Influence of Heat Treatment On the Pulverization and Stabilization Characteristics of Typical Tropical Soils

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Although laboratory investigations have established the feasibility of stabilizing highly plastic clays with stabilizers such as cement, the problem remains of pulverizing and obtaining a uniform mixture of the soils with the stabilizers in the field. The present work deals with an experimental study of (a) the influence of heat treatment on the pulverization characteristics of two typical tropical soils (lateritic and black cotton soils) with and without addition of salts, and (b) the influence of heat treatment and aggregate sizes on the stabilization characteristics of pulverized black cotton soils with 12 percent cement.

The pulverization characteristics were determined in terms of the energy required for the new surface area created due to disaggregation caused by low-velocity impact and cutting. The susceptibility to stabilization of black cotton soil with cement was analyzed from the unconfined compressive strengths of soil cement specimens immersed under water after moist-curing for seven days.

The investigations show that (a) heat treatment and addition of sodium chloride result in a reduction of the plasticity of the soils and in a significant improvement in their pulverization characteristics; (b) there exists an optimum sodium chloride content of 3 percent and heat treatment of 250 C for two hours, at which susceptibility to pulverization is maximum; (c) the smaller the aggregate sizes of the black cotton soil, the greater is its susceptibility to stabilization with cement; and (d) a minimum heat treatment up to 300 C is necessary to improve the stabilization characteristics of black cotton soil aggregates of sizes $^3/_8$ to $^3/_{16}$ in. and $^3/_{16}$ in. to 7 B. S. with cement.

•SOIL STABILIZATION is normally employed where the soils existing at a site are not entirely acceptable in their present state. Although granular soils and lean clays have been successfully stabilized with portland cement, lime, and other admixtures, attempts to stabilize fat clays in the field have not been very successful owing to difficulties in pulverizing them into sufficiently small aggregates and obtaining the desired soil-stabilizer mixtures. The stabilization of highly plastic clays involves adequate pulverization of the soil, optimum mixing of the soil with the stabilizer (and water if necessary) and compaction. At present the processes of pulverization (or comminution) and mixing are accomplished with large amounts of energy, and the final stabilization of the soil at the site may sometimes prove even more expensive than a complete replacement of the clay soil with imported granular materials.

Comminution involves several physical actions but perhaps the most important is the breaking apart of the monolithic soil surface, which has formed into a large, structurally continuous unit through cycles of wetting and drying. Because of the large amount of energy involved in breaking the field soil mass, even small economies developed in these processes have a significant value. This suggests determination of factors influencing pulverization, theories of size reduction, degree of pulverization, optimum aggregate sizes for economical stabilization, etc. Research by Nichols et al (8, 9, 10, 11), Vilenskii (17), Keen (6), Yoder (20), Shaw et al (15), Grimer and Hose (5), Uppal and Bhatia (16), Bose (3), Barbour (1), Chandrasekharan and Chandrasekhar (4), and Scott-Blair (14) permits the following observations:

1. A granular or lumpy structure is the most desirable characteristic necessary from the point of view of plant growth or successful incorporation of stabilizers into soils.
2. The moisture content of the soil is the principal controlling factor in the comminution and workability of cohesive soils. Normally a friable consistency between plastic and shrinkage limit is favorable.
3. The most stable soil-stabilizer system is obtained when certain optimum aggregate sizes are used.
4. Addition of granular materials or certain salts such as sodium chloride into natural soils improves their engineering characteristics and renders them more workable in stabilization processes because of greater ease of pulverization.
5. Adoption of proper techniques of size reduction, namely cutting action for moist soils and impact or attrition for dry soils, yields best results.
6. Effective machine design, with proper shape of cutting edges, tools, and mounting arrangements can save considerable power and improve the degree of pulverization with economy.
7. Depending on the consistency of the soil, operations at lowest possible speeds can minimize the energy required for comminution.
8. There is a definite need to develop theoretical concepts and laboratory techniques to determine the pulverization characteristics of cohesive soils and arrive at methods to improve their susceptibility to pulverization and hence stabilization.

The experimental investigations reported in this paper consist of two parts. The first part deals with the pulverization characteristics of two typical tropical soils (lateritic and black cotton soils) with and without heat treatment and addition of common salt, and the second part deals with the susceptibility to stabilization with cement of the black cotton clay, pulverized and subjected to heat treatment.

DETERMINATION OF PULVERIZATION CHARACTERISTICS OF LATERITIC AND BLACK COTTON SOILS

Soils Used

A lateritic soil from Mysore and a black cotton soil from Coimbatore were used in the investigation. The origin and occurrence of laterite soils and rocks have been described and discussed by Winterkorn and Chandrasekharan (18). These soils are formed in situ and are characterized by the leaching of silica and accumulation of iron and aluminum oxides. The lateritic soil used in this investigation contains 35 percent gravel, 48 percent sand, 13 percent silt, and 4 percent clay (M. I. T. classification) and falls under SC or SF in Casagrande's plasticity chart. The differential thermal analysis (Fig. 1) does not clearly reveal the kaolinite clay mineral, presumably due to the presence of impurities in the soil.

