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*Original article*

# Laboratory Assessment of Recycled Concrete Waste for Improving Sandy Soils in Arid Regions

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**Abstract**
Although desert areas make up the majority of Libya's land area, their use for urban development has been limited due to the challenging building conditions. A detailed study of the engineering characteristics of desert soils is necessary to allow for the sustainable utilization of this area. Although sandy soils have good load-bearing qualities, as the groundwater table rises to levels close to the foundation, their shear strength and overall stability may quickly decrease, requiring soil treatment before construction. One promising soil stabilization technique involves the utilization of recycled concrete waste (RCW), generated from the demolition of aging or damaged structures. Given the substantial increase in construction and demolition waste in Libya in recent years, incorporating such materials into geotechnical applications not only enhances soil performance but also contributes to environmental protection. This study presents a laboratory-based investigation into the influence of varying moisture content on the shear strength and its factors of natural sandy soil, as well as on soil treated with different percentages of (RCW) 0%, 3% and 6% of soil weight. Soil samples were collected from Kufra city in southeastern Libya. A comprehensive series of tests was conducted to determine the physical and mechanical properties of both untreated and treated soils. The results show that reusing construction waste as an efficient soil amendment significantly enhances the shear strength factors of sand at an addition ratio of 3% and 6% in both dry and wet cases, hence supporting sustainable construction practices in arid locations. Also, this addresses environmental issues and improves foundation performance.
**Keywords**. Laboratory Assessment, Recycled Concrete, Sandy Soils, Arid Regions.

## Introduction

The shear strength of soil beneath foundations is considered one of the most critical parameters that must be investigated prior to construction, in order to ensure stability and to prevent failure caused by inadequate strength or shear collapse. The soil's stress primarily depends on parameters of shear strength, specifically angle of internal friction and cohesion, in addition to soil density and moisture content, which vary with fluctuations in the groundwater table. Consequently, certain desert soils require improvement of their engineering properties to withstand the applied loads. This is particularly important in the case of sandy soils, which are collapsible in nature and highly sensitive to moisture variations, increasing their susceptibility to sudden shear failure and, in turn, the failure of structures built upon them. Among the most effective methods for enhancing the engineering properties of soil is the utilization of construction and demolition waste through recycling. Given the noticeable increase in such waste across various Libyan cities, especially in recent years, the main objective of this study is to demonstrate the practical potential of reusing these materials, along with their positive environmental and economic impacts. There are numerous previous studies that have focused on soil improvement using various recycled materials.

Shooshpasha and Shirvani (2015) [1]. A research project was conducted to explore the impact of cement stabilization on the engineering characteristics of sandy soils in northern Iran. The authors used lime Portland cement at 2.5%, 5%, and 7.5% by dry soil weight to perform compaction, unconfined compressive strength (UCS), and direct shear experiments with curing times of 7, 14, and 28 days. The findings showed that cement stabilization considerably improved the UCS, modulus of elasticity, cohesiveness, and the angle of internal friction, while also reducing strain at failure and altering the soil behavior to a more brittle reaction. The study demonstrated that cement stabilization is one of the techniques for increasing the stiffness and strength of sand; it also adds brittle failure characteristics that need to be considered during design.

Majeed et al. (2021) [2] looked at the feasibility of employing construction and demolition (C&D) debris as a soil stabilizer to improve the engineering behavior of unstable soils. The study examined the geotechnical benefits of integrating recycled materials into weak soils, assessing metrics such as compaction, unconfined compressive strength, and shear resistance. The results indicated that C&D waste considerably increased soil density as well as strength while decreasing compressibility, proving its efficacy as an environmentally benign alternative to standard stabilizers. The authors underlined that this strategy not only enhances soil stability under structural loads, but it also adds to long-term management of waste by recycling larger amounts of construction debris.

