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ANALYSIS OF MICROSCOPIC BEHAVIOUR OF FIBER REINFORCED CEMENTED SAND SUBJECTED TO CYCLES OF WETTING AND DRYING

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***Abstract* -** The main objective of this study is to investigate the behaviour of cemented sand under the cycles of wetting and drying and to evaluate the effects of polyvinyl alcohol fiber (PVA) on shear strength of sand by carrying out unconfined compression test on sand samples. The results obtained are compared and inference is drawn towards the usability and effectiveness of fiber reinforcement as a replacement for earthen dam and embankments, as a cost effective approach.

Index Terms — polyvinyl alcohol, unconfined compression test, scanning electron microscope

I. INTRODUCTION

Earthen Structures are the most economical ones. But their strength during alternate wetting and drying is stripped-down. In order to overcome this drawback, granular materials are mixed with cement to improve engineering properties such as cohesion & friction angles. Natural or artificial cementation of sand particles contributes to settlement reduction and bearing capacity increase which are the two key considerations in the field of Geo-tech engineering. Cemented Sand markedly increases Elastic Modulus & Peak strength but they exhibit more brittle stress strain behaviour at higher cement contents. The brittle failure pattern may cause sudden failure of soil structures that are stabilized with cemented materials. To overcome such a brittle nature of cemented sand either natural or artificial syntheticfibres have been included in cemented sands. The addition of fiber to the cemented sand produces bonding and friction between the sand&fibers. The Fiber reinforced cemented sands can sustain a load even after the de-bonding or failure of cemented sand and thus they can effectively improve the brittle behaviour of cemented soils. The addition of some fibers may also cause deviatric stress failure. So the fibers must be chosen according to the properties of the sand. In our project, the sand which is collected from Vel Tech High Tech Dr.Rangarajan Dr.Sakuntala Engineering College is mixed with cement and fiber at different proportions.Behaviour of the cemented sand is observed and the inference is done.

A. CEMENTED SANDS

Many Cemented Sand is widely found in nature. It can be formed in multiple ways, such as precipitation of silicon dioxide and oxidation reaction of the ferric oxide in sand. There are three kinds of cements, which are classified according to their compositions as siliceous cement, carbonate content, clay mineral cement. Since the 1970s, scholars have been researching cemented sand. They examined the stress strain behaviour of artificial cemented sand sample produced with ordinary Portland cement under low confining pressure. By comparing it with uncemented sand, they found that cemented sand has greater strength and stiffness.

Mohr Coulomb strength theory assumes the cohesion and the angle of shearing resistance to be constant values. However for artificial cemented sand, its cohesion and angle of shearing resistance vary with cementing agent content. This means the original Mohr Coulomb strength theory expression is not suitable for artificial cemented sand with different cementing agent content Artificial Cemented Sand prepared by using ordinary Portland Cement (OPC) as the cementing agent.

Fig. 1.1 Cemented Sand

B. POLYVINYL ALCOHOL FIBRE (PVA)

Polyviny1 alcohol is adopted from polyviny1 acetate which is readily hydrolysed by treating an alcoholic solution with aqueous acid or alkali , leading to the structure. PVA contains hydroxyl groups (OH) which have the potential to form hydrogen bond between molecules resulting in a remarkable change in surface bond strength between PVA fibers and the matrix.

PVA is a white powder with specific gravity ranging from 1.2 – 1.3 (1200-1300 kg/m3). This powder is then formed and extruded to become PVA fibers which are commercially produced. PVA fibres mostly have aspect ratios (*Lf*/*df*) of 45 to 250 and different cut length varying from 6 to 30 mm to make fibres suitable for different applications.

Fig. 1.2 PVA fibre sample

PVA fibre has a rough surface. This property significantly improves the mechanical interlocking related adhesion capacity of this fibre in a matrix. Generally, the surface structure of a fibre is very effective on its performance. The highly hydrophobic and smooth surfaces usually reduce the composite performance. To illustrate the surface roughness differences between fibres, SEM images captured at the same magnification of PVA fibre versus Polypropylene (PP) fibre, which has a very smooth surface structure.

C. SCOPE OF THE WORK

The experimental work consists of the following steps:

1. Moisture content determination
2. Specific gravity of soil
3. Particle size distribution by sieve analysis
4. Determination of the maximum dry density (MDD) and the corresponding optimum moisture content (OMC) of the soil by Proctor compaction test
5. Preparation of reinforced soil samples.

