Marshall Characteristics of Asphalt Mixture with Water Hyacinth Ash as Filler

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Marshall Characteristics of Asphalt Mixture with Water Hyacinth Ash as Filler

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Abstract Road pavement is a quite important to support the mobilization of goods or services. Asphalt pavement is the main type of road pavement constructed in Indonesia. This kind of pavement consists of several materials, such as coarse aggregate, fine aggregate, asphalt as binder, and filler. Cement as filler is generally used in Indonesia, however, because of high cost, ones are more preferable to seek the substitute of cement. One type of material that could be used as cement substitute is water hyacinth, due to chemical properties it possesses. Water hyacinth contains chemical cellulose from organic polymers, and in the form of ash, it has a potential to increase the quality of asphalt. The purpose of this study was to evaluate the possibility of the use of water hyacinth ash (WHA) as a part of material of asphalt mixture. The method used was an empirical design method by conducting laboratory works to obtain primary data. The coarse and fine aggregates used came from Gringsing District, Batang Regency, Central Java Province, while the asphalt was the one with penetration grade 60/70. In this study, the content of WHA used as filler was 0, 25, 50, 75 and 100% of the total weight of filler. The results showed that the increasing use of WHA will decrease the stability and durability. Therefore, it is recommended to limit the use of WHA to a maximum of 25% as filler of the asphalt mixture, as a part of the implementation of green technology in practice.

Keywords Water hyacinth ash · Asphalt mixture · Stability · Durability

1 Introduction

An asphalt mixture is generally designed to be composed of constituent materials such as aggregates, asphalt, and fillers and made using standardized methods. The asphalt mixtures also have to be tested to ensure that the properties could fulfill the required specifications. It indicates that to obtain a road pavement structure that meets minimum performance standards, the required specifications to the material

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and supported by standard manufacturing procedures should be sufficient to pro-duce an asphalt mixture that is recognized for its quality.

However, with the reason to reduce materials that are not renewable and not environmentally friendly, there have been many studies conducted to add additives to an asphalt mixture with various objectives, such as increasing the mixture's stability and increasing the durability of the mixture. Likewise, the materials used are generally processed materials, such as rice husk ash, crumb rubber, and fly ash [1–3]. The performance of asphalt mixtures with used material which must be removed is generally compared to that of asphalt mixtures without additive material as a reference, with the main hypothesis is that the additive can improve the performance of one or more properties of the asphalt mixture.

In this study, water hyacinth ash, or called WHA in the rest of the paper, processed from water hyacinth plants, i.e., a plant that is often considered a nuisance at a pond or lake, is used as a partial replacement of cement fillers in asphalt mixtures. Compared to the use of WHA in asphalt mixtures, research on the use of WHA in concrete construction has been widely carried out [4–6]. The high potential for the use of WHA was found in work by Widyaningsih and Sutanto [7], in which a simulation was conducted to find the optimum asphalt content of the mixtures with Portland cement, WHA, or a combination of both as filler. However, the research did not provide detailed analysis results regarding the suitability of the WHA as a filler material in asphalt mixtures. Therefore, this study aims to explore in-depth the opportunities for using WHA as filler material in asphalt mixtures in terms of the physical aspects expressed in Marshall characteristic.

2 Water Hyacinth Ash

Water hyacinth (Eichhornia crassipes) is a floating tropical plant that grows in still or slow-moving fresh water bodies discovered by Carl Friedrich Philipp von Martius, a German botanist, in 1824 while on an expedition on the Brazilian Amazon River [8] Water hyacinth has a high growth speed, so that this plant is considered a weed that can damage the aquatic environment, as shown in Fig. 1.

Water hyacinth plants have the benefit of absorbing nutrients, metals, and trace organic substances from water [8], but due to uncontrolled growth of water, hyacinth causing adverse impacts, such as: (i) increasing evapotranspiration due to their broad leaves and rapid growth; (ii) decreasing the level of dissolved oxygen due to the reduced amount of oxygen entering the waters; (iii) accelerating the silting process, especially by dead water hyacinth plants. In order to overcome this negative impact, some actions are taken such as eradication using herbicides, predatory fish or lifting the water hyacinth and using it to support other useful things; one of them is by processing water hyacinth into water hyacinth ash (WHA) for added materials in construction in the field of Civil Engineering.

