Strength-Maturity Relations of Soil-Cement Mixtures

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Soil-cement was observed to increase in compressive strength with time of curing with a better than random correlation in both a semi-logarithmic and logarithmic manner. Statistical analysis of 417 sets of data representing ages up to 5 years indicates that for granular soil-cement (A-1, A-2, and A-3 soils) the best relationship is semi-logarithmic. This is similar to the relationship observed in concrete, whose constituents are similar to granular soil-cement. Silty or clayey soil-cement (A-4, A-5, A-6, and A-7 soils), on the other hand, exhibits the closest relationship logarithmically. However, high correlations were observed in both a logarithmic and a semi-logarithmic manner in all soils. These correlations were found to exist, independently of changes in cement content, time of curing, temperature of curing, and immersion of test specimen before testing.

These relationships can be used to predict the compressive strength of soil-cement at a future time of curing. The accurate prediction of future compressive strengths can be useful in decreasing the cement content of certain soil-cements, and as a basis for periodically increasing maximum soil-cement road or airfield load capacities. The strength-age relationship of a soil-cement can be determined from data obtained from standard laboratory tests. Statistical analysis of 120 sets of data indicates that a semi-logarithmic plot tends, on the whole, to predict future compressive strengths best for all soil types. Compressive strength can be evaluated both graphically and by equation.

The slope of this strength-age relationship was found to be affected by the physical and chemical properties of the soil, the cement content, and certain chemical additives. Thus, it is evident that the slope of this strength-age relationship is an excellent indicator of the quality of a particular soil-cement mixture. The effect of additives can also be better evaluated by using this relationship. An additive which raises the slope of this strength-age relationship will, in the long run, produce much higher compressive strengths than an additive that merely raises the relationship in a parallel manner.

It is believed that further investigation would indicate a correlation between the slope of the strength-age relationship and the durability of soil-cement mixtures.

•THE ADDITION of portland cement to soil changes the properties and structure of the soil. Probably all soils can be adequately stabilized with cement; however, such stabilization is not always feasible. The compressive strength of soil-cement mixtures will increase with time of curing as does that of concrete. Soils with similar physical properties but different chemical properties may vary widely in compressive strength when stabilized with equal amounts of cement. Thus the interaction of cement with the chemical constituents of the soil can have a major affect on the compressive strength of soil-cement mixtures.

There is no simple way to determine the amount of this interaction or the resulting compressive strength without laboratory tests. Compressive strength and durability tests are used to determine the quality of a soil-cement mixture for a particular construction project. A more complete knowledge of the interaction of soil and cement would help to understand the mechanism of strength development in soil-cement mixtures better.

Although soil-cement is designed on the basis of durability or strength after 7 days of curing, it is recognized that the strength increases with age, probably providing a safety factor in the design. Some soil-cement mixtures, however, develop a strength of over three times the original 7-day strength after an additional interval of curing. If this additional strength could be predicted accurately, more economic mix designs would be forthcoming. Besides benefiting economy, a lower cement content may decrease shrinkage and the resulting cracking of soil-cement pavements. A knowledge of the rate of increase in strength of soil-cement in a road or airfield pavement also might serve as the basis for periodically increasing the maximum load on the pavement.

The objectives of this investigation were threefold: (a) to observe any correlation between the compressive strength of soil-cement mixtures and the time of curing; (b) to determine whether soil-cement mixtures gain strength predictably with time of curing; and (c) to gain an insight into the factors that influence the gain in strength with time of curing of soil-cement mixtures.

Because soil-cement and concrete are basically similar in nature and composition, a review of the strength-maturity relationships found for concrete was made. One extensive investigation indicates that there is a semi-logarithmic relationship between the compressive strength and the maturity of the concrete (9). The maturity is a function of the age and the curing temperature of the concrete.

The strength-maturity relationships of soil-cement were investigated for a curing period up to twelve weeks, using mixtures prepared with five soils (8). These soils ranged from sandy gravel to silty clay and were stabilized with various amounts of portland cement. It was found that the unconfined compressive strengths of the stabilized soils are linear with respect to the logarithm of the curing time. This relationship for soil-cement is similar to that obtained for concrete.

STRENGTH-AGE RELATIONSHIP

To investigate soil-cement for long-term strength prediction, it is first necessary to show that the compressive strength can be related to the curing period in a linear manner. More specifically, by knowing the initial characteristics of the strength-age relationship of the soil-cement, one may be able to determine what the future relationship will be.

