

Valorization of Altered Schist for Road Infrastructure Applications: A Case Study

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Abstract. In Morocco, the management of materials in the road sector is governed by a variety of technical and regulatory standards, including the Moroccan guide for road earthworks, established in 2002. This document, which is inspired by its French counterpart, provides guidelines for the reuse of soils in embankments, a critical component of pavement structures. However, it complicates the use of friable rocks (R category) and places the responsibility of determining the necessary precautions on the geotechnical engineer. This ambiguity often discourages administrative services from considering these materials as reusable, leading them to opt for more stable soils or rocks. This study presents the results of an experimental campaign conducted in the Taza and Taounate Provinces, focusing on several schistose massifs. The findings suggest that these materials can be reused by adapting them through secondary treatment. Furthermore, laboratory tests on samples from various sites indicate that these schists can be used as road aggregates for low-traffic roads. Additionally, treating this rock with hydraulic binders offers a promising and viable solution for its reuse in backfilling and subgrades. The results show that using reduced proportions of binders can significantly improve the behavior of schists and reduce their sensitivity to erosive factors.

Keywords: Road, Schist, Hydraulic binders, Subgrades.

1 Introduction

In the context of road construction projects, the selection of materials for embankments and pavement structures is essential. Moroccan regulations, influenced by European standards, provide guidelines for material selection based on their physico-mechanical properties and interaction with erosive agents, particularly water. The Moroccan Earthworks Guide (GMTR) [1] classifies materials into different categories (e.g., Class A: fine soils, Class B: ...), and extensive experimentation on local sites has led to the proposal of various measures, such as moisture content adjustments, compaction energy

modifications, and treatment with hydraulic binders to optimize the use of available materials. However, current technical standards impose certain restrictions on the use of specific material families, mainly due to their high susceptibility to chemical and water-related degradation or their uncontrolled granulometric evolution caused by transport, compaction, or operational traffic. One such category, evolving rocks (Class R3), is particularly abundant in Morocco, especially in the Rif region along the northern belt of the country. These rocks pose utilization challenges and can significantly impact infrastructure budgets if not managed with a techno-economic approach. Schist, classified as R3, presents difficulties for designers, who often discard it in favor of more expensive and higher-quality materials. While various studies have investigated the mechanical properties of schist, its use in road applications has been overlooked due to its evolving and non-durable nature. However, research conducted by [2] on primary schist from the Tazekka massif has demonstrated its potential for road aggregate production, particularly for low-traffic roads, which account for 70% of the road network in the Taza province. The same study reveals that 50% of the analyzed samples exhibit low mechanical hardness, suggesting that granulometric development through compaction and chemical treatment with hydraulic binders is feasible and can significantly modify the rock's behavior. Additionally, a similar technique applied to marl at the TAZA wind farm in 2021 produced satisfactory results [3]. Soil treatment with hydraulic binders is a well-established technique with a long history of development in France [4], as documented in soil treatment guidelines and applied to construction projects for many years. However, its adoption in Morocco has been limited due to administrative and technical constraints. The method involves incorporating a specific percentage of hydraulic binder into the soil, either in situ or at a production facility. Short-term effects generally include a reduction in soil moisture content due to hydration (in the case of quicklime), evaporation from the heat generated by the exothermic reaction, or the addition of dry material. Furthermore, when incorporated into wet clayey soils, lime alters the electrical charges of fine particles, leading to their flocculation. Geotechnically, this results in a significant increase in the plasticity limit without substantial changes in the liquid limit, an increase in shear strength, and modifications to compaction characteristics. Long-term effects include pozzolanic and syntactic reactions for lime and hydraulic hardening with gel crystallization and solidification for cement. This technique has been extensively studied in the academic literature and has proven effective for clayey and sandy soils in various applications. However, there has been no prior attempt to assess its feasibility for evolving rocks that can be transformed into finer fractions, such as marl or clayey soils. This study represents an initial effort to evaluate the impact of treatment on mechanically degraded schist due to compaction at multiple scales, focusing on mechanical behavior and workability.

2 Study area

Three study areas were chosen to ensure mechanical representativity while considering the regional context.