The Geological Survey of India (3) suggests that the black cotton soil may be derived from the products of continuous weathering of igneous rocks such as gneiss and trap. The black or grey color is due to the presence of titanium along with organic matter. In general the black cotton soils contain montmorillonite and illite minerals to a greater extent and are highly argillaceous and somewhat calcareous. They contain a high percentage of iron oxide and magnesium and calcium carbonates. The black cotton soil used in this investigation contains 4 percent gravel, 9.5 percent sand, 27 percent silt, 59.5 percent clay (M. I. T. classification), and 4 percent of organic matter and falls under the CH group in Casagrande's plasticity chart. The differential thermal analysis (Fig. 1) indicates the presence of montmorillonite with a very high endothermic reaction between 100 and 300 C, a small second endothermic reaction between 500 and

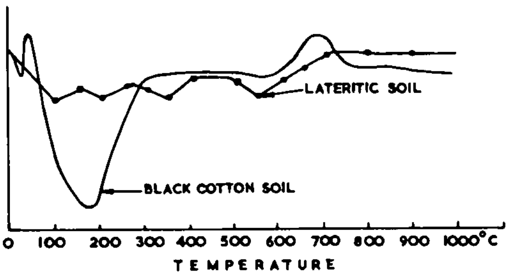

Figure 1. Differential thermal analysis curves for black cotton and lateritic soils.

600 C, and an exothermic reaction between 600 and 750 C.

Tests on Pulverization Characteristics

The two tests conducted to determine the pulverization characteristics were (a) low-velocity impact and (b) cutting. The former was performed on heat-treated black cotton and lateritic soils with and without the addition of sodium chloride and the latter was limited to the black cotton soil subjected to heat treatment alone.

Low-Velocity Impact Test—Various percentages by weight of sodium chloride (½, 1, 3, and 5) were dissolved in suitable quantities of water and the solutions were added to the soil aggregates passing a $^3/_{16}$-in. sieve. The consistency of the soil-water-salt slurry was kept approximately at the respective liquid limits, namely 55 percent for the black cotton soil and 20 percent for the lateritic soil. The slurry was transferred into wooden molds, 1 in. in diameter and 2 in. high, and the sides of the molds were gently tapped in order to obtain a uniform density. The samples were allowed to remain in the molds at the laboratory temperature for 24 hours to allow possible physical and physicochemical changes to occur. A set of three samples for each combination thus obtained was placed in an electrical muffle furnace kept at specified constant temperatures of 100, 200, 300, and 400 C. The samples were heated for a duration of 2 hours. Similar samples were also prepared on the natural soils without salt.

All the samples were subjected to pulverization in a low-velocity impact test. A steel ball weighing 6¼ lb was dropped from a height of 15 in. to fall directly on the soil specimen. The fragments of the crushed specimen were sieved through B. S. sieve sizes of $^3/_8$ and $^3/_{16}$ in. and Nos. 7, 36, and 200 and the weight retained in each was determined. From the mean weighted diameter considerations, the new surface area created was calculated. The potential surface area present in 100 grams of soil was determined for the particle sizes as obtained in a mechanical analysis of the natural soil and this area was assumed to represent the basic standard of 100 percent pulverization. The degree of pulverization was defined as the newly formed surface area of aggregates of particles due to crushing divided by the original potential surface area of the soil particles. Assuming 100 percent efficiency for impact, the energy per degree of pulverization is

$$\frac{\text{Energy Input}}{\text{Degree of Pulverization}}$$

Cutting Tests—The black cotton soil passing a $^3/_{16}$-in. sieve was heated at 100, 200, and 300 C for 24 hours and allowed to cool to room temperature. Samples of 200 grams of the heat-treated aggregates were mixed separately with 10, 15, 20, 25, 35, and 40 percent by weight of water and compacted in Dietert's compaction apparatus (22) suitably modified so that the same dry density of 1.5 g/cc was obtained. A cutting tool of mild steel 7 by 7 by 0.3 cm with the edge sharpened to 0.5 mm in a distance of 2 cm was attached to a proving ring in a compression testing machine and the compacted samples of 5.1 cm diameter and 5.1 cm high were cut at a rate of 1.27 cm per minute. The proving ring readings were noted for every 2.5 mm depth of cutting.

Discussion of Test Results

Effect of Sodium Chloride on Consistency—The results of the consistency tests with and without salt and heat treatment are given in Figure 2. In the case of the black cotton soil, for addition of 1 percent sodium chloride, there is an increase in the liquid

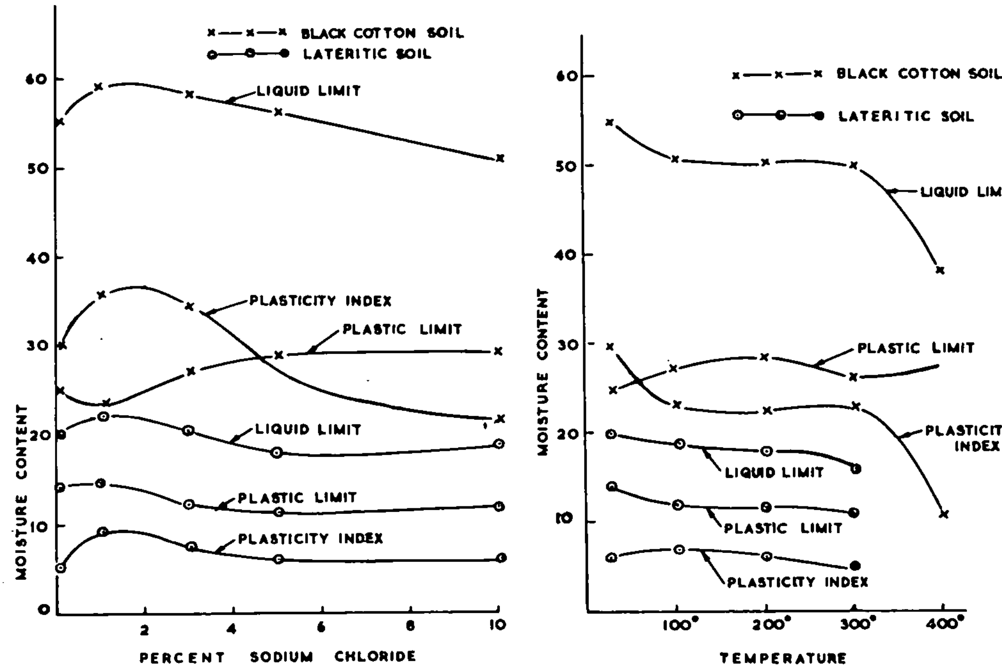

Figure 2. Influence of salt and heat treatment on consistency properties.

