Effects of fibre reinforcement in the shrinkage behaviour of compacted clay

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ABSTRACT: The stability of clay slopes and liners is intimately connected to desiccation cracking. To mitigate this problem, research has been performed on mixtures of soil with additives such as lime, cement and/or fibres. Chemical additives tend to generate stiff materials and may leach and create environmental problems; therefore, fibre reinforcement became an interesting alternative as it reduces the cracking formation and cracking propagation in soils subjected to wetting and drying, as well as accommodating certain displacements. In this article, results of a pilot study on reinforced and unreinforced compacted samples of clay from the Lambeth Group, subjected to desiccation, are presented. The samples were compacted according to the BS 1377-4:1990, using 3 different moisture contents (optimum and optimum plus and minus 2%). For all moisture contents, 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 a homogeneous fibre distribution. While the samples were drying, their height, diameter and weight were measured. Photographs were also taken in order to verify the occurrence of desiccation cracking. The results show that the reinforced samples have a lower volumetric deformation and desiccation cracking was not visible while the unreinforced samples showed a higher volumetric reduction, with large cracks visible between the compacted layers of soil.

1 BACKGROUND

Many earth structures, such as slopes and highway embankments, are constructed of clay soils. During the seasonal effects of drying and wetting, desiccation cracks are formed near the surface. As these cycles continue, water fills these cracks, increasing the depth of the cracked clay zone which may eventually reach 3m or more. A variety of research was done in order to eliminate or mitigate the desiccation cracking in soils. Benson et al. (2004) have considered the use of surface moisture barriers, placed above the soil layer to be protected. Others have considered soil additives (lime, sand and cement) in order to increase the soil strength and resistance to cracking (Omidi et al. 1996;Vipulanandan and Leung 1991). However, based on the previous studies, the additives are not capable of suppressing the desiccation cracking of clayey soils with high water contents and other issues must be considered, such as the environmental impact of such additives.

In order to assess the effect of inclusion of fibres into clay, Abdi et al. (2008) and Rifai and Miller (2004) used a variety of testing programmes. These authors assessed the cracks after shearing samples using triaxial equipment. Prior to shearing, some samples were compacted in a specific mould and the cracks were assessed after the samples were allowed to dry over a certain period of time (24 hours, 3 days or 30 days) while another set of samples were submitted to wetting/drying cycles. Observations of the cracks were done using two distinct methods. In the first method, Harianto et al. (2008) monitor the cracks with the naked eye and collect two types of data: volume change (height and diameter measurements) and surface cracking measurements. The data is 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 sample geometrical features by using digital imaging software where the crack dimensions are measured using the pixel information of the digital images. 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 by Ozkul and Baykal (2006), for specimens without fibres, a few wide cracks developed along the surface. For specimens of the same soil reinforced with fibres, the pattern changes and numerous cracks with smaller dimensions developed. The same authors have also revealed that the inclusion of fibre content, up to a certain percentage, significantly reduces the crack formation. Rifai & Miller (2004) and Tang et al. (2007) concluded that the inclusion of fibres in soil improve the tensile strength, reducing the crack formation. Moreover, the authors concluded that when local cracks appear in a reinforced specimen, the fibres going across these cracks go into tension, transferring these loads to the soil by friction. This effectively impedes further development of cracks and improves the toughness of the stabilized soil, by changing the failure mode of the soil. Fibre reinforcement can also mitigate potential cracking induced by differential settlements because fibre reinforcement increases the ductility of the soil.
REMR (1998) and Ziegler et al. (1998) concluded that exceeding a certain percentage of fibre content was not practical due to the difficulty in mixing the materials to obtain a uniform distribution of fibres within the soil. They found that the inclusion of fibres over certain limits caused the development of voids during the compaction and encouraged crack development. These authors also revealed that fibre contents above 0.6% of the dry weight significantly reduced the crack reduction property of fibres. Additionally, the authors mentioned that when the reinforced soil was subjected to wetting/drying 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 the M25 and M1 motorways, north of London. It is an overconsolidated clay from the Lambeth Group, classified as high-plasticity inorganic clay (CH). The liquid limit and the plastic limit of the clay were found to be 59.5 and 24.1 respectively, while a specific gravity of 2.65 was measured. The grain size distribution is fairly uniform with: 95% passing 0.05mm, 85% passing 0.015mm, 60% passing 0.004mm and 46% passing 0.001mm. The polypropylene fibres used in this investigation have widths 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 the effect of fibres in the OMC and the MD of the soil is negligible, 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).

