STRENGTH AND THERMAL PROPERTIES OF PLAIN AND REINFORCED SOIL-CEMENT

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SUMMARY: The prospects of using steel bar or mesh reinforcement in soil-cement mixture were investigated. A silty clay soil was used. The strength properties such as unconfined compressive, flexural, and bond strength of soil-cement were obtained for different cement contents and curing ages. The linear coefficient of thermal expansion, thermal conductivity, specific heat and thermal diffusivity of soil-cement and of concrete were obtained. A comparison of reinforced soil-cement and concrete pavement was made. It was found that using reinforcement in soil-cement will improve the flexural strength of the mixture and allows reduction in the thickness of soil-cement layers. Reinforced soil-cement have better thermal properties than concrete. There seems to be a possibility of eliminating the joints used in rigid pavements by using reinforced soil-cement.

Key Words: Soil-cement, steel reinforcement, strength properties, thermal properties, concrete.

INTRODUCTION

Soil-cement is a mixture of pulverized soil and measured amount of cement and water, compacted to the desired density and cured. The role of cement is to improve the engineering properties of available soil such as, strength, compressibility, permeability, swelling potential, frost susceptibility and sensitivity to changes in moisture content (1-3).

Soil-cement is mainly used as a base and/or subbase in rigid and flexible highway and airfield pavements (4-6).

Soil-cement materials range from semi-flexible to semi-rigid depending on the type of soil and amount of cement used. When granular soils are used and the concentration of cement is increased, the mixture approaches a rigid behavior.

In rigid pavements usually contraction, expansion, construction, and longitudinal joints are used (5,7). For smooth riding and low-maintenance cost, reduction or elimination of the joints is desirable.

The thermal properties of soils (8-11) such as specific heat, thermal resistivity, and thermal diffusivity are lower than that of concrete.

The thermal properties of soil-cement particularly for finegraine soils are expected to be lower than that of concrete. This will result in lower warping and lesser interior stresses in pavements of soil-cement as compared to concrete in rigid pavement.

Reinforced earth has been used to improve the load carrying capacity of soil in fill construction (12-14).

Armstrong (15) reported the use of steel reinforcement in soil-cement mixture for the purpose of trench capping of low-level nuclear waste disposal trenches of 6m x 3m x 3m.

The scope of this work is to investigate the prospects of using steel reinforcement in soil-cement mixture for highway pavement.

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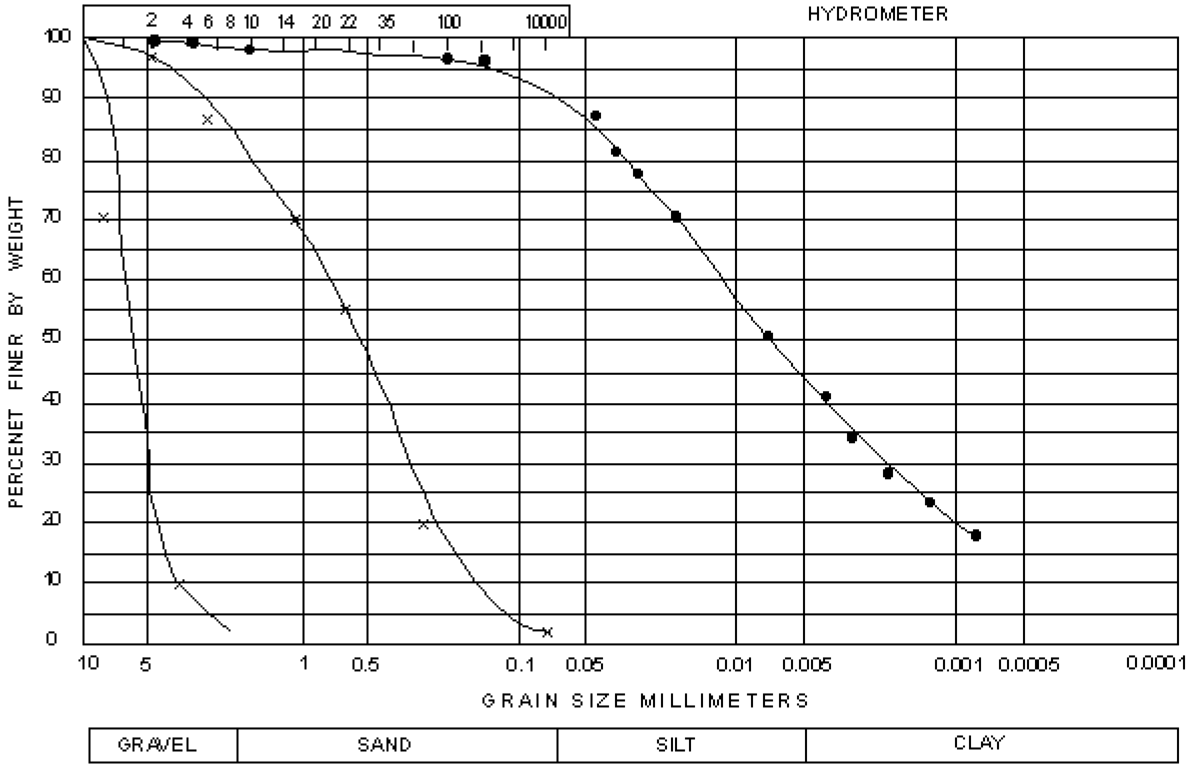
Figure 1: Grain Size Distribution of Soil Used (ASTM).



