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Influence of Plastic Waste Fibers on the Strength of Lime-Rice Husk Ash Stabilized Clay Soil

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Abstract: A study has been undertaken to investigate the strength of stabilized clay-soil reinforced with randomly distributed discrete plastic waste fibers by carrying out unconfined compressive strength and tensile-split strength test. In this study, the clay soil was stabilized with lime and rice husk ash mixtures. The effect of the fiber length and content on the compressive and split tensile strength was investigated. The laboratory investigation results show that inclusion of the plastic waste fiber increased significantly both the unconfined compressive strength and tensile-split strength of the stabilized clay soil. The fiber length plays a significant contribution in increasing the soil strength. To contribute for any significant improvement on compression as well as tensile strength, the fiber length should be in range of 20 mm to 40 mm. Fiber reinforcements also reduced soil brittleness by providing smaller loss of post-peak strength.

Keywords: unconfined compressive strength, split-tensile strength, soil stabilization, lime-rice husk ash, fiber wastes, soil reinforcement.

Introduction

In recent year, environmental issues have driven interest to utilize industrial by-product as alternative construction material. The well-established industrial by-product, such as fly ash, slag, mine tailing, have been obtained and mixed with lime and cement to improve the geotechnical properties of problematic soils. Over the thirty years, research has been carried-out to investigate the utilization of rice husk ash as stabilizing materials in soil improvement technique [1]. Some researches showed that rice husk ash was a promising material to improve lime or cement-stabilized soils [2, 3]. Addition of rice husk ash in lime or cement stabilized soils enhanced the compressive strength significantly [4, 5, 6]. However, the higher strength was obtained at small strain [7, 8]. This characteristic may be improved by means of inclusion of discrete element such as fibers. Stabilized and reinforced soils are, in general, composite materials that result from combination and optimization of the properties of individual constituent materials. A known approach in this area is the use of fiber-shaped waste materials in the composite.

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Plastic-waste materials are produced plentifully such as polyethylene terephthalate (PET) plastic bottles, polypropylene (PP) of plastic sack, and polypropylene (PP) of carpet. But such materials have been used little for engineering purposes, and the overwhelming majority of them have been placed in storage or disposal sites. Experimental results reported by various researchers [9, 10, 11, 12, 13] showed that the fiber-reinforced soil is a potential composite material which can be advantageously employed in improving the structural behavior of the stabilized and unstabilized soils. Investigation of fiber reinforcement system in a cement-stabilized soil have been done successfully by other researchers [14, 15, 16, 17]. Mostly those researches studied the compressive strength behavior of the fiber-reinforced soil-cement mixtures.

The present study examines the influence of inclusion of plastic waste fiber for improving the soil strength. The study focuses on evaluation of the base course material in railway. The specific objectives of this study are to investigate the effect of length and amount of plastic waste fibers on the compressive and tensile strength characteristics.

Experimental Program

The experimental program consisted of the following phases: (1) preliminary laboratory tests that included index properties, grain size analysis, and standard Proctor compaction tests to establish the moisture-density relationships of the unstabilized soil; (2) unconfined compression tests and split tensile tests on various amounts and lengths of fiber specimens.

The soil specimens were mixed with lime and rice husk ash to yield a stabilized soil specimens. The ratio of the lime to rice husk ash is 1 : 1 by their weight. Proportion of the lime added into the mixture was based on ASTM D4609-94 [18], considering plasticity index and lime content relationship as shown in Figure 1. Based on this figure, it was estimated that 12% lime addition is sufficient for improvement.

Various amounts of plastic waste fibers were added into the stabilized soil. The fiber content (P_f) was designed as 0.1%, 0.2%, 0.4%, and 0.8% of dry weight of the soil. Length of the fibers was varied to 10 mm, 20 mm, and 40 mm. Table 1 presents the mix design and type of tests conducted in experimental program.

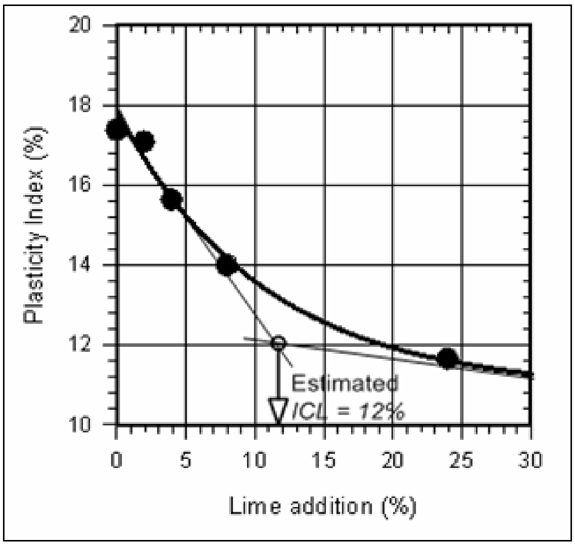


Figure 1. Determination of lime content for stabilization.

