

Acrylic Latexes Prepared Via Miniemulsion Polymerization Technique for Improvement of Soil Behavior

G.A. Farzi^{1,*}, M. Mortezaei²

¹Department of Material and Polymer Engineering, Faculty of Engineering, Hakim Sabzevari University, Sabzevar, Iran.

²Department of Polymer Engineering, Azad University, South Teheran Branch, Tehran, Iran.

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ABSTRACT

The main objective of this work was to prepare acrylic latex in order to exploit as additive for soil; to improve physical and mechanical behavior. To do this, some acrylic monomers were polymerized using miniemulsion polymerization process, and important parameters such as polymer particle size and conversion of reaction were monitored during polymerization. Once acrylic latexes were obtained via miniemulsion polymerization, they were mixed in various ratios with three different soils taken from local sources. Then mechanical properties of modified soils were studied. The weight percent of latex was varied from 0 to 3% relative to soil and unconfined compressive strength of final treated soil were studied under various curing conditions. The results showed that it is possible to use acrylic latexes to ameliorate mechanical properties of soil to adapt it for construction and road bed application. It was shown also that unconfined compressive strength (UCS) of modified soils was improved by increasing weight percent of acrylic latex relative to total weight of sample. The results showed also that when the weight percent of acrylic latex relative to soil was between 2 and 3 %; mechanical properties were improved significantly.

1. Introduction

Soils exhibits undesirable engineering properties in most of the applications such as road or building construction. They can be plastic and compressible and they expand when wetted and shrink when dried. Generally, soils should be modified in order to use as materials for foundations [1], because their expansion and shrinkage make a very undesirable feature. A solution is soil stabilization; which is any process to improve the physical properties of a soil, such as increasing the shear strength, bearing capacity and the resistance to erosion, dust formation, or frost heaving. The stabilization methods used are divided into mechanical, chemical, and electrochemical methods [2].

Different types of materials have been successfully used [3-6] for soil stabilization. Two methods have been used to apply soil stabilizers. The first method contains the combination of modified and non-modified soils together, so called admix way. In the second method, surface penetration plays an important role. This method accomplished by placing a soil treatment material directly to the existing ground surface by spraying or other means of distribution. Some of conventional soil stabilizers are cement, lime, bituminous products and calcium chloride.

Pandey and Singh [7] reviewed the incorporation of fly ash in soil systems. They pointed out some benefit effects for fly ash. However, they stated also some harmful effects to the application of fly ash as soil stabilizer; including: (i) reduction in bioavailability of some nutrients due to high pH (generally from 8 to 12); (ii) high salinity; (iii) high content of phytotoxic elements, especially boron.

A survey in literature showed that when it is desired to modify soil properties such as gradation, workability, and plasticity smaller amounts of additives are required. But when it is desired to improve the strength and durability of soil significantly, larger quantities of additive should be used [2].

Fungaroli and Prager in an early work; have evaluated the use of some acrylic latex for soil stabilization purpose and compared the results with those obtained by cement [8]. However, they used the commercial polymer latex available in the market for soil stabilization, they concluded

that some latex could bring very good improvement for engineering property of soils [8]. A group of researchers discussed the performance of urea-formaldehyde as soil additives in regards to their effect on compressive strength of dune sand [9]. These new soil stabilizers were compositions of a polyanionic component of sulfonate urea-melamin formaldehyde, urea-formaldehyde and other salt additives. Their investigation showed that this type of soil additives is effective in soil stabilization [10] and improves significantly compressive strength of dune sand [9]. More recently, an in situ polymeric impregnation system was designed for producing a sand/polymer system with the desired properties [11]. They used three types of waterborne polymeric emulsions with different chemical and physical properties which were explored as stabilizers for sandy soil. They showed that strength and stiffness of sand can be enhanced significantly with these kinds of stabilizers. Orts et al. discussed some recent commercial application of polyacrylamid (PAM) as a water/ soil additive for controlling wind and water erosion. They concluded that PAM is an effective material for dust stabilization [12].

In recent years, few researches have been carried out for the use of acrylic latexes for soil stabilization to improve mechanical properties in which polymethyl methacrylate (PMMA) has been used as latex [13-15]. It is well known that PMMA is relatively low flexible polymer with a glass transition temperature (T_g) above 100 °C. Therefore, one can expect that PMMA is not the best choice for soil treatment. In order to overcome this weakness of PMMA, in this work, PMMA-Co-PBuA (rich in BuA) which is more flexible latex than PMMA having significantly lower T_g have been used as soil stabilizer.