WHA was produced by collecting, washing, and drying water hyacinth in an oven for a certain period to convert the organic matter into an inorganic substance. The

(a) (b)

Fig. 1 Water hyacinth plant: **a** at Rawa Pening lake, Indonesia [9]; and **b** in the form of ash (WHA) [10]

dried water hyacinth then was ground and passed through a 150-micron sieve to enable the material used as the replacement for cement [4] (see Fig. 1b).

Based on the results of research by Sukarni et al. [11], the top five chemical proper-ties of water hyacinth are O (49.5 ± 6.71%), C (14.4 ± 6.81%), K (8.26 ± 2.62), Si (5.33 ± 4.52) and Fe (4.71 ± 4.32). After drying, one of the major constituents found in WHA is silicon dioxide or silica [10], which is one of the raw materials for Portland Cement. It is a strong reason why WHA has the potential to be investigated for its use as a partial replacement for Portland Cement in Civil Engineering structures. Although WHA has some similar constituent materials like cement, the specific gravity of WHA is much smaller than cement, which is less than 2.5, while the specific gravity of cement is equal to or more than 3.1 [5], and this could affect the calculation of voids in the mixture.

3 Research Methodology

The methodology of this research consists of several steps as follows:

a. Testing of material properties

In this research, an asphalt mixture called asphalt course wearing course (AC-WC) was used. The mixture was composed of dense-graded aggregate and asphalt Penetration 60/70. All materials have to be tested to ensure that their properties could conform to the specification used [12].

b. Mixture preparation

All materials were used to prepare the mixture briquettes in which the optimum asphalt content of the original asphalt mixture (i.e., with no WHA) was determined as the references for the subsequent works. Similar to Widyaningsih and Sutanto [7], four percentages of WHA (25, 50, 75, and 100 as ratio to ordinary cement) were selected in this study.

iii. Testing of the mixtures

The mixture were tested to determine the Marshall characteristics (Marshall stability, flow, VMA, VIM, and VFA) as indicators of the performance of the mixture with the addition of WHA. The mixtures also underwent a durability test by immersing the mixtures in the water at 60° for 1, 3, and 7 days, respectively.

iv. Analysis

The analyses conducted in this study were: (i) comparison of mechanistic and volumetric characteristics of each mixture with WHA against those of the original mixture, (ii) deep analysis of Marshall characteristics, especially volumetric ones, to see a possibility to answer the phenomenon occurred, and (iii) recommendation of the use of WHA in the actual project.

4 Research Methodology

Three fractions of local aggregate from Gringsing District, Central Java Province, Indonesia, i.e., ¾ and ½ in. maximum-size coarse aggregate fraction and fine aggregate fraction, and one type of asphalt, i.e., Pertamina Pen 60/70 asphalt, were used in this study. To ensure that aggregate and asphalt properties conform to the specifications, all materials were tested using ASTM/AASHTO or SNI (Indonesian national standards). The results of the tests are shown in Tables 1 and 2.

Table 1 Results of aggregate tests

No.	Properties	Result	Specification
	Fine aggregate		
1	Passing sieve no. 200 (%)	3.31	Max. 8
2	Water absorption (%)	2.48	Max. 3
3	Specific gravity	2.57	Min. 2.5
4	Sand equivalent value (%)	98.21	Min. 50
	Coarse aggregate		
1	Loss Angeles abrasion value (%)	12.52	Max. 40
2	Affinity for asphalt (%)	97.9	Min. 95
3	Flakiness and elongation indices (%)	8.12	Max.10
4	Passing sieve no. 200 (%)	0.39	Max. 1
5	Water absorption (%)	1.46	Max. 3
6	Specific gravity	2.63	Min. 2.5
7	Angularity with one/two fractured faces (%)	98.21/95.49	Min. 95/90

