Fiber Reinforced Cement Treated Clay

Fibro-ciment renforcé argile traitée

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ABSTRACT: Cement-treated soil has been used widely in ground improvement for several decades. However, its behavior, especially at high cement content, is highly brittle. Previous studies have shown that addition of both fibers and cement in soil improvement seems to be more efficient and attractive than adding fibers or cement alone. This paper presents an experimental study on fiber-reinforced cement-treated marine clay. Two different types of fibers and fiber lengths as well as different fiber contents (0.0%-0.32%) will be investigated with cement content ranging from 20%-50% and water content ranging from 100%-167%. The experiment results indicate that the strength and ductility of cement-admixed marine clay improve significantly with increasing fiber content until an optimum fiber content is reached. It was found that the factors affecting the behavior of fiber-reinforced cement-treated marine clay, such as fiber content, type and cut length and cement soil mix ratio, are not independent. In general, for water content not higher than 100% and cement content higher than 20%, using 12-mm polyvinyl alcohol fiber was found to give higher strength and better ductility than polypropylene or shorter fibers.

RÉSUMÉ : Des études précédentes ont démontré que l'incorporation de fibres et du ciment dans l'amélioration de sol semble être plus efficace et attrayante qu'en ajoutant seulement les fibres ou le ciment. Cet écrit présente une étude expérimentale de l'argile marine traitée au ciment et renforcée avec fibres. Deux différents types et longueurs de fibres de même que des teneurs en fibre différentes (0.0%-0.32%) seront examinés avec une teneur en ciment qui s'étend de 20%-50% et d'eau qui s'étend de 100%-167%. Les résultats de l'expérience indiquent que la résistance et la ductilité du ciment-sol sont améliorées de manière significative avec le contenu croissant de fibres jusqu'à ce qu'une teneur en fibre optimale soit atteinte. Il a été trouvé que les facteurs qui affectent le comportement de l'argile marine traitée au ciment et renforcée avec fibres, tel que la teneur en fibres, la longueur et le type de fibre et la proportion du mélange du sol-ciment, ne sont pas indépendants. En général, pour une teneur en eau ne dépassant pas les 100% et une teneur en ciment de plus de 20%, il a été constaté que l'utilisation de la fibre d'alcool de polyvinyl de 12mm offre une plus haute résistance et une meilleure ductilité que le polypropylène ou des fibres plus courtes.

KEYWORDS: fiber reinforcement, cement treated soil, brittleness index, compressive strength

1 INTRODUCTION

Cement-treated soil has been used widely in ground improvement during the past forty years and is becoming more attractive and efficient method for soil treatment due to its economy, availability and feasibility. However, cement-treated soil, especially at high cement content, tends to be brittle. Previous studies have shown that fiber-reinforcement increases the strength and ductility while decreasing the stiffness of the soil (e.g., Gray & Ohashi 1983). Recent studies have also shown that incorporation of both fibers and cement in soil improvement seems to be more efficient than fibers or cement alone (e.g., Maher and Ho 1993, Consoli et al. 1998). Maher and Ho's work presented a basic study of the mechanical behavior of artificially cemented sand reinforced with randomly distributed glass fibers.

The use of randomly distributed fiber as a new reinforcement material for cement-treated soil has been receiving increasing attention in recent years (e.g., Consoli et al. 2003, Khattak and Alarshidi 2006, Tang et al. 2007, Park 2009; Consoli et al 2011; Ud-din et al. 2011). Previous research works, however, have focused mainly on low cement content ($\leq$10%), sand or sandy soil and particular fiber. In this paper, different fiber types (PP & PVA), fiber lengths (6 & 12mm) and fiber contents (0.0%-0.32% by volume of mixture) will be investigated with different cement and water contents for Singapore marine clay treatment. The specimens were made in laboratory and tested with unconfined compression loading. The strength and ductility of the FRCT marine clay specimens were then analyzed based on the experiment results.

2 EXPERIMENT INVESTIGATIONS

The materials used in the study are Singapore upper marine clay, type I Ordinary Portland cement, and fibers. The constituents of the clay are 24.13% of colloid, 21.77% of clay, 47.71% of silt and 6.39% of very fine to medium sand. Two different fibers were used, namely polypropylene (PP) and polyvinyl alcohol (PVA) fibers. PVA fibers are commonly used in concrete reinforcement to improve the tensile and flexural strength of concrete. The properties of the fibers are given in Table 1. A naphthalene-based superplasticizer (Rheobuilder 1000) was used in some mixtures for workability purpose.