limit and a decrease in the plastic limit with a net increase in the plasticity index from 30 to 35. Further addition of sodium chloride reduces the plasticity index primarily due to reduction in the liquid limit. In the case of the lateritic soil, the same trend of increase in the plasticity index from 5.5 to 9 is revealed for addition of 1 percent sodium chloride. With progressive addition of sodium chloride up to 3 percent, the plasticity index is reduced to that of the natural soil and thereafter there is no further variation. The adsorption of sodium ions on the natural soil may explain the increase in the plasticity index due to dispersion effects and the decrease at the higher salt content may be attributed to some sort of a decrease in double layer repulsion (2). This effect is, however, not very conspicuous in the lateritic soil because of its poor activity.

Effect of Temperature on Consistency—The plasticity index for black cotton soil is reduced gently in the initial ranges of heat treatment between 25 and 200 C, and thereafter the reduction is rather fast and steady for the temperature range from 300 to 400 C. This may be attributed to the change in moisture adsorption characteristics of the predominant clay mineral of montmorillonite present in the soil. The temperature effect on the consistency properties of lateritic soil is not significant, because of the presence of the weakly active clay mineral kaolinite and oxides of iron and aluminum. The plasticity index also remains more or less the same for the ranges of heat treatment adopted in this investigation.

Effect of Sodium Chloride and Temperature on Pulverization—Figures 3 and 4 show the results of low-velocity impact tests. An increase in the temperature of the raw soil shows a decrease in the energy requirement. For the increase in temperature from 100 to 250 C the reduction in energy requirement is quite rapid. Heating the black cotton soils after treatment with sodium chloride results generally in a decrease in the energy for pulverization. However, the 3 percent combination shows less energy requirement than the 5 percent combination, although the plasticity index for the 5 percent combination is less than that for the 3 percent combination. The higher energy requirement for pulverizing the 5 percent combination may have to be attributed to the possible cementation effects due to crystallization of the greater amount of salt present. For a combination of 3 percent salt content and heat treatment at 250 C, the energy

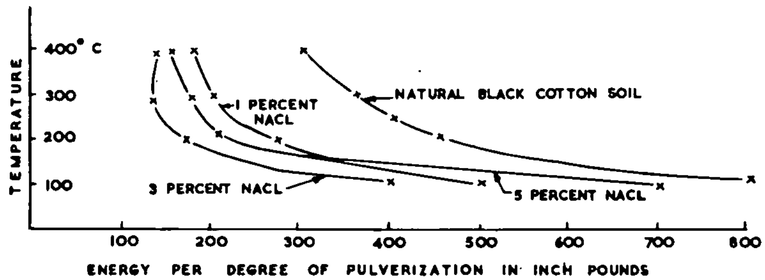

Figure 3. Variation of impact energy for unit degree of pulverization with heat treatment and salt content for black cotton soil.

requirement per unit degree of pulverization is the least. Addition of 3 percent salt and heat treatment up to 100 C has reduced the energy requirement from 800 to 400 in.-lb and this is comparable to the influence of heat treatment alone at 250 C on the natural soil.

The influence of addition of sodium chloride to the lateritic soil is more or less the same as that for the black cotton soil except that the range of energy variation per unit degree of pulverization is very small because of a lower activity of the lateritic soil. At 250 C there is a relative fall in the energy requirement and at 400 C the variation is negligible. The optimum salt content and optimum temperature for improving the susceptibility to pulverization of lateritic soil are 3 percent and 250 C respectively, the same as for the black cotton soil.

The energy spent in cutting the specimen was calculated from the curves correlating cutting load and depth of cutting (Fig. 5). The energy required to make the specimens fail was determined from the area enclosed by the curves up to the peak value and horizontal axis. Figure 6 shows a progressive decrease in energy requirement with increase in heat treatment and the existence of an optimum water content at which the cutting energy is a maximum. Close examination of Figure 6 also reveals that these curves are more or less a replica of the moisture-density curves obtained in conventional compaction tests. In the present series of tests, the dry density was maintained constant and a maximum energy of cutting was required for specimens compacted at a particular moisture content, which may be termed as the "optimum moisture for maximum energy." With progressive increase in temperature of treatment, the maximum cutting energy required reduces with a corresponding increase in the optimum moisture content. At the high ranges of moisture contents, the cutting energies are more or less the same irrespective of the temperature of treatment. For 15 percent moisture content the natural soil (25 C) shows the maximum resistance to cutting while the samples heated to 300 C show approximately the least energy of cutting. This leads to the obvious conclusion that the natural soil containing 15 percent of moisture content

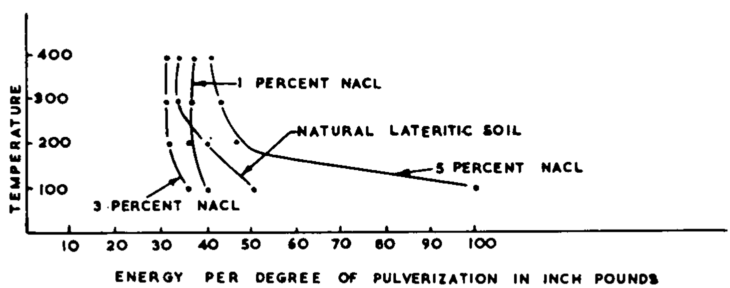

Figure 4. Variation of impact energy for unit degree of pulverization with heat treatment and salt content for lateritic soil.

