphalt buton (as-buton) content in the asphalt mixture will result in a decrease in the flow value. The mobilization of bitumen from the as-buton grain causes the asphalt to become harder. The flow value of asphalt mixture immersed in fresh water decreased by 1.9 mm (decreased by 25.33%), while those immersed in sea water decreased by 1 mm (decreased by 14.08%). Relationship between flow with asphalt buton content in fresh water and sea water immersion is shown in **Figure 4**.

The Marshall Quotient (MQ) value of the asphalt mixture increases with the addition of as-buton content. The MQ value of the modified asphalt buton mixture immersed in sea water is greater than that immersed in fresh water. The increase in MQ value due to the addition of 10% as-buton in fresh water immersion reached 82.67 kg/mm (increased by 53.50%) while in sea water immersion it reached 259.185 kg/mm (increased by 81.17%). The increase of MQ value from modified asphalt buton immersed in sea water was greater than immersed in fresh water. Asphalt mixtures with as-buton grain substitution tend to be stiffer. Relationship between MQ with asphalt buton content in fresh water and sea water immersion is shown in **Figure 5**.

The void in mineral aggregate (VMA) and void in mixture (VIM) values of asphalt mixture also increased with each addition of as-buton levels. The increase in VMA value in fresh water immersion reached 8.44% while in sea water immersion it increased by 4.26%. The increase in the VIM value of the modified as-buton mixture immersed in fresh water reached 140% and in sea water it increased by 68.42%. Meanwhile, the addition of as-buton content in the modified as-buton mixture tends to decrease the voids filled with asphalt (VFA) value. The VFA value in fresh water immersion decreased by 13.32% while that in sea water immersion decreased by 9.45%. The effect of adding asphalt Buton to the modified asphalt mixture on the density value is less significant. The difference in density values in the mixture without as-buton and as-buton substitution by 10% in fresh water immersion only decreased by 0.033 (1.42%) and in sea water immersion decreased by 0.018 (0.78%). The relationship between VMA with asphalt buton content in fresh water and sea water immersion is shown in **Figure 6**, relationship between VIM with asphalt buton content in fresh water and sea water immersion is shown in **Figure 7**, relationship between VFA with asphalt buton content in fresh water and sea water immersion is shown in **Figure 8**, and relationship between density with asphalt buton content in fresh water and sea water immersion is shown in **Figure 9** respectively.

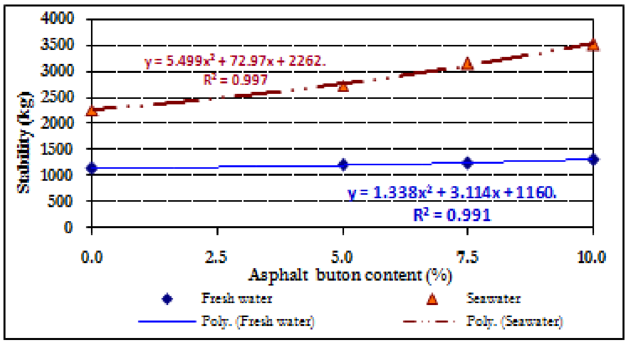



**Figure 3** Relationship between stability with asphalt buton content in freshwater and seawater immersion

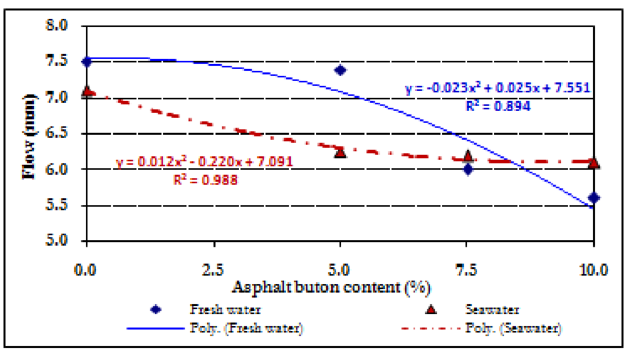



**Figure 4** Relationship between flow with asphalt buton content in freshwater and seawater immersion

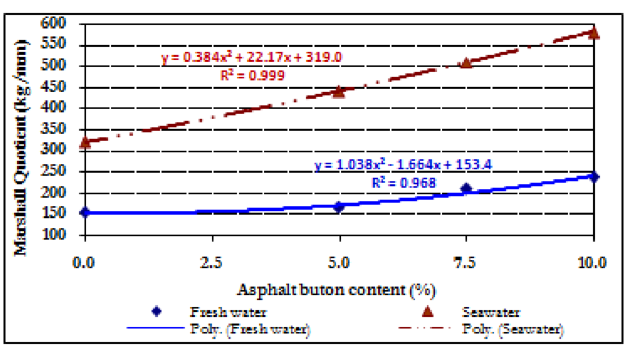



**Figure 5** Relationship between Marshall Quotient with asphalt buton content in freshwater and seawater immersion

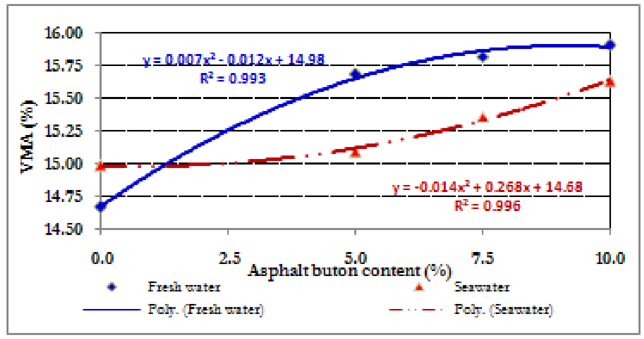



**Figure 6** Relationship between VMA with asphalt buton content in freshwater and seawater immersion

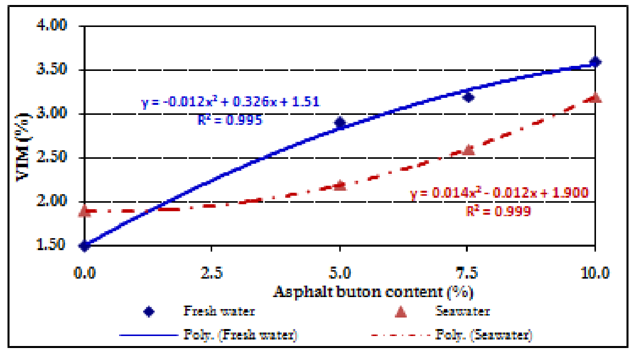



**Figure 7** Relationship between VIM with asphalt buton content in freshwater and seawater immersion

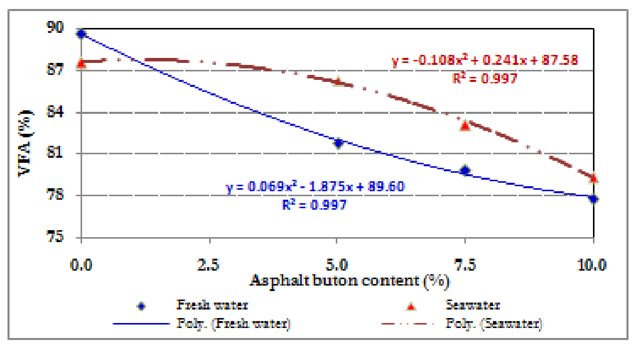



**Figure 8** Relationship between VFA with asphalt buton content in freshwater and seawater immersion

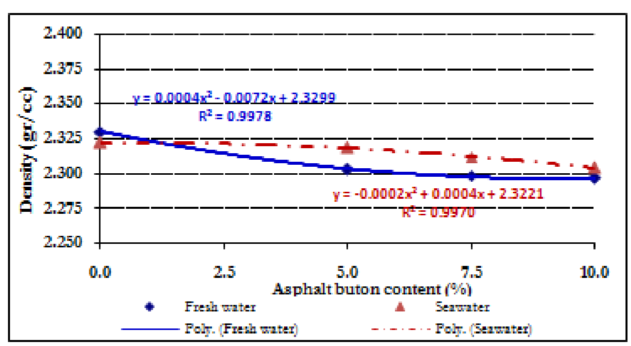



**Figure 9** Relationship between density with asphalt buton content in freshwater and seawater immersion

One of the factors that influences moisture transport of asphalt mixtures is the void structures characterization [40]. The Improvement of adhesive zone will result in porous asphalt concrete with improved the durability, lifetime of mixture [41] [42], and reduce the tire-pavement noise [43] [44]. Because of some of these advantages, the porous asphalt pavement is more efficient than compare with conventional pavements [45]. As mentioned by Ganesan *et al*. in 2013 the replacement of fine aggregate by shredded rubber as much as 15% and 20% improved the fatique strength of self compacting rubberized concrete [46]. In the other study by Qin in 2015 which study about the strategy to mitigate the urban heat island effect using cool pavements development. The heat-harvesting pavements seem interesting to resolve the issue because they stay cool. The heat-harvesting pavements can also be used as a renewable energy source [47].

**Effect of Salt in Flexible Pavement**

The effect of physical chemical properties of sea water on thermodynamics and kinetics of processes in the oceans was studied by Millero [48]. Chloride in tidal water is main contributor that damage on the asphalt pavement [49]. Chemical treatment has an increasing effect on the softening temperatures of bitumen-filler blends [50]. Effect of salt in performance of asphalt binders is accelerates the failure when salt percentage is more than 3% [51]. The other effect of water solution erosion on asphalt mixture is increased the asphalt stiffening and decreased the adhesion [52], cause aggregate raveling in coastal areas [53], water stability of mixture [54]. One of strategy to reduce the effect of salt and increased the resistance temperature is using the rubber power [55].

Sea water immersion has more influence on the value of stability, flow, and Marshall Quotient of asphalt mixture compared to fresh water immersion. The results of the comparison of sea water immersion in modified buton asphalt showed that addition of asphalt buton content increased stability and Marshall Quotient value but decreased the flow value. As mentioned by Gellert and Turley in 1999 which study about the sea water immersion ageing of glass-fibre reinforced polymer laminates. The flexural strength fell by 15–21% for the water saturated polyester and vinyl ester glass fibre reinforced polymer [56] [57].