Alhassani (2021) [3] investigated the enhancement of sand with sustainable resources, as cement kiln dust (CKD) and organic palm fibers. The study examined the mechanical behavior of soils reinforced with varying amounts of palm fibers (0-1.5% by dry mass), with and without CKD treatment. Direct shear and California Bearing Ratio (CBR) testing revealed that palm fibers increased the shear strength, ductility, and CBR values


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of plain sand up to a fiber level of 1%, beyond which performance decreased. However, when palm fibers were mixed with CKD, both shear strength and CBR values were drastically lowered, most likely due to interference with CKD hydration. The data show that, while palm fibers alone are efficient in reinforcing sandy soils, their combination with CKD may not produce desirable geotechnical qualities.

Recent research has demonstrated the viability of recycled concrete aggregate (RCA) as a renewable resource for enhancing the performance of poor sandy soils beneath shallow foundations. Ali and Tobeia (2022) [4], found through experiments and numerical simulations that integrating RCA at different depths and contents can significantly improve its bearing capacity, reaching up to 80% at 15% RCA and 0.5D depth, while also decreasing settling. Similarly, Ahmed and Tobeia (2022) [5] validated these improvements, the best possible outcomes at 15% RCA and a depth of 0.5D, beyond which no additional improvement was observed. Tobeia and Almafragi (2022) [6] extended this line of research by emphasizing RCA's dual role in increasing the ultimate load capacity and minimizing settlement, highlighting its usefulness as an ecologically benign and cost-effective soil stabilization option. This further emphasizes its feasibility as an environmentally benign and cost-effective soil stabilizing option. Overall, these findings provide strong evidence that RCA can be one of the best geotechnical solutions for enhancing shallow foundation stability on weak sandy soils.

Hidalgo et al. (2023) [7] studied the recycling of construction and demolition waste (CDW), brick and tile ceramic pieces, as mixtures of soil alternatives for enhancing pavement subgrade. Laboratory examinations, including the modified Procter test, California Bearing Ratio, and evaluation of solid modulus, demonstrated that CDW improves soil strength and stiffness, resulting in lower pavement thickness needs. The results showed that adding 30-40% CDW enhanced the soil's workability and mechanical performance, whereas greater levels (up to 60%) resulted in elastic values comparable to granular subbases. Economically, CDW integration cut pavement construction expenses by 7-52%. However, the authors emphasized that durability considerations limit only the replacement of granular materials; therefore, CDW-soil combinations with up to 40% content are the most reliable alternative for long-term pavement performance.

Abed and Almashhadany (2024) [8] examine the application of CDW (construction and demolition waste) as a replacement for coarse aggregates in concrete manufacturing. The study stresses the economic and environmental advantages of salvaging CDW while also addressing the strength decrease concern when compared with natural aggregates. Experimental testing revealed that substituting aggregate from nature with up to 25% CDW maintained adequate tensile and compressive strength values, whereas larger replacement ratios resulted in considerable strength losses. The authors concluded that moderate CDW incorporation can combine both environmental and performance requirements, making it a feasible option for ecologically conscious individuals.

Pauzi et al. (2024) [9] studied the ability of Recycled Waste Aggregates (RWA) to improve the bearing capacity, particularly in poor subgrade soils such as clayey silt and silty clay. Analysis of Sieve, compacted, specific gravity, and California Bearing Ratio (CBR) tests was performed in the laboratory with various amounts of RWA (5%, 10%, and 15%). The results showed that adding RWA considerably increased the strength of the soil, with the greatest benefit occurring at a 15% replacement rate, which optimized CBR values and the capacity to bear load. The study underlines the dual benefits of repurposing building and demolition waste, improving soil characteristics, and promoting sustainable and environmentally friendly engineering methods.

Hashem and Shaban's (2024) [10] study examines the sustainable use of reused concrete aggregate (RCA) to improve the engineering properties of poor sandy soils. Laboratory investigations examined the effects of integrating 5-20% RCA with various gradation zones on compaction properties and the California Bearing Ratio (CBR). The results showed that RCA greatly improved optimum dry density and bearing capacity, with 15% RCA being the ideal amount for stability. Well-graded RCA (Zone 4) showed the most noticeable gains, with CBR increasing by up to 125% as compared to normal soil. The findings emphasize RCA's potential as a green alternative to natural stone aggregate, providing both geotechnical advantages and ecological responsibility in asphalt and soil stabilization projects.

