Fibre distribution effect on behavior of fibre-reinforced cement-treated clay

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ABSTRACT

The use of randomly distributed fibre as a reinforcement medium for cement-treated soil has been receiving increasing attention in recent years. Studies have shown this to be an efficient method to control and improve the brittle behavior of cement-treated soil. However, the fibres may be non-uniformly distributed over the mixture. This issue with non-uniform fibre concentration, which may arise from difficulties with fibre mixing, could be significant in the field, and it may affect the overall behavior of the treated soil mass. This paper presents a laboratory study on fibre distribution effect on behavior of fibre-reinforced cement-treated Singapore marine clay. The fibre distribution analysis will be conducted with randomly selected samples while the behaviour will be investigated mainly through unconfined compression testing. Polypropylene (PP) fibres with 6 to 12mm cut length and 0.25% to 2.0% fibre content (by weight) will be mixed with high cement-admixed clay. The results show that for 6mm long PP fibres reinforced mixture, fibre distribution shows higher non-uniformity when fibre content is at low fiber content of 0.5% or high fibre content of 2.0%, which results in higher variability in peak strength and ductility. This non-uniform fibre distribution has more significant effect on ductility than on peak strength. Corresponding density analysis indicates very minor fibre distribution effect. For 12mm long PP fibres reinforced mixture, the high non-uniform fibre distribution due to lower or higher fibre content seems to be more significant. However, the fibre distribution effect on strength and ductility looks quite similar to 6mm long PP fibres reinforced specimens.

Keywords: cement-treated soil, fibre distribution, non-uniformity, unconfined compressive strength, ductility

1. INTRODUCTION

Cement-treated soil has been widely employed for improvement of soft clayey soils. However, one of the drawbacks of cement-treated soil is its post-peak brittle behavior. Previous studies have shown that fibre-reinforcement increases the strength and ductility while decreasing the stiffness of the soil (e.g., Gray & Ohashi 1983). Studies have also shown that incorporation of both fibres and cement in soil improvement seems to be more efficient than fibres or cement alone (e.g., Maher & Ho 1993, Consoli et al. 1998).

The use of randomly distributed fibre as a reinforcement medium for cement-treated soil has been receiving increasing attention in recent years (e.g., Khattak and Alarshidi 2006, Tang et al. 2007, Park 2009, Consoli et al 2011, Xiao et al. 2013, Xiao et al. 2014). Studies have shown this to be an efficient method to control and improve the brittle behavior of cement-treated soil. However, cement-treated soils are known to possess significant heterogeneity. Thus, the fibres may be non-uniformly distributed over the mixture. This issue with non-uniform fibre concentration, arising from difficulties with fibre mixing, could be significant in the field, and it may

affect the overall behavior of the treated soil mass. This paper presents a laboratory study on fibre distribution effect on behavior of fibre-reinforced cement-treated (FRCT) Singapore marine clay. The fibre distribution analysis will be conducted with randomly selected samples while the behaviour will be investigated mainly through unconfined compression tests (UCT). PP fibres with 6 to 12mm cut length and 0.25% to 2.0% fibre content (by weight) will be mixed with high cement-admixed clay. Some factors on fibre distribution will also be discussed in this study.

2 EXPERIMENT INVESTIGATIONS

The materials used in this study are Singapore upper marine clay, type I Ordinary Portland cement (OPC) and fibres. The constituents of the clay are 24.13% col-loid, 21.77% clay, 47.71% silt and 6.39% very fine to medium sand. Two different types of fibres were used, namely polypropylene (PP) and polyvinyl al-cohol (PVA) fibres. The properties of the fibres are given in Table 1. A naphthalene-based super-plasticizer (Rheobuild 1000, BASF) was used in mixture 2:1:3 for workability purpose.