MATERIALS AND METHODS

Soil: Light brown silty clay from Baghdad which is a typical soil in the middle and southern parts of Iraq was selected for the purpose of this study. The physical properties and the chemical analysis of the soil used are given in Tables 1 and 2.

The grain size distribution and the X-Ray Diffraction of the soil are shown in Figures 1 and 2.

Concrete Aggregate: Kerbala sand and Samarra river gravel, locally available, which conform to ASTM-C33-86 were used to prepare the concrete specimens. The gradation of the aggregates is shown in Figure 1.

Cement: Ordinary portland cement-type I conforming to ASTM-C150-82 specification was used.

Water: Potable water was used in preparing the soil-cement and concrete specimens.

Reinforcement: Two sizes of deformed bars, 12 mm, and 8 mm. in diameter (R.B_1 and R.B_2) which conform to ASTM-A615-87 specifications and two gauges of steel welded fabrics B.R.C. mat 4 mm. diameter, 50 mm spacing and 4 mm. diameter, 100 mm. spacing (R.M_1 and R.M_2) which conform ASTM-A185-85 were used in soil-cement specimens.

12 mm. diameter high strenght steel deformed bars (R.B_1) were used to determine the bond strength of concrete.

SPECIMEN PREPARATION AND TESTS

The compaction properties of the soil and the soil with 12% cement content by weight are given in Table 1.

Strength Tests: The strength results reported are the average of three tests.

a. Unconfined compressive strength tests: For soil-cement specimens the unconfined compressive strength tests were made and cured according to ASTM-1632-87, A model hammer and mold were used to prepare specimens of 101.6 mm high and 50.8 mm in diameter. Impact compaction with a compactive effort equivalent to standard Proctor was used. The compression test was carried out at a constant rate of loading of 0.05 in/min (1.3 mm/min).

b. Flexural strength tests: A steel mold of the dimensions 75 x 75 x 375 mm was used to prepare the specimens.

The soil-cement was compacted by static compaction at optimum moisture content to the same dry density obtained by standard Proctor compaction test. At the end of the curing age, the flexural test using

Figure 2: X - Ray diffraction for soil used.

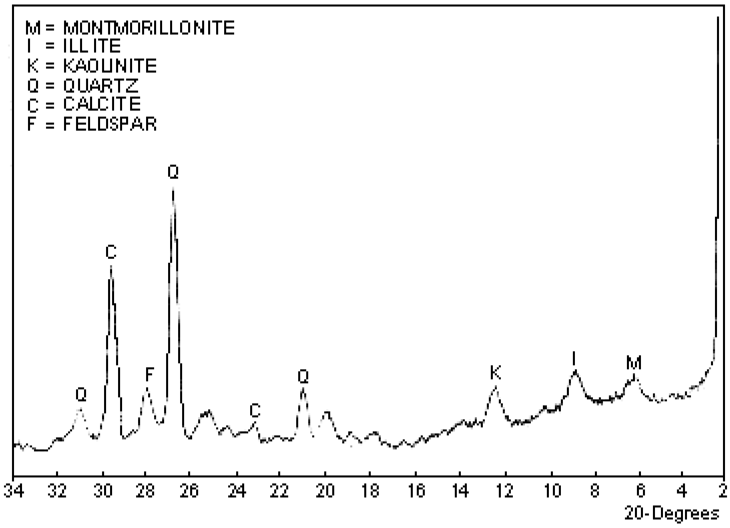


Table 1: Physical Properties of Soil.

Soil Location	Jadiriyah-Baghdah
Specific Gravity (ASTM: D854-83)	2.71
Atterberg Limits	
- Liquid limit (%) (AASHTO T89-86)	35
- Plastic limit (%) (AASHTO T90-86)	22
- Plasticity index (%) (AASHTO T90-86)	13
Grain Size Distribution (ASTM: D422-63)	
- Sand (> 0.074 mm) (%)	7
- silt (< 0.074 and > 0.005 mm) (%)	50
- Clay (< 0.005 mm) (%)	43
Standard Proctor Compaction (ASTM: D698-78)	
- Maximum dry density (kg/m^3)	1678
- Optimum Moisture Content (%)	19
Modified Proctor Compaction (ASTM: D1557-78)	
- Maximum dry density (kg/m^3)	1817
- Optimum Moisture Content (%)	16
California Bearing Ratio (C.B.R.)* (ASTM: D1883-78)	9.3
AASHTO Classification (M145-82)	A-6(9)
Unified Soil Classification (ASTM: D2487-83)	C.L.
Soil Description (ASTM: D2488-69 (75))	light brown
Silty clay has medium dry strength, slow dilatancy, and medium toughness	

* soaked C.B.R. (surcharge load = 4.54 kg).

simple beam with third-point loading test was carried out according to ASTM-D1635-87, The rate of loading used 0.02 mm/min.

c. Bond of reinforcement test: A cubic steel mold 150 x 150 x 150 mm perforated with one 16 mm diameter centric hole at the base used to cast the vertical bar in concentric pullout test specimens.