Table 2 Results of asphalt tests

No.	Properties	Result	Specification
1	Penetration 60/70 Asphalt (0.1 mm)	68.33	60–70
2	Softening point (°C)	50.5	Min. 48
3	Ductility (cm)	127.5	Min. 100
4	Solubility of Trichloroethylene (%)	99.67	Min. 99
5	Specific gravity	1.015	Min. 1
6	Loss on heating (%)	0.4	Max. 0.8
7	Penetration after loss on heating (%)	77.52	Min.54
8	Ductility after loss on heating (cm)	91.5	Min. 50

Tables 1 and 2 indicate that the aggregate and asphalt properties can conform to the specifications. An aggregate gradation has to be selected carefully based on the aggregate gradation specification used; that is, aggregate gradation for the mixture of Asphalt Concrete Wearing Course (AC-WC) [12]. The aggregate gradation selected in this study is shown in Fig. 2.

Using the selected aggregate gradation, the mixtures can be designed using the following variation of WHA—PC compositions (by weight): 0–100%, 25–75%, 50–50%, 75–25%, and 100–25%, which is the similar composition to Widyaningsih and Sutanto [7]. The obtained optimum asphalt content and the Mar-shall characteristics of the mixture with 0–100% composition was used as the reference for the rest of the mixtures.

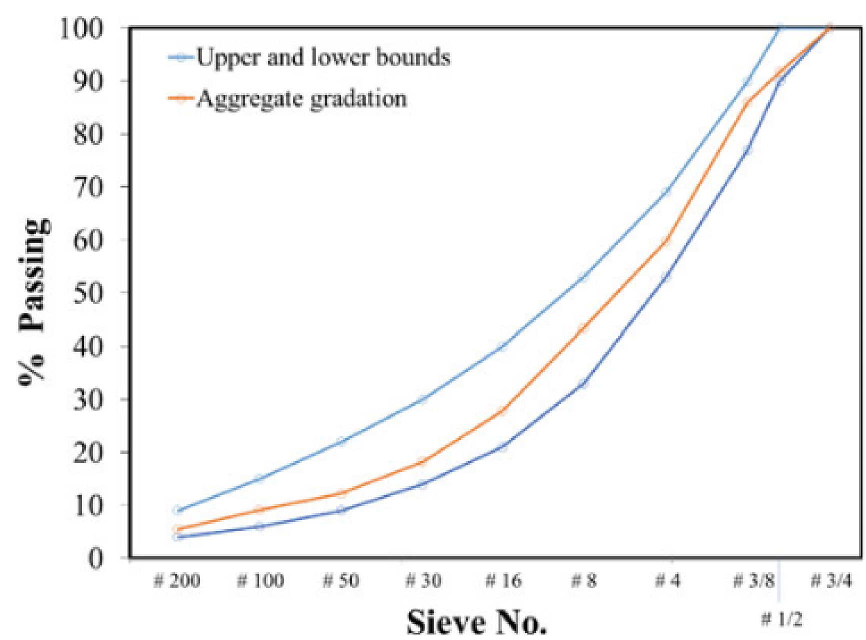

Fig. 2 Aggregate gradation used in this study

The optimum asphalt content of the mixture with 0–100% of WHA—PC composition is 5.5%, and the Marshall characteristics of that mixture at optimum asphalt content are as follows: Marshall stability 1157 kg, Flow 3.77 mm, VMA 17.49%, VIM 5%, and VFA 71.48%. All Marshall properties of the mixture can fulfill the Indonesian specification for the AC-WC mixture [12]. Next, using asphalt optimum content 5.5%, four sets asphalt mixture with different percentages by weight of WHA were prepared. Five Marshall properties (Marshall stability, flow, VMA, VIM, and VFA) were measured and calculated. The comparison among the four-set asphalt mixtures' property values against the reference mixture (i.e., mixture with no WHA) is shown in Fig. 3.

