



Improving pavement load-bearing capacity: An experimental study in the Tigzirt region, Algeria

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Article Info

Abstract

Article History:

Received 02 Jul 2026

Accepted 14 Sep 2026

Keywords:

Bearing capacity;
Crushed marble;
CBR test;
Pavement;
Local materials

The load-bearing capacity of pavements and the availability of construction materials have become critical challenges in many regions. This study aims to enhance the bearing capacity of pavements in the Tigzirt region, an area prone to geotechnical issues by reinforcing local earthwork materials (EM) with crushed marble (CM) additives. An experimental program comprising compaction and bearing capacity tests was conducted to determine the optimal material composition for pavement layers. Results demonstrate that all tested materials comply with relevant standards. Bearing capacity assessment through modified Proctor and CBR tests revealed that the incorporation of 20% crushed marble significantly improves pavement performance, making this approach a viable solution for local construction applications. Indeed, the modified Proctor tests demonstrated a significant improvement in the maximum dry density, estimated at 2.24%, following the optimized addition of (CM). Additionally, the optimal water content recorded a decrease of -8.53%. Furthermore, the results of the CBR tests revealed a marked enhancement in bearing capacity: the CBR index after immersion rose by 32.8%.

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1. Introduction

In today's world, it is imperative to incorporate sustainable development across all sectors in order to protect the environment, manage natural resources efficiently, and build sustainable economic infrastructure that meets technical standards. In this context, recycling local materials and industrial waste for road construction represents an innovative and sustainable approach that helps preserve natural resources while reducing waste generation. By incorporating local materials from earthworks and recycled waste in the form of aggregates, road infrastructure can achieve significantly improved mechanical properties and enhanced durability. This strategy not only cuts costs associated with extracting and transporting virgin materials but also reduces the environmental impact of landfills. Furthermore, using these materials fosters the circular economy by repurposing waste that would otherwise be deemed unusable. However, to maximize the benefits of this approach, it is essential to conduct in-depth studies on the performance and durability of pavements made from recycled materials, while ensuring compliance with current quality and safety standards.

The development of road projects is a key factor in Algeria's expansion and growth. Road and highway construction involves earthworks comprising several stages, including the placement of fill material (embankments) to raise the ground profile. Embankments must be designed according to strict standards, as they provide the solid foundation that ensures the geometry and stability of

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DOI: <http://dx.doi.org/10.17515/resm2026-1818ma0702rs>

Res. Eng. Struct. Mat. Vol. x Iss. x (xxxx) xx-xx

road infrastructure. Indeed, embankments are crucial components of these projects, and their construction requires the supply of materials. Currently, road infrastructure construction demands thousands of tonnes of aggregates. However, this activity has a significant impact due to construction on low-bearing-capacity soils, the depletion of natural reserves, and the scarcity of the high-quality soil needed for these projects. To meet this challenge, it is therefore essential to explore techniques aimed at improving the performance of local materials [1, 2, 3]. These techniques aim to optimize soil properties to make it stable and suitable for specific applications. Studies state that improvements can include increased soil strength, stiffness, durability (wear resistance), and reduced swelling [4]. The most commonly used materials are aggregates, hydraulic binders, hydrocarbons, inert waste, etc. Furthermore, several countries have standardized the reuse of these materials [5].

Previous research conducted by numerous authors around the world has focused on adding various materials such as hydraulic binders, fibers, fine soils, sediments, and largely inert, industrial, and/or mineral waste, glass, plastics, whether incinerated or crushed, etc. Kurban et al., used waste as road foundation fill material to improve its bearing capacity [6]. Jayaprakash et al., used xanthan gum to reduce the potential for soil dispersion and increase strength and erosion resistance [7]. J. Gayda et al., used organic-mineral aggregates to reinforce sandy subsoil [8]. Gonawala et al., studied mixtures of slag and steel industry waste as stabilizers for expansive soils [9]. Raj et al., studied mixtures of slag, copper, and fly ash with cement as a stabilizer for their appropriate use in road construction [10]. Kolay and Aminur, 2011 used fly ash and quicklime to improve the physical and geotechnical characteristics of unstabilized soils [11]. Smith and Brown, 2022 studied the valorization of marl in road infrastructure [12]. Johnson and Smith, 2022; Lee and Kim, 2021 used slag and glass debris in road construction [13, 14]. Disfani et al., used industrial glass debris [15], Smith and Brown, 2021 studied the sludge for use in road construction [16]. Dupont and Martin, 2022 studied the behavior of multilayers of clay-marl [17]. Arulrajah et al., studied the behavior of construction debris used in road construction [18]. Khial and Melbouci studied the mechanical behavior of mixtures of aggregates and household and other plastic waste of different sizes and shapes for possible use in road construction [19, 20, 21].

