Flood water resistance of asphalt concrete by using unconfined compressive strength test

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Abstract. High rain intensity which is more than 20 mm/day and poor drainage can cause a flood on the paved road surface and cause surface pavement damage. The previous study stated that measuring the durability of asphalt concrete with Marshall immersion and indirect tensile strength could not show significant differences on asphalt and aggregate gradation types. Therefore, the aim of this study is to measure the durability of asphalt concrete due to flood water by using compressive strength test. Five types of aggregate gradation of Asphalt Concrete and two types of asphalt binder; Asphalt Cement (AC) 60/70 and Elastomer Modified Asphalt (EMA) were used. Marshall method was used to determine optimum bitumen content. While the compressive strength of asphalt concrete was measured by using the unconfined compressive strength test. This study proposed Gradation Index and equivalent retained the strength of compressive strength (ERS-C). ERS-C is an indicator of durability with 0, 1, 2, 4, and 7 days of immersion time. The result showed that ERS-C can be used to determine the effect of aggregate gradation and asphalt types of asphalt concrete. The durability of asphalt concrete at GI 21.527 up to 27.288 has higher ERS-C and the durability of EMA is better than AC 60/70.

1. Introduction
Indonesia is located around the equator with a tropical climate which is hot and has only dry and rainy seasons. The total area of Indonesian’s sea is approximately 77% of the total area which makes it humid with an average moisture of 82.4%, rainfall is quite high around 1900 - 2500 mm per year in some areas of Kalimantan, Java, Sulawesi, Papua and Bali [1-3]. Directorate General of Water Resources, Ministry of Public Works, Mohammad Hasan said that in Indonesia, there are 20 major cities prone to floods with 18 cities of provincial capital including Jakarta [4]. Floods that occurred in Jakarta on February 2007 caused a puddle up to 7 days and almost 60% of Jakarta Special Region (Daerah Khusus Ibukota, DKI) was flooded [5]. Road damage cases due to floods were: (1) road repairs required billions of rupiahs to deal with 130 kilometers of road damage in Pantura region of Central Java due to flood [6]; and (2) Public Works Agency of DKI Jakarta stated that until January 28, 2014, the number of roads damaged by flood reached 3,905 points in 628 segments of the capital road or if these all were added then no less than 119,448.5 square meters road damage [7].

Testing of water resistance on asphalt mixture can use Marshall immersion method with retained Marshall stability (RMS) indicator at 60 °C or tensile strength method with tensile strength ratio as an
The durability test of the asphalt mixture over 1-day using water at 60 °C was performed by Craus et al. [9]. It is considered that testing with high temperature (60 °C) on the asphalt mixture will make it weakened due to the influence of temperature, not by water. Copeland [10] states that in the late 1970s and early 1980s, Lottman developed the test that currently has the widest acceptance in the pavement industry in the United States of America (USA), the American Association of State Highways and Transportation Officials (AASHTO) T283. The majority of road agencies in the USA account for 82% evaluation of moisture damage to asphalt mixture using AASHTO T283. Standar Nasional Indonesia (SNI) 6753 (2015) [11] has similarities with AASHTO T283. The equality of both methods is to accelerate the saturation of specimens with pressure and water, whereas the difference is that SNI 6753 does not use the freeze-thaw cycle in the test procedure to suit the climatic conditions in Indonesia.

Abo-Qudais [12] examined the effect of different evaluation techniques to assess stripping damage on asphalt mixture in Jordan. The results showed that Marshall test and indirect tensile strength were unable to assess the effect of asphalt and aggregate gradation type on asphalt mixture. Mohamed [13] conducted a study of the debonding location of asphalt from aggregate due to water. The proposed new approach considered some aspects; (1) stripping, (2) water, (3) stress (the traffic load), and (4) temperature. Specimens were obtained by coring road asphalt pavement in the field. Taking the core as specimens first by making a road on the campus of the National Research Council of Canada (NRC) (Trials 1 and 2) and the third road built in Toronto. The specimens were saturated with 35 cm vacuum pressure. The temperature of the water bath varies -29, 2, 18, 43 °C, and the conventional temperature is 60 °C. All specimens were conditioned at room temperature for 2 hours before the test by indirect tensile strength. Indirect tensile strength test was performed at 24 °C with a loading speed of 50 mm/min. The results showed that in 2 days' conditioning, NRC trial 1 with a void in the mix (VIM) of 2-3% predominantly showed that only at -29 °C had a greater tensile strength than unconditioned specimens. NRC trial 2 with VIM majority 5-6% and 6-7% at -29 and 2 °C has greater tensile strength than unconditioned specimens. Finally, Toronto trials with a majority VIM of 4-5% at -29, 2, 18, and 43 °C temperatures have greater tensile strength than unconditioned specimens. Thus, it was concluded that the tensile strength test did not show a decrease in asphalt mixture strength due to immersion at temperatures below about 24 °C.