The study investigates the application of paper sludge ash (PSA) as a geopolymer binder to stabilize loose sandy soils in pavement construction. The research evaluated different concentrations of alkaline activators (NaOH and $Na_2SiO_3$) to conduct direct shear tests (DST), unconfined compressive strength (UCS), California Bearing Ratio (CBR), and cyclic loading. Microstructural analysis (SEM and XRD) was also performed. PSA-based geopolymers, activated with $Na_2SiO_3$, significantly improved soil resilience, stiffness, and resistance to permanent deformation by forming C-A-S-H and N-A-S-H gels. The study emphasizes PSA's ability as a viable, low-carbon choice to cement-based stabilizers used in geotechnical engineering. Hayder et al. (2025) [11].

Al-Adhadh et al (2025) [12]. The present research investigates the use of calcined shale (CS) as a supplemental cementation material for stability in sandy soils with weak shear strength and elevated compressibility. Initially, cement rates of 5%, 10%, and 15% were evaluated, with 10% proving to be the most effective for increasing soil strength while decreasing compressibility. Then, partial cement substitution with 10-70% CS was tested. The results showed that introducing 30% CS alongside cement considerably increased unconfined compressive strength (UCS) and decreased consolidation settlement over 28 days, owing to pozzolanic processes that produced calcium silicate and illuminate hydrates. The data showed


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that CS can minimize cement use, lower $CO_2$ emissions, and enhance engineering performance. Therefore, the purpose of this work is to use direct shear testing to measure the impact of RCW quantity on the strength characteristics of artificially stabilized sandy soils.

## Methods

### *Sandy Soil*

The soil in the study was a sandy soil collected from the city of Kufra in southeast Libya (Al-Jawf). The soil sample shown in (Figure 1) is classified as sand, poorly graded SP, as shown in the chart of practical size distribution in (Figure 2). There are laboratory tests to evaluate its physical and mechanical properties in accordance with ASTM-USCS criteria, and (Table 1) describes some of the soil's engineering properties.

***Figure 1. The sample of soil***

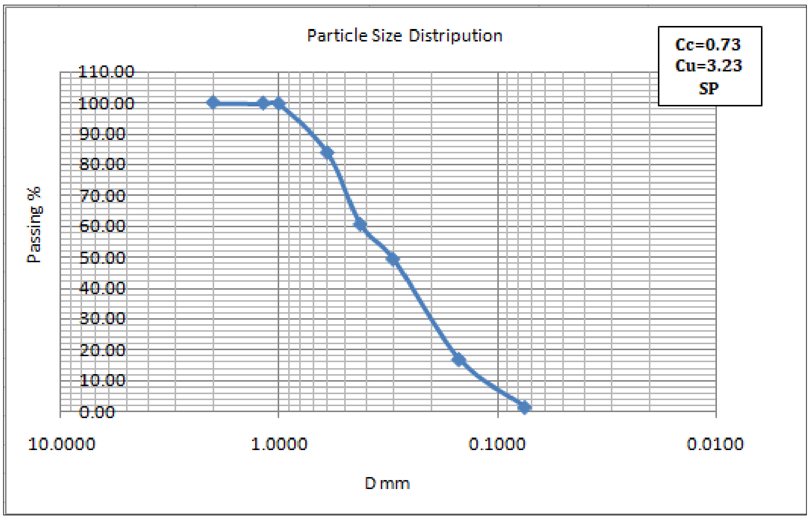


***Figure 2. Practical Size Distribution***

***Table 1. The Soil Properties***

| Property | Value |
|---|---|
| Soil Description | Light Reddish-Brown Sand |
| Specific Gravity | 2.62 |
| Moisture Content | .039% |
| Absorption Rate | 0.8% |
| Unit Weight | 19.12 kN/m$^3$ |
| Relative Density Dr | 49% |
| Coefficient of Uniformity $C_U$ | 3.23 |
| Coefficient of Curvature $C_C$ | 0.73 |
| Soil Classification ASTM-USCS | Poorly Graded Sand SP |
| Angel of Internal Fraction Ø | 28.6 |
| Cohesion C | 17.35 kN/m$^2$ |
| Hydraulic Conductivity | 1.37E-02 m/min |
| Soil State | Dense |


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***Recycle Concrete Waste RCW***
Concrete waste consists of Portland cement, sand, gravel, and water. After recycling and grinding this waste, it can be used as a drying agent when mixed with the foundation layer soil and as a filler material that increases the soil's cohesiveness. Laboratory tests were conducted on the crushed concrete waste that passed through sieve 1.15mm, as shown in (Figure 2), and the results are illustrated in (Table 2).


