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Marl Soil Improvement Using Recycled Concrete Aggregates from Concrete Pipes Factory

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ABSTRACT

The global population continues to grow, ensuing the expansion of urban building construction and the depletion of natural aggregates, which damage the ecosystem. Meanwhile, concrete is one of the most used materials in the civil construction sector, as well as an enormous quantities are produced yearly and poorly regulated due to their harmful environmental impact and significant disposal costs. In addition, the abundance of marl soils in Morocco's Fez-Meknes region, complications with infrastructure and construction projects are eventually anticipated due to the soil's vulnerability to changes in moisture content swelling, shrinking, and mechanical characteristics, associated with, high water absorption, and low bearing capacity. This paper emphasizes the suitability of reusing concrete waste (CW) originated from one of multiple concrete plants in the Fez-Meknes region as recycled concrete aggregates (RCAs) in marl soil's improvement. In this investigation, different mixtures incorporating 15%, 30%, 45%, and 60% of RCAs were examined. The laboratory tests were conducted to classify the soil through the different additions and determine its strength and deformation parameters. Results indicate that higher additions of RCA led to sustainable soil improvement, as evidenced by a decrease in plasticity and an improvement in grain size distribution and compaction quality. The compaction quality improved up to 45% of RCA's addition with an increase in dry density as well as bearing capacity, coupled with a decrease in plasticity values, which indicates the insensitivity to water and the effectiveness of the treatment. This treatment remains an ideal solution to stabilize these types of soil for economic, ecological and technical reasons.

Keywords: recycled concrete aggregates, marl soil, soil properties, proctor, CBR.

INTRODUCTION

One of the major environmental problems threatening the globe is the bad waste management, as global solid waste is expected to grow from 2 billion tons annually to 3.40 billion tons by 2050 (World Bank, 2018). Yet, the Middle East and North Africa regions are only producing 6 percent of the world's waste, while most of it is generated in East Asia and the Pacific region at 23 percent. However, global waste is more likely to increase in low and middle-income countries by approximately 40 percent, which is considered a triple. While urbanization is an unavoidable global process, it is expected to continue in the future, with a tripling of land and a 60% increase in the urban population by 2030 (United Nations, 2020). Urban expansion is nothing but a land use and land cover change process that transforms the natural land cover to build up urban (Qiu et al., 2015). As for, this global process generates huge amounts of construction and demolition wastes (CDWs), turning into a huge concern for its severity, which depends on many factors like population, construction activity, construction materials, traditions, etc. (Pacheco-Torgal et al., 2020). Concrete production plus CDW generation contribute to the constant carbon dioxide emission into the atmosphere, although the demand for construction aggregates will boost when already 50% of natural resources are depleted by the construction industry (Union International Associations, 2018). However, not considering the conservation of the natural resources can lead to further destabilization of the ecosystem; accordingly, a consideration of sustainability is necessary.

Meanwhile, in Morocco, more than 5 million tons of solid waste are generated across the country, with an annual waste generation growth rate touching 3 percent. In this regard, Morocco requests a sustainable development policy that encourages a long-term environmental strategy for environmental protection and the implantation of eco-friendly policies (SNRVD, 2019). 14 Mt of CDW represent almost half of the waste produced when the annual production of inert waste is 26.8 Mt in 2015 (Climate Chance, 2020).

The "take, make, and dispose" pattern has been bad for the environment, with the presence of socio-economic impacts related to the consumption of non-renewable natural resources, waste generation pressure, plus dust and gas emissions. In parallel, the "3 Rs" principal known as "reduce, reuse, and recycle" presents many advantages such as economic advantages, environmental advantages, social advantages, and health advantages (Tseng et al., 2020). By preference, the best approach for optimizing, recycling, and valorizing these wastes for a better sustainable future for the construction industry is to keep moving forward with a circular economy.

CDWs are considered the basis of the environment and the second most consumed material after water (Watts, 2019). The use of CDW proved to be useful in improving the mechanical behavior of soft soils (Silva et al., 2022). Some researchers have explored the idea of using CDW as an alternative binder. Likewise, (Sekkel et al., 2021) studied the swelling behavior of clay while adding a proportion of 5%, 10%, and 20% of fine CW and found that a 4 percent addition proved to be decent compared to 10 and 20 percent, which offer a quick stabilization, driving to the conclusion of studying higher percentages in prospects. On the other hand, other researchers have investigated the use of alternative binders, such as alkali-activated binders made from glass and plastic waste. (Bensaifi et al., 2019) treated compacted marl with crushed granulated blast furnace slag (CGBS) activated by calcined eggshell waste (CES), and the results showed that the UCS increased by 8.5 times compared to the resistance of natural marl when only using 5% of the CGBS-CES binder. Additionally, the results of the soaked CBR test showed that the bearing capacity of marl has improved up to five times, indicating that Portland cement can be replaced by calcined eggshell to activate CGBS for soil stabilization.

Nevertheless, a lot of energy is consumed in order to turn construction wastes into fine aggregates (FAs). Through the rock crushing stage, generating larger proportions of this material requires reducing the gap between the crushing surfaces to increase the pressure and cause micro crack formation in the feed. FAs production expect double the effort and a longer crushing process, which risks the fracture of the crusher's blade and causes a waste of not only energy but also time and money. In contrast, producing larger recycled grain size aggregates will help reduce the CO2 emissions (Rinder & von Hagke, 2021) and present a higher volume-to-surface area ratio. These particles are less likely to become saturated with water, which ensures a better resistance to the forces of compression and tension, especially in concrete and asphalt (Md. Aminur Rahman et al., 2014). Also, larger recycled aggregate particles improve the workability of the mix and require less cement paste to coat them, which reduces the expanses and makes the mix easier to place and finish (Martirena et al., 2017).

Thus, this research evaluates the enhancement and influence of marl soil properties with varying amounts of recycled coarse aggregate additions. The present work is laboratory-oriented, and the findings of the experimental tests conducted are reported in the succeeding parts.