The unconfined compressive strength test is one of testing which can be used to measure the rutting potential of asphalt mixture [14] and to measure the water resistance of asphalt mixture [15] (ASTM D1075, 2000). However, water resistance measurements with compressive strength test did not show any significant difference [16]. Development the unconfined compressive strength test can be used to measure water resistance on asphalt concrete [17].

Modifiers can be used to increase the water resistance of the asphalt mixture. Two modifiers commonly used to modify the performance of asphalt mixtures against water damage are anti-stripping additives and polymer modified asphalt. The overall performance of polymer-modified mixtures is preferred rather than unmodified mixtures and mixtures modified with antistripping additives [18]. Ozen et al [19] said that polymers are effective for road applications. The polymer should be mixed with asphalt cement to improve its resistance to rutting, abrasion, cracking, fatigue, stripping, bleeding, aging, etc., at medium or high temperature without having to make it too viscous at mixing temperatures or too brittle at low temperatures. Tayfur et al. [20] examined the use of some additives in the mastic asphalt (SMA) mixture. These additives are amorphous polialfaolefin, cellulosed fiber, cellulosed fiber mixed with bitumen, polyolefin and styrene-butadiene-styrene copolymer. The results showed that the use of asphalt with styrene-butadiene-styrene additives (SBS) copolymer or asphalt elastomer modification gave the highest deformation resistance value compared to the use of other additives. Gorkem and Sengoz [21] examined the resistance of polymer asphalt against moisture or water. Gorkem and Sengoz research used 50/70 asphalt type, two types of aggregate (basalt-limestone aggregate mixture and limestone aggregate) and three types of additive (elastomers, plastomers and hydrated lime). It was found out that prepared samples with SBS polymer modified asphalt exhibited more resistance to water damage compared to the prepared samples with EVA polymer modified asphalt.
The aim of this research is to measure flood water resistance of asphalt concrete by using unconfined compressive strength test for unmodified asphalt and elastomer modified asphalt. This research also investigates the effect of different aggregate gradation of asphalt concrete so the optimum aggregate gradation for flood water resistance can be chosen.

2. Experimental design

2.1. Material selection
Aggregate derived from Tinalah River, Kulon Progo, Yogyakarta, Indonesia. Tinalah River is one of the quarries for road and building construction in Yogyakarta and its surroundings. The result of aggregate properties showed that the aggregate met the required specifications by Ditjen Bina Marga [8] and Setiawan et al. [22]. 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 figure 1.

Unmodified asphalt cement with penetration of 60/70 Pertamina production and elastomer modified asphalt Starbit E-55 were used as a binder. The result of the physical properties of asphalt showed that AC 60/70 and elastomer modified asphalt (EMA) comply with the requirement for using as a binder of asphalt mixture by Ditjen Bina Marga [8].

2.2. Material selection
The optimum bitumen content (OBC) was determined by Marshall method of narrow range [23] in each type of aggregate gradation based on stability, flow, void in the mix (VIM), void filled with asphalt (VFA), and void in mineral aggregate (VMA) and retained Marshall stability (RMS) criterion. Required criteria based on the range of General Specification of Third Revised Edition 2010 [8]. The characteristics of specimens at optimum bitumen content based on the Marshall method can be seen in table 1.

Immersion conditioning was carried out with an immersion time variation of 0, 1, 2, 4 and 7 days at 25 °C. Temperature selection based on observations during rain by placing specimens with thermometers soaked in drains. Selected immersion media was the water of Selokan Mataram, around the Faculty of Animal Science, Universitas Gadjah Mada Yogyakarta, during the rainy season as a representation of flood waters. Selection of location based on the Marshall immersion test from several water location points that provide the greatest decrease in stability.

