Compaction characteristics of natural cohesive subgrade soil stabilized with local sustainable materials

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Abstract. In traditional road construction, the most common source materials for roadbed layers are the borrow pits. During the construction process, the source's materials, excavation, loading, and handling have been considered significant factors on total construction cost. Improving the geotechnical properties of the locally available source materials using the waste materials of the local industry (as additives) is helped in avoiding undesirable additional costs in the field construction. The present paper explains the results of an experimental study of compaction characteristics for subgrade material of districts of Baghdad, Iraq with two different types of local byproduct materials “cement dust and fly ash materials”. The selected soil, cement dust, and fly ash mixtures were made ready for use in the laboratory, and the mixtures' compaction properties were investigated. Both light and heavy manual compaction tests were carried out and compared. The effect of selected stabilizers on the compaction behavior of the subgrade soil was determined to obtain the optimal values of stabilizer materials. The finding of this paper indicates that the compaction characteristics and behavior of the subgrade soil greatly depend on the type of additives used. However, the subgrade stabilization with local byproduct materials is beneficial from economic and environmental points of view.

1. Introduction
The Transportation plays an important role in the development of countries. This role is increased as the population increased [1]. In Iraq, traditional road construction is a common and widely applied transportation system in comparison to other means. As such, the design of roads and their construction process should get special attention. From an economic point of view, the total cost of road construction is controlled by different factors like the cost of material of roadbed layers. Generally, the soils of the borrow pits are the most common source materials for roadbed layers. The utilization of such soils is most economical in comparison to the replacement process with other local fill materials like "subbase material". However, almost the poor engineering properties of the soils of the borrow pits made the adoption of one of the available stabilization techniques inevitable. This is of the most important to satisfy the requirements of the design of the road [2-3].

There are many stabilization techniques are applied in geotechnical engineering. Thermal, electrical, chemical, or mechanical stabilization is usually used [4]. In highway engineering, chemical techniques are usually adopted at which the soil mixed with chemical materials like lime, cement, asphalt, or salts [5]. In the last decades, chemical substances from the wastes of the industry have been applied as a substitution to the traditional materials [6-8]. This may help in reducing the problem of these materials, on one hand, and to improve the poor properties of the soil, on the other one [9]. However, according to literatures, some of these wastes' materials, such as fly ash, cement kiln dust, ground granulated, blast slag, rice husk ash, etc., have been classified as sustainable materials [10].
These materials also called "sustainability cementitious materials", possess pozzolanic and hydraulic properties as stated by Rios et al. [11]. Stabilization of poor soils with one of these materials can improve their geotechnical properties. The design of roadbed layers itself is, also, affected by these additives, as these layers are made of soil mixed with selected additive.

The required improvement of soil mixed with any of the mentioned chemical additives can be guaranteed by exploring the compaction characteristics and behavior of the resulted mixtures. Laboratory compaction by falling masses and rammers is the main method used to study these characteristics. Indications about reducing the settlement, increasing the shear strength, bearing ratio improvement, reducing the permeability, and controlling the volumes changes in roadbed layers can be obtained from studying the compaction characteristics and its behavior.

The problem in this paper divided into two problems, the local soil and its compaction properties, in one hand, and negative effects of the waste materials from local industry in Iraq. The current paper tried to apply these materials in soil stabilization in an attempt to reduce the negative effects of these materials. The present paper shows the results of an experimental investigation that tries at utilizing cement dust and fly ash materials for the improvement of commonly available subgrade material of districts of Baghdad, Iraq. Cement dust (from local byproduct Iraqi cement industry), and flyash (from the byproduct of the local electrical power plant) have been chosen as stabilizers to the subgrade material. Every year many million tons of these waste materials were generated, and, unfortunately, accumulated and rarely reused or recycled.

The basic properties of the selected soil, cement dust, and fly ash mixtures were determined in the laboratory, and the compaction properties of the mixtures of the soil with these different contents (0%, 10%, 15%, 20%, and 25%) of these materials were investigated. The light manual compaction test and heavy one was carried out and compared in order to determine the effect of selected stabilizers on the compaction behavior of the local cohesive subgrade soil and to obtain the optimal value of these materials.