The use of marble in civil engineering and public works is a relatively recent initiative, primarily utilized in the form of powder derived from the marble industry. Several studies have been conducted on the application of this marble powder in pavements, notably by Haruna and Lin as well as Hwayyiz et al., who achieved very satisfactory results [22, 23]. These studies demonstrated a significant improvement in the geotechnical characteristics of the studied soils. Additionally, Zaryab et al., explored its use to enhance the properties of concrete [24], while Zia incorporated it into various construction materials [25]. These promising results pave the way for new applications and increased valorization of marble waste in the construction sector.

The Tigzirt region in Tizi-Ouzou, like the rest of northern Algeria, has unstable slopes. This instability is linked, in part, to their geological formation, the slope of the terrain, and its sensitivity to water. Indeed, the slope is subject to surface erosion resulting from runoff and deep erosion marked by the presence of water. As a result, numerous geotechnical problems arise in the construction of roads in this region. Furthermore, regarding the impact of traffic volume in this region, the Ministry of Public Works citing **Algérie 360°** has revealed that the accelerated deterioration of the national road network is primarily caused by the widespread overloading of heavy goods vehicles [26]; indeed, the region is experiencing significant growth in construction activity driven by its rising tourism potential. With its picturesque landscapes, attractive beaches, and rich cultural heritage (including Roman ruins in the town center), Tigzirt is becoming a prime destination for both domestic and international visitors. This influx of tourists drives demand for new infrastructure such as hotels, restaurants, and leisure centers, leading to increased investment in the construction sector and, consequently, a higher volume of heavy goods vehicle traffic. Figure 1 below illustrates the deterioration of a road in the Tigzirt region and also shows the type of traffic it carries.



Fig. 1. Example of pavement instability in the Tizirt region

This work is part of an effort to promote the use of earthworks materials (EM) (from excavated soil) in the Tizirt region, while aiming to improve their mechanical characteristics with crushed marble (CM), with a view to using them in road construction. Its purpose is to help alleviate the problems related to pavement durability encountered in this region, to conserve natural resources and protect the environment, by proposing effective solutions for the management and recovery of industrial waste and by-products destined for landfills.

2. Experimental Program

The road sector is looking for ways to use a wide range of local, cheaper, and non-polluting materials, but it is clear that each material must fully meet the quality requirements particularly in technical and environmental terms. Road geotechnics relies on either in-situ or laboratory tests to assess the behavior and conditions of soil use, such as identification tests (grain size, Atterberg limits, etc.) and mechanical behavior tests such as Proctor and CBR. For gravel, other hardness tests such as Los Angeles may be required.

2.1 Materials Used

The materials used in this study come from the Tizirt region.

2.1.1 Crushed Marble (CM)

This material, used as an additive to reinforce the load-bearing capacity of pavements, was obtained by grinding marble waste and then sieving it. The particle size class used is 0/31.5. It is selected as a reinforcing material to leverage its mechanical properties in order to enhance those of the soil matrix [22, 23]. Figure 2 below illustrates the crushed marble used in this research. Also, Figure 3 below illustrates the earthworks materials used in this research. Key characteristics include:

- hardness and rigidity, good resistance to compression and wear, low deformability,
- high density (approx. 2.6 to 2.8 g/cm³). Indeed, adding it to the soil can result in:
- Increased load-bearing capacity, rigidity, and shear strength,
- Reduced settlement (provided compaction is adequate and the particle size distribution is suitable),
- Improved drainage,
- Sensitivity to acidic environments.