## 4.0 CONCLUSION

This research determining the effect of addition of buton asphalt to the modified asphalt mixture and the effect of sea water immersion on asphalt concrete modification buton asphalt (as-buton) based on the Marshall characteristic test. Through this study, addition of buton asphalt increase the stability value, Marshall Quotient, VMA and VIM of asphalt mixture but decrease the value of flow, VFA, and density. The stability value of the modified as-buton mixture immersed in sea water is greater than that in fresh water. The stability value of the 10% modified as-buton mixture in fresh water immersion increased 14.61% and in sea water immersion increased 55.65%. The flow value in fresh water immersion decreased 25.33% while in sea water immersion decreased 14.08%. For the next research, variations in the addition of buton asphalt, variations in the duration and immersion temperature will be carried out to obtain the optimum buton asphalt content.

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**List Revision-1 paper Id No. 16802**
**"The Effect of Sea Water Immersion on Asphalt Concrete Modification Buton Asphalt (As-Buton)"**

| No. | Suggestions from Reviewer | Revision from Author | Page |
|---|---|---|---|
| 1. | In the abstract section, it is recommended to take out the last sentence about future works. Hence, include specific comments in line with the results of the current study. | Thank you for the comment from Reviewer. I agree and take out the last sentence in abstract: "In addition, variations in the duration and immersion temperature of the modified asphalt mixture will also be carried out".<br>The lesson learned and/or new knowledge from this research is the effect of sea water immersion on Buton Asphalt (As-Buton) mixture. The main test of the paper is not only Marshall Stability but also the flow, Marshall quotient, void in mixture, void in mineral aggregate, voids filled with asphalt and density. The novelty of the work is the effect of As-buton to asphalt binder/mixture in the coastal road conditions. The result of this study show that the addition of Buton asphalt increase the value of stability, void in mixture, Marshall quotient, and void in mineral aggregate, but reduce the value of flow, void filled with asphalt, and density. The increase of stability value in sea water immersion due to the addition of buton asphalt was higher than that in freshwater. The stability value of the 10% modified as-buton mixture in freshwater immersion increased by 169.338 kg (14.61%) and in sea water immersion increased by 1261.669 kg (55.65%). The flow value in freshwater immersion decreased by 1.9 mm (25.33%) while in sea water immersion decreased by 1 mm (14.08%). From this result, the further research, variations in the addition of Buton asphalt will be carried out to obtain the optimum Buton asphalt content which produces a modified asphalt mixture with the best performance. | **1 and 9** |
| 2. | In the introduction section, it is not mentioned to the why there is a need to evaluate asphalt binder performance with As-Buton modifier. It is better to touch on this issue more than general literature review about the asphalt mixture performance. | Thank you for the comment. In the introduction section the Author stated that:<br>Water is the main destroyer of road pavement. Especially water that has a high level of acidity such as sea water can affect the bond between asphalt and aggregate which accelerates oxidation, causing premature damage to the road surface layer. Sea water immersion will damage flexible pavement. Feng et al in 2010 stated that salt has a significant effect on the asphalt binders performance on low temperature [10].<br>One effort that can be tried to reduce the damage to flexible pavements due to sea water immersion is the addition of buton asphalt into a modified mixture. The Buton Asphalt (As-buton) is natural rock asphalt in Lawele, South Buton Island, Southeast Sulawesi, Indonesia. As-buton consists of 20-35% high quality bitumen and 65-80% limestone filler. The total deposit is estimated at 650 million tones [25]. The advantages of Buton Asphalt are that it has higher adhesion and more resistant to temperature changes so that it is expected to increase stability to water.<br>This study focuses on determining the effect of the addition of Buton asphalt to the modified asphalt mixture and the effect of sea water immersion on asphalt concrete modification Buton asphalt (as-Buton) based on the Marshall characteristic test. | **2** |

3.

Please include PI calculation results of the samples to the related tables (for all of the samples).

Thank you for this suggestion. Author revision this section as follow:

| Marshal test | Asphalt content (%) | | | | | Specification |
|---|---|---|---|---|---|---|
| | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | |
| Stability (kg) | 1142.76 | 1186.22 | 1102.14 | 1080.20 | 961.43 | Min. 800 |
| Flow (mm) | 4.33 | 5.03 | 5.53 | 5.70 | 8.07 | Min. 3 |
| MQ (kg/mm) | 263.92 | 235.83 | 199.30 | 189.51 | 119.14 | Min. 250 |
| VMA (%) | 16.122 | 17.053 | 17.077 | 16.814 | 16.480 | Min. 14 |
| VIM (%) | 6.40 | 7.50 | 4.10 | 3.80 | 2.20 | 3-5.5 |
| VFA (%) | 60.387 | 58.849 | 78.046 | 77.917 | 86.585 | Min. 63 |
| Density (gr/cc) | 2.257 | 2.217 | 2.282 | 2.274 | 2.296 | - |

Author increase the data before and after immersion for the asphalt mixture. There are seven characteristics of Marshall Test namely void in mixture, void in mineral aggregate, voids filled with asphalt, flow, stability, Marshall quotient, and density. Two condition of immersions are freshwater and sea water immersion. The comparison for seven characteristics of marshall test in before immersion and after immersion can be seen in Table 11.

**Table 11** Marshal test characteristics of asphalt mixture before and after immersion

| Marshal test characteristics | Before immersion | | After immersion | | |
|---|---|---|---|---|---|
| | Result | Spec. | Freshwater | Sea water | Spec. |
| Stability (kg) | 1098.52 | Min. 800 | 1159.01 | 2267.24 | Min.1000 |
| Flow (mm) | 5.85 | Min. 3 | 7.5 | 7.10 | Min. 3 |
| MQ (kg/mm) | 188.94 | Min. 250 | 154.535 | 319.329 | Min. 300 |
| VMA (%) | 17.1 | Min. 14 | 14.675 | 14.993 | Min. 15 |
| VIM (%) | 4.37 | 3-5.5 | 1.50 | 1.90 | 3.5-5.5 |
| VFA (%) | 76.36 | Min. 63 | 89.644 | 87.557 | Min. 65 |
| Density (gr/cc) | 2.249 | - | 2.330 | 2.322 | - |

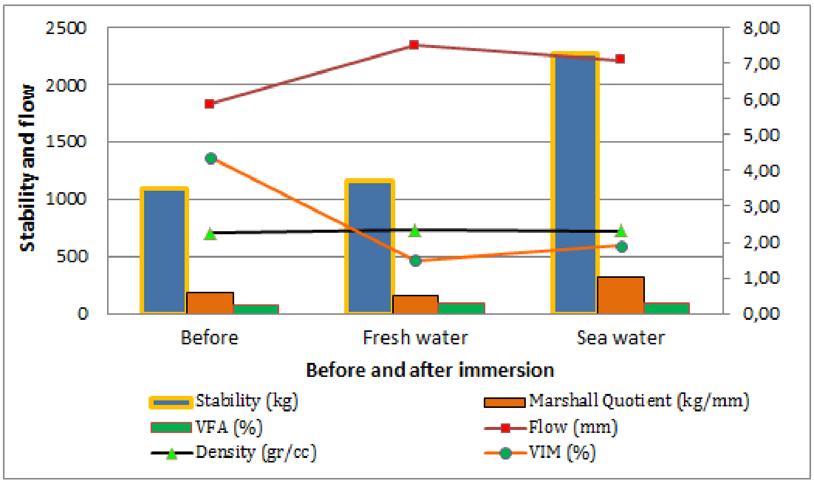



**Figure 3** Comparison of Marshall test characteristics of asphalt mixture before and after immersion

The stability of asphalt mixture before immersion 1098.52 kg and increased 5.5% when soaked in freshwater and increased 106% when soaked in sea water. Stability value that is too high will cause the flexible pavement to become stiff so that its durability is reduced.

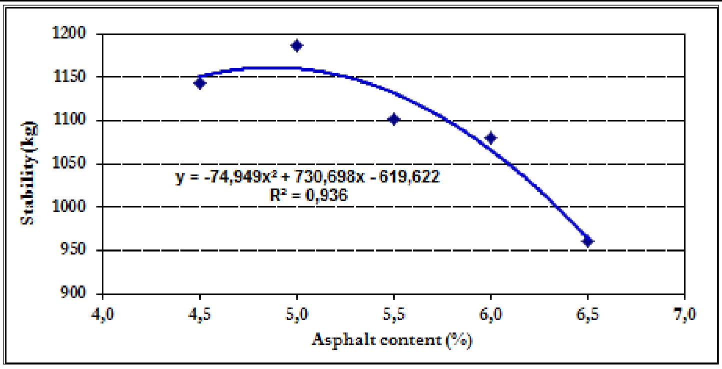
5, 7

| | | | |
|---|---|---|---|
| 4. | Final paragraph of the discussion section is not related to the research purposes and is beside the point. | Thank you for this suggestion. Authors agree with the Reviewer and dele the sentence “As mentioned by Gellert and Turley in 1999 which study about the sea water immersion ageing of glass-fibre reinforced polymer laminates. The flexural strength fell by 15-21% for the water saturated polyester and vinyl ester glass fibre reinforced polymer [56] [57]”. | **9** |