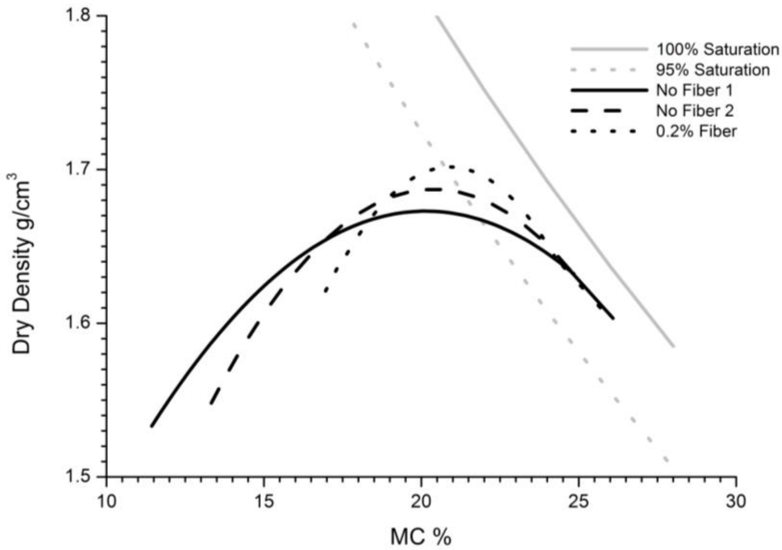

Figure 1. Compaction curves of reinforced and non-reinforced samples

3 EXPERIMENTAL PROCEDURE

Samples were prepared in a CBR mould. The soil was obtained "as dug" from the site, brought to laboratory and chopped in peds of roughly 15mm diameter. Those peds were air-dried and later reduced in size. Samples were brought to the desired moisture content, around 2% below and above the optimum moisture content (Figure 1). The moisture contents used were 20, 22, 24 and 25%. Fibres were hand-mixed at 0%, 0.2% and 0.4% of the dry weight of the soil, and compacted using the light compaction method specified in BS 1377-4:1990.
Al-Rawas and McGown (1999) made an extensive review of the drying techniques, and concluded that there is no single technique that can be claimed to be the best for specimen drying. Therefore, all samples were subjected to air drying, at room temperature, for about 10 to 12 weeks. During this period, the weight was measured regularly, together with an 6 measures of the diameter and 4 measures of the height of the sample. In order to improve accuracy, all measurements of height and diameter were performed at the same points on the sample. MC, degree of saturation and volume change of the 12 samples were calculated afterwards, based on the new and the initial data obtained.

4 RESULTS

The results of the tests conducted on soils treated with a variety of fibre contents are presented in Table 1. The normalised mass against elapsed time is 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). The graph shows that the reduction in mass is mostly affected by the initial moisture content of the sample, before compaction. Therefore, higher moisture contents lead to higher mass loss.