Table 1 Physical and mechanical properties of fibers

Fiber Type	Length (mm)	Diameter (micron)	Aspect ratio	Tensile strength (MPa)	Elastic modulus (GPa)	Density (kg/m^3)
PP6	6	26	231	540	7	910
PP12	12	26	462	540	7	910
PVA6	6	26	231	1600	40	1300
PVA12	12	38	316	1500	40	1300

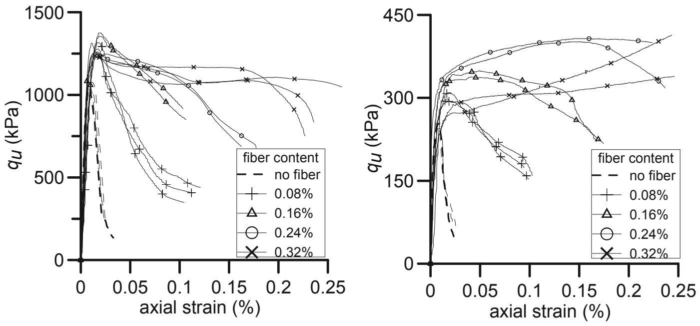
The cement soil mix ratio will be expressed in the form of S:C:W wherein S is mass of soil solid, C the mass of cement and W the mass of water at the point of mixing. The cement content A_w is defined as the ratio of mass of cement to the mass of soil solid. The water content C_w is defined as the ratio of mass of water to the total mass of soil solid and cement. In this study, the cement content ranges from 20 to 50% by weight of soil solid while the water content ranges from 100 to 167% by weight of cement and soil solid. The fiber content is defined as the ratio of volume of fiber to the total volume of the mixture at the point of mixing, and ranges from 0 to 0.32%. The ductility of the fiber-reinforced cement-treated (FRCT) soil is designated herein by the brittleness index (BI), which is defined as the ratio of the peak strength to the strength at a prescribed post-peak strain.

The natural marine clay was first mixed with the prescribed amount of water to achieve 100% moisture content and remoulded. Cement slurry with the water-cement ratio needed to achieve the desired mix ratio was then added to marine clay in a Hobart Mixer and mixed at a rotational speed of 125rpm for around 5 minutes. The fiber was finally added to cement soil mixing and mixed for another 10 minutes. For mixtures with water content of 100%, the superplasticizer was used to improve their workability. The dosage of the superplasticizer was 1.13-2.27l/100kg soil+cement solids. The mixture was placed into a 50mm (diameter) by 100mm (height) cylindrical polyvinyl chloride (PVC) split-mould. No compaction was applied during placement. Specimens were then submerged in distilled water within their split-moulds without loading for curing. The specimens were then taken out after 7 days for unconfined compression testing. The test procedure followed those prescribed in ISO/TS 17892 (2004). The strain rate used for the unconfined compression test was 1.32%/min.

3 EXPREIMENT RESULTS AND ANALYSIS

3.1 *Stress strain behavior*

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.

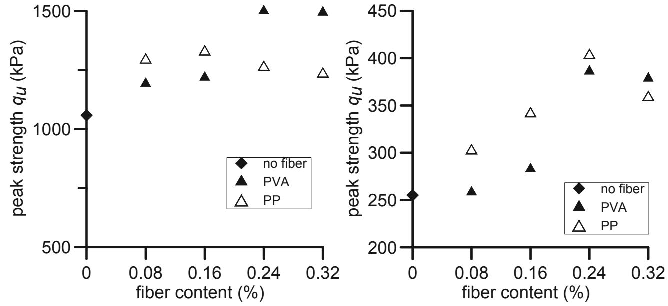


(a) (b)

Figure 1. Stress strain behavior for FRCT soil specimens with 6mm long fiber. (a) 50% cement content and 100% water content; (b) 50% cement content and 167% water content.