MATERIALS AND METHODS

The study was centralized around the Fez-Meknes prefecture due to the abundance of marl soils and the availability of concrete factories all around the region (Figure 2). Thus, experimental procedures were conducted to examine the influence of CW on soil behavior.

MATERIALS

Concrete waste

In Morocco's Fez-Meknes region, many factories produce concrete pipes, and large amount

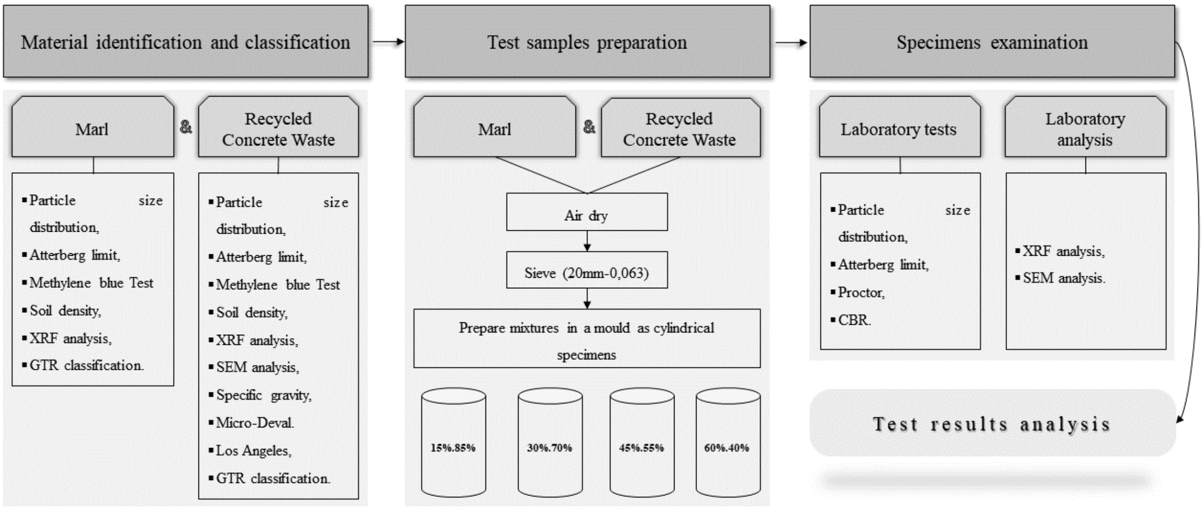

Figure 1. Soil treatment application process flowchart

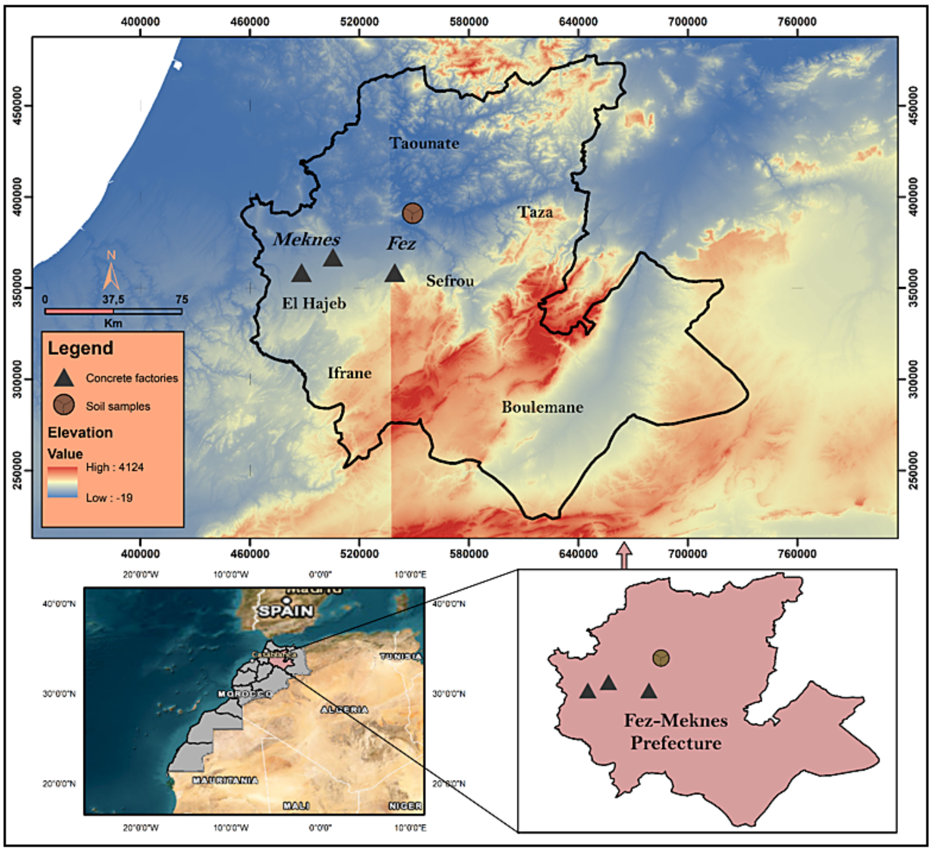

Figure 2. Geographic overview of the study area

of CW is thrown in place by way of a landfill (Figure 3). The waste in issue was crushed in a jaw crusher and then sieved through a 20 mm sieve to obtain RCA. Table 1 summarizes the physical properties of the used waste. In accordance with the GTR classification (NF P 11-300), the material was classified as D1, referred to as porous soil.

Soil

A specimen was collected from the north-eastern region of Fez, more precisely in the area between Douar ed Doum and Ain Kansara. The soil in this locality is recognized for its softness within the pre-Rifain domain. The specimen was obtained from the marly-sandy matrix of the pre-Rifain thrusts' upper Miocene layer, which was created by the forward displacement of the thrust fronts, as explained by (Benyaich, 1991). In conformity with the GTR classification, the soil ranks as A2, known for clay and marl soils with a medium plasticity index. The studied soil is an upper Miocene-Pliocene marl (Figure 4) that conforms to a fine soil with an 84% of elements less than 80μm. Table 2 represents the properties of the used soil.

