Effects of fibre reinforcement in the shrinkage behaviour of compacted clay.

A.Ekinci
University College London

P.M.V Ferreira
University College London

KEYWORDS: Include up to 5 keywords

ABSTRACT: The stability of clay slopes and liners is intimately connected to desiccation cracking. To mitigate this problem, research has been done in mixtures of soil with additives (lime, cement, sand) or with fibres. Chemical additives may leach and create environmental problems, therefore fibre reinforcement became an interesting alternative as it reduce the cracking formation and cracking propagation in soils subjected to wetting and drying. This article presents results of compacted samples of a clay from the Lambeth group, that were allowed to dry for a long period. The samples were compacted according to the BS 1377-4:1990, using 3 different moisture contents (optimum and optimum plus and minus 2%). For every initial moisture content 3 samples were prepared with 0, 0.2% and 0.4 % of fibres by dry weight. Fibres and soil were hand mixed in order to achieve an homogeneous distribution of fibres. While the samples were drying, the height, the diameter and the weight of the samples were measured. Photographs were also taken in order to verify the occurrence of desiccation cracks. The results show that the unreinforced samples have suffered higher volumetric reduction, with large cracks visible between the compacted layers of soil. This behaviour was not observed in the reinforced samples.

1 BACKGROUND

A variety of researches have attempted to overcome the problems of desiccation cracking in soils, by using soils reinforced with fibres. Some have considered the use of surface moisture barriers above the soil layer (Benson et al. 2004). A few have considered soil additives (lime, sand and cement) to increase the soil strength and resistance to cracking (Omidi et al. 1996;VIPULANANDAN and LEUNG 1991). However, based on the previous study, the lime or cement additives beside of there environmental impact would not sufficiently suppress the desiccation crack of clayey soils with high water contents.

Many earth structures such as slopes and highway embankments are constructed of clayey soils. During periods of rainfall that follow the dry spells, water fills the cracks and fissures. Seasonal effects of drying and wetting cycles results in deepening of the cracked clay zone which may eventually reach depth of 3m or more.

In order to assess the effect of inclusion of fibres into clay, the researchers Abdi et al.(2008) and Rifai and Miller (2004)used a variety of testing programmes. Authors assessed the cracks after shearing samples in a triaxial test, compact samples in a specific mould and assessed the cracks after letting the sample dry over a certain period of time (24 hours, 3 days or 30 days) and assessing the cracks after wetting/drying cycles are a few of those testing programmes. Observation of cracks have been done in two distinct methods. In the first method Harianto et al. (2008) monitor the cracks with the naked eye and collect the data. Two types of data were collected: volume change data, i.e. height and diameter measurements, and surface cracking measurements, recorded at the end of drying or at the end of the wetting period, depending on the testing programme. In the second method (Rifai and Miller (2004) recorded geometrical features by using digital imaging software. Crack dimensions are measured using an image pixel method. The data obtained via this method is used to develop a mathematical model to evaluate the magnitude of the desiccation cracks (Harianto et al. 2008;Rifai and Miller 2004).

As reported in studies of Ozkul and Baykal (2006), for specimens without fibres, a few wide cracks developed along the surface. For specimens of the same soil with fibres included, numerous cracks with smaller widths and lengths developed. Analysis of the studies by the above-named authors revealed that inclusion of fibre content up to a certain percentage significantly increases the crack reduction. Rifai & Miller (2004) and Tang et. al. (2007) concluded that fibre inclusion increased the crack reduction significantly due to the increased tensile strength of the soil. Moreover, authors found that when local cracks appear in a specimen, some fibres across these cracks are responsible for the tension in the soil by fibre-soil friction which effectively impedes the further development of cracks and improves the toughness of the stabilized soil and accordingly changes the failure mode of the stabilized specimen. Fibre reinforcement can also mitigate potential cracking induced by differential settlements because fibre reinforcement increases the ductility of the soil.