2.1 Tazekka Massif

Located in the Taza province, the Tazekka Massif spans 50 km in length and 15 km in width [5], covering 138 km². It lies between the Rif and Middle Atlas, with elevations ranging from 500 m to 1987 m. The massif is split into two structural domains, including schists and volcanic detrital complexes.

2.2 Slopes Along RR510 – Taounate Province

The Taounate province features Paleozoic [6] schists and sandstones, with a humid to semi-humid climate. The region experiences high precipitation and significant weathering of schists due to oxidation.

2.3 RR505 Section in Aknoul

The RR505 expressway [7], running 98 km from Aknoul to Al-Hoceima, passes through a humid to semi-humid climate and crosses two major watersheds. The geology of the corridor is mainly Cretaceous, with schists and marls dominating the landscape.

3 Methodology

The methodology involves collecting rock samples, preparing them in the laboratory, conducting laboratory tests according to applicable standards, evaluating the results, applying a degradation procedure for transformation of samples, and finally assessing the relevance of the treatment. The following figure illustrates the adopted process.

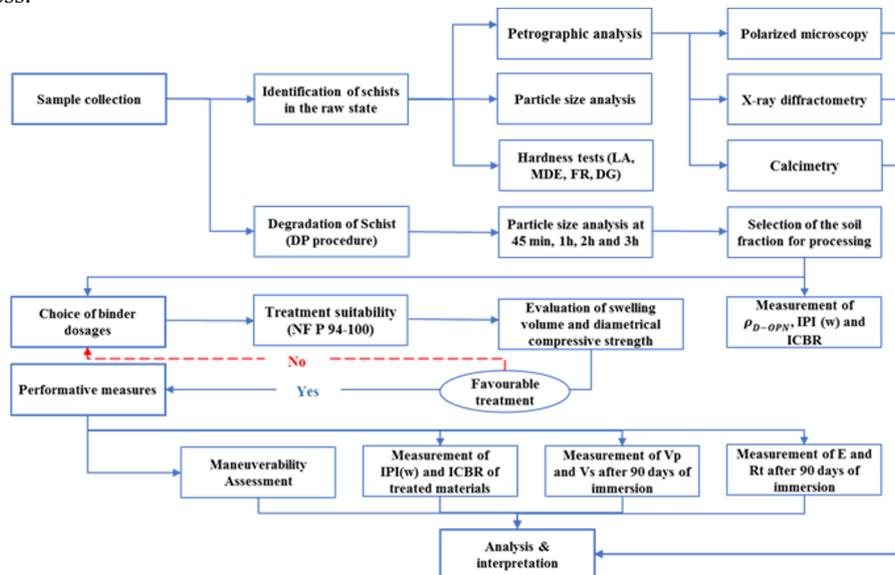


Fig. 1. Methodology flowchart

The samples were collected using manual drilling to a depth of 2.00 meters to avoid highly weathered sections. A total of six sites were explored, providing sufficient quantities for all physical and mechanical identification tests. After extraction, the samples were quickly transported to the laboratory and stored at 25°C with a specific humidity level to preserve their natural state. In this context, six families of samples were subjected to tests, with two samples per homogeneous zone. These families are referred to in the rest of this article using specific nomenclature (P1, P2, Tao1, Tao2, AK1, AK2) based on their sampling site.

The DP Procedure (Degradability Process) is used to develop soil classes (A3/A2) through a degradation process. Shale samples are dried at 60°C for 8 hours, then subjected to stress with metallic balls on an abrasive machine. Samples are taken at intervals of 45 minutes, 1 hour, 2 hours, and 3 hours, and analyzed using granulometric testing. The goal is to observe the shale's degradation over time, determine stabilization duration, and estimate the effort needed to process materials for construction sites using standard equipment like compactors.



Fig. 2. : Untreated samples

4 Results

4.1 Mineralogical Analysis

Scanning Electron Microscopy (SEM) was used to analyze the shape and texture of schist samples. The results show that the studied schists have a complex morphology, with particles of varying sizes, some angular and others lamellar, often irregular at the edges. The samples are primarily composed of fine particles, suggesting a predominance of clay minerals in their microstructure.