Figure 3 shows that only a mixture with WHA content equals 25% among mixtures with four different WHA content, which can satisfy all the Marshall properties. VMA is the only Marshall property that can be fulfilled by all mixtures containing WHA. Surprisingly, this result was supported by the similar findings by Widyaningsih and Sutanto [7], although the similarity of Marshall property trends between this study and the research by Widyaningsih and Sutanto [1] is only on the stability property, i.e., the highest the WHA content, the lowest the Marshall stability will be. This fact is also supported by the decrease of mixture density with the increase of WHA content.

From Fig. 3, it can be summarized that the mixture with a WHA content equal or more than 50% is not recommended due to the Marshall stability of the mixture is lower than the threshold specified by the specification. Marshall stability is one of the important parameters for AC-WC mixture because the advantage of this mixture type is the high Marshall stability value due to the ability to withstand high loads. Besides, high WHA levels also cause high VMA, but this finding is unfavorable, because the voids between aggregates are mostly filled with air voids. The high air void is a consequence of the low VFA in the asphalt mixture with high WHA at the same bitumen content, and this can cause the asphalt mixture to be less durable. The low VFA is also an indicator that the aggregates are not properly bonded to produce sufficient stiffness.

A durability test was also conducted on the mixtures with different WHA content. In this test, the mixtures were immersed for three different immersion periods (1, 3, and 7 days), and at the end of the periods, the mixtures were tested to measure the Marshall stability (see Fig. 4). Asphalt mixtures with a WHA content of 25% surprisingly experienced a significant decrease in stability value initially; however, the stability value did not change much after seven days of immersion and still met the mini-mum requirement of 800 kg. Meanwhile, asphalt mixtures with a WHA content of more than 50% experienced a slow decline in stability; however, due to the high air voids, it contributed to the lack of stiffness, therefore, it is not recommended to be used in practice.

As a closing remark, the use of WHA as a substitute for cement is a good option because it will reduce the cement material, which is an unrenewable material and a significant contributor to greenhouse gases. However, this study's results indicate that the use of WHA as a substitute for cement should be limited because excessive