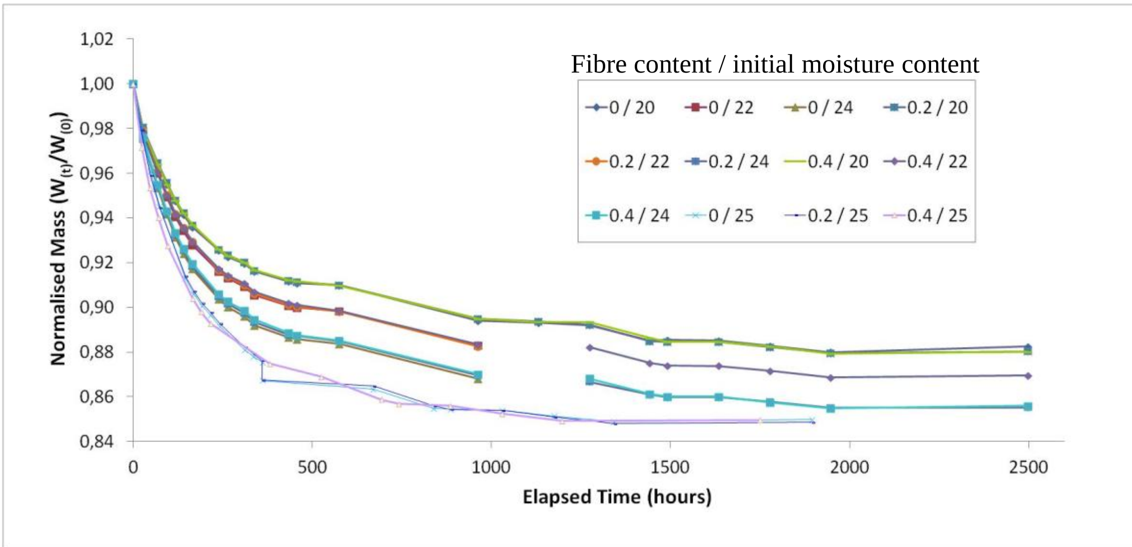

Figure 2. Change in normalised mass of reinforced and unreinforced samples due to free swell

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

Figures 3 and 4 present the percentage reduction in diameter and height, respectively, due to shrinkage, at the end of the drying period. It can be seen in Figure 3 that the reduction in diameter is proportional to the initial moisture content of the sample, while the fibre percentage does not seem to affect dramatically the shrinkage in diameter of the samples.

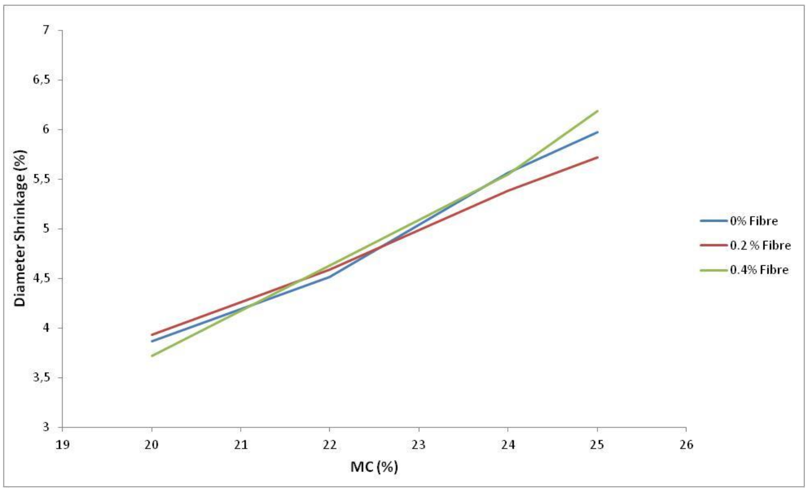

Figure 3. End of drying period diameter shrinkage of samples

Figure 4, however, tells a different story. Again, the reduction in height is proportional to the initial moisture content, with lower initial moisture contents showing less shrinkage than higher initial moisture contents, for every fibre content. However, the reduction in height of the samples is also affected by the fibre percentage. The samples without fibres have shown the highest reduction in height, while the reinforced samples, with 0.4% of fibres, have suffered the lowest height shrinkage with the samples with 0.2% of fibres assuming an intermediate place. The phenomenon of fibres not being effective in a horizontal direction, as would be expected, can be explained by analysing the fibre alignment during the compaction. Ekinci and Ferreira (2012) have shown that nearly 80% of fibres are aligned within ±20º in relation to the horizontal plane. This alignment is caused by the sample preparation procedure as the length of the fibres is longer than the compacted layers. Therefore, in the horizontal direction, the contribution of the fibres is negligible, while in the vertical direction, the soil particles directly act on the surface of fibres preventing shrinkage.