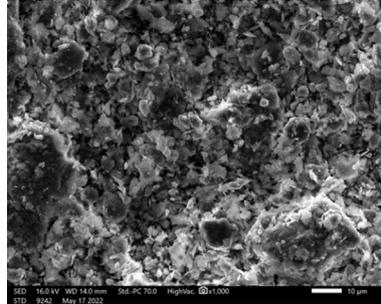


Fig. 3. SEM Imaging - AK2

The SEM micrographs also reveal large pores, and at high magnification, phyllosilicate minerals, such as chlorite, appear as pseudo-hexagonal plates. These observations are consistent with the findings of other researchers, such as Yong-seok Seo in 2006.

Fine clay minerals and large particles, associated with a pore network, form the base of the shale microstructure. Energy Dispersive X-ray (EDX) analysis allowed for determining the predominant chemical composition of the shale, primarily composed of Si, O, Ca, Al, and Mg. TAO-type samples show a high concentration of Si (18.82%) and Al (12.36%), indicating a clayey shale, while P-type samples show a high concentration of Ca (12.29%).

4.2 Degradability tests and granulometric process

The degradability and fragmentability tests indicate that all the samples can be classified as evolving rock. The analysis of the granulometric process results shows that the degradation kinetics of the collected schist samples differ from one sample to another. In fact, it is noted that those from Tazzeka and Taounate are more resistant, with a certain toughness over time.

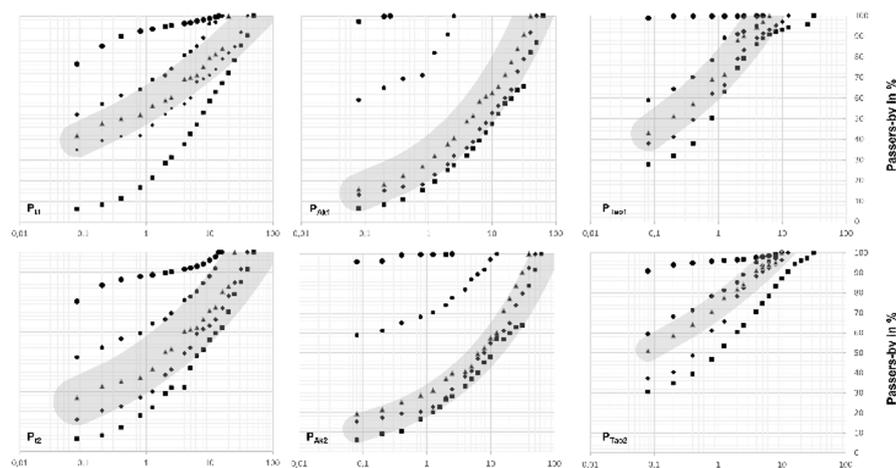


Fig. 4. Evolution of the particle size distribution of the samples following the DP experimental procedure.

To quantify the degradation capacity over time, an indicator called the DP-index was adopted. This index represents the area between the first curve (intact sample) and the last curve at $t = 180$ minutes. It was observed that the higher the DP-index, the faster the shale degrades over time.

The samples used for the performance and suitability tests are those within the gray band, which typically underwent the degradation procedure between 45 and 120 minutes. It is also important to note that a correlation between this laboratory work and the process of shale degradation using construction machinery (such as compactors) is a key perspective. This could help assess the economic and ecological potential of re-using this material.

4.3 Treatment Suitability Tests

These tests were conducted for six improvement formulas on samples from the DP procedure. In this study, the treatment choice was based on lime at dosages of 2%, 2.5%, and 3.00%, as well as formulas based on a mixture of cement and lime with proportions of 1% CaO + 4% CPJ, 1% CaO + 5% CPJ, and 1% CaO + 6% CPJ. The initial selection of these dosages is justified by the recommendations of the GTS and common practices. The results of the suitability tests (Gv and Rtb) are summarized in the following tables:

Table 1. Value of the swelling index Gv (%)