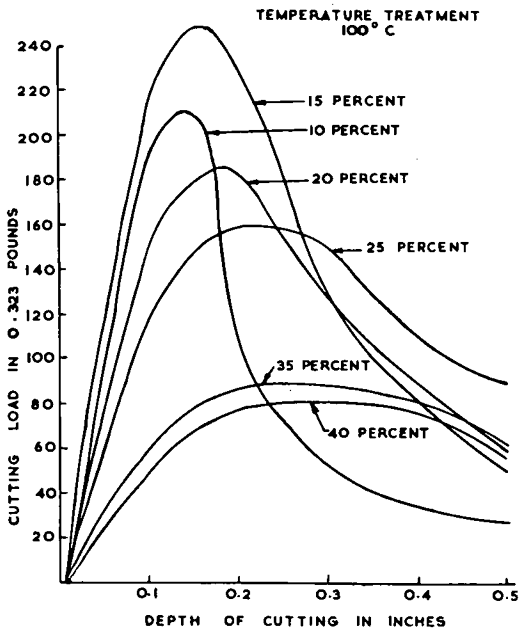

Figure 5. Variation in cutting load with depth of cutting.

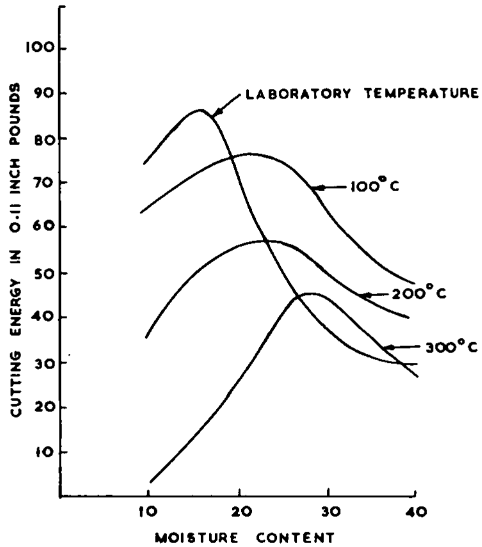

Figure 6. Variation in cutting energy with heat treatment and moisture content for black cotton soil.

is more difficult to cut than the same soil with higher moisture content. The latter condition may therefore seem to be easier for pulverization. From the practical point of view however, pulverization may involve a combination of crushing, impact, and cutting and as such the maximum energy required for cutting under a particular condition need not warrant a correspondingly higher energy for crushing or impact. On the contrary, samples at 15 percent moisture contents could be relatively more brittle, and would be more easily susceptible to pulverization by crushing or impact. A more comprehensive study would have to take into account all these processes affecting pulverization.

SUSCEPTIBILITY TO STABILIZATION OF HEAT-TREATED BLACK COTTON SOIL WITH CEMENT

The objective was the determination of the changes in grain size and physical properties of the black cotton soil of different aggregate sizes due to heat treatment and the susceptibility of the heat-treated soil to stabilization with cement. The intention of heat treatment was not to subject the black cotton soil to high temperatures and convert it into an absolutely non-plastic brick-like material but to spend the least possible heat energy on the black cotton soil and obtain a soil-cement material of requisite stability.

Test Procedure

The black cotton soil was pulverized to different aggregate sizes ($^3/_8$ to $^3/_{16}$ in., $^3/_{16}$ in. to B. S. 7, B. S. 7 to 14, B. S. 14 to 36, and B. S. 36 to 200) by means of a jaw crusher. Samples of different aggregate sizes were subjected to identification and classification tests such as grain size distribution, liquid limit, plastic limit, shrinkage limit, and moisture-density relationship in a Dietert's compaction apparatus. The consistency tests were conducted on the whole soils and not on their -36 (B. S.) fractions as normally done in the standard tests. The different soil aggregates were subjected to heat treatment at constant temperatures of 100, 175, 300, and 400 C for durations of 2 and 8 hours, and in certain cases for 24 hours also. The heat-treated samples were again subjected to the identification and classification tests mentioned. The aggregates, with or without heat treatment, were mixed with 12 percent cement by weight, and six soil-cement specimens, 2 in. in diameter and 2 in. high, were prepared at their respective optimum water contents using Dietert's compaction apparatus and moist-cured for 7 days. One set of three specimens was tested for unconfined compressive strength immediately after the curing, and the other was immersed in water for a week and then tested for unconfined compressive strength. The rate of strain adopted was 0.05 in. per minute.

Discussion of Test Results

Influence of Heat Treatment on Grain Size—Typical results of mechanical analysis conducted on the black cotton soil of different aggregate sizes subjected to heat treatment are given in Table 1. With an increase in temperature there is a general tendency for a reduction in the colloidal content from 35 percent to 21 percent and hence the formation of non-plastic materials. The samples heated to 100 C have, however, shown a higher colloidal content of 45 percent and also a relatively higher percentage of small size fractions than the raw soil. This strange behavior is to be attributed to the possible hydrophilic nature of the organic content (4 percent) in the soil. The reduction in the colloid content, and also the increase in the particle sizes for higher temperature treatment, are to be attributed to the cementation of small particles and formation of stable aggregates called molecular aggregates by Puri (12).