Impact compaction at optimum moisture content was used to produce the same dry density as standard Proctor compaction for the soil-cement.

The essential load required to cause a bar displacement of 0.25 mm was recorded as the nominal bond strength. The test was carried out according to ASTM-C234-8c at rate not greater then 0.05 in/min (1.3 mm/min).

All concrete specimens were 1:2:4 mix at water / cement ratio of 0.5. The compressive strength of concrete was obtained from cube tests according to B.S.1881-1970 standards. Flexural and bond tests were carried out according to ASTM mentioned.

Thermal Tests: For all thermal tests the values reported were the average of three tests.

a. Linear coefficient of thermal expansion: The specimens were similar to the unconfined compressive

Table 2: Chemical Propertiesof Soil.

Oxide	(%) by Wt
Na_2O	0.0
MgO	2.97
Al_2O_3	11.99
SiO_2	62.18
CaO	10.87
F_2O_3	6.32
SO_3	0.0
loss on ignition	5.54
R_2O_3	18.45
pH	7.10

strength specimens. A thermo-couple wires related to a micro processor thermometer, were fixed at mid-height. After curing the specimens were oven dried to 70°C for 12 hours, then cooled to room temperature before testing (8). The test was carried according to ASTM-E831-81 except that a dial gauge of 0.01 mm resulting from specimen elongation sensitivity, fixed by magnet holder for sensing movement of the dumy point, which was held by an adhesive on the specimen face, was used instead of transducer and probe used in the ASTM procedure.

b. Thermal conductivity: Cylindrical specimens 100 mm in height by 27.5 mm diameter were used. Along the height of the specimen two points on line were perforated at the same distance from the top and bottom ends of the specimen for the purpose of fixing the upper and lower thermo-couple wires related to the conductivity apparatus and thermometer. The specimens were oven dried and cooled to room temperature prior to testing.

c. Specific heat: A small piece was fractured from the unconfined compressive strength specimen at the required age was oven drier at 70°C for 12 hours then cooled to room temp.

The test was carried out depending on heat by using isolated glass and measuring the heat degree of its component by means of the microprocessor thermometer.

RESULTS

Results of Strength Tests: From unconfined compressive strength (q_u) and flexural strength tests on specimens with and without steel reinforcement the following results were obtained:

1. For soil-cement mixture both (q_u), and modulus of rupture (M.R) obtained from flexural tests increased with increase in cement content. The relation is linear as shown in Figure 3.

It was found that 14% cement content is requirement to meet the 7 days compressive strength of 300 psi (2100 kN/m^2). This value is not too requirement different from the 16.7% used in 1:2:4 concrete.

The effect of curing age on the compressive strength of soil-cement containing 16.7% cement and concrete of the same cement content is shown in Figure 4a.

2. There was a linear relationship between q_u and static modulus of elasticity for soil-cement and for concrete when the same cement content of 16.7% by weight was used and specimens were cured for differ-