Materials

Soils

The soil samples used in the present experimental tests were obtained from the quarry of double-track railway project in Sentolo, Yogyakarta, Indonesia. Based on the preliminary tests, the specific gravity of the solid was 2.53. The soil specimens comprised of 35% clay-size fraction, 43% silt-size fraction, and 23% sand fraction as shown in the particle size distribution in Figure 2. The liquid limit and plasticity index of the soil were 59% and 29% respectively. The soil was classified as high-plasticity clay (CH) according to Unified Soil Classification System [19].

Lime and Rice Husk Ash (RHA)

Hydrated lime was used as stabilizing agent in this research. Major chemical constituent of lime is calcium hydroxides [$Ca(OH)_2$]. To reduce the carbonation effect due to humidity, the lime was kept in an airtight plastic container. The other stabilizing material was rice husk ash. For this research, merely the grey color ashes were collected, while the others were refused. Then the grey ones are grounded using Los Angeles machine and 40 mild steel bars were used to grind the burnt RHA. The steel bars were 10 mm and 12 mm in diameter and 200 mm to 300 mm long. An amount of 5 kg RHA was placed into the machine, and then, grounded for about 3 hours, which is equivalent to 5000 revolutions. This produces suitable fineness and proper surface area of RHA respectively about 12.4% and 25 mm^2/g. The grounded RHA was then transferred into a plastic bag and stored in an airtight container at room temperature to prevent from atmospheric humidity absorption.

Table 1. Mix Design and Type of Tests Conducted in Experimental Program

Mix No.	Mix design	UCS	STS
F0	Unstabilized Soil (without lime, RHA and fiber)	○	⊙
F1	Soil + 12% lime + 12% RHA (reinforced soil)	⊙	⊙
F11	Soil + 12% lime + 12% RHA + 0.1% fibers (L_f = 10 mm)	⊙	○
F12	Soil + 12% lime + 12% RHA + 0.2% fibers (L_f = 10 mm)	⊙	⊙
F18	Soil + 12% lime + 12% RHA + 0.8% fibers (L_f = 10 mm)	⊙	⊙
F21	Soil + 12% lime + 12% RHA + 0.1% fibers (L_f = 20 mm)	⊙	○
F22	Soil + 12% lime + 12% RHA + 0.2% fibers (L_f = 20 mm)	⊙	⊙
F24	Soil + 12% lime + 12% RHA + 0.4% fibers (L_f = 20 mm)	⊙	⊙
F28	Soil + 12% lime + 12% RHA + 0.8% fibers (L_f = 20 mm)	⊙	⊙
F41	Soil + 12% lime + 12% RHA + 0.1% fibers (L_f = 40 mm)	⊙	⊙
F42	Soil + 12% lime + 12% RHA + 0.2% fibers (L_f = 40 mm)	⊙	⊙
F48	Soil + 12% lime + 12% RHA + 0.8% fibers (L_f = 40 mm)	⊙	⊙

Note: UCS = unconfined compressive strength test, STS = split-tensile strength test, RHA = rice husk ash, L_f = fiber length, ⊙ indicates tested (two specimens), ○ indicates triplicate specimens

Fiber

Plastic fibers used in the present investigation were cut to the designed length from locally available polypropylene plastic-bag wastes. The width of single fiber was approximately 2 mm – 2.5 mm. Tensile strength of the plastic fiber specimens was 62.85 kN/m^2 in average and the strain at rupture was 15.3% in average.

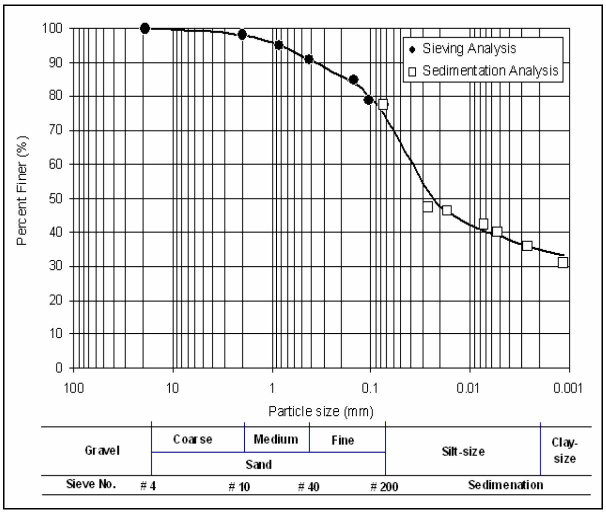


Figure 2. Particle size distribution of the soil used.

