Improvement an Expansive Soil using Polymethacrylate Polymer

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Abstract. One of the worldwide problematic soil is expansive clay accompanied by large volume change response when it subjected to a change in the water content. A chemical method for enhancing the swelling of expansive clayey soil is provided using Polymethacrylate (PMA) polymer material. An expansive soil is prepared in the laboratory by adding bentonite. Then experimental program is conducted to estimate the effects of adding the (PMA) polymer on the properties of the prepared expansive soil. Modified clay specimens are characterized based on sieve analysis, hydrometer, Atterberg limits, standard compaction, swelling potential, swelling pressure, unconfined compression strength and California Bearing Ratio (CBR) tests and 10 groups of soil samples are prepared at three various percentages of PMA (i.e. 3%, 5% and 7% by weight of dry soil). The tests results indicated that the induced of PMA polymers within expansive soil caused a decrease in the liquid limit (LL), plasticity index (PI), free swell%, rebound index (Cr) and optimum moisture content (OMC) and increase in plastic limit (PL), Unconfined Compression Strength (UCS) taken into consideration the influence of increasing curing time, compression index (Cc) and California Bearing Ratio (CBR). Also adding PMA polymers increase maximum dry density (MDD). The swelling potential decreased up to 71.7% with increasing PMA content to 7% respectively. The results of the tests indicated that the polymers significantly overcome the problems of expansive soils. In addition, higher UCS by 52.8% are observed by adding PMA with a percentages of 7%. Also adding same percentages of PMA polymer caused increasing in CBR value by 72.8%.

1. Introduction
Swelling or expansive soils are predominantly exist in arid and semiarid regions of the world. Expansive clays are described as problematic because they swells with absorption of water and shrinks with adsorption. Principally, swelling appears as water infiltrates between the clay particles, making them to separate, and such volume changes caused by swelling and shrinkage movements often distress the infrastructure that is not designed to resist these movements \cite{1}. There are numerous methods of stabilizing soil to have the engineering specifications that are required, these are various from mechanical to chemical methods \cite{2}. The swell potential for the expansive soils is determined by the amount and type of clay minerals such as montmorillonite, smectite, illite and chlorite and thus the natural expansiveness of these soil. Generally, the larger quantity of the minerals presents in the soil, the greater the expansive potential \cite{3}. Improvement using polymer is a new enhancing agent elaborated to improve the mechanical performance and applicability of expansive clayey soils, enhance strength and durability or prevent dust generation and erosion. The use of polymer materials that are nontraditional in improvement of soil is growing daily. In this study, a chemical material is...
used for treating the swelling of prepared expansive clayey soil by adding Polymethacrylate polymer (PMA). An experimental program is provided for investigating the effect of adding Polymethacrylate (PMA) with percentages by weight on the liquid and plastic limits, compaction characteristics, strength, swelling and consolidation characteristics.

2. Materials and Methods

2.1 Bentonite
The Bentonite produced by Turkey CO.LTD, was used throughout this research in order to prepare the expansive soil and the chemical composition are as shown in Table 1.

Table 1. Chemical composition of Bentonite used.

| Chemical Component | Content (%) |
|--------------------|-------------|
| Rubidium           | 14.20       |
| Silicon            | 21.77       |
| Carbon             | 34.42       |
| Oxygen             | 15.04       |
| Sodium             | 12.35       |
| Aluminium          | 8.85        |
| Magnesium          | 2.22        |

2.2 Clayey Soil
The disturbed samples of clay soil used in this study is brought from Baghdad city at a depth of (2 m) under the existing ground level. The soil used was silty clay (58% clay + 42% silt). Therefore, different tests were executed in the laboratories belonging to Civil Engineering Department of Al-Nahrain University on this soil to gain its engineering properties. The grain size distribution of natural soil, bentonite and prepared expansive soils is shown in ‘figure 1’.

