Soil-Cement Interaction

by

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Introduction

WHEN cement is added to soil along with water and the mix is compacted and cured, its strength increases. The degree of strength increase depends upon the type of soil, cement water, method of mixing, compacting and curing etc. This strength development occurs as a result of interaction between soil and cement. Cement hydrates and reacts with soil. The cementitious products so formed, dispose themselves around the soil particles to form a strong mass.

Factors that affect Soil-Cement Reaction

It was observed by Leadabrand, Norling and Hurlen (1956) that the soil series affects the cement requirement for obtaining certain strength. Nature of adsorbed ion and the amount of organic matter associated with the soil was found to affect stabilisation of soil with cement (Catton 1940, Mitchell and Freitag 1959, Sherwood 1962). Degree of compaction and moisture content also affect the strength development in soil-cement (Woods 1960). In 1940, it was postulated by Catton that particles of cement attracted soil grains to form aggregates which increased in size as cement hydrated and crystallised. With an increase in the amount of cement, more aggregate systems were formed to produce a semi-rigid system. In coarse grained soils, cement occupies the points of contact between individual grains (Woods 1960). Thus in the case of densely graded soil, the voids would be lesser and the contact area more numerous, resulting in stronger cementing reaction (Woods 1960).

In 1963, the structure of clay-cement was described by Herzog and Mitchell in terms of a *clay cement skeleton* and a *clay matrix.* Units of the skeleton were said to contain a core of hydrated cementitious gel to which layers of altered clay particles were attached. Alteration of clay particles was attributed to the effect calcium hydroxide. In 1966, the fabric of clay-cement was studied with the electron microscope by Mitchell and Jack. These investigators observed that after one week of curing to bermorite like gels were formed around the edges of the soil particles, producing a compacted structure. Silt particles were chemically attacked in the first week of curing. After 28 days the CSH fibres became more abundant and after 32 weeks both the soil and cement particles were broken down and intimately welded together.

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The nature of products formed during soil-cement reaction has been examined by X-ray diffraction and DTA techniques (Herzog and Mitchell 1963, Benton 1960, Croft 1967, Noble 1967). The results of these investigations indicated that the reaction products of soil-cement depend on the type of soil, amount and type of cement and manner of specimen preparation.

Strength of Soil-Cement

The strength of soil-cement depends on the manner in which the failure plane passes through the various constituents of soil-cement as shown in Figures 1 and 2. If the cementing matrix is continuous and the soil particles act as inert fillers, i.e., no reaction between the matrix and the soil particle takes place, then the strength of soil-cement depends mainly on the cementing matrix. Normally, none of these conditions is satisfied in practice. In such cases the strength of soil-cement depends on :

(a) Area of the failure surface along which shear between hydrated cement and soil takes place and the adhesive bond between soil and cement.
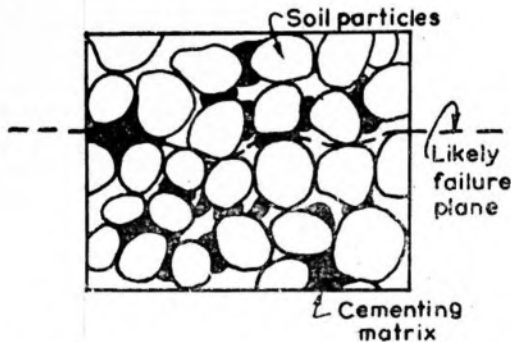

FIGURE 1 : Cementing Matrix—Discontinuous
Failure plane passes through

(a) Area of contact between two soil particles.
(b) Area of contact between cementitious material and soil particles.
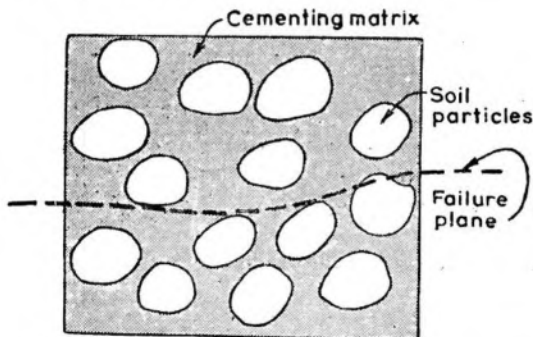(c) Cementitious material.

