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Original Research Article

STRENGTH AND DURABILITY OF CEMENT STABILIZED EXPANSIVE SOIL AMENDED WITH SUGARCANE PRESS MUD

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Abstract

The present investigation delved into the performance of cement stabilized soil amended with sugarcane press mud (PM), an organic waste residue from the sugar industry. An expansive soil was stabilized using 3% and 8% ordinary Portland cement (OPC) and modified with 1%, 3% and 5% PM. Cylindrical samples of dimensions 38 mm diameter and 76 mm height were cast and cured for 7, 14 and 21 days for all combinations considered. After the designated curing periods, the specimens were strained axially until failure to determine the strength of the samples. Samples were also subjected to alternate cycles of wetting and drying and the resistance to loss in weight was determined. The results of the investigation revealed that PM can be considered as a strength accelerator due to enhancement in early strength of the samples at 7 days of curing but beneficial strength gain could not be sustained over extended curing periods considered. However, 1% and 3% PM modified specimens were more resistant to weight loss when compared to pure cement stabilized specimens. Based on the results of the investigation, PM can be considered as a potential auxiliary additive to cement stabilized soil for improving the durability performance of the soil.

Keywords: soil, strength, press mud, sugar waste, stabilization, durability

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1. INTRODUCTION

Expansive soils need no introduction as they are known all over the world for their volume response to change in moisture content and the resulting disastrous effects on the structures built over them. Lime and cement have been the most preferred stabilizers for stabilization of expansive soils for improvement in their performance. Of late, the utilization of industrial wastes as stabilizers and auxiliary additives to cement and lime stabilization of soils has become common [1–3]. Cement and lime being calcium-based stabilizers, the choice of industrial wastes as auxiliary additives can be based on their function as either a pozzolan augmenting the pozzolanic reactions or as a supplementary stabilizer augmenting the supply of calcium ions. One such solid waste generated from sugar industry is sugarcane press mud (PM). PM from carbonation mills is rich in calcium content with as much as 40-45% comprising of calcium oxide on a dry basis [4,5]. In fact, PM can be utilized in the manufacture of cement [6]. There have been few investigations conducted regarding the potential use of PM in the manufacture of cement [7,8]. The utilization of PM in soil stabilization due to its rich calcium and silica content has also been studied by different researchers. James and Pandian [9,10] studied the utilization of PM as an auxiliary additive to lime stabilization of expansive soils. Moghadam et al. [11] investigated the potential of PM mulches on the stabilization of dune sand. Parthiban et al. [12] investigated the influence of PM on lime stabilization. Mansoor et al. [13] delved into the potential of PM in the manufacture of cement-lime stabilized blocks. Kumar and Garg [14] researched the potential of PM and granite dust in improving the strength of clayey subgrade. James [15] investigated the potential of PM on lime stabilized soil with advanced microstructural investigations. A few researchers also attempted using it as a primary stabilizer. Biffi and Janani [16] investigated the potential of PM as a primary stabilizer for clay soil subgrade. Saini et al. [17] attempted to study the enhancement of load carrying capacity of soils using PM. A look at the various investigations revealed that PM as a material with potential in soil stabilization has gained more attention in recent years. Most of the investigations adopted PM in combination with a stabilizer rich in calcium. This may be because of the organic origin of PM. Saini et al. [17] reported a loss on ignition (LOI) of PM to be around 30%. James and Pandian [18] report the organic content to be as high as 65% in PM determined indirectly by LOI whereas Saleh-e-In et al. [19] put it in the range of 69-80%. It is a well-known fact that organic content can be detrimental for soil stabilization [20]. The most common combination adopted with PM was lime in soil stabilization. Moreover, most of the studies were very basic or preliminary investigations with the exception of the work done by James [15]. There is still a need to identify optimal combinations of primary stabilizers with PM, its potential performance under conditions of durability and investigations on improving it as a standalone stabilizer. This investigation attempts to combine two such scenarios wherein PM has been combined with ordinary Portland cement (OPC) rather than lime and its effectiveness under alternative cycles of wetting and drying has been investigated. Thus, the primary objective of this investigation is to gauge the performance of PM modified cement stabilized soil subjected to alternate cycles of wetting and drying.

2. MATERIALS USED

Locally available virgin soil, commercially available ordinary Portland cement and sugarcane PM were the materials used in this investigation.

