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Effect of Moisture on the Strength of Stabilized Clay with Lime-Rice Husk Ash and Fibre Against Wetting-Drying Cycle

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Abstract: This paper presents the stabilisation of clay soil using lime-rice husk ash with polypropylene fibre reinforcement. Environmental effect of wetting and drying cycles was considered as a caused factor for decreasing the performance of the road pavement. Three moisture content regimes, i.e. optimum-dry moisture content (ODM), optimum moisture content (OMC), and optimum-wet moisture content (OWM), are studied as initial condition of the compacted soil. The soil was mixed with 17% lime and 17% rice husk ash and reinforced with 0.4% fibres. This research investigates the effect of moisture content on the strength behaviour of the stabilized soil with lime-RHA and fibres reinforcement under wetting-drying cycles. The specimen experienced up to four W-D cycles. In general, the unconfined compressive strength (qu) increases up to three W-D cycles and thereafter decreases. Wetting-drying cycles reduces qu after fourth cycles and increases the brittleness of the stabilised soil. This study concludes that the stabilised soil with lime-RHA and fibres should be compacted at the optimum wet moisture content to meet the requirement as unbound layer for pavement structure.

Keywords: Wetting-drying, expansive clay, durability, soil stabilization, fibre reinforcement

1. Introduction

Lime stabilisation is the conventional method to improve the strength and geotechnical properties of problematic clay soil [1]-[4]. Several researchers have improved the lime stabilisation by mixing the rice husk ash (RHA) [5]-[8]. Uses of RHA is beneficial to reduce the agriculture-waste and environmental degradation [9]. Combination of lime and RHA formed a cement-like material which is superior for cement replacement. This material is an alternative stabiliser in road construction [7]. The researches have shown that the addition of RHA significantly improves the geotechnical properties and swelling behaviour of the lime-stabilised soil [5], [8], [10]. The stabilised soil with lime and RHA has been known to have high strength but rather brittle especially under dynamic loading [6], [11]. However, Li et al. [12] showed that the cement stabilised clay leads to a considerable improvement the ductile behaviour under curing temperature of 20oC.

Many studies have also been done to reinforce the stabilised soil by fibres. The research found that fibres enhanced the tensile strength and decrease the brittleness behaviour of the stabilised soil [13]-[20]. Fibres roles more effectively restricting the swelling-shrinkage of the stabilised expansive clay [18]. Furthermore, the use of fibre hasconsiderably contributed to improving the tensile strength and ductile behaviour of cemented clay [12], [16], [20]. The contribution of fibres in cemented soil depends on the fibres type, amount, length, and size ratio [16], [19], [21]. Fibres reinforcement at the optimum amount has been found to improve the structural integrity of the road base and pavement performance [22].

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Swelling and shrinkage are the major characteristics of the expansive clay during a seasonal change of wetting and drying. Commonly, the soil strength degrades during swelling and shrinkage. This behaviour imposes a detrimental on the lightweight structure such as light building and pavement [23]. Thus, an improved soil should resist its strength due to the seasonal effect. Long-term performance of the stabilised soil is essential to lead more economical and overwhelming the environmental issues [24]. Determination of durability properties in laboratory soil encounter difficulties for simulating the deterioration effect in the actual field [8]. However, many studies have been performed to investigate the durability of stabilised and reinforced soil, e.g. wetting-drying (W-D) cycles [4], [16], [22], [25], freezing-thawing (F-T) cycles[12], [26], [27], and wetting or soaking [8], [28]. In general, those studies conclude that the soil strength decreases as the increases of W-D or F-T cycles. Some soils ruined during soaking depending on the type of stabiliser and dosage used.

Even many researches have been conducted to study the effect of durability on the strength and performance of stabilised; those studies have not considered the effect of the initial water content of the soil. Mainly, the research compacted the specimens at its optimum moisture content. Hence, this research investigates the effect of moisture content on the strength behaviour of the stabilised soil with lime-RHA and fibres reinforcement under wetting-drying cycles. Three moisture content regimes, i.e. optimum-dry moisture content (ODM), optimum moisture content (OMC), and optimum-wet moisture content (OWM), are studied as an initial condition of the compacted soil. This condition represents the design of the subgrade layer in the road pavement system. The purpose of this study is to examine the effect of moisture content, and wetting-drying cycles on the unconfined compressive strength, secant modulus of elasticity, and brittleness index of the lime-RHA stabilised soil and reinforced with plastic fibres.

