Improving Gypseous Soil Properties by Using Non-Traditional Additives

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ABSTRACT

Gypseous soils are common in several regions in the world including Iraq, where more than 28.6% of the Iraq surface is covered with this type of soil. This soil, with high gypsum content, causes different problems for construction and strategic projects. As a result of water flow through the soil mass, the permeability and chemical arrangement of these soils varies with time due to the solubility and leaching of gypsum. In this study, the soil of 36% gypsum content, was taken from one location, which is about 100 km southwest of Baghdad. The samples were taken from depths of 0.5 and 1 m below the natural ground and mixed with 3%, 6% and 9% of Copolymer and Novolac polymer to improve the collapsibility, permeability and compaction parameters. The results of the experimental work showed a noticeable improvement of the collapsibility and permeability of the soil treated with polymer materials compared to the untreated soil. Furthermore, adding 3% of polymer (copolymer and novolac polymer) materials gave the best improvement in collapsibility which reached a 44.5 and 46%, respectively, in 3 hours. The improvement in permeability reached 98.6% copolymer and 86.2% novolac polymer in 1 day.

1. Introduction

Gypseous soil is considered as one of the most difficult unsaturated soils in the construction of roads and buildings. The presence of the gypsum (Hydrated Calcium Sulphate (CaSO4·2H2O)) in this soil affects its mechanical and physical properties and makes the soil more sensitive to the water. When water reaches gypseous soil from a heavy rainfall, it causes rearrangement of soil particles, and as a result volume change (decrease) occurs. This change in volume significantly causes a structural failure since the soil loses the bond between the particles and becomes weak to withstand and resist the load applied on it depending on the soil nature and geological structure, the primary soil density, soil structure, the imposed stress, and the amount of wetting [1,2]. In civil engineering the soil can be classified as gypseous soil depending on the amount of gypsum content in it, regardless of soil color or shape. Several researchers indicated that a certain percent of gypsum should exist, such as, 3%, 4%, 6% as a lower limit [3]. These rates of gypsum have high effects on the physical and mechanical characteristics of soil, and these effects occur unevenly in the soil according

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https://doi.org/10.30772/qjes.v12i4.637
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to the amount of gypsum. To reduce the damage caused to the structure, the
gypseous soil should be improved in two ways: mechanical and chemical.
The mechanical method is a physical process done by removing and/or
adding another soil. The chemical method is made by adding a chemical
substance that can change soil properties by means of chemical reactions
[4,5,6]. It has become necessary to use non-traditional suburb materials
to achieve the economic and environmental considerations such as polymers
and resins, which are characterized by their effectiveness in a short time.
However, there is still rare information about non-traditional suburb
materials especially for polymers. However, for economic reasons the
chemical composition of polymer is unknown by the companies, which
made the researchers looking for its result in improvement rather than on
performance mode. Since polymers and resins are not widely used in
the past, it has become necessary for many researches to investigate the effect
of these additives on the engineering soil properties of gypseous soils.