Specimens Preparation and Testing Procedures

Specimens are compacted by static compaction method. The known amount of soil was placed into cylindrical mould (Figure 3). During filling, the materials were tamped gently and uniformly so that the upper plug can be inserted about 15 mm. The assembled mould was then placed on hydraulic jack and a force was applied until the upper plug was in contact with the barrel of the mould. The mould was dismantled and the specimen whose dimension of 50 mm in diameter and 100 mm of length. The mass of specimen is determined immediately after preparation and then kept in a plastic bag, thus cured for 7 days.

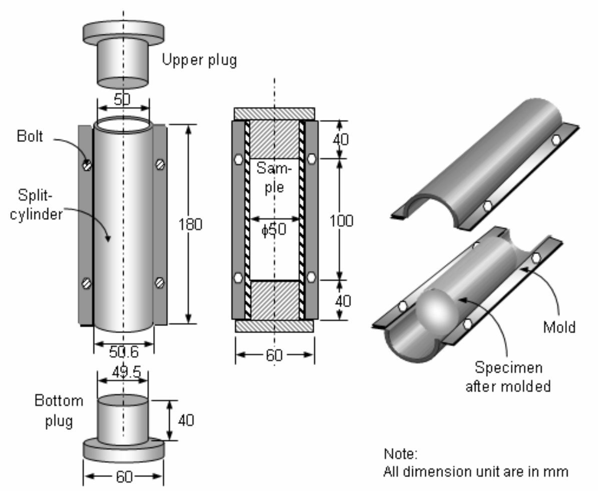


Figure 3 Static compaction mold for preparing the specimen

The unconfined compression tests and the splitting tensile tests were carried out in accordance with ASTM D5102 [20] and ASTM C496 standards [21], respectively. After the curing periods and before testing, the mass and dimension of specimen are recorded. The unconfined compression tests were performed on a 50 kN universal-testing machine. The force was applied so that the loading rate was approximate 1 mm/minute. The standard ASTM C496 procedure only deals with the determination of split tensile strength. To measure the tensile deformation of the horizontal diameter due to compressive loading in an orthogonal direction, two dial gauges were installed (Figure 4). In this study, the split-tensile strength test equipment was modified from unconfined compressive strength test apparatus. The schematic of the test setup is shown in Figure 4. The split tensile strength is calculated according to ASTM C 496, as follows:

$$T = \frac{2P_{\max}}{\pi \cdot L \cdot D} \tag{1}$$

where T is split tensile strength; P_{max} is applied maximum load; L and D are length and diameter of the specimen respectively.