The advantage of polymer latexes over other soil stabilizers can be briefly summarized as: 1. Good interaction of polymer latex with soil at ambient temperature due to relatively low T_g , 2. The small amount of latex is needed for stabilizing the soils because of small size of polymer particles and 3. The conventional stabilization method can be kept except diluted latex in water should be used instead of water for soil stabilization. 4. The dispersion medium of polymer latexes is water, thus the negative environmental effects associated with chemicals found in some soil stabilizations will be eliminated. [11].

Despite to development of soil stabilization with inorganic and organic materials including polymers; to the best of our knowledge the use of nano-scale materials as soil stabilizer has not been reported in open literature. From the other side as one can expect; the benefit of sub-micron materials in soil

*Corresponding Author

Email Address: alifarzi@yahoo.com (G.A. Farzi)

stabilization would be the fact that small quantity of this material meanwhile can brings a significant improvement in soil properties.

The objective of this work is to improve the engineering properties of soils used for building construction and road bed, by means of emulsion polymers as additives. Soil samples were provided from local sources; therefore, the results will bring enormous benefit for building industry and road construction in Tehran urban zone.

2. Experimental Methods

2.1 Materials

Three different types of soils; type 1 (S1), type 2 (S2) and type 3 (S3) were used in this work. S1, S2 and S3 were taken from a heel called Ghochak North-East of Tehran, Garmsar a city situated east of Tehran, and Taleghan North-West of Tehran, respectively. It was tried to choose representative soils for different types of local soils. S1 having a medium compressive strength like agriculture soil, S2 is a silty soil represent a huge area of local soils from two vast central desert of Iran. S3 is a water absorber soil with relatively high swelling and medium compressive strength. They were taken from a depth of 40 – 50 cm to avoid from any effect of organic layer on the properties of soil samples. The characteristics of these soils are given in Table 1. From this table it can be seen that based on USCS classification; S1, S2 and S3 belong to CL, CL-ML and MH group, respectively.

Methyl methacrylate (MMA, 99%), butyl acrylate (BuA) were supplied from ACROS and used as received. Octadecyl acrylate (ODA) (Aldrich, 97%) was hydrophobic agent in the system.

Sodium dodecylbenzenesulfonate (SDBS), Acros, 88%, and ammonium persulfate (APS) were both obtained from ACROS and used as supplied. Deionized water was used as the continuous phase.

Table 1 Characteristics of soils

Properties	Soil 1	Soil 2	Soil 3
Colour	Khaky	Khaky	Beige
Initial moisture %	5.2	2-3	6.35
Liquid limit	41	-	73.1
Optimum Moisture (%)	16	13	24
Dry unit weight (kN/m ³)	17.2	18.5	14.9
UCSC Class	CL	CL-ML	MH

Table 2 Recipe for the preparation of static mixture

Water	MMA	BuA	ODA	SDBS	APS
200 g	32 g	48 g	4 g	3 g/l	0.3 g

2.2 Miniemulsion Polymerization

The commonly used method to prepare miniemulsion is, dissolving the surfactant in deionized water and the hydrophobic agent in monomer, these mixtures are separately stirred, and then organic phase is added to aqueous phase while stirring and homogenized with a homogenization device [16]. Miniemulsion of mixed acrylic monomers (MMA: BuA 40:60 w%) were created using static mixer (SM) according to recipe of Table 2. The benefit and a complete description for the use of SM as homogenizer have been presented in our previous works [17-19]. The polymerization of stable miniemulsions was carried out for all the samples via a batch process in a cylindrical glass reactor (150 ml) with a nitrogen inlet.

After introduction of miniemulsion in to the reactor nitrogen was bubbled through the solution for 30 minutes before the beginning of polymerization process in order to eliminate the oxygen from the mixture.

Miniemulsion has been mixed during polymerization with a glass anchor stirrer in a constant speed of 250 RPM and the temperature was kept constant at 70 °C, using water circulation from a thermostatic bath.

2.3 Sample Preparation and Characterization

In a typical procedure for preparation of samples; 1500 g soil S1 was mixed with 240 g water to obtain a homogeneous mixture (for S2: 195 g and for S3: 360 g water was used). Then, the mixture was placed in a cylindrical mould with 50 mm diameter and was compacted with a load of 10 N falling from a height of 60 cm for 15 times. When polymer latex was used as stabilizers additive; 240 g water solution of latex with different solid content regarding to desired polymer/soil weight percent was used instead of water and previous procedure was followed. The weight percent of latex relative sample was varied from 0 to 3%.