The method of plotting strength against the logarithm of time was first investigated with long-term strengths. Soil-cement samples cured for a period of 5 years by the Portland Cement Association (11) were used (Fig. 1). The curves represent various soil types treated with portland cement. It is seen that the A-1, A-2, and A-4 soil-cements produce an excellent linear relationship for the period of curing. The relationships for the A-6 and A-7 soil cements, however, show a marked divergence from a straight line at long curing intervals.

Further investigation to seek a linear relationship for the A-6 and A-7 soil-cements resulted in a plot of the logarithm of strength against the logarithm of time (Fig. 2). The A-4, A-6, and A-7 soil-cements produced a good linear relationship, whereas the A-1 and A-2 soil-cements showed a poor relationship.

It appears from this preliminary investigation that A-1 and A-2 (granular) soil-cement will produce a linear relationship on a semi-logarithmic scale. A-6 and A-7 (silty and clayey) soil-cement will produce a linear relationship on a logarithmic scale. A-4 soil-

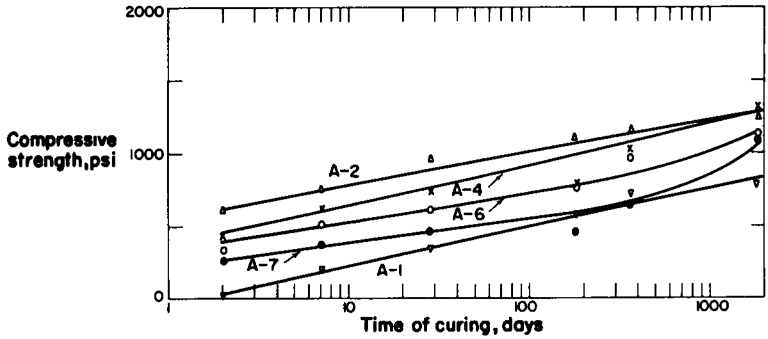

Figure 1. Effect of curing time on unconfined compressive strength of soil-cement mixtures.

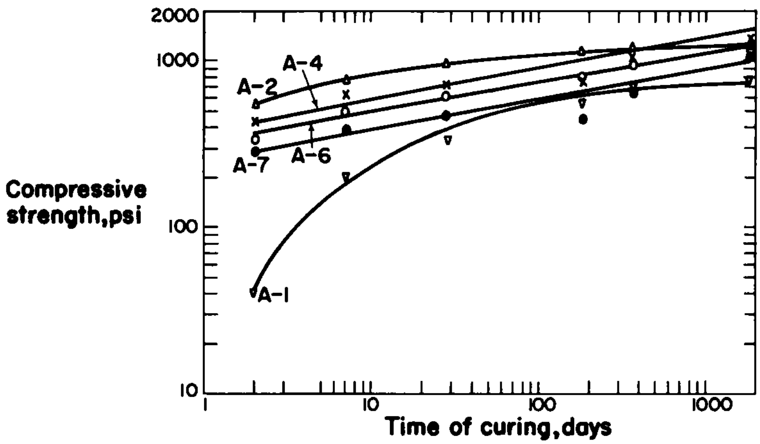

Figure 2. Effect of curing time on unconfined compressive strength of soil-cement mixtures.

cement, however, appears to behave in a transitional manner between granular soil-cement and fine-grained soil-cement.

The form for the linear relationship on the semi-logarithmic plot is

$$S = A + B \log T \tag{1}$$

in which

S = strength;
T = time of curing; and
A, B = constants.

The form for the logarithmic plot is:

$$\log S = \log A + B \log T \tag{2}$$

With a working hypothesis from this preliminary investigation, it seemed logical to continue by seeing if this hypothesis could be considered equally applicable to all soils. The best way to do this would be by a methodical statistical analysis with various amounts of cement tested at various curing intervals.

An equation incorporating both plots was applied, to find out whether the semi-logarithmic, the logarithmic, or a combination of the two plots would be best for a set of data:

$$\log T = A_1 + B_1 [pS + (1-p) \log S] \tag{3}$$

in which p is a parameter that can take on any value between 0 and 1. It is evident that when $p = 0$, the equation is of the logarithmic form; when $p = 1$, the equation is semi-logarithmic. Intermediate values of p would indicate a specific combination of the two equations. It was found that either logarithmic, semi-logarithmic or a combination of the two will produce a good linear relationship. However, the best relationship occurs either at $p = 0$ (logarithmic) or $p = 1$ (semi-logarithmic) (1).

The next set of computations was used to determine whether the logarithmic or semi-logarithmic equation would produce the best correlation for a particular soil type. The results agreed with the initial graphical conclusions. A relative comparison of the average correlation values offered further evidence for the validity of the graphical conclusions (1).