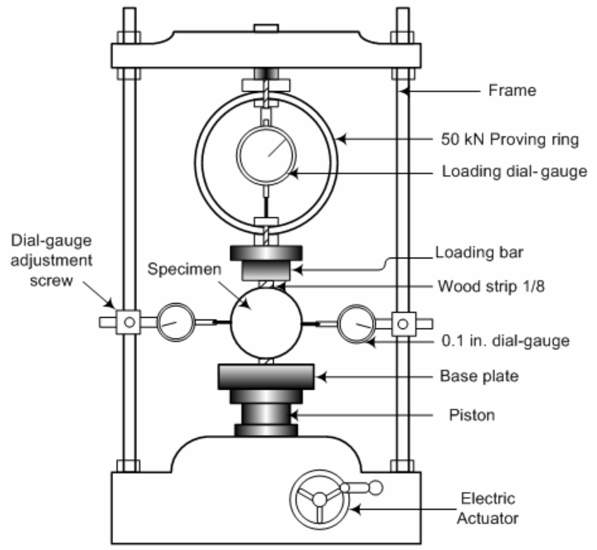


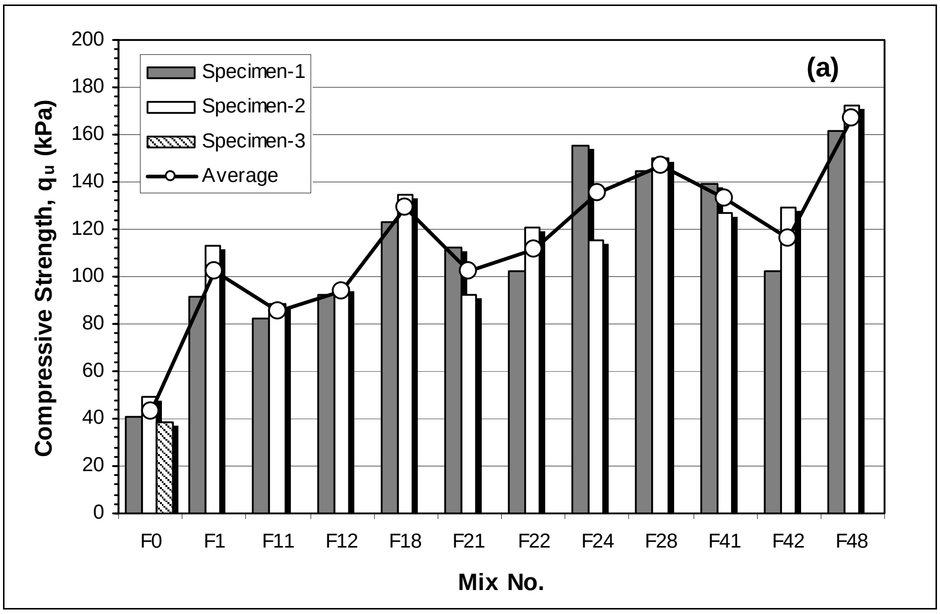
Figure 4. Scheme and arrangement of the apparatus for split-tensile test

Results and Discussion

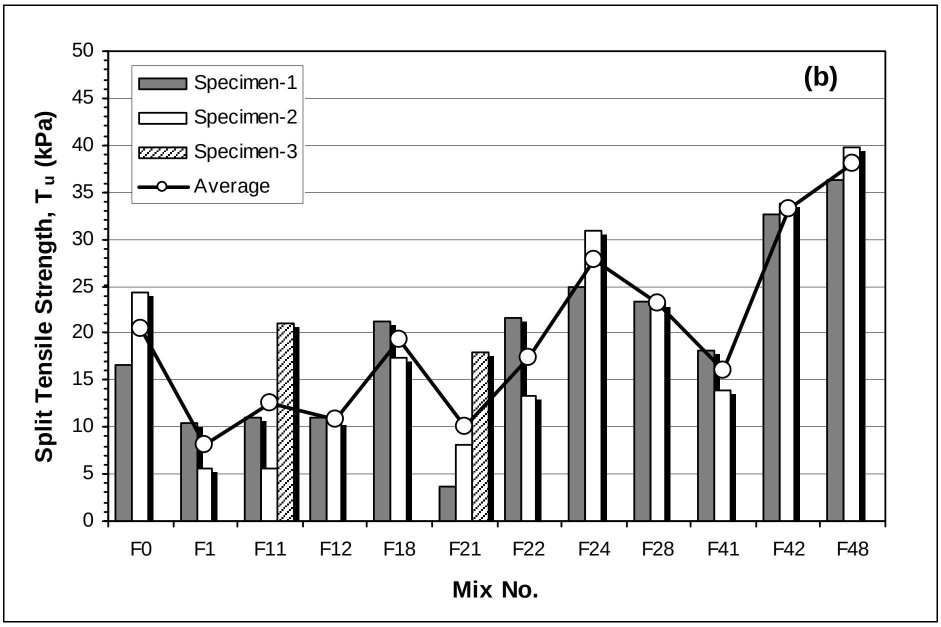
The experimental results of unconfined compressive strength and split tensile strength are presented in Figure 5a and 5b respectively. Stabilization of the soil by lime and rice husk ash (F1) has enhanced significantly the compressive strength from 43 kPa to 102 kPa as shown in figure 5a. This characteristic indicated that there was a chemical reaction among lime, rice husk ash, and soil to form a cementations product. However, addition of lime and rice husk ash did not improve the split tensile strength as shown in Figure 5b. The split tensile strength of the stabilized soil (F1), T_u = 8 kPa, is lower than the unstabilized soil (F0), T_u = 20 kPa. This phenomenon is due to the more brittle behavior exhibited by the stabilized soil compared to the unstabilized soil (F0) as shown in strength and strain curve in Figure 6a and 6b. Figure 6b, shows in case of the stabilized soil the peak stress increases dramatically at small range of axial strain. The stabilized soils tend to fail at strain about 3% – 7%, while strain failure of unstabilized soil ranges from 12% to 14% as shown in Figure 6a. It implies that the stabilized soil exhibits a marked stiffness and brittleness. The brittleness of the stabilized soil specimen is also confirmed by split tensile strength test as shown by load – deformation behavior in Figure 6e. The lateral deformation of the stabilized soil specimen was relatively smaller if compared to unstabilized soil (Figure 6d).

The effect of fiber inclusion in lime-rice husk ash stabilized soil (specimen F24) on the behavior of stress–axial strain is shown in Figure 6c. Upon comparison with Figure 6b, it is readily observed that the peak axial stresses increase and the brittleness reduces with inclusion of fiber. The axial stress increases with an increase in axial strain until the peak value is reached, followed by a sudden drop to zero in stabilized soil, but the post-peak stress reduced gradually when fibers are included.