2.1.2 Earthworks Materials (EM)

The EM tested were obtained from a landfill site in the Tizirt area. The particle size class used is 0/31,5. The steps for obtaining this class are as follows:

- The 0/31.5 particle size class was determined by sieving a quantity of earthworks material; that is, the maximum particle size of the materials tested in this study does not exceed 31.5 mm.
- The composition of this class was determined via particle size analysis using sieving.
- The particle size distribution curve for this class was plotted.
- This curve will subsequently be compared against the regulatory grading envelope (defined by the lower and upper limits) to assess the potential use of the tested materials in the base course.



Fig. 2. Crushed marble used



(a)



(b)

Fig. 3. (a) Sample of earthwork material used and (b) Sieving of the CM

2.2 Composition and Preparation of Composites

The composites tested were prepared according to the percentage of (CM) added to (EM). These percentages varied between 15 and 30%.

2.3 Road Tests Carried Out

The study of the behavior of the composites examined focused on road tests, namely particle size analysis, Atterberg limits, modified Proctor compaction, CBR bearing capacity tests, and Micro-Deval tests in the presence of water.

2.3.1 Road Tests on Crushed Marble (CM)

The (CM) was subjected to the following tests

2.3.1.1 Granulometric Analysis by Sieving

This test determines the weight of the components of a soil (material) according to their size (stones, gravel, coarse sand, fine sand, silt, and clay). Granularity is a parameter used to classify soils according to the size of the elements they contain and to determine the distribution of soil grains according to their size in a sample [27]. The different granular fractions of (CM) chosen for the development of the particle size distribution curve were selected to comply with Algerian standards; in fact, we conformed to the Algerian catalogue for the design of new pavements [31]. The cumulative percentages of material passing, used to plot the particle size distribution curve of (CM) are recapitulated in table 1 below.

Table 1. Cumulative percentages of material passing of (CM)

Sieve Diameter(mm)	40	31.5	20	10	6.3	4	2	0.5	0.2	0.08
Cumulative sieving (%)	100	96.1	89.1	69	52.3	45	30	19	10	8

2.3.1.2 Los Angeles Test

This test is conducted in accordance with French standard [32]. It involves measuring the mass of particles smaller than 1.6 mm that result from the fragmentation of the test material, which has an initial mass of 5,000 g, when subjected to standardized ball impacts within the rotating drum of the Los Angeles machine.

The LA coefficient is derived by comparing the initial mass of the sample to its mass following the controlled wear process. By utilizing the initial mass of 5,000 g and the final mass, we can evaluate the durability of the aggregates by calculating the percentage of material lost during the test.



Fig 4. Los Angeles test



Fig. 5. Granulometric analysis by sieving of EM

Table 2 recapitulates the LA test result.

Table 2. LA test results

Initial mass (g)	5,000
Final mass (g)	3,810

2.3.2. Road Tests Carried Out on Earthworks Materials (EM)

2.3.2.1 Granulometric Analysis by Sieving

This test determines the weight of the components of a soil (material) according to their size (stones, gravel, coarse sand, fine sand, silt, and clay).

The EM particle size distribution curve falls within the particle size range specified in [31], which suggests that this material can be reinforced for use in the base course.

The cumulative percentages of material passing, used to plot the particle size distribution curve of (EM) are recapitulated in table 3 below.

Table 3. Cumulative percentages of material passing of (EM)

Sieve Diameter(mm)	40	31.5	20	10	6.3	4	2	0.5	0.2	0.08
Cumulative sieving (%)	100	95.1	81	60	49	45	35.1	23	15	10

2.3.3 Road Tests Carried Out on (EM) Improved With (CM) Additions

The study of the behavior of the composites examined focused on road tests, namely Atterberg limits, modified Proctor compaction, and CBR bearing capacity tests.

2.3.3.1 Atterberg Limits

This test is carried out in accordance with standard [28]. This test is used to define indicators that qualify the plasticity of a soil, and more specifically to predict its behavior and identification. The purpose of these tests is to determine the consistency limits, which are expressed in terms of water content, marking the limits between solid, plastic, and liquid states. The results of the Atterberg limits test are summarized in the table below.