In 2010, Al-Numani [7] took a soil sample from Najaf that contains
35% of gypsum and treated it with different rates of cement content (4-8%).
The conducted laboratory tests indicated that increasing the cement content
produced an increase in both the optimum water content and maximum dry
density to (23.5 and 7.6%). Vahid and Mohsen [8] used two types of
polymer to improve sandy soil and found an increase in compression strength
from 0.03 MPa to 5.2 MPa. Al-Neami [9] used (2, 4, and 6%) clinker additive
to treat gypsum soil from Al-Exandra, Babylon, and found that the best clinker ratio was (4%) which decreased the collapsibility of
soil. Fattah and Salman [10] used dynamic compaction method to test three
gypseous soil samples with 27, 41.1, and 60.5% gypsum content. The
number of blows used in this study were between 20 and 40. Also, three
heights of the drop were used: 35, 50, and 65 cm. The experimental results
showed that the best collapsibility was obtained when the samples
compacted to 20 blows. The results also showed that the dynamic
compaction had a greater effect with increased gypsum content. Aldaood
and Al-Kiki [11] used samples with 20% gypsum and improved by 4% lime
and the samples were treated for 2 days. The results showed that when
increasing the water velocity through the soil mass, the weight of soil and
gypsum are decreased. They noticed a reduction in strength with increasing
soaking time. Aldaood and Al-Mukhtar [12] studied the effect of soaking
on the mechanical properties of gypseous soil that was treated with 3% lime
and cured for 28 days. It was noticed that a long time soaking had a great
effect on the unconfined compressive strength and volume change of the
stabilized soil particles. Fattah, et al. [13] used four samples of gypseous
soil with different percentages and treated them by grouting acrylate liquid
to reduce the collapsibility. The treated samples showed that the acrylate
liquid reduced the collapsibility of the soil by more than 60–70% and this
behavior may be attributed to the fact that acrylate liquid coated the soil
particles, and thus, isolated them from being subjected to the effect
of water. The improved samples showed a low collapse potential where
acrylate liquid reduced the collapsibility of samples by more than 50–60%
and increased the cohesion of the soil. Majeed et al. [14] took two sandy
clay samples from the AL- Basra Governorate and improved them by the
cement of a percentage of 2, 4, and 6% and by novolac polymer with
percentages of 0.2, 0.4, and 0.6%. The test results showed that these ratios
were sufficient to obtain a high dry density and increase the strength by 15
and 18.75% with a duration of less than three hours. However, the addition
of 6% cement and 0.6% Novolac polymer led to increase the maximum dry
density by 2.33 and 3.5 % and the angle of internal friction but reduced the
optimum water content. Furthermore, this method reduced the cost by 50%
compared to the method of replacing soil with sand. Ibrahim and Mahmoud,
[15] took two gypseous soil samples from Baiji and Al-Thurthar and mixed
them with 5, 2.5, and 6% of hydrated lime, hydrated calcium chloride, and
kaolin to improve the collapsibility of soil. It was found that the calcium
chloride and kaolin achieved the best results while the lime reduced the soil
collapsibility to a small degree. Ibrahim and Schanz [16] used a mixture of
30% of Silber sand and 70 % of Pure Gypsum and treated it with different
percentages of silicone oil to improve the engineering properties. The study
results showed the silicone oil was able to improve the collapsibility and
shear parameters of the gypseous soil. Al- Hadidi and AL-Maamori [17]
used gypsum soil samples with 42.55% gypsum from Karbala city. Different
water cement ratios (W/C) were used to decrease the collapsibility of
the earth canal and the results showed that 2 % of W/C led to decrease
the collapsibility of soil. Vahid and Mohsen [18] took sand samples from
Kerman city, Iran, and mixed them with 2, 4, and 6% of polymer with
different periods of treatment (3, 7, and 28 days). They found that when the
polymer content increased to 6%, the unconfined compressive strength
increased by (66.31 %) in 28 days compared with 3 days. Al-Hadidi, and
Ibrahim [19] used 6, 10, and 12% of polyurethane to reduce the soil erosion
of the irrigation canal which was made from gypsum soil in Karbala city
with 41% gypsum. The researchers found the best percentage to use was
10% which reduced the erosion by 86.2%.

The main goal of this study is to improve the properties of gypsum soil
(collapsibility, permeability and compaction parameter) with small
quantities and suitable prices by using new non-traditional materials, so
the materials that used are copolymer and novolac polymer.

2. Materials and Experimental Procedure

2.1. Materials

2.1.1. Gypseous Soil

To achieve the purpose of study, natural gypseous soil of 36% gypsum;
is taken from one location about 100 km southwest of Baghdad. The
samples were taken from depths 0.5 – 1 m below the natural ground surface.
The unit weight of the soil in the location was 14.5 kN/m³ and the natural
water content 5%. The undisturbed soil samples were air dried, made
homogeneous, put in plastic bags, and transported to soil mechanics
laboratory at civil engineering department, college of engineering at Al-
Qadisiyah University to evaluate the engineering properties of the soil.

2.1.2. Copolymer

Copolymer is a mix of non-ionic environmentally safe co-polymer
products, where it is considered a new material used for treatment. The
material is diluted with water and added to the soil and characterized by the
following properties [20]:

- Do not pollute groundwater.
- Safe to plant and animal life in the soil.
- Contains soil moistening agents.
- Good resistance to the Ultraviolet rays.
- Good resistance to erosion.
- Penetrates the soil or any particulate materials.