Technical Note of REMR (1998) and study of Ziegler et al. (1998) concluded that exceeding the certain percentage of fibre content was not practical due to difficulty in fibre-soil mixing to obtain a uniform distribution of fibres within the soil. Additionally, inclusion of fibres over the limit caused the development of voids during the compaction and encouraged crack development. Those studies revealed that above 0.6% of addition of fibres significantly reduce the effect of crack reduction property of fibres. Similarly, when the reinforced soil was subjected to wet/dry cycles, the effectiveness of the fibres was not as evident.

2 MATERIALS

The soil used in this study was obtained from an embankment of the junction between Motorways M25 and M1, north of London. It is an overconsolidated clay from the Lambeth Group, classified as high plasticity inorganic Clay (CH). Liquid limit and Plastic limit of the clay found to be 59.5 and 24.1 respectively and the specific gravity is 2.65. The grain size distribution is fairly uniform with 95% passing 0.05mm, 85% passing 0.015, 60% passing 0.004mm and 46% passing 0.001mm. The polypropylene fibres used in this investigation have a width of 4mm, length of 63mm and thickness of about 0.021mm.

Compaction tests (Figure 1) were carried out to obtain the optimum moisture content (OMC) and the maximum density (MD). The results confirmed that there was no effect of fibres in the OMC and the MD of the soil, with the OMD being equal to 21% for the compacted samples and around 21.5% for the compacted soil with fibres. The maximum dry density of reinforced and non-reinforced compacted samples was found to be 1.70g/cm3 and 1.68 respectively (Figure 1).

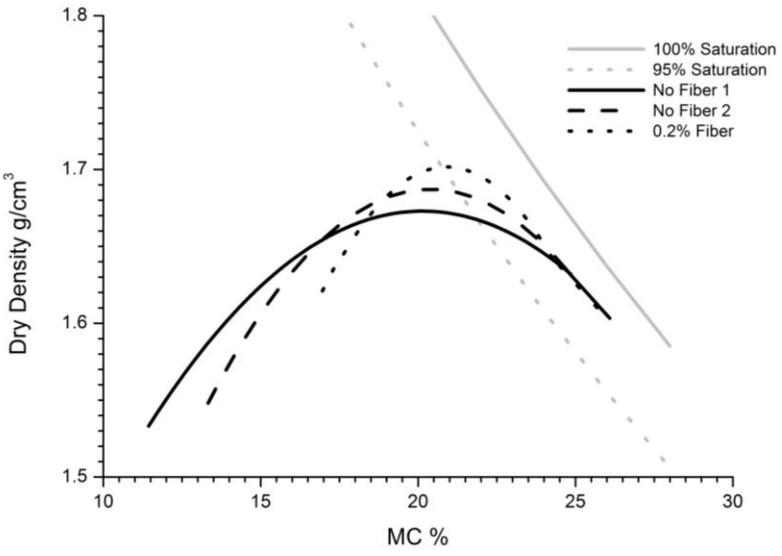

Figure 1: Compaction Curves of reinforced and non-reinforced samples

3 EXPERIMENTAL PROCEDURE

Samples are prepared in CBR mould. Soil obtained "As dug" from the site brought to laboratory and chopped in 15mm diameter pieces. Those pieces are let to air dry and further crashed by hand in order not to apply excessive effort to break the natural particle size of the material. Following this procedure samples are brought to desired moisture content, below and above the optimum moisture content as obtained in Figure 1, which are 20, 22, 24 and 25 %. In order to test a wide range of polymer contents, fibres was hand mixed at 0%, 0.2% and 0,4% of the dry weight of the soil and compacted with light compaction method specified in BS 1377-4:1990. As previous studies have suggested, for effectiveness of fibres, additives are added at contents less then 0.4% of the dry weight of soil

Al-Rawas and McGown (1999) made an extensive review of drying techniques, and concluded that there is no single technique that can be claimed to be the best for specimen drying. Air drying was therefore used in this study. In order to avoid any alteration in the micro fabric of the specimens during the drying period, they were just dried at normal Laboratory temperature for about 10 to 12 weeks. Weight, diameter and height have been monitored and MC, saturation and volume change of the 12 samples have been calculated in regards to obtained values.

