Evaluation of Flood Water Damage on Asphalt Concrete Using Elastic Modulus Ratio

Arief Setiawan, Latif Budi Suparma, and Agus Taufik Mulyono

Abstract— **Urban floods are a frequent disaster in Indonesia and cause road damage with the relatively high cost of repairs every year. Durability test of water damage of asphalt mixture on mild temperatures, such as indirect tensile test did not show the weakness of asphalt mixture. Therefore, this study aims to use an elastic modulus ratio, which is the result of an unconfined compressive strength test, as an indicator of the water damage of asphalt mixture. Five types of aggregate gradations of asphalt concrete wearing course and AC 60/70 asphalt at optimum bitumen content were selected. The specimen was treated with three conditions of aging, namely no aging, short-term oven aging and long-term oven aging. Immersion conditioning was carried out of 0, 1, 2, 4 and 7 days at 25 °C. Selokan Mataram Yogyakarta water in the rainy season was used as a medium attack. This study proposed equivalent retained strength of elastic modulus as the durability indicator of the asphalt mixture. The results show that elastic modulus can assess the effect of water damage on asphalt concrete, aging of asphalt concrete has a significant effect at more than 4 days immersion, and the optimum gradation of flood water resistance has Gradation Index 21.53-27.29%.**

Index Terms— **Asphalt concrete, elastic modulus, flood water, water damage**

I. Introduction

Indonesia is located around the equator so it has a tropical climate and two seasons namely dry and rainy season. Rainfall in some areas of the island of Borneo, Java, Sulawesi, Papua, and Bali is quite high around 1900-2500 mm per year [1]. Inadequate drainage channels capacity during the rainy season can cause flooding on the surface of road pavement that causes damage and decreases the safety and convenience of road users. Director General of Water Resources Ministry of Public Works, Mohammad Hasan said that in Indonesia

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there are 20 major cities prone to floods with 18 cities of which is the capital of the province including Jakarta [2]. The results of the inventory by the Directorate General of Highways at the Ministry of Public Works showed that the need for funds for the handling of national road damage due to floods and landslides in Indonesia reached Rp 2.12 trillion [3].

Previous research, [4] investigated rubberized asphalt concrete containing reclaimed asphalt pavement (RAP). The control specimen neither contains rubber nor RAP. Two aggregate sources and two types of asphalt performance grade or PG (PG 64-22 and PG 52-28) were used for preparing the specimen. Indirect tensile strength (ITS) was used to measure water resistance of asphalt concrete. There were three wet and three dry samples at room temperature (25 °C) for ITS tests. The specimens were fabricated to meet the target air void content of 7±1%. The ITS was obtained according to the specifications and procedures described in ASTM D 4123 at optimum bitumen content. The result showed that the control specimens have tensile strength ratio (TSR) more than 1.00 that means ITS is not properly to assess the water damage on short time immersion and mild temperature of the asphalt mixture.

Another research [5] showed the results of his research that indirect tensile strength at a mild temperature (around 25 °C) did not show the decrease of asphalt mixture strength. However, TSR has good prospect to see the effect of water on asphalt mixture if the long-term immersion was applied. The other research [6] said that Marshall and Indirect Tensile Strength (ITS) test were unable to assess the effect of the asphalt and aggregate gradation type of asphalt mixture. Therefore, this research uses the elastic modulus to measure water damage on asphalt concrete.

An aging on asphalt mixtures could increase cracking and aggregate loss and also decrease wear resistance and moisture susceptibility [7]. Although asphalt mixes are in dry conditions, stripping can occur due to the aging of asphalt [8].

The aim of this research is to evaluate water damage of the asphalt mixture due to flood water. This research also investigated the effect of aging on the durability of the asphalt mixture in term of water damage. The indicator of water damage is the elastic modulus ratio of asphalt mixture during the immersion period by using unconfined compressive strength (UCS) test. UCS test not only uses to measure the rutting potential, but it also uses to determine the elastic modulus of asphalt concrete.

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II. Experimental Design

A. Material selection

Aggregate derived from Tinalah River, Kulon Progo, Yogyakarta, Indonesia. The aggregate properties met the specifications required by [9]. Five aggregate gradation types of asphalt concrete wearing course were (1) upper limit or UL; (2) upper-middle or UM; (3) mid-range or MR; (4) mid-lower or ML; and (5) lower limit or LL. Five types of aggregate gradations selected can be seen in Fig. 1.

