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# Utilization of Recycled Carpet Waste in Clay Soil Mixtures: Mechanical Properties and Environmental Benefits

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**Abstract:**
In line with sustainable strategies for soil improvement, this study investigated the mechanical behavior of clay soil reinforced with various percentages of recycled carpet waste (RCW) through compaction, unconfined compressive strength (UCS), and direct shear tests (DST). The results indicated that with increasing RCW content, the maximum dry unit weight (MDUW) decreased, while the optimum moisture content (OMC) increased, primarily due to the lower specific gravity and greater water absorption capacity of the carpet fibers. The UCS and secant modulus at 50% of peak stress (E50) increased up to 1% RCW, reaching 216.7 kPa and 3342 kPa, respectively. However, beyond this content, both strength and stiffness declined, likely due to weakened internal bonding and increased void ratio in the soil-fiber mixture. In terms of shear strength parameters, both cohesion and the internal friction angle improved up to 1% RCW (70.2 kPa and 18.7°, respectively), followed by a decrease at higher dosages. These changes are attributed to the improved interlocking and bonding between soil particles and the distributed fibers at lower contents. Overall, incorporating RCW up to approximately 1% offers a practical and environmentally responsible approach for enhancing the engineering properties of clay soils.



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## 1. Introduction

Soil improvement is a fundamental component of geotechnical engineering, which aims to improve the physical, mechanical, and chemical properties of soils in order to increase their performance in construction projects. Natural soils typically have undesirable properties that can lead to serious problems in various stages of construction. These problems include properties such as low tensile strength, high settlements, excessive expansion, low density, or lack of load-bearing capacity, which may lead to structural instability and increased maintenance costs. Therefore, soil improvement is essential as a solution to these problems to achieve suitable and sustainable conditions in structures and construction projects [1]. There are various methods for improving soil properties that are selected depending on the type of soil, environmental conditions, type of project, and its specific needs. One of the common methods of soil improvement is mechanical stabilization, which is carried out by further compacting the soil. In this method, the soil is mechanically compressed to increase its bearing capacity [2]. Another important method is chemical stabilization of the soil, in which its physical and mechanical properties are improved by adding various chemicals such as lime, cement, or polymeric materials to the soil. These materials increase the cohesion of the soil and help reduce the ability of the soil to settle and expand. This method is especially used to improve clay and soft soils that have problematic characteristics [3]. Another type of soil improvement method is the use of geosynthetic materials, which include various types of synthetic materials such as geotextiles, geogrids, and geomembranes. These materials can help strengthen the soil and prevent its displacement and instability. The use of these materials is especially useful in sandy and clay soils that are subject to displacement due to loading or moisture changes. Geosynthetic materials are used as an effective solution in strengthening the tensile strength of the soil and preventing excessive settlements [4, 5]. Other methods, such as biological improvement, thermal and hydraulic improvement, and the use of injection methods, are also used to stabilize soil conditions [6-9]. With the advancement of technology and the need to use sustainable resources,