METHODS

The investigation of the mixture's behavior requires first a deeper characterization of the components (marl and CW). In this regard, identification tests, mechanical properties, and mineralogical analysis were performed. In order to determine the effect of RCA on soil behavior, other laboratory tests were also conducted.

Table 1. Physical and mechanical properties of RCA

Properties	Norms	Units	Values
Specific gravity	NF P 94-054	kg/m^3	1.35
Micro-deval	NF P 18-572	%	19
Aggregate abrasion value	NF P 18-573	%	28

Mix design

Initially, the marl was air-dried, and the CW was separated manually from the reinforcement using a hummer. The collected fragments were crushed, and then sieved through a 20 mm sieve to a 0,063 mm sieve following the given procedures in the NF P 94-056 standard. To respect the mold diameters in which the mixtures will be compacted and prepared as cylindrical specimens (Figure 6), a series of modified proctor tests were performed, with an increment of 15%; a proportion of crushed RCA was added to the soil by mass varying from 0% to 60%.

Testing procedures

The study analyzed the effect of adding RCA to marl soil by conducting laboratory tests such as particle size distribution, Atterberg limit, Standard Proctor Compaction, and California bearing tests. The tests were used to evaluate the soil's

Figure 3. Concrete pipes waste disposal

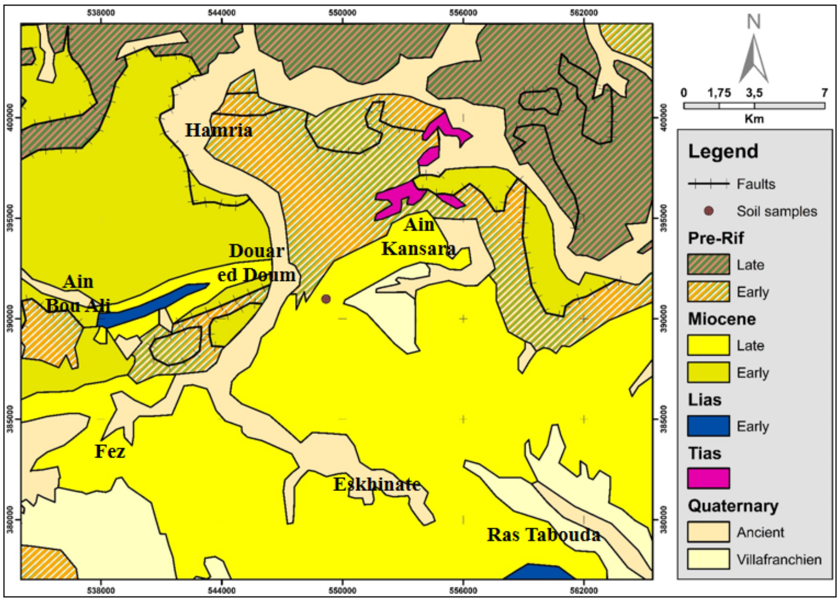

Figure 4. Geological context of the sampling location

properties, including its ability to settle or consolidate under load, response to water, and quality of compaction. Mineralogical and microstructural properties of the soil were also analyzed.

Particle size distribution

The particle size analysis was carried out on the raw materials, using the sieving method in accordance with the NF P 94-056 standard. This test determines the different families of grains as for their sizes and weight percentages.

Atterberg limit

This test assesses the qualification of the three different states of soil (liquid state, plastic state, solid state). The plasticity of specimen was accessed by Casagrande test specified in NF P 94-068. The plasticity index (PI) is calculated by the following formula:

$$PI = WL\text{-}WP \qquad (1)$$

where: WL – liquid limit, WP – plasticity limit.

Methylene blue test

In accordance with the NF P 94-068, the property of each specimen was identified thanks to the absorption ability of the methylene blue substance.

Soil density

The soil wet and dry density was employed for the specimen identification, in accordance with NF P 94-050 standard.

Table 2. Physical and mechanical properties of marl soil

Properties	Norms	Units	Values
Elements less than 0.08 mm	NF P94-056	%	84
Elements less than 0.4 mm	NF P94-056	%	91
Liquid limit	NF P94-051	%	44
Plastic limit	NF P94-051	%	20
Plasticity index	NF P94-051	%	24
VBS	NF P 94-068	-	3,3
Maximum dry density	NF P94-093	yt/m^3	1.81
Optimum water content (modified)	NF P94-093	%	14
CBR (unsoaked)	NF P94-078	%	2
GTR classification	-	-	A2
LCPC classification	-	-	AT-AP

Proctor test

Besides, the quality of a soil is identified by the quality of its compaction. By this means, the Proctor test specifies dry densities corresponding to their specific water contents for each of the untreated and treated soils. Accordingly, the optimal water content (Wopt) and the maximum dry density (MDD) for each proportion of the mixtures were determined.

California bearing ratio (CBR)

The CBR index defined the bearing capacity of soils in road structures by estimating their resistance to punching via different penetration efforts. The CBR tests were performed at different compaction

Figure 5. Marl from study area

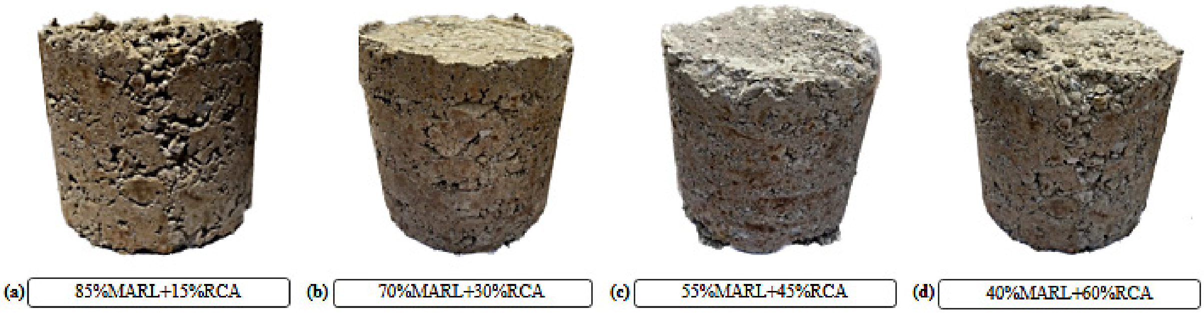

Figure 6. Cylindrical specimens

energies (14, 25, and 56 strokes) in compliance with the water content at the optimal proctor. Through this, the samples were prepared and immersed for 4 days, then disposed to dry. Finally, CBR calculations were made through a penetration test and plotted graphically. The experimental protocols of CBR test are more detailed in the NF P94-078 standard.