Table 1. shows the technical properties and form of Copolymers [20]:
2.1.3. Novolac Polymer

Novolac polymer can be defined as the reaction between phenol-formaldehyde and phenol in acid catalyst media and it involves 5 to 6 % of gasoline rings per molecule. The common properties of Novolac polymer are [21]:

1. It has a small molecular weight and it is thermoplastic.
2. Porous arrangement with less mechanical possessions.
3. The curing reaction for the novolac polymer is carried out over 100 ºC.
4. It has a density of 1 to 2 % of the density of natural soil and has a color ranging from yellow to orange.

2.2. Experimental Work

2.2.1. Compaction Test

Standard Proctor compaction test was carried out following (ASTM 698) method A [22]. A mold of 10 cm in diameter and 16.5 cm in height was used. The samples were compacted in three layers with 25 blows for each layer using a 2.5 kg hammer which is dropped from 30.5 cm height and this test was carried out for treated and untreated soils.

2.2.2. Collapse Test

Single collapse test was carried out according to the guide proposed by Jennings and Knights [23] and ASTM D5333 [24] on natural compacted and treated gypseous soil samples with various ratios of co-polymers, novolac polymer. The dry weight of specimens was obtained to determine the change in compressibility properties of gypseous soil by using specimens equipped with a ring that was 50 mm in diameter and 19 mm in height. The samples were left in the water for 24 hours with a pressure of 200 kPa and then additional static load was applied until it reached 800 kPa then samples were unloaded. The collapse index is obtained from the formula below by using (ε-log p) graph under the effect of a certain stress level.

\[ C.P = \frac{\Delta e}{(1 + e)^3} \] ............................... (1)

Where:
C.P = Collapse Potential,
\( \Delta e \) = void ratio before and after soaking,
\( e^o \) = Initial voids ratio.

2.2.3. Permeability Test

Permeability test was performed for all samples (treated and untreated soil) according to ASTM D-2434 [25]. A mould with 10 cm in diameter and 13 cm in height was used. The mould was connected at the top inlet to a water source at a height of 180 cm. The mould had a side outlet at the bottom for the water to flow out of the sample. The quantity of flow for a certain period was collected and recorded. The permeability coefficient was calculated using the equation:

\[ K = \frac{Q}{(A \times t)} \] ............................... (2)

where:
\( k \) = coefficient of permeability,
\( Q = V/T \) quantity of water discharged,
\( A \) = cross-sectional area of mold,
\( t \) = total time of discharge.
\( h \) = the loss of water.

2.2.4. Physical Test

The specific gravity of the soil is determined according to BS 1377[26], but Kerosene was used instead of water due to the dissolution action of gypsum in water.

The soil was subjected to grain size distribution test according to ASTM D422 [27] to classify the soil. Fig. 1, clearly shows that the soil can be classified as poor grade sand (SP) according to the Unified Soil Classification System (USCS). The engineering and physical properties of the soil are shown in Table 2.

**Figure 1.** Grain size distribution of gypseous soil

### Table 1. The properties of Copolymers

<table>
<thead>
<tr>
<th>Element</th>
<th>Style</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>white (transparent once dried)</td>
</tr>
<tr>
<td>Form</td>
<td>liquid</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.03</td>
</tr>
<tr>
<td>Solid content</td>
<td>20-22 %</td>
</tr>
<tr>
<td>Viscosity</td>
<td>300 – 350 mPas</td>
</tr>
<tr>
<td>Surface Tension</td>
<td>40 mN/m</td>
</tr>
<tr>
<td>Freezing point</td>
<td>0 ºC</td>
</tr>
<tr>
<td>Boiling point</td>
<td>100 ºC</td>
</tr>
<tr>
<td>pH</td>
<td>5.5</td>
</tr>
</tbody>
</table>