Influence of Heat Treatment on Consistency—Typical results of consistency tests conducted on black cotton soil aggregates of different sizes heated to 100 C and 175 C for durations of 2, 8, and 24 hours, and 300 C and 400 C for durations of 2 and 8 hours, are given in Table 1. In general, with increased heat treatment there is a tendency for a decrease in liquid limit and an increase in shrinkage limit. The plastic limit does not vary appreciably. The net result is a decrease in the plasticity index values, and for the aggregate size of B. S. 36 to 200 heated to 8 hours at 400 C, the soil exhibits no plasticity at all because no plastic limit test was possible. In one or two in-

TABLE 1

MECHANICAL ANALYSIS OF HEAT-TREATED BLACK COTTON SOIL

Soil Properties	Sieve No.				
	B.S. 3/8-3/16 in.	B.S. 3/16 in.-7	B.S. 7-14	B.S. 14-36	B.S. 36-200
(a) Aggregates at Laboratory Temperature					
Percentage clay	59.5		58.5		52.5
Liquid limit	56.0		57.0		60.0
Plastic limit	27.0		28.0		24.0
Plasticity index	29.0		29.0		36.0
Shrinkage limit	6.3		7.0		6.0
Optimum moisture content	15.90	17.10	20.0	20.30	23.50
Maximum dry density, g/cc	1.750	1.660	1.720	1.710	1.600
Unconfined Compressive Strength, psi					
Moist curing	322.00	220.00	214.00	431.00	582.00
Immersion curing	39.00	57.10	323.00	415.00	441.00
(b) Aggregates Heated at 300 C for 8 Hours					
Percentage clay	47.50		40.00		35.50
Liquid limit	38.00		34.00		34.00
Plastic limit	29.00		24.00		25.00
Plasticity index	9.00		10.00		9.00
Shrinkage limit	15.10		15.70		16.20
Optimum moisture content	16.80	11.50	16.30	17.50	18.90
Maximum dry density, g/cc	1.76	1.65	1.80	1.79	1.68
Unconfined Compressive Strength, psi					
Moist curing	423.00	265.00	410.00	588.00	606.00
Immersion curing	224.00	188.00	282.00	468.00	439.00

stances the general trend of an increase in the shrinkage limit with increase in heat treatment has been reversed. The tendency for the liquid limit to decrease with an increase in heat treatment has also been reversed in some instances, particularly at low temperatures. For example, in the case of $^3/_8$ to $^3/_{16}$ in. aggregates the heat treatment up to 100 C results in an increase in the liquid limit with a net increase in the plasticity index from 28.0 from the natural soil to 33.0 for the heated soil. The shrinkage limit also confirms the higher plasticity characteristics. This anomaly could again be attributed to the presence of organic matter, the exact behavior of which is still unknown. Usually the presence of all types of organic materials destroys the plasticity; the reason for enhancing the plasticity probably depends on the nature of the organic material and one would suspect that such organic materials would provide particularly hydrophilic surfaces (12).

From a study of Table 1 and other data obtained during the investigation, it is seen that a minimum heat treatment up to 300 C seems essential for eliminating the hygroscopic moisture and rendering the material distinctly less plastic. This is also apparent from the initial endothermic reaction in the differential thermal curve up to 300 C in Figure 1. Bose (3) has reported the conversion of black cotton soil into a non-plastic material by heat treatment at 400 C for an hour. Uppal and Bhatia (16) indicated such a conversion by heat treatment of 500 C for 2 hours. The present work indicates a commencement of the change even at 300 C and completion at 400 C for the soil aggregates tested.

Moisture-Density Relationship—Table 1 shows typical results of tests on the influence of heat treatment on the moisture-density relationship of the soil-cement specimens. With decrease in the aggregate sizes, there is an increase in the optimum