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research has moved towards the use of new additives such as nanoparticles (such as nanosilica, nanoclay, nano iron), chemical polymers, geopolymers, natural and synthetic fibers, and recycled materials [10, 11]. In the present era, when the problem of increasing industrial and urban waste has become a global challenge, the use of recycled materials and waste such as rubber waste, plastic fibers, textile residues, fly ash, carpet waste, and construction waste in soil improvement has been introduced as a very cost-effective solution. From an economic point of view, the lower cost of these materials compared to traditional and modern materials reduces the overall costs of the project. In some countries, rubber and plastic waste are available at very low prices or even free of charge, and their use reduces the costs of raw materials. From an environmental point of view, the use of waste helps to reduce its entry into the environment and landfills, and reduces soil, water, and air pollution. The use of recycled materials also reduces the need to extract new natural resources and reduces energy consumption in the process of producing new materials. Due to its environmental and economic benefits, the use of recycled materials in soil improvement is becoming a popular option in geotechnical engineering projects [12]. Various recycled materials can be used in soil improvement. Concrete waste includes broken concrete pieces from construction projects or demolitions. These materials usually have suitable physical properties, such as particle size and high strength, which can be effectively used in strengthening and improving weak and soft soils [13]. Fly ash is a by-product of coal combustion in power plants. Due to its pozzolanic properties, this material has the ability to react with water and calcium compounds and can greatly improve the chemical and physical properties of the soil. The use of fly ash in clay soils is particularly effective in increasing stability, reducing settlement, and improving their reinforced properties [14]. Plastics, especially polyethylene, polypropylene, and polystyrene, can be used as effective reinforcements in combination with weak soils due to their high tensile strength and ductility [15]. Waste glass, especially when powdered, can be used as an additive to soils in improvement projects. Glass powder improves the density and compressive strength of soils due to its physical properties, such as hardness and fine particle size. Also, due to the low coefficient of thermal expansion of glass, it can be useful in areas with high temperature changes [16, 17]. Waste tires, either crushed or in the form of fibers, can also be used effectively in reducing settlement and increasing the bearing capacity of soils due to their elasticity and good stability against environmental changes [18]. Carpet waste refers to waste from the production, installation, use, or recycling of carpets. This waste includes cut pieces of carpet, worn and discarded carpets, and even fibers separated from the structure of carpets, which are usually made of materials such as polypropylene, nylon, polyester, and in some cases, natural wool. Due to the resistant and flexible composition of these fibers, carpet waste can be reused in various industries, including civil and geotechnical engineering. In recent years, scientific research has shown that carpet waste can be used as a type of reinforcing fiber in weak soils. When added to soil, these fibers are randomly distributed among soil particles and, by creating frictional and mechanical bonds, increase shear strength, reduce settlement, reduce swelling, and increase soil ductility. In other words, carpet waste, with a performance similar to commercial synthetic fibers, plays an effective role against soil rupture and failure [19, 20]. A study was conducted to investigate the effect of using synthetic fibers derived from carpet waste to improve the strength properties of fine sandy soils. Drained triaxial tests were conducted on samples compacted at optimum moisture content, with key variables including the aspect ratio and weight percentage of fiber strips. The results demonstrated that incorporating carpet waste fibers significantly enhanced the shear strength of silty sand. Furthermore, a model was developed to simulate the effect of fiber inclusion, accurately predicting the influence of strip content, aspect ratio, and confining pressure on the shear strength of the reinforced soil [21]. Another study explored the use of nylon-based carpet waste to improve clay soils similar to those from demolition sites. Up to 10% shredded carpet waste was added by weight, and samples were tested using standard compaction and unconfined compressive strength (UCS) methods. Results showed that carpet fibers enhanced strength over time, mainly due to improved soil-fiber interaction. This indicates that recycled carpet waste can serve as an effective and sustainable solution for enhancing weak soils in civil engineering applications [22]. In another study, researchers investigated the effect of reinforcing silty sand soil with carpet waste strips on its dynamic shear modulus. In this study, silty sand samples were prepared with different percentages of carpet waste strips and different aspect ratios, and the shear wave and dynamic shear modulus were measured at different frequencies and strains. The results showed that the addition of carpet strips significantly increased the shear modulus of the soil, especially at low strain values. These findings indicate that carpet waste can improve not only the static properties but also the dynamic behavior of the soil, which is important for geotechnical applications in seismic areas [23]. The results of a study on the use of carpet waste fibers in clay reinforcement showed that the addition of carpet waste fibers to clay soils can significantly increase the unconfined compressive strength and change the fracture behavior from brittle to ductile. The results also showed that the relative benefits of fibers for increasing the unconfined compressive strength of clay soils are highly dependent on the initial dry unit weight and soil moisture content [24]. Another study investigates the potential of using carpet waste fibers to improve the swelling properties of clay soils. Two types of clay with different plasticity indices (17% and 31.5%) were mixed with carpet waste fibers in varying amounts (1%, 3%, and 5% by weight). The samples were prepared with different densities and moisture contents, and swelling tests were conducted on them. The results showed that the behavior of the fiber-reinforced clays was dependent on the initial compaction state and moisture content. Increasing the fiber content significantly reduced the swelling pressure, particularly in samples with maximum dry density and optimum moisture content. Additionally, reducing dry density or increasing moisture content led to an increase in swelling pressure [25]. Another study also examined the effect of calcium nano carbonate and carpet waste on clay soil. The results of unconsolidated undrained triaxial tests showed that the used fibers alter the sample behavior in high strains. Also, the use of nano calcium carbonate and carpet waste fibers together almost doubled the undrained cohesion [26]. Also, another study investigated the effect of carpet waste on the geotechnical properties of sandy soil, and the results of direct shear and standard compaction tests reveal that the addition of carpet waste to sandy soil improves the shear strength parameters, reduces the maximum dry unit weight, and increases the optimum moisture content. Thus, due to the recyclability of this type of material, its use in civil engineering and geotechnical projects is both economically viable and reduces the environmental problems [27]. Another study investigated the effect of carpet waste on the strength characteristics of cement-stabilized sandy soil. The results showed that adding carpet waste to cement-stabilized sandy soil improved the parameters of unconfined compressive strength and also positive changes in the speed of ultrasonic waves [28]. Given the desirable mechanical properties of carpet waste, along with their economic and environmental benefits, the use of these materials in geotechnical projects as an innovative and efficient method of soil improvement has received increasing attention from engineers and researchers, and paying attention to this approach in the future of geotechnical engineering and sustainable development of infrastructure is an undeniable necessity.

