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Chemical influence of nano-magnesium-oxide on properties of soft subgrade soil

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ABSTRACT

Improving the properties of soft subgrade soils greatly helps in construction of strong and economical pavements. For this purpose, there are many traditional additives. However, these are often expensive and their production causes consumption of large amounts of energy and increases environmental pollution. Therefore, this study suggests the use of a modern alternative, nano-Magnesium-Oxide. In this study, soil from Baghdad city was selected and treated using different doses of the proposed additive namely (0.20, 0.40, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, and 2.00) % by weight of dry soil to study the changes in its engineering properties. The study included conducting laboratory tests to compare the soil properties before and after treatment. These include the California Bearing Ratio Test (CBR) and measuring the swelling ratio to determine the changes in engineering properties and to determine the optimum dose. Thereafter, an Energy-Dispersive X-Ray Spectroscopy (EDXR- Spectroscopy) test was performed to determine the chemical reactions that contributed in changing of soil properties. The results showed noticeable improvement in the properties of the soil. CBR value of the soil treated with optimum dose (which is 0.80%) increased to about 1200% of its value for original soil. Moreover, swelling ratio of the soil treated with optimum dose decreased to about 10% of that recorded in original soil. EDXR- Spectroscopy tests exhibited the presence of influential chemical reactions between the additive and the soil that may create Magnesium Silicate Hydrate which formed strong bonds between the soil particles increased its tightness.

Keywords: Nano-MgO, Subgrade, CBR, EDXR-Spectroscopy, Chemical reactions

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1. Introduction

Roads network are considered one of the most important infrastructures that contribute to the growth and prosperity of countries' economies [1-5], as they are the main means of transporting people and goods [6-9], especially in developing countries [10, 11]. The pavement layer system is one of the most important elements of the road [12, 13], as it is responsible for carrying the repeated traffic loads from vehicles, especially heavy ones [14, 15]. The thickness of these layers varies according to the strength of the subgrade layer on which these layers' rest [16, 17]. Usually, the subgrade layer is the local soil, and it differs in terms of durability from one site to another. If the sub-layer is strong, the rest of the layers can be designed with a relatively small thickness, which reduces the cost in an effective way, and vice versa [18]. However, the construction of pavement layers on a solid foundation soil is not available in many locations where the properties of that soil cannot be controlled due to the restrictions of the site the road passes through [19]. To ensure the tightness of subgrade soil under the pavements system, the soil can be replaced with one of better properties [20]. Nevertheless, this action is costly and impractical due to the large size and extent of road projects [21]. To solve the problem, another alternative could be proposed which is improving the properties of the local soil with additives [22]. In this field, Portland cement, lime, and liquid asphalt are commonly used [23-27]. However, those traditional alternatives are costly on the one hand and polluting the environment on the other hand as their production consumes a lot of energy and releases large quantities of gases polluting the environment [20, 28, 29]. Therefore, finding other alternatives is a vital requirement to ensure keeping pace with the growing need to adopt sustainability in civil engineering works [8, 30-34] especially road projects as these are of the largest projects consuming construction materials and energy. There is a revolution in recent years in the utilizing nanotechnology in various fields of engineering [35, 36]. Therefore, to keep pace with that revolution, this study suggests the use of nanoparticles to improve the properties of soft subgrade soils in pavements constructions as an alternate for traditional additives. There are many types of the nano-materials available in the specialized markets. Some of these were selected in improving the properties of construction materials and have shown a remarkable role in improving the properties of those materials; however, other nano-materials failed. In this study, the nano-Magnesium-Oxide was chosen due to its low cost and low energy spent in its production. In addition, adding a new alternative in this field opens a portal for scientific research in pavements industry to adopt new alternatives rather than traditional ones. This study, mainly, adopts a laboratory approach by selecting soil from Baghdad city. The physical and chemical properties of the selected soil were analyzed. After that, a number of samples were prepared for the original soil and a number of other samples were mixed with different doses of nano-Magnesium-Oxide and were treated in a humid medium for 28 days. Afterward, laboratory tests were conducted on the original samples and on those treated with the additive. A comparison was made among the results in order to identify the changes in the engineering properties of the soil after treatment. This study, mainly, adopted the California Bearing Ratio Test (CBR). To investigate the causes of changes in properties, chemical analyses were performed using Energy-Dispersive X-Ray Spectroscopy (EDXR- Spectroscopy) on samples of original and improved soils.