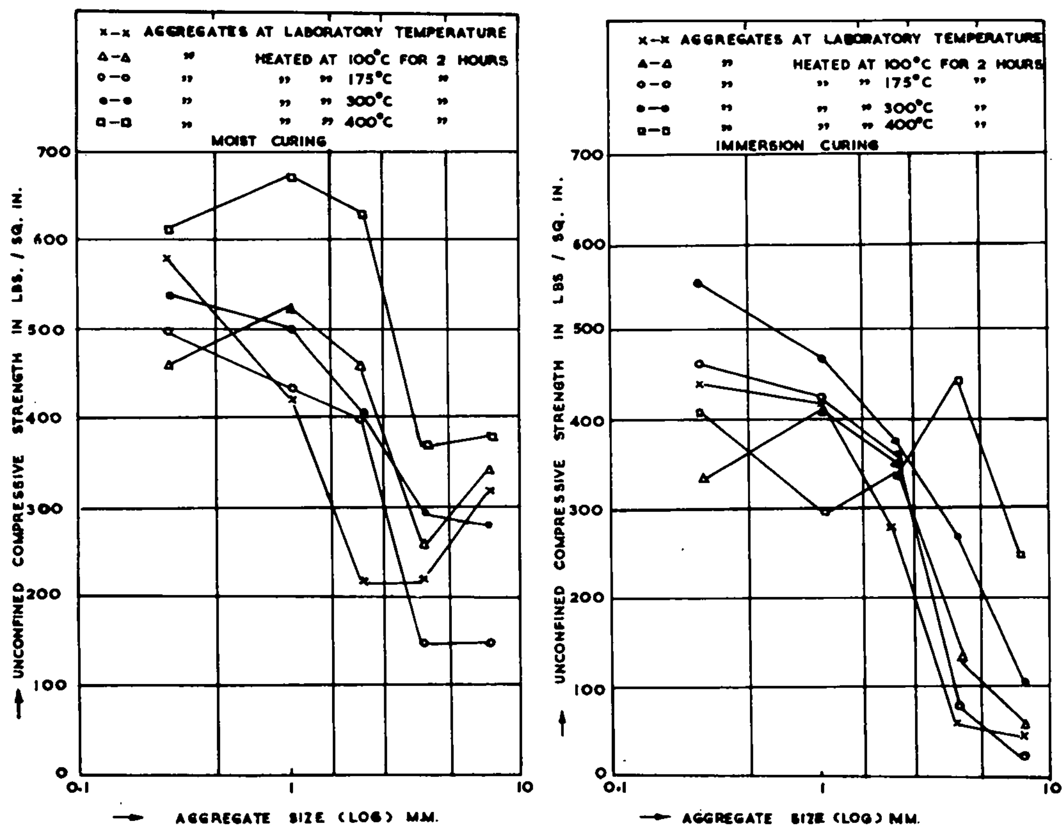

Figure 7. Variation in unconfined compressive strength of cement-stabilized black cotton soil of different aggregate sizes with heat treatment for 2 hours.

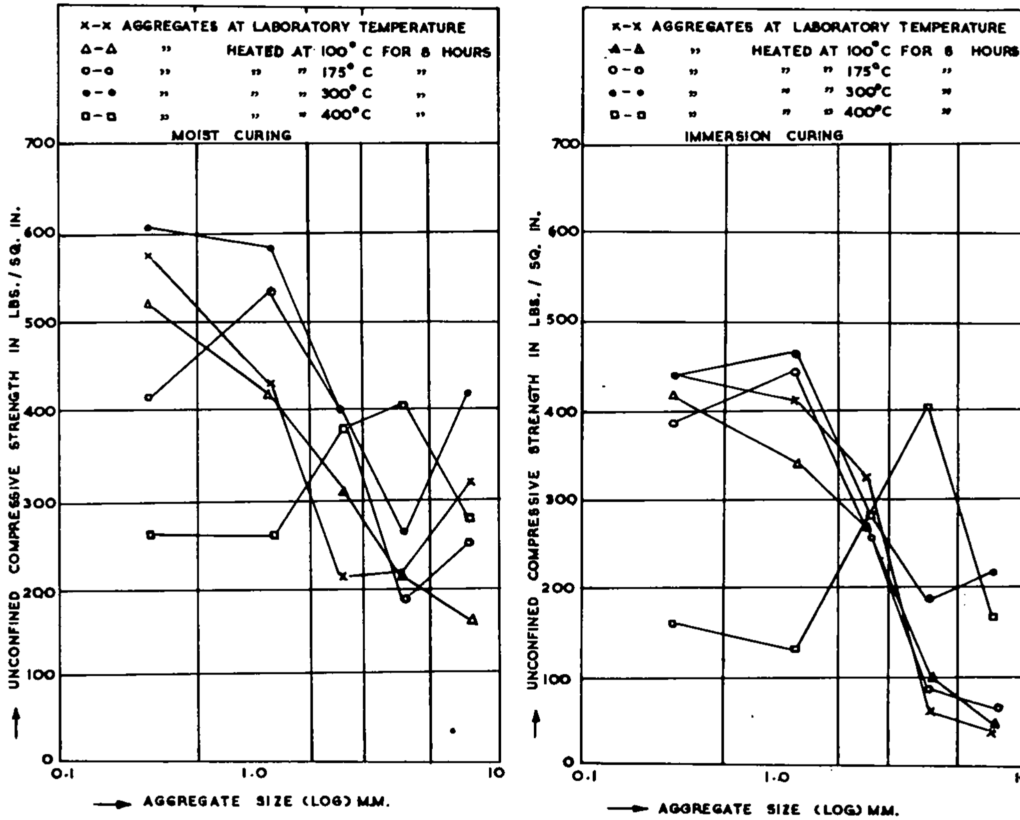

Figure 8. Variation in unconfined compressive strength of cement-stabilized black cotton soil of different aggregate sizes with heat treatment for 8 hours.

moisture content, which may be attributed to the progressively increased surface area to be covered by the water films. The maximum dry density shows a high value for aggregate sizes of $^3/_8$ to $^3/_{16}$-in., with a decrease for the next smaller size, then an increase, reaching a maximum value before finally decreasing for the aggregate size of B. S. 36-200. For higher temperatures of 300 and 400 C, there is a distinct tendency for a reduction in the optimum water content. The maximum dry density of 1.80 g/cc has been obtained for aggregates of size B. S. 7-14 heated at 300 C for 8 hours and $^3/_8$-$^3/_{16}$ in. heated at 400 C for 8 hours. The least value of 1.56 g/cc has been obtained for B. S. 14-36 aggregates heated at 400 C for 8 hours. This is the temperature range at which the material has exhibited very little plasticity and is evidently sandy in texture. This poor density value has to be attributed to the poor compactibility of the (poorly graded) sandy material obtained by heating, whereas the material which gave the maximum density might be considered to be fairly well graded with adequate fines to permit maximum compaction.