## 2. Significance and Novelty

This study aims to investigate the impact of recycled carpet waste (RCW) on the physical and mechanical properties of clay soils, with an emphasis on its innovative application in geotechnical engineering. The use of carpet waste as an additive not only addresses the growing environmental concerns associated with waste accumulation but also introduces a sustainable, low-cost solution for improving soil behavior in construction projects. The novelty of this research lies in the systematic evaluation of varying RCW contents and their influence on key mechanical characteristics, including unconfined compressive strength, stiffness modulus ($E_{50}$), and shear strength parameters, under standard laboratory conditions. Moreover, this study presents a comprehensive environmental-economic perspective, highlighting the potential of RCW to significantly lower material costs and reduce the ecological footprint of ground improvement techniques. By advancing the practical use of industrial textile waste in geotechnical applications, this work contributes to bridging the gap between sustainable waste management and soil stabilization technologies.

## 3. Materials and Methods

### 3.1. Materials Used

#### 3.1.1.Clay Soil Characteristics

The soil studied in this study is a clayey type with low plasticity (CL). This soil has a grain size composition of 0% coarse grains, 22% sand, and 78% clay and silt, which was analyzed according to ASTM D422-63(2007) [29]. Based on the Unified Soil Classification system, this soil is classified as a low plasticity soil according to ASTM D2487-17e1 [30]. The appearance of the clayey soil studied is presented in Figure 1, and its physical properties are presented in Table 1.

**Figure 1.** **Clay soil used in this study**

**Table 1.** **Physical characteristics of soil**

| Soil properties | standard | Value |
|---|---|---|
| Specific Gravity, $G_s$ | ASTM D854-14 [31] | 2.7 |
| Atterberg limits result | | |
| Liquid Limit,% | ASTM D4318-17e1 [32] | 38 |
| Plastic Limit,% | | 18.5 |
| Plasticity Index,% | | 19.5 |
| Compaction study | | |
| MDUW, $kN/m^3$ | ASTM D698-12e2 [33] | 17.8 |
| OMC, % | | 16.5 |

#### 3.1.2. Carpet Waste Types and Properties

The reinforcing element used in this study is RCW, prepared by cutting and shredding excess carpet strips into approximately 0.5 cm pieces. Due to its low specific gravity and suitable flexibility, RCW can be effectively mixed with soil materials and plays a significant role in improving the physical and mechanical properties of the soil. The tensile strength of RCW is 7.13 kgf, its maximum elongation before failure is 12.96 mm, and its specific gravity is 1.07 $kN/m^3$. The use of this recycled material not only helps reduce the volume of industrial waste and its environmental impacts but also offers a cost-effective and readily available option for soil improvement in construction projects. The physical appearance of the RCW used in this study is shown in Figure 2.