2. Materials

Samples of selected soil from Baghdad-Iraq have been prepared for tests before and after the improvement using Magnesium-Oxide nanoparticles. The properties of the original soil used are presented in Table 1. An amount of the additive used (nano-Magnesium-Oxide) was purchased from the local markets. The purchased amount was made in China by a well known manufacturing company. The additive is white in color with particles diameter not greater than 110 nanometer and purity more than 96%.

Table 1. Properties of original soil

Physical and engineering properties	
Soil Class according to AASHTO[1]	A-7-6
Soil Class according to USCS[2]	CH
Liquid Limit (LL)	51%
Plastic Limit (PL)	27%
CBR	2.9%
Swelling Ratio	4.1%
Chemical composition	
SiO_2	61.97%
Al_2O_3	29.83%
Fe_2O_3	4.76%
TiO_2	1.36%
CaO	0.75%
K_2O	0.63%
MgO	0.55%
SO_3	0.09%
ZrO_2	0.03%
Other	0.03%

[1]AASHTO: American Association of State Highways and Transportation Officials
[2]USCS: Unified Soil Classification System

3. Testing Procedure

In this study, the selected soil was treated using different doses of the proposed additive to examine the changes in its engineering properties and chemical reactions. The study included conducting laboratory tests to compare the soil properties before and after adding the additive with different doses. These include CBR Test and measure the value of swelling to determine the changes in engineering properties as well as determine the optimum dose. Thereafter, an Energy-Dispersive X-Ray Spectroscopy (EDXR- Spectroscopy) test was performed to determine the chemical reactions that contributed to change in soil properties.

3.1. CBR Test

California Bearing Ratio Test (CBR) was performed on samples of original soil and treated soil with different doses of nano-Magnesium-Oxide for the purpose of showing the change in soil properties after treatment with additive. The percentages chosen were: (0.20, 0.40, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, and 2.00)% by weight of dry soil. The samples were prepared according to the standard method using the optimum water content. After that, these samples were wrapped in tight bags to preserve the water content in them. The samples were left for 28 days to ensure the occurrence of the chemical reactions. After the end of the treatment period (28 days), the samples were submerged in water for a period of 4 days and then the soil swelling was measured according to the standard method. Afterward, the standard piston penetration test was performed for the purpose of calculating CBR values. CBR values reflect the tightness of subgrade soil; the higher the value the tighter the soil and vice versa. In addition, the swelling ratios reflect the susceptibility of subgrade soil to volumetric change which. Subgrade soil swelling causes severe damages in pavements which increases the maintenance cost and reduces the service life of the pavements. The optimum ratio of the additive was determined by the results of the test.

3.2. EDXR-Spectroscopy test

This test was carried out on samples of the original soil, soil mixed with the optimum dose of the additive in dry condition, and soil mixed with the optimum dose of the additive after wet treatment according to the optimum water content and for a period of 28 days for the purpose of showing the changes in the concentrations of the main elements involved in the composition of the soil before and after blending as well as after wet treatment.

4. Results and Discussion

Through tests carried out on the original soil, it was found that it is, relatively, poor soil if used as a subgrade for pavements. As its usage requires design and construction of layers of, relatively, have large thickness which is extremely expensive. In addition, the original soil has high swelling susceptibility. This means that it may cause considerable damages to the pavements if it is exposed to cycles of full or partial saturation. Therefore, improving the properties of this soil is an imperative requirement in this field. The results of tests used in this study are explained in the following subsections.

4.1. CBR Results

The results of this test showed that the CBR values of soil treated with different doses of the additive are higher than that recorded for the original soil as shown in Figure 1. It is observed through the figure that the CBR values increases with increasing of additive amount. Nevertheless, CBR reaches the maximum at the dose of 0.80% and then the values decrease with the increasing of additive amount. The CBR value of soil treated with 0.80% of nano-Magnesium-Oxide after wet treatment for 28 days has reached about 1200% more than that of the original soil as shown in Figure 2. This reflects a tremendous improvement in the properties of pavement subgrade soil and increases its capability to withstood high traffic loads and thus leads to a great reduction in pavements thickness which in turn leads to a great reduction in the construction cost.