Influence of Heat Treatment on Strength—The results of unconfined compression tests on moist-cured and immersed soil-cement specimens are shown in Figures 7, 8, and 9. In general, a tendency for an increase in the unconfined compressive strength with a decrease in the aggregate sizes is noticed for both sets of specimens. However, the immersed samples show a more consistent and reliable trend than the moist-cured ones. A comparison of the influence of different degrees of heat treatment shows no significant improvement for the immersion-cured strength at 100 C and 175 C for the coarser aggregates ($^3/_8$ to $^3/_{16}$ in. and $^3/_{16}$ in. to B. S. 7). The position is, however, much improved for the same aggregates when treated at 300 C, and the best results are obtained for a heat treatment at 400 C. In the case of other small sizes the heat treatment has not very much altered the immersion-cured strength except in the case of samples heated to 400 C for 8 hours. In most of the cases the smaller aggregate sizes of B. S. 7-14, 14-36, and 36-200 show much-reduced strength values for immersion-cured specimens, probably indicating the creation of too much of a non-plastic material such as sand or silty sand, which have smaller unconfined compressive strength values than the untreated clay soil of similar aggregate sizes. The decrease in strength, however, should not be taken as a deterioration in the quality of the resultant material, because a stabilized sand-cement may show higher strength values under confined conditions than a clay-cement under similar conditions (21). The importance of volume relationships in soil stabilization is also brought out in the results (19).

It is clear from the foregoing that the larger aggregates warrant higher heat energy and the smaller aggregates may lose strength and stability characteristics at certain temperatures higher than an optimum for which best results can be obtained. If unconfined compressive strengths as determined from these tests are taken as the criteria, over-heating may give rise to non-plastic materials, which may require higher cement content for best results to be obtained. The study reveals that the degree and duration of heat treatment will have to be tied down to the size of aggregates or clay clods that have to be rendered less plastic or workable. Further, it is seen that for a given percentage of cement (12 percent in this case), the optimum conditions for maximum unconfined compressive strength exist not when the soil is absolutely non-plastic, but when it contains certain poorly plastic fractions, which probably render the compacted material more dense and stable. The objective, therefore, should be to obtain the best possible structural arrangement of the soil-stabilizer system, which gives the requisite strength and stability at a minimum cost and which may involve various opera-

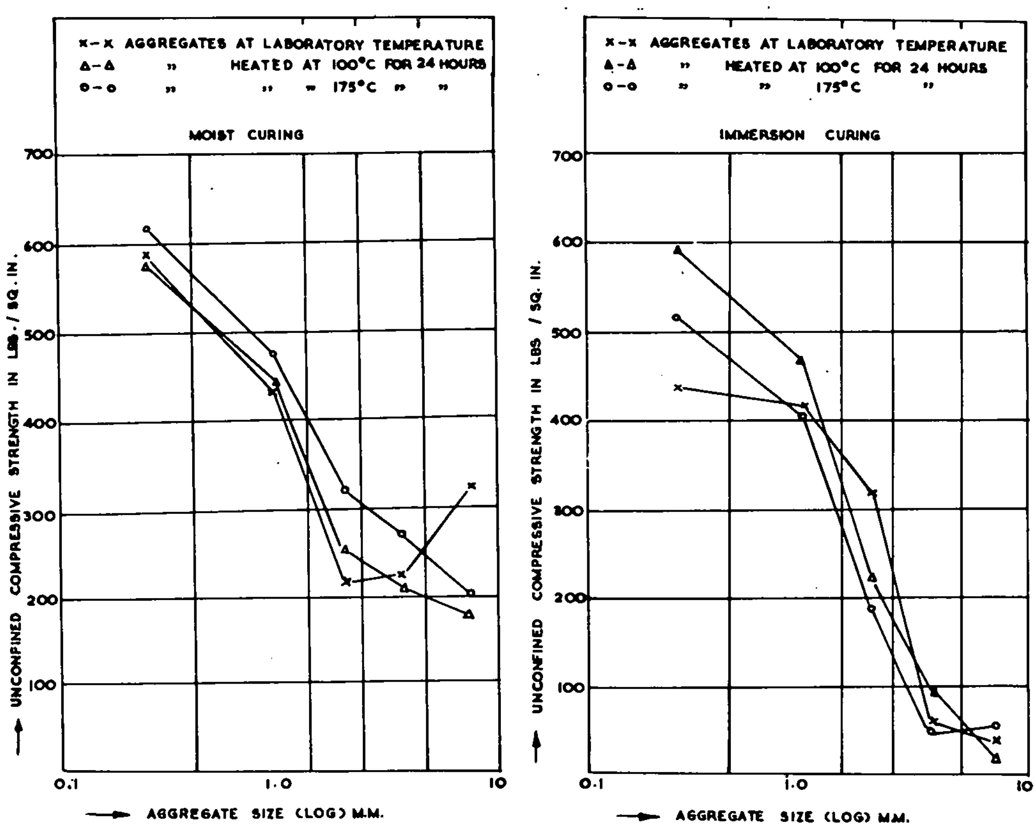

Figure 9. Variation in unconfined compressive strength of cement-stabilized black cotton soil of different aggregate sizes with heat treatment for 24 hours.

tions, namely conversion of the highly plastic clay into a poorly plastic material and processing it with a minimum amount of stabilizer. The poor stabilization characteristics of the non-plastic material obtained by high heat treatment have also been reported by Bose (3).