X-ray fluorescence (XRF) analysis

The chemical composition was assessed by quantitative X-ray fluorescence (XRF) in fused beads. The elements of sample are tracked due to the interaction of the X-ray with the sample's atoms.

X-ray diffraction (XRD) analysis

The crystalline phases of the marl soil and the RCA were identified by X-ray diffraction (XRD), using a PANalytical X'Pert Pro diffractometer with CuKα radiation at 40 kV and 25 mA, in the 5–80° 2θ range at 6°/min scan speed Each mixture was also analyzed to determine the effect of RCA on soil's mineralogical composition. All specimens were grinded into fine powder using and RM200, before the XRD analysis.

Scanning electron microscopy (SEM)

The scanning electron microscopy (SEM) analysis is performed to determine the morphology of RCA and their effect on the soil microstructure. The microstructural characteristics of the RCA sample are identified by scanning its surface using a focused beam of electrons generated by an electron microscope with high resolution up to nanometers.

RESULTS AND DISCUSSIONS

Characterization of the raw materials

Particle size distribution

Figure 7 shows the particle size distribution of raw materials, established by French standard NF P 94-056. Analyzed RCA shows a continuous size distribution curve with a maximum diameter of 20 mm and a small fine fraction <80 µm, representing less than 5%. In contrast, marl soil shows higher fine elements with 84% of particles <80 µm, indicating a non-uniform material (Guide LCPC, 2000).

Atterberg limit

The results of Atterberg limits tests showed that RCA plasticity is unmeasurable, while marl soil presents a moderate degree of plasticity and sensitivity to water (Figure 8).

Methylene blue test

The property of soil is identified thanks to the absorption ability of the methylene blue substance. Methylene Blue Test indicates the quantity and quality of the clay fraction present in the given samples (Figure 9). The values of the methylene blue test (VB) of RCA and marl are 0,02 and 3,3 respectively.

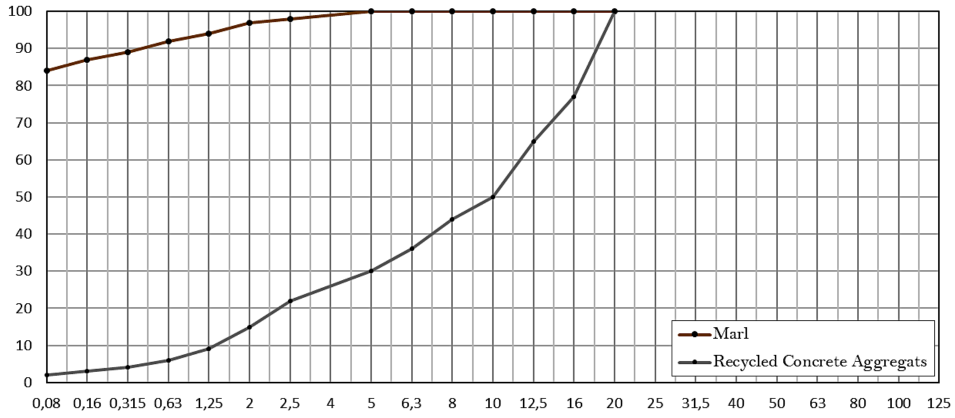

Figure 7. Particle size distribution results

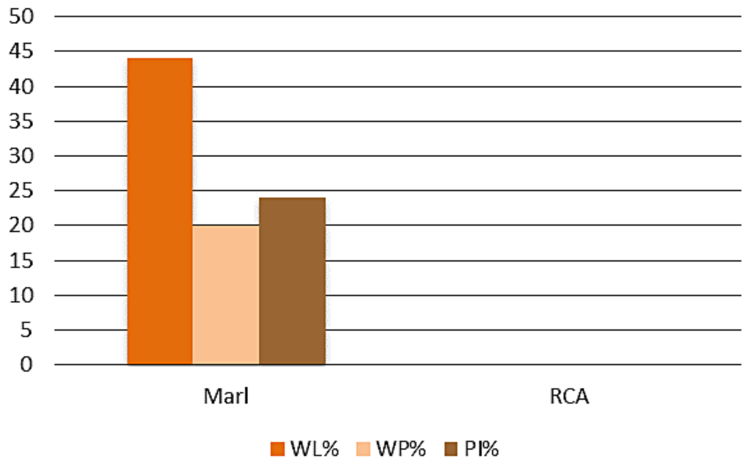

Figure 8. Atterberg limit results

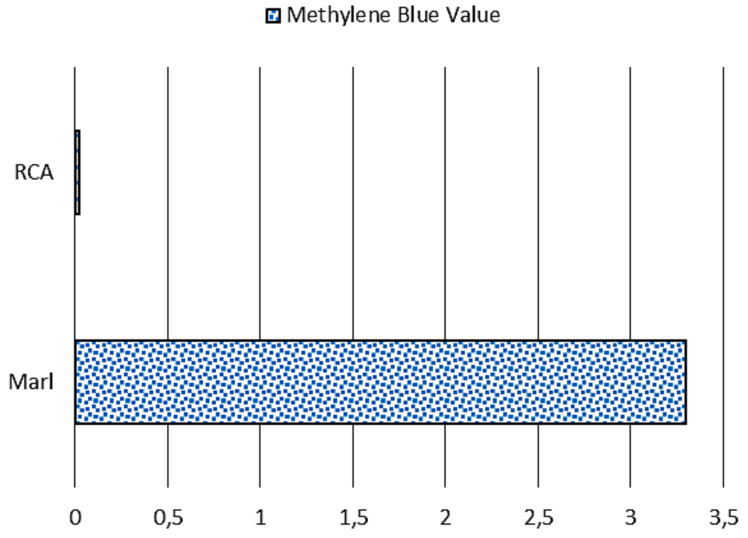

Figure 9. Methylene blue test results

Mineralogical (XRD) and chemical analysis (XRF)