4 RESULTS

Results of tests conducted on soils treated with verity of fibre contents are presented in Table 1. The normalised mass against elapsed time was presented in Figure 2. The mass was normalised by dividing the weight of soil specimen at each time W(t) by the initial weight of soil specimen W(0).It can be concluded that regardless to different content of fibre addition reduction in mass is mostly affected by the compaction moisture content of the samples. Where increase in moisture content is leading to higher mass loss.

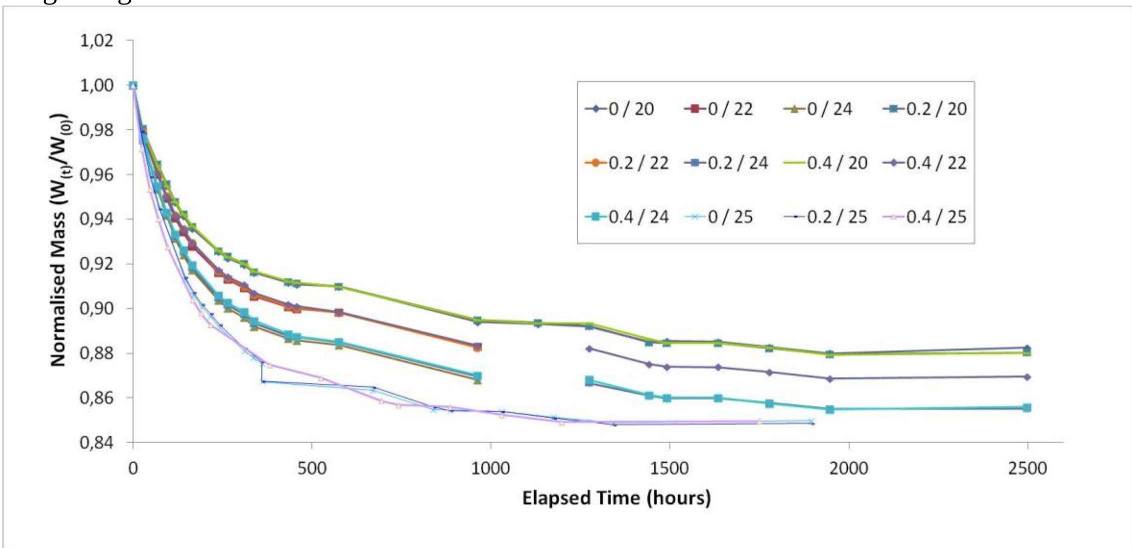

Figure 2.Change in normalised mass of reinforced and unreinforced samples due to free swell

Table. 1 Results of free swell tests

Sample	0-20	0-22	0-24	0-25	0.2-20	0.2-22	0.2-24	0.2-25	0.4-20	0.4-22	0.4-24	0.4-25
Duration (hr)	1894	1894	1894	1894	1894	1894	1894	1894	1894	1894	1894	1894
MC (%)	20	22	24	25	20	22	24	25	20	22	24	25
FC (%)	0	0	0	0	0,2	0,2	0,2	0,2	0,4	0,4	0,4	0,4
Int. Height (mm)	127,73	127,31	127,02	128,06	128,53	127,52	127,66	128,29	128,56	127,59	127,48	127,825
Int. Diameter (mm)	151,89	151,89	152,15	152,35	151,98	152,04	152,47	152,00	152,12	152,12	152,02	152,325
Int. Volume (mm^2)	2314,217	2306,61	2309,48	2334,47	2331,43	2315,18	2330,65	2334	2336,5	2318,88	2313,84	2329,42
Final Height (mm)	124,84	123,12	121,66	121,56	126,65	123,55	122,44	122,45	126,42	123,98	122,98	122,24
Final Diameter (mm)	146,02	145,03	143,68	143,25	146,00	145,06	144,26	143,30	146,46	145,07	143,59	142,90
Final Volume (mm^2)	2050,53	1998,35	1961,70	1959,02	2058,37	2034,17	1982,49	1974,94	2103,77	2041,76	2003,86	2000,77
Hei. Shrinkage (%)	2,258062	3,2919	4,22432	5,07575	1,46145	3,11324	4,08972	4,5459	1,6653	2,82676	3,52997	4,36925
Dia. Shrinkage (%)	3,864766	4,51658	5,56687	5,97637	3,93157	4,5909	5,38484	5,7237	3,724	4,6345	5,54532	6,18743
Vol. Shrinkage (%)	11,39423	13,3643	15,0587	16,0828	11,7119	12,1377	14,9383	15,384	9,9595	11,9509	13,3966	14,1089