3.2 *Effect of fiber content*

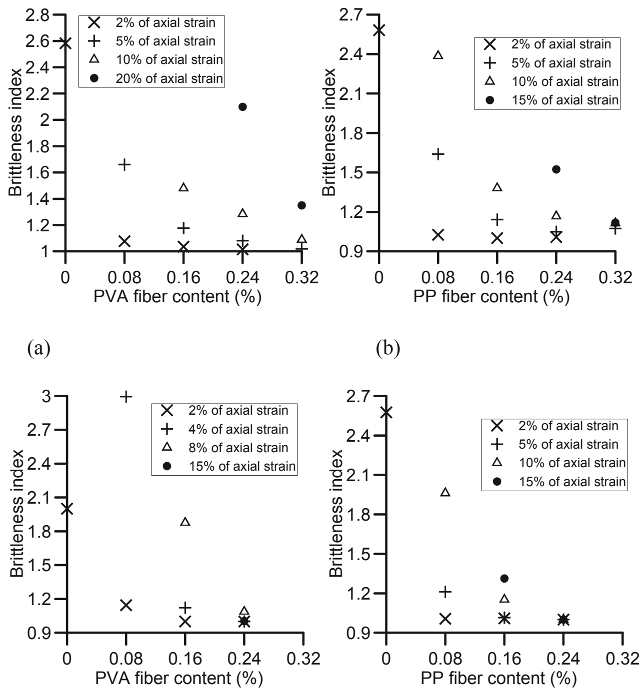
Figures 2-3 present the effect of fiber content on peak strength and brittle index of FRCT soil specimens. As Figure 2a shows, for both PP and PVA reinforced specimens with mix ratio 2:1:3 (cement content 50%, water content 100%), the peak strength increases with fiber content until a certain fiber content (0.16-0.24%), after which it decreases slightly. A similar trend is also observed in Figure 2b for specimens with mix ratio 2:1:5 (cement content 50%, water content 167%).



(a) (b)

Figure 2. Effect of fiber content on strength for FRCT soil specimens. (a) Specimens with mix ratio 2:1:3 (cement content 50%, water content 100%); (b) Specimens with mix ratio 2:1:5 (cement content 50%, water content 167%).

Figures 3a-3b show that the BI, evaluated at four different axial strain levels between 2% and 20%, reduces significantly with both PP and PVA fiber content for specimens with mix ratio 2:1:3. A similar trend is also observed from Figures 3c-3d for specimens with mix ratio 2:1:5. At higher fiber content, that is, higher than 0.32% for mix ratio 2:1:3 and 0.24% for mix ratio 2:1:5, the results were very scattered due to the poor workability of the mix, which can be observed in Figure 1b. Hence, with current mixing condition, the optimum fiber content, taking into account performance and workability, is 0.32% and 0.24% for specimens with mix ratio 2:1:3 and 2:1:5 respectively. For mix ratios 2:1:4, 20:7:27 and 5:1:6, the optimum fiber content is 0.24%.



(a) (b)

(c) (d)

Figure 3. Effect of fiber content on ductility for FRCT soil specimens. (a) PVA reinforced specimens with mix ratio 2:1:3 (cement content 50%, water content 100%); (b) PP reinforced specimens with mix ratio 2:1:3 (cement content 50%, water content 100%); (c) PVA reinforced specimens with mix ratio 2:1:5 (cement content 50%, water content 167%); (d) PP reinforced specimens with mix ratio 2:1:5 (cement content 50%, water content 167%).

3.3 *Effect of fiber length*

For 12mm fiber reinforcement, 0.08% and 0.16% fiber content was used. It was found that 0.16% fiber reinforcement is much better than 0.08% fiber reinforcement (see Figure 4). Hence, only results of 0.16% fiber content were compared. Figure 5 presents the effect of fiber length on the strength and ductility of the FRCT soil. It can be seen from Figure 5a that for PVA-reinforced specimens, 12mm fiber confers distinctly higher strength than 6-mm fibers. For PP fibers, the difference in peak strength is small.

Figure 5b shows that for specimens with different mix ratio and a given type of fiber (PVA), longer fibers consistently give a lower BI than shorter fibers; the difference increasing with strain level. Similar trend is also observed in specimens reinforced by PP fibers. Therefore, the effect of fiber length on ductility of FRCT soil is significant for both PP and PVA fiber type.