From the foregoing graphical and statistical investigation it appears that the strength of granular soil-cement correlates best with time of curing in a semi-logarithmic manner, but the strength of silty or clayey soil-cement correlates best with time of curing in a logarithmic manner. Although data for A-5 soil-cements were not available, it seems logical to assume that the increase in strength with time of curing would also be logarithmic.

An over-all evaluation of the degree of correlation observed for semi-logarithmic and logarithmic relationships for 417 sets of data indicates that high correlations exist in both a semi-logarithmic and logarithmic manner for all soil-cements (1).

PREDICTION OF UNCONFINED COMPRESSIVE STRENGTH

Because a definite correlation for the increase in strength with time of curing for soil-cement has been established, a method of prediction should be easily adaptable. Logically, the type of prediction equations should follow the previous conclusions; namely, that granular soil-cement would be semi-logarithmic, and fine-grained soil-cement would be logarithmic. However, due to the high correlations found both logarithmically and semi-logarithmically for all soil types, this should be further investigated.

A reasonable test for predictability which is in keeping with the manner in which prediction would be carried out in practice is as follows:

1. The equation for strength is determined by using the first few points (strength values for brief curing intervals) of a set of data.
2. The strength at a future time of curing is predicted with the use of this equation.
3. The predicted strength is compared with the actual strength at that given time.

The points used to determine the equation of each set of data were the strength values at the three curing times corresponding most closely to 2, 7, and 28 days. These are the curing times used by the Portland Cement Association (10) in standard tests on soil-cement mixtures. By the use of these equations, the last two points (strength values for long curing intervals) in each set of data were computed and compared with the actual strengths at this time of curing. The equation, whether semi-logarithmic or logarithmic, that gave the closest prediction was considered best for that particular soil.

The results of this investigation indicated that most predicted strengths are close to the actual strengths, even up to prediction periods of 5 years (Table 1). This was accomplished from equations derived, for the most part, from the 2-, 7-, and 28-day strengths of each set of data. Inasmuch as both logarithmic and semi-logarithmic equations seem to give similar results, a detailed analysis of this was considered to determine which type of equation would best predict future compressive strengths.

TABLE 1

COMPARISON OF ACTUAL AND PREDICTED COMPRESSIVE STRENGTHS OF SOIL-CEMENT BY LOGARITHMIC AND SEMI-LOGARITHMIC EQUATIONS

Soil Type	Time of Curing (days)	Actual Strength (psi)	Predicted Strength (psi)	
			Log	Semi-Log
A-1	365	1,160	1,802	1,375
	1,825	1,380	2,657	1,643
	365	2,525	3,609	2,615
	1,825	2,950	5,501	3,135
	365	150	125	89
	1,825	170	215	111
	365	380	7,030	919
	1,825	520	45,234	1,219
	365	710	5,767	672
	1,825	770	28,349	870
A-2	28	300	319	217
	56	350	544	259
	28	450	510	411
	56	500	713	475
	28	475	477	419
	56	625	603	475
	28	615	687	614
	56	800	867	696
	120	560	792	525
	365	620	1,323	637
	120	1,775	3,329	2,014
	365	1,920	5,964	2,460
	120	2,650	5,410	3,501
	365	3,550	9,176	4,247
	120	3,400	6,034	4,045
	365	3,750	9,922	4,884
	120	4,000	660	4,734
	365	4,150	1,019	5,655
	120	4,050	7,647	5,263
	365	4,650	12,352	6,345
	365	1,540	1,933	1,453
	1,825	1,650	2,908	1,746
	365	1,140	1,452	1,272
	1,825	1,230	1,893	1,477
	365	1,840	2,303	1,991
	1,825	2,470	3,044	2,320
A-3	60	483	944	662
	90	507	1,344	761
	60	774	1,286	889
	90	965	1,816	1,021
	60	881	1,087	996
	90	1,066	1,256	1,089
A-4	365	490	479	432
	1,825	630	589	488
	365	1,020	1,292	1,049
	1,825	1,300	1,800	1,237
	120	430	515	476
	120	725	906	723
	365	960	1,307	858
	120	1,100	885	853

TABLE 1 (continued)