2. Materials used and testing program

The materials used in this paper are soil, cement dust, and flyash. The soil of the study is of the commonly available subgrade material of districts of Baghdad, Iraq. The soil sample was collected from the south of Baghdad city. The soil sample was prepared for laboratory testing and subjected to basic tests to identify and classify it according to the international standards. The investigated subgrade has low plasticity as its liquid limit, plastic limit, and plasticity index are 33%, 20%, and 13%, respectively [12]. The grain size distribution of the soil was determined according to ASTM D422 [13] as shown in Figure 1. The soil has a specific gravity of 2.66 (ASTM D854[14]). According to the results of basic tests, the investigated soil is a lean clay according to ASTM classification (ASTM D2487[15]), or clayey soil (A-6) as per AASHTO Classification System [16]. According to AASHTO, the general rating of the selected subgrade soil is "Fair to Poor". As such, improvement is required to raise the rating of the subgrade soil.

The cement dust used in this paper has been collected from the byproduct waste material of one local Iraqi cement factory located southwest of Baghdad (about 100 km). The sample of the cement dust was subjected to laboratory tests to determine its properties. The result showed that the cement dust has a specific gravity of 3.0, it is non-plastic material with grained size lies in the range of silt size material (passing sieve no.200 is 100%).

The third material used in this paper is the flyash. This material was collected from the waste generated during the operation of the electrical power plant, an electrical plant in Baghdad city. This material is black light weight material (Gs= 2.1). It is non-plastic and has a fine-grained texture (100% pass sieve number 200).

The selected soil, cement dust, and fly ash mixtures were oven-dried (105-110 °C) to make ready for use in the laboratory. The mixtures of soil-cement dust and soil-flyash were prepared by dry mixing to the following contents of cement dust and flyash (by dry weight of the subgrade soil) with the soil, 10%, 15%, 20%, and 25%. For each mixture type, the light manual compaction test, ASTM D698 [17], and heavy one, ASTM D1557 [18], was carried out. A 944 cm³ cylindrical mold of 10.16 cm in diameter and 11.64 cm in height was used. The designed mixtures were compacted inside the
cylindrical mold using lightweight and heavyweight manual rammer. For the lightweight procedure, the effort that applied to compact the soil-waste mixtures equal to "600 kN.m/m$^3$", while heavy rammer, the effort used is equal to 2700 kN.m/m$^3$.

3. Results evaluation and discussion
The objective of this paper is to study the effect of selected sustainable materials on the compaction behavior and properties of the local natural cohesive subgrade soil and to obtain the optimal value of these materials. The results of compaction tests are presented in Figures 2 to 5.

By examination soil-cement dust mixtures (Figure 2), using the lightweight rammer led to a slight reduction in "maximum dry unit weight", where "maximum dry unit weight" decreased by increasing the content of cement dust. On the other hand, the values of optimum molding water content showed different behavior, it seems to increase with increase the cement dust until it reaches a maximum value at 15% cement dust, then it decreases to reach a minimum value (below the value of the natural soil) at cement dust content of 25%. As a conclusion, the compaction of soil-cement dust mixtures by applying light effort "600 kN.m/m$^3$" has a slight effect on the unit weight while its effect is well pronounced on "optimum water content". The addition of cement dust (more than 10%) under light compaction has a significant effect on the shape of the compaction curve.

The behavior of the compacted soil-cement dust mixtures using heavy-weight rammer, Figure 3, is differed from that of lightweight rammer (Figure 2). Figure 3 shows a positive effect of cement dust material, in general, the "dry unit weight" of the compacted mixtures was increased in comparison to natural subgrade soil. However, the "maximum dry unit weight" reached its best value at 10% cement dust. Actually, at this dust content, the required water content to reach the best unit weight is at its minimum value. As a conclusion, the compaction of soil-cement dust mixtures by applying heavy effort "2700 kN.m/m$^3$" has a good improving effect on the compaction characteristics (both the unit weight and molding water content) in comparison to the natural subgrade soil. Nevertheless, the shape of the compaction curve was slightly or not affected by the addition of cement dust waste material.
Figure 2. Compaction curves for soil-cement dust mixtures (lightweight rammer).

