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DURABILITY OF EXPANSIVE SOIL USING ADVANCED NANOCOMPOSITE STABILIZATION

Waseim Ragab Azzam[1]

[1]Faculty of Engineering, Tanta University, Egypt.

ABSTRACT: This article describes the effect of creating nanocomposite materials on the long-term durability of expansive soil. A series of tests were performed to examine the effect of induced nanocomposites on the durability behaviors of the expansive clay. Tests were carried out at different polymer contents and curing time. The nano-structure was examined to confirm the occurrence of nanocomposites through the stabilized samples. The results showed that the curing time can be modified the consistency state of stabilized samples. The induced nanocomposites within the swelling clay can be attributed to non-plastic properties and acted as a hydraulic binder with lesser swelling potential. After long term curing time 28 days, the use of 15% polymer content reduced the swell percent by 90% and increased the stiffness by 4.5 time of its initial value. The improving factor in its unconfined strength was found to be 220%. This can be tended to improve the long term durability and increased the resistance to immersion which confirmed the produced durable hydrophobic material.

Keywords Expansive soil, Nanocomposites, Durability, Toughness.

1. INTRODUCTION

For all engineering structures constructed on clayey soils, these soils create swelling when they are exposed to water and shrink once water is squeezed out. These volumetric changes cause considerable failure to the foundation and damage to the civil infrastructure. The types of structure that are damaged are foundations, retaining walls, pavements, airports, sidewalks, canal beds, and linings. The types of problems that have caused the damage are diagonal cracks above doors and windows, pavement cracking, and heaving of floors. The cost of repair the damage caused by expansive soils to civil engineering structures per annum is estimated many billions of dollars worldwide [1].

Expansive soil or swelling clays are mostly found in arid and semiarid regions of the world. In Egypt, swelling clays cover most of greater Cairo, including Nasr City, 6th of October City, and Zayed City. Expansive soils derive their swelling potential mainly from Montomorillonite mineral, which is present in these soils.

Extensive geotechnical investigations have been carried out to study the swelling clay improvement for foundation uses and to control volume changes. There are many methods of stabilizing soil to gain required engineering specifications. These methods range from mechanical to chemical stabilization. Most of these methods are relatively expansive to be implemented by slowly developing nations and the best way is to use locally available materials with relatively cheap costs affordable by their internal funds [2]. Stabilization by admixtures has been used to prevent volume changes or adequately modify volume changes characteristics of such clays.

Lime, cement, Pozzolonic fly ash, basalt, furnace slag and fibers can be used fairly to stabilize expansive high-plastic clays [3] -[9].

All of the previous studies have focused on the use of lime fly ash, cement and fibers to enhance relatively the geotechnical properties of swelling clay, whereas the application of the use of chemical materials has been limited. Especially stabilization of expansive soil by polymer technique to create a nanocomposites material have not thoroughly investigated and applied in the geotechnical engineering.

Polymers are recognized as one of the most promising research areas in science and technology in the 21st century. They are used in a wide range of applications to improve and reinforce several material properties [10], [11].

From the chemical point of view, the modification of the swelling clay microstructure has been done by the use of polymers to produce nanocomposites materials with components of expansive clay. But these studies were not diverted to geotechnical consideration. Others were used the chemical additives in the different form to improve the shrinkage swelling potential [12]-[19].

The application of nanocomposites technology with swelling clay as a geotechnical study is limited. The effect of induced nanocomposites in reducing the swelling potential and improving the geotechnical properties of swelling clay was discussed [20]. This investigation was carried out without considering the polymer effect and the produced nano-sized materials on the durability of treated swelling clay. Moreover, studies related to using liquid chemical additives and the long-term stability characteristics with respect to the influence of environmental factors (durability) of treated expansive soils are restricted.

The long-term stability characteristics referred to, as durability in this paper can be better interpreted if the influence of time on engineering properties is studied. However, studies related to using polymer stabilization and the long-term stability characteristics with respect to the influence of environmental factors (durability) of treated expansive soils are limited. There are several questions that are not well understood with respect to the durability characteristics of the induced nanocomposites within the expansive soils in spite of being used as a recent technique to improve the properties of expansive soils.

Therefore, in this research, an attempt was made to apply the technique of polymer nanocomposites from the chemical point of view to geotechnical considerations. The use of a polymer to create a new durable and hydrophobic material with swelling clay was studied. The research mainly aimed at studying the effect of induced nanocomposites on the long-term characteristics of expansive soils.

2. EXPERIMENTAL

2.1. Characterization of the swelling clay and polymer

The initial physical properties of the selected swelling soils were determined according to the American Society for Testing and Materials (ASTM) specifications. The physical properties of the tested soils are shown in Table 1. The swelling characteristics of the tested samples were investigated with a standard odometer. The free swelling was found to be 30The swelling pressure was found to be 260 kN/m^2. The swelling of the clay under investigation was classified as marginal swelling as stated by [21].

The polymer used in this investigation was a polypropylene homopolymer (H030SG) was obtained from the petrochemical factory in Alexandria, Egypt with a melt flow index of 3. This polymer was commercially available and environmentally friendly accepted (according to its specification). It was used as a nanofiller to obtain a nanocomposites material with expansive soils.