The results illustrated that soil swelling ratios of the treated samples is lower than the swelling ratio of the original soil. The lowest swelling ratio was recorded for the samples treated with 0.80% of nano-Magnesium-Oxide, as shown in Figures 3 and 4. The minimum swelling ratio was about 10% of that recorded in the original soil. This considerable decrease in swelling indicates a considerable improvement in the capability of treated soil to resist volumetric changes under saturation. Consequently, the expected damages in the pavements system due to swelling can be minimized which leads to reduction in pavements maintenance cost as well as a noticeable increase in its service life.

Based on these results, 0.80% of nano-Magnesium-Oxide can be considered as the optimum dose that is recommended to be used to improve this type of soft subgrade soils. This improvement in soil properties can be attributed to the formation of strong (chemical and electrical) bonds between soil particles through chemical reaction between nano-Magnesium-Oxide and soil components through wet treatment. In order to realize the chemical reaction, EDXR- Spectroscopy was conducted as described in the following subsection.

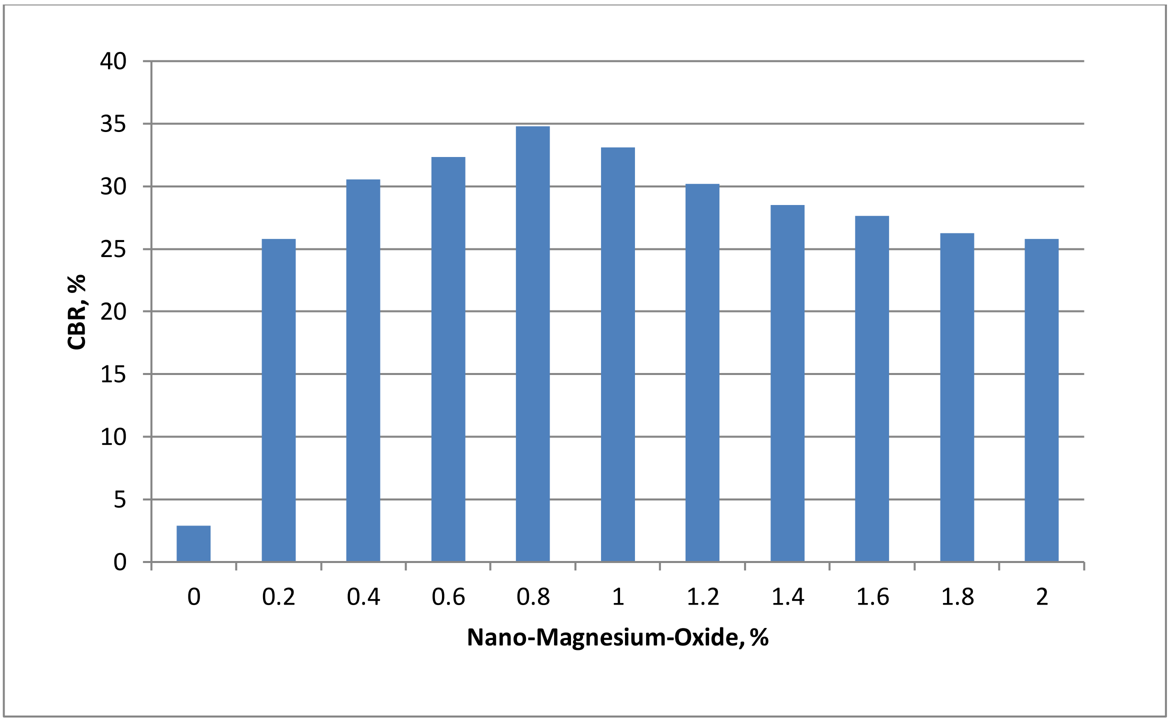

Figure 1. The results of CBR test with different percentage of nano-magnesium-oxide