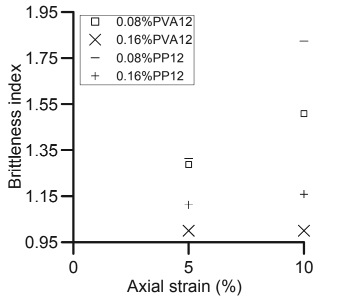
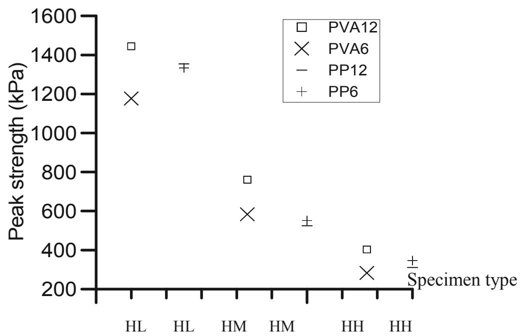
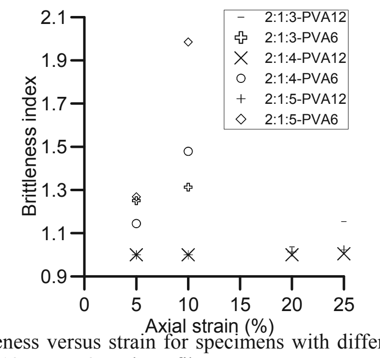


Figure 4. Ductility of RFCT soil with 0.08% and 0.16% 12mm long fiber (50% cement and 100% water content).



(a) Comparison in peak strength for specimens with 50% cement content, 100%-167% water content, and 0.16% of 12mm or 6 mm long fiber (HL, HM, HH denote cement and water content, see Table 2).



(b) Brittleness versus strain for specimens with different mix ratio and 0.16% of 12mm or 6mm long fiber.

Figure 5. Effect of fiber length on strength and ductility for RFCT soil specimens.

3.4 *Effect of fiber type*

For simplicity and convenience, FRCT soil specimens are categorized in Table 2 according to their cement content and water content together with their performance at optimum fiber content. As discussed in the previous section, the optimum short fiber content is 0.32% for mix ratio 2:1:3 while it is 0.24% for mix ratio 2:1:4, 2:1:5, 20:7:27 and 5:1:6. For long fiber, the optimum fiber content is 0.16%.

Figures 6-7 present the effect of fiber type on the strength and BI of the FRCA soil. It can be seen from Table 2 and Figure 6 that 12mm PVA fiber reinforcement always gives higher strength than 12mm PP fiber reinforcement due to PVA's higher strength. For water content at and below 133% and cement content not less than 35%, 6mm PVA fiber reinforcement gives higher strength than 6mm PP fiber reinforcement due to the same reason above. For low cement content (20%) and low water content (100%) or high cement (50%) and high water content (167%), short PP fiber gives slightly higher strength than short PVA fiber.

Table 2. Peak strength and BI of specimens with different mix ratios and fiber types, at optimum fiber content.

Mix proportion		*2:1:3*	*2:1:4*	*2:1:5*	*20:7:27*	*5:1:6*
A_w (%)		50	50	50	35	20
C_w (%)		100	133	167	100	100
catogery		high A_w, low C_w (HL)	high A_w, mid C_w (HM)	high A_w & C_w (HH)	mid A_w, low C_w (ML)	low A_w & C_w (LL)
Peak stren-gth q_u (kPa)	SF	1494 (PVA), 1240 (PP)	752 (PVA), 632 (PP)	386 (PVA), 405 (PP)	1053 (PVA), 874 (PP)	455 (PVA), 471 (PP)
	LF	1445 (PVA), 1354 (PP)	761 (PVA), 628 (PP)	403 (PVA), 313 (PP)	NA	NA
Duc-tility	SF	PVA>PP	PVA=PP	PVA=PP	PVA=PP	PVA<PP
	LF	PVA>PP	PVA=PP	PVA>PP	NA	NA
Perfor-mance		PVA>PP	PVA>PP	PVA ≈ PP (short) PVA>PP (long)	PVA>PP	PVA<PP