In the next step; compacted sample was placed in laboratory temperature of 22 °C in order to complete curing of sample. During the

curing process considerable amount of moisture evaporated from the samples over the time hardening of treated soil occurred.

The effect of acrylic latex on the swelling properties and water resistance of soil were also investigated. Unconfined compressive strength (UCS) of soils (S1, S2 and S3) was studied as a function of acrylic latex weight percent, curing time and curing condition. In every case, three samples were prepared for repeatability study and their average was reported.

2.4 Characterization Methods for Improved Soils

In order to compare treated and un-treated soils from the engineering properties point of view, some experimental tests have been carried out; such as swelling and UCS.

2.5 UCS Tests

The UCS tests were performed in accordance with ASTM D 2166. The samples were a cylinder prepared via previously described method with a dimension of 40 mm diameter and 80 mm length.

3. Results and Discussion

3.1 Characterization of Soils

In order to gain an insight to the morphology of three previously mentioned soils, they were characterized using particle size analysis according to ASTM D 422 method. Further characterization was achieved also by elementary analysis for un-modified soils.

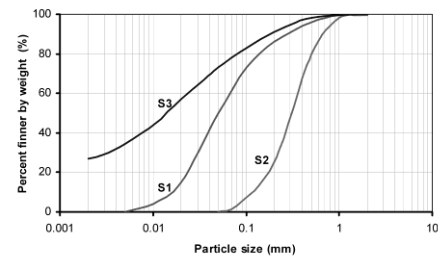


Fig. 1 Distribution of particle size for Soil S1, Soil S2 and Soil S3

Particle size distribution of S1, S2 and S3 were illustrated in Fig. 1. As can be seen from this figure S3 has finest particles and S1 and S2 are in second and third steps. However, S2 has relatively a narrow particle size distribution.

Some characteristics of soils S1, S2 and S3 are given in Table 1. As can be seen from this table, initial moisture in S3 is higher than S1 which is higher than S2. S3 presents also higher water absorption at liquid limit point relative two other soils. This indicates that swelling is important for S3 and will be discussed later in this work.

The optimum moisture of soil was obtained for S1 and S3 according to ASTM 2216 and maximum dry unit weight of modified soils were determined using ASTM D 2216- 80. As can be seen in this result the addition of acrylic latex did not cause any considerable increase in the maximum dry unit weight of samples compared to that of un-treated soil sample.

It should be notified that the optimum moisture does not make sense for S2 because of its non- water absorptive nature compared S1 and S3.

3.2 Synthesis and Characterization of Acrylic Latex

In the first step; miniemulsions were prepared using mentioned recipe and SM PAC at 120 mL/s flow rate. The condition and set-up of SM were exactly according to method described in our previous work [17] (except flow rate which was fixed as mentioned at 120 mL/s). Homogenization was carried out using SM for 30 minutes, and droplet size was measured at the end of homogenization process using a Malvern zeta sizer which was 155 nm. The stability of miniemulsions was verified by periodically measuring of droplet size for 4 hours, and it was found that it is relatively stable with maximum 15 nm increase within 4 hours.

Then in the second step; the miniemulsion polymerization was carried out for 5 hours according to the procedure described above. The conversion of monomer to polymer particles was determined gravimetrically to be about 96% at the end of polymerization.

Polymer particle size was decreased to about 120 nm after polymerization showing probably partially homogeneous nucleation in the course of polymerization period. This relatively small particle size provides huge specific surface area of polymer particles, which enable small quantity of the latex interacts with considerable amount of soil and modify its properties. Polydispersity index (PI) provided by Malvern

software was varied from 0.18 for miniemulsion to 0.07 for latex indicating the narrowness of particle size distribution for latex. Up to this point; it was verified whether or not it is possible to obtain acrylic latex rich in BuA using SM as homogenization device in order to use for soil treatment. Once, the latex was synthesized successfully, it was characterized with DSC showing a moderate glass transition temperature ($T_g = 5^\circ\text{C}$) which is expected to allow a good interaction between latex and soil. Then this latex was used for soil modification in next steps. Fig. 2 shows a sample of acrylic latex.