Table 4. Results of the Atterberg limits test on improved EM with CM additions

Atterberg limits	Values obtained
Liquidity limit WL in %	27
Plasticity limit Wp in %	13.9
Plasticity index Ip	13.1

2.3.3.2 Modified Proctor Test

This test is performed in accordance with French standard [29]. The optimum water content W_{opt} and maximum dry density γ_{dmax} are determined. Proctor curves are plotted taking into account the different percentages of powdered and granulated cork added. The results are then compared with those obtained on natural aggregates without additives.

The Proctor curves are plotted taking into account the different percentages of crushed marble added.



Fig. 6. Compaction operation



Fig. 7. Sample tested after penetration with the CBR apparatus

3. Results and discussion

3.1 Tests on Crushed Marble (CM)

3.1.1 Granulometric Analysis by Sieving

Fig 8 below shows the particle size distribution curve obtained by sieving (CM).

The particle size analysis by sieving of the (CM) used in this research is represented by a decreasing curved blue line on a semi-logarithmic curve. The x-axis represents the sieve diameter in millimeters, and the y-axis represents the cumulative sieving percentage. This line begins at the intersection of the points corresponding to 100% of the cumulative sieving (y-axis) and a 40 mm sieve diameter (x-axis), and ends at the intersection of the points corresponding to 8% of the cumulative sieving (y-axis) and a 0.08 mm sieve diameter (x-axis). This line is situated between two other lines of similar shape: one green, representing the lower boundary, and the other red, representing the upper boundary, as dictated by the standardized particle size distribution for Algeria [31]. This curve falls within the particle size distribution range dictated by this standard.

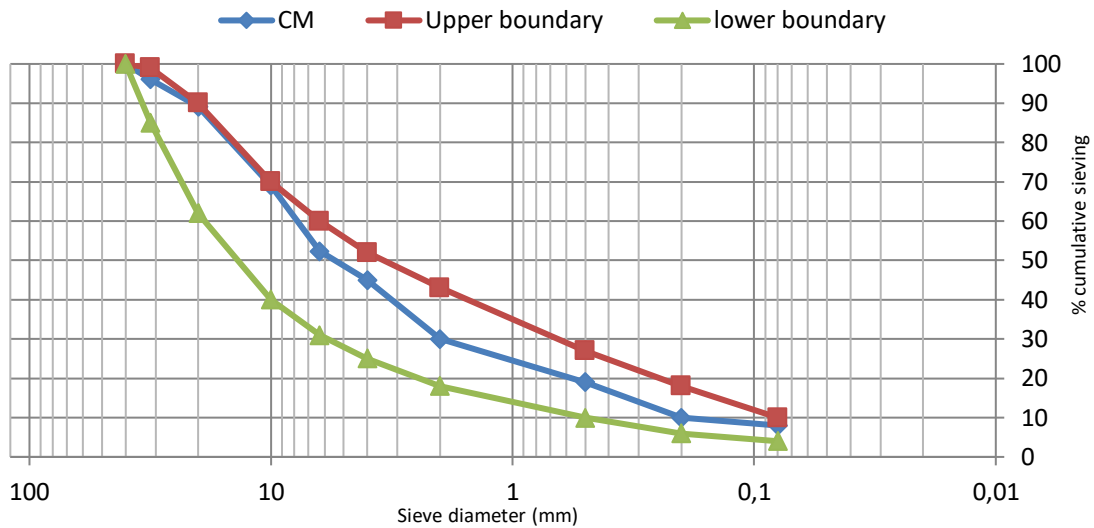


Fig. 8. (CM) particle size distribution curve

3.1.2 Los Angeles Test

A crucial aspect of the Los Angeles test is the threshold established for aggregate suitability based on performance. According to [31], aggregates with a Los Angeles test value below 40% are considered suitable for various construction applications, including use as a component of the base course.

$$LA = (5000 - 3810) / 5000 * 100 = 23.8\% \quad (1)$$

In this study, the result of 23.8% is well below the 40% threshold. This indicates that the material possesses good durability and wear resistance, making it a suitable choice for use in the base course. Using materials with lower Los Angeles test values in the base course is beneficial, as it enhances the overall stability and longevity of the pavement structure. Consequently, since the aggregate meets this quality criterion, it can be used with confidence in the base course of construction projects, thereby contributing to the structural integrity and performance of the pavement.