Soil Type	Time of Curing (days)	Actual Strength (psi)	Predicted Strength (psi)	
			Log	Semi-Log
A-4 (continued)	365	1,600	1,030	949
	120	1,400	1,212	1,067
	365	2,000	1,569	1,231
	120	1,960	1,918	1,612
	365	2,850	2,611	1,886
	120	1,920	1,498	1,351
	365	2,100	1,895	1,549
	120	2,525	2,198	1,929
	365	3,100	2,907	2,247
	60	635	957	699
	300	1,049	2,119	962
	200	1,460	1,481	1,242
	600	1,910	2,323	1,556
	365	2,220	2,381	1,354
	600	2,540	5,315	1,774
	365	180	204	204
	1,825	425	211	209
	365	760	379	371
	1,825	1,060	414	400
A-6	365	450	568	503
	1,825	460	734	582
	365	960	1,114	875
	1,825	1,090	1,600	1,038
	365	1,215	1,804	1,353
	1,825	1,800	2,742	1,631
	28	425	573	528
A-6	56	500	692	591
	28	560	581	554
	56	625	666	607
	28	625	687	649
	56	750	803	717
	28	900	883	844
	56	1,050	1,017	927
	60	461	479	439
	90	486	530	467
	60	573	610	590
	90	694	652	619
	60	861	732	724
	90	905	771	752
	8	875	966	960
	14	900	1,091	1,056
A-7	28	285	282	274
	56	300	318	298
	28	340	346	328
	56	380	400	360
	28	525	499	471
	56	550	580	519
	120	330	345	312
	120	730	1,046	793
	365	925	1,630	958
	120	1,200	1,309	1,080

TABLE 1 (continued)

Soil Type	Time of Curing (days)	Actual Strength (psi)	Predicted Strength (psi)	
			Log	Semi-Log
A-7 (continued)	365	1,525	1,850	1,279
	120	1,375	1,696	1,355
	365	2,000	2,554	1,632
	120	1,475	1,820	1,434
	365	2,100	2,706	1,721
	120	1,725	2,110	1,676
	365	2,300	3,065	1,993
	120	1,825	2,346	1,713
	365	2,050	3,726	2,073
	365	640	772	654
	1,825	1,080	1,043	767
	60	254	326	293
	90	293	380	319
	60	422	404	394
A-7	90	434	433	415
	60	657	631	609
	90	699	686	647
	21	610	673	650
	28	700	728	688

A comparison of the actual and predicted soil-cement strengths for each of the 120 sets of data used indicated a definite preference for a semi-logarithmic plot for all soil types except A-4. The percent of error in strength prediction was lowest for the semi-logarithmic plot for all soil types. Also, the semi-logarithmic plot tended to predict strength on the safe side of (below) the actual strength, but the logarithmic plot predicted strengths on the unsafe side of (above) the actual strength (1).

Further evidence for favoring semi-logarithmic plotting was adduced as follows. A statistical test (7) of the hypothesis that the linear relationship for brief curing intervals if valid also for the longest available curing interval was performed. This test, conducted both for the semi-logarithmic and logarithmic relationships, showed the previous hypothesis to be more tenable in the semi-logarithmic case (1).

Thus, from the foregoing investigations, it is apparent that the best equation to use for predictability would be one of the semi-logarithmic type. Although there is some doubt about A-4 and A-5 soil-cements, because the soil types on both sides (granular and clayey) exhibit a definite preference for a semi-logarithmic equation, it should be safe to assume that they could also be predicted best semi-logarithmically.

Before practical use can be made of this method of prediction, a margin of error should be determined to predict safely compressive strengths. The use of a percent error was found not to be subject to any simple pattern. However, because the statistical test shows the plausibility of a single linear relation valid over all curing intervals, it is reasonable to explore the possibility that, for a given soil type, prediction error is proportional to the difference between the logarithm of the median of the curing times on the basis of which the prediction equation is computed (Fig. 3). This proportionality was found to apply. In addition, the proportionality factors for various soil types proved to be similar enough to suggest the use of the average proportionality factor, of approximately 80 psi for all soil types (1). An approximate expression for expected discrepancy is therefore given by

$$S_1 - S_2 = 80 \log \left(\frac{T}{\bar{T}}\right) \qquad (4)$$

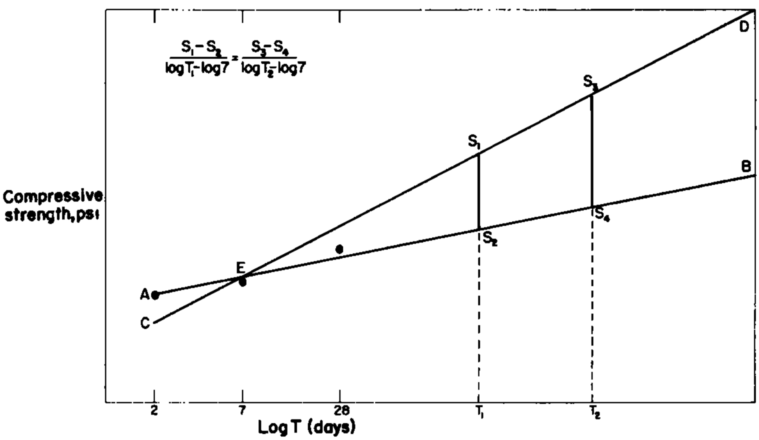

Figure 3. Determination of experimental error expected from use of semi-logarithmic prediction equation.

in which

$S_1 - S_2$ = difference between actual and predicted strength (psi); and
T = time of curing at which strength is to be predicted (days).