2. Material

2.1 Soil

The soil used in this study was collected from the Kasihan, Bantul district of the Yogyakarta. The index and geotechnical properties of the soil is presented in Table 1. The soil is classified as high-plasticity clay and symbolised with CH. Muntohar and Saputro [29] indicated the presence of montmorillonite mineral in the soil. Then, the soil can be classified as expansive clay. According to the expansiveness criteria [30], [31] and the activity (see Table 1), the swelling potential of the soil is about 10%. The soil was remarked as a medium to high expansiveness according to the criteria proposed by Seed et al. [30] and Muntohar [31].

Table 1 - Index and geotechnical properties of the soil

Parameter	
Specific Gravity, Gs	2.67
Atteberg limits:	
Liquid limit, LL	65.6%
Plastic Limit, PL	33.5%
Plasticity Index, PI	32.1%
Standard Proctor compaction:	
Maximum dry density, MDD (kN/m^3)	13.05
Optimum moisture content, OMC	32.5%
Particle sizes:	
Fines: Clay/Silt	85%
Coarse: Sand	15%
Activity, A = PI/clay content	4.1

2.2 Lime and Rice Husk Ash

A quick-lime was used in this study. The lime was locally available in a coarse grain form. Rice husk ash was collected by open-burning of husk from the paddy field in Godean village, Yogyakarta. Fineness is one of the controlling factors in the chemical reaction of cementing agents. A finer material is better in the rate of reaction and gain of strength development. Then, the lime and open-burnt RHA was ground separately in Los Angeles machine. The grinding process used each 20 steel rods of 10 and 20 mm in diameter and 500 mm length. The grinding was conducted for ± 2 hours. The grinding produced a finer grain size of lime and RHA.

The specific surface area of the fine quicklime and fine RHA were 3.5 m2/g and 25 m2/g, which was tested by Brunauer-Emmett-Teller (BET) nitrogen adsorption test. The X-ray fluorescence test was adopted to determine the chemical elements of the quicklime and RHA. The major chemical element of quicklime is presented in Table 2. The summation of SiO2, Al2O3, and Fe2O3 elements of RHA leads to categorising the RHA as pozzolan.

Table 2 The major chemical element of the additives

Major Chemical	Lime	RH
CaO	95%	1.29
Al2O3	0.13%	1.75
Fe2O3	0.08%	0.78
MgO	0.25%	-
SiO2	-	89.08%

2.3 Polypropylene Plastic Fibres

The fibres were obtained by cutting the woven plastic sack (Fig. 1a) into a length of 40 mm to produce a discrete fibre (Fig. 1(b)). The width of single woven fibre was about 2 mm [15], [16]. The thickness of the fibre was about 0.06 mm. Hence, the length and thickness ratio of the fibre (l/d) was 666.7. The weight of fibre was 117 g/m2. The tensile strength of the fibre was tested on the woven plastic sheet of 100 mm x 200 mm sizes. The maximum tensile strength and failure strain was 67 kN, and 17% respectively.

(a) (b)

Fig. 1 - (a) Woven polypropylene plastic sack, (b) Fibres obtained from the cutting of plastic sack

3. Design of Experiment

The main laboratory test in this study was unconfined compressive strength (UCS) test. The UCS was evaluated after the specimen was cured for seven days and subject to wetting and drying cycles. The curing period is recommended by the Indonesian Standard SNI-03-3437-1994 for the stabilised base course layer [32]. One cycle is determined as a day of wetting by soaking under water and one day of air drying at normal room temperature about 27-30°C. The specimen experienced up to four W-D cycles. Table 3 presents the design of the experiment. The soil was mixed with lime, RHA, and fibres at three moisture condition and statically compacted in the cylindrical steel mould of 50 mm in diameter and 100 mm in height. The specimen was compacted at the MDD and 95% MDD (see Fig. 2), i.e. at the optimum-dry moisture content (ODM), optimum moisture content (OMC), and optimum-wet moisture content (OWM).