6. Determination of the shear strength by
   i) Unconfined compression test (UCS).

D. PREPARATION OF SAMPLES

- All the sand samples are compacted at their respective maximum dry density (MDD) and optimum moisture content (OMC) , corresponding to standard proctor compaction tests.
- Content of fiber in the sand is herein decided by the following equation:

$$\rho_f = \frac{W_f}{W}$$

Where, ρ_f= ratio of fiber content
W_f = weight of the fiber
W = weight of the air-dried soil

- The different values adopted in the present study for the percentage of fiber reinforcement are 0, 0.3, 0.6, and 0.9.
- The values adopted in the study for the percentage of cement are 10, 15, 20.
- In the preparation of samples, if fiber is not used then, the air-dried sand was mixed with an amount of cement and water that depends on the OMC of the sand.
- If fiber reinforcement was used, the adopted content of fibers was first mixed with the air-dried sand and cement in small increments by hand, making sure that all the fibers were mixed thoroughly, so that a fairly homogenous mixture is obtained, and then the required water was added.

E. ADVANTAGES

It has high aspect ratio, high ultimate tensile strength, relatively high modulus of elasticity, good chemical compatibility with Portland cement, good affinity with water and no health risks.

PVA fibres also provide a good interfacial bond with the cement matrix, they generally have a positive effect on the bending strength and other mechanical properties of their composites.

The very strong chemical bonding of PVA fibres with cementitious materials, which is due to the presence of the hydroxyl group in PVA molecular chains.

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II. METHODOLOGY

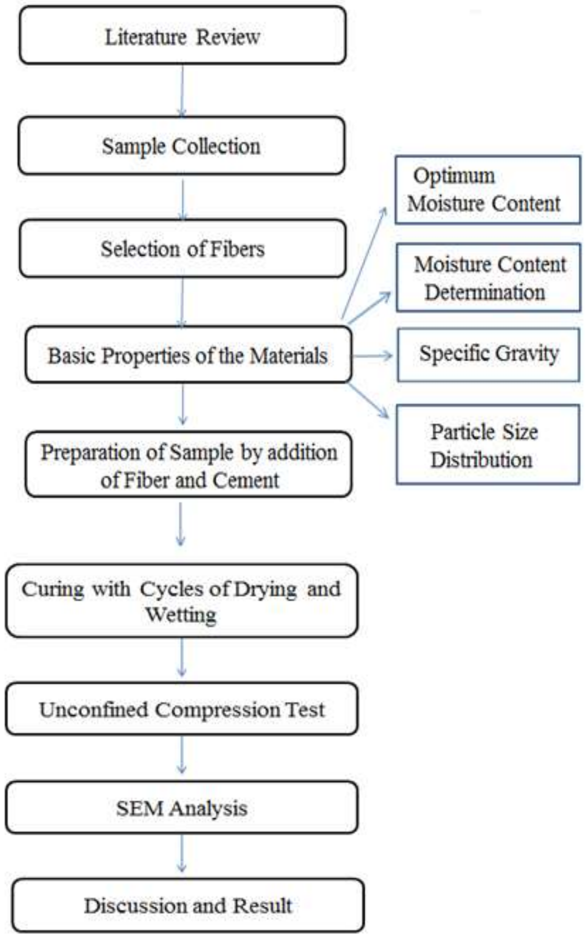

Fig.2.1 Flow chart

III. UNCONFINED COMPRESSION TEST

This test is a specific case of triaxial test where the horizontal forces acting are zero. There is no confining pressure in this test and the soil sample tested is subjected to vertical loading only. This experiment is used to determine the unconfined compressive strength of the soil sample which in turn is used to calculate the unconsolidated, undrained shear strength of unconfined soil.