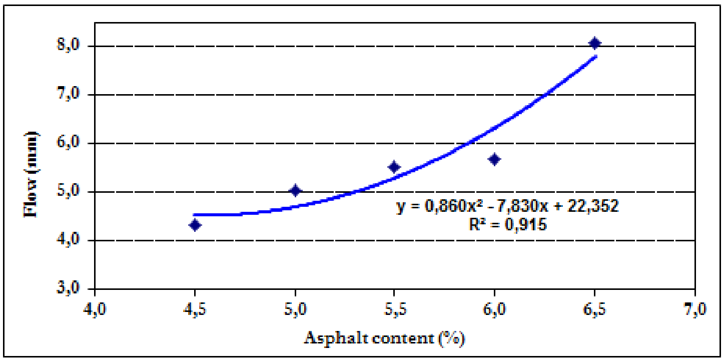
**List Revision-2 Paper Id. 16802**
**"The Effect of Sea Water Immersion on Asphalt Concrete Modification Buton Asphalt (As-Buton)"**

| No. | Suggestions from Reviewer | Revision from Author | Page |
|---|---|---|---|
| 1. | The title of manuscript (revise this part of title) | Thank you for this suggestion. The title of manuscript is replacing:<br>**Before**: "The Effect of Sea Water Immersion on Asphalt Concrete Modification Buton Asphalt (As-Buton)"<br>**After**: "**The Effect of Sea Water Immersion on Buton Asphalt (As-Buton) Mixture"** | **1** |
| 2. | The percentage of Buton asphalt used is 0%, 5%, 7.5%, and 10% | Thank you for this suggestion. Author revision this sentence in the abstract.<br>Before:<br>The percentage of Buton asphalt used is 0%, 5%, 7.5%, and 10%.<br>After:<br>The percentage **by weight** of Buton asphalt used is 0%, 5%, 7.5%, and 10%. | **1** |
| 3. | Introduction: The explanation should be restructured properly clear story and good continuity | Thank you for this suggestion. Author revision the introduction as follow:<br>One type of road pavement construction is flexible pavement, namely pavement using asphalt as a binding material. Flexible pavement consists of pavement layers that carry and spread traffic loads to the subgrade. Flexible pavement is a composite material consisting of aggregate, asphalt mastic, air void, and filler. It is considered the primary paving type of road, taxiway, and runway, due to their good riding quality, fast construction speed, low noise, excellent durability, and stability [1], recyclability, and easy maintenance [2] [3]. In last decades, Indonesia intended to improve infrastructure by increasing highway network and building the asphalt pavement almost 329,926 km [4]. In China more than 90% is flexible pavement [5] and in the United State of America, flexible pavements represent 95% of total pavement [6].<br>Asphalt surface layer plays a fundamental role in flexible pavement structure; withstanding varying traffic loads and constantly changing environmental conditions. However, under the effects of repeated vehicle loading flexible pavements are susceptible to thermal cracking, low temperatures, and freeze-thaw cycles [7]. Many factors cause damage to flexible pavements. Asphalt pavement degradation is an inevitable phenomenon due to combined effects of high traffic loads or overloading, low speed vehicles [8] [9], and harsh environmental conditions. Environmental conditions include unstable subgrade conditions, temperature, weather, and water. Water is the main destroyer of road pavement. Especially water that has a high level of acidity such as sea water can affect the bond between asphalt and aggregate which accelerates oxidation, causing premature damage to the road surface layer. The influence of climate change causes natural phenomena such as tides, winds, waves, and ocean currents, which have a significant effect in parts of Indonesia, in coastal areas. The phenomenon of rising sea water causes tidal flooding so that roads near coastal areas are prone to experiencing sea water inundation either for a | **2-3** |

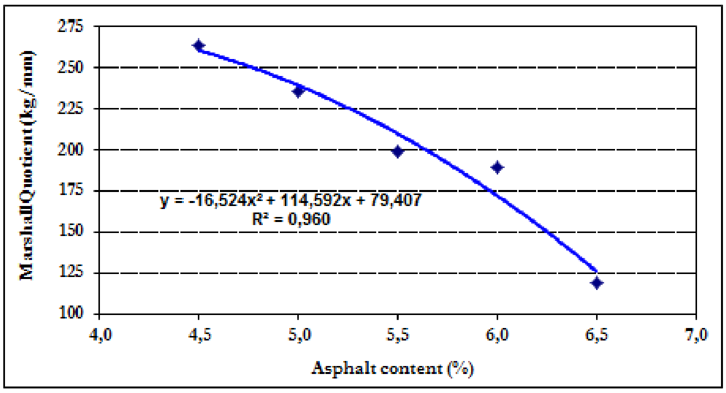
| | | | |
|---|---|---|---|
| | | short time or for a long time. Sea water immersion will damage flexible pavement. Feng et al in 2010 stated that salt has a significant effect on the asphalt binder's performance on low temperature [10]. Asphalt concrete performance in sulfate solution is more severe than in water. The brucite fiber in the mixture has an excellent effect on enhancement, stability, and reinforcement [11].<br>One effort that can be tried to reduce the damage to flexible pavements due to sea water immersion is the addition of buton asphalt into a modified mixture. The Buton Asphalt (As-buton) is natural rock asphalt in Lawele, South Buton Island, Southeast Sulawesi, Indonesia. As-buton consists of 20-35% high quality bitumen and 65-80% limestone filler. The total deposit is estimated at 650 million tones [25]. The advantages of Buton Asphalt are that it has higher adhesion and more resistance to temperature changes so that it is expected to increase stability to water. The aim of this research is to identify the effect of sea water immersion on asphalt concrete modification buton asphalt (as-buton). Experimental investigation based on characteristics of Marshall conducted to determine the effect of sea water on the modification asphalt containing as-buton. The novelty of this research is that the composition of the modified as-buton asphalt mixture was produced and the effect of the buton asphalt mixture in sea water immersion was based on Marshall characteristic test results. | |
| 4. | The sentence "The Chinese government increasing highway network 130,000 km [5], more than 90% of that is flexible pavement [6]" not so relevant in the introduction. | Author revision this sentence. "In China more than 90% is flexible pavement [5] and in the United State of America, flexible pavements represent 95% of total pavement [6]". | **2** |
| 5. | Should include the characteristic of the sea water used in this study | Thank you for this suggestion. The Author increase the sentence: The characteristic of the sea water used in this study from Teluk Penyu Beach, salinity value 25 ‰ and the Potential of Hydrogen (pH) value 8.52. | **3** |
| 6. | The number of modified asphalt samples: 12 or 9 samples? | Thank you for this suggestion. Total samples in this study are 39 units, 15 samples for Marshall Test characteristic to get the optimum asphalt content value from AC-WC mixture and 24 samples for freshwater and sea water immersion test. There are 9 samples of modification buton asphalt (as-buton) for freshwater immersion test, and 9 samples of as-buton mixture for sea water immersion test. The percentage by weight of Buton asphalt used is 0%, 5%, 7.5%, and 10%. The number of samples of each asphalt contents is 3 samples. | **3** |
| 7. | The plot Figure 1 Marshall Test analysis results for AC-WC mixture is quite small | Thank you for this suggestion. The Author replaces and enlarges the Figure 1 as follows:. | **5-6** |