Table 3 – The design of experiment

Cycle No.	Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0								T								
1st	Moist curing for 7 days (specimen was placed in sealed plastic bag)							W	D	T						
2nd								W	D	W	D	T				
3rd								W	D	W	D	W	D	T		
4th								W	D	W	D	W	D	W	D	T

Note: W wetting D drying T unconfined compressive strength test

4. Specimen Preparation and Testing Procedure

In this study, the lime required for stabilisation was determined by Eades and Grim method as standardised in ASTM D6276 [33]. The test suggested the optimum lime content was 17%. Muntohar [11] proposed the 1:1 mixing ratio of the lime and RHA for stabilisation. The fibres added in the soil were 0.4% of the dry weight of soil. The specimen was prepared in the cylindrical size of 50 mm in diameter and 100 mm in height. An amount of the oven dry soil was mixed with 17% lime, 17% RHA, and 0,4% fibres thoroughly. The amount of lime, RHA, and fibres was determined by the percentage of the dry weight of soil. Water was added in the soil mixtures according to the designed moisture in Fig. 2. The moisture content was 25%, 32.5%, and 40% for ODM, OMC, and OWM respectively. Addition of water produced soil slurry. The slurry was transferred into a cylindrical mould (Fig. 3) and statically compacted to produce a compacted specimen. The static compaction was performed to maintain the density of the specimen as required.

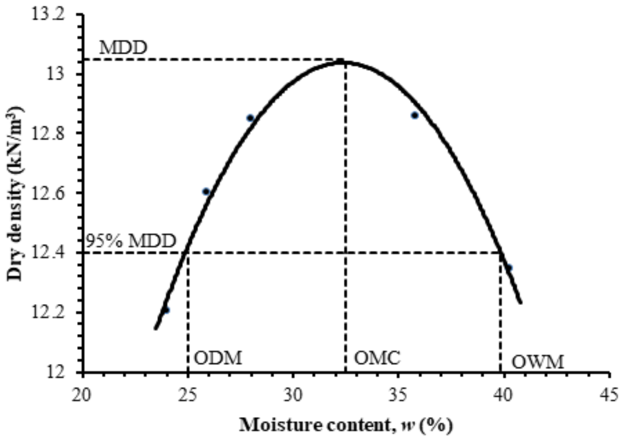

Fig. 2 - The compaction curve of the soil and the designed moisture and density

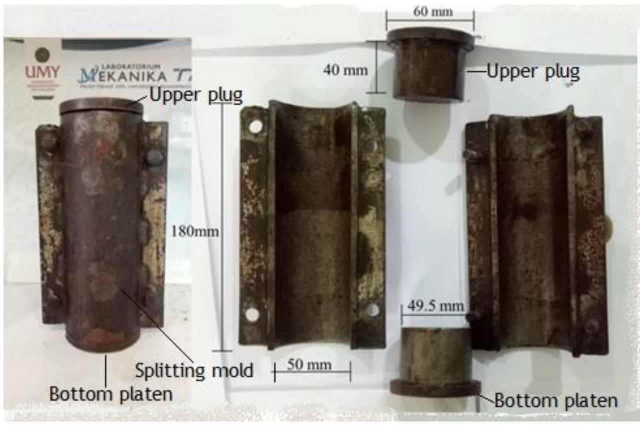

Fig. 3 - Splitting mould for static-compaction to control the density

After compaction, the specimen was stored in a sealed plastic bag and cured for seven days. Since there is no standard for lime-RHA stabilisation, hence the curing period adopted the standard for lime and cement stabilisation. The required curing by the Indonesian Standard SNI-03-3437-1994 [32] and SNI-03-3438-1994 [34] is seven days for base course layer. After seven days of moist curing, the specimens were subjected to unconfined compressive strength test and W-D cycles as designed in Table 3. Two specimens were prepared for each test. Before and after each wetting and drying, the weight and dimension of the specimenwere measured to record the moisture and volume change. The change of moisture content after wetting and drying was determined by the difference between the mass of specimen after wetting or drying and the mass of specimen at initial compacted. After completed W-D treatment, each specimen was subjected to the UCS test.