As shown in load–deformation curve of split tensile strength test (Figure 6f), the lateral deformation of the reinforced soil specimen is relatively longer compared with the stabilized-soil specimen. As a



(a) unconfined compressive strength



(b) split tensile strength

Figure 5. Test results of various mix design

result, the reinforced soil specimen can retain a much higher applied load. Undoubtedly, one of the main advantages of fiber reinforcement when applied to soil is the improvement in material ductility. A similar research result was also revealed by Consoli et al. [15], Kaniraj and Havanagi [16]. Those researches also concluded that inclusions of randomly oriented polyester fiber increased the strength of the raw fly ash–soil specimens as well as that of the cement-stabilized specimens and changed their brittle behavior to ductile behavior.

Effect of The Fiber Content on Unconfined Compressive Strength and split Tensile Strength

Effect of fiber inclusion on the unconfined compressive strength (UCS) and split tensile strength specimens was determined as function of fiber content and length. Figure 7 shows the effect of fiber content on the change of compressive strength and split tensile strength. Figure 7a and 7b, show that the compressive and split tensile strength of the reinforced soil increases with increasing fiber content. The fiber can efficiently reduce the further development of tension cracks and the deformation of the soil subject to applied load. Tang et al. [17] mentioned this behavior as "bridge" effect of fiber inclusion. Figure 7a and 7b shows that the compressive strength and plit tensile strength of the reinforced soil increased slightly with addition of 0.1% fibers, indicating the inclusion 0.1% fibers content was insufficient to retain the axial load in soil-fiber matrix. Then, additional mixing of the fiber up to 0.4% was able to enhance considerably both the compressive strength and split tensile strength of the stabilized soil. This maybe can be explained that the total contact area between fibers and soil particles increases while increasing the fiber content and consequently the friction between them increases, which contributes to the increase in resistance to forces applied. This phenomenon was also observed by Cai et al. [22].