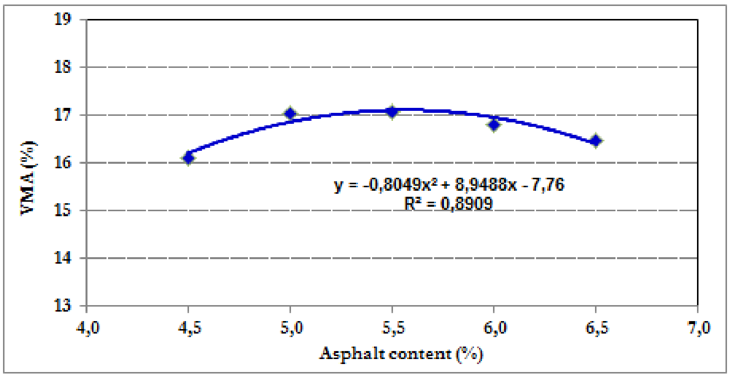

a. Relationship asphalt content and stability



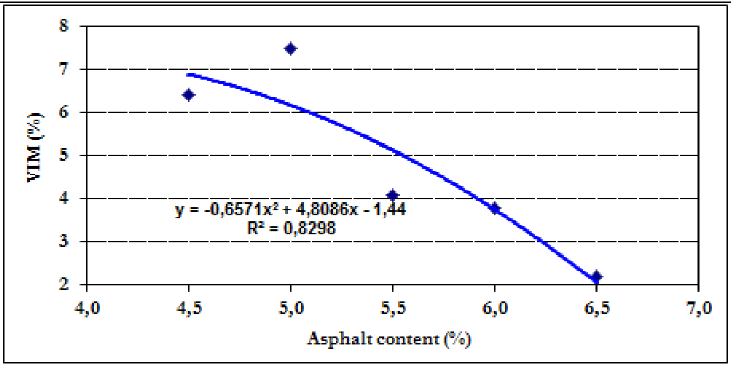

b. Relationship asphalt content and flow



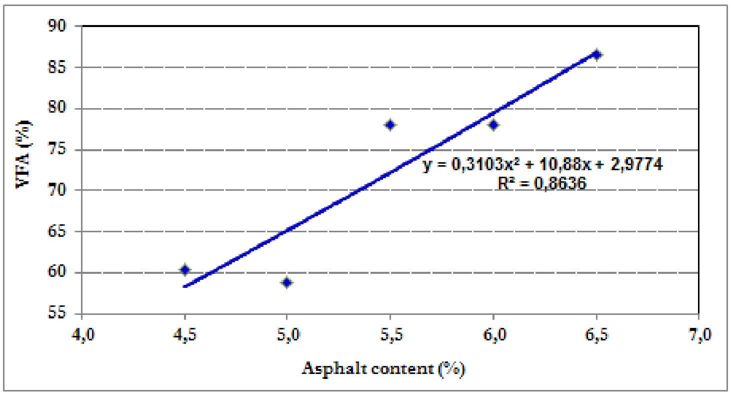

c. Relationship asphalt content and marshall quotient



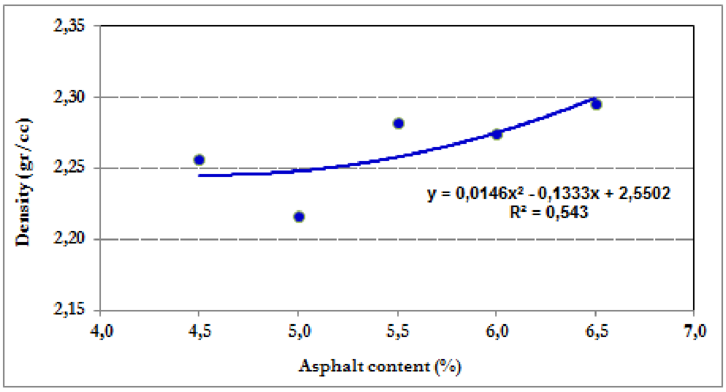

d. Relationship asphalt content and void in mineral aggregate




e. Relationship asphalt content and void in mixture




f. Relationship asphalt content and voids filled with asphalt




g. Relationship asphalt content and density

**Figure 1.** Marshall Test analysis results for AC-WC mixture.

| | | | |
|---|---|---|---|
| 8. | The Marshall Quotient is not complying with the standard, is too much bitumen? | Thank you for this suggestion. From seven characteristics Marshall test only Marshall Quotient (MQ) that doesn't comply with the Bina Marga specification. The higher MQ value, the higher stiffness of a mixture and more susceptible the mixture to cracking. As for the other six parameters comply with the Bina Marga specifications. A stability value of asphalt mixture that is too high will result in a pavement that is too stiff so that its durability is reduced. | **6** |
| 9. | Should provide the data before and after immersion for comparison especially with as-buton | Thank you for this suggestion. Author increase the data before and after immersion for the asphalt mixture. There are seven characteristics of Marshall Test namely void in mixture, void in mineral aggregate, voids filled with asphalt, flow, stability, Marshall quotient, and density. Two condition of immersions are freshwater and sea water immersion. The comparison for seven characteristics of marshall test in before immersion and after immersion can be seen in Table 11. | **7** |

**Table 11** Marshal test characteristics of asphalt mixture before and after immersion

| Marshal test characteristics | Before immersion | | After immersion | | |
|---|---|---|---|---|---|
| | Result | Spec. | Freshwater | Sea water | Spec. |
| Stability (kg) | 1098.52 | Min. 800 | 1159.01 | 2267.24 | Min.1000 |
| Flow (mm) | 5.85 | Min. 3 | 7.5 | 7.10 | Min. 3 |
| MQ (kg/mm) | 188.94 | Min. 250 | 154.535 | 319.329 | Min. 300 |
| VMA (%) | 17.1 | Min. 14 | 14.675 | 14.993 | Min. 15 |
| VIM (%) | 4.37 | 3-5.5 | 1.50 | 1.90 | 3.5-5.5 |
| VFA (%) | 76.36 | Min. 63 | 89.644 | 87.557 | Min. 65 |
| Density (gr/cc) | 2.249 | - | 2.330 | 2.322 | - |

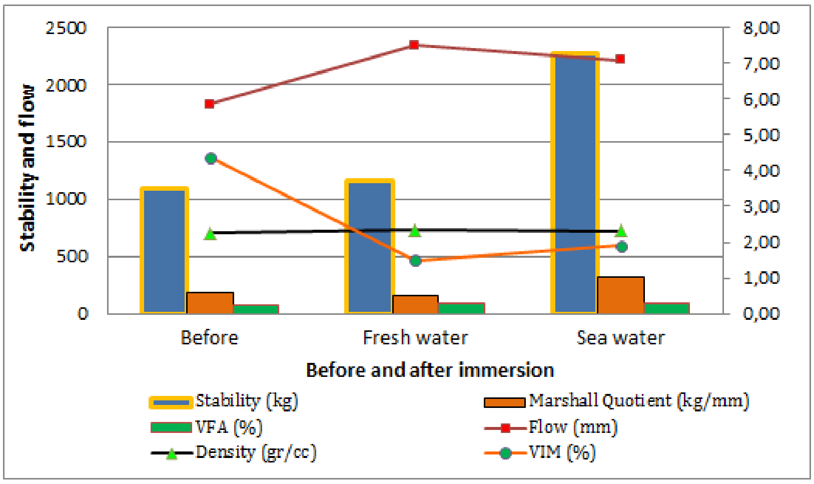



**Figure 3** Comparison of Marshall test characteristics of asphalt mixture before and after immersion

The stability of asphalt mixture before immersion 1098.52 kg and increased 5.5% when soaked in freshwater and increased 106% when soaked in sea water. Stability value that is too high will cause the flexible pavement to become stiff so that its durability is reduced.

| | | | |
|---|---|---|---|
| 10. | The explanation effect of salt in flexible pavement is not good, should revise. Explain clearly the impact of sea water on asphalt and how the as-buton could improve the properties. | Thank you for this suggestion. Author revised the discusion about the impact of sea water on asphalt. Sea water immersion increases the stability of asphalt mixture, so that its durability is reduced. The result of this study is similar to the study by Millero [47] and Setiadji et al. [48]. Chloride in tidal water is the main contributor to damage on the asphalt pavement [48]. Effect of salt in performance of asphalt binders accelerates the failure when salt percentage is more than 3% [49], increases the asphalt stiffening and decrease the adhesion [50], causes aggregate raveling in coastal areas [51], and water stability of mixture [52].<br>The advantages of Buton Asphalt are that it has higher adhesion and more resistance to temperature changes so that it is expected to increase stability to water. | **9** |
| 11. | Conclusion only repeats the result, no inclusive conclusion showing the impact of sea water and as-buton. | Thank you for this suggestion. Author revised the conclusion as follow:<br>This research determines the effect of addition of buton asphalt to the modified asphalt mixture and the effect of sea water immersion on buton asphalt (as-buton) mixture based on the Marshall characteristic test. Through this study, the addition of as-buton makes the asphalt mixture more resistant to temperature changes | **10** |

| | | | |
|---|---|---|---|
| | | and increases stability to water. The addition of buton asphalt increases the stability, void in mixture, Marshall quotient, and void in mineral aggregate, but reduces the value of flow, void filled with asphalt, and density. The stability and marshall quotient value of the modified as-buton mixture immersed in sea water is greater than that in freshwater. | |

# JT#16802: THE EFFECT OF SEA WATER IMMERSION ON BUTON ASPHALT (AS-BUTON) MIXTURE

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# THE EFFECT OF SEA WATER IMMERSION ON BUTON ASPHALT (AS-BUTON) MIXTURE

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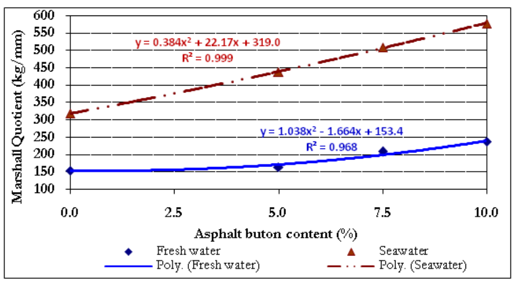
**Graphical abstract**




**Abstract**

One of the causes of flexible pavement damage is being submerged in water with a high acidity, such as sea water. To overcome this condition, a study on the use of Buton asphalt as a mixture of modified asphalt (as-buton) was conducted. The advantages of Buton asphalt are that it has higher adhesion and is more resistant to temperature changes. As-buton modification by mixing Lawele Buton Asphalt Southeast Sulawesi, Indonesia with oil asphalt pen 60/70. This study focuses on determining the effect of the addition of Buton asphalt to the modified asphalt mixture and the effect of sea water immersion on asphalt concrete modification Buton asphalt (as-buton) based on the Marshall characteristic test. The percentage by weight of Buton asphalt used is 5%, 7.5%, and 10%. The immersion was carried out in two conditions, namely freshwater immersion and sea water immersion for up to 24 hours at a temperature of 30°C. The result of this study show that the addition of Buton asphalt increase the value of stability, void in mixture, Marshall quotient, and void in mineral aggregate, but reduce the value of flow, void filled with asphalt, and density. The increase of stability and marshall quotient value in sea water immersion due to the addition of buton asphalt was higher than that in freshwater. The stability value of the 10% modified as-buton mixture in freshwater immersion increased by 169.338 kg (14.61%) and in sea water immersion increased by 1261.669 kg (55.65%). The flow value in freshwater immersion decreased by 1.9 mm (25.33%) while in sea water immersion decreased by 1 mm (14.08%). For further research, variations in the addition of Buton asphalt will be carried out to obtain the optimum Buton asphalt content which produces a modified asphalt mixture with the best performance.

*Keywords*: Marshall characteristics, asbuton, asphalt concrete wearing course, sea water immersion, asphalt mixture



## 1.0 INTRODUCTION

One type of road pavement construction is flexible pavement, namely pavement using asphalt as a binding material. Flexible pavement consists of pavement layers that carry and spread traffic loads to the subgrade. Flexible pavement is a composite material consisting of aggregate, asphalt mastic, air void, and filler. It is considered the primary paving type of road, taxiway, and runway, due to their good riding quality, fast construction speed, low noise, excellent durability, and stability [1], recyclability, and easy maintenance [2], [3]. In last decades, Indonesia intended to improve infrastructure by increasing highway network and building the asphalt pavement almost 329,926 km [4]. In China more than 90% is flexible pavement [5] and in the United State of America, flexible pavements represent 95% of total pavement [6].

Asphalt surface layer plays a fundamental role in flexible pavement structure, withstanding varying traffic loads and constantly changing environmental conditions. However, under the effects of repeated vehicle loading flexible pavements are susceptible to thermal cracking, low temperatures, and freeze-thaw cycles [7]. Many factors cause damage to flexible pavements. Asphalt pavement degradation is an inevitable phenomenon due to combined effects of high traffic loads or overloading, low speed vehicles [8] [9] and harsh environmental conditions. Environmental conditions include unstable subgrade conditions, temperature, weather, and water. Water is the main destroyer of road pavement. Especially water that has a high level of acidity such as sea water can affect the bond between asphalt and aggregate which accelerates oxidation, causing premature damage to the road surface layer. The influence of climate change causes natural phenomena such as tides, winds, waves, and ocean currents, which have a significant effect in parts of Indonesia, in coastal areas. The phenomenon of rising sea water causes tidal flooding so that roads near coastal areas are prone to experiencing sea water inundation either for a short time or for a long time. Sea water immersion will damage flexible pavement. Feng *et al*. in 2010 stated that salt has a significant effect on the asphalt binders performance on low temperature [10]. Asphalt concrete performance in sulfate solution is more severe than in water. The brucite fiber in the mixture has an excellent effect on enhancement, stability, and reinforcement [11].

