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CBR strength of London Clay reinforced with polypropylene fibre

Force CBR de London Clay renforcée avec de la fibre de polypropylène

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ABSTRACT: The benefits of soil reinforced by randomly distributed fibres have been widely investigated in the last couple of decades, but the main focus has been on coarse-grained soils. The effect of random inclusion of polypropylene fibres on bearing capacity characteristics of a fine-grained soil, London Clay, is presented in this paper. A series of laboratory California Bearing Ratio tests were conducted on London Clay reinforced with polypropylene fibres. The fibre inclusion ratio was varied from 0.3% to 0.9% by weight of dry soil and fibre length were 6 mm and 12 mm. It is shown from the test results that the addition of the fibre leads to a significant increase in CBR strength and stiffness. In addition, samples reinforced with shorter fibres show better behaviour than those reinforced with longer fibres. It can be concluded that polypropylene fibre has potential as reinforcement material in road construction and the investigation results could be influential in related engineering design.

RÉSUMÉ: Les avantages des sols renforcés par des fibres distribuées de manière aléatoire ont été largement étudiés au cours des deux dernières décennies, mais l'accent a principalement été mis sur les sols à grains grossiers. Cet article présente l'effet de l'inclusion aléatoire de fibres de polypropylène sur les caractéristiques de capacité portante d'un sol à grain fin, l'argile de Londres. Une série d'essais en laboratoire sur le rapport de roulement California ont été menées sur de l'argile de Londres renforcée de fibres de polypropylène. Le taux d'inclusion des fibres variait de 0,3% à 0,9% en poids de sol sec et la longueur du feu était de 6 mm à 12 mm. Les résultats des tests montrent que l'ajout de la fibre entraîne une augmentation significative de la résistance et de la rigidité CBR. De plus, les échantillons renforcés avec des fibres plus courtes présentent un meilleur comportement que ceux renforcés avec des fibres plus longues. On peut en conclure que la fibre de polypropylène a un potentiel en tant que matériau de renforcement dans la construction de routes et les résultats de l'enquête peuvent être une référence dans la conception technique correspondante.

Keywords: Fibre reinforced soil; road construction; CBR test; polypropylene fibre

1 INTRODUCTION

Bearing capacity plays a significant role in road construction and directly influences the design of a pavement. According to the DMRB (EHA, 2006), the increase of the CBR strength of a subgrade can lead to the decrease of required thickness of the pavement. Therefore, the project cost and construction period are affected by the bearing capacity. To improve the performance of soil with low bearing capacity, reinforcement materials such as chemical additives (e.g. lime, cement) or geosynthetics (geogrid, geotextile, etc.) are added in engineering conventionally. In recent years, using randomly distributed discrete fibres to reinforce soil has obtained widespread attention in geotechnical engineering. Fibres used as soil reinforcement can be generally divided into natural fibres (coconut, coir, jute, etc.) and synthetic fibres (polypropylene, polyester, nylon, glass, etc.). Among these fibres, polypropylene is the most widely used in published studies (e.g. Fletcher et al. 1991; Ple et al. 2012; Tang et al. 2012) for its stable performance, competitive cost and easy accessibility. As for the soil type used in previous studies, the majority of the published literature on fibre reinforced soil is focussed on granular materials (e.g. Gray et al. 1983; Michalowski et al. 2003; Consoli et al. 2009; Dos Santos et al. 2010; Lirer et al. 2011; Najjar et al. 2013).

For the reason that excavated fine grained soils can be potential material in backfill to geotechnical structures such as slopes, embankments and dams, the behaviour of fibre reinforced cohesive soils is also a valuable research area. Limited studies have been conducted on the mechanical behaviour of fibre reinforced clay (Maher and Ho 1994; Tang et al. 2012; Estabragh et al. 2012; Chebbi et al. 2017), however, to date there has been no general consensus reached regarding the effects of polypropylene fibres on the engineering characteristics of cohesive soils, especially bearing capacity on high plasticity clay.