### 3.2. Methods

#### 3.2.1.Experimental Program

Figure 2. **RCW used in this study**

The experimental program was designed to investigate the effects of RCW on the physical properties and mechanical behavior of soil mixtures. The program includes a series of laboratory tests, including standard compaction tests (according to ASTM D698-12e2 [33]), unconfined compressive strength (UCS) tests (according to ASTM D2166/D2166M-13 [34]), and direct shear tests (according to ASTM D3080/D3080M-11 [35]) under normal loads of 100, 200, and 300 kPa. These tests were conducted on soil samples mixed with different percentages of RCW (from 0% to 2%) to investigate their effects on parameters such as maximum unit dry weight (MDUW), optimum moisture content (OMC), UCS, modulus of elasticity, strain at break, and shear strength parameters. Each experiment was conducted with appropriate controls and necessary replicates to ensure that the results were valid and accurate, providing a comprehensive dataset for analyzing the potential of RCW in soil stabilization and its environmental and economic benefits.

### 3.3. Sample Preparation

To prepare the samples, the clay soil was first dried and then mixed with different percentages of RCW. The percentages of RCW used were 0.5, 1, 1.5, and 2% by weight. Then, to achieve a homogeneous and better mixture, the required amount of water obtained from the standard compaction test was added to the sample. After complete mixing, these mixtures were uniformly compacted in standard laboratory molds. The curing time of the sample was also considered to be 28 days, under standard laboratory temperature conditions. Finally, after curing, the samples were tested according to the relevant standards.

## 4. Results and Discussion

### 4.1. Effect of Carpet Waste on Compaction of Samples

The results of the standard compaction test are shown in Figure 3. As the percentage of RCW increases, the MDUW decreases. In the control sample (RCW = 0%), the MDUW is 17.8 kN/m³. However, with the addition of carpet waste, it decreases to 17.3 kN/m³ at 0.5% RCW and further reduces to 16.2 kN/m³ at 2% RCW. This reduction can be attributed to the replacement of denser clay particles with lighter carpet fibers, leading to lower compactability of the mixture. On the other hand, the OMC shows an increasing trend. In the control sample, the OMC is 16.5%, which rises to 17.2% at 0.5% RCW and reaches 20.4% at 2% RCW. This increase is likely due to the higher water absorption capacity of carpet fibers compared to clay particles, resulting in a greater moisture demand to achieve optimal compaction. These findings indicate that incorporating carpet waste into clay mixtures reduces the dry unit weight while increasing the optimum moisture content.

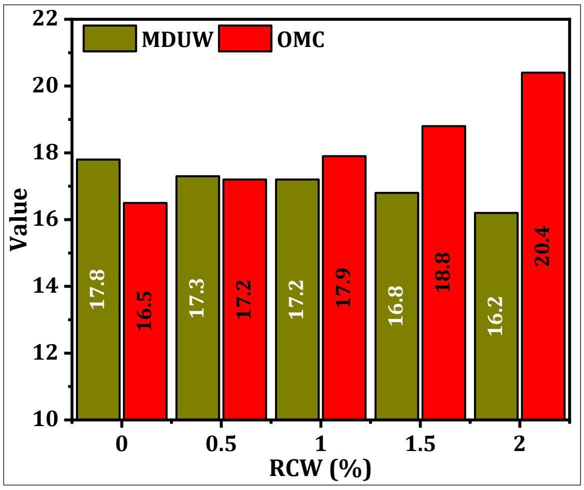



Figure 3. **Effect of RCW percentage on MDUW and OMC in the standard compaction test**