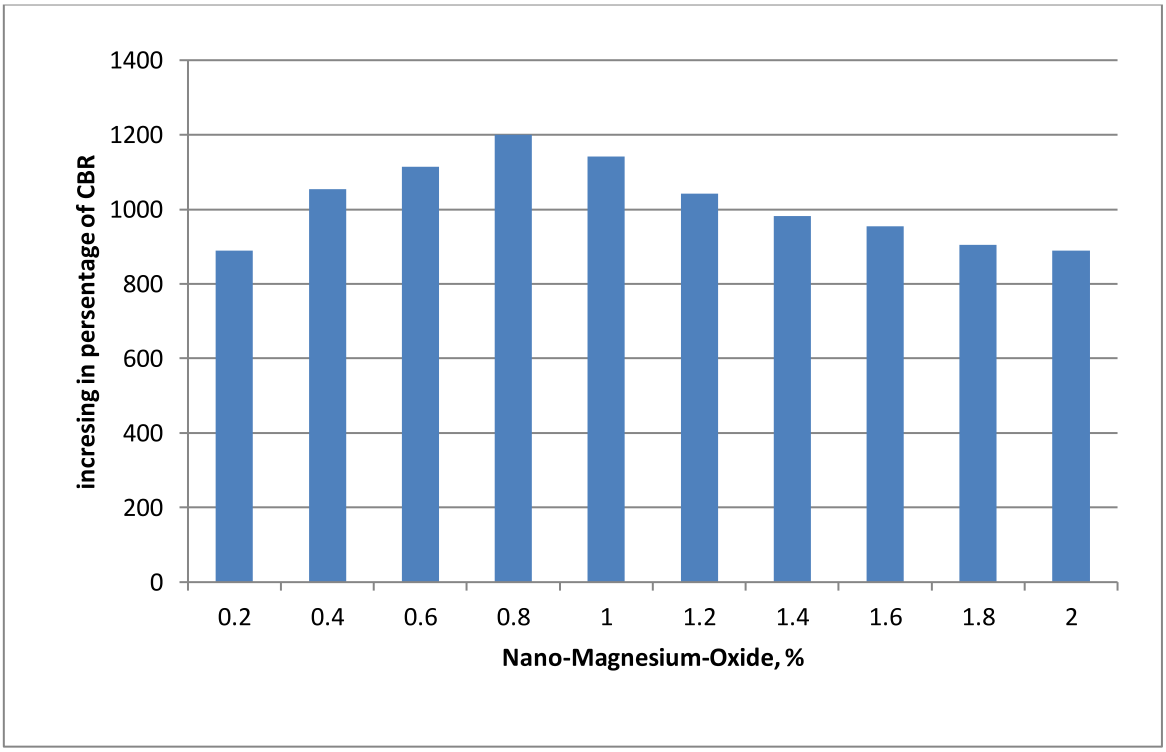

Figure 2. The increasing in percentage of CBR with different percentage of nano-magnesium-oxide

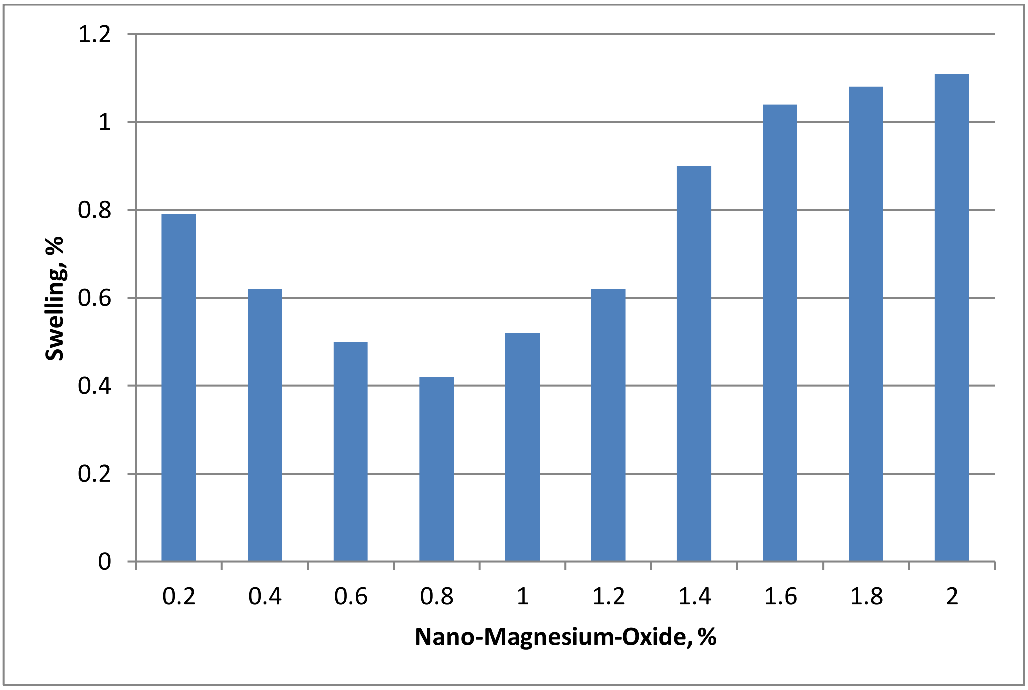

Figure 3. The results of swelling test with different percentage of nano-magnesium-oxide