2.1 Soil

The soil used in this investigation was collected from Thaiyur lake in Kalavakkam, Tamilnadu, India. The soil was prepared based on Bureau of Indian Standards (BIS) code [21] for preparation of soil sample. The soil was tested in the laboratory for characterizing its various geotechnical properties. Table 1 tabulates the properties of the soil. Based on the properties of the soil, the soil was classified as high plastic clay (CH) based on BIS code [22].

Table 1. Properties of the Soil

Properties	Values
Specific Gravity [23]	2.68
Liquid Limit [24]	70%
Plastic Limit [24]	22.80%
Shrinkage limit [25]	9.00%
Maximum Dry density [26]	13.4 kN/m^3
Optimum moisture content [26]	28.40%
UCS [27]	103.1 kPa
Free swell index [28]	120%
Classification [22]	CH

2.2 Ordinary Portland Cement

OPC used in this investigation was commercially available 53 grade cement. No special preparation techniques were adopted for the preparation of OPC and it was used as available from the commercial packages.

2.3 Press Mud

Sugarcane PM is the residue left behind from the extraction and clarification of sugarcane juice from the cane [29]. After the juice is clarified, the residues settle at the bottom of the tank having the appearance of mud. The worldwide generation of PM is estimated to be around 30 million tonnes [30]. Indian sugar mills generate around 12 million tonnes of PM [29]. PM has applications like biosorbents, fertilizers, animal feed and as a chemical extraction source. However, its application as a soil stabilizer has not been researched significantly [10]. The PM used in this investigation was sourced from EID Parry Sugar Mills, Nellikuppam, in Cuddalore district of Tamilnadu, India. The sugarcane PM obtained from the mill was dried in sunlight to reduce its moisture content followed by sieving it through 150-micron BIS sieve for reducing its particle size as well as to remove microscopic bagasse fibres.

3. METHODS

The investigation began with the collection and preparation of materials. The soil sample as well as PM were subjected to preparation methods as mentioned earlier. OPC was used as available from the market. This was followed by fixing of stabilizer as well additive contents. Cement stabilization involving less than 5% cement is called as soil cement whereas cement stabilization using higher percentage is called as cement bound material [31]. Based on this, two random cement contents, one below and one above 5%, were chosen for evaluation. Similar choice of cement contents have been adopted in earlier investigations as well [32,33]. Saini et al. [17] report maximum strength when 5% PM was used for stabilizing the soil whereas Biffi and Janani [16] achieved maximum strength at 15%. Since PM is an organic material, the maximum PM content in this investigation was fixed as 5% to limit the detrimental effects of the organic nature of the material. The compaction characteristics of the soil modified with cement were determined using the mini compaction apparatus [34]. Based on the results of the compaction characteristics test, UCS specimens of dimensions 38 mm diameter and 76 mm height were cast at their corresponding optimum moisture contents and maximum dry densities. These formed the control specimens. The stabilization mix was modified with the three chosen PM contents (1%, 3% and 5%) to study the effect of PM on the cement stabilization of the soil. All specimens including PM modified specimens were cast to a target density and moisture content based on similar procedure adopted in a few earlier investigations [35–37]. Three samples were cast for evaluating the strength of each combination. The specimens were cured for periods of 7, 14 and 21 days of curing inside sealed polythene covers at room temperature to prevent the loss of moisture. At the end of the designated curing periods, the specimens were loaded axially at a rate of 1.25 mm per minute until failure. In order to study the durability of the specimens, 21 days cured samples of all combinations, were subjected to alternate cycles of wetting and drying. This was done by completely soaking the samples in a bed of wet cotton for a period of 24 hours followed by drying in the open air for another period of 24 hours. The loss in weight of the specimens were measured after each cycle of wetting and drying and were studied to evaluate the durability of specimens. Table 2 shows the combinations considered in this investigation.

Table 2. Stabilizer Combinations

Cement %	Press Mud %	Notation
3	0	3C0PM
	1	3C1PM
	3	3C3PM
	5	3C5PM
8	0	8C0PM
	1	8C1PM
	3	8C3PM
	5	8C5PM

4. RESULTS AND DISCUSSION

The soil under investigation was stabilized with 3% and 8% cement contents and modified with PM contents of 1%, 3% and 5%. The results of the investigation are summarized in the following subsections.