Fig. 2 A sample of synthetic acrylic latex

3.3 Effect of Acrylic Latex Stabilization on UCS

The weight percent of acrylic latex relative to soils S1, S2 and S3 was varied from 0 to 3 and UCS was measured for different curing periods of time from 1 to 28 days according to mentioned method. UCS as a function of curing period is illustrated in Fig. 3 for all soils (S1, S2 and S3). As can be seen in Fig. 3a when the acrylic latex content was increased from 0 to 3%, for soil S1, UCS increased significantly. However, when the latex weight percent is low (0 or 1 W%), UCS increases rapidly and then when latex weight percent increase from 2 to 3 W% UCS increase less. This shows that the amount of latex weight percent relative to soil is somewhere between 2 and 3 W% especially when the economic aspects is taken in account simultaneously with mechanical improvement.

When curing time increase from 1 to 28 days in a given weight percent of polymer latex UCS increases first and then after about 14 days become relatively constant. This shows that after 14 days the interactions of latex and soil have already completed and UCS reaches to its maximum value. In control sample that contain 0 % of latex UCS increase slightly as a function of curing time. The optimum amount of acrylic latex was shown to be in the order of two percent relative total soil weight, this is significantly lower than the value obtained with other investigators who improved soil with traditional material and methods like (e.g. fly ash = 25%). It is believed that this is because of the small size of polymer particles in polymer latex.

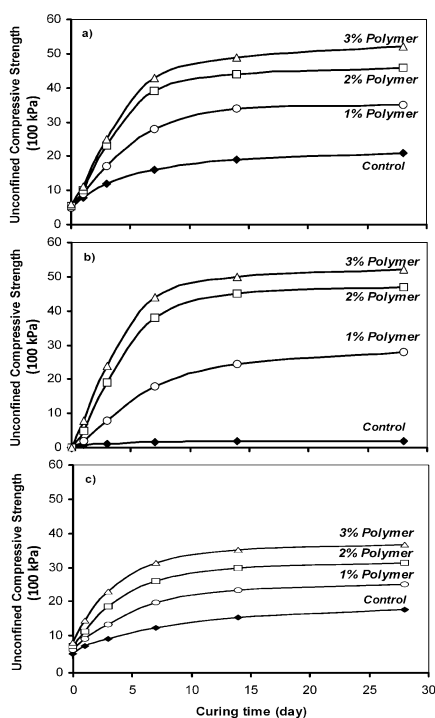


Fig. 3 The effect of latex weight percent and curing time on unconfined compressive strength of different soils; a: Soil S1, b: Soil S2 and c: Soil S3

Fig. 3b illustrates the effect of various amount of latex on UCS of soil S2 as a function of curing time. As can be seen the trend of result is similar as soil S1, however, the value of UCS is nearer to zero for S2 when there is no latex in the sample, then with 1 and 2 w% polymer latex, UCS increased rapidly. Then by increasing the weight percent of polymer from 2 to 3 w% UCS increase slightly. The evaluation of curing time on UCS of soil S2 showed the similar trend as soil S1. Constant UCS can be seen after 14 days for S2 showing that the interaction between polymer chains and the components of soil S2 has been completed within 14 days same as soil S1.

Fig. 3c shows the effect of polymer latex W% and its curing time on UCS of soil S3, again the trend is similar as soil S1. It can be seen that the increase of UCS by polymer latex addition for soil 3 is more regular in compare with soil S1 and S2. Then, UCS is nearly zero for soil S2 and it is about 5 kg/cm² for two other soils. This is due to the nature of these tree soils, for soil S2, the silty soil presents any UCS without polymer latex, indicating the existence of any adhesion between its particles in the absence of latex.

It is worth to note that UCS of S1 has changed from 15 to 53 kg/cm², and for S2; UCS moved from 2 to 51 kg/cm² and UCS of S3 varied from 12 to 33 kg/cm² when the weight percent of latex varied from 0 to 3%. In other words; mechanical properties of S2 was improved much better than S1 itself better than S3. The order efficient mechanical modification is S2 > S1 > S3.

These results can be explain by the fact that in S2 (silty soil), total surface of particles available to interact with polymer particles is higher than S1 which is itself higher than S3.