Index	Lime 2%	Lime 2.5%	Lime 3%	1% Cao + 4% CPJ	1% Cao + 5% CPJ	1% Cao + 6% CPJ
P1_T	2.50	2.71	2.74	3.10	3.25	3.40
P2_T	2.42	2.61	2.65	3.04	3.14	3.28
P1_Ak	2.69	2.81	2.84	3.11	3.78	4.81
P2_AK	2.33	2.41	2.91	3.38	3.85	4.32

P1_TAO	3.14	3.18	3.20	3.25	4.00	4.22
P2_TAO	3.01	3.22	3.39	3.47	3.66	4.05

In summary, all the samples are suitable for treatment, as their volumetric swelling values remain acceptable, ranging from 2.33% to 4.81%. It is observed that the swelling kinetics depend on the origin of the tested sample as well as the proposed treatment formulation:

- The swelling reaction is more intense with lime treatment for the P1-Tao and P1-T samples, with average reaction speeds (rate of change in swelling coefficient with dosage) of 0.38 and 0.24, respectively.
- A similar trend is observed with cement-based treatments, where the P1-Tao and P1-T samples exhibit higher reaction speeds with increasing dosages, with swelling coefficient variation rates of 0.85 and 0.48, respectively.

Additionally, compressive strength values were recorded for the hydraulic binder treatment. Post-treatment identification of the chosen samples was performed in accordance with the GMTR, which generally classifies them as A3.

Table 2. Results of the suitability tests (Rtb)

Index	1% Cao + 4% CPJ	1% Cao + 5% CPJ	1% Cao + 6% CPJ
P1_T	0.51	0.57	0.62
P2_T	0.65	0.68	0.75
P1_Ak	0.33	0.41	0.45
P2_AK	0.29	0.35	0.38
P1_TAO	0.24	0.28	0.32

4.4 Portor tests

To assess the effects of the addition of additives for the different lime and lime/cement-based formulations, several Proctor OPN tests were conducted for the six schists families PT1, PT2, P1_AK, P2_AK, P1_TAO, and P2_TAO. The following figures respectively show the results of this test for the lime-based formulations and the lime-cement formulations for the PT1 sample.

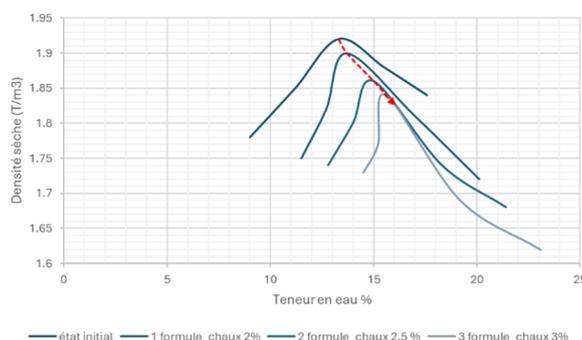


Fig. 5. Results of the Proctor tests on the PT1 sample treated with lime-based formulas.

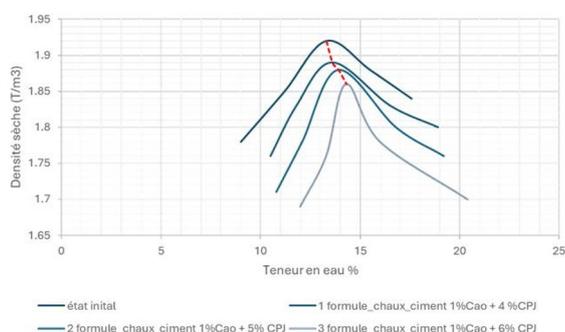


Fig. 6. Results of the Proctor tests on the PT1 sample treated with lime-cement formulas

Overall, several trends were noted:

- **Increase in Additive Dosage:** The increase in the additive dosage has the primary effect of decreasing the optimal compaction density. This effect can be explained by the increase in the cohesion of the mixture relative to the increase in dosage, leading to a decrease in the energy required to achieve the optimal state.
- **Increase in Water Content:** The increase in additive dosage leads to an increase in the optimal water content.
- **TAO Samples:** The TAO samples are the most affected by the addition of additives in terms of the optimal parameters.

4.5 IPI tests

The analysis of the short-term behavior of the mixture is carried out using the IPI index. The following figures illustrate the evolution of this index as a function of water content for the different solutions based on the PT1 samples.