In Wang et al. (2018) the authors describe a series of compaction tests and linear shrinkage tests on fibre reinforced London Clay finding that fibre reinforcement reduces both the maximum dry density (MDD) and optimum moisture content (OMC) of London Clay, as well as linear shrinkage. In this study, the bearing capacity of fibre reinforced soil is investigated and the results from an experimental programme of laboratory California Bearing Capacity (CBR) tests described which evaluate the effects of both fibre inclusion ratio and fibre length on CBR value of London Clay.

2 MATERIALS AND METHODS

2.1 Soils and Fibres

The soil used in this study was obtained from an excavation site in Clapham, London, UK. The soil was air dried, crushed and sieved at 2 mm in the laboratory after which classification tests were conducted in accordance with BS 1377-2 (BSI, 1990). Chopped polypropylene (PP) fibres supplied by ADFIL (ADFIL, 2018) were used as reinforcement in this study. Two different lengths of fibre (6 and 12 mm) were used in the study to investigate the effect of fibre length on reinforcement. The properties of these two materials are shown in Tables 1 and 2, respectively.

2.2 Sample Preparation

To prepare the fibre reinforced soil (FRS) specimens, the desired masses of fibres were weighed and mixed with the crushed soil in a dry state by hand, making sure that a homogeneous composite was achieved without any visible aggregation of fibres. After that, distilled water was added to the mixture with a spray bottle until the target moisture content was achieved. It is worth nothing that two opertations were required to ensure uniform distributions of water and fibres: initial mixing performed with a pallet knife and further mixing in a mechanical mixer.

The well mixed soil-fibre composite is shown in Figure 1. The fibre inclusion ratio (ρ) is defined herein as

$$\rho = \frac{w_f}{w_s} \tag{1}$$

where w_f is the mass of fibre and w_s is the mass of dry soil. The tests were conducted at various fibre inclusions of 0.0%, 0.3%, 0.6% and 0.9% (by mass of the dry soil). The test program is shown in Table 3. Each sample was prepared at its own optimum moisture content, obtained from Standard Proctor tests and as shown in Table 3. The material was then allowed to cure overnight in a sealed plastic bag.

Table 1. Properties of London Clay used in study

Soil Properties	Value
Sand (%)	7.9
Silt and Clay (%)	92.1
Specific Gravity	2.72
Liquid limit (%)	58.2
Plastic limit (%)	20.9
USCS classification	CH

Table 2. Properties of PP fibre used in study

Fibre Properties	Value
Specific Gravity	0.91
Fibre Type	Monofilament
Length (mm)	6 & 12
Average Diameter (µm)	22
Tensile Strength (MPa)	416

Figure 1. Soil-Fibre composite after mixing

2.3 Test procudure

The CBR samples were prepared by compacting FRS in a steel CBR mould of 150 mm diameter and 127 mm height in three equal layers to the maximum dry density (see Table 3). Then the mould along with the compacted soil was transferred to a tank containing water for soaking. A surcharge disc of 2 kg was placed on the top of the specimen for the soaking period of 96 hours (see in Figure 2). Following this, the sample was taken out of the tank and penetrated by the apparatus shown in Figure 3. The load-penetration curves were plotted and CBR values calculated as per BS 1377-4 (BSI, 1990).

Table 3. Test program in the study

Soil type	Fibre ratio (%)	Fibre Length (mm)	OMC (%)	MDD (g/cm³)
A0	0	0	22.2	1.581
B1	0.3	6	22.1	1.559
B2	0.6	6	21.8	1.551
B3	0.9	6	21.3	1.546
C1	0.3	12	21.9	1.570
C2	0.6	12	21.7	1.558
C3	0.9	12	21.6	1.548