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Table 1 Properties of the tested samples

Property	Value
Specific gravity	2.61
Compacted dry density (kN/m^3)	14.8
Initial water content (%)	13
Liquid limit (%)	52
Plasticity index (%)	30
Sand fraction (2 mm - 75i)	5
Silt fraction (75i - 2i)	55
Clay fraction (<2i)	40
Activity	0.75
Permeability (m/s)	14 x 10^{-4}

The X-ray diffraction (XRD) results of the tested samples refer to the mineralogical compositions, and the percentages of Montomorillonite, Kaolinite, and Illite were 55, 25, and 17%, respectively.

The absence of a characteristics peak at 7.5^o for the clay–polymer stabilized sample in the region 2–10 in XRD, as shown in Fig. 1, indicated the total dispersion and delimitation (exfoliation) of the fine nano-clay layers in the matrix. Interestingly, the polymer clearly was able to exfoliate both the pure clay and modified clays (at 10% polymer content), as evident from the XRD studies.
The structures of treated samples were elucidated by many sophisticated techniques, including scanning electron microscopy (SEM), and transmission electron microscopy (TEM). These techniques were done to study and characterize the behavior of the stabilized samples and measured the shape of the development nanocomposites.

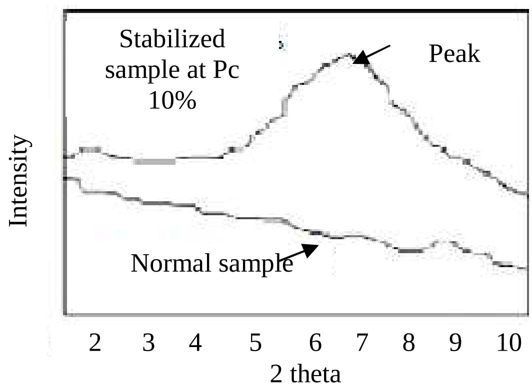


Fig. 1 XRD diffractogram normal and stabilized sample at 10% polymer contents**.**

2.2. Preparation of the polypropylene–clay composites

To prepare the polypropylene–clay composites, physical mixing was adopted according to [22]. In this method, the clay was dried in an oven at a temperature of 110^o for 24 h. The clay was accurately weighted and mixed with polypropylene in a solution form with xylene as the solvent. Xylene was added to a 1000 mL beaker containing polypropylene. After the mixing process was finished, the beaker was kept open for a few hours to evaporate xylene. Then, the prepared polymer–clay composite was mixed well mechanically.

3. TESTING PROGRAM

The amounts of polymer added to the swelling clay soil samples, as percentage of the dry soil mass, were 5, 10, and 15%. All of the samples were remolded at their optimum moisture contents (OMCs) and maximum dry densities (MDDs) with the Proctor test according to the ASTM specification of the compaction test. The compaction characteristics for mixes of different plasticity values prepared with different percentages of polymer are shown in Fig. 2.

The addition of polymer to form a nanocomposites material with the clay remarkably decreased the resulting dry density with increasing polymer contents. As a result the optimum moisture content OMC was decreased slightly with increasing polymer content (Fig. 2a). This decrease in OMC was backed to chemical reaction and ion change mechanism which dissipated and absorbed the water during the chemical reaction. The dry density also decreased gradually in a small range with increasing polymer content because of the formed nanocomposites acted as nano-fillers thus, the volume of sample increased (Fig. 2b). In addition the stabilized samples were lost a quantity of water during ion-change mechanism. Therefore, the sample weight was decreased and produced hydrophobic material.

After the mixing process, the admixture was compacted to the desired density (MDDs) and placed in a PVC cylinder mold (76 mm in height and 38 mm in diameter) to be tested by an unconfined compression shear testing procedure of ASTM. All samples were preserved to test for different curing time (3, 7 and 28 days) as discussed by [16] at temperature 25°C. These curing periods were adopted for stabilized samples to achieve its potential strength and durability.

Atterberge limits were used to determine the consistency and toughness of stabilized samples at different polymer content and curing time.

A series of tests were conducted to examine the effect of the induced nanocomposites on the geotechnical properties of the stabilized expansive clay samples with an odometer cell at different curing time. With a fixed ring odometer, the free-swelling test was performed to determine the swelling potential at different polymer contents.

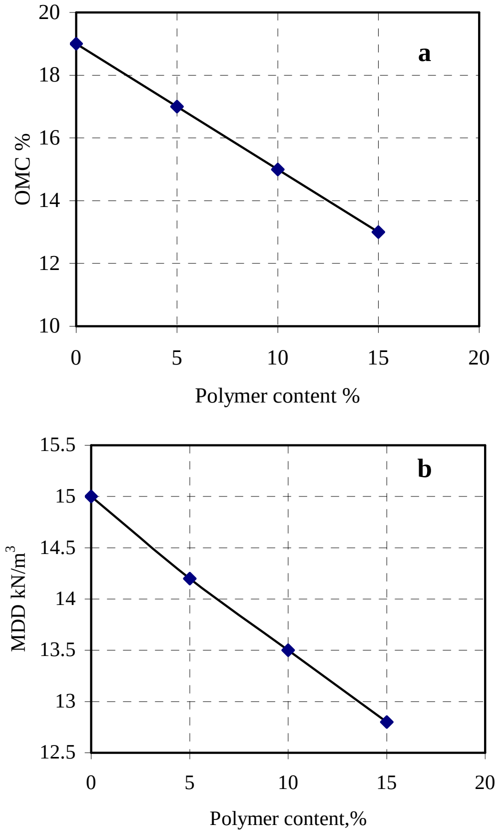


Fig. 2 Variation of the polymer content with a- optimum moisture content, b- Maximum Dry Density.