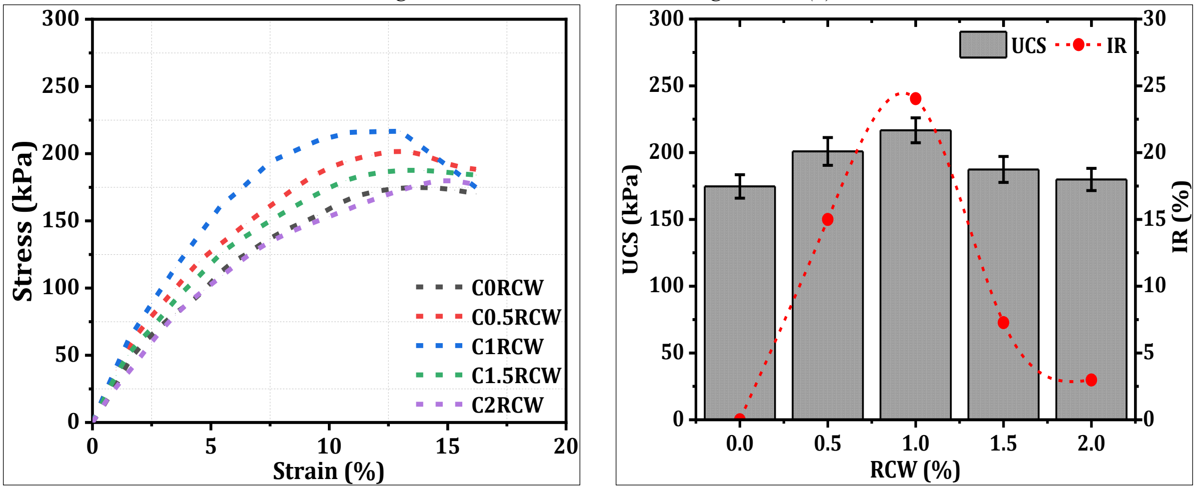
### 4.2. Effect of Carpet Waste on UCS of Samples

The results of the unconfined compressive strength (UCS) test are shown in Figure 4. As the percentage of RCW increases, the UCS first increases and then decreases. In the control sample (RCW = 0%), the UCS value is 174.7 kPa, which increases to 200.9 kPa at 0.5% RCW and 216.7 kPa at 1% RCW. This increase in resistance can be attributed to the improved bonding between soil particles and carpet fibers, which strengthens the mixture structure [28].

However, at higher RCW percentages, especially at 1.5% and 2% RCW, the UCS decreases to 187.4 kPa and 179.9 kPa, respectively. This reduction may be due to an increase in porosity and a decrease in the bonding between soil particles, weakening the mixture structure.

Regarding the failure strain, it is observed that as the RCW percentage increases, this value also increases from 13.5% in the control sample to 15% at 2% RCW. This indicates that with the addition of carpet waste, the soil tends to exhibit more flexible behavior and, in this case, shows more ductility [28].

In terms of percentage change in UCS relative to the control sample, the greatest increase in UCS is observed at 1% RCW with a 24% increase and at 0.5% RCW with a 15% increase. At higher RCW percentages, this increase diminishes, with changes of 7.3% and 3% at 1.5% and 2% RCW, respectively. This indicates that adding carpet waste up to around 1% helps enhance the UCS, but at higher amounts, negative effects begin to appear. Additionally, the standard deviation (STD) ranges from 8.3 to 10.4 kPa, indicating relatively stable data with low variability in the measured strengths.




(a) (b)

**Figure 4. (a) Stress-strain curve showing the effect of RCW on samples. (b) Changes in UCS and percentage rate of change relative to clay soil for different RCW percentages**

The results of the secant modulus at 50% of peak stress ($E_{50}$) are presented in Figure 5. As the RCW content increases up to 1%, the $E_{50}$ value rises from 2212 kPa in the control sample to 3342 kPa, indicating an improvement in stiffness and initial resistance to deformation. However, beyond this point, $E_{50}$ decreases, reaching 2225 kPa at 2% RCW, which is nearly equal to the initial value. This reduction may be attributed to decreased particle bonding and increased void ratio in the mixture.