### Table 2. The results of the classification of soil test and physical properties of gypseous soil.

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Value</th>
<th>Standard of the test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Dry Unit Weight</td>
<td>16.28</td>
<td>ASTM, 698 [22]</td>
</tr>
<tr>
<td>( \gamma_{\text{max}} ) (kN/m³)</td>
<td>9.47</td>
<td>ASTM D5333 [24]</td>
</tr>
<tr>
<td>Permeability (cm/sec)</td>
<td>1.7×10⁻³</td>
<td>ASTM D-2434 [25]</td>
</tr>
<tr>
<td>Specific gravity, GS</td>
<td>2.54</td>
<td>B.S1377:1975[26]</td>
</tr>
<tr>
<td>D10</td>
<td>0.1</td>
<td>ASTM 422[27]</td>
</tr>
<tr>
<td>D30</td>
<td>0.19</td>
<td>---</td>
</tr>
<tr>
<td>D60</td>
<td>0.3</td>
<td>---</td>
</tr>
<tr>
<td>Coefficient of curvature, Cc</td>
<td>1.203</td>
<td>---</td>
</tr>
<tr>
<td>Coefficient of uniformity, Cu</td>
<td>3</td>
<td>---</td>
</tr>
<tr>
<td>Unified Classification system</td>
<td>SP</td>
<td>---</td>
</tr>
<tr>
<td>Optimum Water content Wopt (%)</td>
<td>11</td>
<td>ASTM, 2216[28]</td>
</tr>
</tbody>
</table>
### 2.3. Chemical Tests

Several chemical tests were carried out on the soil as shown in Table 3. These tests included:

1. Gypsum content which was determined by using the hydration method recommended by Nashat and Al Mufty [29] and S.O.R.B/R6[30]. The hydration method consisted of oven drying the soil sample at 45°C until the sample weight became constant. The sample weight at 45°C was recorded. After that, the same sample was dried at 110°C until the weight became constant and recorded. The gypsum content was found according to the equation:

\[
X\% = \frac{(W45^\circ C - W110^\circ C) \times 4.778}{W45^\circ C} \times 100 \quad \text{..................................(3)}
\]

Where:
- \(X\%\) = gypsum content (%).
- \(W45^\circ C\) = Weight of the soil sample at (45°C).
- \(W110^\circ C\) = Weight of the soil sample at (110°C).

2. Total Sulfate Constant (SO₃) Test

This test was carried out according to S.O.R.B/R6. In this test natural gypseous soil was used as follows:

1. Take 2 g of soil and add 200 g of hydrochloric acid at a concentration of 10%.
2. Heat the sample to boil and filter using filter paper No. 42.
3. Remove the sample from the heating and add 25 ml of barium chloride with 5% concentration and leave it for the second day.
4. Filter the sample using filter paper No. 54 and wash the precipitate well with hot water until cleaned and place it in a weighed beaker.
5. Put the beaker in the oven to 850°C for a quarter of an hour and then leave it to cool and take the weight. SO₃ was found according to the equation:

\[
SO3\% = \frac{(W2 - W1) \times 34.3}{W} \quad \text{..................................(4)}
\]

Where:
- \(W\) = the weight of the sample.
- \(W1\) = the weight of the sample after heating.
- \(W2\) = the weight of the sample after heating.

3. Total Soluble Salts (T.S.S) Test

T.S.S test was performed according to S.O.R.B/R6 on natural gypseous soil as follows:

1. Take an empty weighted beaker.
2. Place 25 ml of the filtrate sample in the beaker and heat to dry.
3. Remove the sample from heating and leave it to cool and then take the weight again. T.S.S was found according to the equation:

\[
T.S.S = \frac{(W1 - W2) \times 10}{V} \quad \text{..................................(5)}
\]

Where:
- \(W1\) = the weight of beaker before heating.
- \(W2\) = the weight of beaker after heating.
- \(V\) = the volume of filtrate.

4. The X-ray Test

The X-ray tests were carried out on natural gypseous soil identifies the clay and non-clay minerals. These tests were carried out with the assistance of the laboratories of the state company of Geological Surveying and Mining. Results of the X-ray diffraction test are shown in Table 4, and Table 5, shows the details of the test designation.