Figure 10 shows the X-ray diffraction patterns of raw materials, recorded in the 2θ range of 5–80°. The mineralogical composition of RCA indicates a prevalence of minerals from limestone aggregate, used in the formulation of parent concrete, such as calcite ($CaCO_3$), and dolomite ($MgCa(CO_3)_2$). The peaks corresponding to those minerals have a relatively high intensity in the concrete waste compared with the marl soil. In addition, the intensity of portlandite ($Ca(OH)_2$) peak at angle 2θ =18° for RCA attributed to the product of cement hydration. Other minerals were identified in the marl soil include kaolinite ($Al_2Si_2O_5(OH)_4$), muscovite ($KAl_2(AlSi_3O_{10})$). Table 3 presents the chemical compositions of RCA and marl soil identified by X-ray Fluorescence Spectrometry (XRF) method. The major chemical elements of SiO_2 and Al_2O_3 in marl soil correspond to the presence of silica, and clay minerals. It is also necessary to note relatively high contents of Fe_2O_3. Higher MgO and CaO contents in the RCA sample reveal the presence of carbonate phases such as dolomite and calcite, which was also found by the XRD analysis.

Scanning electron microscopy (SEM)

Particle morphologies of the raw materials are given in Figure 11. SEM analysis showed

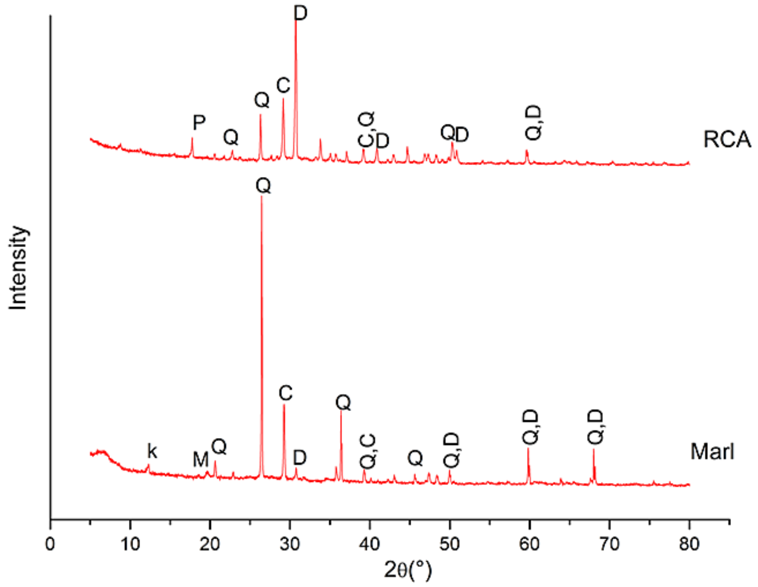

Figure 10. XRD analysis of raw materials

Table 3. XRF analysis of raw materials

Chemical compositions, %		
Compound	Marl	RCA
SiO_2	37.28	12.6
MgO	3.79	11.9
Al_2O_3	13.45	2.502
CaO	16.22	34.85
Fe_2O_3	4.483	1.471
K_2O	1.642	0.372
Na_2O	0.568	0.2006
SO_3	0.1397	0.8671
P_2O_5	0.1986	0.05273
TiO_2	0.5326	0.1357
SrO	0.06613	0.02888
Cl	0.05683	0.08692
MnO	0.04863	0.03235
NiO	0.01203	0.01115
Rb_2O	0.01191	0.005581
ZnO	0.0107	0.01064
CuO	0.004557	0.01405
Cr_2O_3	0.01191	-
ZrO_2	0.03501	-
V_2O_5	0.01685	-
PbO	0.003845	-
Y_2O_3	0.003284	-
P.a.F	21.42	35.56
Total	100%	

that RCA consists of fine particle with irregular and angular shape (Figure 11.b), when marl soil shows fine particles (Figure 11.a).

Characterization of the mixtures

Particle size distribution of the mixtures

The particle size distributions of raw materials and mixtures (marl/RCA) are reported in (Figure 12). Interpretation of the results can vary based on the specific region and the corresponding guidelines and standards adopted in that area. The studied soil was classified as A2 (GTR guide) and AT-AP (LCPC guide), defined as marl with medium plasticity, known to be vulnerable compared with other soils due to its behavior in contact with water (Vijayan & Parthiban, 2020). In accordance with GTR guide, the present material is prohibited for use as backfill under heavy rainfall conditions and as subgrade soil unless it is treated. By incorporating several additions of RCA, material with higher additions was classified as B5 (GTR guide) and GL (LCPC guide), which is commonly associated with silty gravel of low plasticity.

Mixtures have a varying particle size distribution, ranging from fine to coarse grading. Among different types of soils, clays are generally considered unsuitable for use in paving applications. This is primarily attributed to the fact that soils with finer particle sizes tend to have lower load-bearing capacity and are less suitable as a foundation or sub-base (Yuan et al., 2022). On the other hand, soils with a coarser grading tend to be more resistant and stable due to their reduced lubricating power, which allows water to drain more easily. Referring to the (GTR guide, 2001), specifically Leaflet 3, Chapters 2 and 3, the obtained material has proven to be suitable for use as a backfill soil. This is attributed to its plasticity index, which doesn't exceed 20%, and its fines passing the 0.080 sieve, accounting for more than 35% of the total. Moreover, the mixture can serve as subgrade soil due to its limited plasticity, not surpassing 10%. Consequently, bending marl with a high proportion of RCA yields a compliant material with better characteristics.