Table 1 Physical and mechanical properties of fibers

Fiber Type	Length (mm)	Diameter (micron)	Tensile strength (MPa)	Elastic modulus (GPa)	Density (kg/m ³)
PP6	6	31	540	7	910
PP12	12	26	540	7	910
PVA6	6	26	1600	40	1300

The mix ratio is expressed in terms of mass ratios S:C:W wherein S is mass of dry soil solid, C the mass of cement and W the mass of water at the point of mixing. The cement content Aw is defined as the ratio of mass of cement to the mass of dry soil solid, that is C:S. The water content Cw is defined as the ratio of mass of water to the total mass of dry soil solid and cement, that is W/(S+C). In this study, the cement content is 50% to 100% while the water content ranges from 100% to 133%. The fibre content is defined as the ratio of the mass of fibre to the total mass of the soil cement water mixture at the point of mixing, and ranges from 0.25% to 2.0%. The ductility index is defined herein as the ratio of the average post-peak strength up to a certain post-peak strain to the peak strength (see Xiao et al. 2014).

As the preparation of the FRCT clay specimen has been described in details by Xiao et al. (2013), it will not be repeated here. Before specimens were casted, 14 to 28 samples were randomly collected and weighted quickly for fibre distribution analysis from the mixture and put into small plastic containers just after the mixing. The average weight of the sample is about 30g. Thus the total weight of the samples selected is about 20% to 40% of the total mixture, which ensures the sampling is representative of the mixture. The small sample was then put into very fine sieve (25 μ m) and the fibres were picked out very carefully when the soil was flushed with small water flow. The fibres picked out were kept in tin foil and put into the oven for 24 hours. Consequently, the fibre weight of the sample can be obtained and the fibre content determined for each sample. Specimens for UCT test were cured in PVC split moulds in distilled water without loading under a controlled temperature of 25 °C. The specimens were then taken out after 7 days for UCT test using a nominal deformation rate of 1mm per minute. The tests were performed according to ISO/TS 17892 (2004).

3 EXPERIMENTAL RESULTS AND ANALYSIS

Figure 1 shows the typical stress strain behavior of FRCT soil specimens under unconfined compression. Compared to purely cement-treated soil, fiber reinforcement increases the strength and ductility significantly, the ductility increasing with fiber content. Figure 1 also indicated that the stress strain curves are significantly scattered at lower (0.5% for PP6, 0.25% for PP12) or higher (2% for PP6, 1.0% for PP12) fibre content.

Fig. 1. Stress strain behavior for FRCT soil specimens with PP fiber. (a) and (b): PP6, (c) and (d): PP12. (for (a) and (c), 50% cement content and 133% water content; for (b) and (d), 50% cement content and 100% water content).

Figure 2 shows the fiber distribution of cement soil mixture with PP6 fibre for different mix ratio. The

corresponding coefficient of variation (CV) is shown in Figure 3a, which indicates higher non-uniformity of fibre distribution when fibre content of the mixture is low (0.5%) or high (2%). This induced higher variability of stress strain curve as shown in Figure 1. As such, Figure 3b to 3c show higher variability of peak strength and ductility (at 6% post peak strain) of FRCT specimen at lower or higher fibre content for all mix ratios studied here, with more significant effect on ductility. However, the strain at peak strength does not show similar trend (Figure 3d) for all mix ratios.

Fig. 2. Fibre distribution of FRCT soil mixture reinforced with PP6 fiber. (a) 50% cement content and 133% water content; (b) 50% cement content and 100% water content; (c) 75% cement content and 100% water content; (d) 100% cement content and 100% water content.

Fig. 3. Fibre distribution effect on behavior of FRCT soil specimen reinforced with PP6 fiber. (a) variability of fibre distribution; (b) variability of peak strength; (c) variability of ductility; (d) variability of strain at peak strength.

Similar tests and analysis were also conducted for cement soil mixture with PP12 fibres. The results shown in Figure 4 and Figure 5a indicate that for PP12 reinforced cement soil mixture, the non-uniformity in the fibre distribution is more significant for the lowest or highest fibre content of 0.25% or 1.0% respectively. However, the fibre distribution effect on strength and ductility (at 8% strain after peak strength) looks quite similar to 6mm long PP fibres reinforced specimens (see Figures 1c to 1d and 5b to 5d).

(a)

(b)

(c)

(d)

Fig. 4. Fibre distribution of cement soil mixture with PP12 fiber. (a) 50% cement content and 133% water content; (b) 50% cement content and 100% water content; (c) 75% cement content and 100% water content; (d) 100% cement content and 100% water content.

(a)

(b)

(c)

(d)

Fig. 5. Fibre distribution effect on behavior of FRCT soil specimen reinforced with PP12 fiber. (a) variability of fibre distribution; (b) variability of peak strength; (c) variability of ductility; (d) variability of strain at peak strength.