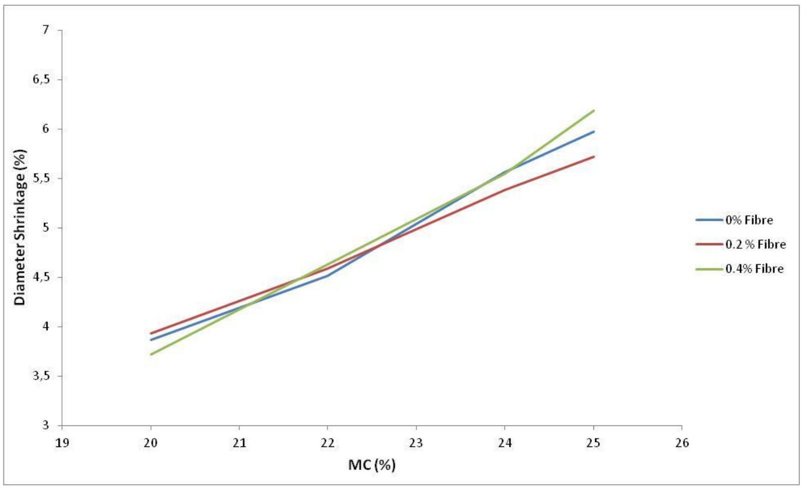

Figure 3.End of drying period diameter shrinkage of samples

Figure 3 and 4 presents the diameter and height shrinkage findings from the end of drying period. One can see in Figure 3, that increase of moisture content leads to increase of diameter shrinkage in any fibre content. Where this shows different pattern in below and above the optimum moisture content. Below optimum moisture content, 0.2% fibre addition seams to allow grater shrinkage then 0% and 0.4% fibre contents opposite findings are observed in moisture contents above optimum. Nevertheless contribution of fibres in horizontal and global shrinkage of the sample is negligible.

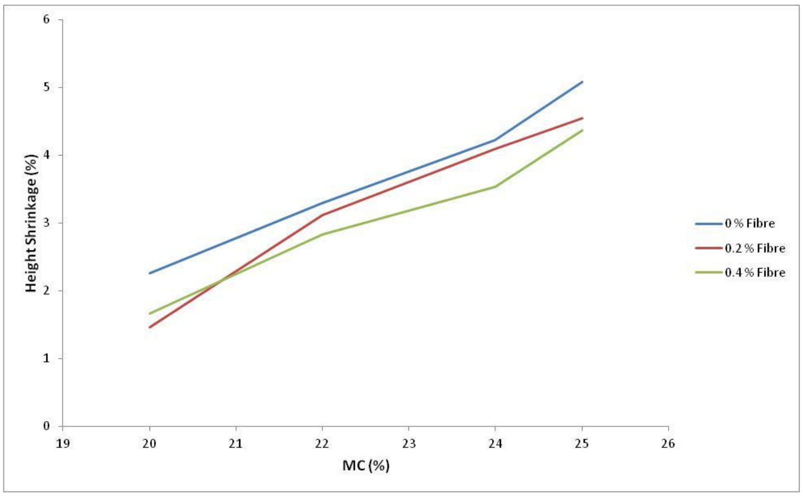

Figure 4.End of drying period height shrinkage of sample

As can be seen in Figure 4 there seams to be a persistence in results with divers fibre contents and moisture contents. In any moisture content, addition of fibres are reducing the vertical shrinkage of the sample. The phenomena of fibres not being effective in horizontal direction can be explained with the arrangement of the fibres due to compaction procedure. In the study of Ekinci and Ferreira (2012)authors concluded that nearly 80% of fibres are aligned within ±20º with the horizontal plane. This alignment is caused by the sample preparation procedure as the fibre length is higher than the compaction layer. Due to incompetency of fibres in compression, there is no contribution of fibres where sample is shrinking in horizontal direction. However in vertical shrinkage, soil particles directly act on the surface of fibres and prevent shrinkage.