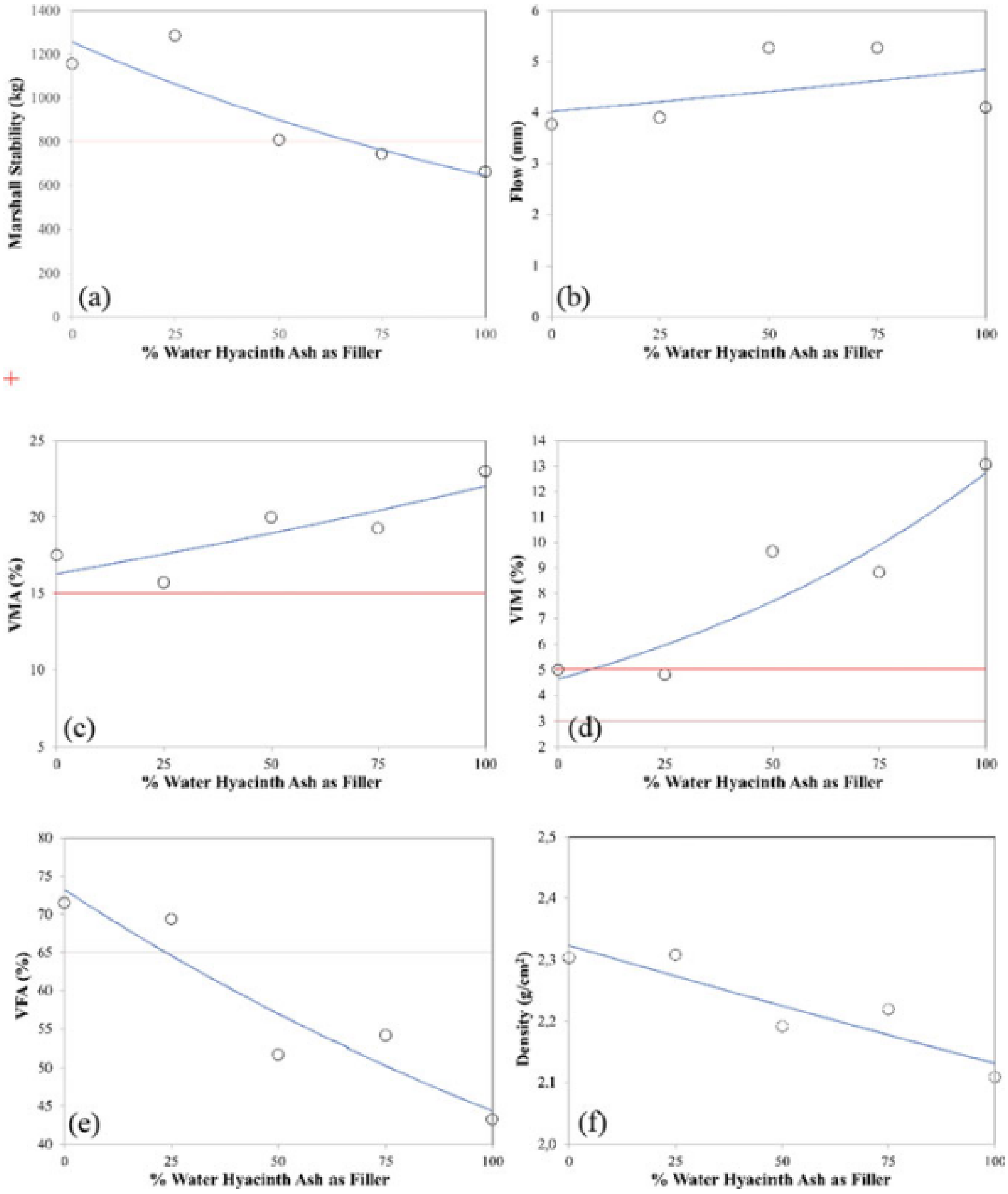

Fig. 3 Comparison of Marshall properties for asphalt mixtures with various WHA as filler: **a** Marshall stability; **b** Flow; **c** VMA; **d** VIM; **e** VFA; **f** density

use of WHA will reduce the stiffness of the mixture and absorb more asphalt causing increased air voids so that it reduces the durability of the mixtures.

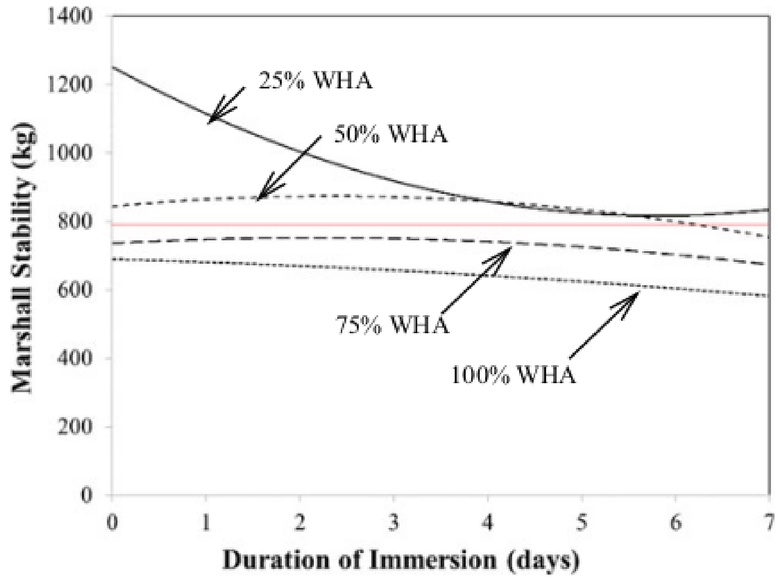

Fig. 4 Comparison of the results of durability test

5 Conclusions

This paper presented an evaluation of water Hyacinth Ash (WHA) used as a filler in asphalt mixture. To find out the influence of WHA on Marshall mixture's properties, five combination WHA—PC, i.e., 0, 25, 50, 75, and 100% WHA, were used. The results of this study indicated that the increasing use of WHA will decrease the stability. The use of WHA also could make the mixtures less durable due to high asphalt absorption and causing the increase of VIM. As a part of the implementation of green technology in practice, this study recommended a limit use of WHA to a maximum of 25% as filler of the asphalt mixture.

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