4.1 UCS of Cement Stabilized Soil Modified with PM

Figure 1 shows the strength of 3% cement stabilized soil modified with PM. It can be seen that the addition of PM does not result in any beneficial improvement in the strength of the stabilized soil. The addition of PM results in a loss in strength of the stabilized soil across curing periods for all PM contents. At 7 days of curing, the strength of the cement stabilized soil marginally increases from 352.4 kPa to 363.8 kPa for 1% PM modification and reduces on further increase in PM content. At 14 days of curing, the strength of 1% PM modified soil increases to 396 kPa from 370.2 kPa. However, at 14 days of curing, even 3% and 5% PM resulted in a better strength than the control specimen with strengths of 408.9 kPa and 389.2 kPa, respectively. But further curing could not sustain the increase in strength achieved due to PM amendment. Irrespective of PM content, at 21 days of curing, all combinations resulted in strengths lower than the control specimen. The strength steadily reduced from 467.7 kPa for the control specimen to 423.2 kPa for 5% PM modification. One thing that was clearly evident for the 21-day strength curve was that the increase in PM content from 3% to 5% did not have much influence on the strength of the stabilized soil specimen. This can be inferred from the flattening of the curve beyond 3% PM content. Similarly, James and Pandian [9] found that addition of 2% PM to lime stabilized soil resulted in enhanced early strength at 7 days of curing. They also found that further increase in PM content resulted in a reduction in strength. In the present study as well, low quantities of PM resulted in an enhanced early strength.

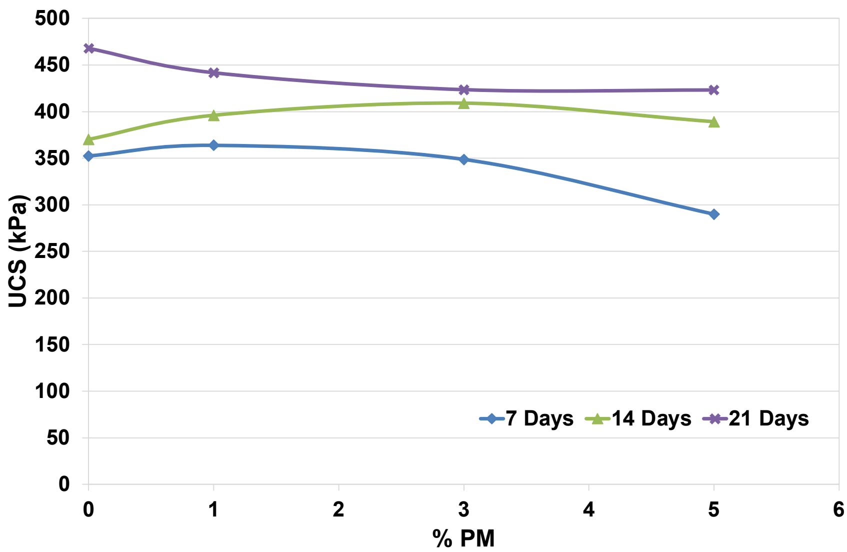

Fig. 1. Strength of 3% Cement Stabilized Soil Modified with PM

Figure 2 shows the strength of 8% cement stabilized specimens modified with PM. At a higher dosage of cement as well, it can be seen that the addition of PM does not produce any beneficial effect on the strength of the specimen. At 7 days of curing, addition of 1% PM results in an improved strength when compared to the control specimen. The strength of 8% cement stabilized soil increases from 1128.4 kPa to 1233.9 kPa. On further increase in PM content, there is no big gain in strength. 3% PM addition gives a strength of 1129.5 kPa, which is almost same as that of the control specimen. 5% PM addition resulted in a loss in strength of the specimen to 1029.4 kPa. At higher curing periods of 14 days and 21 days, the beneficial effects of even 1% and 3% PM modifications could not be sustained. At 14 days of curing, there was a steady decrease in the strength of the specimens with increase in PM content. The strength decreased from 1597 kPa to 1254.3 kPa for 5% PM addition. At 21 days of curing, there was a clear reduction in strength for 1% PM addition to 1784.4 kPa from 2032.5 kPa for the control specimen. On further increase in PM content, the rate of decrease in strength loss reduced, as evident from the reduction in slope of the curve beyond 1% PM addition. The strength reduced to 1643.8 kPa for 5% PM addition. James and Pandian [9,10], in their investigations found that addition of small quantities of PM to lime stabilization (equal to or higher than initial consumption of lime) resulted in enhanced early strength at 7 days of curing. Based on the results of the strength tests, it can be stated that addition of PM to cement stabilization of the soil under investigation does not produce any beneficial effects. However, it can be seen that irrespective of cement content, the strength of the specimens modified with 1% PM content was higher than control at 7 days of curing.