UCS of soil S1, S2 and S3 is evaluated when polymer weight percent was varied from 0 to 3 under different curing conditions and the results are shown in Figure 4. Three different curing conditions are as following; i) 7 days at 25 °C, ii) 1 day at 25 °C and one day at 40 °C and iii) one day at 25 °C and one day at 70 °C. In general, curing condition is important for coalescence of latex on the surface of soil particles. The coalescence of polymer particles occurs simultaneously with water evaporation from latex system. Therefore, temperature can affect this process via water evaporation rate enhancing. The more the temperature is high, the faster evaporation occurs. This lead to rapid coalescence of latex particles and soil will be in its final state.

Fig. 4a shows the effect of curing conditions on UCS when weight percent of polymer latex varies from 0 to 3 for soil S1. As can be seen from this figure under curing condition of 7 days and also under one day 25 °C + one day 70 °C, UCS of S1 increase from about 15 to more than 40 Kg/cm² when latex weight percent varies from 0 to 3.

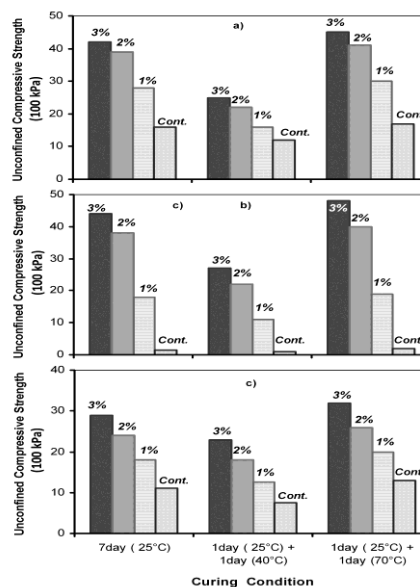


Fig. 4 Effect of curing condition of latex on unconfined compressive strength of soils a: Soil S1, b: Soil S2 and c: Soil S3

However under curing condition of 1 day 25 °C + 1 day 40 °C; UCS increases up to about 25 Kg/cm². It seems that when the samples exposed to latter condition, coalescence of latex is not complete because of low temperature and/or insufficient time. Similar results are obtained for soil S2 and S3, except for soil S2 the UCS is lower than two other soil in accordance with previous results. This could be due to the nature of soil S3 –which is clay- and under any condition UCS exceed 33 Kg/cm².

The effect of polymer weight percent on UCS of soil S1, S2 and S3 was evaluated under dry, wet and soak state and the results are shown in Fig.

5. As can be seen from Fig. 5a, UCS of soil S1 is illustrated as a function of polymer latex weight percent for three state of dry, wet and soak. This figure shows that UCS increases for all soil types till 2 W% of polymer latex then reaches to a plateau. However, UCS decreases form dry state to wet and soak both with and without polymer. When soils are modified with polymer, UCS decreases much less than non-modified soils. These results can be explained by the fact that when there is no polymer latex in the samples, the soil is itself responsible of cohesion of particles and grouts. Although, when polymer is used an additional force appears to keep small particle together and increase cohesion level of grouts in modified soil. This high level of cohesion; contribute to higher UCS of soil.

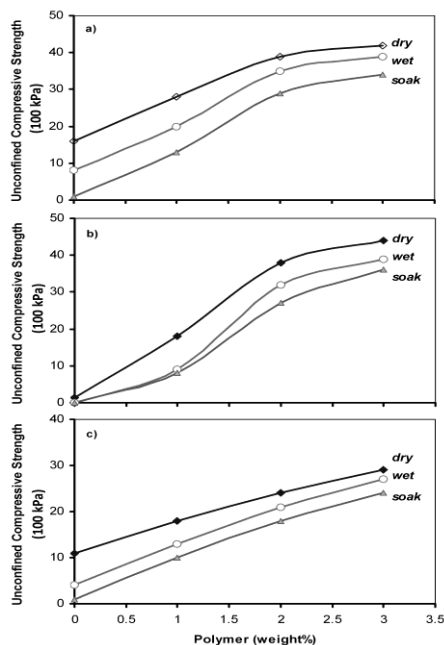


Fig. 5 Effect of latex weight percent on unconfined compressive strength under dry, wet and soak state; a: Soil S1, b: Soil S2, c: Soil S3

Fig. 5b shows UCS of soil S2 as a function of polymer latex weight percent for three state of dry, wet and soak. These results are more or less similar to those of soil S1.

Fig. 5c shows that UCS of soil S3 for different weight percent of polymer latex under dry, wet and soak states. It can be seen that UCS increases when polymer latex weight percent increases. However, contrary to soil S1 and S2 there is no plateau when polymer latex weight percent increases. The relationship between UCS and polymer weight percent for soil S3 seems to be linear. It appears that UCS decreases form dry state to wet and soak for all types of soils.