The binder is Asphalt Cement (AC) 60/70 ex. Pertamina. The result of the physical properties of asphalt showed that AC 60/70 comply with the standard of Bina Marga [9] to use as a binder of asphalt mixture [10].

B. Mix Design and Conditioning

Five types of asphalt concrete mixture at optimum bitumen content (OBC) comply with the General Specification of Third Revised Edition 2010 [9]. The dimension of the specimens is the 3-inch diameter and 6-inch height as can be seen in Fig. 2a and Fig.2b. The void in the mix of the specimen is 3-5%. The testing temperature of 25 °C and the variation of immersion time of 0, 1, 2, 4 and 7 days. The temperature was selected based on observation during the rainy season at the core of the specimen. One of twelve locations of flood water was selected as a medium attack on asphalt concrete and the water of Selokan Mataram, around the Faculty of Animal Science, Universitas Gadjah Mada Yogyakarta Indonesia, during the rainy season would be chosen as a medium attack for further observation (Fig. 2c). The characteristics of the flood water are pH 7.1 and Total suspended solids (TSS) 194.2 mg/L. The consideration of medium attack selection was the lowest immersion stability of asphalt concrete on the Marshall test.

There were three conditions for aging namely no aging (original), short-term oven aging (STOA) and long-term oven aging (LTOA). STOA is a laboratory aging procedure to simulate the aging effects of hot asphalt mixtures due to asphalt absorption during production in an asphalt mixing plant, transport, and spreading at work sites [11]. The preparation of the STOA test specimen was carried out in a loose asphalt mixture in the tray with a thickness of 25-50 mm, then put in the oven at 135 °C for 4 hours and compacted according to the compaction temperature. LTOA is a laboratory aging procedure used to simulate the effect of aging on an asphalt mixture during the pavement service life. Compacted asphalt mixture after STOA conditioning put in an oven at 85 °C for 48 hours to simulate 5 years of age on asphalt pavement [11].

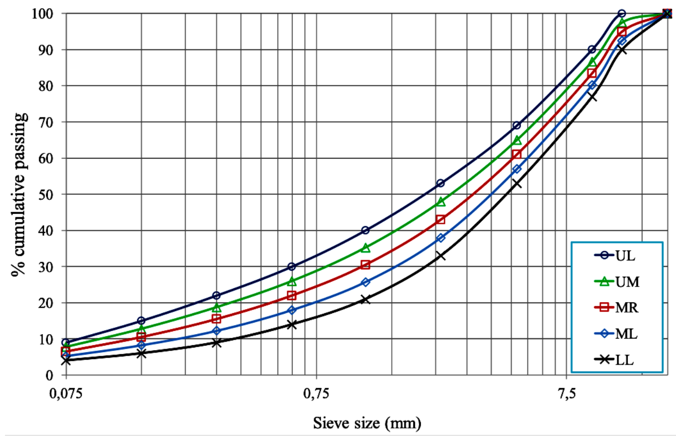

Fig. 1. Types of aggregate gradation selected

(a) 6-inch height (b) 3-inch diameter (c) Source of water selected

Fig. 2. UCS specimen (a, b) and water for medium attack as representing of flood water ©

C. Elastic Modulus

Unconfined compressive strength (UCS) test has been used for determining the elastic modulus of the asphalt mixture [12-14]. Young's modulus or elastic modulus (E) is measured at the stress-strain value position of 25% to 50% of the ultimate strength. The selection of the elastic part is based on the observation of the linear line on the strain-stress curve. Equation 1 is proposed to determine the elastic modulus based on the UCS test [14].

$$E = [100\ (\sigma_{0.5}-\sigma_{0.25})]/(\varepsilon_{0.5}-\varepsilon_{0.25}) \quad (1)$$

where; E is elastic modulus (MPa), $\sigma_{0.25}$ is stress at 0.25 ultimate stress (MPa), $\sigma_{0.5}$ is stress at 0.5 ultimate stress (MPa), $\varepsilon_{0.5}$ is strain at 0.5 ultimate stress (%), $\varepsilon_{0.25}$ is strain at 0.25 ultimate stress (%).

1. Elastic Modulus ratio

The durability indicator is measured by the ratio of wet-dry conditions to asphalt mixtures. Equation 2 is proposed to determine the indicator of the durability of the asphalt mixture.

$$ER = (E_2/E_1).100 \quad (2)$$

where; ER is elastic modulus ratio (%), E_1 is the average of elastic modulus in dry condition (MPa), and E_2 is the average of elastic modulus in wet condition (MPa).