The procedure of the UCS test was in accordance with ASTM D 5102.The uniaxial-load testing machine was used for the test. The machine was equipped by 50 kN proving ring and 25 mm dial gauge indicator to measure the axial force and deformation respectively.

5. Results and Discussion

5.1 Effect on the Unconfined Compressive Strength

The average unconfined compressive strength (qu) of each moisture content and number of cycles are presented in Fig. 4(a). In general, the qu increases up to three W-D cycles and after that decreases. The increases in qu during W-D cycles because of two reasons: (1) the time of chemical reaction increases with the number of W-D cycles, and (2) the cementitious compound increases during W-D cycles. This result was also found by Muntohar et al. [16], Hoy et al. [35], Sivapullaiah and Moghal [36], Kamei et al. [37]. The Figure 5 shows surface crack after two W-D cycles. Increase in W-D cycles adversely influence on surface deterioration and develops cracks (see Fig. 5), and lead to degrading the unconfined compressive strength. The result has been concluded by Aldaood et al. [4], Hoy et al. [35], Avirneni et al. [38], Du et al. [39].

The results in Fig. 4(a) indicates that moisture content controls the qu. Specimen prepared at ODM always experiences the lowest qu, but the highest qu is obtained at OWM specimen. The qu of the soil compacted at ODM is about 25% lower than the OMC, while the soil at OWM is 18% higher than those compacted at OMC. This result is in contrary to the previous studies for silty, sandy soils, and rammed earth [11], [40], [41] that concluded that the strength decreases with the increases in moisture content. However, this characteristic can be explained by the strength development as shown in Fig. 4(b). The figure illustrates the strength index during W-D cycles. The strength index (Iqu) represents the strength development as written in Eq. (1).

$$I_{q_u} = \frac{q_{u(\text{after W-D cycle})}}{q_{u(\text{untreated or no W-D cycle})}} \tag{1}$$

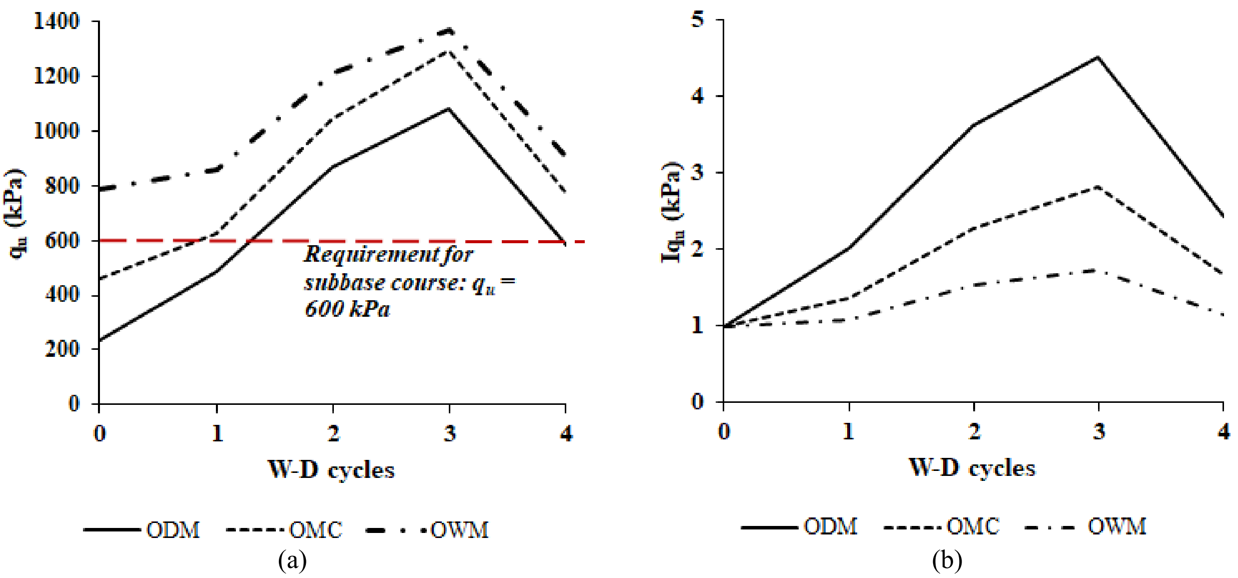

Fig. 4 - (a) Variation of unconfined compressive strength, (b) Strength development due to W-D cycles