Meanwhile, the failure strain increases from 13.5% in the control sample to 15% at 2% RCW. This inverse relationship between E50 and failure strain indicates that at lower RCW contents, the mixture exhibits higher stiffness and fails at lower strains, reflecting a more brittle behavior. In contrast, as the RCW content increases, the stiffness decreases, allowing the material to undergo greater deformation before failure, which implies a transition toward more ductile and flexible mechanical behavior. This trend highlights the role of carpet fibers in altering the deformation characteristics of the soil-fiber matrix, where higher fiber content provides more energy absorption and strain tolerance.

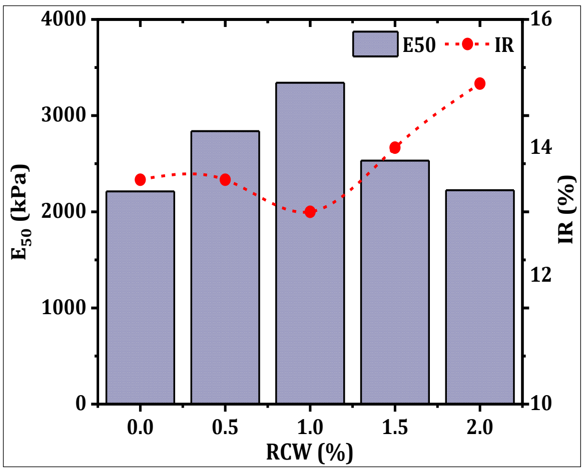



**Figure 5. Effect of RCW content on secant modulus (E50) and failure strain**

## 4.3. Effect of Carpet Waste on Shear Strength of Samples

The results of the direct shear test under three levels of normal stress (100, 200, and 300 kPa) are presented in Figure 6. As the RCW content increases up to 1%, the maximum shear stress (MSS) increases significantly across all normal stresses. For example, at 200 kPa normal stress, the shear stress increases from 109.9 kPa in the control sample to 152.1 kPa at 1% RCW. This improvement can be attributed to enhanced particle interlocking and internal friction within the mixture.

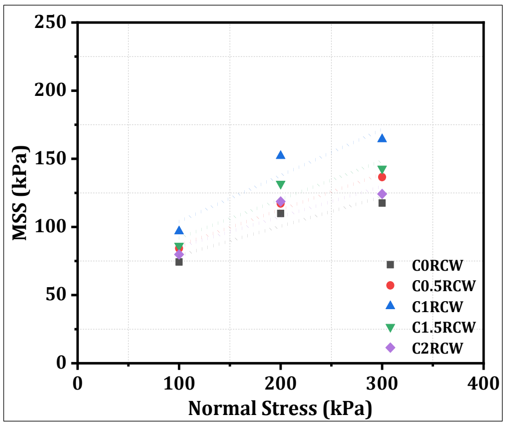
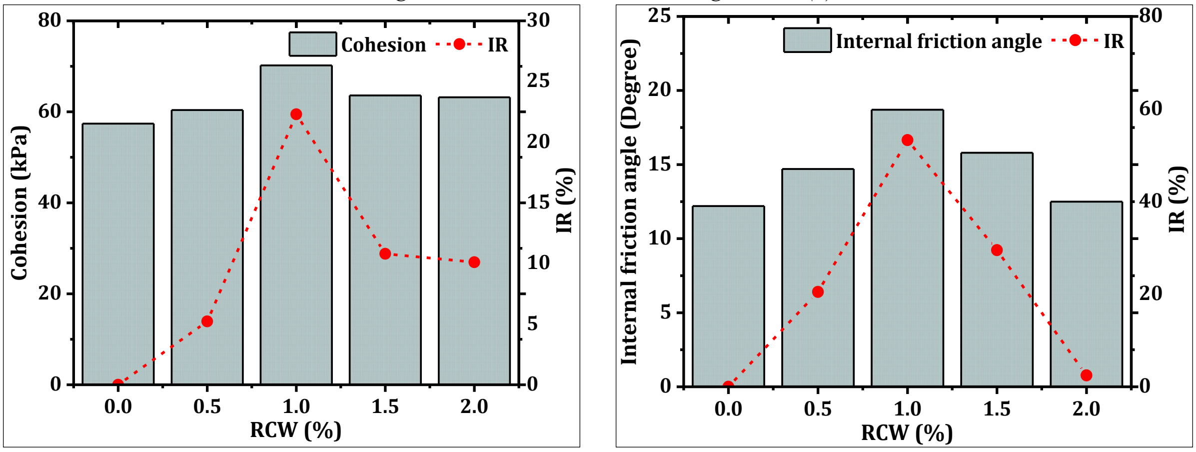



