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Evaluation of Cement-Stabilized Mine Tailings as Pavement Foundation Materials

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Abstract Waste disposal is an important topic for cities today. We have shown for the first time how to make sewage sludge disposal safer, more environmentally friendly and still to obtain some benefit from it, namely energy, from its organic content. The main purpose of this paper is to present a laboratory tests results based on investigation carried out on the tailings of Boukhadra Mine in Algeria, in order to find out their suitability for use in road embankments, and pavement foundations. Three types of tailings, namely as marl, limestone and iron ore wastes, were initially tested to find the most suitable of them for application in pavement structures. Having presented more compliant properties, limestone waste, after being treated with cement, was tested with modified Proctor compaction, compressive strength (CS) and California Bearing Ratio (CBR) tests. At 2% intervals, the cement content of the mixtures is varied from 0 to 6%. Test results showed that an increase of cement content in the mixture would increase maximum dry density and decrease optimum moisture content of the compacted mixture. The increases in CBR and CS values qualifying the mixtures for use in Algerian pavement foundation were also noted, indicating that the limestone waste from Boukhadra Mine has the potential to be directed to an outlet for recycling.

Keywords Waste characterization · Embankments · Limestone · Boukhadra Mine · NE Algeria

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1 Introduction

Anthropogenic impact on the environment involves changes to physical setting, and natural resources (Jain and Das 2017; Abdelouahad et al. 2018). Some human activities causes damages to the environment on a global scale include depletion of resources, destruction of ecosystems, extinction of wildlife, and pollution (Govorushko 2016; Hadji et al. 2018; Besser et al. 2018). Almost all industrial and mining activities produce waste. The increase and accumulation of those waste is one of principal sources which causes environmental and economic-related issues around the

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foundation materials. Since that the limestone waste are still requires improvement to become suitable for a sustainable pavement layer, a stabilization was chosen in this case.

3.2 Laboratory Experiments

Laboratory investigations have been carried out to investigate necessary mechanical properties of the stabilized tailing materials. For use in pavement foundation, limestone waste of maximum 31.5 mm in size was chosen for further laboratorial study. In order to understanding the effect of cement in stabilizing limestone tailings and to increase material strength, cement content added with 2% intervals to the tailings varied from 0% to 6% by the weight of dry aggregate, where the ordinary portland cement (OPC) grade 42.5 was procured from cement factory of El Malabiod-Tebessa (Table 2). Compaction characteristics, CS and CBR tests were carried out on cement-stabilized limestone mixtures.

Table 2 Physico-chemical properties of El Malabiod OPC

Designation CPA-CEM I 42.5	
Physical characteristics	
Density (g/cm^3)	3.2
Initial setting (min)	140–195
End setting (min)	195–290
Shrinkage at 28 days	0.3–2.5 mm
Specific surface area (cm^2/g)	2900
Compressive strength at 28 days (MPa)	$\geq$ 42.5
Chemical characteristics	
SiO_2 (%)	20.01
Fe_2O_3 (%)	2.97
Al_2O_3 (%)	4.65
CaO (%)	64.01
MgO (%)	0.62
SO_3 (%)	2.15
Cl (%)	0.015
Na_2O (%)	0.24
PF (%)	4.34

3.2.1 *Modified Proctor Compaction Test*

Modified Proctor compaction tests were conducted on the cement-treated limestone waste under optimum Proctor conditions. In this case, the treated material contained a large proportion of coarse particles of 75.2% and 20% sand. Treatments with cement were done according to Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort ASTM D1557 (ASTM 2012). Bell-shaped dry density curves against water content were plotted to figure out optimum moisture content (OMC) within the mixtures and maximum dry density (MDD) (Fig. 6). The OMC values for mixtures with 2% and 4% cement contents appeared to be very close to that of the control mix (limestone tailings with no cement); however, adding extra cement up to 6% significantly reduced OMC to about 4.5%.

3.2.2 *CBR Test*

California Bearing Ratio test is a measure to evaluate the stability and bearing capacity of compacted samples of subgrade soils and other constitute materials of pavement structures (Tajdini et al. 2016). The test is to drive a piston into the specimen of compacted material while applying standard static load values of 13.44 and 20.16 kN for 2.5 and 5.0 mm penetration stages, respectively. The CBR for this study was done in accordance to standard test method for CBR ASTM D1883-14. After relevant OMC water was added to the treated limestone waste mixtures of various cement contents, samples were compacted to their corresponding MDD (according to modified Proctor) in CBR test molds. To simulate the worst possible condition and based on the standard test method for CBR, the samples were then cured in water at 20 °C for 4 days before being tested using a CBR test equipment. The CBR values for different mixtures are illustrated in Fig. 7.