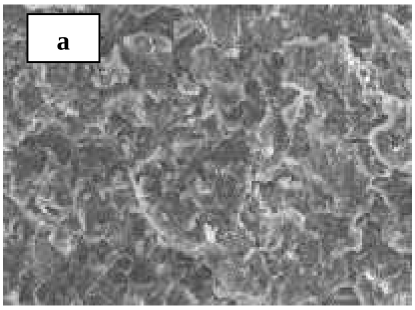
For determination the volumetric shrinkage strain, reconstituted soil was mixed with water at the liquid limit state to form slurry. The mix was then poured into the mold and lightly tamped. Subsequently, the specimen in the mold was placed in an oven at 80 C for 48h. During this period, the mold was turned upside down and rotated regularly to allow uniform shrinking and drying of the specimen such that cracks could be avoided or minimized. Thereafter, the diameter and height were measured at three different locations, and the averages were noted to calculate the volumetric shrinkage strain values.

A series of unconfined compression tests were run to study the effect of samples immersion in water at different curing time and polymer content. A simple method was examined by evaluating the compressive strength of the cylindrical specimens under both soaked and un-soaked conditions as stated by [23]. In general, the stabilized soil experienced reduction in the unconfined compressive strength subjected to the immersion test. It indicated by values of resistance to immersion (RI), the ratio between unconfined compression strength of soaked samples to un-soaked one [23].

4. RESULTS AND DISCUSSION

4.1 Analysis of the Swelling Clay Nanostructure

Clay–polymer stabilization with polypropylene is a recent field of stabilization and was applied in this research to improve and modify the durability behavior of the swelling clay at different curing time. The micro-structural behavior of treated samples was examined by microscopic technique. Understanding the nature of materials and their structures has always been significant. The microscopic structure of treated soils can be used as an index in identifying the type of environmental processes and in estimating their resistance. In observing soil structure on a small scale, some novel methods of investigations in the nanometer range and for particulate analysis have been suggested by using the scanning electron microscopy (SEM), and Transverse electron microscopy (TEM). These direct methods are applied for particulate imaging at the nanoscale level that provides information such as the dimension, shape, and morphology of created particles.



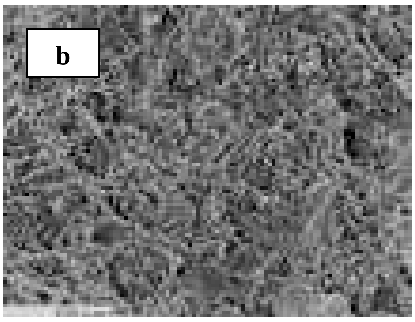


Fig. 3 SEM image of the tested samples a- SEM Image of exfoliated structure of a swelling clay-sample. b- SEM image of the fractured surface of a polymer–clay nanocomposites (polymer concentration = 10%).

Therefore, (SEM) has been widely used to study the nanostructure of stabilized tested samples. Fig. 3 presents the SEM image of the swelling clay without and with polymer stabilization. Fig. (3a) shows an aggregate of Montomorillonite platelets exfoliated during dispersion in water during sample preparation. The fractured surface of the swelling clay composite with polymer (Fig. 3b) showed that the clay interacted with polymer and produced a new matrix in the form of nano-sizes. It indicated a homogeneous distribution of polymer within the clay layers. The produced nano-sizes distinctly increased both the cohesion and the net electrical attraction between adjacent grains. It also improved the grain surface of the swelling clay against water by constructing the nanocomposites as a hydrophobic material and preventing the affectivity of the Montomorillonite. The polymer here modified the microstructure of the soil-like nanofiller to produce a new skeleton and altered the texture of the clay by reducing the fine particles. Furthermore, it produced nanocomposites materials inside the soil galleries. The ion-change phenomenon distinctly describes this mechanism as confirmed by [24], [25].

While the TEM images show that the nanocomposites were induced with variable size related to amount of added polymer. The TEM analysis was helped to measure the size of formed nano-particles within the clay layer at different polymer contents (Fig.4a to d). It has been established that the sizes of the produced nano-sizes increased with the increase of the polymer concentration. Fig. 5 shows the linear variation of the produced nanocomposites with the amount of added polymer. It also confirmed the occurrence of nanocomposites and showed that, the nano-size was increased with the increase of amount of polymer.

The measured sizes of constructed nanocomposites were found in range (10 nm to 23.5 nm) at polymer content of 5% and 15% respectively. This indicted that the polymer dispersed in clay matrices and partially to totally fill the voids to form the new filling material.

Finally, TEM completed and showed the effectiveness of constructing the new inclusions due to the proper clay – polymer interaction.