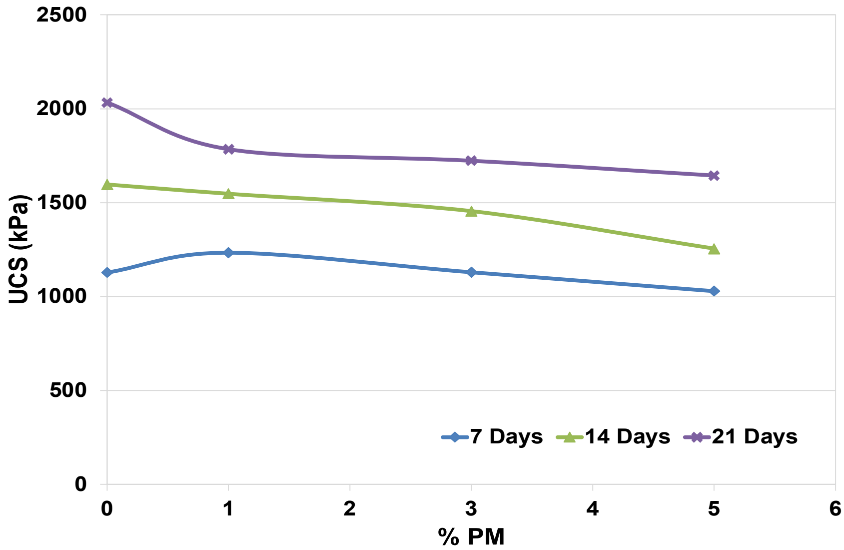

Fig. 2. Strength of 8% Cement Stabilized Soil Modified with PM

4.2 Percentage Strength Change of PM Amended Cement Stabilized Soil

To better understand the early strength gain of the PM amended cement stabilized soil, a percentage strength gain analysis was performed. Figures 3 and 4 show the percentage strength change of 3% and 8% cement stabilized soil, respectively. In Figure 3, a look at the strength change reveals that 1% PM has a strength gain of 3.2% at 7 days of curing and almost 7% at 14 days of curing. Even 3% PM content, was able to produce 10.5% strength gain at 14 days of curing. However, increase in PM content to 5% resulted in a significant loss of 17.8% strength at 7 days of curing but still was able to produce a strength gain of 5.1% at 14 days of curing which seems to be an anomalous behaviour and needs more investigation. James and Pandian [9] stated in their investigation that significant gain in strength can be achieved only when sufficient lime is available for stabilization. In the present study as well, 3% cement may not be sufficient for stabilizing the soil for significant gain in strength and consequently, modification of this process with PM did not result in a significant gain in strength.