The unconfined compressive strength (q_u) is the compressive stress at which the unconfined cylindrical soil sample fails under simple compressive test. The experimental setup constitutes of the compression device and dial gauges for load and deformation. The load was taken for different readings of strain dial gauge. The corrected cross-sectional area was calculated and then the compressive stress was calculated by dividing the load with the corrected area.

$$q_u = \frac{Load}{Corrected Area\,(A')}$$

where ,q_u= compressive stress

$$A' = \frac{Cross-Sectional Area}{1-\varepsilon}$$

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IV. CURING CONDITIONS

Table 4.1: Curing Conditions of Fiber Reinforced Cemented Sand

TEST ID	CEMENT RATIO	FIBER RATIO	CURING CONDITION AC+ (UC) DAYS
A-1 (F-0) A-2 (F-1) A-3 (F-2) A-4 (F-3) A-5 (F-4)	10	0	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
A-6 (F-5) A-7 (F-6) A-8 (F-7) A-9 (F-8) A-10 (F-9)	10	0.3	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
A-11 (F-10) A-12 (F-11) A-13 (F-12) A-14 (F-13) A-15 (F-14)	10	0.6	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
A-16 (F-15) A-17 (F-16) A-18 (F-17) A-19 (F-18) A-20 (F-19	10	0.9	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
B-1 (F-0) B-2 (F-1) B-3 (F-2) B-4 (F-3) B-5 (F-4)	15	0	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
B-6 (F-5) B-7 (F-6) B-8 (F-7) B-9 (F-8) B-10 (F-9)	15	0.3	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
B-11 (F-10) B-12 (F-11) B-13 (F-12) B-14 (F-13) B-15 (F-14)	15	0.6	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4
B-16 (F-15) B-17 (F-16) B-18 (F-17) B-19 (F-18) B-20 (F-19)	15	0.9	28 27+(1) 13+(1)+14 7+(1)+7+(1)+7+(1)+4 6+(1)+5+(1)+5+(1)+4+(1)+4

V. RESULTS AND DISCUSSIONS

Table 5.1: Moisture Content Determination

Mass Container+ Wet soil (M1) in grams	96g
Mass Container+ Dry soil (M2) in grams	94g
Empty container (M3) in grams	19g
Moisture content (M1-M2)/(M2-M3) in grams	0.026g
Moisture content (%)	2.6%

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Table 5.2: Specific Gravity Determination

Sample Number	2
Mass of Empty Bottle (M1) in gms.	648
Mass of Bottle+ Dry soil (M2) in gms.	948
Mass of Bottle + Dry soil + Water (M3) in gms.	1720
Mass of Bottle + Water (M4) in gms.	1540
Specific Gravity	2.5

Table 5.3: Particle Size Distribution

Sieve Size	Retained (g)	Retained (%)	Cumulative Retained (%)	Percentage Passing(%)
4.75mm	34	3.4	3.4	96.6
2.36mm	32	3.2	6.6	93.4
1.4mm	109	10.9	17.5	82.5
600µ	169	16.9	34.4	65.6
425µ	173	17.3	51.7	48.3
300µ	162	16.2	67.9	32.1
150µ	279	27.9	95.8	4.2
75µ	29	2.9	98.7	1.3
Pan	10	1.0	99.7	0.3

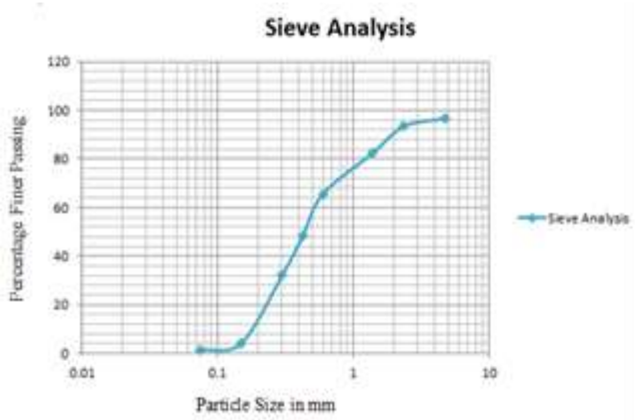

Fig.5.1 Particle size distribution curve

Uniformity Coefficient (Cu) = D_{60}/ D_{10} = 2.66

Coefficient of Curvature (Cc) = $(D_{30})^2/ (D_{60} \times D_{10})$ = 0.829

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Table 5.4: Proctor Compaction Test

DESCRIPTION	I	II	III	IV	V	VI	VII	VIII
Weight of Mould (W1)	3901	3901	3901	3901	3901	3901	3901	3901
Weight of Mould + Compacted Soil (W2)	5661	5687	5764	5805	5872	5908	5926	5933
Weight of Compacted Soil (W2-W1)	1760	1786	1863	1904	1971	2007	2025	2032
Bulk Density (γ_b)	1.87	1.9	1.98	2.02	2.09	2.13	2.15	2.16
Dry Density (γ_d)	1.78	1.78	1.8	1.82	1.82	1.81	1.79	1.69
Weight of Container + Wet Sample	65	78	76	82	81	72	73	74
Weight of Container + Dry Sample	63	74	71	76	73	64	65	62
Water Content	0.05	0.07	0.10	0.11	0.15	0.18	0.20	0.28
Water Content (%)	5	7	10	11	15	18	20	28