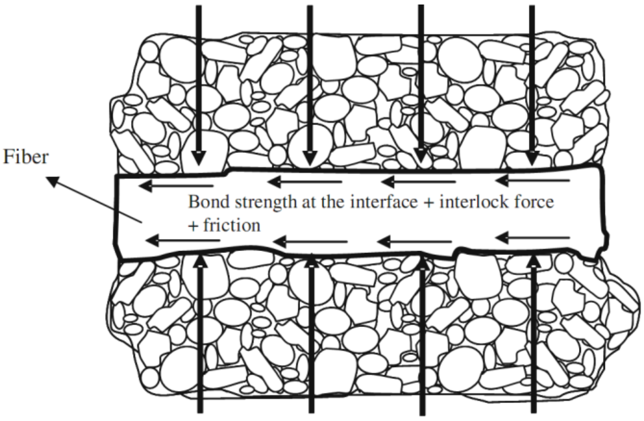

Figure 5.Schematic diagram of mechanical behaviour at interface between fiber surface and soil particles (Tang et al. 2007)

Contribution of horizontally aligned fibres in vertical shrinkage of samples can be explained with the aid of Figure 5. It can be seen that the fibre surface is attached by many soil particles which make contribution to the strength and friction between soil particles and fibres.

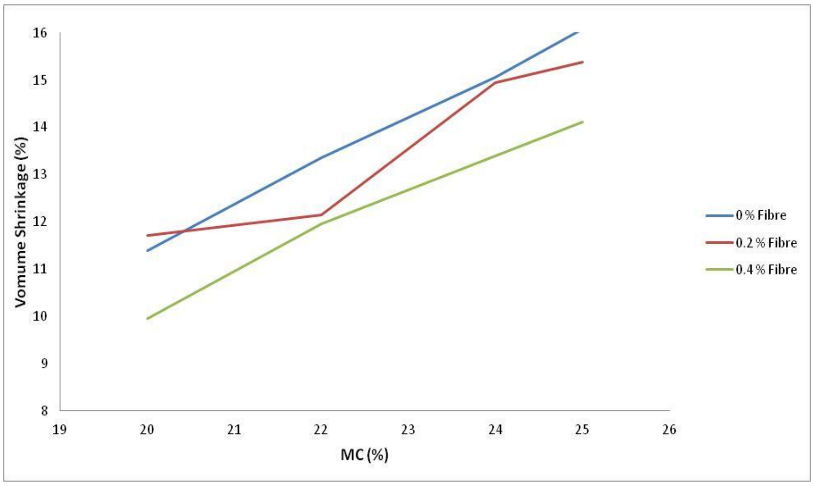

Figure 6.End of drying period Volume of samples

Variations of the volume shrinkage as function of fibre content and moisture content are shown in Figure 6. It can be seen that regardless of increasing moisture content, increasing fibre content, resulted in reduction of volumetric shrinkage. The resulted reduction in volumetric shrinkage become more pronounced at 0.4 % fibre content compared to 0.2 %. This significant decrease means that samples reinforced with random inclusion of fibres experienced less volumetric change due to desiccation. Decrease in volumetric shrinkage means that increase in fibre content having greater surface contacts with the soil have shown greater resistance to volume change on desiccation. It can be said, with the evaluation of height and diameter shrinkage findings with volumetric shrinkage findings, random inclusion improved the soil tensile strength very effectively, thus resisting shrinkage on desiccation.
Observations of cracks have been done by monitor the cracks with the naked eye and collect the data. As can bee seen on Figure 7, increase of moisture content does not resist crack development. Where by increasing fibre content, the extent and depth of cracks were significantly reduced. It can be seen that in any moisture content of unreinforced samples extensive, deep and wide cracks were formed. The reinforced samples, however, has mainly experienced smaller volume reduction as mentioned above and no visible sign of crack formation on the surface of the sample. This clearly shows the effectiveness of random fibre inclusion in resisting and reducing desiccation cracking. Therefore, it can be concluded that random fibre inclusion seems to be a practical and effective method of increasing tensile strength of the clayey soils to resist volumetric changes