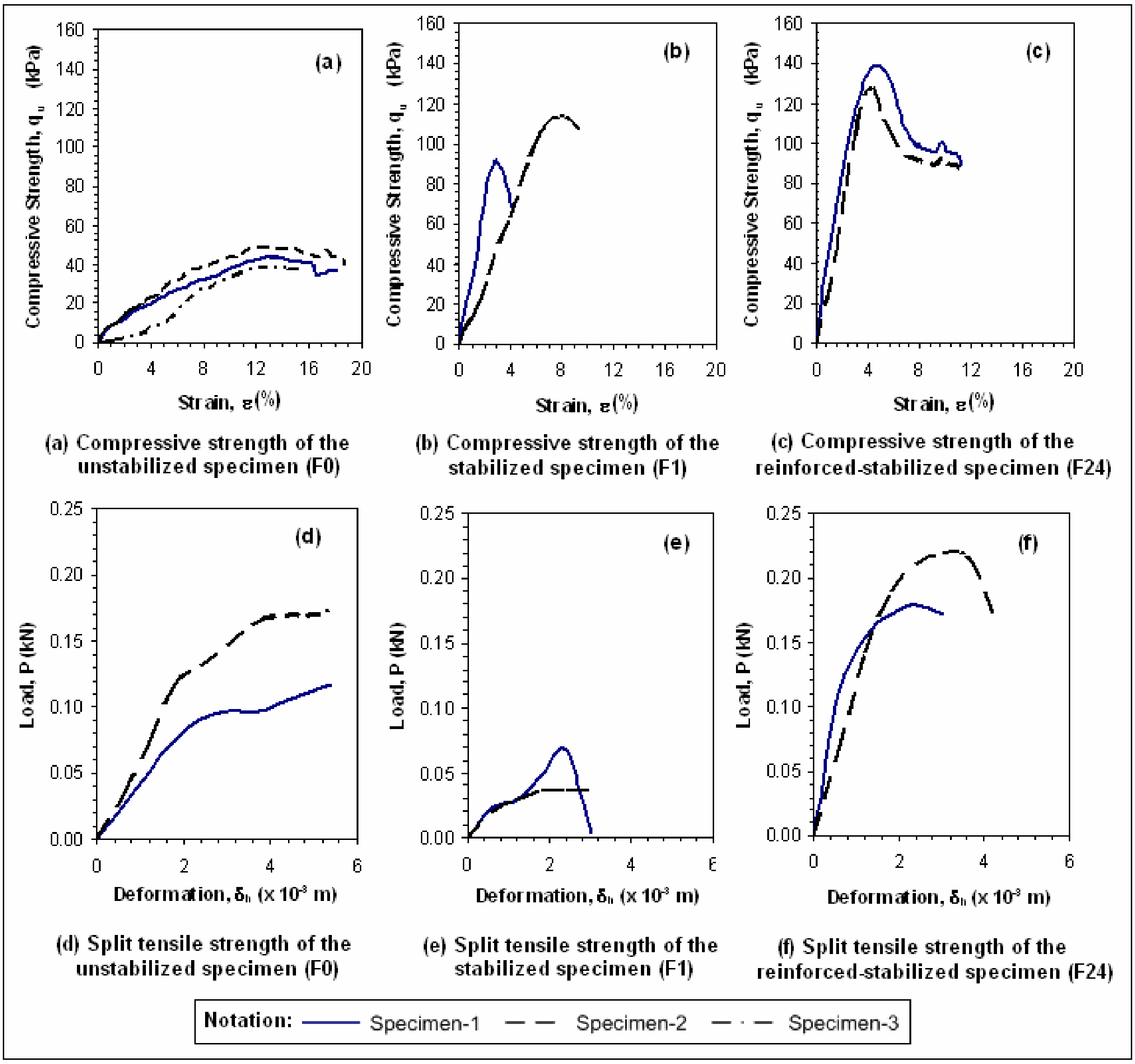
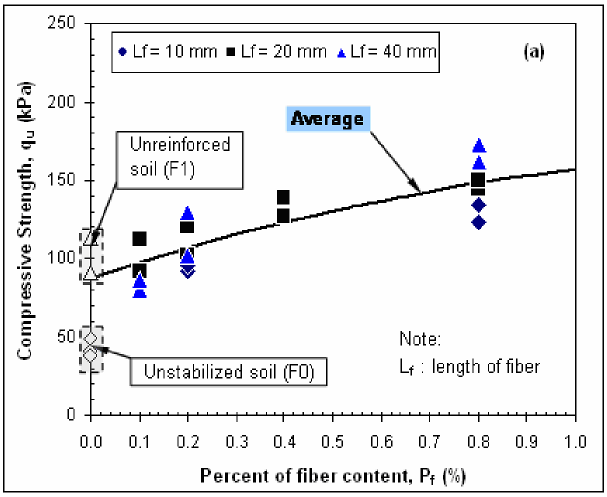
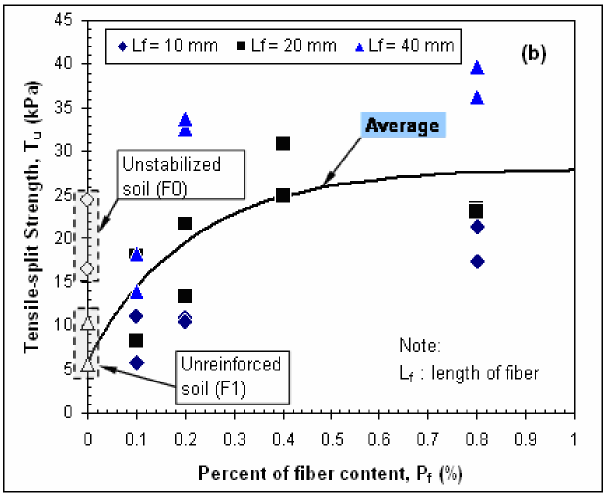


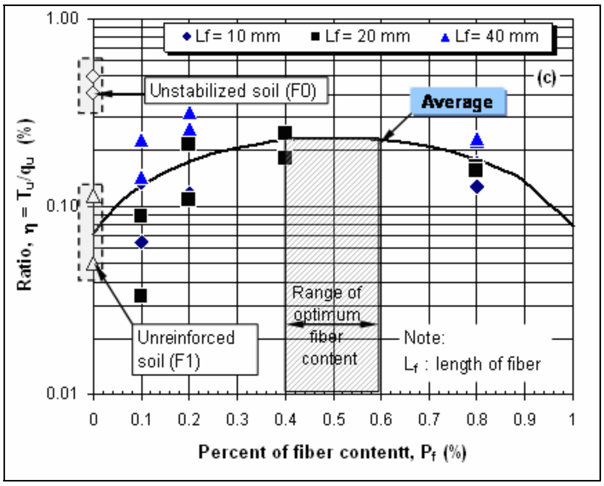
Figure 6. Strength and deformation characteristics (a – c), and load – deformation characteristics (d – f)