SEM and TEM of treated samples were examined at different time. It noticed that there is no clear effect of curing time in the formed nanocomposites size. The induced sizes were remained constant but, the hardened behavior was modified as expected from micro-structural analysis.

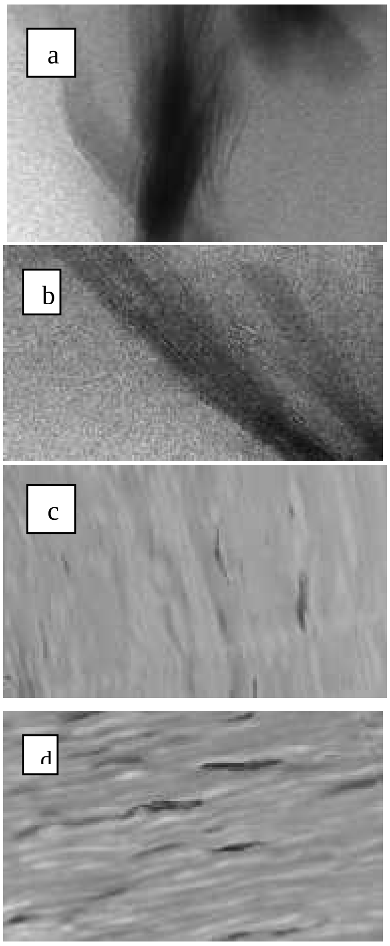


Fig. 4 TEM micrograph of a- The pure clay, and (b, c and d) TEM micrograph of the clay stabilized with the polymer (polymer concentration = 5, 10 and 15 % respectively).

4.2. Effect of curing time and nanocomposites on the durability characteristics

The plasticity of stabilized samples was examined by using Atterberge limits. The liquid limit, plastic plasticity index of the untreated and treated samples with polymer is shown in Fig. 6. The results showed that there is a decrease in both liquid limit and plasticity index with increasing the polymer content and continue with an increase in curing time. It is found that the induced nanocomposites had a great effect on decreasing the plasticity index. This reduction was due to the absorption of excess water during the interaction between the clay and polymer through ion change reaction. At polymer content of 15%, the percentage reduction in plasticity index reached to 43, 53 and 73% of its initial values at corresponding curing time of 3, 7 and 28 days respectively. The curing time can be modified the consistency state of stabilized samples. It also confirmed that the nanocomposites were effectively hardened with the increasing of curing time. The induced nanocomposites within the swelling clay can be attributed to non-plastic properties and acted as a hydraulic binder. The reduction of plasticity index is an indicator of improvement which can be related to the increase in soil strength and the decrease in the swelling potential [21].

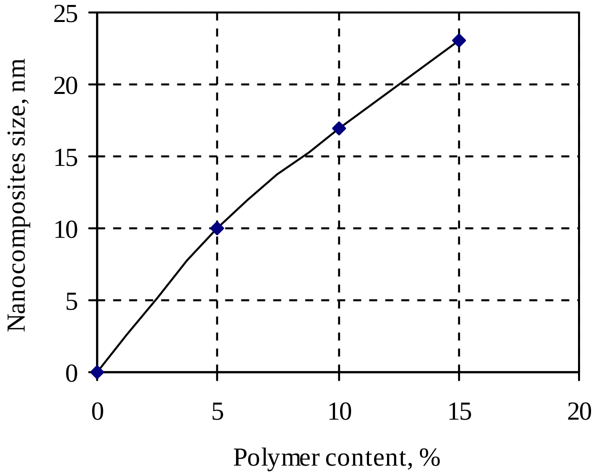


Fig. 5 Variation of nanocomposites size with polymer contents.

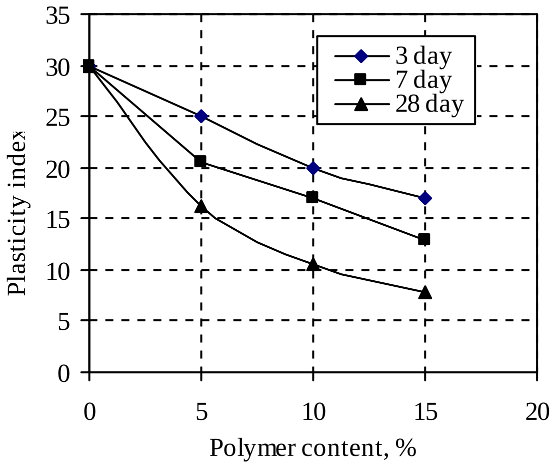
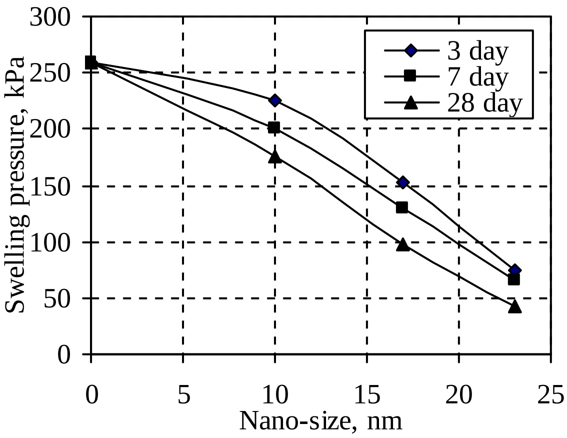


Fig. 6 Relations between polymer content and plasticity index at different curing time.