Note: SF and LF denotes short and long fiber respectively

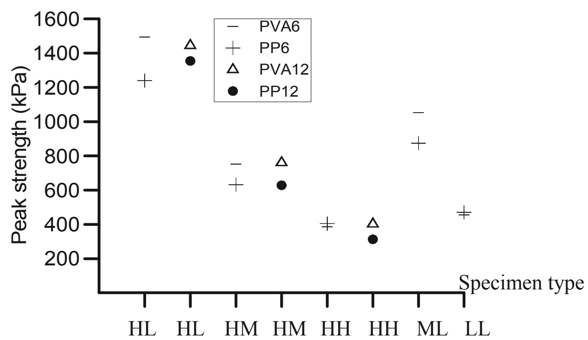
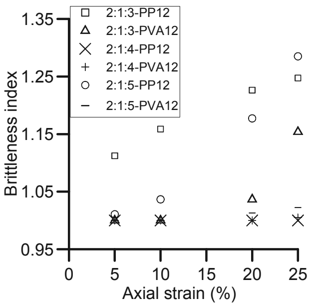


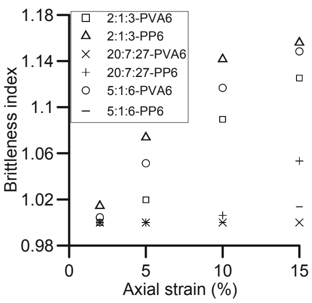
Figure 6. Effect of fiber type on strength of RFCT soil specimens with 20%-50% cement content, 100%-167% water content, 0.24-0.32% of 6mm long fiber or 0.16% of 12mm long fiber.

For 12mm fiber reinforcement, Figure 7a shows that for specimens with high cement content (50%) and low or high water content (100% or 167%), PVA fiber gives lower BI values at four different strain levels between 5%-25% than PP fiber. For specimens with high cement content and mid high water content (133%), no fiber type effect is observed. This may be explained as below. For high cement content and low water content, there is stronger interaction between PVA fiber and cement-soil body due to PVA's higher strength, which results in higher ductility in long PVA fiber reinforced soil specimens. For high cement and water content, there is high PP fiber concentration due to PP's higher aspect ratio, which induces lower ductility in long PP fiber reinforced soil specimens.

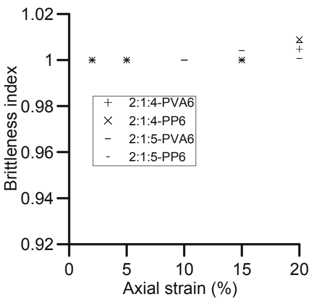
For 6mm fiber reinforcement, Figure 7b shows that for low water content (100%) and high cement content (50%), PVA fiber gives lower BI values at four different strain levels between 2%-15% than PP fiber. For low cement content (20%) and low water content, PVA gives higher BI values than PP fiber. This suggests that short PP fiber interacts with cement-soil body better than PVA fiber of the same length, at low cement and water content. Figures 7b-7c also show that for mid-high cement (35%) and low water content or high cement and mid to high water content, fiber type effect is very small. Therefore, short PVA fiber generally gives ductility not lower than PP fiber except for low cement content and low water content.



(a) Brittleness index versus strain for 12mm long fiber reinforcement (fiber content, 0.16%).



(b) Brittleness index versus strain for 6mm long fiber reinforcement (low water content, 100%; cement content, 20%-50%; fiber content 0.24-0.32%).



(c) Brittleness index versus strain for 6mm long fiber reinforcement (mid to high water content, 133%-167%; high cement content, 50%; fiber content, 0.24%).

Figure 7. Effect of fiber type on ductility for RFCT soil specimens with 20%-50% cement content, 100%-167% water content, fiber cut length 6-12mm and 0.16-0.32% fiber.

In summary, as Table 2 shows, by considering of the strength and ductility of FRCT soil specimens, PVA fiber reinforcement is generally better than PP fiber except for low cement content and water content.

4 CONCLUSIONS

Based on the results and analysis, the main conclusions may be drawn as below.

The strength and ductility of cement-treated marine clay was improved significantly by fiber reinforcement. There is optimum fiber content, considering performance and workability of cement-treated soil specimens. PVA fiber reinforcement is generally better than PP fiber reinforcement except for low cement content and water content.

It was observed that the fiber cut length has significant effect on the ductility of cement-treated soil. However, the cut length effect on strength for PP fiber reinforcement is much smaller than that for PVA fiber reinforcement.

5 ACKNOWLEDGEMENTS

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