SUGGESTED PREDICTION PROCEDURE

The following procedure would be used to predict what the future strength of soil cement would be. The strength is plotted against the logarithm of the time of curing. At least two points must be plotted, although the more points plotted the more accurate will be the predicted strengths. The best straight line is drawn through these points and projected into the future time and strength of the graph. This line would be the strength-age line, from which strengths corresponding with future curing times can be evaluated.

This line can be expressed by

$$S = A + B \log (T/7) \tag{5}$$

The constant A is evaluated as the strength at which the line begins, in this case taken as the 7-day strength. The constant B is the slope of the line. The time of curing, T, is the time at which the strength is to be predicted.

The expected discrepancy may be incorporated into the equation to determine the range wherein the actual strength would be expected to lie. Thus, the prediction equation would be

$$S = A + (B \pm 80) \log (T/7) \tag{6}$$

If the strength of a soil-cement mixture at 7 days is 250 psi and the slope from the graph is determined to be 400: $S = 250 + (400 \pm 80) \log (T/7)$. If the strength at 1 year (365 days) is to be evaluated, the solution would be $S = 250 + (400 \pm 80) \log (365/7)$; $S = 938 \pm 138$ psi. Therefore, the actual strength would probably lie somewhere between 800 and 1,076 psi. The data for this investigation were taken from the reports on several researches (2, 3, 4, 5, 11).

The relationships observed, in view of various experimental conditions inherent in the sources, should be generally applicable to all soil-cement mixtures. The various methods of testing indicate that the relationships are linear, independently of changes in (a) time of curing up to 5 years, (b) curing temperature, (c) cement content, (d) size of test specimen, (e) type of soil, or (f) immersion of test specimen before testing. Provided the curing conditions are kept constant, the unconfined compressive strength of a soil-cement mixture can be predicted for periods up to 5 years with reasonable and estimable precision.

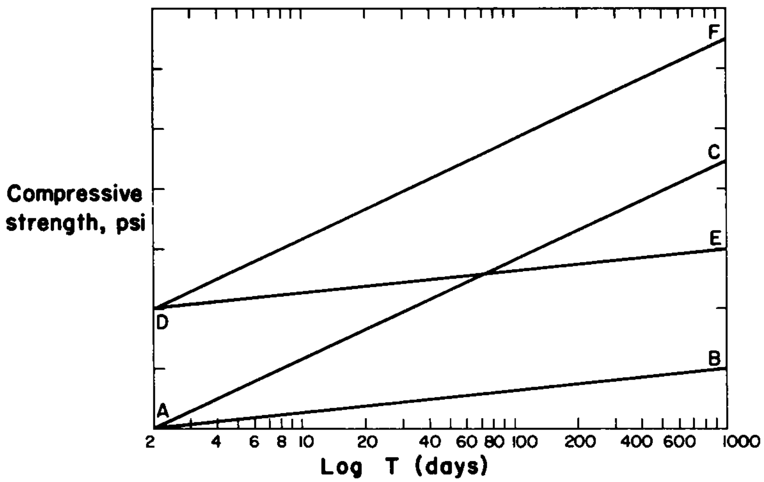

Figure 4. Effect of an additive on strength-age relationship of a soil-cement mixture.

FACTORS INFLUENCING SLOPE OF STRENGTH-AGE RELATIONSHIP

An experimental investigation of the observed strength-age relationships would be of value. If these relationships could be altered physically or chemically and if the causes of the relationships could be understood, possibly better soil-cement might be obtained at a significantly lower cost.

The most important single feature of the strength-age relationship is the slope of the line, which represents the rate of increase in the compressive strength of the soil-cement mixture with time of curing. An unstabilized soil would have a horizontal slope of zero, and the ultimate in a stabilized soil, academically speaking, would be a vertical slope of infinity.

Between these two extremes is a wide range of values which the slope of a soil-cement relationship can assume. The higher the rate of increase in strength of a soil-cement mixture, the higher the unconfined compressive strength will be. Thus, the slope would affect the 7-day compressive strength of a soil cement mixture, often used as a criterion of quality.