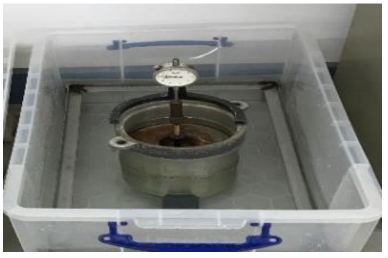

Figure 2. CBR sample in soaked condition

Figure 3. CBR penetration apparatus

3 RESULTS AND DISCUSSION

The load-penetration curves obtained from the CBR tests for unreinforced soil and FRS samples are shown in Figure 4. It can be seen from these curves that the addition of randomly distributed polypropylene fibres in soil increases the load carried at a given penetration depth. Moreover, the initial slope of the load-penetration curve is significantly steepened due to the addition of PP fibres. When it comes to the fibre length, it can be seen from Figure 4 that samples reinforced with shorter fibres (group B) have a higher penetration resistance before 5 mm, beyond which the samples reinforced with longer fibres (group C) tend to approach the performance of shorter fibre samples. This may be a result of a longer fibre giving greater capacity to accommodate very high strains, as compared with the shorter fibres.

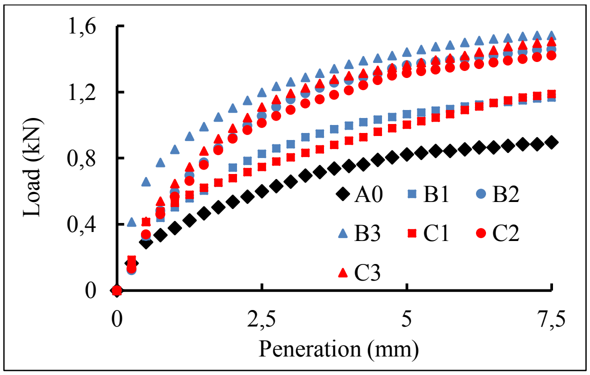

Figure 4. Load penetration curves for unreinforced and FRS samples

The variation of CBR value for fibre reinforced soil with different fibre contents at various fibre lengths is shown in Figure 5. Firstly, it is clear that addition of fibres to London Clay results in a significant increase in CBR value, and this can be observed for both the fibre lengths. Secondly, the results show that maximum increase in CBR value is approximately 200 % of that for untreated soil; the maximum value being seen with a sample reinforced with 6 mm long fibres at content of 0.9 %; while the minimum increase is approximately 125% to that of untreated soil (for a fibre content of 0.3 % with for the 12 mm long fibres). In addition, the rate of increase tends to slow down as the fibre inclusion ratio increase, which indicates that there could be a threshold value for the fibre inclusion in improving soil CBR values. The maximum fibre inclusion ratio in this study was limited to 0.9% because it was found hard to make homogenous samples when the fibre inclusion ratio was higher. The improvement in CBR values seen here is believed to be due to fibres interacting with the soil particles, consequently generating surface friction and tensile capacity which is not present in the unreinforced soil. In order to compare the increase in the CBR value due to the presence of fibres, a dimensionless term (named California bearing ratio index, CBRI) has been introduced. It is defined as the ratio of the CBR value of reinforced soil to the CBR value of unreinforced soil.

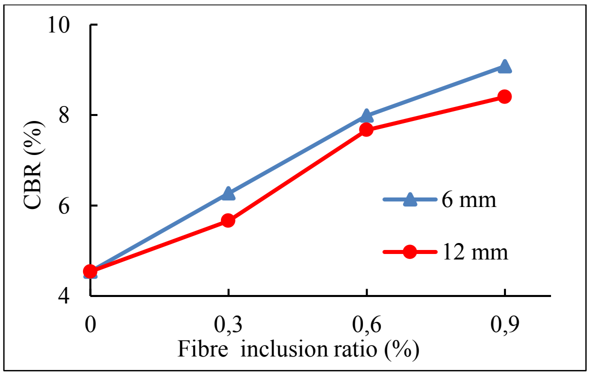

Figure 5. Variation of CBR value with fibre inclusion ratio at different fibre lengths