3.2.3 *Compressive Strength Test*

Compressive strength (CS) testing of the study mixtures were conducted following standard test method for compressive strength of cylindrical concrete specimens ASTM C 39/C 39M (ASTM 2012). Mixtures of various cement contents were prepared at their respective OMC. Cylinder samples of 152 mm in

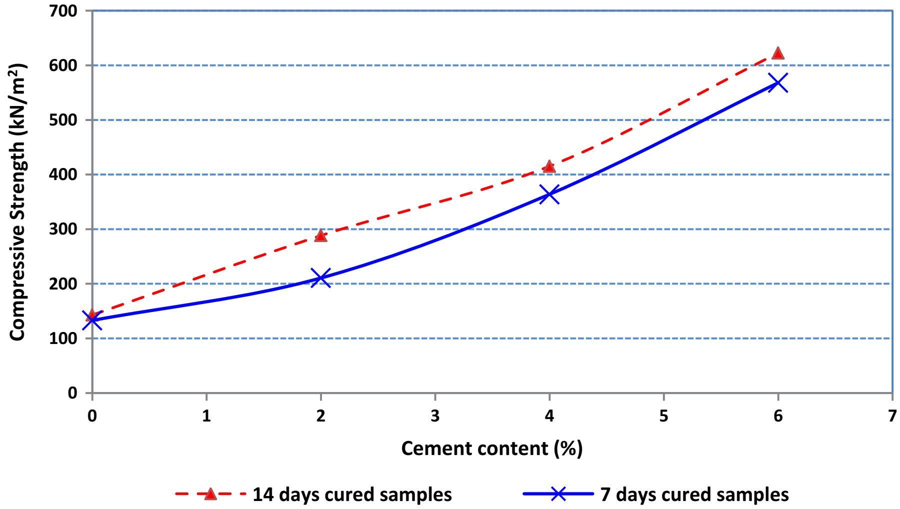

Fig. 8 Compressive strength values of samples cured for 7 and 14 days

added. Cement contents of 4% and 6% developed about four times higher bearing capacity compared to the compacted limestone waste with no treatment. According to Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations—Airfield and Heliport Design (FM 5-430-00-1 1994), 2% cement-stabilized limestone waste is sufficiently strong to be used in pavement foundation. A large fraction of limestone waste is composed of granular particles having insignificant, if any, cohesion. Therefore, the strength offered by compacted samples comes mainly due to the mobilization of particles' surface friction. Hydrated cement forms insoluble C–S–H gels which are in charge of binding the limestone particles together, hence, development of cohesion within the mixture. As a result, cement-treated mixture gained further bearing capacity. With increase in cement content in the mixture up to an optimum dosage, further volume of gel formation develops. The particles bind more effectively, resulting in higher CBR values. The foundations designed with treated materials, gives larger CBR values, which resist larger to the magnitude and frequency of loads induced by traffic, and leading in more durable pavement structures.

4.3 Compressive Strength

Compressive strength of cement-stabilized limestone waste samples was tested after 7 and 14 days of curing (Fig. 8). It is seen that the mixtures have earned strength in the course of time within the study period of 2 weeks, and the magnitude of compressive strength has increased with increasing cement content. Secondly, addition of cement (up to a level) to limestone waste assists material compaction, and increase density of compacted material. Once cement hydration develops strength, higher density shares effect in higher compressive strength. During CS tests, stable ductile crack propagation behavior was observed, where the material could sustain permanent deformations without losing its ability to resist the loading.

Cement-stabilized limestone wastes have demonstrated different behaviors when their mechanical properties of CBR and CS were tested. CBR test was not able to characterize the effect of 6% cement and showed nearly as equal bearing capacity for 4% as that for 6% cement-stabilized material. However, CS test clearly showed that the additional 2% cement enhanced compressive strength of the mixture with 4% cement for at least 50%. It is understood that CBR test would not be an appropriate testing method to study the effect of adding cement to limestone waste after a certain cement dosage. Once the material rigidifies, CBR test mechanism will not be able to provide any realistic measure of the mixture.

According to the CBR test results, the mixtures with 4% and 6% cement contents became rigid in 4 days time. This fact is significantly notable when such a mixture is under construction. The earlier the material reaches to a certain bearing capacity to allow for the construction machinery, the sooner

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