The road pavement surface damage factor is one of the causes of traffic accidents [12]. It is necessary to seek efforts to repair road damage. High concentration of salt spray in the environment deteriorates asphalt mixtures durability [13]. Chen and Xu investigate the fibers in reinforcing effects and mechanisms for stabilizing and reinforcing asphalt binder. Fibers improve asphalt binder's resistance to rutting, flow, and dynamic shear modulus [14]. Tahmoorian and Samali using recycled construction aggregate in asphalt mixtures. Mixtures containing recycled construction aggregate have better workability, deformation resistance and compaction in comparison with basalt [15]. The previous study, Sugiyanto in 2017 identified the asphalt concrete characteristic produced from scrapped tire rubber. Scrapped tire rubber can improve resistance to permanent deformation due to ruts, provide better resistance in high temperatures [16], and resistance to water [17]. Liu *et al*. added the steel wool [18] and Do *et al*. using recycled waste lime in asphalt concrete mixture. Recycled waste lime improves stiffness, permanent deformation characteristics, and fatigue endurance of asphalt concrete [19]. Bowers *et al*. in 2014 investigated the reclaimed asphalt pavement blending efficiency through gel permeation chromatography. Blending occurs throughout all layers of the asphalt mixture [20]. As mentioned by Ge *et al.* in 2017 penetration and asphalts ductility decreased and softening point of asphalts increased after modified with Sasobit and Polyphosphoric acid [21]. The other study, addition of nanoclay and carbon microfiber improve mixture's moisture susceptibility performance [22]. Polyester fibers improve properties of asphalt mixture [23]. The pulling rate and asphalt film thickness have an equivalent relation. As mentioned by Huang *et al*. binder bond strength tests could be applied to reflect mixture resistance in modified asphalt mixtures [24].

One effort that can be tried to reduce the damage to flexible pavements due to sea water immersion is addition of buton asphalt into a modified mixture. The Buton Asphalt (As-buton) is natural rock asphalt in Lawele, South Buton Island, Southeast Sulawesi, Indonesia. As-buton consists of 20-35% high quality bitumen and 65-80% limestone filler. The total deposit is estimated at 650 million tones [25]. The advantages of Buton Asphalt are that it has higher adhesion and more resistance to temperature changes so that it is expected to increase stability to water. The aim of this research is to identify the effect of sea water immersion on asphalt concrete modification buton asphalt (as-buton). Experimental investigation based on characteristics of Marshall conducted to determine the effect of sea water on the modification asphalt containing as-buton. The novelty of this research is that the composition of the modified as-buton asphalt mixture was produced and the effect of the buton asphalt mixture in sea water immersion was based on Marshall characteristic test results.

## 2.0 METHODOLOGY

### 2.1 Asphalt Mixture and Gradation of Aggregate

In this research, a layer of asphalt concrete type namely Asphalt Concrete-Wearing Course (AC-WC) with maximum aggregate size is 19 mm. The aggregate gradations limit specification by the Ministry of Public Work Republic of Indonesia: *Bina Marga* 2010 (Revision 3) as stated in Table 1 [26].

### 2.2 Material

Materials in this research consists of coarse and fine aggregate, filler using stone ash, asphalt Buton, asphalt with the penetration grade 60-70 from PERTAMINA, Indonesia and sea water. Asphalt buton from deposits on Lawele, South Buton Island, Southeast Sulawesi. Sea water used in this research is taken from Teluk Penyu Beach, in Cilacap District, Central Java Province, Indonesia. The characteristics of the sea water from Teluk Penyu Beach, salinity value 25 ‰ and the Potential of Hydrogen (pH) value 8.52.

**Table 1** Specification of aggregate gradation limits for AC-WC Mixture [26]

| Size of sieve (mm) | Sieve number | Percentage passing of sieve (%) Lower limit | Upper limit |
|---|---|---|---|
| 19.1 | ¾ inch | - | 100 |
| 12.7 | ½ inch | 90 | 100 |
| 9.52 | 3/8 inch | 77 | 90 |
| 4.76 | No. 4 | 53 | 69 |
| 2.38 | No. 8 | 33 | 53 |
| 1,18 | No. 16 | 21 | 40 |
| 0.59 | No. 30 | 14 | 30 |
| 0.279 | No. 50 | 9 | 22 |
| 0.149 | No. 100 | 6 | 15 |
| 0.074 | No. 200 | 4 | 9 |

## 2.3 Methods

The test methods and standards for coarse and fine aggregate and asphalt followed the Indonesian specification or Standard National of Indonesia (SNI). The conducted tests are water absorption, specific gravity, abrasion, adhesive of aggregate and asphalt. Standards used namely SNI 1969-2008 [27] for bulk specific gravity and water absorption test, SNI 2417-2008 [28] for abrasion test, SNI 06-2456-2011 [29] for penetration test of asphalt, SNI 2441-2011 [30] for specific gravity of asphalt test, SNI 2432-2011 [31] for ductility asphalt test, SNI 2433-2011 [32] for flash and fire point of asphalt test, SNI 2434-2011 [33] for softening point of bitumen test, and SNI 7729-2011 [34] for viscosity asphalt test. Asphalt content ranges from 4.5 to 6.5% based on the study by Sugiyanto *et al*. in 2015 [35]. To determine the optimum asphalt content, the AC-WC mixture was varied from 4.5 to 6.5% at 0.5% interval. The specimens were immersed in freshwater and sea water for up to 24 hours at a temperature of 30°C.

Seven characteristics of Marshall Test namely void in mixture, void in mineral aggregate, voids filled with asphalt, flow, stability, Marshall quotient, and density. Total samples in this study are 39 units, 15 samples for Marshall Test characteristic to get the optimum asphalt content value from AC-WC mixture and 24 samples for freshwater and sea water immersion test. There are 9 samples of modification buton asphalt (as-buton) for freshwater immersion test, and 9 samples of as-buton mixture for sea water immersion test. The percentage by weight of Buton asphalt used is 5%, 7.5%, and 10%. The number of samples of each asphalt content is 3 samples. Details of the mixture type and number of samples of AC-WC mixture for Marshall Test characteristic are shown in Table 2. Details of the number of samples of asphalt mixture and modification as-buton mixture (The percentage by weight of Buton asphalt 5%, 7.5% and 10%) for freshwater and sea water immersion test are shown in Table 3.

**Table 2** Number of samples of AC-WC mixture for Marshall Test

| Mixture type | Asphalt content (%) | The number of samples |
|---|---|---|
| AC-WC | 4.5 | 3 |
| AC-WC | 5.0 | 3 |
| AC-WC | 5.5 | 3 |
| AC-WC | 6.0 | 3 |
| AC-WC | 6.5 | 3 |
| | Total | 15 |

**Table 3** Number of samples of asphalt mixture for freshwater and sea water immersion test

| Asphalt Buton content (%) | The number of samples Freshwater immersion | Sea water immersion |
|---|---|---|
| 0 | 3 | 3 |
| 5 | 3 | 3 |
| 7.5 | 3 | 3 |
| 10 | 3 | 3 |
| Total | 12 | 12 |

# 3.0 RESULTS AND DISCUSSION

## 3.1 Aggregate Test Results

The aggregate physical properties and characteristics of coarse aggregate, fine aggregate, and filler are determined based on the aggregate tests. The physical properties test results of coarse aggregate include specific gravity, water absorption, and abrasion test as shown in Table 4. The physical properties of fine aggregate and filler can be seen in Table 5.

**Table 4** Physical properties of coarse aggregate

| Tests (unit) | Result | Specification | Standard |
|---|---|---|---|
| Bulk specific gravity (gr/cc) | 2.57 | Min. 2.50 | SNI 1969-2008 |
| SSD specific gravity (gr/cc) | 2.58 | Min. 2.50 | SNI 1969-2008 |
| Effective specific gravity (gr/cc) | 2.58 | Min. 2.50 | SNI 1969-2008 |
| Water absorption (%) | 0.28 | Max. 3% | SNI 1969-2008 |
| Abrasion test with Los Angeles machine 100 rotations (%) | 4 | Max. 6% | SNI 2417-2008 |
| Abrasion test with Los Angeles machine 500 rotations (%) | 11 | Max. 30% | SNI 2417-2008 |

Based on Table 4, the physical properties test results of coarse aggregate include: bulk specific gravity is 2.57 (min. specification 2.50), water absorption 0.28% (max. specification 3%), the abrasion with Los Angeles Machine 100 rotation for asphalt mixture 4% (max. specification 6%), and the abrasion with Los Angeles Machine 500 rotation for as-buton modification mixture 11% (max. specification 30%). It means that coarse aggregate: crushed stone is complying with required specification standards and can be used as a coarse aggregate in asphalt concrete mixture and as-buton modification mixture. Based on Table 5, the result of physical properties of fine aggregate are water absorption is 0.42% (maximum specification 3%), the bulk specific gravity is 2.56 (minimum specification 2.50). The specific gravity of stone ash as filler in the asphalt mixture is 2.56 (minimum specification 2.5). The results of aggregate gradation examination obtained the percentage of coarse aggregate, namely aggregate grains which have a larger grain size than sieve no. 4 (4.76 mm) of 39%. Fine aggregate which has a finer grain size than sieve no. 4 (4.76 mm) of 54.5% and filler is 6.5%.