Figure 3. Compaction curves for soil-cement dust mixtures (heavy weight rammer).

The effect of different contents of flyash on the compaction characteristics of the natural subgrade soil is shown in Figures 3 and 4. The natural subgrade soil was mixed with 10%, 15%, 20%, and 25% flyash, and subjected to light compaction effort and heavy effort compaction. As can see, the shape of the compaction curve is clearly affected by adding flyash waste to the natural subgrade soil.

By examination soil-flyash mixtures (Figure 3), using the lightweight rammer led to a clear decreasing in "maximum dry unit weight", where "maximum dry unit weight" decreased by increasing the content of flyash from 0% to 25%. On the other hand, the optimum molding water content values exhibited different behavior, it looks to be higher as the content of flyash increased, it seems proportion to the content of flyash at which it reaches the maximum value at 25% flyash. As a conclusion, the compaction of soil-flyash mixtures by applying light effort "600 kN.m/m$^3$" cause a reduction in the unit weight, this is due to the lightweight of flyash with specific gravity value 2.1, while its effect is clear in increasing the "optimum water content".
The heavy compaction test results are presented in Figure 5. An analysis of the soil-flyash mixtures reveals that the mixing of the flyash waste with natural subgrade causes a slight reduction in the unit weight, this reduction increase with increasing the content of flyash material. A reverse behavior can be noted in the values of optimum 'water content': for soil mixed with 10% flyash, the mixtures exhibit a slight increase in water content, while for 15% flyash and more, a very well pronounced increase in the value of the water content can be noticed. It appears in Figure 5 that the effect of flyash content on the compaction characteristics and behavior of subgrade soil (compacted using heavy rammer with an effort 2700 kN.m/m3) is very limited for flyash content greater than or equal 15%. 
Figure 5. Compaction curves for soil-flyash mixtures (heavy weight rammer).

4. Conclusions

The present paper shows the results of an experimental compaction investigation (using lightweight rammer and heavy one) that tries at utilizing different contents (0%, 10%, 15%, 20%, 25%) of cement dust and fly ash materials for the improvement of commonly available subgrade material of districts of Baghdad, Iraq. The commonly available subgrade material is A-6 soil and rated as "Fair to Poor" subgrade soil. The selected sustainable materials are the non-plastic material fine-grained cement dust and the black light-weight non-plastic fine-grained flyash material. The finding of this investigation showed that

1. The compaction of soil-cement dust mixtures by applying light effort "600 kN.m/m$^3$" has a slight effect on the unit weight while its effect is well pronounced on "optimum water content". While the compaction of soil-cement dust mixtures by applying heavy effort "2700 kN.m/m$^3$" has a good improving effect on the compaction characteristics (both the unit weight and molding water content) in comparison to the natural subgrade soil. However, the "maximum dry unit weight" reaches its best value at 10% cement dust.

2. The addition of cement dust under light compaction effort has a significant effect on the shape of the compaction curve, while the shape of the compaction curves was slightly or not affected for soil-cement dust mixtures subjected to heavy compaction effort.

3. The compaction of soil-flyash mixtures by applying light effort "600 kN.m/m$^3$" cause a reduction in the unit weight, this is due to the lightweight of flyash with specific gravity value 2.1, while its effect is clear in increasing the "optimum water content". Also, the effect of flyash content on the compaction characteristics and behavior of subgrade soil (compacted using heavy rammer with an effort 2700 kN.m/m$^3$) is very limited for flyash content greater than or equal 15%.

4. The shape of the compaction curve is clearly affected by adding flyash waste to the natural subgrade soil.

5. The finding of this paper indicates that the subgrade stabilization with local byproduct materials is beneficial from economic and environmental points of view.

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