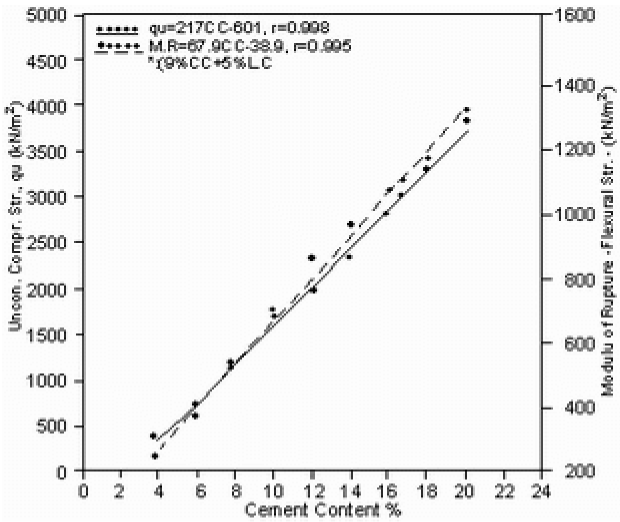
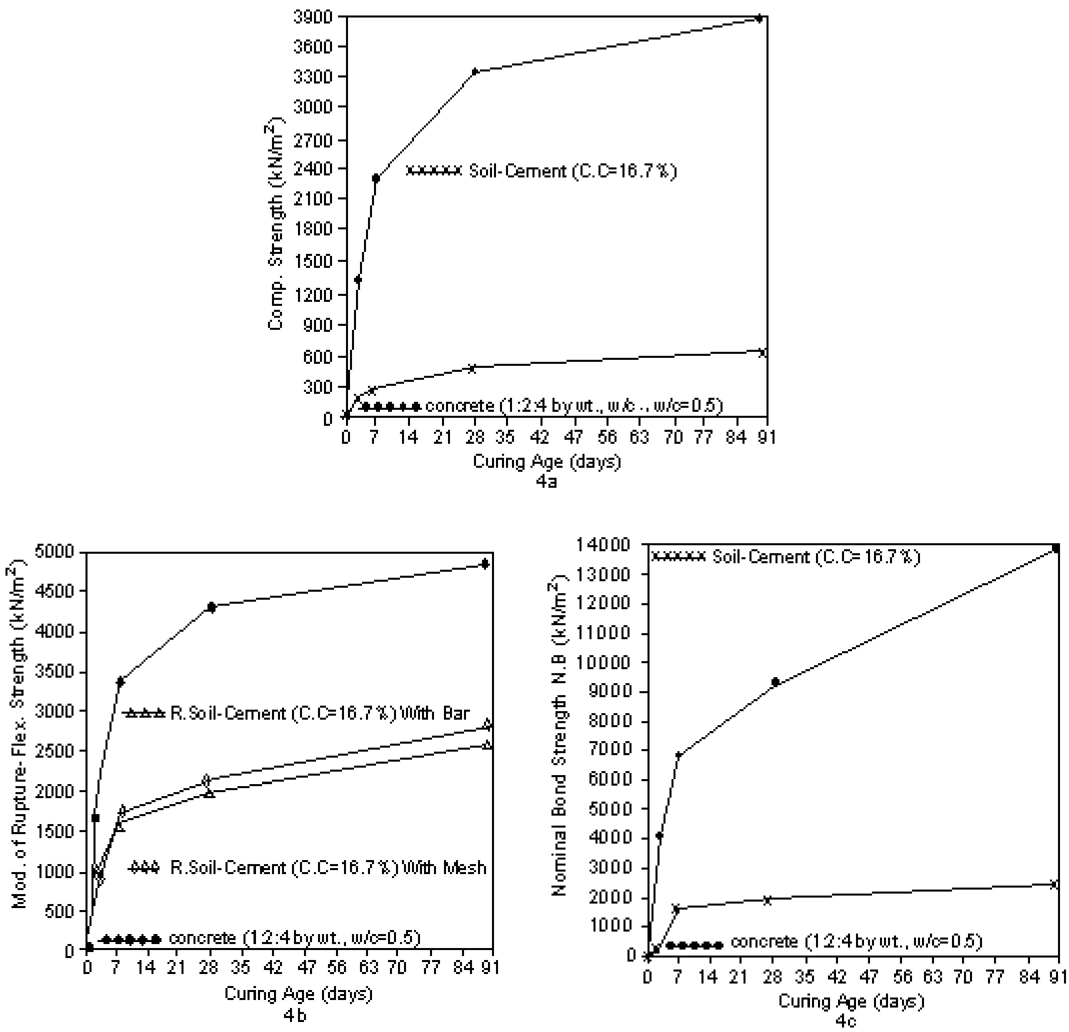


Figure 3: Effect of cement content on the unconfined compressive and flexural strength of soil x-cement specimens cured for 7-days, at temperature of 20°C.

Figure 4: Effect of curing age on the strength properties of plain and reinforced soil-cement specimens, compared to concrete specimens, at temperature of 20°C.



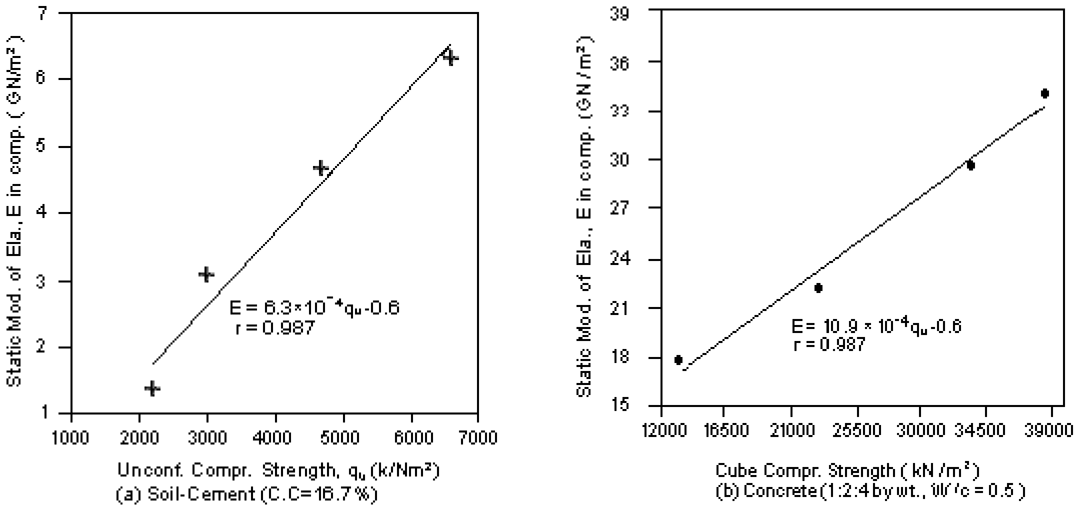
ent curing age at temp. of 20°C as shown in Figure 5.