***Figure 3. The sample of Concrete Waste***

***Table 2. The Concrete Waste Properties***

| **Property** | **Value** |
|---|---|
| Specific Gravity | 2.57 |
| Absorption Rate | 7.1% |
| Unit Weight | 9.03 $kN/m^3$ |

## Methods
The physical properties as total density, specific gravity, and permeability, were investigated according to ASTM for untreated samples and treated samples with a different percentage of RCW. The RCW was added to the sand in proportions (0%, 3%, and 6%) of the soil weight, with different moisture content of 0% and 15% for each addition ratio. Also, the direct shear test was conducted according to ASTM D3080 to illustrate the values of shear strength and its characteristics of sand, both with and without the addition of enhancing materials. This was accomplished by applying typical stresses of 5.55, 11.11, and 22.22 $kN/m^2$ for all samples.

## Results and Discussion
***Total Density, Specific Gravity, and Permeability***
The results of laboratory tests on natural and improved samples showed that concrete waste led to a decrease in values of both total density and specific gravity due to the density of concrete waste is less than the density of sand by 52.82%. Also, the permeability of the soil significantly decreased with the addition of the improving material, as the hydraulic conductivity value decreased by 65.9% and 99.8% for the samples treated with concrete waste at 3% and 6% ratios, respectively, compared to the reference sample. Although the concrete waste penetrated the soil voids and increased the friction between its particles, the absorption property of the concrete waste led to a decrease in the values of the hydraulic conductivity coefficient.

***Direct Shear Test***
Figures 4 and 5 illustrate the impact of stabilization on the stress-strain behavior of normal and enhanced sand associated with Mohr-Coulomb failure envelopes. RCW stabilization causes a considerable increase in maximum shear stress, assuming a certain amount of normal stress in dry and wet cases. The best result in the dry case was with percentages of 3% and 6% similarly, therefore, the amount of shear strength increased by 11.3 %. Another key point to note in this section is that the maximum shear stress fell significantly after mixing the water with the untreated sample by 6.8%, demonstrating a rise in pore water pressure, which lowers effective stress. After adding RCW, the values of strength were enhanced with both percent of 3% and 6% by 19.2%.


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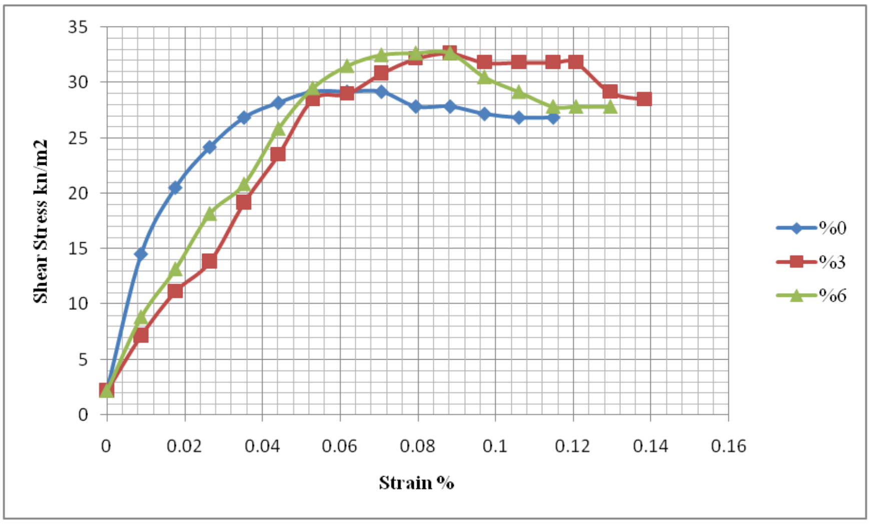