4 DISCUSSIONS

As mentioned before (Section 2), the total number of samples for fibre distribution analysis for each mixture is fixed at 14, which is about 20% of the total weight of the mixture. To verify the sampling reliability, 28 samples (about 40% of the mixture) were selected from FRCT soil mixture with 1% and 2% fibre (mix ratio 2:1:4). Figure 6 shows the fibre distribution from 14 and 28 samples, which indicates very minor difference between different numbers of samples.

The results of the previous section has shown that for cement soil mixture with PP12 fibre, the non-uniformity in the fibre distribution at fibre contents of 0.25% and 1% looks more significant (Figure 5a) compared to the PP6 fibre results (Figure 3). This may be due to lower mixability when the fibre length was increased from 6mm to 12mm. In fact, high concentrated fibre lumps were easily detected in the mixture after fixing. To improve the fibre uniformity, hand mixing was applied just after mixer mixing.

Figure 7 shows the fibre distribution for mixture with and without hand mixing. The CV values of fibre distribution for mix ratio 2:1:4 and 2:1:3 with 1% PP12 fibre are now significantly reduced from 0.1478 and 0.1214 to 0.0746 and 0.069 respectively. As such, the variability of stress strain curves is also largely reduced (see Figure 8). This indicates that hand mixing can improve the fibre uniformity and reduce the variability of behavior of FRCT soil specimen, which may be useful to laboratory study especially for cement soil mixture with long fibres.

Fig. 6. Fibre distribution of FRCT soil mixture reinforced with 1% and 2% PP6 fiber (50% cement content and 133% water content, 14 and 28 samples).

Fig. 7. Fibre distribution of FRCT soil mixture reinforced with 1% PP12 fiber (group A and B:50% cement content and 133% water content; group C and D: 50% cement content and 100% water content). H denotes handing mixing after mixer mixing.

Fig. 8. Stress strain behavior for FRCT soil specimens with 12mm long PP fiber (group A and B:50% cement content and 133% water content; group C and D: 50% cement content and 100% water content). H denotes handing mixing after mixer mixing.

The previous experiment results and analysis only introduced PP fibre reinforcement. As Table 1 shows, PVA fibre has different physical and mechanical properties from PP fibre. Therefore, the same test procedure and analysis was also employed for cement soil mixture with PVA fibre reinforcement. It was observed that fibre distributions of cement soil mixtures with PVA6 fibres showed similar trend to those with PP6 fibres. Figure 9 shows the variations of fibre distribution, peak strength, ductility and strain at peak, which is basically similar to those with PP6 fibres (Figure 3).

Besides the UCT test, density analysis was also conducted in this study. Figures 10 and 11 show the density and variation of the density of the FRCT soil specimens. As Figure 11 shows, the fibre distribution effect on density is very minor.

(a)

(b)

(c)

(d)

Fig. 9. Fibre distribution effect on behavior of FRCT soil specimen reinforced with PVA6 fiber. (a) variability of fibre distribution; (b) variability of peak strength; (c) variability of ductility; (d) variability of strain at peak strength. (Cement content 75% and 100%; water content 100%).

Fig. 10. Typical results for density of FRCT soil specimens reinforced with PP6 fiber. (50% cement content and 133% water content).

(a)

(b)

Fig. 11. Fibre distribution effect on density of FRCT soil specimen reinforced with PP fiber. (a) PP6 fibre; (b) PP12 fibre.

5 CONCLUSIONS

Fibre distribution effect on behavior of FRCT clay

was studied mainly through UCT test. The results showed that for 6mm long PP and PVA fibres reinforced mixture, fibre distribution shows higher non-uniformity for both low (0.5%) or high (2.0%) fibre contents, which results in higher variability in peak strength and ductility. This non-uniform fibre distribution has more significant effect on ductility than on peak strength. Corresponding density analysis indicates very minor fibre distribution effect. For 12mm long PP fibres reinforced mixture, the non-uniformity in the fibre distribution at low (0.25%) and high (1%) fibre content seems to be more significant. However, the fibre distribution effect on strength and ductility looks quite similar to 6mm long PP fibres-reinforced specimens.

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