3. When steel reinforcement is used in soil-cement mixtures, the M.R. increased. The increase is more pronounced at higher cement contents. The relation between the modulus of rupture and cement content was found to be linear for both bar and mesh reinforcement as shown in Figure 6. There is clear difference between slopes of lines due to the role of the reinforcement. Even with steel reinforcement a relatively high cement content (29.35%) will be required at 7 days curing age to reach the same modulus of rupture of concrete.

The effect of curing age on M.R. of reinforced soil-cement and concrete is given in Figure 4b which shows that the M.R of reinforced soil-cement is about half that of concrete. Table 3 illustrates the effect of using combination of 2 bars of a surface area of 188.6 cm^2 instead of 1 bar of a surface approximate cross sectional area of 141.4 cm^2 on flexural strength of soil-cement. The result show slight increase in flexural strength with increasing the surface area of the reinforcement.

4. The effect of the position of the reinforcement on flexural strength of soil-cement was investigated. As

Figure 5: Relationship between static modulus of elasticity and compressive strength of soil-cement concrete, different curing ages, at temperature of 20°C.



shown in Figure 7, the best reinforcement position was when the reinforcements were at 1/3 from the bottom of the specimen regardless of the type of reinforcement used.

5. The results of bond strength between steel reinforcement and soil-cement compared with that of concrete is given in Table 4.

The results indicate that nominal bond strength of reinforced soil-cement increases nearly with increase in cement content. This is mainly due to an increase in cohesion of soil-cement (16). The effect of curing age of soil-cement on the bond strength compared to that of concrete of same cement content is shown in Figure 4c.

6. For the soil-cement, the relationship between the unconfined compressive strength and both bond strength and flexural strength was found to be linear as shown in Figure 8.

7. Replacement of part of the cement content (up to 5%) by lime in soil-cement mixtures resulted in about the same unconfined compressive strength and flexural strength.

However the bond strength obtained was lower than the original soil-cement mixture without lime.

8. Up to 90 days the reinforcement in soil-cement mixture did not exhibit any appreciable amount of corrosion when examined by visual inspection.

Figure 6: Effect of content on the flexural of soil-cement specimens, plain and reinforced with either bar or mesh reinforcement and cured for 7-days, at temperature of 20°C.

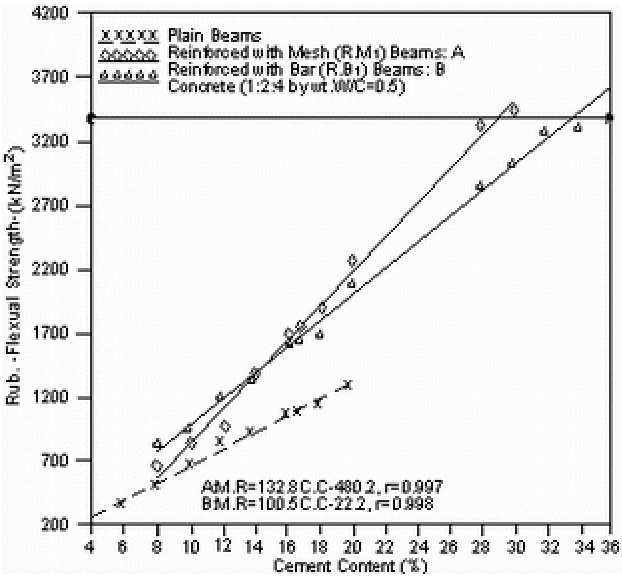


Table 3: Effect of type of reinforcement and cement content on flexural stregth of reinforced soil - cement. a.

Type of Reinforcement	Mix Proportion	7 - days flexural strength "kN/m^2"
(1) bar (R.B_1)	C.C % 8	841
surface area = 141 cm^2	10	959
cross sec. area = 2 %	12	1214
	14	1324
	16	1600
	16.7	1627
	18	1690
	20	2055
	-	-
	-	-
	-	-
	28	2842
	30	3011
	32	3274
	34	3295
Mesh (R.M_1)	C.C % 8	662
surface area = 150.8 cm^2	10	848
cross sec. area = 0.5 %	12	972
	14	1379
	16	1661
	16.7	1740
	18	1883
	20	2250
	-	-
	-	-
	-	-
	28	3324
	30	3420
(2) bars (R.B_2) surface area = 188.6 cm^2 cross sec. area = 1.8 %	14 % C.C	1490
(1) bar (R.B_1) in the bottom + Mesh (R.B_1) in the top	14 % C.C	1448
(2) bars (R.B_2) in the bottom + Mesh (R.M_2) in the top	14 % C.C	1571
(1) bar (R.B_1)	9 % C.C + 5 % L.C	1260

a : bottom cover = 1/3 depth.

Table 4: Effect of mix proportion bond strength between steel reinforcement and soil-cement compared to that of concrete.