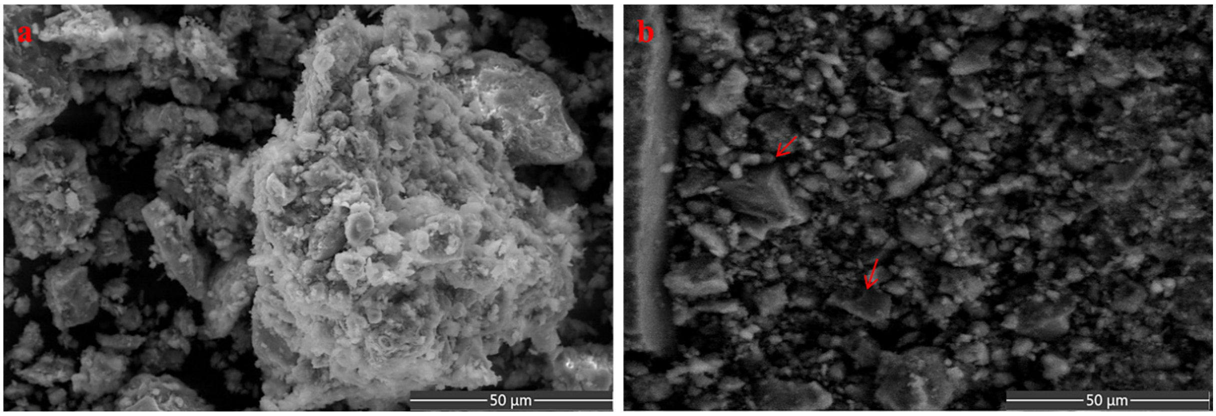

Figure 11. SEM images of raw materials; a) SEM image of marl, b) SEM image of RCA

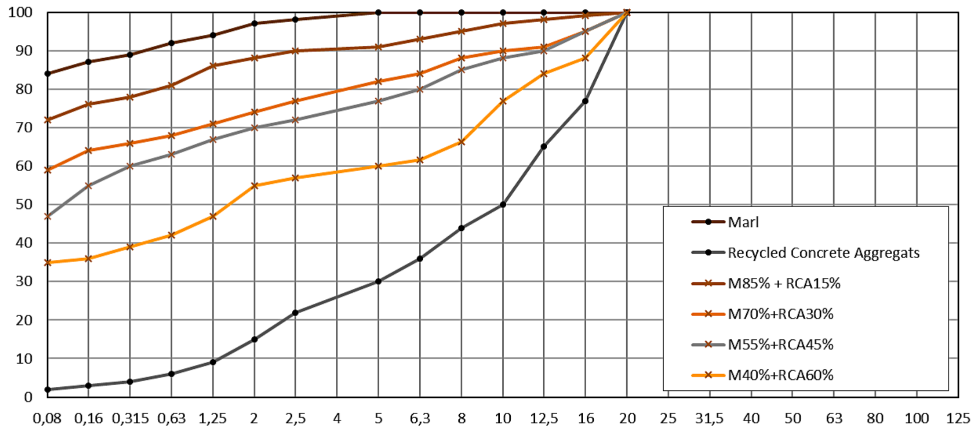

Figure 12. Particle size distribution of mixtures

Atterberg limit of the mixtures

Figure 13 illustrates the influence of RCA additions on the LL, WL, and PI values of marl soil. Notably, when 45% of RCA is added, the PI value decreases of approximately 33%. This significant reduction is attributed to the presence of fines with a particle size smaller than 0.080, which decreases from 84% for marl soil down to 35% for marl soil with a 60% addition of RCA. This reduction in PI values highlights the potential advantages of incorporating these mixtures, as it signifies a favorable change in the soil's plasticity characteristics (BİLGEN, 2020). In addition, the increase of RCA content led to a noteworthy enhancement of the soil structure, resulting in a sandy consistency that exhibited larger pore sizes and increased saturated hydraulic conductivity (Sandin et al., 2017). The plasticity of a soil is also related to its chemical components Na_2O, and Fe_2O_3, where higher contents of the latter increase the clay activity (Raini et al., 2020).

Proctor

Figure 14 illustrates the changes in dry densities and water content regarding the behavior of the soil's mixture. Compared to the curve of the untreated (natural) marl soil, the Proctor curve of the treated marl is displaced to the left and upward. This is attributed to the fine grains of the RCA reducing the specific surface area of clayey particles in the mixture, leading to a decrease in water content (Jiang et al., 2020).

The addition of RCA triggers changes in the compaction curve of marl soil. An increase in density of 1.86, 1.91, and 2.01 was caught at 15%, 30%, and 45% of addition. These findings align with the concept of intergranular void ratio, indicating that the quality of compaction improves

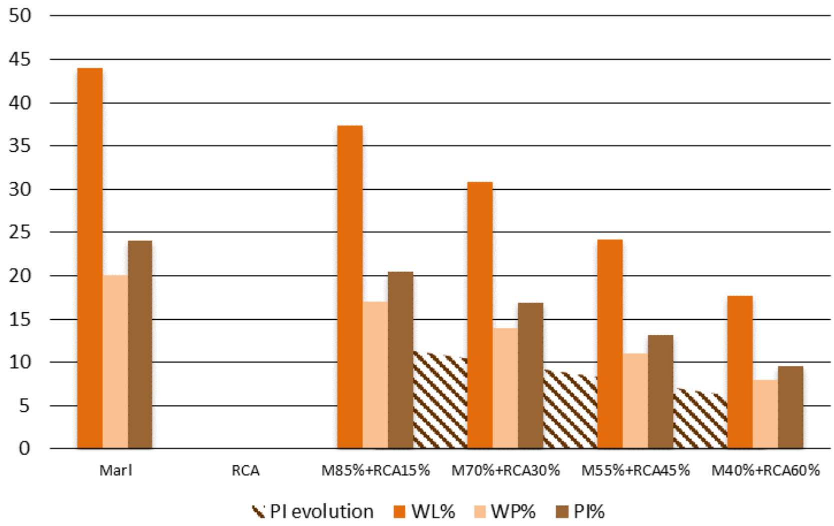

Figure 13. Atterberg limit results of mixtures

as the void ratio decreases; Small pore size are developed as a result of fine marl particles filling the voids between the RCA (Maroof et al., 2022).