#### Table 3. The results of chemical properties tests of gypseous soil

<table>
<thead>
<tr>
<th>Chemical Property</th>
<th>Value</th>
<th>Natural value</th>
<th>Standard of the test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (SO₃ %)</td>
<td>13.87</td>
<td>5%</td>
<td>S.O.R.B/R6 [30]</td>
</tr>
<tr>
<td>Total soluble salts (T.S.S %)</td>
<td>9.8</td>
<td>Max 10%</td>
<td>---</td>
</tr>
<tr>
<td>Gypsum content (%)</td>
<td>36</td>
<td>Max 10.75%</td>
<td>---</td>
</tr>
<tr>
<td>PH value</td>
<td>8.21</td>
<td>0-14</td>
<td>---</td>
</tr>
<tr>
<td>O.M (%)</td>
<td>0.86</td>
<td>Max 2%</td>
<td>B.S 1377-3-1990</td>
</tr>
</tbody>
</table>

#### Table 4. The results of the X-ray test of gypseous soil

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt. %</th>
<th>Wt. % sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>53.46</td>
<td>0.3</td>
</tr>
<tr>
<td>Na</td>
<td>0.56</td>
<td>0.07</td>
</tr>
<tr>
<td>Mg</td>
<td>1.8</td>
<td>0.07</td>
</tr>
<tr>
<td>Al</td>
<td>3.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Si</td>
<td>20.08</td>
<td>0.18</td>
</tr>
<tr>
<td>S</td>
<td>5.06</td>
<td>0.1</td>
</tr>
<tr>
<td>K</td>
<td>1.64</td>
<td>0.07</td>
</tr>
<tr>
<td>Ca</td>
<td>11.65</td>
<td>0.14</td>
</tr>
<tr>
<td>Ti</td>
<td>0.13</td>
<td>0.06</td>
</tr>
</tbody>
</table>

#### Table 5. Details of the test designation

<table>
<thead>
<tr>
<th>Test designation</th>
<th>Soil state</th>
</tr>
</thead>
<tbody>
<tr>
<td>0G</td>
<td>Gypseous soil without any added material</td>
</tr>
<tr>
<td>3GP</td>
<td>Gypseous soil with adding 3% of Copolymer by weight</td>
</tr>
<tr>
<td>6GP</td>
<td>Gypseous soil with adding 6% of Copolymer by weight</td>
</tr>
<tr>
<td>9GP</td>
<td>Gypseous soil with adding 9% of Copolymer by weight</td>
</tr>
<tr>
<td>3GN</td>
<td>Gypseous soil with adding 3% of Novolac polymer by weight</td>
</tr>
<tr>
<td>6GN</td>
<td>Gypseous soil with adding 6% of Novolac polymer by weight</td>
</tr>
<tr>
<td>9GN</td>
<td>Gypseous soil with adding 9% of Novolac polymer by weight</td>
</tr>
</tbody>
</table>

### 3. Analysis and Discussion of the results

#### 3.1. Compaction test

The results of the compaction test are shown below in Fig. 2. and Fig. 3.
Several observations can be drawn from Fig. 2 and Fig. 3 as illustrated in the following:

1. Little change was observed in the dry unit weight of the improved soil where it increased with increasing the polymer material to 3%. This behaviour may be attributed to the fact that these materials filled the voids between soil particles and had low specific gravity which let them replace some of the soil mass. Subsequently, this led to create a new structure with a large volume and decreased sample weight.

2. The optimum moisture content seemed to stay constant in percentages of 6% and 9% of the co-polymers where these materials worked as waterproof while it began to increase with increasing novolac polymer percentage to 9% where the novolac polymer (solid form) needed more water to attach to the soil particles.

### Table 6. The result of compaction test of the gypseous soil treated by copolymer and Novolac polymer

<table>
<thead>
<tr>
<th>Materials</th>
<th>Maximum dry unit weight (kN/m³)</th>
<th>Optimum moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0G</td>
<td>16.28</td>
<td>11</td>
</tr>
<tr>
<td>3GP</td>
<td>16.77</td>
<td>13</td>
</tr>
<tr>
<td>6GP</td>
<td>16.59</td>
<td>8</td>
</tr>
<tr>
<td>9GP</td>
<td>16.51</td>
<td>8</td>
</tr>
<tr>
<td>3GN</td>
<td>17.18</td>
<td>13</td>
</tr>
<tr>
<td>6GN</td>
<td>16.5</td>
<td>16</td>
</tr>
<tr>
<td>9GN</td>
<td>16</td>
<td>17</td>
</tr>
</tbody>
</table>

