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Effect of water immersion on the AC-WC mixture utilizing elastomeric modified asphalt to compressive strength, elastic modulus and durability

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ABSTRACT

Indonesia has relatively high rainfall with a long duration of rain. It can result in a flood on the surface of the road. A flood can reduce the strength of materials from the asphalt mixture and cut the life of the road plan. Therefore, it is necessary to conduct a study that can measure the durability level of the asphalt material mixture on the surface layer of the road to the flood water bath. The study used an Asphalt Concrete-Wearing Course (AC-WC) mixture with Elastomeric Modified Asphalt (EMA), and an Upper Limit (UL), Middle Range (MR), and Lower Limit (LL) gradation based on specification. The Optimum Bitumen Content (OBC) value was obtained from each gradation by applying the Marshall test. The value of the OBC was used to create specimens that had a diameter of 3 inches and a height of 6 inches, and they were using an Unconfined Compression Strength (UCS) test. This study measures the durability of compressive strength and elastic modulus from a mixture of flood water immersion for 1, 2, 4, and 7 days. To calculate the durability using Retained Strength Index (RSI), First Durability Index (r), and Second Durability Index (a). The results showed that there was a decrease in the compressive strength of the mixture on gradations of UL, MR, and LL on days 1, 2, 4, and 7. It meant that the longer the immersion time more reduced the compressive strength of the mixture. The UL-gradedraded mixture had the best durability when it was compared to the MR and LL gradations up to the 7th-day immersion, with an RSI of 91.19%, (r) of 7.44%, and (a) of 6.93%. At the same time, in the elastic modulus of the mixture, there was no significant effect on the duration of immersion because it had a fluctuating value of the elastic modulus to the duration of immersion.

1. Introduction

Indonesia belongs to a tropical country which has a relatively high rainfall with long duration of rain. It can result in puddles (flood) in the surface of the road. Flood can cause road damage because water can loosen the bond between the aggregate and the asphalt. When asphalt and aggregate bonds are loosened by water, passing vehicles will carry a cracking load or other road damage that may reduce the life of the road plan. Asphalt concrete is a mixture that comprises hard asphalt as a binder and coarse with fine and filler aggregates, by mixing and compacting under certain heat and temperature conditions [1]. The asphalt concrete into 3 different mixtures: Asphalt Concrete - Wearing Course (AC-WC), the Asphalt Concrete - Binder Course (AC-BC) and Asphalt Concrete - Base Course (AC-Base), with the maximum aggregate size of each mixture is 19 mm,

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Nomenclature:

IRS	Index Retained Strength (%)		
Sn	Strength on immersion n days	*ε*	axial strain
So	Strength on immersion 0 days	*ΔL*	change of length of specimen (m)
r	the value of the strength drop (%) on the first durability index	*Lo*	length of established specimen (m)
a	the value of the strength drop (%) on the second durability index	*σ*	axial stress
Si	percent of strength remaining at time t_i	*P*	load axial (kg)
$S_{(i+1)}$	percent of strength remaining at time $t_{(i+1)}$	*E*	elastic modulus
ti, $t_{(i+1)}$	immersion time (starting from the beginning of the test)	*Δσ*	the axial voltage difference
t_n	Immersion at n time	*Δε*	the axial strain difference

25.4 mm and 37.5 mm, respectively [2]. Based on [3], aggregates are grouped into : Course Aggregate; that is an aggregate retained sieve No.4 (4.75 mm), Fine Aggregate; that is an aggregate that passes the No.4 (4.75 mm) sieve and The filler; that is a part of the fine aggregate that passes No. 200 (0.075 mm). Asphalt modification is a conventional asphalt which is modified by the addition of additives on conventional asphalt. [3] says that asphalt modification includes latex or synthetic asbuton and elastomeric. Added polymer type is often used in the manufacture of pavement as an asphalt modifier. Polymers are generally divided into two categories: plastomers and elastomers, in which elastomers are polymers of an elastic nature, when pulled, the voltage is given back to its original state. One of the major roles of elastomeric modified asphalt (EMA) in asphalt mixture is to increase asphalt resistance to permanent deformation at high temperature without harming bitumen or bitumen properties. As a result, polymer asphalt has high resistance to deformation and crack damage. The use of polymer modified asphalt polymer (EMA) on the surface layer (AC-WC) is expected to improve the performance of the mixture as well as the quality of the binder asphalt.

