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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 ($CaSO_4.2H_2O$)) 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

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 (23.3 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-Exandria, 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 compressibility 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 compressibility. The treated samples showed that the acrylate liquid reduced the compressibility 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 Mahmood, [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/m^3 and the natural water content 5%. The undisturbed soil samples were air dried, made homogenous, 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]:

Table 1. The properties of Copolymers

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

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 Procter 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-polymer, 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 (e-log p) graph under the effect of a certain stress level.

$$C.P = \frac{\Delta e}{\left(1 \oplus e^{\circ}\right)} \quad \text{..(1)}$$

Where:

C.P = Collapse Potential.

Δe = void ratio before and after soaking.

e° = 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:

$$K = \frac{Q}{\left(A \times I\right)} \quad \text{...(2)}$$

where:

k = coefficient of permeability.

Q = V/T quantity of water discharged.

L = the height of the mold.

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.**
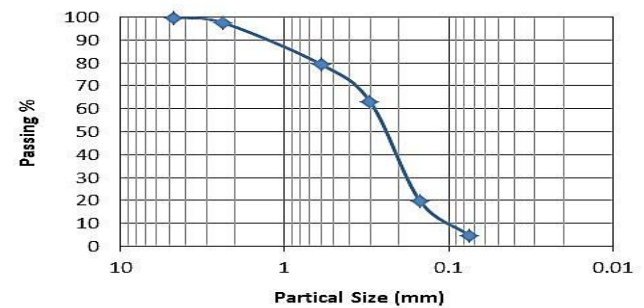

Figure 1. Grain size distribution of gypseous

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

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

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℃ until the sample weight became constant. The sample weight at 45℃ was recorded. After that, the same sample was dried at 110℃ until the weight became constant and recorded.

The gypsum content was found according to the equation:

$$X\% = \frac{(W45c° - W110c°) \times 4.778}{W45c°} \times 100 \quad \cdots\cdots\cdots\cdots\cdots(3)$$

Where:

X = gypsum content (%).

W45°C = Weight of the soil sample at (45°C).

W110°C = Weight of the soil sample at (110°C).

2. Total Sulfate Constant (SO_3) 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 weighted beaker.
5. Put the beaker in the oven to 850℃ for a quarter of an hour and then leave it to cool and take the weight. SO_3 was found according to the equation:

$$SO3\% = \frac{(W2 - W1) \times 34.3}{W} \quad \cdots\cdots\cdots\cdots\cdots\cdots(4)$$

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:

$$T.S.S = \frac{(W1 - W2) \times (10)6}{V} \quad \cdots\cdots\cdots\cdots\cdots(5)$$

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

Chemical Property	Value	Natural value	Standard of the test
Total (SO_3%)	13.87	5%	S.O.R.B/R6 [30]
Total soluble salts (T.S.S %)	9.8	Max 10%	---
Gypsum content (%)	36	Max 10.75%	---
PH value	8.21	0-14	---
O.M (%)	0.86	Max 2%	B.S 1377-3-1990 [31]

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

Element	Wt. %	Wt. % sigma
O	53.46	0.3
Na	0.56	0.07
Mg	1.8	0.07
Al	3.4	0.08
Si	20.08	0.18
S	5.06	0.1
K	1.64	0.07
Ca	11.65	0.14
Ti	0.13	0.06

Table 5. Details of the test designation

Test designation	Soil state
0G	Gypseous soil without any added material
3GP	Gypseous soil with adding 3% of Copolymer by weight
6GP	Gypseous soil with adding 6% of Copolymer by weight
9GP	Gypseous soil with adding 9% of Copolymer by weight
3GN	Gypseous soil with adding 3% of Novolac polymer by weight
6GN	Gypseous soil with adding 6% of Novolac polymer by weight
9GN	Gypseous soil with adding 9% of Novolac polymer by weight

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.**
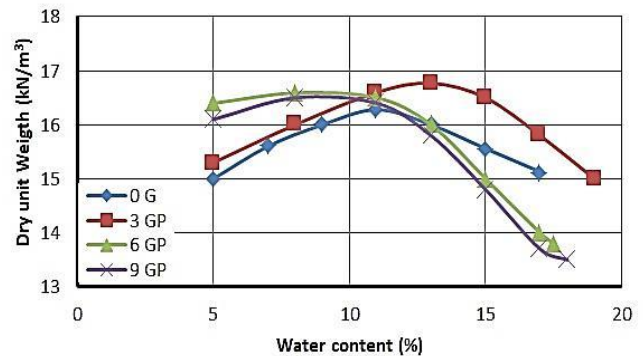