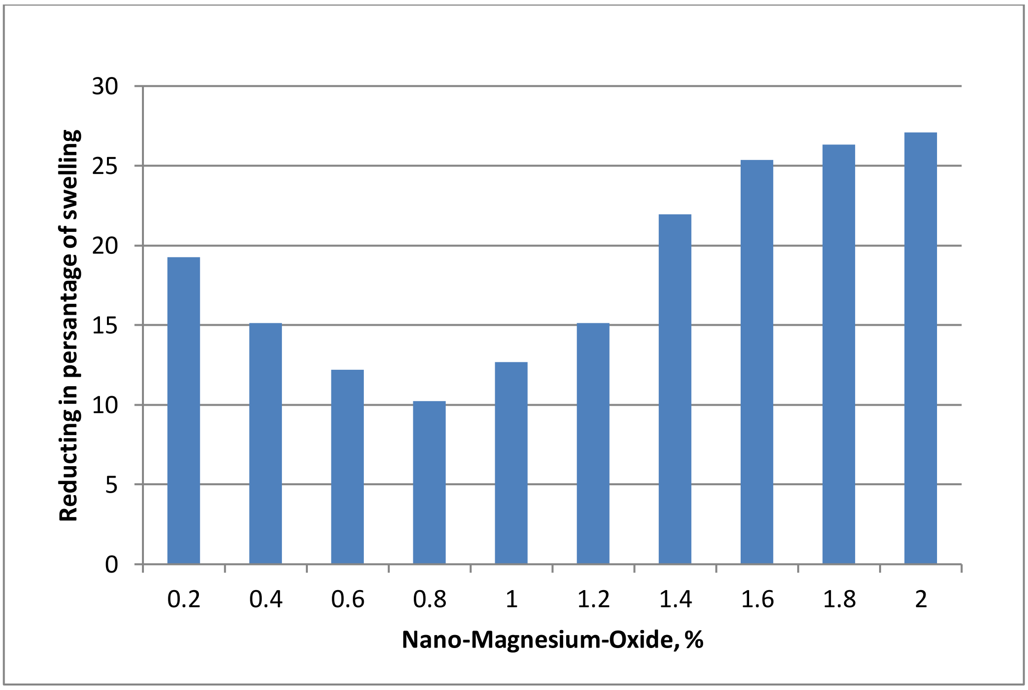

Figure 4. The reducing in percentage of swelling with different percentage of nano-magnesium-oxide

4.2. Results of EDXR-Spectroscopy

This test was carried out on samples from the original soil and soil mixed with nano-Magnesium-Oxide before and after wet treatment for 28 days to investigate the changes in the concentrations of the main elements involved in the composition of the soil before and after mixing and wet treatment. Figures 5, 6 and 7 show the results of these tests for the original soil, soil mixed with optimum dose of the additive before wetting, and soil mixed with optimum dose of the additive after wet treatment for 28 days respectively. The results showed noticeable changes in the concentrations of the main elements of the original soil and soil mixed with additive after wet treatment; Table 3.

Through the comparison between the examined samples of original soil and those of soil mixed with the additive under dry conditions, an increase in concentrations of Magnesium and Oxygen and a decrease in concentrations of Aluminum and Silicon in an amount commensurate with the ratio of the additive. This indicates that there is no reaction under dry conditions. However, by comparison between the dry and wet mixes of soil and additive, there is another increase in the Oxygen and Magnesium concentrations against decrease in Aluminum and Silicon concentrations. This is a clear evidence of a chemical reaction between the nano-Magnesium-Oxide and the soil components. The difference in the concentrations of these materials can be explained by the following points. First: reaction of nano-Magnesium-Oxide and water created compound of Magnesium Hydroxide. Second: an amount of Aluminum and Silicon dissolved in the Hydroxide solution. Third: with the melting of Aluminum and Silicon, their concentration decreased in the mixture and consequently the concentration of Magnesium and Oxygen increased. Fourth: in addition to increasing the concentration of Oxygen and the decrease in concentrations of Aluminum and Silicon, there is an additional increase in the concentration of Oxygen caused by the reaction of nano-Magnesium-Oxide with water, as this reaction added another Oxygen atom that comes from the water. These reactions can create Magnesium Silicate Hydrate compound that produced from reaction between Magnesium Hydroxide and Silica exists in the original soil. This compound may be responsible for creating strong bonding forces between the soil particles. This reaction is similar to the reaction of Portland cement with clay soils which is a compound of Calcium Silicate Hydrate [37, 38]. The superior fineness of nano-Magnesium-Oxide contributed to increase reaction intensity and, hence, led to an increase in the bonding compounds between the soil particles and improved their engineering properties.