3.2 Road Tests Carried Out on Earthworks Materials (EM)

3.2.1 Sieve Analysis

Fig 9 below shows the sieve analysis curve for (EM).

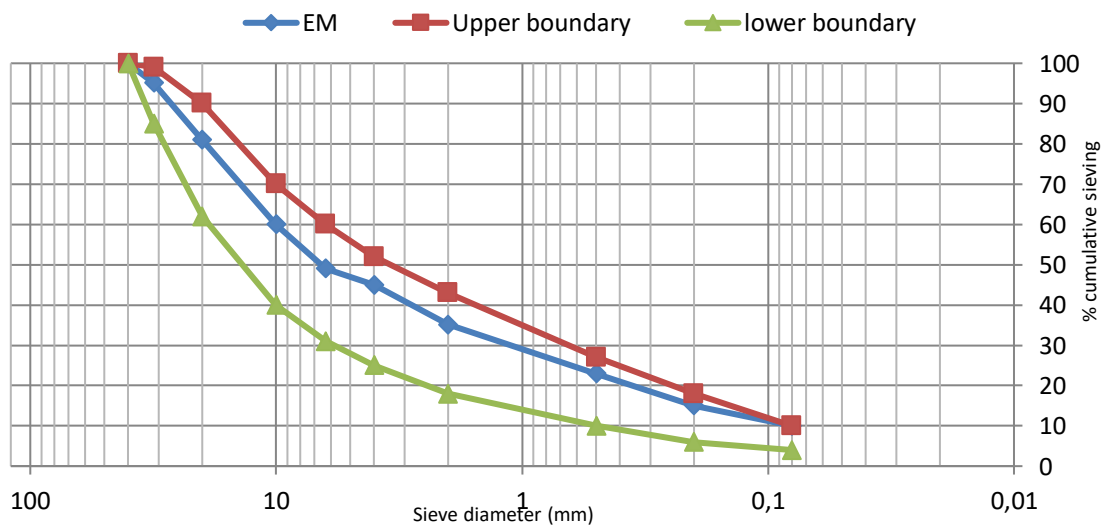


Fig. 9. (EM) particle size distribution curve

The interpretation of this figure is identical to that of Figure 4 above; it should be noted that this curve falls within the particle size distribution range defined by [31].

3.3 Road Tests Carried Out On (EM) Improved With (CM) Additions

The study of the behavior of the composites examined focused on road tests, namely Atterberg limits, modified Proctor compaction, and CBR bearing capacity tests.

3.3.1 Atterberg Limits

The Atterberg limits test made it possible to characterize the plasticity of the fine fraction of the 0/31.5 material. It serves as a key indicator for assessing the quality of the material used in road design. A suitable material must exhibit low plasticity to ensure the durability and stability of the pavement. The results obtained from the Atterberg limits test are as follows:

- The liquid limit (WL) is 27%, indicating a tendency for the soil to exhibit liquid-like behavior. However, this value is below the 40% threshold considered acceptable for road construction materials (according to [28]); consequently, the soil is relatively stable and capable of bearing loads without deformation.

The plastic limit (Wp) is 13.9%; this relatively low value helps reduce the risk of permanent deformation. Furthermore, this value makes the tested material suitable for use in road pavements.

The plasticity index (Ip) is calculated as follows:

- $I_p = WL - W_p = 27 - 13.9 = 13.1$.

This I_p value of 13.1 indicates plastic behavior; the material meets standard acceptability criteria. Nevertheless, additional precautions may be warranted.

Based on the results, the tested material is suitable for road pavement construction and falls within standard limits. However, the recorded plasticity index is relatively high, necessitating proper moisture management and appropriate compaction techniques to mitigate the risk of settlement.

3.3.2 Modified Proctor Test

Fig 10 below summarizes the modified Proctor curves which determine the variation in the water content (W) and dry density (ρ_d) as a function of the different percentages of (CM) additions (without addition: 0%, 15%, 20%, 25%, and 30%).