***Figure 4. Stress-strain relationship of treated and untreated sand for normal stress of 22.2 kPa(Dry Case)***

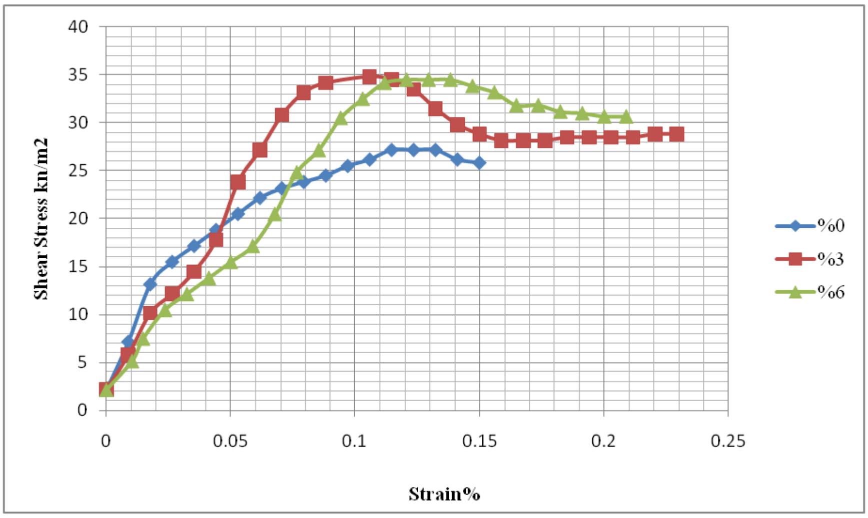


***Figure 5. Stress-strain relationship of treated and untreated sand for normal stress of 22.2 kPa (Wet Case)***

***Characteristics of Shear Strength***
***Internal Friction Angle***

The shear resistance parameters of the soil changed when treated with concrete waste. As the angle of internal friction (Φ) improved and its values increased by 21% and 30% for 3% and 6% additions, respectively, compared to the angle of internal friction of the reference sample in the dry air-dry state. Although the concrete powder reduced the soil density, its high load resistance increased the soil resistance, which resulted from the increased friction between the grains. In the case of increasing the moisture content by 15%, the friction angle increased by 1% for the natural sample due to partial saturation. The presence of a small amount of water may initially improve bonding, but when too much water is added, the bonds weaken, and the actual friction decreases. Therefore, the improvement was 16% and 35% for the samples treated with 3% and 6% additions, respectively. Table 4 displays the values of the angle of internal friction with addition ratios, while (Figure 4) depicts the relationship between them in wet and dry cases.

***Table 3. The Relation between the internal friction angle and the percentage of additive***

| **Dry Case** | | | |
|---|---|---|---|
| Percent of RCW | Φ | Improvement Ratio | Water Content |
| 0 | 29 | - | 0.39 |
| 3 | 34.7 | 21 | 0.36 |
| 6 | 37.3 | 30 | 0.35 |
| **Wet Case** | | | |
| 0 | 30 | 1 | 13.66 |
| 3 | 33.2 | 16 | 13.53 |
| 6 | 38.8 | 35 | 13.76 |


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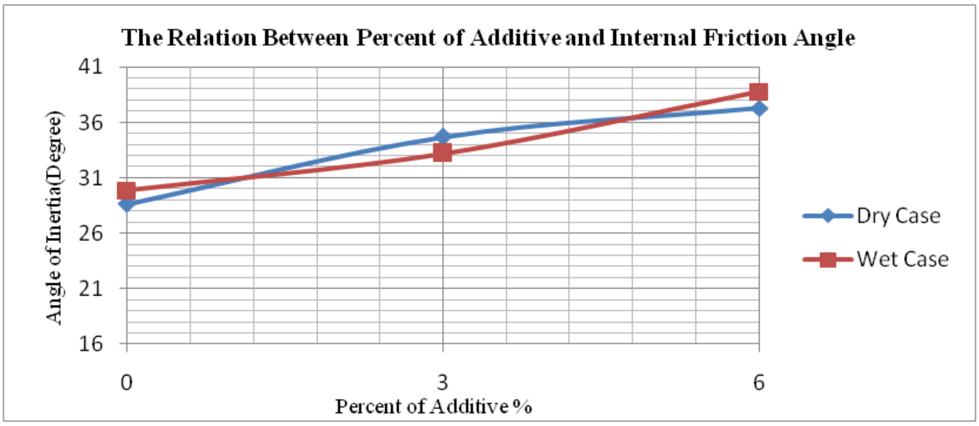