The durability test based on SNI M-58-1990 only measures the level of mixture durability with water immersion to its stability value only, whereas durability can be seen from the compressive strength and elastic modulus. [4] and [5] in his research say that the use of immersion using the type of flood water has a lower durability value compared with laboratory water. This is due to the dissolved content (mud particles) contained in the flood water is greater than the laboratory water. The mastic layer on the asphalt mixture becomes easily eroded by the sludge contained in the flood waters through the advective transport process.

On a road pavement, the compressive strength can be represented as the maximum strength of the mixture in receiving the direct load from the vehicle, while the elastic modulus is the value of the stiffness of the mixture itself. [6] states that in order to know the compressive strength of a material, it is necessary to compress the press compression to understand the compressive strength of a material in order to know the reasonable limits of loading. [7] conducted a study to see the stress-strain relationship on asphalt concrete using pressure. The results of his research on asphalt concrete specimens with aggregates, compaction efforts, asphalt percentages, different size and type of loading exhibited a pattern similar to the stress-strain relationship commonly used on cement concrete. His research also found that there was a linear relationship between the modulus of elasticity and its compressive strength. From the above problems regarding the low durability of the asphalt mixture due to flood (even though the asphalt mixture has standards requirement of Marshall immersion), and the use of polymer asphalt has high resistance to deformation and crack damage, this study was designed using the AC-WC mixture. As for the purpose of this research is to know the effect of flood water immersion on AC-WC mixture with elastomeric asphalt (EMA) asphalt on the compressive strength and mixed elastic modulus with the following objectives:

1. Designing a mixture of Asphalt Concrete Wearing Course (AC-WC) using Elastomeric Modified Asphalt (EMA) on different gradations.
2. Finding out the effect of flood water immersion on AC-WC mixture by using Elastomeric Modified Asphalt (EMA) on different gradations evaluated from compressive strength and elastic modulus.
3. Finding out the durability of the AC-WC mixture by using Elastomeric Modified Asphalt (EMA) immersed in flood waters toward compressive strength and elastic modulus of the mixture.

2. Methodology

The study was conducted in the Transportation Engineering Laboratory of Civil and Environmental Engineering Department, Faculty of Engineering, Gadjah Mada University, Yogyakarta. The conceptual framework of the study is shown in Fig. 1.

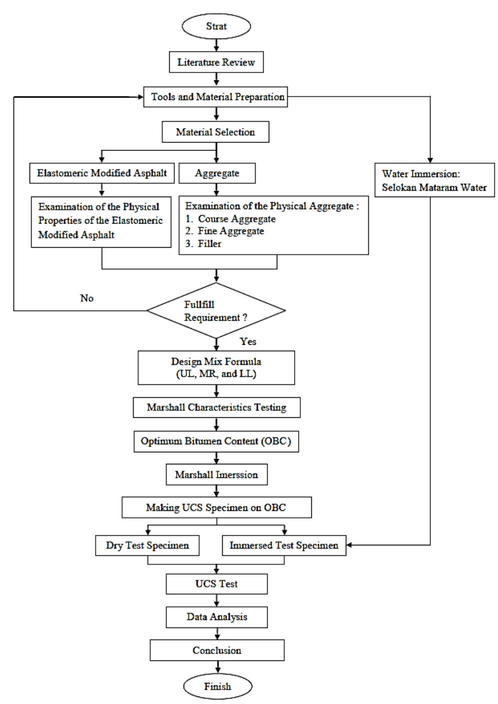

Figure 1. Research flow chart

2.1. Marshall characteristics

The Marshall test method is the most commonly used and standardized method in the American Society for Testing and Materials 1993 (ASTM D 1553). The results of Marshall testing obtain the result of hot asphalt mixture characteristics, which include [8]:

1. Density; that is the weight of the mixture measured per unit volume. The density value is influenced by several factors such as high asphalt content and asphalt viscosity.
2. Void in the Mineral Aggregate (VMA); that is the space between the aggregate particles on an asphalt pavement, including the air cavity and the effective asphalt volume (excluding aggregate absorbed asphalt volume).
3. Void in the Mix (VITM). In the asphalt pavement mixture, it comprises the air space between the asphalt aggregate particles.
4. Void Filled with Asphalt (VFWA); that is the percent of the void in the mineral aggregate (VMA) filled with asphalt, not including the asphalt absorbed by the aggregate.
5. Marshall Stability value is obtained based on the value indicated by the dial needle on the Marshall stability proving ring attached to the Marshall device, then converted into the calibration table according to the proving ring used.
6. Marshall Flow is shown in the needle indicated by the number in the dial flow, in units of which 1 unit = 0.01 mm (millimeters). Consequently, there is no need for the conversion of numbers on flow measurements.
7. Marshall Quotient (MQ) is used to determine the stiffness of asphalt concrete mixture. Marshall Quotient (MQ) is the result of Marshall's stability by Marshall flow.