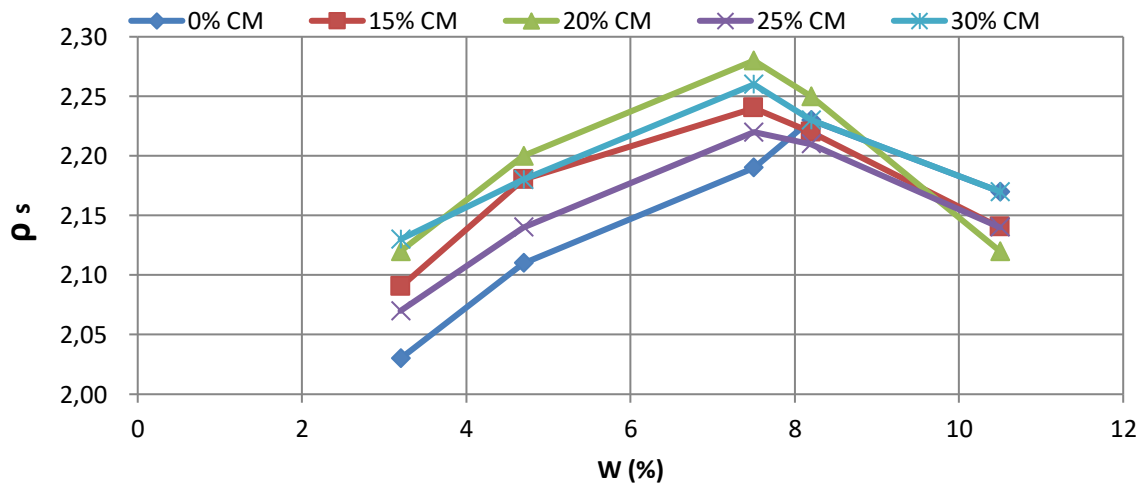


Fig. 10. Modified Proctor curves showing the variation of W and ρ_d as a function of different %CM additions

According to this figure, we observe that:

- The maximum dry density is obtained by adding 20% (CM). With this percentage of addition, it reaches 2.28.
- The optimal water content is 7.5% for the different percentages of (CM) addition.

Adding (CM), which is a dense and rigid material, to (EM) increases the mixture's overall density. Furthermore, the compaction of the (EM) is improved by the addition of CM; the material's internal structure changes as the (CM) grains distribute themselves among the (EM) particles during compaction, filling voids and reducing the spaces between particles. Fig 11 below illustrates the maximum dry densities obtained for each percentage of (CM) addition.

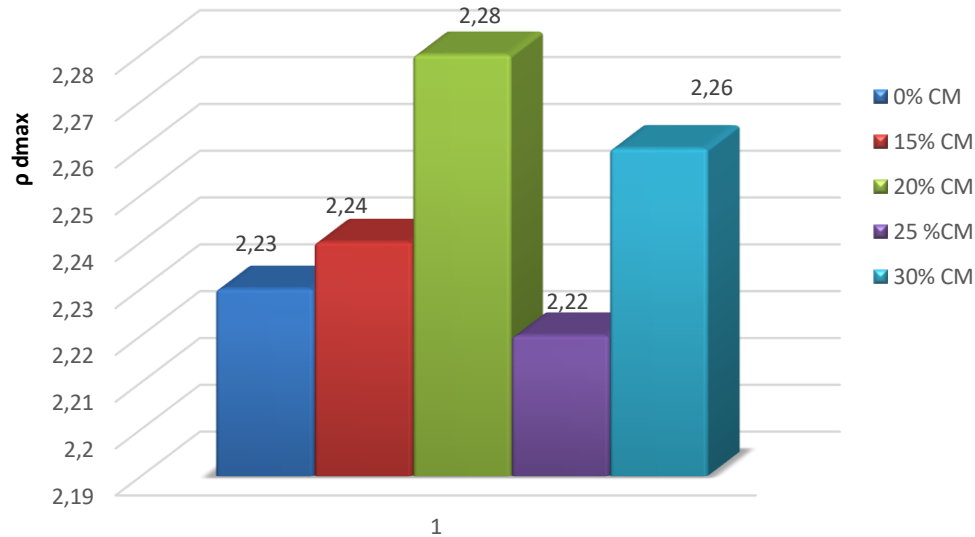


Fig. 11. Maximum dry densities obtained for each percentage of (CM) addition

The figure shows that: dry density increases with increasing percentage of added (CM) up to a certain threshold, which corresponds to the maximum dry density, obtained with the addition of 20% (CM). Beyond this percentage, it gradually decreases. This can be explained as follows:

The higher the water content, the higher the dry density, because the more water is added, the more the particles in the mixture become hydrated. Indeed, water ensures cohesion between the particles since it plays an essential role in chemical and physical reactions. At a water content of 7.5%, the mixture can be compacted optimally ($\rho_s = 2.28$), which helps to reach the maximum dry density, because the water helps lubricate the mixture during compaction. Furthermore, it improves the mechanical properties of the mixture, thus facilitating the achievement of a higher density. Indeed, the maximum dry density is obtained by adding 20% (CM), which is 2.28, an improvement over the value for the material without additives, which is 2.23, and therefore more favorable. In fact, the improvement rate is estimated at 2.24%.

The maximum dry density decreases beyond a 20% addition of (CM), which may be due to:

- Increasing the percentage of added (CM) can create voids resulting from the poor arrangement of particles, which tends to reduce the dry density.
- When the percentage of added (CM) exceeds 20%, maintaining the homogeneous distribution of grains in the mixture becomes difficult. Although the density of marble is high, the (CM) has distinctive sizes and shapes, which can lead to fragile areas or aggregates that do not compact effectively.
- When the percentage of marble increases beyond the maximum percentage, the amount of (CM) increases; however, the amount of (EM) in the mixture decreases, which can alter the adhesion and cohesion properties; therefore, the ability of the mixture to compact effectively would be affected, therefore the density would be limited.

Fig 12 below illustrates the optimal water contents obtained for each percentage of (CM) addition. According to the figure, we can see that:

The optimum water content is 7.5% for all percentages of (CM) addition to (EM), we note that this content is lower than that of the material without addition, which is 8.2%, which is advantageous because the percentage of water used during compaction for road construction has decreased by -

8,53%. This decrease in water content can be explained by the fact that the (CM) material has a lower absorption capacity than material (EM). Indeed, as the percentage of (CM) added to the mixture with (EM) increases, the proportion of (CM) in the final sample rises. This increase in (CM) reduces the sample's overall absorption; consequently, the sample as a whole becomes less prone to taking up and retaining water. As a result, a significant decrease in the water content of the tested sample is observed.

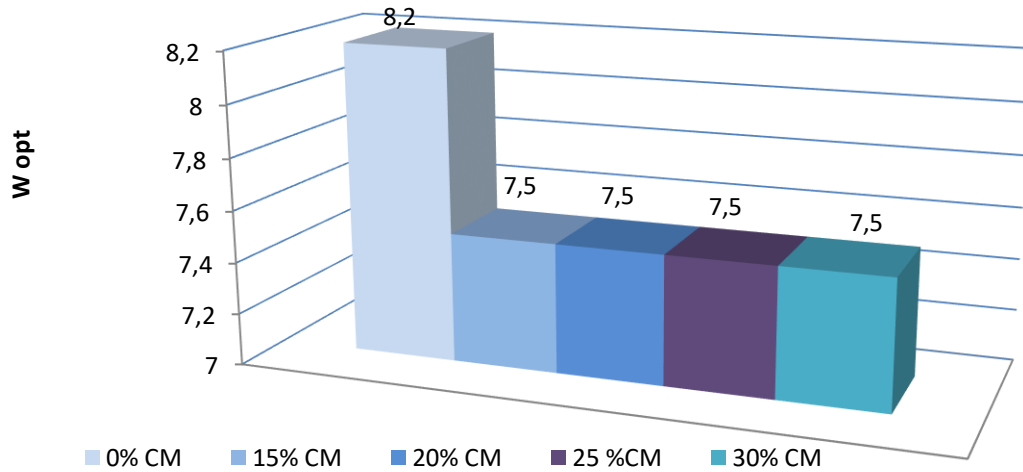


Fig. 12. Optimum water contents obtained for each percentage of (CM)

3.3.3 CBR Test

This test is carried out in accordance with French standard [30]. Its purpose is to determine the bearing capacity of the composites tested. The bearing capacity of these materials depends considerably on their state characteristics.

Figure 13 below illustrates the results of the CBR tests after immersion, specifically the soaked CBR index values, obtained based on the percentages of (CM) added.