FIGURE 2 : Cementing Matrix—Continuous.
Failure plane passes mostly through the cementitious material.

(b) Area of the failure surface along which shear between cement and cement takes place, and the strength of the cementing matrix.

(c) Frictional resistance mobilised due to the rolling, sliding and interlocking.

Manner in which the failure surface passes through soil particles, cementitious materials, voids and the soil-cement contact surface; at the strength of the adhesive bonds, strength of cement and the frictional resistance depend on the amount and type of cement, soil and the nature of reaction products formed.

Chemical Interaction

Hydration of cement results in the formation of compounds like hydrated calcium silicates, calcium hydroxide, hydrated calcium aluminates, hydrated calcium ferrites, calcium sulfate hydrate and others. The exact compositions of these compounds depend upon the concentrations of lime in the solution.

Differential Thermal Analysis Results

The DTA curves for clay, cement (cured for 28 days), clay-cement (cured for 7 and 28 days) are shown in Figure 3. The peak temperatures and approximate area of the peaks are given in Table I.

TABLE I

Differential Thermal Analysis Results

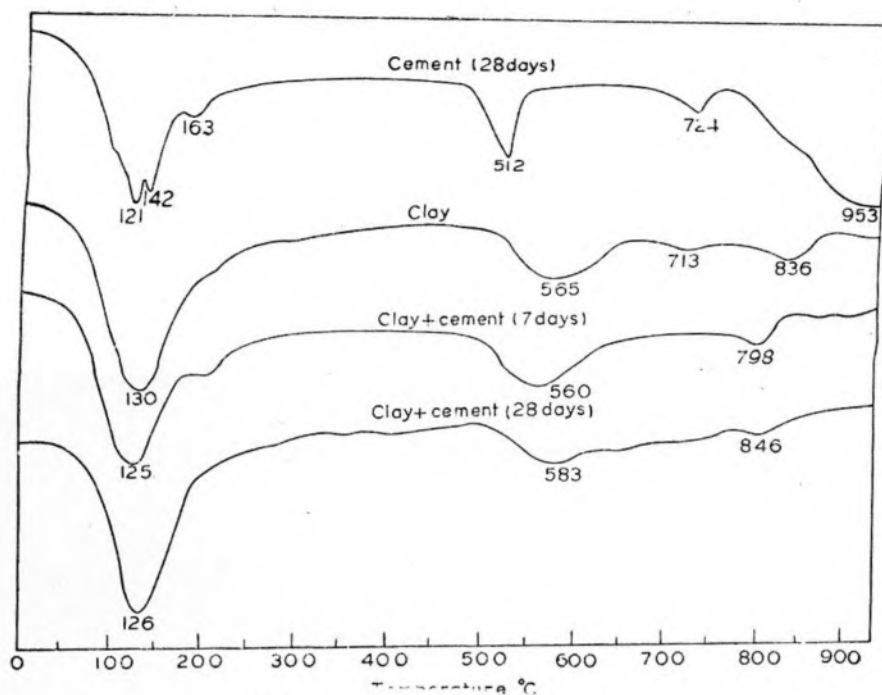| Sl. No.	System	Endothermic reaction		Exothermic reaction	
		Peak temp. in°C	Approximate area in sq cm	Peak temp. in°C	Approximate area in sq cm
1.	Clay	130	12.90	863	0·25
		565	2·93		
		713	0·15		
		836	0·60		
2.	Cement (112 days)	121	6·02		
		142	2·41		
		163	1·38		
		512	1·86		
		724	0·71		
3.	Clay-cement (7 days)	125	16·86	824	0·19
		560	5·18		
		798	0·42		
4.	Clay-cement (28 days)	126	14·07		
		583	1·06		
		846	0·42		

FIGURE 3 : Differential thermal Curves.

On comparing the DTA curve for clay with standard ones, it appears that the clay specimen contains a major amount of beidellite. The base exchange capacity for colloidal clay fraction was 78 milli equivalents per 100 grams of clay. Thus the clay fraction is likely to contain clay mineral of the montmorillonite group.