2.2. Durability testing

Testing of the durability of the flood water immersion in this study used three methods.

1. Index Retained Strength (IRS)

$$IRS = \frac{Sn}{So} x\ 100\% \tag{1}$$

2. First Durability Index (r)

First Durability Index is defined as the number of successive gradients of the durability curve, expressed in equation below.

$$r = \sum_{i=0}^{n-1} \frac{S_1 - S_{i+1}}{t_{i+1} - t_1} \tag{2}$$

3. Second Durability Index (a)

It is defined as the area of loss of average strength between the durability curve with the line So = 100%, expressed in equation below.

$$a = \frac{1}{t_n} \sum_{i=0}^{n} a_1 = \frac{1}{2t_n} (S_i - S_{i+1})[2t_n - (t_i + t_{i+1})] \tag{3}$$

2.3. Unconfined compression strength

Unconfined Compression Strength (UCS) test is used to determine the compressive strength of the material with a cylindrical sample. For compressive strength testing, the ratio L = 2D is generally used, where L is the length and D is the diameter of the sample. There are ways to obtain maximum compressive strength value and elastic modulus value by doing some calculation stages using the following equations:

1. Axial Strain (ε)

$$\varepsilon = \frac{\Delta L}{Lo} x\ 100\% \tag{4}$$

2. Axial Stress (σ)

$$\sigma = \frac{P}{A} \tag{5}$$

3. Stress-strain curve, It is made by connecting axial stress (σ) data on the axis and the axial strain (ε) on the ordinate axis. The axial compressive strength is determined based on the maximum axial value where, Pmax = σ_{max}.

4. Elastic Modulus (E)

The elastic modulus is the slope in the stress-strain curve located in the elastic linear region. Modulus of elasticity is calculated as follows:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{6}$$

3. Analysis and discussions

3.1. AC-WC Mixed design

Determination of aggregate weight on each filter size was adjusted to General Specification of Bina Marga 2010, 3rd Revision (2014) with the target of gradation taken from Upper Limit (UL), Middle Range (MR) and Lower Limit (LL). Preparation of the specimen used 5 variations of bitumen content of the estimate bitumen content (Pb), Pb-1%, Pb-0,5%, Pb, Pb + 0,5%, and Pb + 1%. From the specimen on the five variations of the bitumen content, Marshall test was conducted and the Optimum Bitumen Content (OBC) was obtained. The OBC values were derived from graphs of Marshall characteristic relationships. They were density, VMA, VITM, VFWA, Marshall Stability, Marshall Flow, and MQ, where the graphic relationship showed the asphalt rate range that met the blend specification with the Narrow Range method. As it used 3 gradation targets (UL, MR, and LL) it would get 3 different OBCs according to the target gradation. Marshall test results for the determination of OBC in each gradation can be seen in Fig. 2, Fig. 3, and Fig. 4.

Based on the results of OBC with the Narrow Range method shown in Fig. 2, Fig. 3, and Fig. 4, the value of the OBC UL gradation was 5.71%, the OBC MR gradation was 5.53%, and the OBC of LL gradation was 6.97%.

3.2. AC-WC Mixed design for UCS specimen

Designing the weight of the aggregate on the AC-WC mixture for UCS specimen was carried out using a diameter of 3 inches and a height of 6 inches (see Fig. 5). The design of material proportions can be seen in Table 1.

3.3. Test Result compressive strength from duration of immersion

The test specimen of compressive strength can see from Fig. 6, and the results of compressive strength against the duration of immersion in the gradations of UL, MR, and LL can be seen in Fig. 7.