(a) compressive strength



(b) split tensile strength



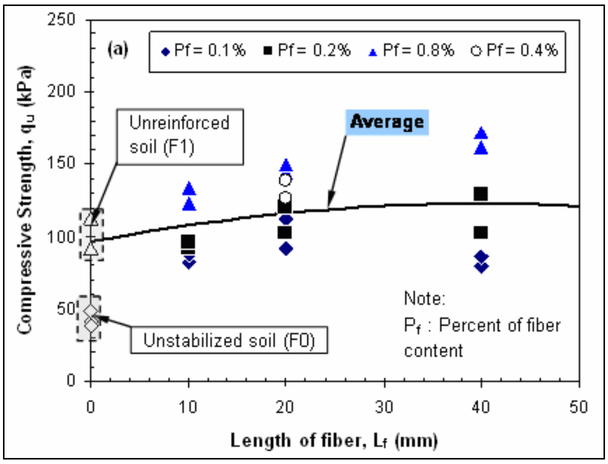
(c) ratio between split tensile and compressive strength

Figure 7. Effect of plastic waste fiber content on strength of the tested soils.

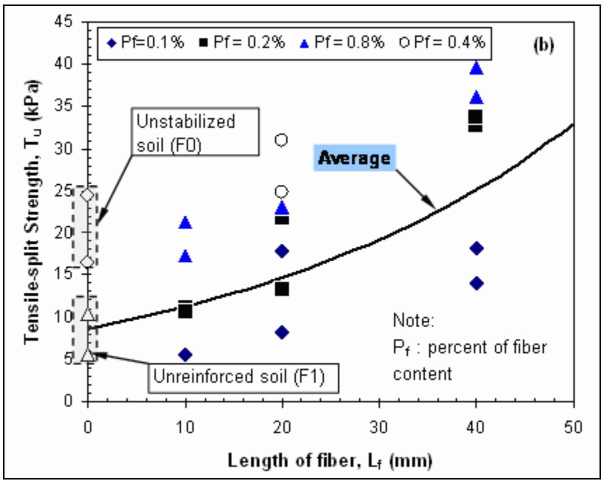
Increasing both compressive and split tensile strength of the stabilized soil was an beneficial of the fiber inclusion in soil – lime – rice husk matrix. In the figure 7c shows the influence of fiber content on the ratio of tensile to compressive strength (T_u/q_u). In general, the value of tensile strength and compressive strength ratio is about 0.2 in average. It means that the split tensile strength of the specimen reinforced with plastic fibers is 20% of its compressive strength. The relationship between fiber content and ratio of Tu/qu was parabolic. Thus, one can find a optimum fiber content that should be mixed in soil – lim – rice husk ash matrix. It is observed clearly that the fibers inclusion in the stabilized soil range between 0.4% to 0.6%. This range can be defined as optimum range of fiber content that results in higher tensile and compressive strength.

Effect of Fiber Length on Unconfined Compressive Strength and Split Tensile Strength

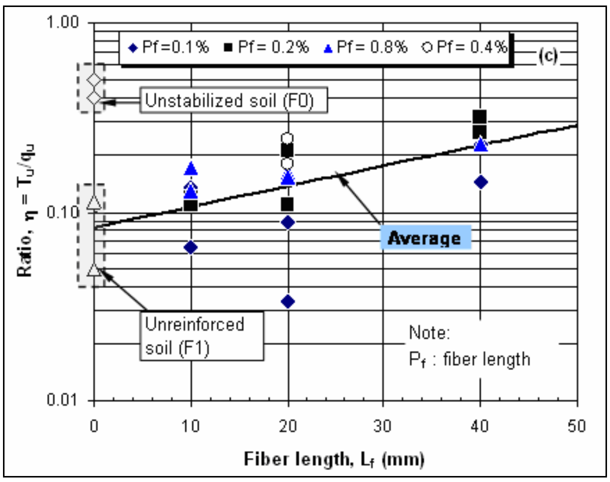
The effect of fiber length on the unconfined compressive strength and split tensile strength specimens is shown in figure 8. Figure 8a and 8b show the change in compressive strength and split tensile strength respectively. However, as expected, the lime –rice husk ash mixture was responsible for the major change observed in the compressive strength. In figure 8a, increasing of fiber length slightly affect the compressive strength of the stabilized soil if amount of the fiber inclusion is 0.1% and 0.2%. But, if the proportion of fiber is increased to 0.8% and the fiber length is 40 mm, the compressive strength increase about 64% from 102 kPa (specimen F1) to 167 kPa (specimen F48). At lower fiber content and shorter fiber length, based on probability principle, the fibers lead to distribute easily on shear plane and lead to increase peak strength of the reinforced soils. However, when unstable phase was attained at yielding stage, a shorter fiber is easier to pull out from the soil-fiber matrix if compare with a longer fiber length. This behavior initiates a lower compressive strength. In figure 8b, the split tensile strength has a tendency to increase considerably with increasing of fiber length. This characteristics differ with the previous research [11] which the variation in FL did not show any influence on soil response. It was presumably due to the lack of friction mobilization between the fiber and the cemented soil matrix, which is probably related to the smooth nature of fibers. However, consider the principle soil reinforcement, the applied load was transferred from soil skeleton to the fiber through friction interface between soils – fibers system. Thus, increasing fiber length or aspect ratio leads to augment the friction interface. This behavior results in increasing its frictional resistance between soils and fibers.