Fig. 5 - Condition of the specimens after (a) 1, (b) 2, (c) 3, and (d) 4 W-D cycles

The specimen at dry compaction or ODM has a higher strength development than those of OMC and OWM sides. A cementitious compound in the stabilised soil needs moisture to maintain and develop the reaction. The moisture was adsorbed during the wetting process. At a dry side of optimum moisture content, the specimen has high suction and be able to attract more water than at the optimum or wet side of optimum moisture content for a chemical reaction (see Fig. 6). This behaviour was also confirmed by Muntohar [11], Park [28], Beckett and Ciancio [41].

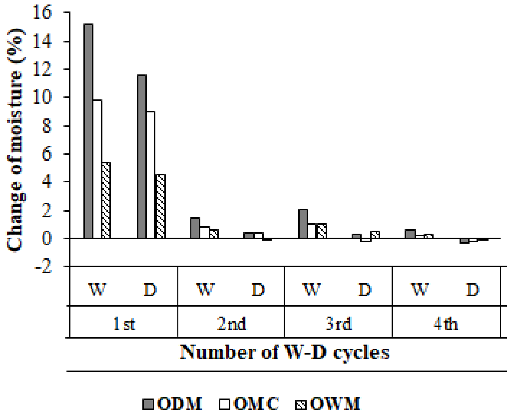

Fig. 6 - Variation of soil moisture due to W-D cycles

5.2 Stress-Strain Behaviour

The behaviour of the stabilised soil can be observed from the stress-strain curve. Typical stress and strain relationship of the specimen with the number of W-D cycles is presented in Fig. 7(a), 7(b), and 7(c) respectively for ODM, OMC, and OWM states. The specimen without W-D cycles tends to reach the peak stress at larger strain about 8-10%. Using the Mohr failure criteria for uniaxial load, the failure is attained at the maximum axial stress, then the failure strain decrease with W-D cycles. It is observed that the failure strain is about 4-6% after 4th W-D cycles. Post-peak strength was observed for all specimens which are defined as residual stress or ultimate strength because of the presenceof fibres in the stabilised soil. This ultimate strength was also identified by previous research [13], [16], [22], [42].