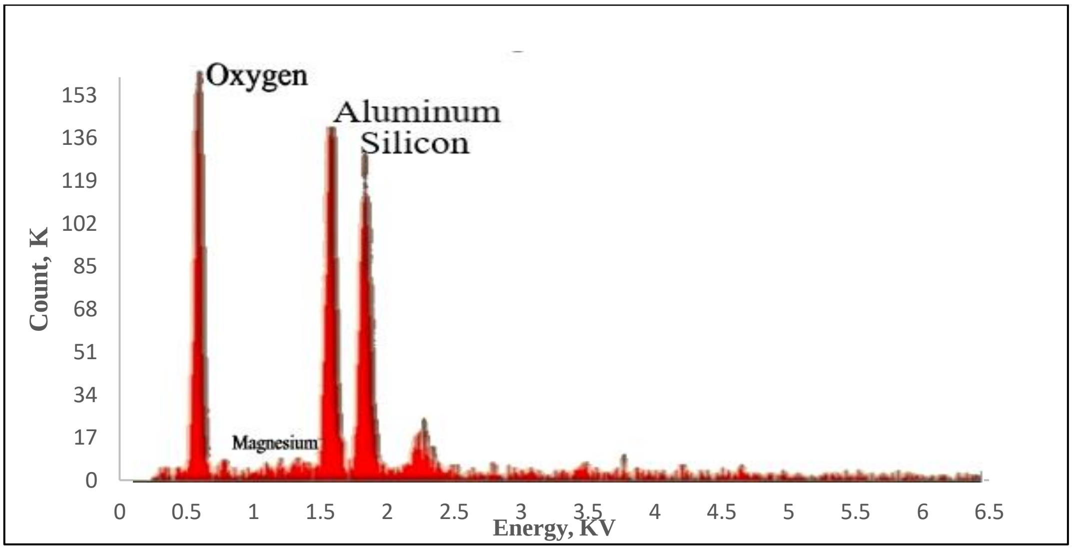

Figure 5. The result of Energy-dispersive X-ray spectroscopy for selected soil

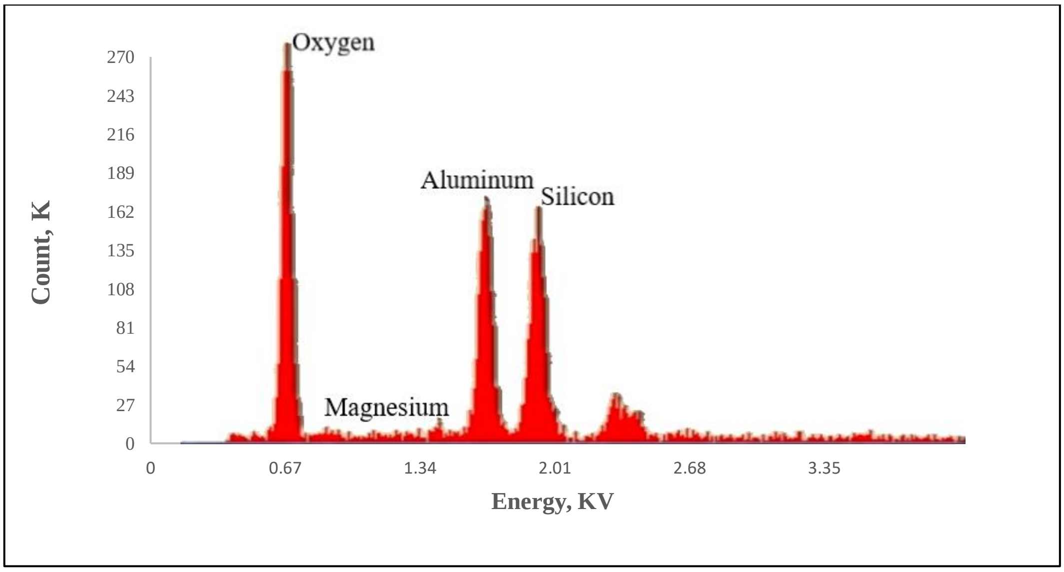

Figure 6. The result of Energy-dispersive X-ray spectroscopy for dry selected soil with nano-magnesium-oxide