Table 1. Characteristics of Specimens at OBC

| Gradation Type (Gradation Index) | UL [18,65] | UM [21,53] | MR [24,41] | ML [27,29] | LL [30,17] | UL [18,65] | UM [21,53] | MR [24,41] | ML [27,29] | LL [30,17] |
|---------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| OBC (% mix)                    | 5.97       | 5.84       | 5.56       | 5.65       | 7.09       | 5.71       | 5.50       | 5.53       | 5.40       | 6.97       |
| Stability (kg)                  | 1889.95    | 1661.24    | 1827.81    | 1410.23    | 1188.29    | 2470.10    | 2292.89    | 2064.71    | 1794.67    | 1695.67    |
| Flow (mm)                       | 3.30       | 3.50       | 3.60       | 3.85       | 3.60       | 3.60       | 4.50       | 4.30       | 4.00       |
| Density (g/cm$^3$)              | 2.38       | 2.36       | 2.37       | 2.33       | 2.31       | 2.36       | 2.36       | 2.35       | 2.34       | 2.31       |
| VIM (%)                         | 3.52       | 4.20       | 3.51       | 3.85       | 4.64       | 3.40       | 4.14       | 4.45       | 4.54       | 4.73       |
| VMA (%)                         | 15.72      | 15.64      | 15.03      | 16.32      | 18.21      | 15.75      | 15.66      | 15.75      | 15.74      | 18.07      |
| VFA (%)                         | 77.64      | 73.12      | 76.70      | 73.12      | 74.55      | 78.40      | 73.57      | 71.73      | 71.22      | 73.82      |
| RMS (%)                         | 90.3       | 92.0       | 93.0       | 95.3       | 92.6       | 92.4       | 96.14      | 95.42      | 99.71      | 99.57      |

2.3. Gradation index
Gradation Index (GI) is proposed in order to interpret the behavior of the asphalt mixture on a continuous scale so as to obtain the relationship between gradation changes with certain properties of the asphalt mixture. The GI is defined as the ratio of the retained percentage curve area to a total of the aggregate gradation curve. The calculations for determining the GI are very easy to do and consider all the sieve sizes in the specification. The GI is formulated in equations 1 and 2 [24].
where \( G \) is gradation index (\%), \( \alpha \) is retained curve area (mm\(^2\)), \( A \) is a total area (mm\(^2\)), \( S_{ri} \) is sieve size (mm), and \( T_i \) is cumulative retained aggregate [10%=10mm] (mm).

\[
G I = \frac{\alpha}{A} \times 100
\]

\[
\alpha = \sum_{i=0}^{n} \left( \frac{S_{ri} + S_{r(i+1)}}{2} \right) (T_i - T_{i+1})
\]

**Figure 1.** Selected aggregate gradation.

2.4. **Unconfined compressive strength test**

Unconfined compressive strength (UCS) test has been used for determining the compressive strength of the asphalt mixture. A set of molds was made to manufacture the specimen with a height \( (L) \) divided by diameter \( (D) \) close to 2. The mold diameter around 3 meets the minimum thickness of the pavement based on the aggregate nominal maximum size. The value of VIM was 3%-5% to control the optimum void of the specimen. The vibratory compactor, which specifications are input 900-Watt, impact per minute 2900, and impact energy per stroke 8.5 Joule, was used to compact the specimens.

The required test equipment is a compression machine with 10,000 lbs of proving ring; 2 dials Mitutoyo 543-390B 0.001 mm x 12.7 mm; 2 data cables are used to transfer data; data logger, and Delta Dimensi Software for controlling process and test visualization. The capability of Delta Dimensions Software is to assist readings and data storage of proving ring deflection as well as vertical strain changes of test specimens at the same time with intervals of less than 1 second.

The maximum load has been divided by a cross-section specimen is a compressive strength. The equations used to determine the compressive strength can be seen in equations 3 to 6.

\[
\sigma = \frac{P}{A_c} \times ht
\]

\[
A_0 = 0.25\pi D^2
\]

\[
A_c = \frac{A_0}{(100 - \varepsilon v)}
\]

\[
\varepsilon v = \frac{\delta v}{h} \times 100
\]
where $\sigma$ is compressive strength (MPa), $P$ is load (N), $h_t$ is the height of specimen corrected (mm), $A_c$ is cross section corrected ($mm^2$), $A_0$ is the initial cross-section of specimen ($mm^2$), $D$ is diameter of specimen (mm), $\varepsilon_v$ is vertical strain ($\%$), $\delta_v$ is vertical deflection (mm), and $h$ is length of gauge (mm).

2.5. Equivalent retained strength

Craus et al. [9] introduced the term Equivalent Retained Strength (ERS). ERS is used as a parameter to determine the water resistance of asphalt mixture by immersion time more than 1 day. The compressive strength of UCS as a result of long-term immersion is a measurement of water resistance of the asphalt mixture so that the equivalent retained strength in this research is called equivalent retained strength of compressive strength (ERS-C). The proposed equation for determining ERS-C can be seen in equations 7 and 8 [25].

\[
ERS_C = \frac{A}{t_n}
\]  
\[
A = \frac{1}{2} \sum_{i=0}^{n} (S_i - S_{i+1}) \cdot t_i
\]

where $A$ is an area of the curve (percent strength/days), $t_n$ is total immersion time (days), $S_i$ is retained strength of $t_i$ ($\%$), $S_{i+1}$ is retained strength of $t_{i+1}$ ($\%$) and $t_i$, $t_{i+1}$ are immersion time at $i$ days (days).