![Figure 1](image)

**Figure 1.** The grain-size distributions of natural soil, prepared soil and bentonite.

2.3 Polymethacrylate (PMA)
The Acrylic polymer polymethacrylate (PMA) produced by Interchimiques SA company in France was used in this study according to the physical properties given in Table 2. Acrylic is water-soluble polymer which is considered as an emulsion elastic chemical material that shows higher bonding with the substrate as an additive in optimum water content, and the cohesion and the strength as well. Thus, synthetic polymer emulsions consisting primarily of acetate polymers that are produced specifically for soil stabilization. In addition, at higher application such soil stabilization synthetic polymer is diluted with water as an emulsion and then mixed-in to the soils. So, polymethacrylate polymer has relatively low curing time for stabilized samples, and has long-term durability and thus can be easily applied to the soils, therefore this is considered as an advantages to be used in geotechnical engineering projects [4]. Figure 2 shows the SEM for untreated and treated soil with PMA polymer carried out by the Department of Physics science at Al-Nahrain University.

| Chemical formula | \((C_2O_2H_4)_n\) |
|------------------|-----------------|
| Physical state   | Liquid          |
| Solubility in water | solution      |
| color            | White           |
| Assay            | 99.9%           |
| Appearance (Form)| powder          |
| Molecular weight | 8000            |

Table 2. Physical properties of PMA polymer used.

2.4 Prepared Expansive Soil
To achieve the research aims for describe the effect of polymer materials on the properties of expansive clay and as the natural soil has swell of 1% and is classified as CL, bentonite with a percentage of 30% was added to 70% of natural soil in laboratory to prepare the expansive clayey soil used in this study. The prepared soil swell was increased to 18 % and is classified as CH according to Unified Classification System (UCS).

Figure 2. SEM for (a) of untreated soil and (b) treated soil with PMA polymer.
2.5 Preparation of the Soil Mixture for Testing
At oven with temperature of 105°C the soil is dried first for 24 hours before it is used in the mixtures and then by Los Angeles machine it is pulverized. After that 30% of bentonite was mixed with 70% of this dried natural soil to prepare high plasticity expansive clayey soil. Polymethacrylaye (PMA) polymer is an aqueous acrylic emulsion that is diluted in water in accordance with manufacturer’s recommendations by dissolving 10g L in tap water at 10-65ºC by magnetic stirrer, then, the various percentages of polymers blended with prepared soil by mixer until a homogeneous color was obtained then left to air to dry out.

3. Experimental work
Classification tests [5], Atterberg limit tests [6], compaction test [7], unconfined compression test [8], consolidation test [9] and California Bearing Ratio test (CBR) [10] together with chemical tests are conducted on the expansive and stabilized soils. The physical and chemical properties obtained for prepared expansive clayey soil are as shown in Table 3 and Table 4 respectively.

| Properties          | Standard          | Expansive soil |
|---------------------|-------------------|----------------|
| Sand (%)            | ASTM D 422        | 0              |
| Silt (%)            | ASTM D 422        | 37             |
| Clay (%)            | ASTM D 422        | 63             |
| Liquid limit        | ASTM D4318        | 82             |
| Plastic limit       | ASTM D4318        | 30             |
| Plasticity index    | ASTM D4318        | 52             |
| Optimum moisture content (%) | ASTM D 698   | 27.7           |
| Max. dry density (kN/m³) | ASTM D 698  | 1.49           |
| Specific gravity, Gs | ASTM D 854        | 2.68           |

| Chemical element     | Percent (%)       |
|----------------------|-------------------|
| SiO₂                 | 58.5              |
| Al₂O₃                | 14.4              |
| CaO                  | 8.1               |
| MgO                  | 3.8               |
| Na₂O                 | 2.2               |
| FeO                  | 1.7               |
| K₂O                  | 1.2               |
| BaO                  | 0.8               |
4. Results
The physical tests that are conducted on the prepared expansive soil before and after improvement were swelling potential, unconfined compression strength, consolidation and California bearing ratio (CBR) tests. The following are the results of these tests.