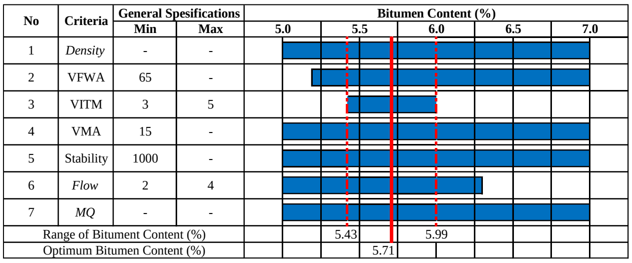

Figure 2. OBC results of UL gradation

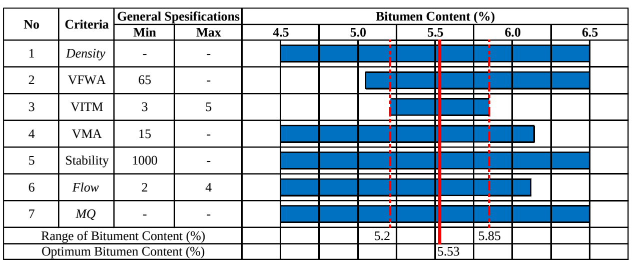

Figure 3. OBC results of MR gradation

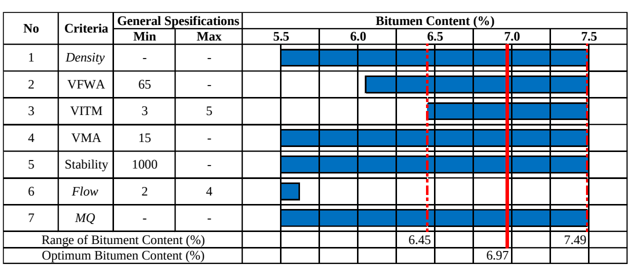

Figure 4. OBC results of LL gradation

Table 1. Design of material proportions for UCS specimen

No	Details		Formula	Gradation Types		
				UL	MR	LL
1	OBC (%)	(a)	-	5.71	5.53	6.97
2	Volume (cc)	(b)	-	731.00	731.00	731.00
3	Density (gr/cc)	(c)	-	2.35	2.36	2.33
4	W Mixture, gram	(d)	(b) x (c) x 1,03	1768.99	1778.79	1751.12
5	W Bitumen, gram	(e)	[(a)/ 100] x (d)	101.01	98.37	122.05
6	W Agare-gate, gram	(f)	(d) - (e)	1667.98	1680.42	1629.06
7	W Course Aggregate, gram	(g)	[(j)/ 100] x (f)	783.95	957.84	1091.47
8	W Fine Aggregate, gram	(h)	[(k)/ 100] x (f)	733.91	613.35	472.43
9	W filler, gram	(i)	[(l)/ 100] x (f)	150.12	109.23	65.16
Aggregate Composition:						
10	Course Aggregate (%)	(j)	-	47	57	67
11	Fine Aggregate (%)	(k)	-	44	36.5	29
12	Filler (%)	(l)	-	9	6.5	4

a b

Figure 5. (a) Design UCS mold; (b) Sample of UCS specimen.

Figure 6. (a) Specimen immersion; (b) specimen UCS test; (c) specimen after UCS test

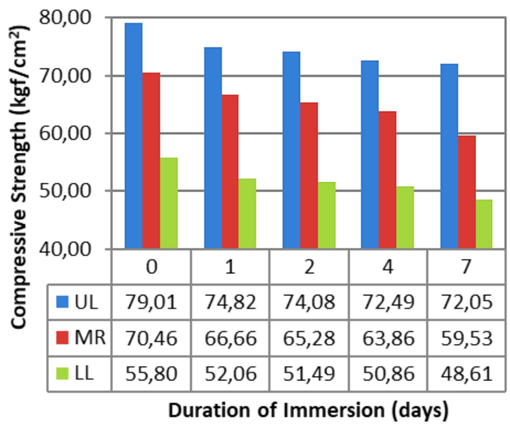

Figure 7. The value of compressive strength on the gradations of UL, MR, and LL due to the duration of immersion

Based on Fig. 7, it was shown that all three types of gradations, namely, the gradations of UL, MR, and LL had the same effects as the duration of immersion, the longer the immersion time the compressive strength value would decrease. The value of compressive strength decreasing along with the length of time of this immersion was due to oxidation process in the mixture where the water intrusion into the mixture would weaken the bond between the asphalt and the aggregate causing the compressive strength value of the mixture to decrease.