Density was compared across various RCA additions, and the highest density was obtained at 45% of addition. However, when the RCA addition exceeded this threshold, the density decreased. This fluctuation in density can be attributed to several factors. The filling of voids by fine particles contributes to a decrease in permeability, while a higher fine content reduces the interlocking and bonding between aggregate particles. This reduction in interparticle bonding leads to a diminution in stiffness and an increase in permanent deformation. These findings are consistent with previous studies published by (Cabalar et al., 2019).

Additionally, as highlighted in the study by (Sinan Coban et al., 2022), RCA seeks mechanical degradation more than natural aggregate. They also exhibit high water absorption due to the presence of old mortar in them (Cabalar et al., 2017). Consequently, the compaction process induces grain breakage and decreases the gravel fraction, raising the fine content and resulting in more absorption (water holding capacity) on account of the specific surface area increment.

CBR

Figure 15 illustrates the changes in CBR values regarding the behavior of the soil's mixture. CBR value of marl soil alone reached 2% as a maximum value, which is considered to be low; Limiting its use in civil engineering and infrastructure works (GTR guide, 2001). The implementation of marl soil is found to be difficult due to its low bearing capacity.

As RCA additions increased, the CBR value reaches its highest point at 45% of addition. However, beyond this threshold, CBR value started decreasing. This can be explained by the reduction in the void ratio and the enhanced cohesion between aggregates, which positively influence the soil's strength and the compaction of its constituent elements. CDWs are proved to have equal or superior CBR values compared to those of natural aggregates (Cardoso et al., 2016).

According to (Chakravarthi & B.Jyotshna, 2013), the plasticity of soil is directly linked to its bearing capacity. Hence, adding RCA reinforced the soil and reduced its plasticity. As the plasticity index of soil decreases, the optimum moisture content (OMC) drops and the maximum dry density (MDD) increases, resulting in better compaction conditions, a reduced clay fraction, and a higher bearing capacity of the soil. However, as the RCA reaches 45%, these positive effects begin to diminish.

Ultimately, according to the GTR guide, as the value of CBR rises, treating subgrade soils provides the advantage of reducing the base layer's thickness to decrease, minimizing the contribution of precious materials (quarried aggregates). At 45% of addition, the mixture value provides the most favorable performance and is classified as S2 in accordance with the CBR classification. The findings are consistent with prior research, such as that of (Sharma & Hymavathi, 2016).

The results of the previous investigations are summarized in Table 4, which focuses on the properties of marl soil change as RCA additions rise. This table shows a significant increase in the effectiveness of using this type of soil.