4.1 Atterberg limits
According to Casagrande method the Liquid limit tests are carried out on the soil samples [6] and then the plastic limits were obtained for the samples. The liquid and plastic limits test has been carried out with various percentages of PMA polymer soil mixtures. The effects of adding different percentages of PMA polymer (3, 5, and 7%) on the consistency limits values are given in Table 5 and plotted in ‘figure 3’. The results indicate that the liquid limit (LL) and plasticity index (PI) values decreased with increasing PMA content, while plastic limit (PL) increases with increasing amount of PMA. The maximum decrease in liquid limit and plasticity index is found with increasing PMA up to 7% PMA, these additions reduced the liquid limit (LL) to 76.2 % and (PI) to 32.8%. However, the plastic limit increases with the increasing in PMA content up to 7% to about 38.2 % as shown in Table 5. This decrease in liquid and plasticity index may be due to the synthetic polymer emulsion (PMA), which may bond soil particles together and lower the soil ability to adsorbing excess water by creation of composites effectively modifying and decreases the clay plasticity. Thus, at higher application rates emulsions can be used to stabilize soils [11].

| Property          | Prepared expansive soil | Treated soil with 3% PMA | Treated soil with 5% PMA | Treated soil with 7% PMA |
|-------------------|-------------------------|--------------------------|--------------------------|--------------------------|
| Liquid limit (%)  | 82                      | 76.2                     | 74                       | 71                       |
| Plastic limit (%) | 30                      | 33.4                     | 35.8                     | 38.2                     |
| Plasticity index (%) | 52                   | 42.8                     | 38.2                     | 32.8                     |

**Figure 3.** The effect of adding PMA polymer on Atterberg limit of expansive clayey soil.
4.2 Compaction test
The compaction test that was carried out on the soil samples is standard one according to [7]. Such test was carried out on expansive and stabilized soil samples. The curves that represents the results of compaction test are plotted in ‘figure 4’ and Table 6 summarized the amounts of optimum moisture content and maximum dry unit weight obtained for different percentages of polymer-soil mixtures. It is observed that the addition of PMA affected the compaction parameters of clayey soil and the maximum dry density increased with the addition of polymer while optimum water content decreased as shown in ‘figure 4’. The reducing in the optimum moisture content may be because of the change in composite samples surface area. The higher maximum dry density may be due to the behavior of clayey soil mixed with synthetic emulsion polymer which may effect on the texture, changing it from plastic to non-plastic soils and this phenomenon being higher with the increase of adding emulsion PMA polymer.

![Figure 4](image)

**Figure 4.** The effect of adding PMA on dry density-water content relationship.

|                            | Prepared expansive soil | Treated soil with 3% PMA | Treated soil with 5% PMA | Treated soil with 7% PMA |
|---------------------------|-------------------------|--------------------------|--------------------------|--------------------------|
| Max. dry density (g/cm³)  | 1.49                    | 1.5                      | 1.54                     | 1.59                     |
| Optimum moisture content %| 27.7                    | 24                       | 21.8                     | 20                       |

4.3 Swelling test
The values of swelling of the prepared clayey soil with the addition of polymer are shown in ‘figure 5’. As it can be observed from the results, the addition of PMA decreased the swelling of clayey soil–emulsion mixtures. The free swell decreased from 18% to 5 % by adding up to 7% PMA polymer. Therefore, the addition of PMA emulsion polymer may surround the silt and clay particles and filled the voids in the samples and hence decrease the permeability of expansive clayey soil.
4.4 Unconfined compression test