### 3.2. Collapse Test

The samples that were used in this test were compacted to 16.28 kN/m³ maximum unit weight and 11% optimum water content. As a result of the high gypsum content for natural soil that was used in this research (which is 36%), the collapse potential was 9.47% which was classified as Moderately severe (explained in a drop of the curve for natural soil in Figs 4 and 5) according to the ASTM D5333. The addition of polymer materials caused a reduction in the collapse index depending on the amount of improving materials. Figs 4 and 5 below shows the results of collapse tests for samples.
The collapse index decreased with increasing polymer materials to 3%. This behaviour of soil may be attributed to the fact that these materials covered the soil particles and increased the bonding action between the soil particles. On the other hand, after 3% polymer content, the polymers made soil particles flocculate and slide causing a drop in soil cohesion. This made the structure of the mass weak and increase soil particles covered. The results are shown in Table 7 and Table 8.

### Table 7. The results of a single collapse test before and after improvement

<table>
<thead>
<tr>
<th>Materials (%)</th>
<th>Collapse Index, IC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0G</td>
<td>9.47</td>
</tr>
<tr>
<td>3GP</td>
<td>5.26</td>
</tr>
<tr>
<td>6GP</td>
<td>6.2</td>
</tr>
<tr>
<td>9GP</td>
<td>6.57</td>
</tr>
<tr>
<td>3GN</td>
<td>5.16</td>
</tr>
<tr>
<td>6GN</td>
<td>6.31</td>
</tr>
<tr>
<td>9GN</td>
<td>7.8</td>
</tr>
</tbody>
</table>

### Table 8. The summery of decrease in collapse potential

<table>
<thead>
<tr>
<th>Materials (%)</th>
<th>Improving in Collapse Index, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GP</td>
<td>44.5</td>
</tr>
<tr>
<td>6GP</td>
<td>36.6</td>
</tr>
<tr>
<td>9GP</td>
<td>31.0</td>
</tr>
<tr>
<td>3GN</td>
<td>46.0</td>
</tr>
<tr>
<td>6GN</td>
<td>33.4</td>
</tr>
<tr>
<td>9GN</td>
<td>17.0</td>
</tr>
</tbody>
</table>

#### 3.3. Permeability test:

All the results of the permeability tests are shown in Table 9. In this test the natural and treated soil samples were compacted to the maximum dry unit weight. It was noticed that the soil showed high reduction in the permeability coefficient with the addition of the additive materials. The polymer materials worked as waterproofing, covered the gypsum particles, and filled the voids causing reduction in gypsum dissolution and subsequently the destruction of soil mass structure.

### Table 9. Results of permeability test before and after improvement

<table>
<thead>
<tr>
<th>Materials (%)</th>
<th>Coefficient of permeability (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0G</td>
<td>1.7 x10^-3</td>
</tr>
<tr>
<td>3GP</td>
<td>1.98 x10^-4</td>
</tr>
<tr>
<td>6GP</td>
<td>2.3 x10^-4</td>
</tr>
<tr>
<td>9GP</td>
<td>5.1 x10^-4</td>
</tr>
<tr>
<td>3GN</td>
<td>5.31 x10^-4</td>
</tr>
<tr>
<td>6GN</td>
<td>2.35 x10^-4</td>
</tr>
<tr>
<td>9GN</td>
<td>3.69 x10^-4</td>
</tr>
</tbody>
</table>

#### 4. Conclusions

1. The maximum dry unit weight increased with adding polymer materials to 3% and began to decrease after that. Also, clear changes in optimum water content were observed where optimum moisture content decreased to 8% with increasing the copolymers and increased to 17% with added the novolac polymer.

2. High reduction in collapse potentials was noticed by increasing the polymer materials to a small amount (3%) from the copolymer and novolac polymer and the improvement reached to 44.5 and 46%.

3. The coefficient of permeability had lower value with the addition of 6% of the copolymer and the improvement reached 98.6%, while with adding 6% of the novolac polymer the improvement reached 86.2%.

4. In terms of cost, these materials are expensive. The basic structure of these materials is oil derivatives and the high price of it is due to the technology used in manufacturing and importing as mentioned before. However, if there is a production factory inside the country that provides such kinds of additives, the cost might be lower or even close to the cement price.

### Reference


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