A physical treatment or chemical additive to soil-cement may alter the strength-age relationship in one of three ways (Fig. 4). AB represents the strength-age relationship of a normal soil-cement. The first change that could take place is represented by AC: the slope of the strength-age relationship could be increased, producing much higher compressive strengths than those of the normal soil-cement mixture as the curing interval is increased.

Second, as shown by the DE, the relationship may merely be raised parallel to that of the normal soil-cement mixture. This would be less desirable than the first change, because the compressive strength would be raised by the same constant amount throughout the curing interval. Third, a combination of the first two alterations might result, as shown by the DF. This would be the best achievement, resulting in extremely improved soil-cement mixtures.

Previous empirical testing of the effect of additives on soil-cement by the relative comparison of compressive strengths do not bring out the effect of the strength-age relationship in soil-cement. Indeed, erroneous conclusions may be reached by the comparison of compressive strengths. For example, an additive that produces the relationship of the second case (DE) might be considered much better than an additive that results in the first case (AC) on the basis of early compressive strengths. However, after a longer curing interval the latter soil-cement mixture may attain the highest compressive strengths.

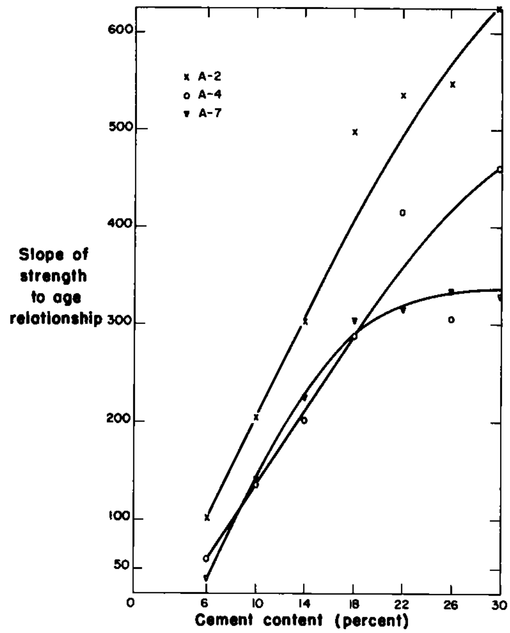

Figure 5. Effect of cement content on slope of strength-age relationship of soil-cement mixtures.

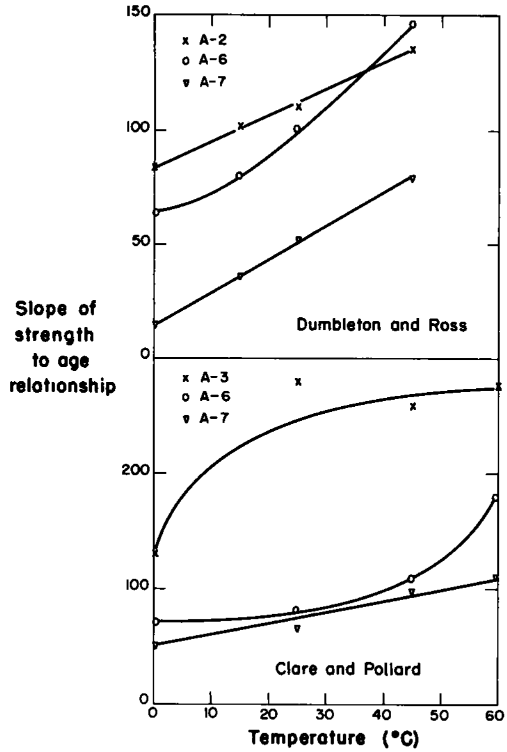

Figure 6. Effect of curing temperature on slope of strength-age relationship of soil-cement mixtures.

Thus it appears that the slope of the strength-age relationship is an excellent indicator of the quality of a soil-cement mixture, and of the beneficial effect of additives. Normally, the compressive strength of a soil-cement mixture can be increased if the cement content is increased. However, if it were possible to increase the slope of the strength-age relationship by the use of an additive or an alteration of the properties of a mixture, an equally high compressive strength might be realized with a lower cement content.

Physical or chemical properties of the soil-cement mixture that influence the slope of the strength-age relationship could be regulated during construction to produce maximum beneficial effects. This might be useful in obtaining a better quality of soil-cement. The following sections will be concerned with the factors that could influence the rate of increase in strength of soil-cement mixtures. The data of Winterkorn, Gibbs, and Fehrman (12), and Lambe and Moh (6) were used in this investigation along with the data from the sources mentioned previously.