DTA curve of cement exhibits five distinct endothermic peaks at 121, 141, 163, 512 and 724°C. A considerable shift in the base line is observed after the last peak. The first three peaks may be attributed to the presence of hydrated gels. The peaks at 512°C and 724°C are possibly due to the presence of lime and carbonates respectively.

The effect of cement and also of the curing period is evident in the clay-cement reaction. A comparison of the DTA pattern of clay and clay-cement after 7 days of curing shows an increase in the area of first and second peaks, while the peak at 713°C in the case of clay is absent in the case of clay-cement. The increase in the area of the first peak may be attributed to formation of hydrated gel and the small increase in the area of the second peak appears to be due to precipitation of calcium hydroxide, as a result of hydration of cement. The absence of the peak at 713°C appears to be due to the breakdown of the clay mineral represented by this peak. A comparison of the thermal characteristics after 7 and 28 days of curing indicates a decrease in the areas of the first and second peak and a shift in the third peak from 798°C to 846°C accompanied with a small reduction in area. The decrease in the area of the first peak probably suggests crystallisation of a part of the hydrated gels. A decrease in the area of the second peak may be attributed to the consumption of lime and

also due to partial breakdown of the clay mineral structure. Thus cement reacts with clay in a significant way and the reaction continues up to 28 days.

X-Ray Results

The powder photograph of the clay specimen indicated diffraction lines at 15.5, 10.6, 4.34, 2.49, 1.69, 1.64 1.51, 1.29 and 1.25 A°. These lines suggest presence of clay minerals of nontronite-beidellite type.

For the cement specimen after 112 days of curing, the X-ray film exhibited lines at 14.32, 3.26, 2.97, 2.74, 2.69, 2.62, 2.48, 2.26, 2.16, 2.07, 1.96, 1.90, 1.80, 1.78, 1.69, 1.65, 1.59, and 1.52 A°. On comparison with the standard values, products similar to C_3SH_2, $C_2SH_{0.5}$, CAH_{10}, C_4AF, and calcium hydroxide (C-CaO, A-Al_2O_3, S-SiO_2, H-H_2O) were identified.

The X-ray photograph of clay-cement cured for 112 days exhibits diffraction lines at 12.9, 10.68, 4.34, 3.25, 2.97, 2.55, 2.26, 2.06, 1.90, 1.86, 1.85, 1.65, 1.59, 1.51, 1.43, 1.41, 1.37, 1.30, 1.25 and 1.15 A°. Out of these 8 lines resemble the lines for clay minerals and 13 lines indicate presence of products similar to usual hydration products of cement. The results of X-ray analysis appear to suggest that the products of clay-cement reaction contain clay minerals in the slightly modified form and hydration products of cement. The DTA pattern of clay-cement had indicated that with increase in curing period a part of hydrated gels appeared to crystallise, though the products could not be identified. It is possible to observe from the X-ray results that these crystalline products appear to be similar to the hydration products of cement.

Effectiveness of Cement in Soil-Cement

To study the effectiveness of cement in soil-cement, unconfined compressive strength of specimens of cement, clay-cement and sand-cement were obtained. The results of these studies are presented and discussed below.

Specimens of neat cement paste and clay-cement, 3·8 cm in height and 1·9 cm in diameter were prepared and were subjected to strength tests after 7 days of curing and 24 hours of soaking. The unconfined compressive strength of cement specimen involving 18 gm of dry cement was 153 kg/sq cm. The strength of clay-cement specimen involving 17 gm of clay and 1 gm of cement was 4·86 kg/sq cm.

It is thus observed that in the case of neat cement paste, 18 gm of cement give a strength of 153 kg/sq cm. Therefore the strength contributed by 1 gm of cement in the specimen of neat cement paste would be $\dfrac{153 \times 1}{18}$ ≈ 9 kg/sq cm. Whereas the total strength of 1 gm of cement together with 17 gm of clay in a clay-cement specimen is only 4·86 kg/sq cm. Thus the strength of clay-cement specimen is less than the strength of an equivalent amount of cement, which is 1 gm in this case, when present in a specimen of cement alone. It has been observed as a result of differential thermal analysis and X-ray diffraction results that the type of cementitious products formed in a clay specimen are different than the products formed in a specimen of cement alone. It is now observed from the strength results that the strength of products formed in a clay-cement specimen appears to be considerably less than the strength of products formed in a cement specimen.