4.3. Effect of curing time and nanocomposites on swelling characteristics

The effect of curing time and induced nanocomposites size on the swelling behaviors of tested samples is shown in Fig.7. It has been found that the produced nanocomposites through the swelling soil was sharply decreased the obtained swelling pressure. The increase of nanocomposites size leads to decrease in the swelling pressure. The reduction in the swelling pressure related to both the size of nanocomposites and the curing time. It noticed that the variation of the swelling pressure with curing time indicated that, the swelling pressure was reduced by as much as 86% at a maximum nanocomposites size (23 nm) within 28 days of curing. Whereas, after 3 days curing (nano-size = 10 nm) the swelling pressure was reduced by as smallest amount as 13%. This suggested that the adopted polymer with adequate curing time was an effective method to eliminate the swelling pressure. It also confirmed that the polymer stabilization can be produced a durable material when mixed with swelling soils and cured for sufficient time. This can be established that, the improvement in chemical durability of the stabilized samples is achieved as stated by [12].



.Fig. 7 Variation of the swelling pressure with nano-size at different curing time.

Fig. 8 again indicates that the polymer significantly controlled and reduced the free swelling and had a considerable effect on the modification of the swelling potential of the new nanocomposites materials. It also confirmed the effectiveness of curing time and produced the chemical durability. The free swell can be totally eliminated according to curing time and size of nanocomposites. At curing time 28 days (15% polymer content), the reduction in the free swell was found to be 90%. Whereas it can be observed around 16% for sample stabilized by 5% polymer content and cured for 3 days.

4.4. Effect of curing time on the volumetric shrinkage

The variations in volumetric shrinkage strain with nano-size at different curing time are shown in Fig. 9. From this Fig., it concluded that, the addition of polymer to form nanocomposite materials considerably reduced the volumetric shrinkage strain of the tested soils. The increase of nano-size significantly decreased the volumetric shrinkage with an increase in curing time.

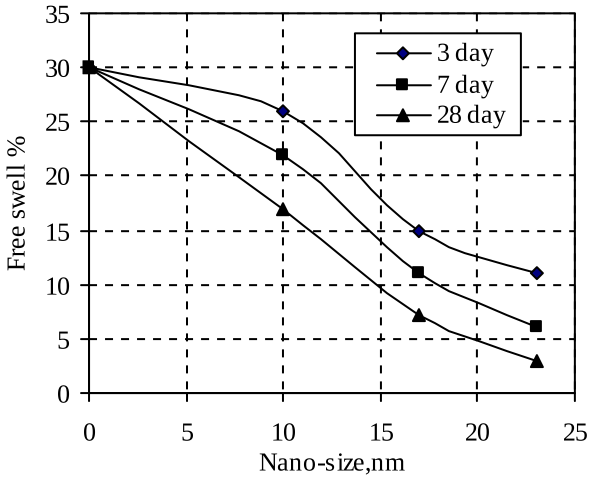


Fig. 8 Variation of the free swell with nano-size at different curing time.

The volumetric shrinkage strains can be partially or totally eliminated according to polymer contents. The maximum effective results were gained when the samples stabilized by 15 % polymer content (nano-size = 23 nm) and cured for 28 days. The volumetric shrinkage strains were found to be 0.3 % consequently; the volumetric strains can be totally eliminated. As a result, the created binders can distinctly improve the long-term stability of swelling clay. In general, the use of such polymers for stabilization processes shows isotropic durable behavior with respect to both the diametrical and axial shrinkages because there is a noticeably reduction in the volumetric shrinkage with time.

4.5. Effect of curing time on toughness and shear strength

The deformation characteristics of stabilized swelling clay by such nanocomposites technique at different curing time was investigated by the term of toughness. The toughness index is the ratio of plasticity index to flow index. It was determined for tested samples at different polymer contents. The variations of the toughness with nano-size were plotted as shown in Fig. 10. It has been found that increasing the curing period increased the resistance to deformation with upon increase in nanocomposites size. The durability/ sustainability of geotechnical material which is defined as the resistance of material against weathering conditions. More the toughness index indicates to better improvement for the stiffness of treated samples. It can be concluded that the increase of toughness index proved that, the nanocomposites technique produced a sustainable material with lesser deformation.

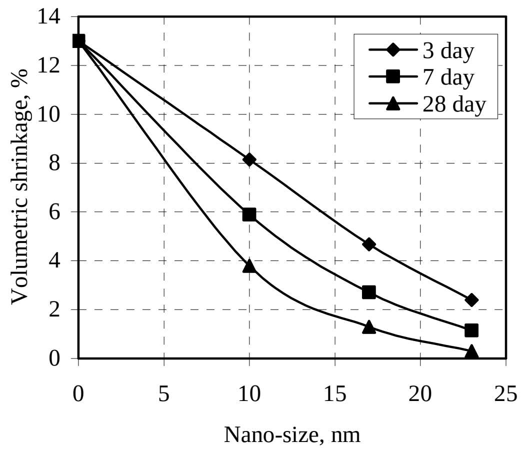


Fig. 9 Variation of the volumetric shrinkage with nano-size at different curing time.