**Table 5** Physical properties of fine aggregate and filler

| Tests (unit) | Result | Specification | Standard |
|---|---|---|---|
| Bulk specific gravity of fine aggregate (gr/cc) | 2.56 | Min. 2.50 | SNI 1969-2008 |
| SSD specific gravity of fine aggregate (gr/cc) | 2.57 | Min. 2.50 | SNI 1969-2008 |
| Effective specific gravity of fine aggregate (gr/cc) | 2.57 | Min. 2.50 | SNI 1969-2008 |
| Water absorption (%) | 0.42 | Max. 3% | SNI 1969-2008 |
| Filler specific gravity (gr/cc) | 2.56 | Min. 2.50 | SNI 1969-2008 |

## 3.2 Asphalt Test Results

Asphalt with the penetration grade 60-70 from PERTAMINA, Indonesia was used in this research. Asphalt test includes penetration of asphalt, softening point, ductility, specific gravity, flash and fire point, and viscosity. The asphalt test results can be seen in Table 6. The asphalt buton modification test results with 5%, 7.5% and 10% as-buton can be seen in Table 7.

**Table 6** Asphalt test results

| Tests (unit) | Result | Specification | Standard |
|---|---|---|---|
| Penetration (dmm) | 63.6 | 60-70 | SNI 06-2456-2011 |
| Softening point (°C) | 54 | ≥ 48 | SNI 2434-2011 |
| Flash point (°C) | 282 | Min. 200 | SNI 2433-2011 |
| Fire point (°C) | 333 | - | SNI 2433-2011 |
| Ductility (cm) | 124.5 | Min. 100 | SNI 2432-2011 |
| Specific gravity (gr/cc) | 1.046 | ≥ 1.00 | SNI 2441-2011 |
| Viscosity (cSt) | | - | SNI 7729-2011 |
| Mixing temp. (°C) | 153 | | |
| Compaction temp. (°C) | 143.5 | | |

Based on Table 6, the penetration test in temperature 25$^0$C is 63.6 dmm (specification 60-70 dmm). The softening point of asphalt based on the ring and ball test method is 54°C (min. specification 48°C). Based on the penetration value and softening point of asphalt can be analyzed the penetration index. Flash and fire points of asphalt using Cleveland open cup method [32]. The value of the flash point is 282°C (min. specification 200°C) and the fire point of asphalt is 333°C. The ductility of asphalt is 124.5 cm (specification ≥ 100 cm). The specific gravity value of asphalt is 1.046 (min. specification 1.0). Asphalt with the penetration grade 60-70 from PERTAMINA is compliant with the required specification *Bina Marga* 2010 (Rev. 3) and can be used as bitumen in AC-WC mixture.

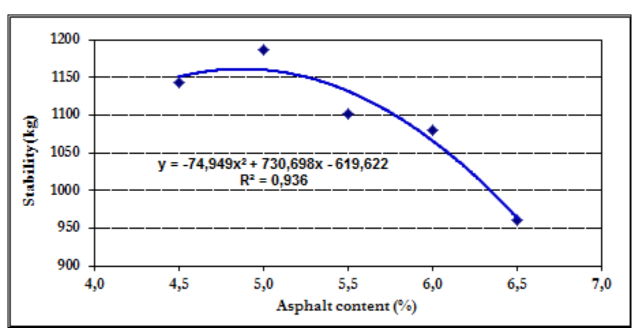
**Table 7** As-buton modification test results

| Tests (unit) | Asphalt buton content (%) | | | Speci-fication |
|---|---|---|---|---|
| | 5 | 7.5 | 10 | |
| Penetration (dmm) | 53 | 52 | 51.5 | Min. 50 |
| Softening point (°C) | 54.4 | 54.7 | 55 | ≥ 53 |
| Ductility (cm) | 104.5 | 102.5 | 100 | ≥ 100 |
| Specific gravity (gr/cc) | 1.060 | 1.078 | 1.097 | ≥ 1.00 |

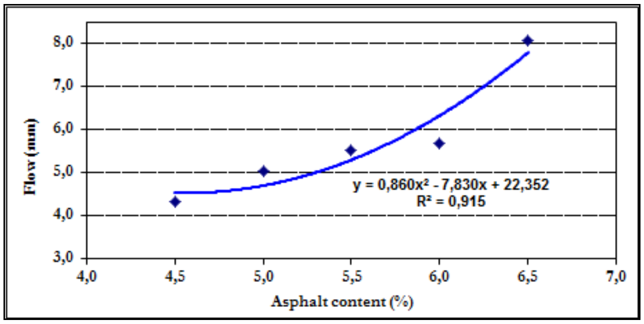
Based on Table 7, the penetration value for as-buton modification 5% is 53 dmm, as-buton modification 7.5% is 52 dmm, and 51.5 dmm for as-buton modification 10% (min. specification 50 dmm). The softening point of asphalt based on the ring and ball test method is 54.4 °C for 5% as-buton, 54.7 °C for 7.5% as-buton, and 55°C (min. specification 53°C). The specific gravity of as-buton modification 5% is 1.060, 7.5% is 1.078, and 1.097 for as-buton 10% (min. specification 1.0). As-buton modification is complying with the required specification Ministry of Public Works *Bina Marga* 2010 (Rev. 3) [26].

## 3.3 Marshall Test Result

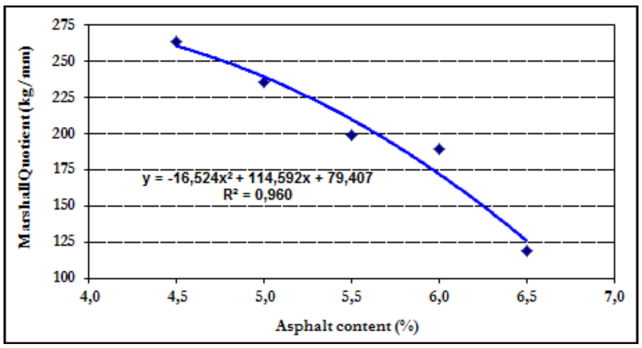
Marshall tests characteristic for the AC-WC or Asphalt Concrete-Wearing Course mixture with asphalt content range from 4.5 to 6.5%. Seven characteristics of Marshall Test namely Void in Mixture (VIM in % volume), Void in Mineral Aggregate (VMA in % volume), Voids Filled with Asphalt (VFA in % VMA), flow in mm, stability in kg, Marshall Quotient (MQ) in kg/mm and density in gr/cc. Specification for Marshall Test based on specification *Bina Marga* 2010 (Rev. 3) [26]. Marshall Test results for AC-WC mixture for seven characteristics can be seen in Figure 1.



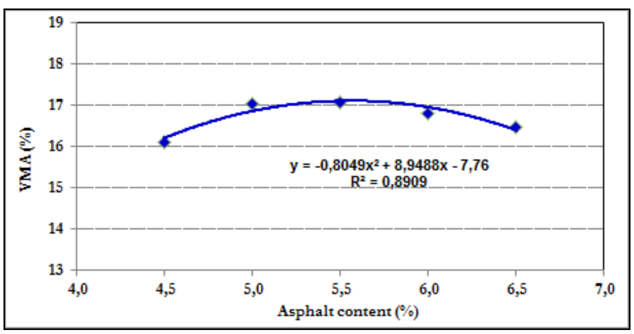

a. Relationship asphalt content and stability



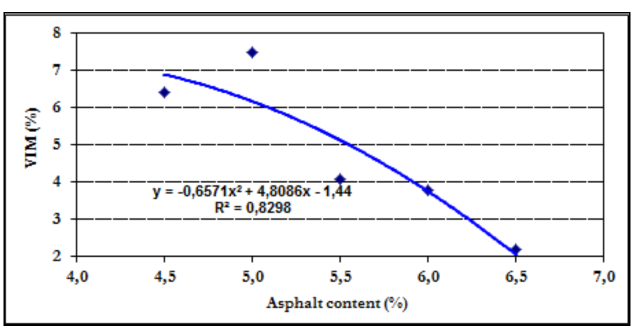

b. Relationship asphalt content and flow



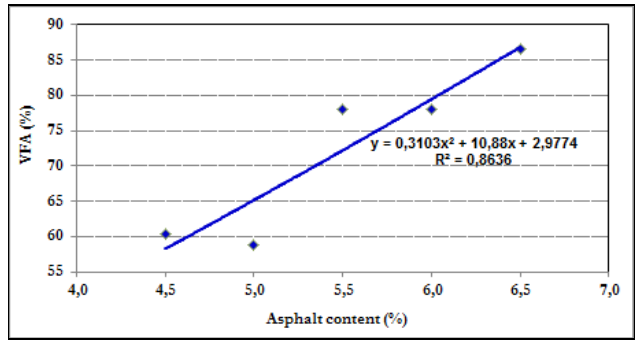

c. Relationship asphalt content and marshall quotient



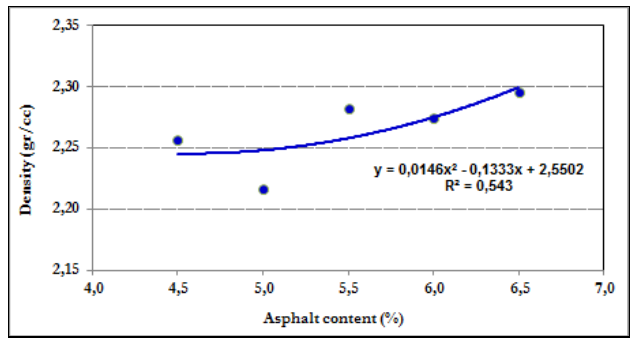

d. Relationship asphalt content and void in mineral aggregate




e. Relationship asphalt content and void in mixture




f. Relationship asphalt content and voids filled with asphalt




g. Relationship asphalt content and density

**Figure 1** Marshall Test analysis results for AC-WC mixture

The flow result test of AC-WC mixture is increasing with the addition of asphalt content. For the asphalt content value from 4.5 to 6.5%, the flow value of asphalt mixture is 4.33-8.07 mm (≥ 3 mm), so that the asphalt mixture is complying with the required specification standard for the asphalt content from 4.5 to 6.5%. The third parameter Marshall Quotient (MQ) values for AC-WC mixture is 119.14 to 263.92 kg/mm (min. 250 kg/mm) [26]. The MQ values for AC-WC mixture is complying with the required specification for asphalt content from 4.5 to 4.75%. VMA shows the percentage of the number of air voids in the aggregate that can be filled with asphalt. The greater of the air voids between the aggregate grains, the greater the value of the air voids in the mixture. The VMA value for asphalt content of 4.5-6.5% obtained a value of 16.122 to 17.077%, it has complied with the requirements of the Highways specification is 14%. The VFA value shows the amount of cavity in the mixture filled with asphalt. The VFA value from test results obtained from 58.849 to 86.585%. The minimum requirement for a VFA value is 63%.