Fig. 6 shows water resistance of soil (S3) before and after treatment with acrylic latex. It can be seen that water absorption of modified soil is improved and also its mechanical properties in water medium is ameliorated. After one week the whole block prepared with unmodified soil is destructed, however; only half of latex modified block is wetted and it is relatively resistant to water penetration.

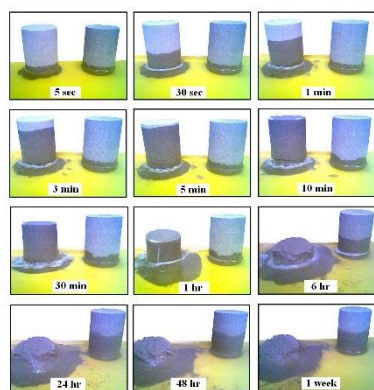


Fig. 6 Water resistant of latex modified soil and unmodified soil, in left hand side the block is made with modified soil and the right hand side sample is made with unmodified soil, the photos are taken at 5, 30 second, 1, 3, 5, 10, 30 and 60 minute, 6, 24, and 48 hours and 1 week after immersing of sample in water.

Microstructure of latex modified soils has been studied using electronic microscope in order to gain an insight to the mechanism of interaction between polymer particles in latex and soil particles. Electronic microscopic image was obtained for samples improved with 1 to 3 W% of polymer latex are shown in Fig. 7. As can be seen from Fig. 7 a, unmodified soil has some inter- pores whereas any inter- pores can be observed for modified soil with 1 or 3 W% latex from Fig. 7b and c. It is worthy to note that there are some intra- pores in these figures instead of inter-pores. It is proposed that the presence of polymer in modified soil makes some aggregates with defined borders from one side and covers inter-pores from other side. When the mixture of polymer and soil cure and simultaneously water evaporates, the small particles of polymers could make some shells around soil particles, some other polymer particles fill out the porosity of soil, in this way soil properties ameliorate. This in accordance with the founding of other researchers when they mention that in modified soil the majority of soil aggregates may cover with a latex shell causing a decrease in mechanical or swelling properties [20].

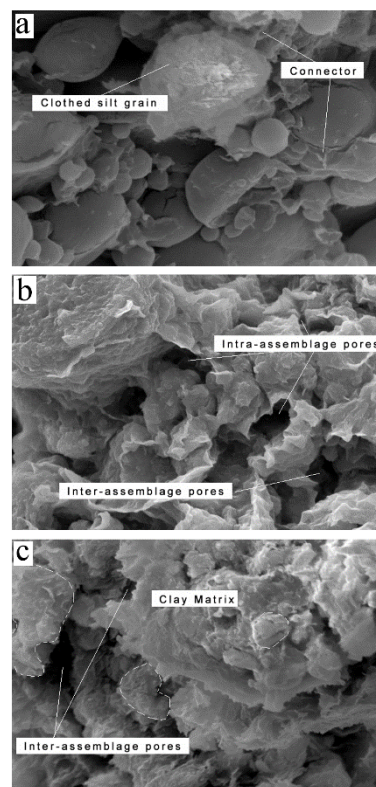


Fig. 7 Electronic microscopic images of unmodified soil S3 (a) and modified soil S3 with 1% polymer (b), Soil S3 with 3% polymer (c) all 2000 times

4. Conclusion

It was shown that it is possible to obtain a BuA-rich latex using SM as homogenizer which was expected to have acceptable T_g enable to improve soil properties. It was found that the use of acrylic latex for soil treatment has a considerable effect on physical and mechanical behavior of soil including; Swelling, Water resistance, UCS. The more the weight percent of latex was increased for stabilization of soil, the better improvement of soil behavior was seen for different types of soil. Optimum weight percent of latex relative total weight of samples was found to be between 2 to maximum 3 W%. In this range of latex weight percent relative total weight of soil sample; Swelling of soil (S3) was decreased from 22% to about 6% and UCS was increased from 2 to 51 Kg/cm² for S2, from 15 to 51 Kg/cm² for S1 and from 12 to 33 Kg/cm² for S3. The advantage of these nano-scale latexes over conventional soil stabilization materials is simple application method and being efficient in low weight percent because of their relatively smaller particle size.

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