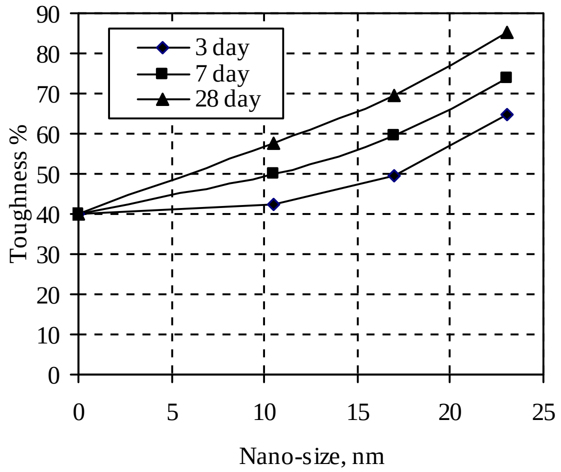


Fig. 10 Variation of the measured toughness with nano-size at different curing time.

The toughness index for stabilized samples by polymer content of 15 % reached to 85% at curing time 28 days. While it was found to be 42% for samples stabilized by 5% polymer contents and cured within 3 days. This verified that induced nanocomposites inside the swelling clay galleries were improved the adhesive and bond among grain particles. It also increased the shear strength characteristics and decreased the deformation under any external compressive stress as justified by Fig. 11. It shows the effect of the curing time and the induced binders on the compressive strength of treated soil. Compressive strength of a soil is a significant factor to estimate the design criteria for the foundation, a pavement and construction material. Fig. (11a) shows the stress–strain curves of samples stabilized by the polymer contents of 15% at different curing time. The achieved nanocomposite (polymer effect) at different curing time significantly modified the stress–strain relationship. Increasing the curing time distinctly increased the stress and decreased the vertical strain because of the full strength of treated samples were fully attained with sufficient curing time.

The unconfined compressive strength of stabilized soils in relation to curing time, for the entire polymer content increases more rapidly with the increase of the curing time (Fig. 11b). Increasing the nanocomposites size can increase the shear strength, because the achieved nanocomposites were modified the consistency state of treated clay to be in a stiff consistency [26]. The interaction between the soil grains and induced nanocomposites had increased the cohesion and limited the deformation. Unconfined compressive strength ranging from (100 to 200 Kpa) is considered as a stiff consistency. This also confirmed the effect of such technique in improving the toughness of treated samples.

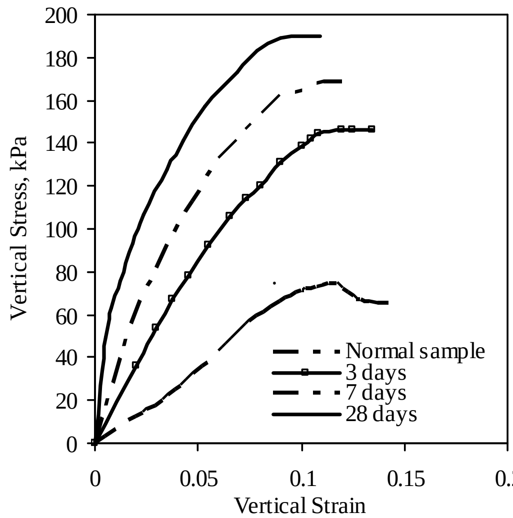


Fig. 11a Stress-strain curve for stabilized sample with polymer content of 15%.rent curing time.

The curing time and the polymer contents can play an important role in increasing the unconfined compression strength. So the variation of improvement factor (IF) with curing time is plotted in Fig. 12. Note, IF = q_u/q_o, where q_u is the unconfined compression strength of stabilized samples and q_o is the unconfined compression strength of normal sample without stabilization. It noticed that, the improvement in the unconfined compression strength increases rapidly within the first 7 days. While the little variation was observed until reach to 28 days of curing. The rate of change in improvement factor until reaching to 15 days curing time was turned slowly and equal to 10% for the polymer content of 10 and 15%. This rate was decreased to 3% for polymer content of 5%. One can concluded that the most improvement in unconfined compression strength was gained at the first 7 days of curing. The maximum degree of improvement in unconfined compression strength at this time was found to be 181% and 225 % at the polymer content 10 % and 15% respectively.

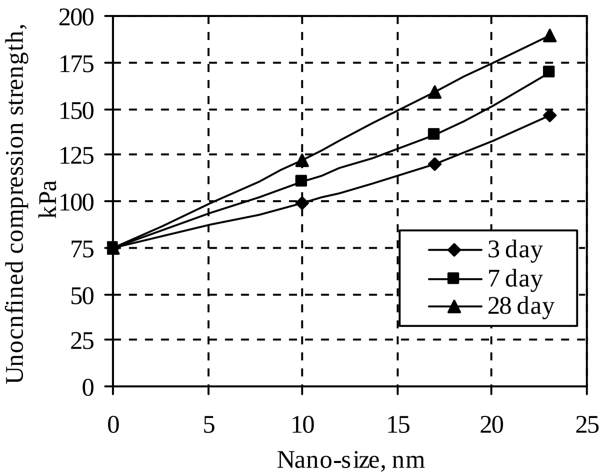


Fig. 11b Variation of the unconfined compression strength with nano-size at different curing time.