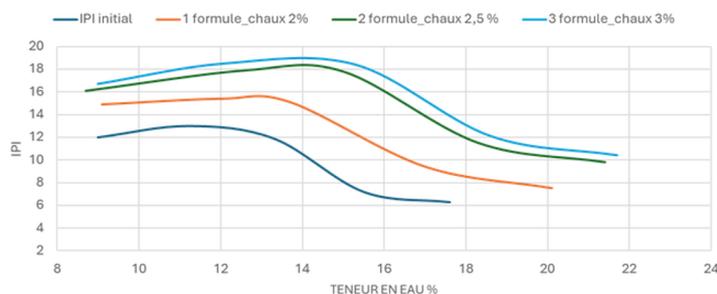


Fig. 7. Variation of the IPI index as a function of water content – PT1 samples treated with lime

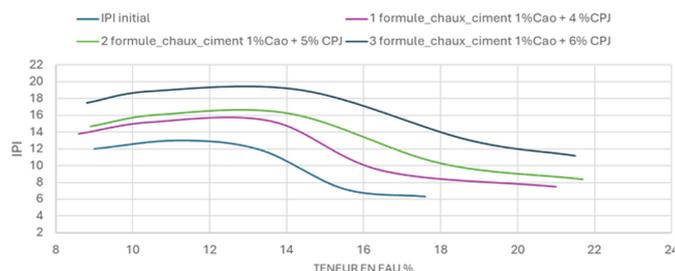


Fig. 8. Variation of the IPI index as a function of water content – PT1 samples treated with lime-cement.

It is observed that the IPI increases with the addition of the additive, which is expected [4]. Furthermore, the kinetics of this evolution are more significant for lime/cement-based solutions, where the improvements are more pronounced for all samples. Additionally, it is important to note that the ideal range for ensuring the proper implementation of the mixture lies between 0.9 wopn and 1.1 wopn.

4.6 Compressive and tensile strength

The compression strength (UCS) test on intact samples showed varying results. The Tazzeke samples exhibited relatively high values (19.1 MPa and 22.3 MPa), while Aknoul samples showed moderate values (13.95 MPa on average), and the Taounate samples had poor values. Sample saturation affected the results, as immersion for 48 hours caused partial or complete degradation of the Taounate and Aknoul samples, resulting in a pasty marl/soil. After drying the samples for 2 weeks, compression tests on treated samples revealed an improvement in strength for Taounate and Aknoul specimens, indicating better cohesion. However, the Tazzeke samples showed a slight decrease in compression strength, which could be due to the homogenization of the sample and improved erosion resistance.

The tensile strengths of the samples were determined using the Brazilian method (diametral compression test). The results showed that the PT1 sample performed best, with a minimum tensile strength of 0.68 MPa and a maximum of 0.99 MPa. The Aknoul samples had the lowest resistance. The comparison with the suitability tests confirmed an improvement in tensile strength after 3 months of curing, even under unfavorable saturation conditions. This improvement was particularly significant for the Taounate and Aknoul samples, showing an enhancement ratio of 2.5 to 3. Furthermore, lime-based formulations (formulas 1, 2, and 3) performed better than the mixed formulations (lime + cement).

5 Conclusion and discussion

The studied schist samples are classified as an R3 rock, which limits its use in road construction. Given the challenges posed by climate change and the depletion of natural resources, reusing locally available materials has become increasingly important and is encouraged by project owners. This study demonstrates that by mechanically treating

schist from three different sites with controlled granulometric evolution, it is possible to create a usable matrix for road construction. The treatment process, which can be performed both in the lab and on-site, shows that schist can be reused for embankments and subgrades. Laboratory tests on treated schist samples reveal that the addition of hydraulic binders or lime improves the material's performance. Mechanical performance tests confirm that treated schist is suitable for use in both embankments and more demanding road layers. The use of such additives is becoming more common in modern projects, as seen in the successful implementation at the Taza wind farm site. This work highlights the potential for reusing local schist resources and calls for further studies and a comprehensive guide to promote the valorization of inert or sterile materials at the national level.

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