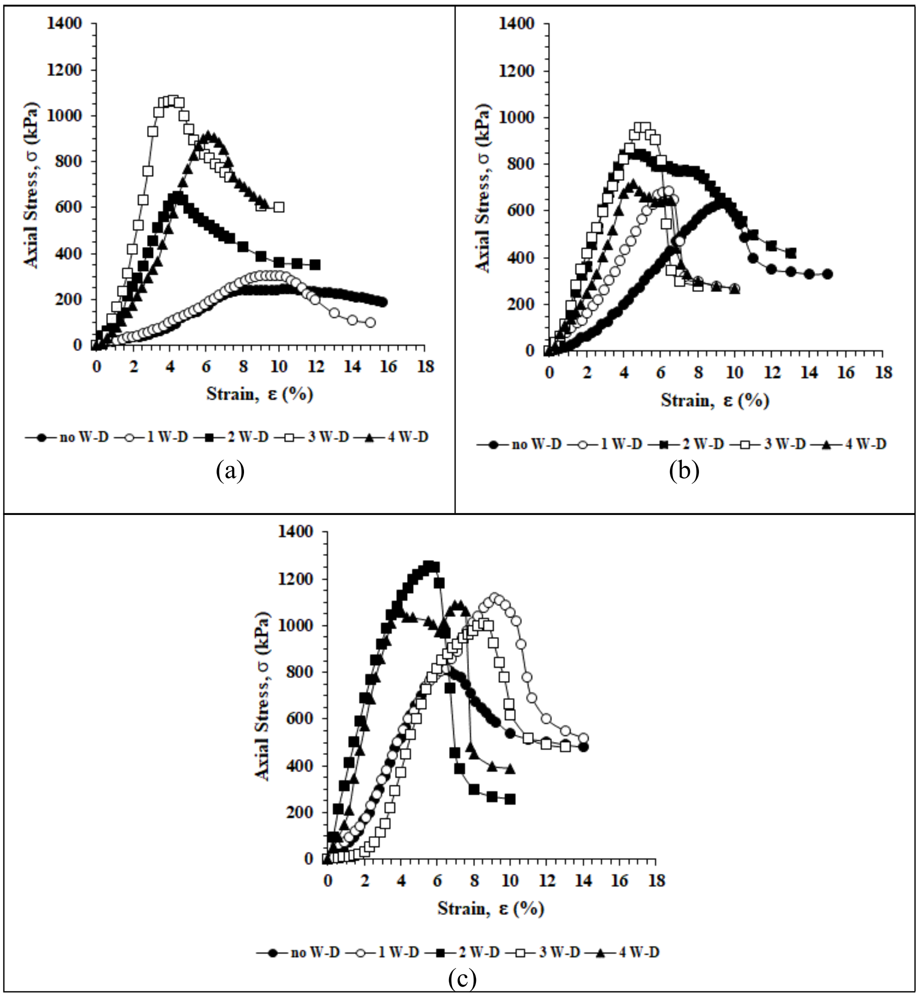

Fig. 7 - Typical stress-strain of the stabilised soil compacted at (a) ODM, (b) OMC, and (c) OWM conditions

The behaviour of a stabilised soil, commonly, can be determined by the secant modulus of elasticity (E50), and brittleness index (I_b). The E50 is determined as a ratio of half of qu, and its corresponds strain [16]. The secant modulus of elasticity or modulus of deformation is often used in the mechanistic-empiric (M-E) pavement design for evaluating the deformation and the thickness of the pavement structure. The resilient modulus is commonly correlated from the secant modulus obtained from static unconsolidated-undrained triaxial test and unconfined compressive strength test. A higher secant modulus and unconfined compressive strength indicates a higher resilient modulus and results in reducing of deformation [43].

Change of E50 due to W-D cycles is illustrated in Fig. 8. The increasing of E50 corresponds to the increase in qu with the W-D cycles. For the specimen without W-D, the E50 is 4.3 MPa, 6.95 MPa, and 13.2 MPa respectively for ODM, OMC, and OWM states. The results clearly show that the specimen compacted at OWM has the highest modulus of elasticity, and the specimen at ODM results in the lowest modulus of elasticity. Higher strength and smaller strain contribute to the increase in E50 at the OWM condition. The stress-strain curve in Fig. 7 clearly shows that the failure was attained at smaller strain in associate with the increasing of W-D cycles. As a result, the E50 increases with the number of W-D cycles, but after the fourth W-D cycles the E50 decreases as the qu decreases too. It was shown in Fig 6 that the peak stress of the soil compacted at OWM increases dramatically and exhibit a marked stiffness. This characteristic might be contributed by the pozzolanic gels produced during the lime-RHA reaction and result in increasing of inter-particle bonding [20].

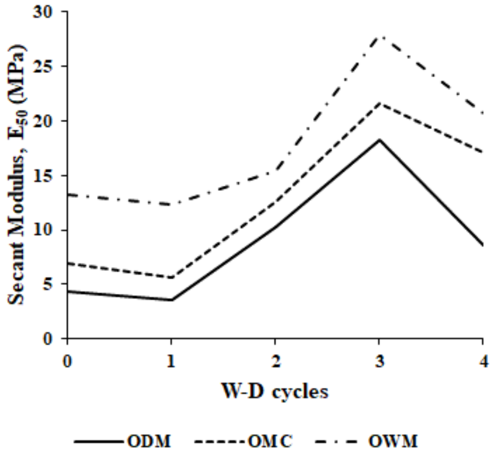

Fig. 8 - Variation of the secant modulus of elasticity E50 due to W-D cycles

Traditionally, the stabilised soil has shown a brittle behaviour. It is often undesirable for structure over the soil. Brittleness index (Ib) can be used to evaluate the ductility of stabilised soil, which is expressed as in Eq. (2).

$$I_b = \frac{\sigma_f}{\sigma_{ult}} - 1 \qquad (2)$$

where σ_f and σ_{ult} are peak axial stress and residual stress respectively obtained from the stress-strain curve. The I_b values range from zero to one, which I_b = 0 indicates a ductile behaviour, and I_b = 1 implies a brittle behaviour.