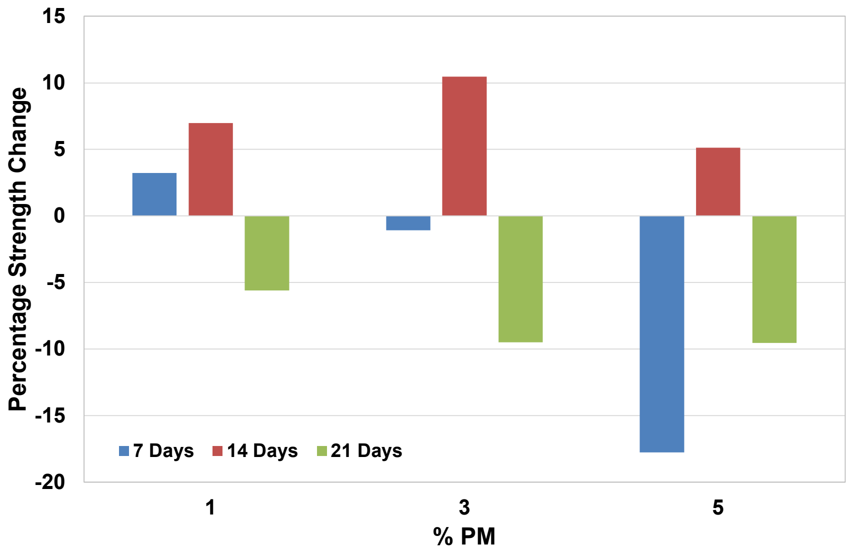

Fig. 3. Percentage Strength Change for 3% Cement Stabilized Soil Amended with PM

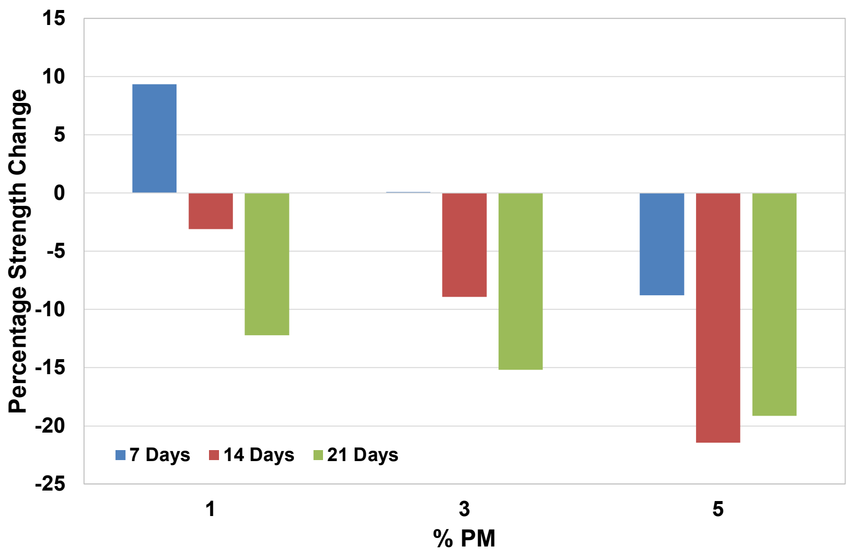

Fig. 4. Percentage Strength Change for 8% Cement Stabilized Soil Amended with PM

From Figure 4, it is evident that at a higher cement content, only 1% PM was able to produce positive strength gain of 9.3% at 7 days of curing, whereas higher PM contents as well as curing periods resulted in strength loss. This was against expectation wherein higher cement content would have resulted in better performance with PM. PM modification resulted in an improved performance of lime stabilization with increase in lime content, especially early strength [10,15]. Thus, it can be concluded that 1% PM can be effectively valorized in cement stabilization of soil for enhanced early strength without much loss in delayed strength. James [15], in his investigation, recommended the use of PM as a strength accelerator in lime stabilization. A similar application of PM is possible in the case of cement stabilization, however, higher cement content beyond 8% also need to be investigated to confirm this behaviour of PM in cement stabilization.

4.3 Durability of PM Modified Cement Stabilized Soil

The durability of the stabilized specimens was determined by subjecting all the combinations to alternate cycles of wetting and drying and weighing the specimens after each cycle. Figure 5 shows the durability of 3% cement stabilized soil amended with PM. From the figure, it can be clearly seen that 1% PM amended specimen is more durable when compared to the control specimen as evident from the position and length of the curve. There was a comparative lesser loss in weight with increase in number of cycles which resulted in the durability curve of 1% PM amendment lying above the other curves. Moreover, the curve is longer because it survived 7 cycles of wetting and drying when compared to the other combinations which survived only 6 cycles. Harichane et al. [38] adopted a similar weight loss procedure for determining the durability of soil stabilized with lime and natural pozzolana and found different combinations surviving between 4 to 12 cycles. Figure 6 shows the durability of 8% cement stabilized soil amended with PM. At the outset, it can be seen that higher cement content of 8% results in better durability when compared to 3% cement stabilization. 8% cement stabilization results in the specimens surviving 10 cycles of wetting and drying compared to 6 cycles for 3% cement stabilized soil. From the figure it is clearly evident that the durability of PM amended specimens is better than pure cement stabilized soil at higher cement content as well. At higher cement content of 8%, both 1% as well as 3% PM amendment results in more durable specimens as is evident from the higher position of the durability curves when compared to the control specimen. However, addition of PM to 8% cement stabilization does not increase the number of cycles of survival but reduces the weight loss alone. 5% PM amendment is less durable comparatively as seen from the lesser number of cycles of survival. Thus, it can be stated that PM modification of cement stabilization can definitely prove to be beneficial for increased durability of the stabilized specimens under conditions of wetting and drying.