Mix Type	Mix proportion	7- days Bond Strength strength "kNm2"
Soil-Cement C.C (16.7 %) reinforced with steel bar (R.B1)	C.C % 8	321
	10	473
	12	746
	14	1075
	16	1548
	16.7	1677
	18	1870
	20	2250
Soil-Cement reinforced with steel mesh (R.M1)	14 % C.C	1375[a]
Soil-Cement with H-lime as replacer with steel bar (R.B1)	9 % C.C + 5 % L.C	697
Concrete with steel bar (R.B1)	1 : 2 : 4 BY wt.	6895

a : At (0.27 mm slip), weld shear failure in steel mesh occurred.

9. At the age of 16 months, the bond strength of reinforced soil-cement which was 2487 kN/m^2 shows little gain in strength compared with 2403 kN/m^2 at 90 days.

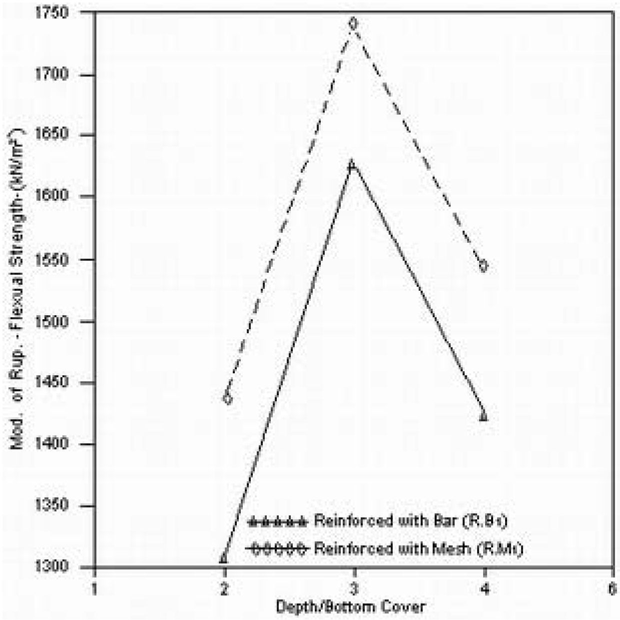
Visual inspection shows very little amount of corrosion on the reinforcement.

Results of Thermal Tests:

1. The linear coefficient of thermal expansion of soil-cement was found to be lower than that of concrete when the same cement content was used. In both cases the coefficient was reduced with curing age in similar manner as shown in Figure 9a.

2. Thermal conductivity of both soil-cement and concrete decrease with curing age. The values obtained for soil-cement were lower than that of concrete as shown in Figure 9b.

Figure 7: Effect of reiforcement position on the flexural strength of reinforced soil-cement specimens (C.C = 16.7%) cured for 7-days, at temperature of 20 °C.



3. The specific heat of soil-cement and concrete was reduced with curing age up to 28 days. Curing age after 28 days did not affect the specific heat. Again the specific heat of concrete was higher than correspon-

Figure 8: Nomograph for nominal bond, flexural strengths and unconfined compressive strength of soil-cement speciment, different cement contents, cured for 7 days.