(a) compressive strength



(b) split tensile strength



(c) ratio between split tensile and compressive strength

Figure 8. Effect of fiber length on strength of the tested soils

Figure 8c illustrates relationship between ratio of tensile and compressive strength with fiber length. This characteristic explains that the soil strength increase with increasing fiber length. A longer fiber length was difficult to distribute uniformly in friction interface of soil– fiber matrix. Furthermore, it caused slippage plane in soil. This behavior was also discussed by Al-Refei [23]. Based on this behavior, combining figure 7c and 8c, the effective fiber length readably ranges from 20 mm to 40 mm in which corresponds to fiber content 0.4% - 0.6%. For the practical purposes, this effective fiber length was to assure that the fiber could be distributed uniformly. As result, the fiber can prevent effectively tension cracks become gradually larger.

Secant Modulus (E_{50})

Secant modulus (E_{50}) is one of parameter to determine stiffness or elasticity of soil. The value of E_{50} was defined from axial strength and strain relationship of unconfined compressive strength test in laboratory (figure 6). Thus, the E_{50} is expressed as

$$E_{50} = \frac{q_{50}}{\varepsilon_{50}};$$

where q_{50} is a half of the peak compressive strength, and ε_{50} is strain which corresponds to q_{50}. Figure 9 presents various values of the secant modulus of each mixture design. The figure shows that the unstabilized soil specimen (F0 specimen) has lowest secant modulus among other mixture specimen. In general, inclusion of the fibers in lime-rice husk ash and soil mixtures enhanced the secant modulus (E_{50}). The highest secant modulus was obtained if the lime-rice husk ash and soils mixtures were mixed with 0.2% fiber and 10 mm to 20 mm fiber length. The secant modulus of the reinforced soils decreased if the fiber content was greater than 0.2% and longer than 20 mm.

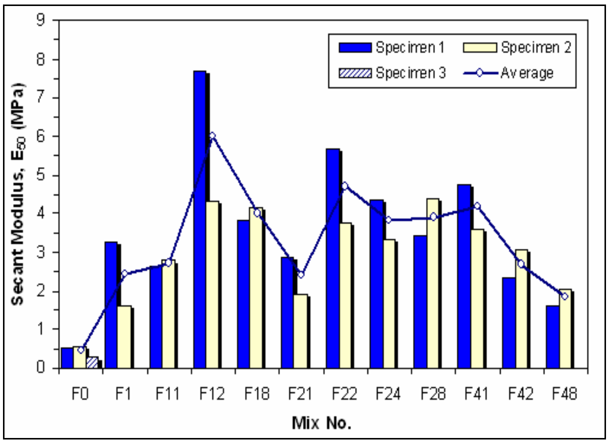


Figure 9. Secant modulus of the specimens from unconfined compressive strength test

Conclusions

A series of tests were performed to study the effects of randomly distributed plastic waste fiber reinforcement on the strength of stabilized soil with lime-rice husk ash mixtures. The effects of fiber inclusions in soil and lime-rice husk ash mixtures on unconfined compressive strength, split tensile strength, stiffness and ductility of soil specimens were determined. Following conclusions can be drawn from this study:

1. Soil stabilization using lime and rice husk ash mixtures enhanced the compressive strength of the soil 2.4 times approximately. However, the stabilizing materials were not able to improve the split tensile strength of the soil specimens.
2. The unconfined compressive strength of reinforced soil specimen with plastic fibers was affected mostly by the amount of fiber mixed in soil mixtures. The unconfined compressive strength increased in association with increasing fiber content.
3. The split tensile strength of the reinforced specimens increased significantly with increasing fiber length.
4. According to the ratio between split tensile and compressive strength, the optimum amount of fiber mixed in soil-lime-rice husk ash mixtures range from 0.4% to 0.6%. The effective fiber length correspond to the fiber content range between 20 mm–40 mm.
5. Fiber reinforcement increased the stiffness of stabilized soil and changed the stabilized soil's brittle behavior to a more ductile behavior. In general, inclusion of the plastic waste fiber increased the secant modulus (E_{50}) of the stabilized soil specimen.

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