2. Equivalent Retained Strength (ERS) of Elastic Modulus

The ERS is used to determine the water damage indicator of the asphalt mixture by immersion time for more than 1 day. The elastic modulus of the UCS test as a result of long-term immersion in this research is called equivalent retained strength of elastic modulus (ERS-E). The proposed equation can be seen in Equation 3 and 4. Fig. 3 depicted the A and ERS

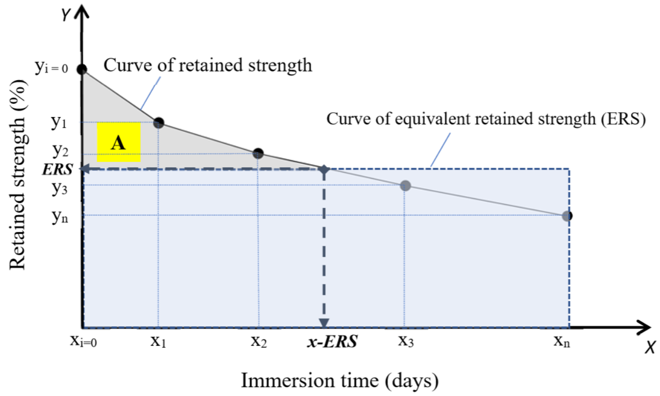

Fig. 3. Determining the equivalent retained strength of asphalt mixture

$$ERS = A/T \qquad (3)$$

$$A = \frac{1}{2}\sum_{i=0}^{n}(x_i\, y_{i+1} - x_{i+1}\, y_i) \qquad (4)$$

where; A is an area of strength curve (percent of unit strength per day), T is maximum immersion time, and (x,y) is coordinate of the curve.

III. Results and Discussion

A. Effect of immersion time and aggregate gradation on elastic modulus asphalt concrete

Fig. 4 shows clearly that during immersion, the modulus of elasticity decreases, it means that the asphalt concrete mixture is damaged because of water. Decreasing value of elastic modulus occurs in all types of gradations and aging during the immersion period. Fig. 4 also demonstrated that STOA and LTOA decrease more dramatic than no aging of asphalt concrete. Fig. 4 also illustrated that different type of gradation will get the different performance of the elastic modulus. Analysis of variance (ANOVA) of 95 % confidence level in Table I shows that aggregate gradation and time immersion have a significant effect on the elastic modulus of asphalt concrete.

The ratio of modulus of elasticity is affected by aggregate gradation and aging conditions during the immersion period. Therefore, the equivalent retained strength-elastic modulus use as an indicator of water damage, since the reduction is taken into account thoroughly during the immersion period rather than the ratio of elastic modulus to the same immersion period.

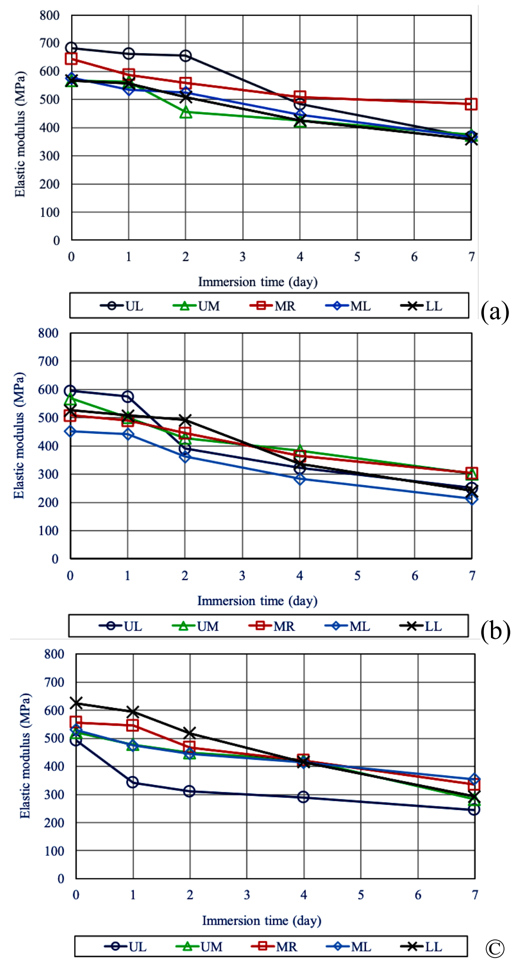

Fig. 4. Elastic Modulus for each type of gradation asphalt concrete during 7 days immersion: (a) no aging (b) STOA (c) LTOA