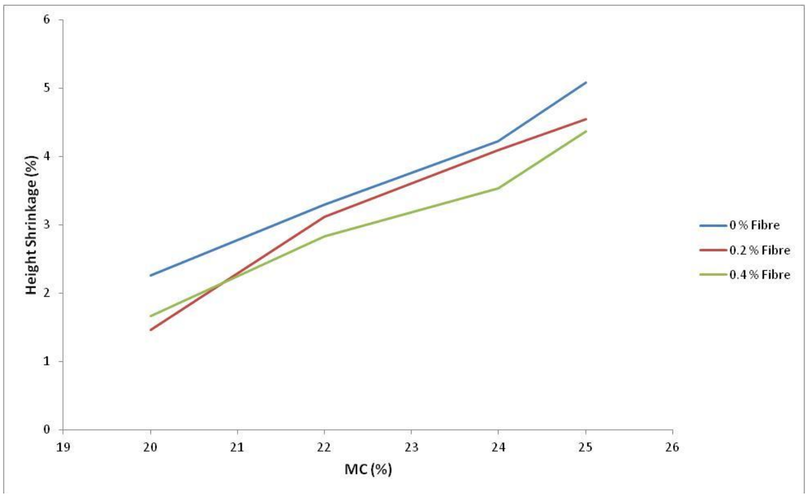

Figure 4. End of drying period height shrinkage of sample

The contribution of the 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 a contribution to the strength and friction between soil particles and fibres.

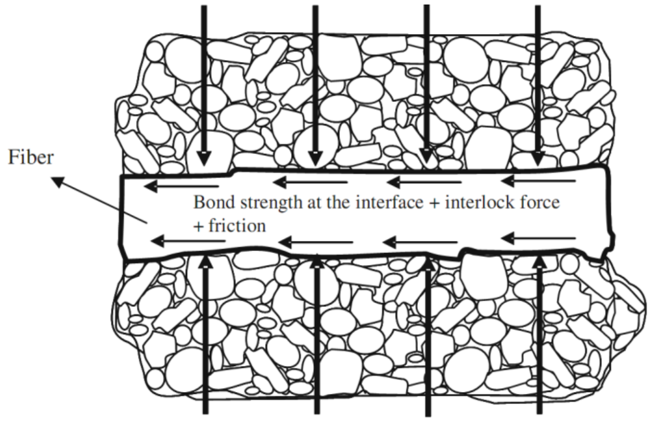

Figure 5. Schematic diagram of mechanical behaviour at the interface between fibre surface and soil particles (Tang et al. 2007).

Variations of the volume shrinkage as a 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 a lower volumetric shrinkage. From the results, it is not clear whether a higher percentage of fibres could be used to reduce the shrinkage even further; however, higher percentages become difficult to mix in the soil mass.

Desiccation cracks occurring on the samples were monitored with the naked eye when measuring the sample details. Figure 7 shows pictures of the samples monitored, according to the initial moisture content, fibre percentage and elapsed time. As can be seen in Figure 7, increases of initial moisture content do not improve the soil resistance to desiccation cracking. However, by introducing a fibre reinforcement, 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, mainly experienced smaller volume reduction as mentioned above and no visible signs of crack formation on the surface of the sample. This clearly shows the effectiveness of fibre reinforcement in resisting and reducing desiccation cracking.