The determination of optimum asphalt content value for the AC-WC mixture based on Marshall Test characteristics is shown in Figure 2. In the AC-WC mixture, seven characteristics of Marshall Test include: stability, flow, VMA, and density value are appropriate for the asphalt content from 4.5 to 6.5%. VIM value is appropriate for asphalt content from 5.34 to 6.235%, VFA appropriate for asphalt content from 4.848 to 6.5% and MQ for asphalt content 4.5 to 4.75%. The asphalt content that can satisfy six specifications of Marshall Test characteristic is from 5.34 to 6.235%. So the optimum asphalt content value of the AC-WC mixture is the median from 5.34 to 6.235% is 5.79% (indicated by the blue arrow in Figure 2).

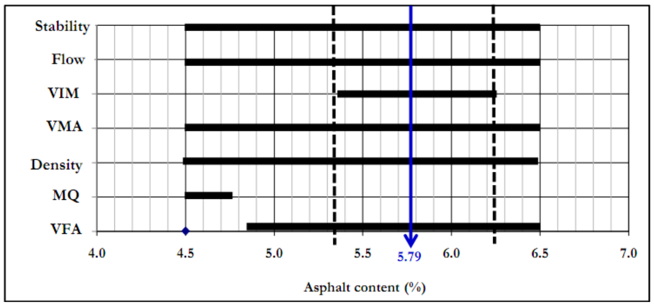



**Figure 2** Optimum asphalt content determination for the AC-WC mixture

The value of each Marshall Test analysis results for the AC-WC mixture with optimum asphalt content 5.79% is shown in Table 8. The specification of each parameter based on the Minister of Public Works: *Bina Marga* 2010 (Rev. 3) [26].

**Table 8** Marshall Test analysis results for AC-WC with optimum asphalt content 5.79%

| Marshall Test | Result for 5.79% | Specification |
|---|---|---|
| Stability (kg) | 1098.52 | Min. 800 |
| Flow (mm) | 5.85 | Min. 3 |
| MQ (kg/mm) | 188.94 | Min. 250 |
| VMA (%) | 17.1 | Min. 14 |
| VIM (%) | 4.37 | 3-5.5 |
| VFA (%) | 76.36 | Min. 63 |
| Density (gr/cc) | 2.249 | - |

Based on Table 8, with optimum asphalt content value for AC-WC mixture is 5.79%, from seven characteristics Marshall tests only Marshall Quotient (MQ) that doesn't comply with the Bina Marga specification. The higher MQ value, the higher stiffness of a mixture and more susceptible the mixture to cracking. A stability value of asphalt mixture that is too high will result in a pavement that is too stiff so that its durability is reduced. As for the other six parameters comply with the Bina Marga specifications. The void in mixture value of asphalt mixture must be maintained. Void in mixture value required for AC-WC mixture is between 3.5 to 5.5%. The asphalt mixture with void in mixture or VIM value range between 3 to 5.5% is not susceptible to flowing, melting, and plastic deformation. A very high VFA value will cause bleeding. Based on the optimum asphalt content result, the next step is making the asphalt buton modification with the percentage by weight of Buton asphalt used is 5%, 7.5%, and 10%.

## 3.4 Marshall Immersion Test Result

The results of Marshall Immersion for AC-WC mixture (without as-buton (0%) and asphalt buton modifications 5% (as-buton 5%), as-buton 7.5%, and as-buton 10% are shown in Table 9 that immersed in freshwater and Table 10 for sea water immersion up to 24 hours at temperature of 30°C. Seven parameters of Marshall Test characteristics include stability, VIM or Void in Mixture, VMA or Void in Mineral Aggregate, VFA or Voids Filled with Asphalt, flow, Marshall Quotient (MQ), and density.

**Table 9** Marshal test characteristics of modification asphalt buton mixture in freshwater immersion

| Marshal test characteristics | Asphalt buton content (%) 0 | 5 | 7.5 | 10 | Speci-fication |
|---|---|---|---|---|---|
| Stability (kg) | 1159.01 | 1215.61 | 1250.12 | 1328.35 | Min.1000 |
| Flow (mm) | 7.5 | 7.4 | 6.0 | 5.6 | Min. 3 |
| MQ (kg/mm) | 154.535 | 164.271 | 208.354 | 237.206 | Min. 300 |
| VMA (%) | 14.675 | 15.690 | 15.825 | 15.914 | Min. 15 |
| VIM (%) | 1.50 | 2.90 | 3.20 | 3.60 | 3.5-5.5 |
| VFA (%) | 89.644 | 81.731 | 79.779 | 77.703 | Min. 65 |
| Density (gr/cc) | 2.330 | 2.303 | 2.299 | 2.297 | - |

**Table 10** Marshal test characteristics of modification asphalt buton mixture in sea water immersion

| Marshal test characteristics | Asphalt buton content (%) 0 | 5 | 7.5 | 10 | Speci-fication |
|---|---|---|---|---|---|
| Stability (kg) | 2267.24 | 2738.19 | 3155.24 | 3528.94 | Min.1000 |
| Flow (mm) | 7.10 | 6.25 | 6.20 | 6.10 | Min. 3 |
| MQ (kg/mm) | 319.329 | 438.111 | 508.909 | 578.514 | Min. 300 |
| VMA (%) | 14.993 | 15.099 | 15.366 | 15.632 | Min. 15 |
| VIM (%) | 1.90 | 2.20 | 2.60 | 3.20 | 3.5-5.5 |
| VFA (%) | 87.557 | 86.274 | 83.079 | 79.284 | Min. 65 |
| Density (gr/cc) | 2.322 | 2.319 | 2.312 | 2.304 | - |

## 3.5 Before and After Immersion

There are seven characteristics of Marshall Test of asphalt mixture in before and after immersion. Two conditions of immersions are in freshwater and sea water immersion. The comparison for seven characteristics of marshall test in before immersion and after immersion can be seen in Table 11.

**Table 11** Marshal test characteristics of asphalt mixture before and after immersion

| Marshal test characteristics | Before immersion Result | Spec. | After immersion Freshwater | Sea water | Spec. |
|---|---|---|---|---|---|
| Stability (kg) | 1098.52 | Min. 800 | 1159.01 | 2267.24 | Min.1000 |
| Flow (mm) | 5.85 | Min. 3 | 7.5 | 7.10 | Min. 3 |
| MQ (kg/mm) | 188.94 | Min. 250 | 154.535 | 319.329 | Min. 300 |
| VMA (%) | 17.1 | Min. 14 | 14.675 | 14.993 | Min. 15 |
| VIM (%) | 4.37 | 3-5.5 | 1.50 | 1.90 | 3.5-5.5 |
| VFA (%) | 76.36 | Min. 63 | 89.644 | 87.557 | Min. 65 |
| Density (gr/cc) | 2.249 | - | 2.330 | 2.322 | - |

### 3.6 Discussion

The comparison of Marshall test characteristics of asphalt mixture before and after immersion can be seen in Figure 3. The stability of the asphalt mixture before immersion was 1098.52 kg and increased 5.5% when soaked in freshwater and increased 106% when soaked in sea water. Stability value that is too high will cause the flexible pavement to become stiff so that its durability is reduced.

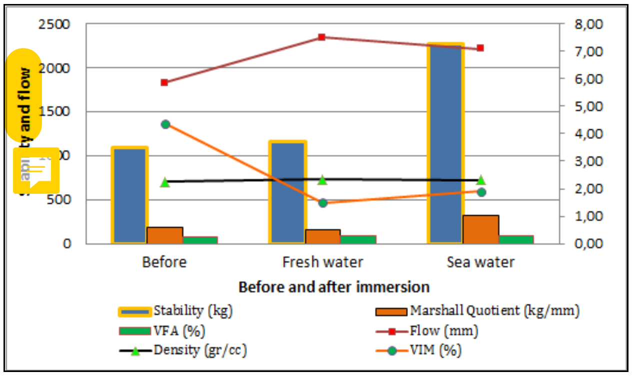



**Figure 3** Comparison of Marshall test characteristics of asphalt mixture before and after immersion

The adding Buton asphalt effect to the modified asphalt mixture and effect of soaking the mixture in sea water can be explained as follows: as depicted in Table 9 and Table 10, the results show that the asphalt mixture stability will increase with addition of Buton asphalt content. This occurs because the bitumen contained in grain buton asphalt mixes with asphalt with the penetration grade 60/70 in the asphalt mixture and causes the adhesion of the asphalt mixture to be better. The stability value of the modified asphalt buton mixture immersed in sea water is also greater than that immersed in freshwater. The increase in stability value due to the addition of buton asphalt as much as 10% in freshwater immersion reached 169.338 kg (increased by 14.61%) while sea water immersion reached 1261.669 kg (increased by 55.65%).

Relationship between stability with asphalt buton content in freshwater and sea water immersion is shown in Figure 4. The addition of asphalt buton (as-buton) content in the asphalt mixture will result in a decrease in the flow value. The mobilization of bitumen from the as-buton grain causes the asphalt to become harder. The flow value of asphalt mixture immersed in freshwater decreased by 1.9 mm (decreased by 25.33%), while those immersed in sea water decreased by 1 mm (decreased by 14.08%). The higher the stability value, the more rigid the asphalt mixture, so that the level of durability decreases. Relationship between flow with asphalt buton content in freshwater and sea water immersion is shown in Figure 5.

The Marshall Quotient (MQ) value of the asphalt mixture increases with the addition of as-buton content. The MQ value of the modified asphalt buton mixture immersed in sea water is greater than that immersed in freshwater. The increase in MQ value due to the addition of 10% as-buton in freshwater immersion reached 82.67 kg/mm (increased by 53.50%) while in sea water immersion it reached 259.185 kg/mm (increased by 81.17%). The increase of MQ value from modified asphalt buton immersed in sea water was greater than immersed in freshwater. Asphalt mixtures with as-buton grain substitution tend to be stiffer. Relationship between MQ with asphalt buton content in freshwater and sea water immersion is shown in Figure 6.