In a mixture of sand-cement the strength mainly depends upon the hydrated products of cement and also on the disposition of this hydrated cement around the sand particles. Hydrated cementitious material may be present at points of contact of sand particles; on the surface of sand particles without bonding two or more particles or on the surface of sand particles but bonding two or more sand particles. Cement would contribute more towards the strength of sand-cement if it is present in the first or the third way. The disposition of cement around sand seems to depend on the size, shape and degree of compaction of sand.

A sand specimen with particles ranging from 0·075 mm to 1·632 mm was separated into three fractions; F_1 with size from 0·249 mm to 0·075 mm; F_2 from 0·638 mm to 0·249 mm; and F_3 from 1·632 mm to 0·638 mm. Strength of sand and its different fractions treated with 2 percent, 8 percent, 11 percent and 15 percent of cement were determined after 14 days of curing and 24 hours of soaking using specimens of 7·6 cm height and 3·8 cm diameter. Strength of a specimen made out of cement alone under similar conditions was found to be 183 kg/sq cm. The strength of sand specimens treated with various percentages of cement are given below. C_{eq} represents the strength contributed by an equivalent amount of cement in the specimen made of cement alone.

Percent of cement	Sand	F_1	F_2	F_3	C_{eq}
	14-day unconfined compressive strength in kg/sq cm				
2	3·2	3·4	3·6	3·6	3·66
8	12·6	10·5	11·1	10·4	14·64
11	14·3	13 9	17·36	14·9	20·13
15	19·81	15·4	25·2	17·7	27·45

It is evident from these results that the strength of equivalent amount of cement is more than that of sand or any of its fractions treated with cement. This difference seems to be mainly due to hydration of a part of cement on the surface of sand particles without bonding two or more sand particles as seen in Figure 1. The loss in strength in this manner appears to depend on the amount of cement and also on the size of sand particles.

It is sometimes argued that in soil-cement the volume of cementitious material is more than in the neat cement paste. Such a comparison is however not correct as the type of cementing material is different in both the cases. In reply to a discussion by the present author, Kapur (1972) concluded, without citing any evidence or giving any reasons, that the strength increase due to the addition of a small quantity of cement to a soil will be more than the strength of the same quantity of cement. In the light of results presented for clay-cement and sand-cement, in this paper it is clear that the strength of soil-cement is less than the strength contributed by the same amount of cement in a specimen of cement alone.

Summary and Conclusions

The strength of soil-cement depends not only on the strength of products formed as a result of soil-cement interaction, but also on the disposition of this cementitious material in relation with soil particles and its bonding characteristics with soil. In the case of clayey soils, the hydration products of cement are different than those obtained in soil-cement mixture. The products identified in hydrated cement are C_3SH_2, $C_2SH_{0.5}$, CAH_{10}, hydrated CAF and hydrated calcium hydroxide. Differential thermal analysis results of clay-cement indicate formation of calcium hydroxide and its reactions with clay minerals with the passage of time. The strength results indicate that both in the case of clay-cement and sand-cement the strength is less than the strength of the same amount of cement when present in a specimen of cement alone. The effectiveness of cement in sand-cement depends on the amount of cement and the size of sand particles.

APPENDIX

Properties of Clay

The clay used in this investigation was a 1 micron fraction separated from a black cotton soil without using any dispersing agent. The clay minerals present are of the nontronite-beidellite type, as identified by the differential thermal analysis and X-ray analysis results. The chemical analysis of clay shows; silica$=51.48$, ferric oxide$=5.79$ percent, alumina$=23.41$ percent, calcium oxide$=5.95$ percent, magnesium oxide$=2.93$ percent, B.E.C.$=78$ m.eq./100 gm.

Method of DTA and X-Ray Analysis

The specimens were cured, soaked in water, dried at $60°$ C for 15 minutes and were then powdered in the agate. Differential thermal analysis was carried out by using a chrome-nickel thermocouple. Alumina was used as a standard for comparison. Temperature was increased at the rate of $10°$ C/minute. Analysis was continued up to $940°$ C. X-ray analysis was obtained by using Fe-radiation for three hours at 35 kV and 11 amps current in a 57 cm diameter camera.

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