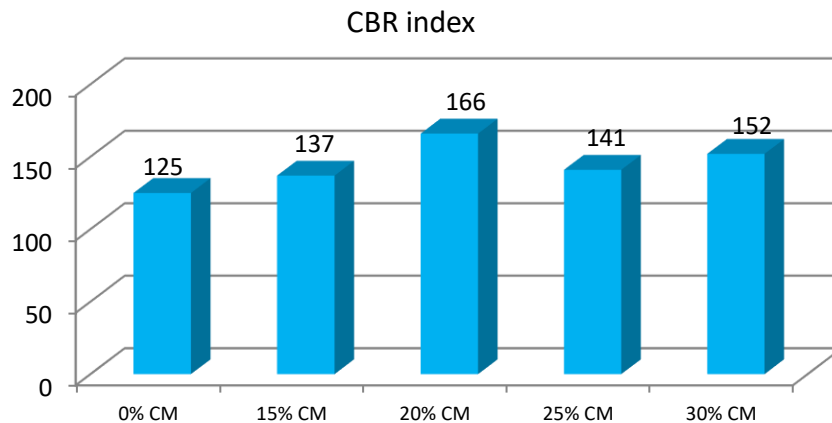


Fig. 13. Soaked CBR index values, obtained based on the percentages of (CM) added

Regarding the CBR index after immersion, it reaches its highest level with the addition of 20% (CM), peaking at 166%, compared to 125% for the material before enhancement. This increase may be attributed to the change in the granular structure, which becomes more rigid. In fact, the improvement rate is 32.8%, likely due to the addition of (CM), which acts as a shock absorber. This results in high resistance and, consequently, better load-bearing capacity. Additionally, the material demonstrates positive behavior in terms of the load-bearing capacity of road surfaces after exposure to harsh weather conditions.

4. Conclusions

This study investigates the subsidence of road surfaces constructed from marble waste in the Tizirt region of Algeria. The focus was on the geotechnical properties of earthworks materials enhanced with (CM). To assess the effectiveness of this reinforcement, various tests were conducted, including the modified Proctor test and California Bearing Ratio (CBR) tests.

The research involved a systematic approach to evaluate the performance of road materials augmented with 20% of (CM). The modified Proctor test was utilized to determine the optimum moisture content and maximum dry density of the materials. Simultaneously, CBR tests were performed to assess the bearing capacity of the treated materials. These tests are crucial for understanding how the addition of (CM) affects the mechanical properties and overall suitability of the materials for road construction. Indeed, the results of this research revealed the following:

- **Modified Proctor Test Results**

- The introduction of 20% CM led to a significant improvement in the maximum dry density of the material, which increased by 2.24% compared to the control sample without any addition. This enhancement suggests that the (CM) contributes positively to the compaction characteristics of the (EM).
- Furthermore, the addition of 20% CM resulted in a lower optimal water content compared to the reference material (-8.53%). This reduction in water requirement indicates improved workability and compaction efficiency, essential factors for achieving durable road surfaces.

- **CBR Test Results**

The CBR tests revealed a marked improvement in the bearing capacity of the material treated with 20% (CM). Specifically, the CBR index after immersion increased by 32.8%, which is indicative of a substantial enhancement in the material's load-bearing capabilities. This improvement is crucial for the performance of roadways, as it translates to better resistance to deformation and structural integrity under traffic loads.

The findings of this study underscore the potential benefits of using marble waste as a reinforcing agent in road construction. The enhanced mechanical properties exhibited by the materials treated with (CM) not only meet the current engineering standards but also present a sustainable alternative to traditional materials. By utilizing waste materials, this approach contributes to environmental sustainability and waste reduction in construction practices. Finally, this research highlights a promising technique for reinforcing road materials with marble waste in the Tizirt region. The positive outcomes from both the modified Proctor and CBR tests indicate that the incorporation of 20% (CM) can lead to significant improvements in the performance of road construction materials. This innovative method not only offers a technical advantage but also supports environmental conservation efforts by promoting the use of recycled materials. Future projects in road infrastructure could greatly benefit from adopting this approach, paving the way for more sustainable and cost-effective construction practices.

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