The void in mineral aggregate (VMA) and void in mixture (VIM) values of asphalt mixture also increased with each addition of as-buton levels. The increase in VMA value in freshwater immersion reached 8.44% while in sea water immersion it increased by 4.26%. The increase in the VIM value of the modified as-buton mixture immersed in freshwater reached 140% and in sea water it increased by 68.42%. Meanwhile, the addition of as-buton content in the modified as-buton mixture tends to decrease the voids filled with asphalt (VFA) value. The VFA value in freshwater immersion decreased by 13.32% while that in sea water immersion decreased by 9.45%. The effect of adding asphalt buton to the modified asphalt mixture on the density value is less significant. The difference in density values in the mixture without as-buton and as-buton substitution by 10% in freshwater immersion only decreased by 0.033 (1.42%) and in sea water immersion decreased by 0.018 (0.78%). The relationship between VMA with asphalt buton content in freshwater and sea water immersion is shown in Figure 7, relationship between VIM with asphalt buton content in freshwater and sea water immersion is shown in Figure 8, relationship between VFA with asphalt buton content in freshwater and sea water immersion is shown in Figure 9, and relationship between density with asphalt buton content in freshwater and sea water immersion is shown in Figure 10 respectively.

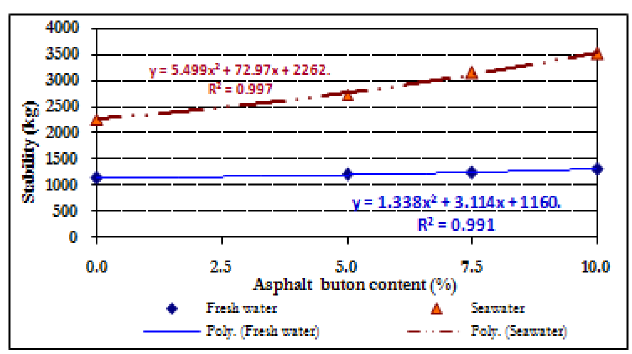



**Figure 4** Relationship between stability with asphalt buton content in freshwater and sea water immersion

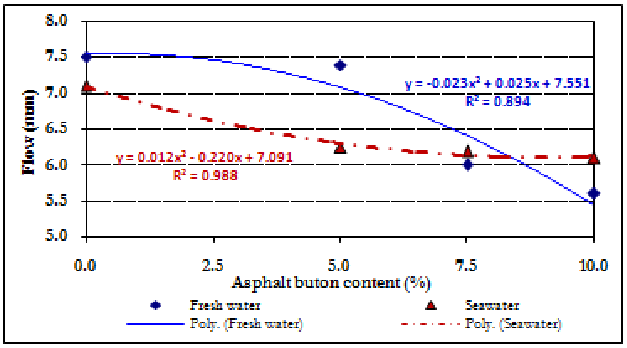



**Figure 5** Relationship between flow with asphalt buton content in freshwater and sea water immersion

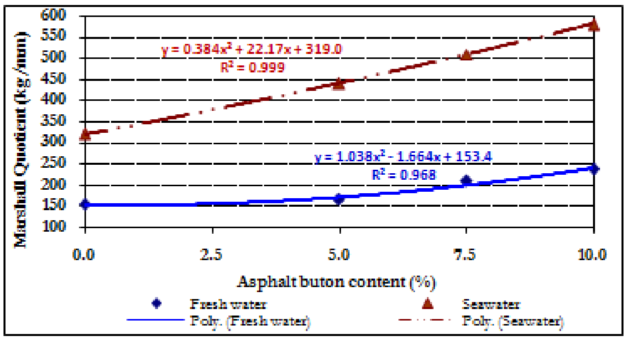



**Figure 6** Relationship between Marshall Quotient with asphalt buton content in freshwater and sea water immersion

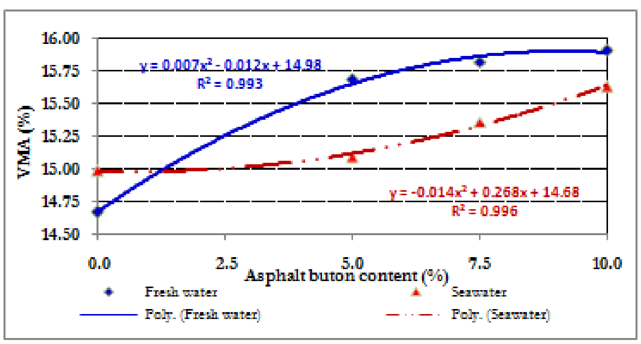



**Figure 7** Relationship between VMA with asphalt buton content in freshwater and sea water immersion

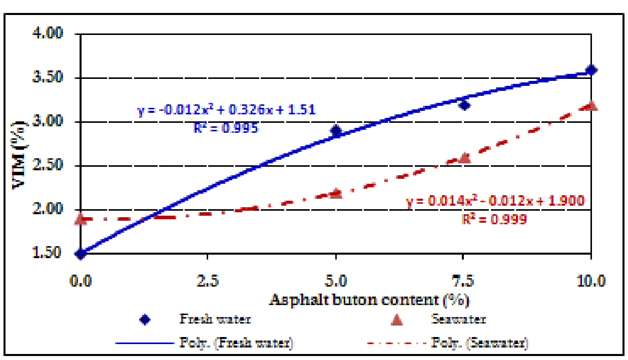



**Figure 8** Relationship between VIM with asphalt buton content in freshwater and sea water immersion

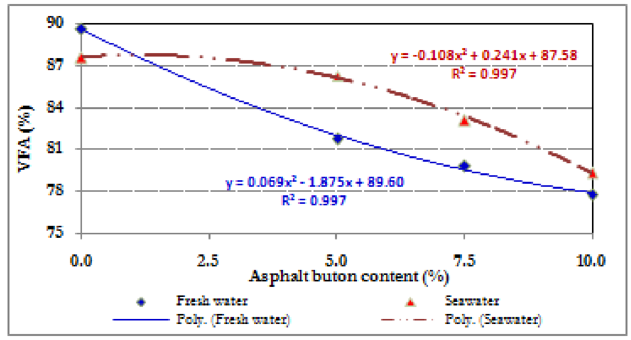



**Figure 9** Relationship between VFA with asphalt buton content in freshwater and sea water immersion

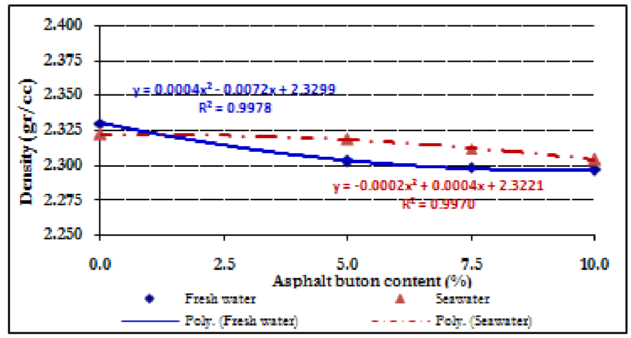



**Figure 10** Relationship between density with asphalt buton content in freshwater and sea water immersion

One of the factors that influences moisture transport of asphalt mixtures is the void structures characterization [36]. The Improvement of the adhesive zone will result in porous asphalt concrete which will improved the durability, lifetime of mixture [37] [38], and reduce the tire-pavement noise [39] [40]. Because of some of these advantages, the porous asphalt pavement is more efficient than conventional pavements [41]. As mentioned by Ganesan *et al*. in 2013 the replacement of fine aggregate by shredded rubber as much as 15% and 20% improved the fatigue strength of self compacting rubberized concrete [42]. In the other study by Qin in 2015 which studied the strategy to mitigate the urban heat island effect using cool pavements development. The heat-harvesting pavements seem interesting to resolve the issue because they stay cool. The heat-harvesting pavements can also be used as a renewable energy source [43]. The interaction level between filler and bitumen is highly dependent on the polymer modification type [44]. Asphalt porous concrete mix had better aggregates interlocking, homogeneous void structure [45], improved adhesion properties, and higher number of asphalt fibrils with longer lengths relative to the neat asphalt [46].

Sea water immersion increases the stability of asphalt mixture, so that its durability is reduced. The result of this study is similar to the study by Millero [47] and Setiadji *et* al. [48]. Chloride in tidal water is the main contributor to damage on the asphalt pavement [48]. Effect of salt in performance of asphalt binders accelerates the failure when salt percentage is more than 3% [49], increases the asphalt stiffening and decrease the adhesion [50], causes aggregate raveling in coastal areas [51], and water stability of mixture [52]. Sea water immersion has more influence on the value of stability, flow, and Marshall Quotient of asphalt mixture compared to freshwater immersion. The results of the comparison of sea water immersion in modified buton asphalt showed that addition of asphalt buton content increased stability and Marshall Quotient value but decreased the flow value.

## 4.0 CONCLUSION

This research determines the effect of addition of buton asphalt to the modified asphalt mixture and the effect of sea water immersion on buton asphalt (as-buton) mixture based on the Marshall characteristic test. Through this study, the addition of as-buton makes the asphalt mixture more resistant to temperature changes and increases stability to water. The addition of buton asphalt increases the stability, void in mixture, Marshall quotient, and void in mineral aggregate, but reduces the value of flow, void filled with asphalt, and density. The stability and Marshall quotient value of the modified as-buton mixture immersed in sea water is greater than that in freshwater. The stability value with 10% modified as-buton mixture in freshwater immersion increased 14.61% and in sea water immersion increased 55.65%. The flow value in freshwater immersion decreased 25.33% while in sea water immersion decreased 14.08%. For further research, variations in the addition of buton asphalt will be carried out to obtain the optimum buton asphalt content which produces a modified asphalt mixture with the best performance.

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