Cement Content

Cement, considered the important constituent of soil-cement, is considered first. Plots of the slope of the strength-age relationship for various cement contents of each soil are shown in Figure 5. The slope is low at low cement contents and increases as the cement content is increased. In the range of cement contents feasible for soil-cement is a linear relationship between the amount of cement and the slope of the strength-age relationship. Therefore, as the cement content of a soil-cement mixture is increased, there is a corresponding increase in the rate of increase in strength.

Temperature of Curing

An increase in curing temperature will produce an increase in the compressive

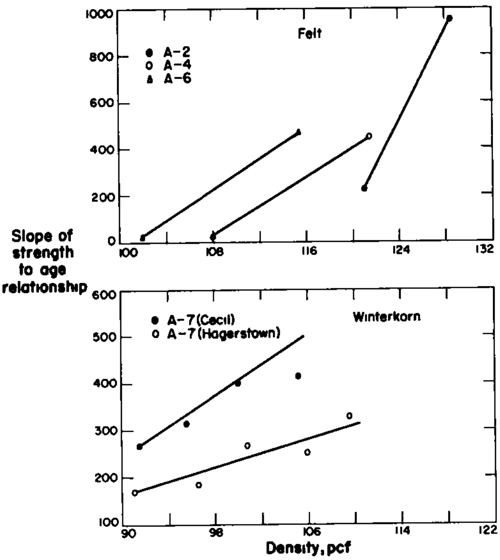

Figure 7. Effect of density on slope of strength-age relationship of soil-cement mixtures.

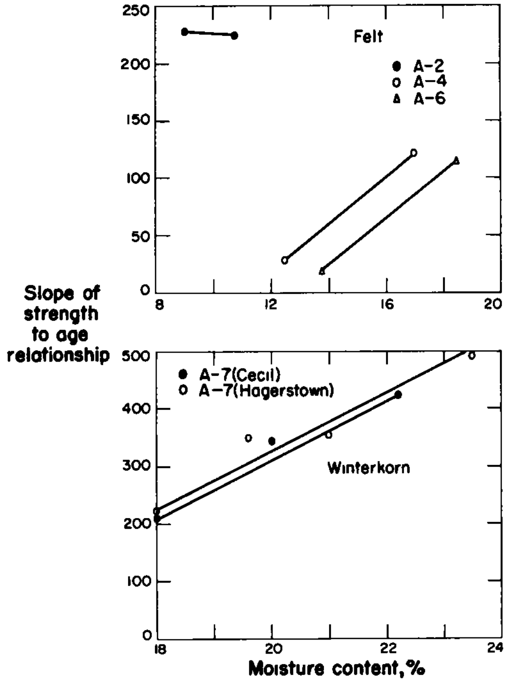

Figure 8. Effect of moisture content on slope of strength-age relationship of soil-cement mixtures.

strength of a soil-cement mixture. Figure 6 shows the effect of curing temperatures on the slope of the strength-age relationships. It can be observed that all data indicate a general increase in the slope of the relationship as the temperature of curing is increased, supporting the tentative conclusion that an increase in the curing temperature causes an increase in the slope of the strength-age relationship.

Density

The density of a compacted soil-cement mixture has an important effect on the compressive strength and durability of the cured soil-cement. The test specimens used in Felt's study were molded at AASHO-modified optimum moisture content to both standard Proctor and modified AASHO maximum density. The data of Winterkorn represents clay soil specimens molded at or near standard optimum moisture content to various densities. Standard Proctor densities were 95.5 pfc for the Cecil clay and 96.5 pcf for the Hagerstown clay.

Figure 7 shows the effect of density on the slope of the strength-age relationship. It can be seen that an increase in the density of a soil-cement mixture will produce an increase in the slope of the strength-age relationship. This is in accordance with the accepted fact that an increase in the density of a soil-cement mixture will generally increase the compressive strength of the mixture.

Moisture Content

The moisture content of a soil-cement mixture is important in obtaining the desired compacted density. Figure 8 shows the effect of moisture content during standard Proctor compaction on the slope of the strength-age relationship. It is apparent from the graph that an increase in the moisture content has a definite effect on the rate of strength increase in the case of the fine grained soils studied. The right points in the plots of Felt's data indicate the optimum moisture content. The standard Proctor optimum moisture contents were 20.5 percent for the Cecil clay and 19.6 percent for the Hagerstown clay. A small increase in the moisture content above optimum might increase the slope of the strength-age relationship for fine-grained soils, thereby increasing the resulting compressive strength of the soil-cement mixture.