CONCLUSIONS AND RECOMMENDATIONS

This study on the pulverization and stabilization characteristics of clay soils due to heat treatment and addition of salt has led to the following conclusions and recommendations:

1. Addition of common salt (sodium chloride) improves the susceptibility of plastic soils to pulverization and the energy requirement is minimum for an optimum salt content of 3 percent.
2. For the test conditions and temperature ranges adopted, heat treatment at 250 C for two hours appears to be the desirable minimum to facilitate easy pulverization.
3. Optimum pulverization characteristics are obtained for a combination of a salt content of 3 percent and a heat treatment at 250 C.
4. Whereas the effect of heat treatment may be permanent, the addition of salt both on the pulverization and stability characteristics would need further investigation, since the salt may be susceptible to leaching and may adversely influence the setting of the stabilizer.
5. The energy per degree of pulverization as defined in this work forms a useful basis for comparing the energy requirements in the pulverization of soils. Although the expression for energy per degree of pulverization involves the use of the potential surface area of the individual particles of natural soils as obtained from mechanical analysis, a more appropriate expression would take into account the surface area of optimum aggregate sizes for the soils used and processes involved in a given stabilization work.
6. Heat treatment of pulverized black cotton soil at 300 C reduces the black cotton soil to a medium plastic material and that at 400 C to a poorly plastic or non-plastic one. The reduction in the plasticity characteristics improves the strength of the soil-cement specimens made of coarser aggregate sizes ($^3/_8$ to $^3/_{16}$-in. and $^3/_{16}$-in. to B. S. 7). In the case of the finer aggregates, their conversion into non-plastic material has not resulted in any increase in the unconfined compressive strength but only a decrease. The decrease in strength may not be taken as a reflection of the quality of the resulting material, because a stabilized sand-cement may show higher strength under confined conditions than a clay-cement under identical field conditions. Volume relationships seem to play a significant role in the stability of such soil-stabilizer systems.

ACKNOWLEDGMENT

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REFERENCES

1. Barbour, A. O. The Comminution of Cohesive Soils and the Workability of Soil Bitumen Mixtures. MSE thesis, Princeton University, 1964.
2. Baver, L. D. Soil Physics. John Wiley and Sons, New York, 1956.
3. Bose, S. K. Stabilization of Certain Clayey Soils in India by Thermal Treatment. Jour. Indian Road Congress, New Delhi, Vol. 18, paper 168, 1953.
4. Chandrasekharan, E. C., and Chandrasekhar, T. S. Stabilized Soil Construction in the Formation of Tuticorin Thiruchendur Road. Jour. Indian Road Congress, Vol. 20, Part I, paper 180, Oct. 1955.
5. Grimer, F. J., and Hose, N. F. The Effect of Pulverization on the Quality of Clay Cement. Proc. Fourth Internat. Conf. on Soil Mech. and Found. Engineering, Vol. 2, p. 109-113, 1957.

6. Keen, B. A. The Physical Properties of the Soil. Longmans, Green and Co., New York, 1931.
7. Narayanaswamy Setty, K. R. Influence of Heat Treatment on Pulverized Black Cotton Soils for Stabilization. MSc (Eng.) thesis, Madras University, 1968.
8. Nichols, M. L., and Baver, L. R. An Interpretation of the Physical Properties of Soil Affecting Tillage and Implement Design by Means of the Atterberg-Consistency Constants. Proc. Second Internat. Conf. on Soil Science, No. 6, p. 175-188, 1930.
9. Nichols, M. L., Reed, I. R., and Reaves, C. A. Soil Reaction to Plow Ware Design. Agri. Eng., Vol. 39, p. 326-329, 1958.
10. Nichols, M. L. The Dynamic Properties of Soils, I. Agri. Eng., Vol. 12, p. 259-264, 1931.
11. Nichols, M. L. The Dynamic Properties of Soils, II. Agri. Eng., Vol. 12, p. 321-324, 1931.
12. Puri, A. N. Soils—Their Physics and Chemistry. Reinhold Publishing Corp., New York, 1949.
13. Sadayan, E. Influence of Heat Treatment and Chemicals on the Pulverization Characteristics of Clay Soils. MSc (Eng.) thesis, Madras University, 1968.
14. Scott-Blair, G. W. Measurement of the Plasticity of Clays. Jour. Physics Chem. No. 35, p. 374-382, 1931.
15. Shaw, B. T., Haise, H. R., and Farnesworth, R. B. Four Years Experience With Soil Penetrometer. Soil Science Soc. of Amer. Proc., No. 7, p. 48-55, 1937.
16. Uppal, H. C., and Bhatia, H. S. Stabilization of Black Cotton Soil for Use in Road Construction. Indian Road Congress Road Research Bull. No. 5, 1958.
17. Vilenskii, D. G. Soil Science. State Teachers College Publishing House, Ministry of Culture, Moscow, p. 213-215, 1957.
18. Winterkorn, H. F., and Chandrasekharan, E. C. Laterite Soils and Their Stabilization. HRB Bull. 44, p. 10-29, 1951.
19. Winterkorn, H. F., and Dutta Choudhury, A. N. Importance of Volume Relationships in Soil Stabilization. HRB Proc., p. 553-560, 1949.
20. Yoder, R. E. The Significance of Soil Structure in Relation to the Tilth Problem. Soil Science Soc. of Amer. Proc., No. 2, p. 21-33, 1937.
21. Annual Report of Highway Research Station, Madras, p. 174-175, 1960-1961.
22. Soil Mechanics for Road Engineers. Her Majesty's Stationery Office, London, 1955.