Figure 2. Results of compaction test of gypseous soil treated by different percentage of Copolymer
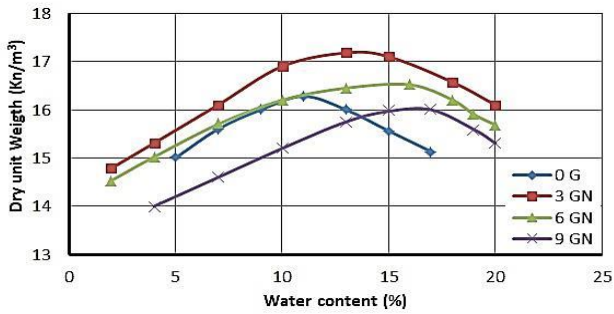
Figure 3. Results of compaction test of gypseous soil treated by different percentage of Novolac polymer

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

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

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.
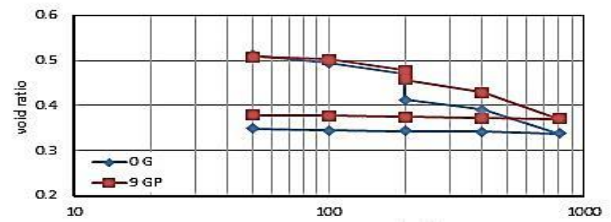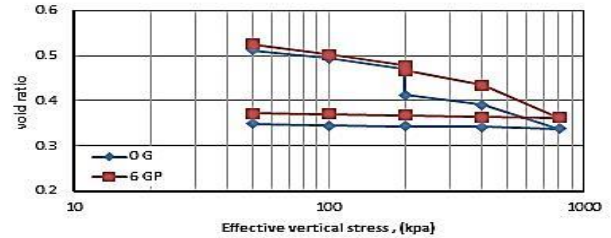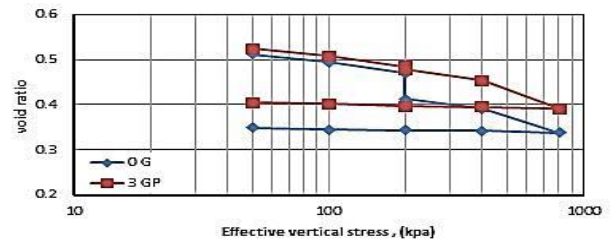

Figure 4. Results of single collapse test of gypseous soil treated by different percentage of Copolymer
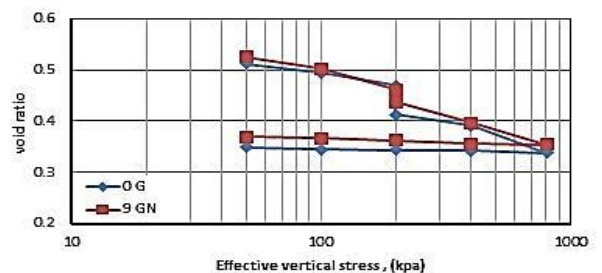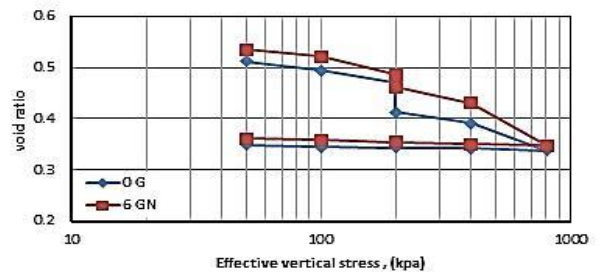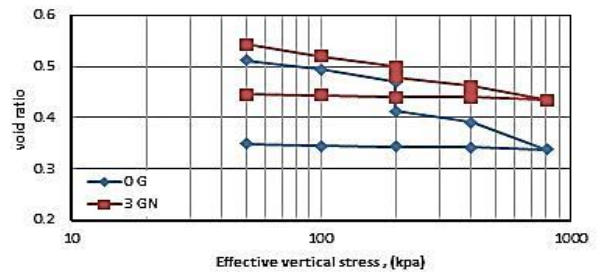

Figure 5. Results of the single collapse test of gypseous soil treated by different percentages of Novolac polymer.

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 increased the collapse potential, volume of samples, and reduction in dry unit weight. The results are shown in **Table 7.** and **Table 8.**

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

Materials (%)	Collapse Index, Ie (%)
0G	9.47
3GP	5.26
6GP	6
9GP	6.57
3GN	5.16
6GN	6.31
9GN	7.8

Table 8. The summery of decrease in collapse potential

Materials (%)	Improving in Collapse Index, (%)
3GP	44.5
6GP	36.6
9GP	31
3GN	46
6GN	33.4
9GN	17

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

Materials (%)	Coefficient of permeability (cm/sec)
0G	1.7×10^{-3}
3GP	1.98×10^{-4}
6GP	2.3×10^{-5}
9GP	5.1×10^{-5}
3GN	5.31×10^{-4}
6GN	2.35×10^{-4}
9GN	3.69×10^{-4}

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.

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