Figure 6 gives the variation of CBRI with fibre inclusion ratio at different fibre lengths. It can be seen that CBRI values increase as a result of any fibre addition. The CBRI values of samples B1, B2 and B3 were found to be 1.38, 1.76, and 2.00 respectively. For samples C1, C2, C3, the values were 1.25, 1.69 and 1.85. By comparing CBRI values between group B (6 mm) and group C (12 mm), the influence of fibre length to CBR improvement can be assessed. For different fibre lengths, the figure shows that shorter fibres have a higher CBRI for the given fibre inclusion ratio, e.g. 6 mm long fibres made a greater improvement in the CBR value of London Clay than 12 mm long fibres. A similar trend was shown by Akhtar et al. (2015). This could be attributed to the fact that the same weight of shorter fibres has two times the quantity of individual fibres than longer fibres perhaps leading to a more homogeneous distribution within the sample. However, according to Marandi et al. (2008), when the fibre length is relatively long compared to the sample size, the increase in fibre length effectively increases CBR value.

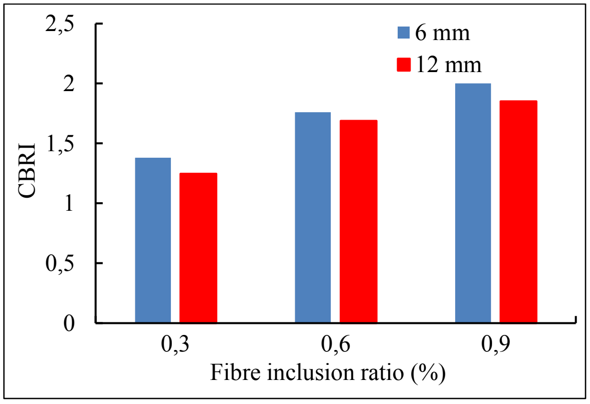

Figure 6. Variation of CBR Index with fibre inclusion ratio at different lengths

The variation in secant modulus (defined as the ratio of stress at a penetration of 2.5 mm to the strain of penetration of 2.5 mm) of FRS with different fibre contents and fibre lengths is shown in Figure 7. Similar to the CBR values, the secant modulus of the soil increases as the fibre inclusion ratio increases, which means fibres contribute to a higher stiffness of the soil. For example, the secant modulus of unreinforced soil was 18 MPa, which increases to 24.8 MPa when 0.3% of 6 mm long fibre is introduced into the soil. When the fibre inclusion ratio increases from 0.3% to 0.6%, the secant modulus increases to 31.7 MPa.

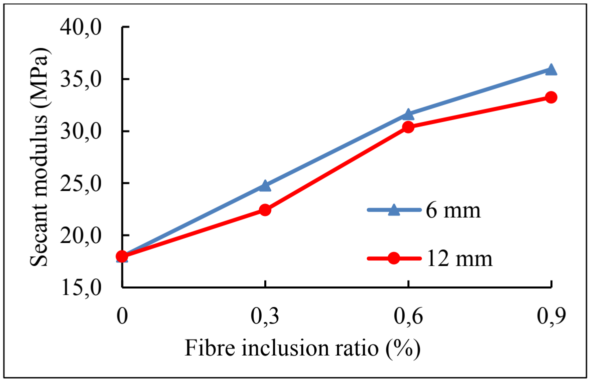

Figure 7. Variation of secant modulus with fibre inclusion ratio at different lengths

4 CONCLUSIONS

The feasibility of utilizing polypropylene fibre as reinforcement material in fine grained soil was investigated in this study. Laboratory CBR tests on unreinforced and reinforced London Clay were conducted to evaluate the influence of fibre on CBR value and secant modulus of soil. Based on the results, the following conclusions can be drawn:

(1) Adding randomly distributed polypropylene fibre can increase CBR value and the secant modulus of London Clay.

(2) The reinforcement benefit increases with the fibre inclusion ratio. The maximum improvement in CBR and secant modulus is found in this study when the fibre inclusion is 0.9%.

(3) Soil reinforced with 6 mm fibres has a higher CBR2.5 value than that with 12 mm fibres, however the latter one exhibits higher resistance to deformation when penetration occurs beyond 5 mm.

(4) The maximum CBR value of reinforced soil is 200% that of untreated London Clay, found in soil reinforced with 6 mm length fibre with 0.9% fibre content.