Unconfined compressive strength tests were conducted according to [8] on samples of prepared expansive soil and treated soil with the different content of PMA polymer at different curing intervals of 7 and 21 days and the same tests on these soils were conducted on samples without curing. The results are shown in figures 6’ (a), (b) and (c) and Table 7. It has been indicated that the increase in PMA amount and curing period has improved the unconfined compressive strength of treated samples. Though, the addition of PMA polymer played an important role in development of the UCS of polymer mixed soil. The percent for PMA at which maximum strength is achieved was 7% for both 7 days and 21 days curing period which predicts increasing in the UCS value up to 390.88 kPa and 440.18 kPa for 7 days and 21 days curing period respectively, so, the induced PMA led to a significant increase in the unconfined compressive strength of stabilized soil and this is attributed to the adsorption mechanism of polymer emulsion that more likely to bond to the clay content (fine particle size) as reinforcement and formation of strong hydrogen bonds between the surface hydroxyls of the clays and the carbonyl groups of the polymer molecules. So, the molecules of polymer easily can form an electrostatic bond with clay particles then their retention on clay which is mostly through sorption of polymer molecules can occur on both internal and external pore surfaces or microscopic interlayer spaces that cause more cohesion of particles of clay and an increase in value of UCS. In addition, adsorption of polymer can be show a greater strength, this means that the increase in polymer content leads to an increase in the stiffness of soil samples [4].

| PMA% | UCS(kPa) without curing | UCS(kPa) for 7day curing | UCS (kPa) for 21day curing |
|------|-------------------------|--------------------------|---------------------------|
| 0    | 200.84                  | -                        | -                         |
| 3    | 250.70                  | 295.412                  | 382.42                    |
| 5    | 307.85                  | 355.86                   | 408.11                    |
| 7    | 352.82                  | 390.88                   | 440.18                    |
Figure 6. The effect of different percentages of polymer on UCS (Kpa) at (a) without curing period (b) 7 days curing period and (c) 21 days curing period.
4.5 Consolidation test
Compression index (Cc), swelling Index (Cr) and coefficient of consolidation (Cv) values of expansive clayey soil treated with different percentages of PMA polymer are shown in ‘figure 7’. The value of (Cc) decreased with the increase of addition PMA content and value of the rebound index (Cr) also decrease with increase of addition of PMA content for all soil samples. The coefficient of consolidation (Cv) is slightly increases upon the addition of PMA polymer emulsion as shown in ‘figure 7’.

![Figure 7. Consolidation test for different PMA content.](image)

4.6 Effect of adding PMA polymer on California Bearing Ratio (CBR)
The influence of adding PMA polymer on CBR values for the expansive clayey soil is shown in ‘figure 8’. Generally CBR value increases with higher percentage of PMA polymer content. Thus, the maximum percentage of PMA which gives the optimum value of CBR is found when adding up to 7% PMA and this percentage shows improvement in the CBR value from 5.3 % to 19.0%. The soil stabilization with emulsion polymer (i.e., PMA) improves the strength behavior of clayey soils and the increasing polymer content lead to higher stiffness of soil samples.

![Figure 8. Effect of adding PMA polymer on California Bearing Ratio (CBR).](image)
6. Conclusions
The addition of PMA decrease the liquid limit (LL) and the plasticity index (PI) while the plastic limit (PL) increases with increasing PMA polymer amount. The higher decrease in liquid limit and plasticity index is obtained with the addition of 7% PMA where LL and PI becomes 71% and 32.8% respectively whilst the PL is increased to about 38.2%. The maximum dry unit weight increase from 1.49 gm/cm$^3$ to 1.59 gm/cm$^3$ with the increase of the PMA content to 7%, however optimum moisture content decreases with addition of 7% PMA from 27.5% to 20%. The swelling potential values decreased with increasing PMA polymer content. The maximum percentage of PMA that gives the lowest free swell is 7% which reduced the free swell to 5%. PMA improved the unconfined compressive strength by 24.8% when increasing percentage from 0% to 3%, and then the unconfined compressive strength increased by another 22.8% at 5% of PMA content. As well as, curing period improves unconfined compressive strength for 21 days from 200.84 kPa for 0% PMA to 440.18 kPa for 7% PMA content. Both the compression index (Cc) and the rebound index (Cr) decreases with increasing addition of PMA percentage and the optimum percentage of PMA polymer causes the higher reduction in (Cc) and (Cr) is found to be 7%. Thus, the coefficient of consolidation (c$_v$) is slightly increase with increasing PMA percentage. The value of CBR increase with addition of PMA polymer. The optimum percent of addition which gives a higher enhancement in CBR value is found with adding 7% PMA where its value improved from 5.3 to 19.0.

6. References
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