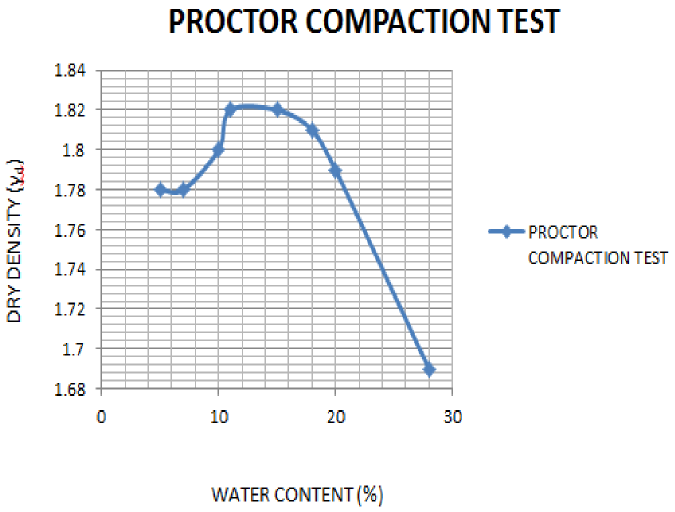

Fig 5.2 Proctor compaction test curve

Table 5.5: UCS test observation for sand sample with 10% cement 0.9% fiber (3)

Axial Deformation (mm)	Proving Ring Dial (div)	Compressive Load (kg)	Specimen Length (mm)	Specimen Area (cm^2)	Compressive Stress (kg/cm^2)	Axial Strain (mm)
0	0	0	79	12.56	0	0
0.5	1.6	0.2291	78.5	12.64	0.018	0.632
1	2	0.2864	78	12.72	0.022	1.26
1.5	19.2	2.749	77.5	12.80	0.2147	1.89
2	22.4	3.207	77	12.89	0.248	2.53
2.5	35.6	5.097	76.5	12.97	0.392	3.16
3	45.6	6.529	76	13.06	0.499	3.79
3.5	56	8.0192	75.5	13.14	0.610	4.43
4	70.2	10.05	75	13.23	0.759	5.06
4.5	83	11.88	74.5	13.32	0.891	5.69
5	75	1074	74	13.41	0.800	6.329

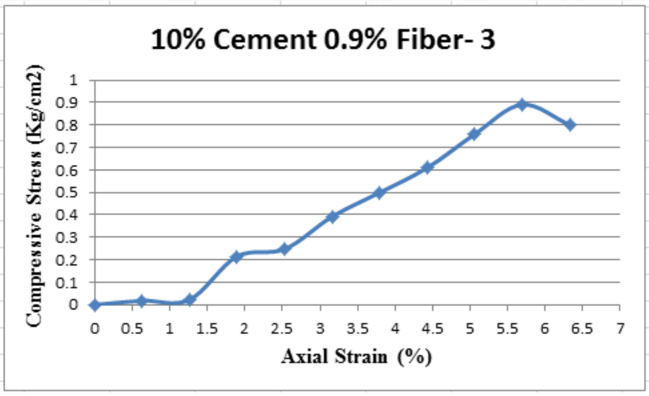

Fig 5.3 UCS curve for sand sample with 10% cement 0.9% fiber (3)

As obtained from graph,
UCS = 0.891 Kg/cm^2.

Table 5.6: UCS test observation for sand sample with 15% cement 0.9% fiber (3)

Axial Deformation (mm)	Proving Ring Dial (div)	Compressive Load (kg)	Specimen Length (mm)	Specimen Area (cm^2)	Compressive Stress (kg/cm^2)	Axial Strain (mm)
0	0	0	79	12.56	0	0
0.5	15.4	2.205	78.5	12.64	0.174	0.632
1	27.2	3.895	78	12.72	0.306	1.26
1.5	39.2	5.6134	77.5	12.80	0.438	1.89
2	49.4	7.074	77	12.89	0.5488	2.53
2.5	58.6	8.391	76.5	12.97	0.646	3.16
3	61.2	8.763	76	13.06	0.671	3.79
3.5	61.4	8.79	75.5	13.14	0.669	4.43
4	60	8.592	75	13.23	0.649	5.06