(5) The increase in the soil bearing capacity due to fibres can result in the reduction of pavement thickness and project cost. Therefore PP fibres are potential reinforcement materials in subgrade engineering.

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6 REFERENCES

ADFIL (2018), 'Product data'.URL: http://www.adfil.com/products/microsynthetic-fibres/monofilament-fibres/

Aggarwal, P. and Sharma, B., 2010, September. Application of jute fiber in the improvement of subgrade characteristics. *In Proc of int conf on adva in civ eng*, 27-30. Trabzon, Turkey

British Standard Institution, 1990. Methods of test for soils for civil engineering purposes-Part2: Classification tests. British Standards Institution, London, UK.

British Standard Institution, 1990. Methods of test for soils for civil engineering purposes-Part4: Compaction-related tests. British Standards Institution, London, UK.

Chebbi, M., Guiras, H. and Jamei, M., 2017. Tensile behaviour analysis of compacted clayey soil reinforced with natural and synthetic fibers: effect of initial compaction conditions. *European Journal of Environmental and Civil Engineering*, **1**,1-27.

Consoli, N.C., Casagrande, M.D.T., Thomé, A., Dalla Rosa, F. and Fahey, M., 2009. Effect of relative density on plate loading tests on fibre-reinforced sand. *Géotechnique*, **59**(5), 471-476.

Dos Santos, A.S., Consoli, N.C. and Baudet, B.A., 2010. The mechanics of fibre-reinforced sand. *Geotechnique*, **60**(10), 791-799.

England Highway Agency, 2006. UK Design Manual for Roads & Bridges (DMRB). Highways England, Guildford, UK.

Estabragh, A.R., Bordbar, A.T. and Javadi, A.A., 2013. A study on the mechanical behavior of a fiber-clay composite with natural fiber. *Geotechnical and Geological Engineering*, **31**(2), 501-510.

Fletcher, C.S. and Humphries, W.K., 1991. California bearing ratio improvement of remolded soils by the addition of polypropylene fiber reinforcement. Transportation Research Record, 1295.

Gray, D.H. and Ohashi, H., 1983. Mechanics of fiber reinforcement in sand. *Journal of Geotechnical Engineering,* **109**(3), 335-353.

Lirer, S., Flora, A. and Consoli, N.C., 2011. On the strength of fibre-reinforced soils. *Soils and foundations*, **51**(4), 601-609.

Maher, M.H. and Ho, Y.C., 1994. Mechanical properties of kaolinite/fiber soil composite. *Journal of Geotechnical Engineering*, **120**(8), 1381-1393.

Marandi, S.M., Bagheripour, M.H., Rahgozar, R. and Zare, H., 2008. Strength and ductility of randomly distributed palm fibers reinforced silty-sand soils. *American Journal of Applied Sciences*, **5**(3), 209-220.

Michalowski, R.L. and Čermák, J., 2003. Triaxial compression of sand reinforced with fibers. *Journal of geotechnical and geoenvironmental engineering*, **129**(2), 125-136.

Najjar, S.S., Sadek, S. and Alcovero, A., 2012. Quantification of model uncertainty in shear strength predictions for fiber-reinforced sand. *Journal of Geotechnical and Geo-environmental Engineering*, **139**(1), 116-133.

Plé, O. and Lê, T.N.H., 2012. Effect of polypropylene fiber-reinforcement on the mechanical behavior of silty clay. *Geotextiles and Geomembranes*, **32**. 111-116.

Tang, C.S., Shi, B., Cui, Y.J., Liu, C. and Gu, K., 2012. Desiccation cracking behavior of polypropylene fiber–reinforced clayey soil. *Canadian Geotechnical Journal*, **49**(9), 1088-1101.

Wang, J., Sadler, A., Hughes, P. and Augarde, C., 2018. Compaction Characteristics and Shrinkage Properties of Fibre Reinforced London Clay. *In Proceedings of China-Europe Conference on Geotechnical Engineering*, 858-861. Springer, Cham.