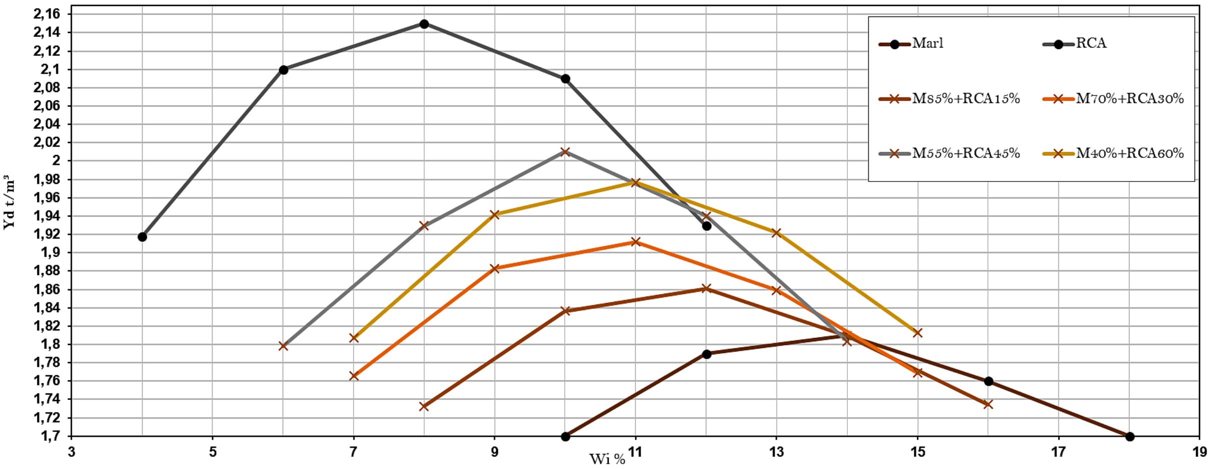

Figure 14. Influence of RCA addition on compaction curves

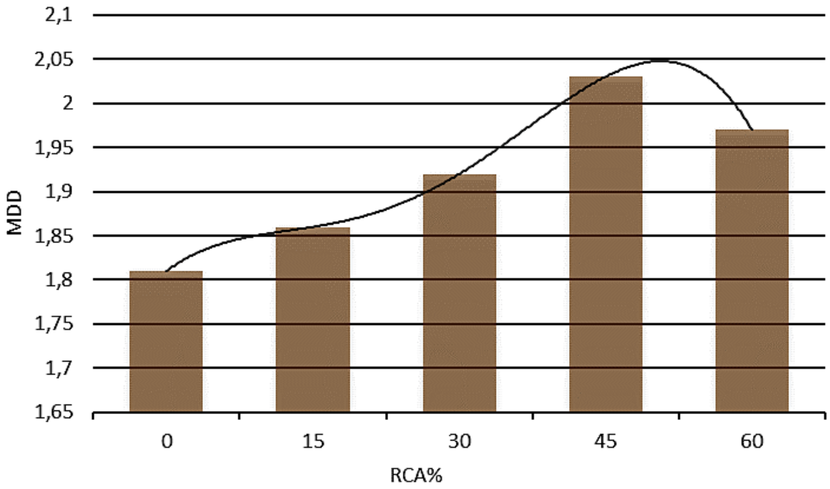

Figure 15. Evolution of MDD through RCA additions to marl soil

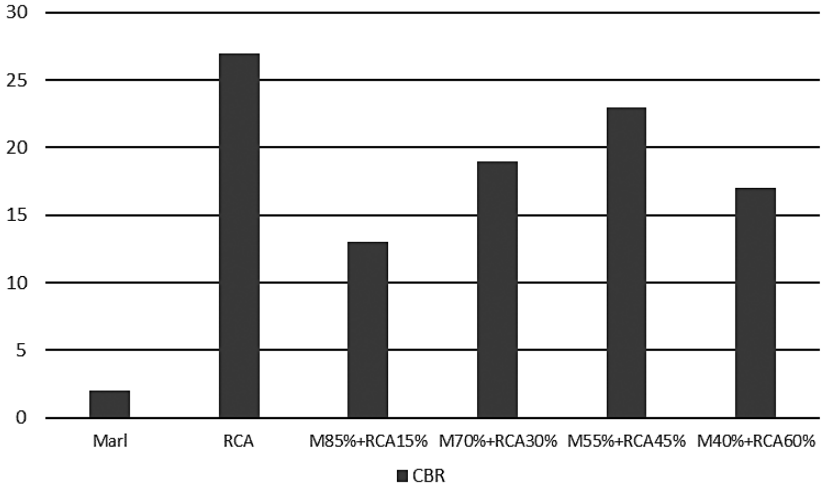

Figure 16. Variation of OMC with RCA addition

CDWs are employed in various civil engineering projects, providing economic and environmental benefits, notably in the realm of soil stabilization (Sangeetha et al., 2022). Multiple techniques exist for using CDW to improve the engineering properties of a soil, such as mechanical stabilization, chemical stabilization, binder stabilization, reinforcement stabilization, and grouting (William Powrie, 2014). When treating marl soil, which is cohesive in nature and often exhibits high compressibility and low shear strength, mechanical stabilization techniques can be valued above others for these types of soil (clayey or silty soils), as highlighted in the review conducted by (Afrin, 2021).

In comparison to other treatments, mechanical stabilization using RCA materials has shown higher efficacy in improving the load-bearing capacity of expansive soils (Saeed & Rashed, 2020). In particular, chemical stabilization is frequently used in granular soils to increase cohesion and reduce permeability (S. et al., 2018). Binder stabilization is beneficial for both cohesive and granular soils (Chen et al., 2020), whereas for weak or loose soils, reinforcement stabilization is frequently used to reduce soil movement, erosion, or slope failure (Aga, 2021). On the other hand, grouting is a more common technique for loose or unconsolidated soils despite having higher costs (Zheng et al., 2016). In addition to being technically advantageous, using RCA to stabilize marl soil benefits both the environment and the economy because it is readily available, does not need to be extracted or processed again in order to be recycled or reproduced, and is relatively inexpensive. This lowers the need to buy expensive additives or binders, especially for large-scale projects involving marl soils (Sarté, 2014).

Table 4. Outline physical and mechanical variation with RCA additions

Compound	Identification tests						Mechanical tests			Classification	
	Particle size distribution		Atterberg limit			Methylene blue test	Proctor		CBR index	LCPC	GTR
	NF P94-056		NF P94-051			NF P94-068	NF P94-093		NF P94-078		
	<0.4	<0.08	WL, %	WP, %	PI, %	-	W_{opt}, %	$\gamma t/m^3$	%	-	-
Marl	91	84	44	20	24	3,3	14	1,81	2	AT-AP	A2
RCA	6	2	Non-mesurable	Non-mesurable	Non-plastic	0,02	8	2,15	27	Gb	D2
RCA15% + M85%	80	72	37	17	20	2,8	12	1,86	13	AT-AP	A2
RCA30% + M70%	69	59	31	14	17	2,3	11	1,92	19	AP	A1
RCA45% + M55%	62	47	24	11	13	1,8	10	2,03	23	GA	A1
RCA60% + M40%	41	35	18	8	10	1,3	11	1.97	17	GA	B5

CONCLUSIONS

The addition of RCA to marl is of great economic, ecological and environmental interest, as well as an innovation opportunity for the materials recycling industry. The use of these local materials (marl and waste) offers several advantages, including their availability, ease of preparation and collection, time and transportation savings, and environmental protection. This operation will also eliminate tons of waste while will exploit marl deposits as raw material for road construction. This study emphasizes RCA and incorporating it into marl soil to improve its technical and mechanical features. Obtained results indicate a number of significant improvements:

Grain size distribution improved through RCA additions, and percentage of fines passing 0.080 at 60% of addition are above 35%. A well sorted grain distribution assures a better compaction quality. Higher RCA additions decrease the plasticity index of soil, especially at high incorporation rates of 60%. With the RCA addition of up to 45%, the optimum moisture content (OMC) of mixtures grows while the maximum dry density (MDD) decreases. At the same rates of addition, the low bearing capacity was found to be optimal. However, further addition, caused a reduction in the quality of the mixture.

Combining RCA with marl soil, reduce their individual drawbacks and prevent environment and construction problems. The mixtures are categorized as A1 and B5, which indicates due to its fine-grained and granular texture, plus strength and bearing capacity that it is suitable in various road construction applications. The specific application, however, will depend on the characteristics of the specific mix and the requirements of the construction project. Overall, the combination of RCA and marly soil provides a viable solution for enhancing the properties of this soil type, improving its technical and mechanical performance, while also being a sustainable and environmentally friendly alternative to using natural aggregates. For that, it is necessary to mobilize the economic actors, the administrations, the power and the researchers to encourage and develop the use of these materials and others in various fields of the construction.

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