3.4. Durability of compressive strength from duration of immersion

1. Index Retained Strength (IRS)

The degree of durability of the pavement was obtained from the value of the Index Retained Strength (IRS) in which the IRS value represented the durability of the asphalt mixture after immersion. The result of calculation of Index Retained Strength (IRS) and comparison of IRS value due to soaking period can be seen in Fig. 8.

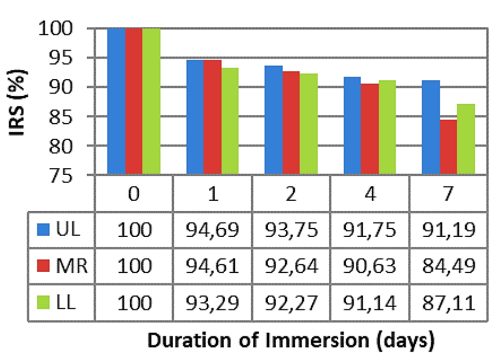

Figure 8. Index retained strength (IRS) of compresive strength due to duration of immersion on the gradations of UL, MR, and LL due to the duration of immersion

Fig. 8 shows that the IRS value of compressive strength decreased due to the duration of the immersion, and the UL graded mixture, it was the best-durable mixture of immersion duration at 1, 2, 4, and 7 with the highest compressive IRS value between the graded mixture of MR as well as LL graded mixture.

2. First Durability Index (r)

The First Durability Index was a method of measuring the loss of strength that could describe the durability of hot mix asphalt developed by Crauss et al. [9]. The First Durability Index score was denoted by (r) representing the decreasing value of the compressive strength of a mixture due to immersion. The results of the calculation of First Durability Index can be seen in Fig. 9.

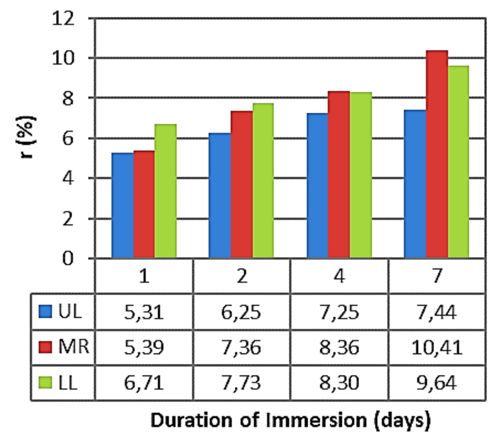

Figure 9. First durability index (r)

Based on Fig. 9, it could be seen that the UL graded mixture had the lowest compressive strength value (r) compressive strength compared to other graded mixtures of MR and LL graded mixture both at 1, 2, 4, and even 7 days of immersion. This indicated that the UL graded mixture was the most resistant mixture to the duration of submersion when compared to the graded mixture of MR and LL. The compressive strength value is greater in the UL gradation because the UL gradation has a larger composition of fine aggregate and filler than the MR gradation and LL gradation, thus causing the specimens with UL gradation to be easier to compact and also tend to have higher density.

3. Second Durability Index (a)

The Second Durability Index was a continuation method after the First Durability Index which measured the loss of strength through a durability curve that could illustrate the durability of hot mix asphalt. It was also developed by Crauss et al. [9] The Second Durability Index showed a strength loss (a) of the mixture. The results of the calculation of the Second Durability Index for the gradations of UL, MR, and LL could be seen in Fig. 10.

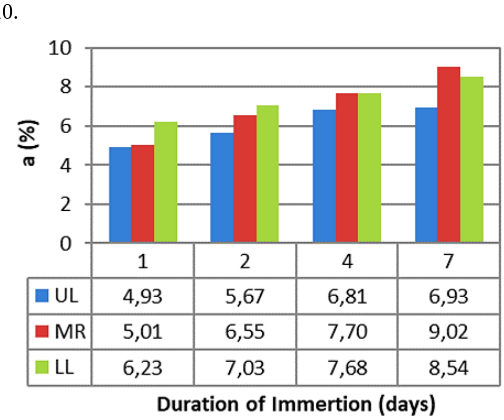

Figure 10. Second durability index (a)

Similarly with the First Durability Index, from Fig. 10 it could be seen that the UL graded mixture had the lowest loss value of compressive strength of the lowest survival curve (a) compared to the other graded mixtures (the MR and LL graded mixture both at 1 day immersion, 2, 4, even 7 days). This indicated that the UL graded mixture was the most resistant mixture to the duration of immersion when compared with the graded mixture of MR and LL.