Adsorbed Cations

Certain adsorbed cations on clay surfaces are known to benefit the compressive strength of a soil-cement mixture (12). Adsorbed cations may affect the slope of the strength-age relationship in various ways (Table 2). The slope for the Cecil clay increases or decreases depending on the cation. With the Hagerstown clay the slope decreases in all cases. These different effects could be due to the different chemical properties of the two natural soils.

From the foregoing it is evident that cations associated with the soil clay (either natural or artificially introduced) have a definite effect on the slope of the soil-cement strength-age relationship. Further investigation may indicate cations that can be added to certain soils to produce steeper slopes and correspondingly higher compressive strengths.

TABLE 2

EFFECT OF CATIONS ADSORBED BY SOIL CLAY ON THE RATE OF INCREASE IN COMPRESSIVE STRENGTH OF SOIL-CEMENT MIXTURES[a]

Cation	Slope of Strength-Age Relationship	
	Cecil Clay	Hagerstown Clay
Natural	208	349
H	200	100
Na	250	215
K	166	250
Mg	208	166
Ca	316	333
Al	200	133
Fe	316	100

[a]After Winterkorn et al. (12).

Chemical Additives

The effect of chemical additives on the slope of the strength-age relationship may indicate which additives best improve the quality of soil-cement mixtures. Knowing these effects may indicate why some natural soils do not respond well to chemical stabilization. Optimum amounts of chemical additives should be easier to evaluate using the slope of the strength-age relationship rather than making a relative comparison of the compressive strength data.

Table 3 shows the effect of chemical additives on the slope of the strength-age relationship. It can be observed that certain additives, such as Quadrafos, seem to greatly improve the slope of the strength-age relationship. Others, such as $Ca(OH)_2$, give no significant improvement. Thus, after equal curing intervals, Quadrafos additive would be expected to produce much higher compressive strengths than a $Ca(OH)_2$ additive.

TABLE 3

EFFECT OF CHEMICAL ADDITIVES ON RATE OF INCREASE IN COMPRESSIVE STRENGTH OF SOIL-CEMENT MIXTURES, NEW HAMPSHIRE SILT, 5 PERCENT CEMENT[a]

Additive		Slope of Strength-Age Relationship
Type	%	
None		50
$Ca(OH)_2$	0.5	66
	1.0	66
$CaCl_2$	0.5	83
	1.0	83
NaOH	0 5	100
	1.0	166
KCl	0.5	17
	1.0	233
Quadrafos	0.5	150
	1.0	224

[a]After Lambe and Moh (6).

Summary

This investigation was not conducted to produce any definite conclusions concerning the effect of any physical or chemical property on the slope of the strength-age relationship of a soil-cement mixture. Rather it was aimed at showing that the slope of the strength-age relationship is, indeed, influenced by the physical and chemical properties of soil-cement mixtures. Future research in the field of soil-cement stabilization may utilize this fact to good advantage. A more complete understanding of the effect of additives in soil-cement might be realized. Individual natural soils might be evaluated as to their value for soil-cement. Various physical and chemical properties of the soil-cement mixture could be better understood.

A reduction in the normal cement requirement of certain soils should be possible. The desired strength and durability might be obtained by controlling those factors that would produce the necessary strength-age relationship. This could lessen construction costs and widen the usage of cement stabilization.

Because the density and compressive strength of a soil-cement mixture influences the durability of the mixture, it is believed that further investigation will establish a correlation between the slope of the strength-age relationship and the durability of a soil-cement mixture. This might lead to the possibility of eliminating one or more of the durability tests, substituting the slope of the strength-age relationship as a criterion for durability. This slope might be used in conjunction with the 7-day strength to provide an over-all index of the quality of a soil-cement mixture.

CONCLUSIONS

Soil-cement was observed to increase in unconfined compressive strength with time of curing with a better than random correlation in both a semi-logarithmic and logarithmic manner. The best relationship for granular soil-cement is semi-logarithmic; silty and clayey soil-cement exhibit the best relationship logarithmically. These correlations were found to exist, independently of changes in (a) cement content, (b) time of curing up to 5 years, (c) curing temperature, (d) size of test specimen, (e) type of soil, and (f) immersion of test specimen before testing.

These relationships can be used to predict the compressive strength of soil-cement. The strength-age relationship can be determined from data obtained in standard laboratory tests. A semi-logarithmic relationship tends best to predict future compressive strength for all soil types. Compressive strength can be predicted both graphically and by equation with a reasonable degree of accuracy.

The slope of the strength-age relationship was found to be affected by the physical and chemical properties of the soil, the cement content, and certain chemical additives. Thus, it is evident that the slope of the strength-age relationship can be used as an indicator of the quality of a soil-cement mixture. Also the effect of additives can be better evaluated by using this relationship.

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