Fig. 9 shows the variation of the I_b in associated with the number of W-D cycles. The brittleness index ranges between 0.2 to 0.5, which increases with W-D cycles. This condition implies that the stabilised soil close to ductile behaviour before the W-D process and behave to brittle due to W-D cycles. It is noticed that the strength at dry state is higher than after wetting process. After drying, the moisture content of the soil decreases (see Fig. 6) and tends to reduce the plasticity. As a result, the microcrack (see Fig. 5(b) to 5(d)) propagates to be macropores and increases the brittleness [4]. After the first W-D cycle, the brittleness index increases about 45 to 70%, then slightly increases with the further W-D cycles. This result can be confirmed that the absorbed water during soaking was truly needed for chemical reaction to form a new cementitious material in the stabilised soil [21], [28]. As the consequence, the brittleness increases considerably after the first W-D.

Likewise, the specimen prepared at OMC shows more brittle than the specimens at OWM and ODM. The brittleness is caused by a higher dry density of the specimen prepared at the OMC (see Fig. 2). The specimen prepared at the ODM and OWM theoretically has the same dry density. But the soil at OWM is more brittle than the soil at ODM, which is indicated by the higher brittleness index of OWM. In this case, it is attributable by the highest quand lowest post-peak strength of OWM due to the chemical reaction in the soil such as hydration, pozzolanic, or carbonation [21]. This result is alluding to conclude that the brittleness of the stabilised soil is controlled by the dry density and the moisture content.

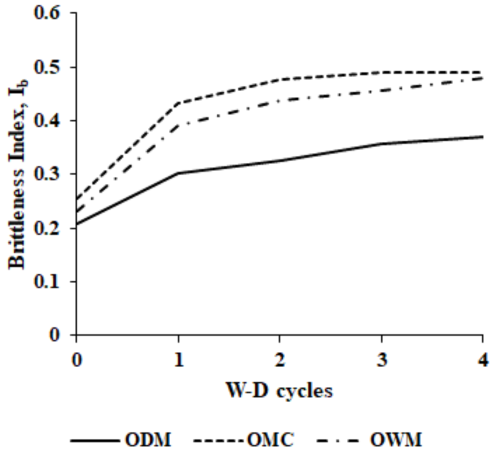

Fig. 9 - Variation of brittleness index Ib due to W-D cycles

6. Conclusion

This research has successfully studied the effect of wetting-drying cycles and moisture content on the unconfined compressive strength of the stabilised soil with lime-RHA and fibres. The moisture content significantly affects the unconfined compressive strength of the lime-RHA-fibres stabilised soil. The highest and lowest unconfined compressive strength value is obtained when the soil is compacted at OWM and ODM state respectively. This result concludes that the unconfined compressive strength increases with the moisture content. However, the strength development of the soil compacted at ODM is higher than the OMC and OWM states. The unconfined compressive strength of the soil compacted at ODM is about 25% lower than the OMC, while the soil at OWM is 18% higher than those compacted at OMC. At the same density, the stabilized-soil compacted at the OWM exhibits more brittle behaviour than the compacted at ODM.

The wetting-drying greatly affect the unconfined compressive strength of the stabilized soil. In general, the unconfined compressive strength of stabilised soil increased as the W-D increases, but the strength tends to decrease after the fours time W-D cycles. Correspond to the behaviour of the unconfined compressive strength, the secant modulus of elasticity increased from 69-89% due to the wetting-drying cycles. After experiencing an increase in the number of cycles, the secant modulus of elasticity decreases at the fourth W-D cycles. Likewise, the brittleness index increases with the W-D cycles. In addition, the brittleness is controlled by the density and moisture content of the stabilised soil.

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