		Moisture Content (%)		
Day	**FC (%)**	**20**	**22**	**24**
0	**0**			
0	**0.2**			
0	**0.4**			
7	**0**			
7	**0.2**			
7	**0.4**			
21	**0**			
21	**0.2**			
21	**0.4**			

Figure 7.Desiccation cracking

5 CONCLUSIONS

In the current study, influence of moisture content and fibre content in soil reinforcement have been studied. By analysing the experimental results, the following conclusions were made;

- Regardless of different fibre content, reduction in mass is mostly influenced by the compaction moisture content of the samples.
- Contribution of fibres are more pronounced in vertical shrinkage compare to horizontal. This behaviour can be explained by the horizontal alignment of the fibres due to compaction process.
- Increase of fibre content leads to reduction of volumetric shrinkage due to increase of soil fibre contact area and improvement of soil tensile strength thus resisting shrinkage on desiccation.
- Finally visual observations clearly shows the effectiveness of random fibre inclusions in resisting and reducing desiccation cracking.

6 References

Abdi, M.R., Parsapajouh, A., & Arjomand, M.A. (2008). Effects of random Finer Inclusion on Consolidation, Hydraulic Conductivity, Swelling, Shrinkage Limit and Desiccation Cracking of Clays. *International Journal of Civil Engineering*, 6, (4)

AL-RAWAS, A.A. & MCGOWN, A. (1999). Micro structure of Omani expansive soils. *Canadian Geotechnical Journal*, 2, (36) 272-290

Benson, C.H., Gee, G.W., Roesler, A.C., Abichou, T., Apiwantragoon, P., Lyles, B.F., & Rock, S.A. (2004). Field Water Balance of Landfill Final Covers. *Journal of Environmental Quality*, 33, (6) 2317-2332

Ekinci, A. & Ferreira, P. M. V. (2012).The undrained mechanical behaviour of a fibre-reinforced heavily over-consolidated clay Proceedings to International Symposium on Ground Improvement, *In ISSMGE - TC 211 International Symposium on Ground Improvement*.

Harianto, T., Hayashi, S., Du, Y.J., & Suetsugu, D. (2008). Effects of Fiber Additives on the Desiccation Crack Behavior of the Compacted Akaboku Soil as A Material for Landfill Cover Barrier. *Water, Air, & Soil Pollution*, 194, (1) 141-149

Omidi, G.H., Thomas, J.C., & Brown, K.W. (1996). Effect of desiccation cracking on the hydraulic conductivity of a compacted clay liner. *Water, Air, & Soil Pollution*, 89, (1) 91-103

Ozkul, Z.H. & Baykal, G. (2006). Shear Strength of Clay with Rubber Fiber Inclusions. *Geosynthetics International*, 13, (5)

REMR Technical Note 1998, *influence of Short Polymeric Fibers ib Crack Development of Clays*.

Rifai, S. & Miller, C. (2004). Fiber Reinforcement for Waste Containment Soil Liners. *Journal of Environmental Engineering*, 130, (8)

Tang, C., Bin, S., Wei, G., Chen, F., & Cai, Y. (2007). Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. *Geotextiles and Geomembranes*, 25, 194-202

VIPULANANDAN, C. & LEUNG, M. (1991). Seepage Control in Contaminated and Permeable Houston Clay: A Laboratory Study. *Hazardous Waste and Hazardous Materials*, 8, (1) 17-32

Ziegler, S., Leshchinsky, D., Ling, H.I., & Perry, E.B. (1998). Effect of short Polymeric Fibers on Crack Development in Clay. *The Japanese Geotechnical Society*, 38, (1)