TABLE I
ANOVA Test Results to Determine the Influence of Gradation Type and the Duration of Immersion to the Modulus of Elasticity of Asphalt Concrete

Source of variation	p-value	Significant
1. No aging		
a. Gradation type	0.0011	Yes
b. Immersion time	$1.79\ 10^{-07}$	Yes
2. STOA		
a. Gradation type	0.0096	Yes
b. Immersion time	$6.54\ 10^{-09}$	Yes
3. LTOA		
a. Gradation type	$8.99\ 10^{-05}$	Yes
b. Immersion time	$2.38\ 10^{-07}$	Yes

B. Effect of aging on the elastic modulus of asphalt concrete

Fig. 4 depicted that aging condition (STOA and LTOA) will decrease the elastic modulus of asphalt concrete. Even though the asphalt concrete is in a dry condition at STOA and LTOA, it decreased the elastic modulus. It proves that stripping could happen in dry condition.

A dramatic decrease occurs in the type of UL gradation, the probable cause is the highest of mastic content (44% fine aggregate and 5.97% asphalt). It will cause stripping between the coarse aggregates and the mastic due to asphalt hardening and continuous loading. Fig. 4a for no aging specimen demonstrated that UL (finer gradation) has the highest of elastic modulus, but in Fig. 4b the elastic modulus of UL will lower than no aging. Fig. 4c showed that UL will be the lowest elastic modulus. LL has the lowest mastic has the opposite result with UL.

Table II shows that aging has a significant effect on 4-7 days of immersion of flood water. The research of [15] showed that occurs seepage phenomena in the void of asphalt mixture at 4 days immersion thus it will reduce the bonding of the asphalt mixture. Hardening of asphalt and long-term immersion of flood water will increase significantly the elastic modulus of asphalt concrete.

TABLE II
ANOVA TEST RESULTS TO DETERMINE THE INFLUENCE OF AGING ON THE MODULUS OF ELASTICITY OF ASPHALT CONCRETE

Source of variation	p-value	Significant
Aging on 0-day immersion (dry)	0.1248	No
Aging on 1-day immersion	0.1733	No
Aging on 2-days immersion	0.0765	No
Aging on 4-days immersion	0.0103	Yes
Aging on 7-days immersion	0.0018	Yes

C. Elastic modulus ratio and optimum aggregate gradation of asphalt concrete due to flood water

Elastic modulus ratio or retained elastic modulus uses to determine equivalent retained strength-elastic modulus (ERS-E) based on Equation 3. ERS-E as durability indicator presented in Table III. Moreover, the optimum aggregate gradation of asphalt concrete uses the ranking of ERS-E and equivalent retained strength-indirect tensile strength (ERS-ITS) [16]. The ranking of ERS-E and ERS-ITS are presented in Table IV.

The elastic modulus ratio for each type of aggregate gradation, immersion time, and aging are demonstrated in Fig. 5. Fig. 5a is for no aging condition and the ratio of elastic modulus at 7 days immersion around 50-70%. Fig .5b for STOA condition that depicted the elastic modulus ratio at 7 days immersion around 40-60%. Elastic modulus ratio at 7 days immersion about 40-70% is depicted in Fig. 5c for LTOA condition. In general, STOA and LTOA condition have a lower elastic modulus ratio than no aging.

Table III shows that ERS-E no aging (78.45-82.97%) is higher than STOA (63.41-78.81%) and LTOA (62.21-80.05%). It proves that aging will increase water damage on asphalt concrete and the aging process should be adopted to measure the durability of asphalt concrete in term of flood water resistance. Based on 7 days critical immersion time, the representative immersion time (x-ERS) is 4 days. It means if the asphalt mixture has possible immersion until 7 days, 4 days immersion can be used to determine the equivalent retained the strength of asphalt mixture. Table III also gives Gradation Index (GI) was used to characterize aggregate gradation in a continuous scale [17].