3.5. Effect of immersion of elastic modulus

The elastic modulus value (E) was obtained from the stress-strain relationship curve in the elastic linear region. The test object used in the calculation of the value of elastic modulus was the same test object with the calculation on the specimen on the compression value of compressive strength. The results of elastic modulus testing on the duration of immersion can be seen in Fig. 11.

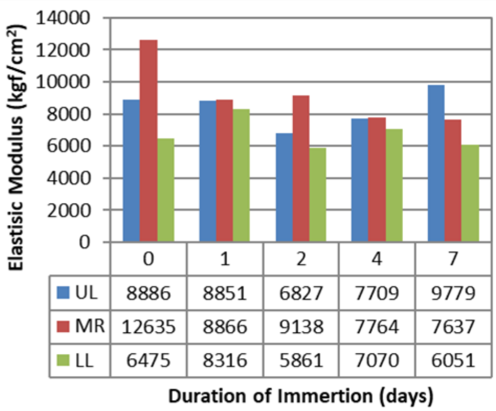

Figure 11. The elastic modulus value due to the duration of immersion

Based on Fig. 11, it can be seen that the value of elastic modulus (E) resulting from the duration of immersion in the UL graded mixture decreased in soaking days 1 and 2, and again increased in soaking days 4 and 7. For the MR graded mixture, the elasticity modulus (E) value due to the duration of the immersion decreased until the 7th day of immersion, despite the increase in the modulus of elasticity (E) value from the first day immersion to the second day immersion. As for the LL graded mixture, the elastic modulus (E) was fluctuating, which meant that the value of elastic modulus (E) experienced up and down until the 7th day immersion. By looking at the nature of the modulus value of elasticity (E), it could be said that in the three types of gradations, UL, MR, and LL, there was no effect of elasticity modulus (E) on the duration of immersion.

4. Conclusions

1. From the design results of the test object, the value of Optimum Bitumen Content on the gradations of the boundary LL, MR and UL was obtained as follows: 6,97%, 5,53% dan 5,71%.

2. The average value of the compressive strength test after immersion for 0, 1, 2, 4, and 7 consecutive days on the gradation of MR was as follows: 70,46 kgf/cm^2, 66,66 kgf/cm^2, 65,28 kgf/cm^2, 63,86 kgf/cm^2, 59,53 kgf/cm^2, the UL gradation is: 79,01 kgf/cm^2, 74,82 kgf/cm^2, 74,08 kgf/cm^2, 72,49 kgf/cm^2, 72,05 kgf/cm^2, and LL gradation are : 55,80 kgf/cm^2**, 52,06** kgf/cm^2**, 51,49** kgf/cm^2**, 50,86** kgf/cm^2**, 48,61** kgf/cm^2**.** From the test results of compressive strength shows that the longer the immersion, the lower the compressive strength in the three types of gradation.

3. The level of mixed durability based on IRS value at 1, 2, 4 and 7 days respectively on gradation of MR was as follows: 94,61%; 92,64%; 90,63%; 84,49%, UL gradation is: 94,69%; 93,75%; 91,75%; 91,19%, and LL gradation is: 93,29%; 92,27%; 91,14%; 87.11%. Based on the value of the First Durability Index (r) and the Second Durability Index (a), the gradation of MR had the greatest loss of strength at the time of immersion until the 7th day with a strength loss value (r) of 10,41%, and the loss value Strength (a) of 9,02%, and had a residual strength value (Sa) of 90,98%.

4. The mean values of elastic modulus testing after immersion for 0, 1, 2, 4, and 7 consecutive days on the MR gradation was as follows: 12635 kgf/cm^2, 8866 kgf/cm^2, 9138 kgf/cm^2, 7764 kgf/cm^2, 7637 kgf/cm^2, UL gradation is: 8886 kgf/cm^2, 8851 kgf/cm^2, 6827 kgf/cm^2, 7709 kgf/cm^2, 9779 kgf/cm^2, and LL gradaation are : 6475 kgf/cm^2, 8316 kgf/cm^2, 5861 kgf/cm^2, 7070 kgf/cm^2, 6051 kgf/cm^2. The results of examination of elastic modulus value that was fluctuating to the duration of immersion indicated no significant influence between the value of elastic modulus with the duration of immersion.

Authors' contribution
All authors contributed equally to the preparation of this article.

Declaration of competing interest
The authors declare no conflicts of interest.

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