4.6. Comparison of modulus of elasticity for stabilized soil

The modulus of elasticity of samples with and without stabilization for various curing time was calculated from stress strain curve relationships of the performed unconfined compression tests.

Fig.13 is presented the ratio of modified modulus of elasticity, Es and original subgrade modulus, E (obtained from initial tangent). From this Figure it is observed that the ratio of (Es/E) is increased from 1.15 up to 2.73 times at the earlier stages of loading. These ratios are observed for the polymer content of 5% and 15%, upper and lower limit, at curing time 3 days. These ratios were also ranged between (1.78 and 4.50) for 5 and 15% polymer contents, respectively and at curing time of 28 days. It can be seen that the induced nanocomposites appreciably improved the stiffness of expansive clay according to polymer content and curing time. It can be added that, the polymer stabilization produced a durable material which again confirmed the toughness analysis and improvement in the shear strength.

4.7. Effect of curing time and nanocomposites on Resistance to Immersion

A stabilized soil should be durable in which it has ability to retain its integrity and strength under service environmental conditions. The conformity to this requirement is more critical when the strength of the stabilized soils is low. The determination of the durability properties of the soils mixtures is a problem since it is difficult to simulate the detrimental action in laboratory comparable to that produced by damage in the field. Fig. 14 presents variation of the resistance to immersion of stabilized soil-mixtures with different polymer contents.

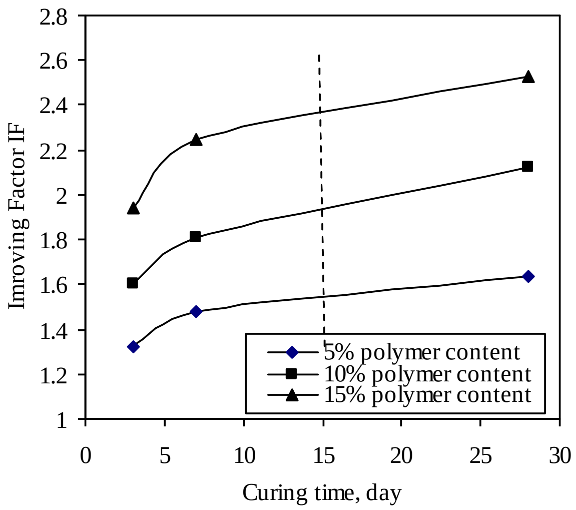


Fig. 12 Variation of the improving factor with curing time at different polymer contents.

In general, the stabilized soil experienced reduction in the unconfined compressive strength when subjected to the immersion test. The loss of strength indicated by values of RI lowers than 1. It observed that the induced nanocomposites produced a durable hydrophobic material and filling the voids therefore the hydraulic conductivity is decreased [20]. So, the stabilized samples tended to impermeable material that prevented the flow of water inside the assembling pores. It also found that the induced nanocomposites acted as a hydraulic binder inside the clay galleries. Consequently, the bond and interaction between soil grains is increased thus the resistance to immersion were increased and produced water resist materials. As regarded in relevant Figure, the stabilized samples by such nanocomposites are considered durable because of the values of Ri ≥ 80% which agree with [23].

On the other hand, the maximum lose in the strength was found at 28 days curing with minimum polymer content. Specimens solely cured at 28 days showed considerable loss in strength. Increasing the polymer content would help increase the resistance to immersion. Fig. 14 also depicts that stabilized sample with 5% and cured within 28 days failed to retain their structural integrity, which the strength lost is located below the marginal range of 80%. In a brief, Increases the polymer contents served to increase the strength which led to create a durable material.

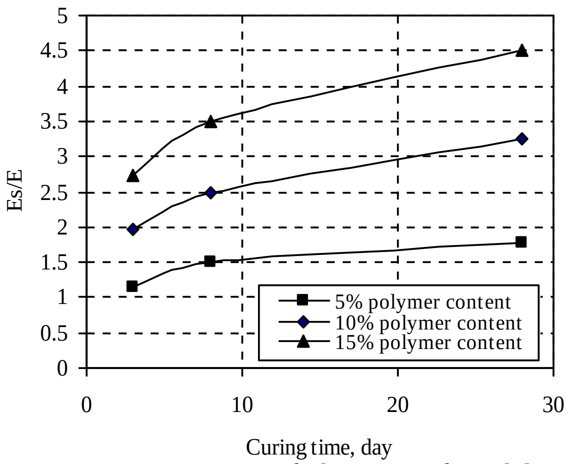


Fig. 13 Variation of the ratio of modulus of elasticity with curing time at different polymer contents.