Resistance to moisture damage, stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance on asphalt concrete is affected by aggregate gradation [18, 19]. If the designer of asphalt mixture wants certain properties of asphalt mixture then must consider the aggregate gradation [19]. Based on aggregate gradation, Table IV gives the ranking of the durability of asphalt concrete against flood water. The ranking was divided into 5 levels. The best durability is given ranking 1 and 5 for the lowest one. The results show that the range of aggregate gradation at GI 21.53-27.29% gives the best durability against flood water. The range was determined by the first ranking of ITS and UCS tests in different aggregate gradation, and aging condition.

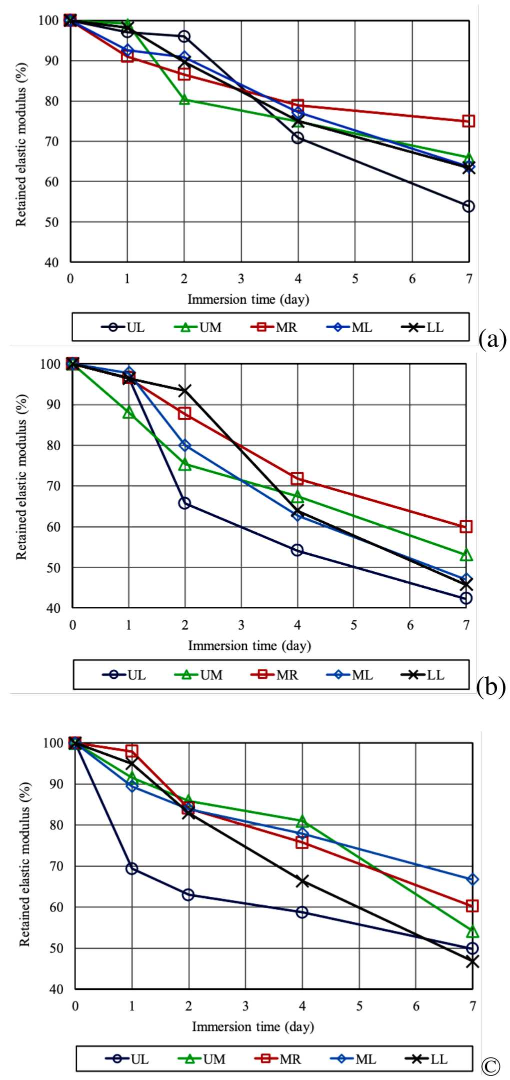

Fig. 5. Retained Elastic Modulus for each type of gradation asphalt concrete during 7 days immersion: (a) no aging (b) STOA (c) LTOA

TABLE III
ERS-E AND REPRESENTATIVE IMMERSION TIME (X-ERS)

Gradation type	Gradation Index (%)	No aging		STOA		LTOA	
		ERS-E (%)	x-ERS (day)	ERS-E (%)	x-ERS (day)	ERS-E (%)	x-ERS (day)
UL	18.65	78.45	2-4	63.41	2-4	62.21	2-4
UM	21.53	79.44	2-4	71.35	2-4	79.17	4-7
MR	24.41	82.97	2-4	78.18	2-4	79.10	2-4
ML	27.29	81.09	2-4	70.74	2-4	80.05	2-4
LL	30.17	80.78	2-4	73.55	2-4	72.22	2-4

TABLE IV

THE RANKING DURABILITY OF ASPHALT CONCRETE BASED ON ERS-ITS AND ERS-E

Gradation type	Gradation Index (%)	Ranking					
		ERS-ITS			ERS-E		
		No aging	STOA	LTOA	No aging	STOA	LTOA
UL	18.65	5	2	5	5	5	5
UM	**21.53**	2	**1**	**1**	4	3	2
MR	**24.41**	3	3	3	**1**	**1**	3
ML	**27.29**	**1**	5	2	2	4	**1**
LL	30.17	4	4	4	3	2	4

IV. CONCLUSIONS

Based on the laboratory tests and analysis, the following conclusions can be summarized:

1. Immersion time series and type of aggregate gradation have a significant effect on elastic modulus of asphalt concrete.
2. Elastic modulus and elastic modulus ratio of unconfined compressive strength can be used to assess flood water damage on asphalt concrete.
3. Aging has a significant effect after 4 days of immersion of flood water. It means that should apply long-term water immersion which is more 4 days to see the effect of water damage on the aging condition of asphalt concrete.

It is suggested that the optimum gradation of asphalt concrete of flood water resistance lies in the range of Gradation Index 21.53-27.29%.

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