***Figure 4. The relation between the percent of RCW and Φ***

***Cohesion***

As for the soil cohesion (C)), the results did not show any significant improvement with 3% and 6% additions in the air-dry condition, while the cohesion values increased in the case of adding water at a rate of 15% of the weight of the treated sample, where its values increased by 4% and 23% for the natural soil and the soil treated with 3%,6% respectively. At the same time, cohesion decreased by 3% with the addition of 6% despite the reduction in void ratio, indicating that the cohesion of sandy soil is not a fixed amount that is affected by the void ratio. It also increases due to the contact forces at the points where the grains collide with each other, which decrease in the case of failure as the grains start to move and overlap. Therefore, the soil's cohesion and angle of internal friction do not depend solely on the void ratio, but also on the soil's condition and properties, the value of the applied loads, and the volumetric changes that occur during the direct shear test [13]. (Table 4) shows the values of cohesion with addition ratios, and (Figures 5) illustrate the relationship between them in both cases.

***Table 4. The Relation between Cohesion and the percentage of additive***

| **Dry Case** | | | |
|---|---|---|---|
| Percent of RCW | C kN/m$^2$ | Improvement Ratio% | Water Content |
| 0 | 17.35 | - | 0.39 |
| 3 | 17 | 2 | 0.36 |
| 6 | 17 | 2 | 0.35 |
| **Wet Case** | | | |
| 0 | 18.05 | 4 | 13.66 |
| 3 | 21.3 | 22.8 | 13.53 |
| 6 | 16.85 | -2.8 | 13.76 |

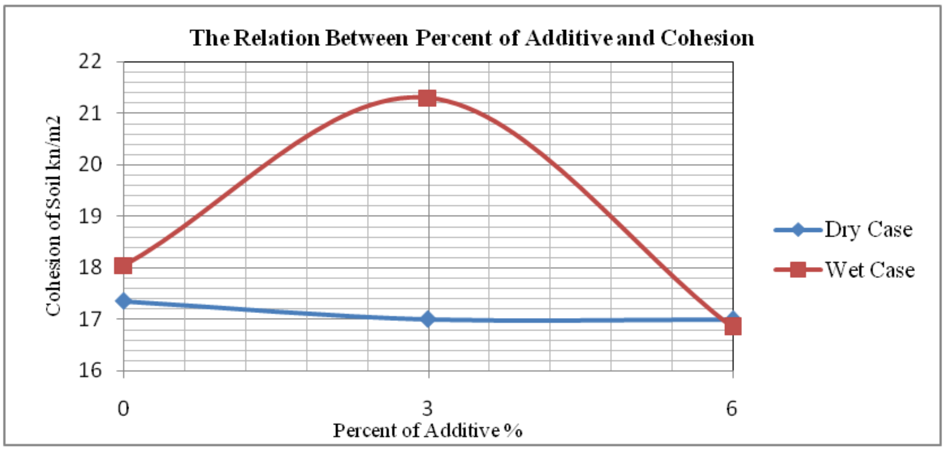


***Figure 5. The relation between the percent of RCW and C***

## Conclusion

This challenge is further complicated by the fact that variations in moisture content significantly influence other soil properties, including density, unit weight, permeability, and void ratio, all of which play a crucial role in determining the shear strength parameters of soils. The results of the previously conducted tests confirmed that an increase in moisture content negatively impacts the shear strength of natural soil. However, when concrete powder was added, the soil properties improved, and its shear strength increased despite the higher moisture content. Overall, the test results demonstrated the effectiveness of incorporating


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concrete waste into sandy soils under both dry and wet conditions, as it consistently enhanced the shear strength parameters and maximum stress.

***Conflict of interest***. Nil

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