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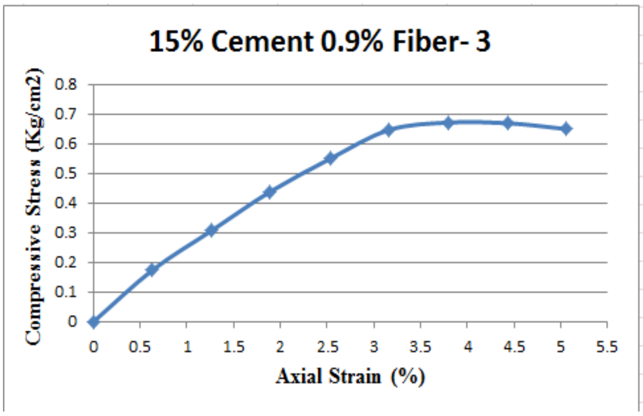

Fig 5.4 UCS curve for sand sample with 15% cement 0.9% fiber (3)

As obtained from graph,
UCS = 0.69 Kg/cm^2.

VI. SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS

1. Scanning Electron Microscope is done to observe the microscopic structure, density before and after curing etc.,
2. By using the image tools of GIS, the grey SEM image were transformed to binary black and white image and the pores are represented by black pixels.
3. The increase in UCS seemed to be because of binding of the sand particles with PVA fiber and cement.
4. The analysis revealed that the improvement in UCS afforded by cemented sand proportions because of the filling to the void between sand particles and unity of particles.
5. When the specimens are under load, the 'Bridge Effect' efficiently impede the further development of tension crack and deformation of soil.

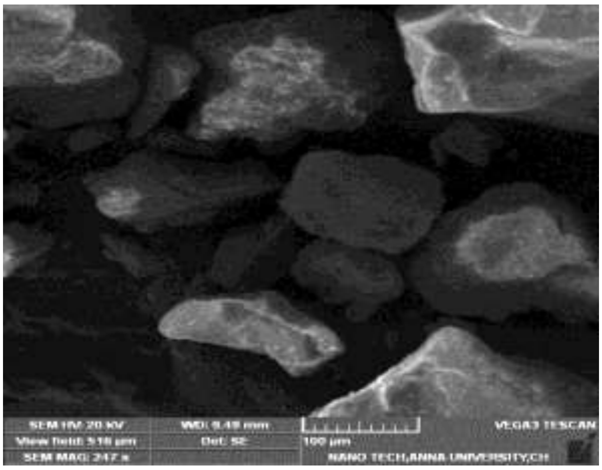

Fig.6.1 SEM images for sand sample collected from Vel Tech High Tech Dr.Rangarajan Dr.Sakuntala Engineering College.

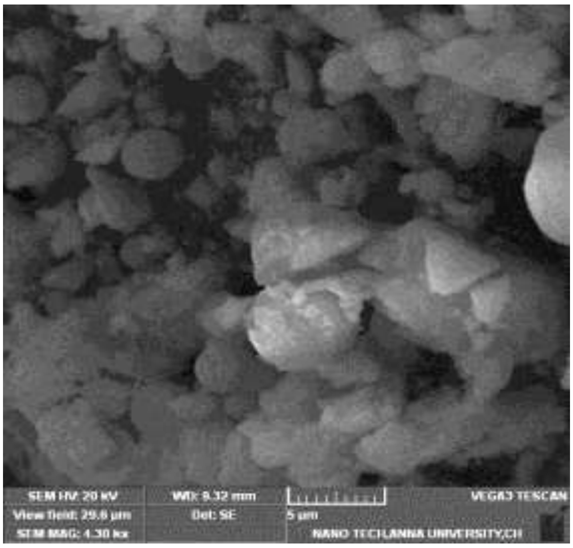

Fig 6.2 SEM image for fiber reinforced cemented sand(15%cement 0.9% fiber)

VII. CONCLUSION

There is a general perception that addition of fibres in cemented sand leads to increase in its strength but with this research we have found that this perception is contradictory as the addition of fibres for 10 % and 15% cement content shows reduction in UCC strength. Also, the cycles of wetting for the cemented sand proves to be in our favour compared to the condition of drying as the curing condition E (6+(1)+5+(1)+5+(1)+4+(1)+4) has shown the highest strength in most cases.

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