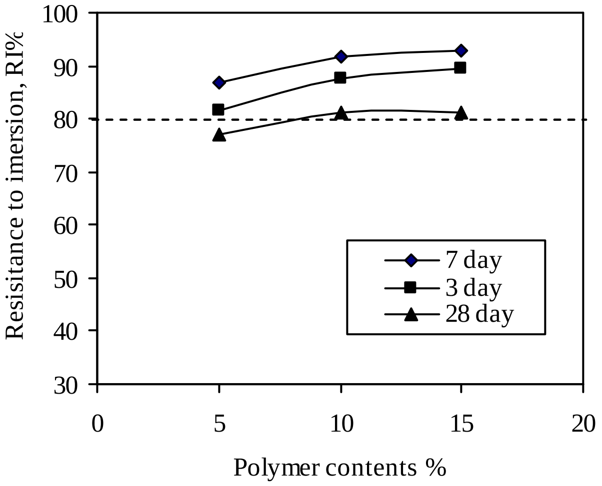


Fig. 14 Variation of the resistance to immersion with polymer contents at different curing time.

4.7. Comparative study with different stabilization techniques

In order to show the beneficial effect of polymer stabilization by constructing the nanocomposites within the swelling clay on the long-term stability, a comparative study with different stabilization techniques were carried out. The effect of curing time on the improving factor (IF) of unconfined compression strength was plotted in Fig. 15 for different materials. It has been found that, the nanocomposites technique is distinctly increased the shear strength with the increase of curing time of the samples stabilized by 15% polymer contents. Comparing these results with different investigators that used alternative materials to improve the swelling characteristic as chemical additive in the form Addicrete P [16], lime [27] and polypropylene fibers [29]. Comparatively, both the adopted technique of nanocomposites and lime modification contributed to the marked increase in the unconfined compressive strength of the expansive soil that was cured for 3–28 days. Due to the expansive soil developed strong lime-modification and soil-lime pozzolanic reactions. In this way, polymer stabilization was also produced a coherent composite materials due to the developments of binders. The induced nanocomposite was produced a higher shear strength materials as shown in the relevant Figure, in addition to its importance in controlling the swell-shrink potentials of expansive .

Whereas, the stabilization by polypropylene fibers as presented by [28], showed that a relatively improvement in the shear strength with time. While the use of chemical stabilization by Addicrete P as stated by [16] showed that, an insignificant effect in improving the shear strength of swelling soils. The rate of improving in unconfined compressive strength of soil decreases with using such additives in the long-term curing.

It can be concluded that the nanocomposites is considered to be an advanced and effective methods to increase the long-term stability of expansive soils.

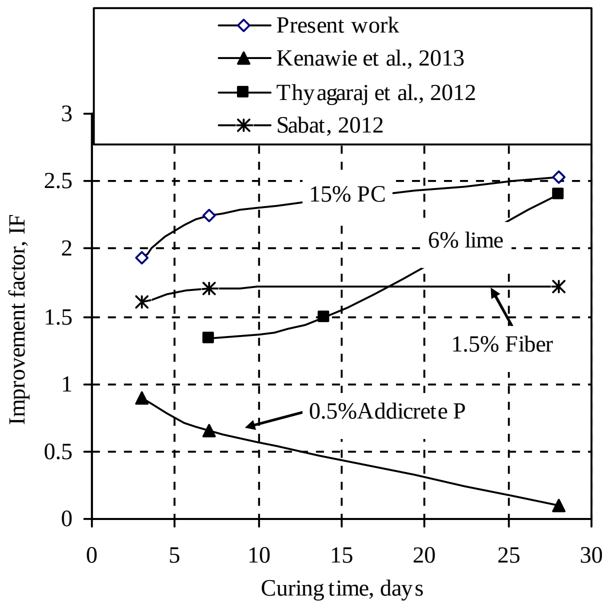


Fig. 15 Comparison of the improvement in the shear strength of stabilized samples with curing time.

5. CONCLUSIONS

The stabilization by nanocomposite technology is a good method to increase the durability of expansive soils and it can be applied in a wide range of geotechnical engineering application especially roads, pavement and foundation to ensure the long-term stability with good strength. From the results of this study, the following conclusions can be drawn

1. The micro-structural analysis of stabilized swelling clay samples confirmed the creation of nanocomposites with different sizes.
2. Increasing the polymer contents increased the nanocomposites size which attributed to non-plastic properties and acted as a hydraulic binder with stiff consistency.
3. The polymer stabilization and Ion-change mechanism were improved the chemical durability of treated samples as a result the swelling pressure was reduced by as much as 86%.
4. The free swell can be partially or totally eliminated according to curing time and size of nanocomposites. The reduction in the free swell was reached to 90% at 15% polymer content and 28 days of curing.
5. The increase of nano-size significantly decreased the volumetric shrinkage with an increase in the curing time. The volumetric strains was found to be 0.3% consequently; the volumetric strains can be totally eliminated.
6. The unconfined compression strength of the stabilized expansive soil by polymer increased up to 220% at polymer content 15% within 28 days of curing.
7. The degree of the improvement in the unconfined compression strength ratio increases rapidly within the first 7 days. While the little variation was observed until reach to 28 days of curing.
8. The induced nanocomposites significantly improved the stiffness of expansive clay; the ratio of Es/E is increased from 1.15 up to 2.73 times at polymer content of 5 and 15%, respectively, during the curing time of 3 days. These ratios were ranged between (1.78 and 4.50) for polymer contents of 5% and 15%, respectively and at curing time of 28 days
9. Increases in polymer contents served to increase the strength and the resistance to immersion which led to create a hydrophobic durable material with lesser lose in its strength.

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Corresponding Author: Waseim Ragab Azzam