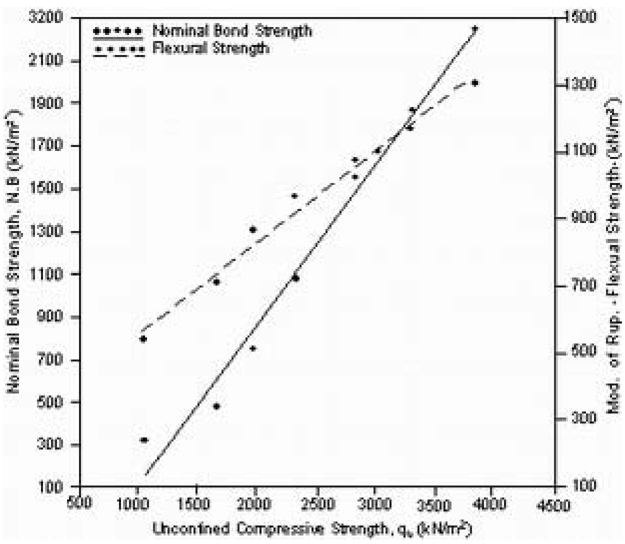
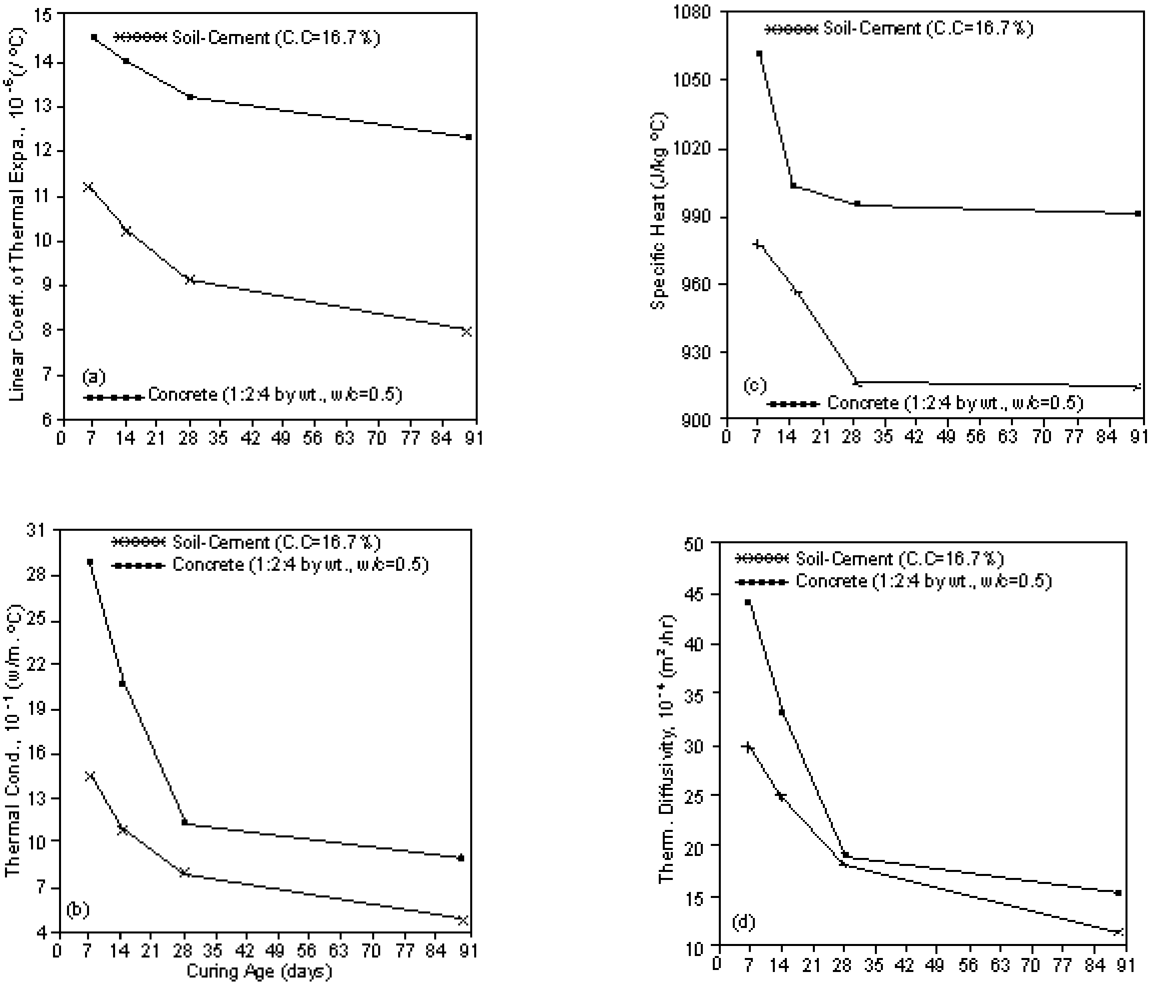


Figure 9: Effect of curing age on the thermal properties of rdied soil-cement specimens, compared to dried concrete specimens with the same cement content.



ding specimen of soil-cement mixture as shown in Figure 9c.

4. Thermal diffusivity (δ) may be regarded as an index that shows how the material undergo temperature changes.

The larger the value of (δ) the faster will heat diffuse through the material.

(δ) was calculated from the formula:

$$\delta = \frac{k}{c\rho} \times 3600$$

where δ = Thermal diffusivity (m^2 / hr)

k = Thermal conductivity (W/m°C)

c = Specific heat (J/Kg.°C)

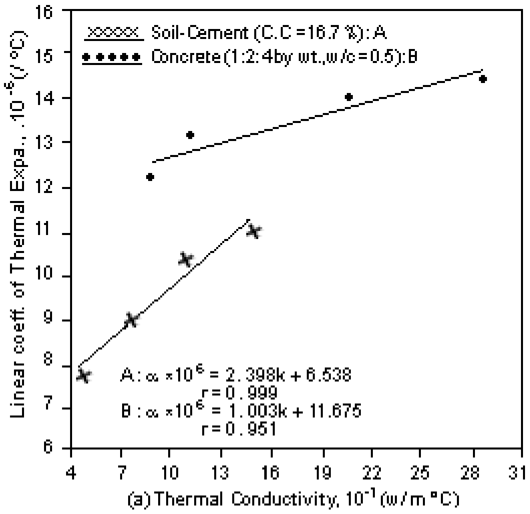
ρ = Density (Kg/m^3).

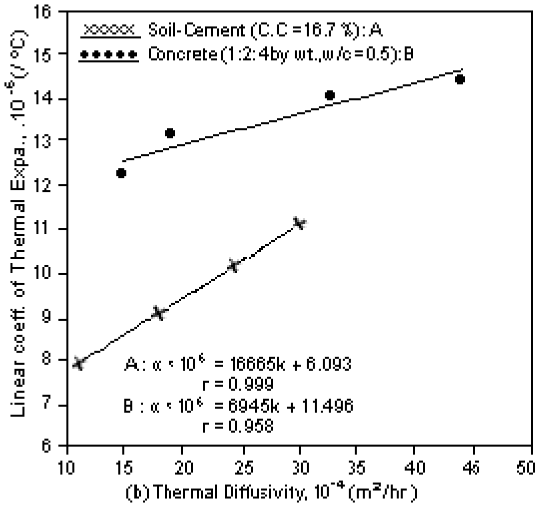
Figure 9d shows the effect of curing age on thermal diffusivity of soil-cement which is lower than that of concrete. (δ) is reduced with curing age.