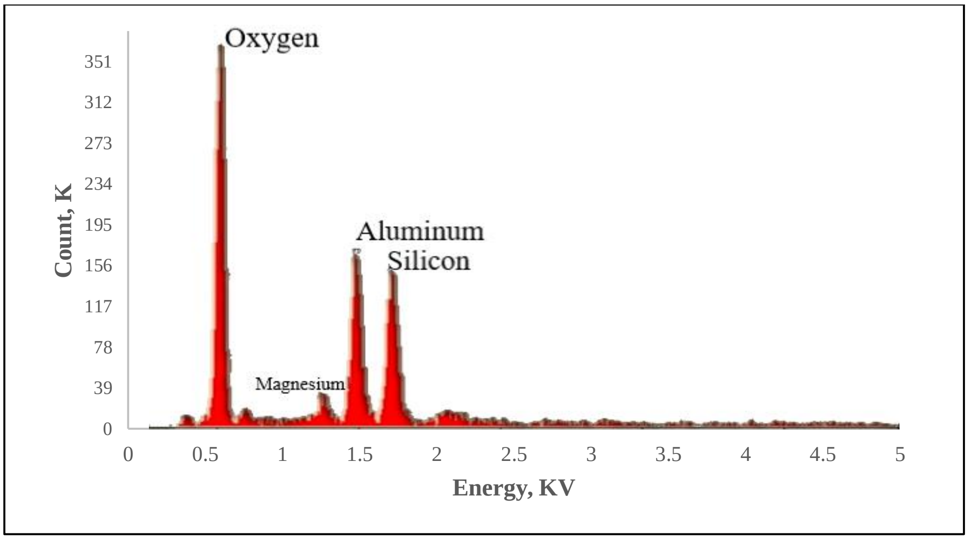

Figure 7. The result of Energy-dispersive X-ray spectroscopy for wet selected soil with nano-magnesium-oxide

Table 3 The main elements of the soil and the mix

The mix	Mg, %	Al, %	Si, %	O, %
Original soil	0.31	28.62	29.87	41.2
Dry soil with nano-Magnesium-Oxide	2.65	23.49	27.75	46.11
Wet soil with nano-Magnesium-Oxide	3.33	21.26	23.13	52.28

5. Conclusions

The present study adopted an experimental approach that mainly depends on laboratory tests to investigate the effects of nano-Magnesium-Oxide on soft subgrade soil. The results showed a noticeable improvement in the engineering properties of the selected soil. Through these results, the following conclusions were reached:

1. The usage of the additive suggested in this study, considerably, increases the CBR value of the treated soil. CBR value reaches its maximum when adding 0.80% of the additive. Adding this dose to soil increases the CBR value by about 1200% of its value in the original soil.
2. The usage of the additive suggested in this study, considerably, decreases the swelling ratio of the treated soil. Swelling ratio reaches its minimum when adding 0.80% of the additive. Adding this dose to soil decreases the CBR value to about 10% of its value in the original soil.
3. Based on the first and second conclusions, the optimum dose of the additive can be considered to be 0.8% by the weight of the dry soil. This dosage is very small compared to the required dosages in traditional additives used in the field of paving industry. The usage of small amounts of this, relatively, economical substance can eliminate the costs.
4. Adding nano-Magnesium-Oxide to clay soils can initiate chemical reactions creating compounds that form the bonding forces between the soil particles as it helps in their agglomeration and thus improving their engineering properties and increasing their durability.
5. The super fineness (nano-size) of the additive suggested in this study, significantly, contributes in increasing the intensity of the reactions.
6. This paper can open a wide gateway to scientific research in this direction through studying the usage of nano-Magnesium-Oxide on other types of soils or on other soil properties.

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