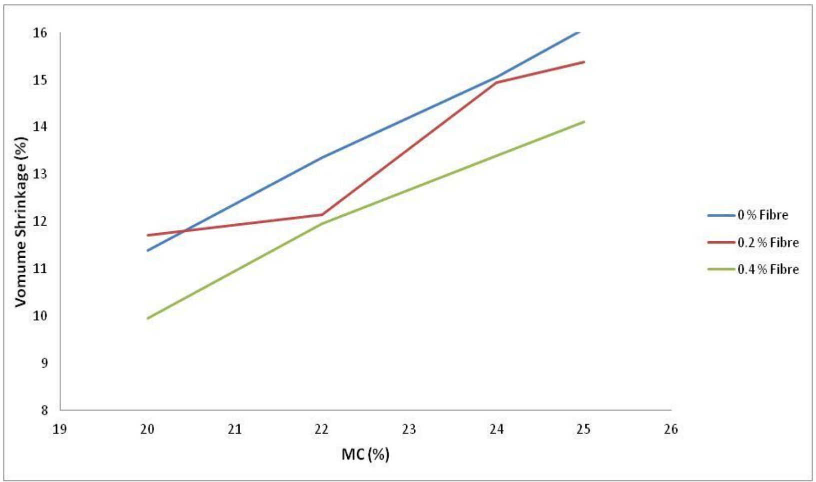

Figure 6. End of drying period volume of samples

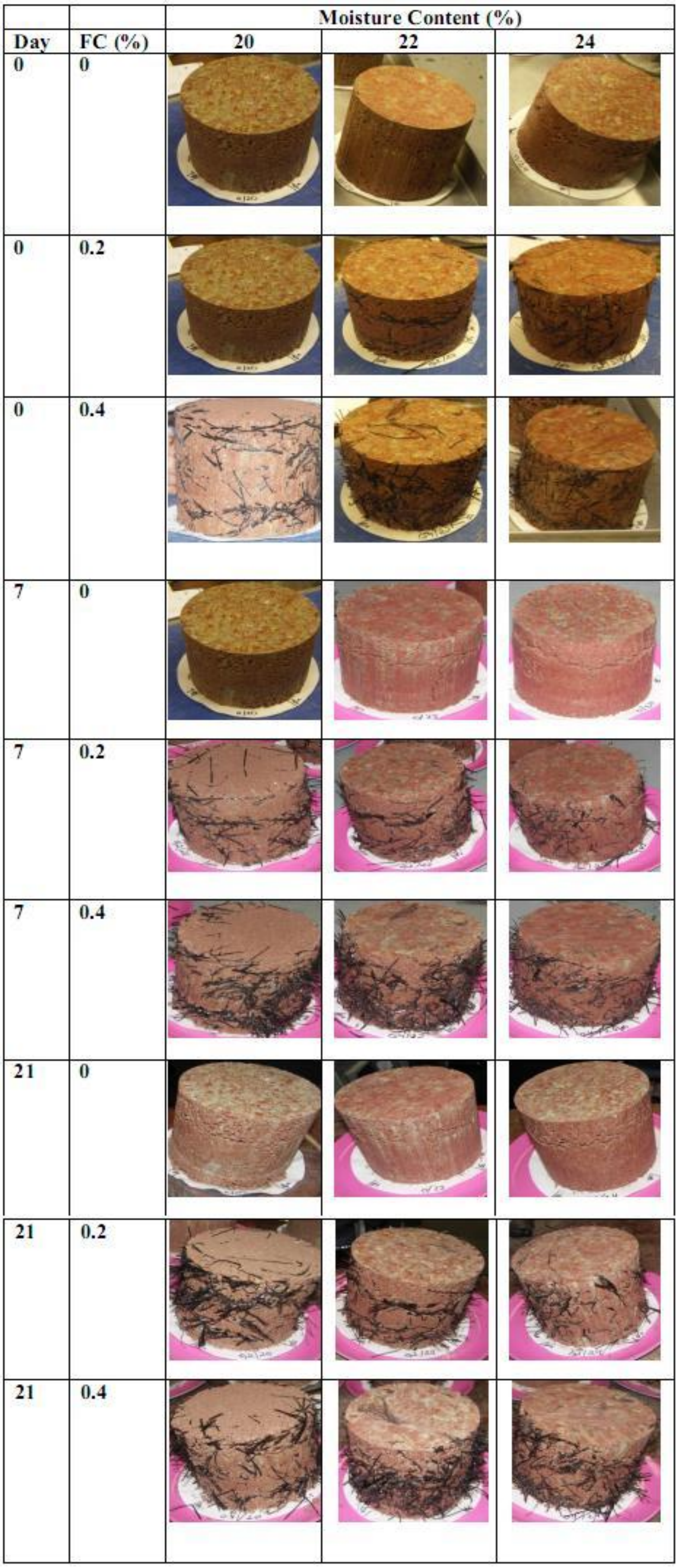

Figure 7. Desiccation cracking

5 CONCLUSIONS

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

- Regardless of the different fibre content, the reduction in mass is mostly influenced by the initial compaction moisture content of the samples.
- The contribution of the fibres is more pronounced in the height of the samples as reinforced samples had a lower reduction of height due to desiccation. This behaviour is attributed to the horizontal alignment of the fibres due to the compaction process.
- Increasing fibre content leads to a reduction of volumetric shrinkage due to an increase of soil fibre contact area and improvement of soil tensile strength.
- Finally the visual observations clearly show the effectiveness of random fibre inclusions in resisting and reducing desiccation cracking.

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