5. For the soil-cement and concrete tested there was a linear relationship between linear coefficient of thermal expansion and thermal conductivity and thermal diffusivity as shown in Figure 10.

6. Using the above thermal results, Figure 11 can be plotted which relates thermal diffusivity, thermal conductivity and linear coefficient of thermal expansion.

Figure 10: Relationship between the linear coefficient of thermal expansion and the thermal conductivity diffusivity of dry soil-cement, compared to dry concrete with the same cement content, different curing ages.





Prospects of using reinforcement in soil-cement mixture:

1. If the reinforced soil-cement pavement is analyzed as a rigid pavement and the chart presented by Moore and Pasco (17) which has a wide range is used for 18-Kip single axle load for categories 1,2 PCA (for residential and collector streets), Alwash (18) found that 7.5 in. (0.19 m) plain concrete pavement will correspond to 9.5 in. (0.24 m) thickness of soil-cement reinforced with mesh reinforcement.

If bar reinforcement is used in soil-cement then the pavement thickness will be 10.5 in (0.27 m).

For 18-Kip single axle load and for categories 3 and 4 according to PCA manual (arterial streets and express ways) (19) the pavement thickness in case of concrete will be 0.23 m corresponding to 0.28 m and 0.31 m for soil-cement reinforced with steel mesh and bar respectively.

2. The results obtained by Al-Wash (18) shows that there is about 50% decrease in edge, interior warping stresses in case of reinforced soil-cement compared to that of concrete.

3. The use of reinforcement in soil-cement mixtures seems to depend on the economical justification which vary from one country to another.

CONCLUSIONS

Limited to the soil used and test conditions mentioned the following conclusions are drawn:

1. The unconfined compressive strength, the flexural strength and bond strength of reinforced soil-cement increases with curing age and the increase in cement content. For the same cement content the strength of soil-cement is lower than that of concrete.

2. The best position of reinforcement in soil-cement specimens was found when the reinforcement was placed at 1/3 of the depth from the bottom.

3. For the soil-cement, linear relationships were obtained between nominal bond strength and flexural strength with the unconfined compressive strength when cured for the same age.

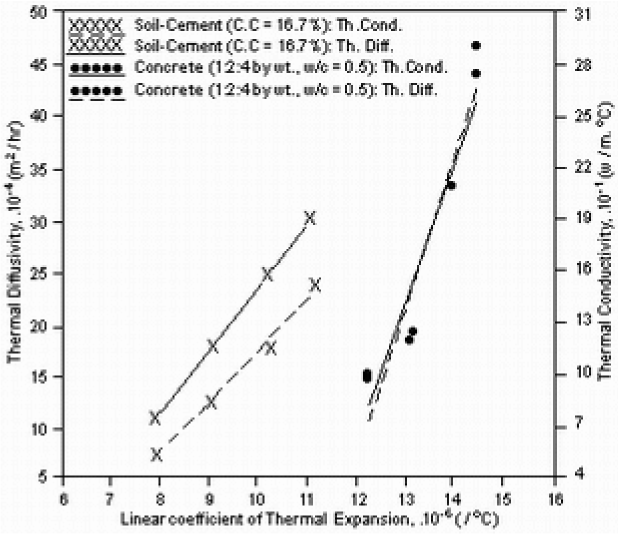
4. Bond strength with reinforcement continue to improve with age. And there is very little amount of corrosion noticed.

5. The linear coefficient of thermal expansion, thermal conductivity, specific heat and thermal diffusivity, of both soil-cement and concrete decease with curing age.

For the same cement content, the values of soil-cement are lower than that of concrete.

6. Linear relationships were obtained between

Figure 11: Nomograph for thermal diffusivity, conductivity and linear coefficient of thermal expansion of dry soil-cement and of dry concrete with the same cement content, different curing ages.



linear coefficient of thermal expansion and both thermal conductivity and thermal diffusivity for soil-cement and for concrete.

7. The edge, interior warping stresses in case of reinforced soil-cement were lower than that of concrete.

8. There seems to be a good prospect for using reinforcement in soil-cement mixtures.APPENDIX - NOTATION:

The following symbols are used in this paper:

AASHTO = American Association of State Highways and Transportation Officials;

ASTM= American Society for Testing and Material;

c = Specific heat;

C.C = Cement content (%) by dry soil weight;

C.B.R. = California Bearing Ratio;

H. lime = Hydrated lime;

hr = hour;

J = Joule;

k = Thermal conductivity;

L.C. = Hydrated lime (%) by dry soil weight;

M.R. = Modulus of rupture;

N.B. = Nomial bond strength;

PCA =Portland cement association;

qu = Unconfined compressive strength;

r = Correlation coefficient;

w = Watt;

W/C = Water to cement ratio;

wt = Weight;

X.R.D. = X-Ray/diffraction;

d = Thermal diffusivity; and

ρ = Density

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