3. Results and Discussion

3.1. Effects of aggregate gradation on compressive strength

The result of compressive strength which is obtained from the average of 2 or 3 UCS specimens, can be seen in figure 2. The magnitude of the compressive strength shows the ability of the materials to change into the vertical direction. The observations made on the specimens showed that the bulging specimen specifies the presence of cohesive damage or asphalt damage. This shear damage is due to adhesive damage between the aggregate and the asphalt. The change of aggregate gradation type indicates a change of damage type.

UL has the greatest compressive strength because of it has higher mastic than other aggregate gradation in the mixture [22]. LL aggregate gradation has the lowest compressive strength. However, in mixtures with higher fine aggregate content such as UL gradation with GI = 18.646, shows shear damage.

3.2. Effects of immersion time on compressive strength

Figure 2 shows that the longer immersion time will decrease the strength of the asphalt concrete mixture for all gradation and asphalt types. Water weakens the bond between asphalt-aggregate and asphalt-asphalt in the mixture.

Figure 2 also shows a decreasing in compressive strength during the period of relative steepness. This is caused by conditioning at 25 °C. Conditioning at temperatures mild temperature around 25 °C does not result in the loss of the thin layer of asphalt film around the aggregate particles even with the addition of the immersion duration. Separation after damage does not show the asphalt loss of the aggregate as a whole [13].

3.3. Effects of asphalt type on compressive strength

The compressive strength of EMA is higher than AC 60/70 because EMA has better cohesive strength than AC 60/70. The thermoplastic elastomer, which can increase the elasticity of bitumen [21]. The addition elastomer such as SBS in asphalt makes the binder relatively very ductile, which is due to the increase of viscoelasticity of the binder. In contrast, unmodified bitumen is lower than SBS modified asphalt. The high strength of the modified-bitumen is derived from the three-dimensional network formed by the physical crosslinking of SBS [26].

As could be seen in figure 2 and figure 3, elastomer modified asphalt indicated more flood-water-resistance than AC 60/70 in terms of compressive strength and retained of compressive strength (ERS-
C). EMA shows improved water-resistance by both increasing the cohesion within the binder and by increasing the adhesion between the binder and the aggregate [21]. The results clearly confirm that the EMA is a useful asphalt to enhance the durability of asphalt road–pavement mixtures.

![Figure. 2](image1.png)

**Figure. 2** Relationship between immersion time and compressive strength of asphalt concrete with different aggregate gradation (a) AC 60/70 (b) EMA.

![Figure. 3](image2.png)

**Figure. 3** Relationship between immersion time and retained compressive strength of asphalt concrete with different aggregate gradation (a) AC 60/70 (b) EMA.

3.4. **Optimum aggregate gradation for flood water resistance**

Aggregate gradation optimization is conducted by modeling the relationship between GI and ERS-C. Polynomial regression has a good agreement with determination coefficient are 0.946 and 0.794 for asphalt mixture AC 60/70 and EMA, respectively. Figure 4 shows that ERS-C increased along the increment of the GI until it reaches its peak and then it decreases. The increase of ERS-C is caused by the reduced mastic in the mixture so that the asphalt will cover the aggregates and mastic make the asphalt mixture denser. However, too little mastic will make water diffuse into asphalt easily then it makes a cohesive failure. Two mechanism failure modes caused by diffusion are adhesion and cohesive failures [27].

The relationship model between GI and ERS-C shows the range of optimum aggregate gradation that provides optimum flood water resistance for AC 60/70 and EMA. The aggregate gradation located between UM and ML with the peak position approaching the MR gradation. GI can be used as an aggregate gradation position size so that the aggregate gradation selection range for flooded road...
conditions is GI = 21.527 up to 27.288 for AC 60/70. Figure 4 shows that asphalt concrete with AME has a flatter curve and higher ERS-C than AC 60/70. It can be said that AME supports all type of aggregate gradation in this research to be better flood water resistance.

![Figure 4 Relationship between gradation index and ERS-C with different asphalt type.](image)

4. Conclusions

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

- Lower gradation index has the highest compressive strength of asphalt concrete because of the mastic in the asphalt mixture. Aggregate gradation differences will result in different types of damage. Gradations with finer aggregate content will result in shear damage whereas if the fine aggregate content is less then there will be cohesive damage.
- Long-term flood water immersion gives a more significant effect of decreasing strength. ERS-C can be used to measure the decrease in strength during the immersion period.
- The relationship between ERS-C and GI provides aggregate gradation that is resistant to flood water immersion. Aggregate gradation with GI 21.527 up to 27.288 which has a lower decreasing on compressive strength during flood water immersion.
- Compressive strength and durability of asphalt concrete due to flood water show that EMA is better than AC 60/70 of the asphalt mixture.

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