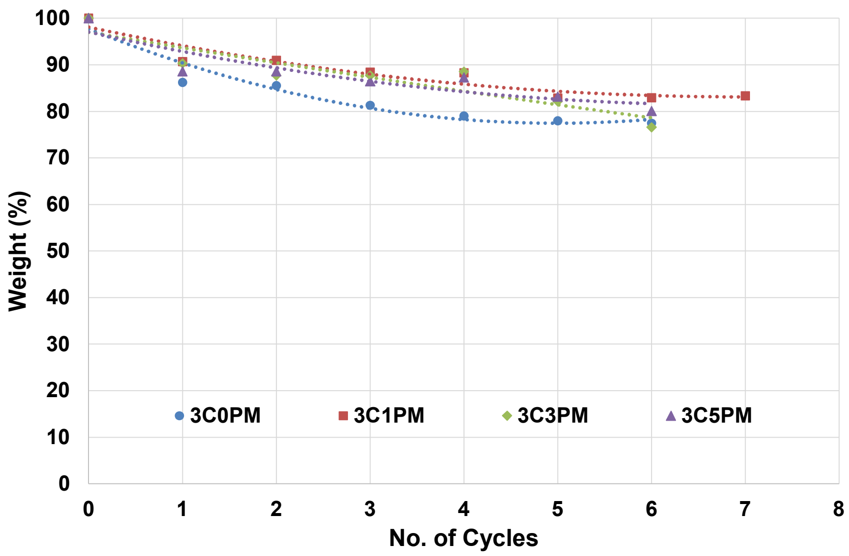

Fig. 5. Durability of 3% Cement Stabilized Soil Amended with PM

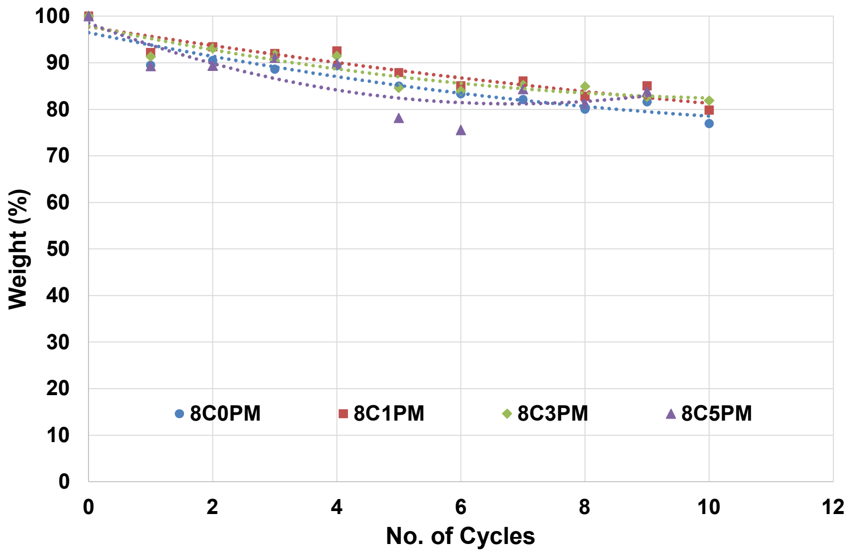

Fig. 6. Durability of 8% Cement Stabilized Soil Amended with PM

5. CONCLUSIONS

The present investigation attempted to study the effect of PM on the cement stabilization of an expansive soil under normal conditions as well as conditions of alternate wetting and drying. Based on the results of the investigation, the following points can be concluded.

(i) The addition of PM did not result in any improvement in the strength of the cement stabilized soil at 21 days of curing irrespective of cement content considered in this investigation. Thus, it can be concluded that PM modification of cement stabilization of an expansive soil under normal conditions does not offer any benefit in strength.

(ii) Increase in PM content resulted in a steady reduction in strength irrespective of cement content. Thus, it can be stated that high contents of PM cannot be valorised in cement stabilization just like lime stabilization due to its organic nature.

(iii) The early strength of amended soil was higher than pure cement stabilization irrespective of cement content, when 1% PM was used to modify the stabilization process. Thus, it can be stated that PM can be possibly used as a strength accelerator to achieve higher early strength without a significant loss in delayed strength.

(iv) Addition of PM to cement stabilization resulted in the specimens resisting weight loss due to alternate cycles of wetting and drying. At 3% cement stabilization, addition of 1% PM resulted in better durability performance whereas in the case of 8% cement stabilization both 1% as well as 3% PM amendments resulted in better durability performance. Thus, it can be concluded that the introduction of PM in cement stabilization can increase the durability of the stabilized soil. Moreover, higher cement content stabilized specimens can be durable at higher PM contents as well.

The results of the present investigation can definitely act as a precursor for more detailed investigations into the performance of PM in cement stabilized soils. Future investigations can focus on higher cement contents to contradict or reinforce the initial trends obtained in this investigation. The organic origin of PM being a big deterrent in its valorisation, thermal treatment of PM can also be considered in future investigations.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest in the publication of this article.

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