**Figure 6. Maximum shear stress values at different normal stresses for the samples**

At RCW contents above 1%, the shear strength begins to decline, a trend observed across all normal stress levels. At 2% RCW, the maximum shear stress values are lower than those at 1%, likely due to excess fibers disrupting bonding and weakening stress transfer in the matrix. Overall, the inclusion of RCW improves shear strength up to a certain point, beyond which the benefits diminish. The shear strength parameters of the RCW-treated soil mixtures are illustrated in Figure 7, where Figure 7-a presents cohesion values along with their percentage increase relative to untreated clay, and Figure 7-b shows the internal friction angle and its corresponding rate of change.




(a) (b)

**Figure 7. Values of shear strength parameters for samples (a) Cohesion (b) internal friction angle**

Cohesion increased up to 1% RCW, rising from 57.4 kPa in the control sample to 70.2 kPa, a 22.3% increase. This enhancement can be attributed to improved bonding between fibers and soil particles, as well as greater matrix integrity [27]. Beyond 1% RCW, cohesion decreased, with values dropping to 63.6 kPa and 63.2 kPa at 1.5% and 2%, respectively. This decline is likely due to excessive fiber content disrupting the compact soil structure and reducing effective interparticle contact, which weakens the overall mixture.

## 4.4. Environmental and Economic Analysis

The incorporation of recycled materials, particularly textile industry waste such as RCW, offers substantial environmental and economic advantages. As the global environmental crisis deepens, the demand for sustainable alternatives in construction has become increasingly urgent, especially in the field of geotechnical engineering. Traditional soil improvement methods often involve high energy use and resource depletion, contributing to environmental degradation. In this context, integrating RCW into soil mixtures emerges as a practical and eco-conscious strategy, delivering both cost-effectiveness and a reduction in the environmental footprint of construction activities.

### 4.4.1.Environmental Impact: Waste Reduction and Resource Conservation

One of the most significant advantages of incorporating RCW into soil mixtures is its potential to reduce environmental pollution. The carpet industry is a major contributor to global waste, with millions of tons of used carpets ending up in landfills every year. This results in not only waste accumulation but also the release of harmful substances into the environment as these materials degrade. By reusing carpet waste, the burden on landfills is reduced, leading to a decrease in the environmental impact associated with waste disposal. Moreover, the recycling of carpet waste conserves valuable raw materials that would otherwise be used in the production of new construction materials (e.g., clay and sand), promoting a more circular economy [36-39]. This sustainable practice contributes to the reduction of resource extraction, energy consumption, and the carbon footprint of construction projects.

Additionally, the use of carpet fibers in soil mixtures may help mitigate some of the negative impacts caused by traditional soil stabilization methods, such as the use of cement or lime, which require energy-intensive processes for production and release significant amounts of carbon dioxide ($CO_2$) into the atmosphere. The substitution of carpet waste for these materials can significantly reduce greenhouse gas emissions associated with soil stabilization. The carbon footprint of a project incorporating RCW would, therefore, be much lower compared to conventional methods, making it an eco-friendlier alternative.

### 4.4.2. Economic Benefits: Cost Savings and Resource Efficiency

From an economic perspective, utilizing RCW in soil stabilization can lead to substantial cost savings. The cost of carpet waste is typically low or even negligible, as it is often discarded by carpet manufacturers or disposed of by consumers. The availability of this waste material at little or no cost significantly reduces the expenses associated with purchasing traditional soil stabilization materials, which can be costly and require significant transportation and processing.

The economic advantages are further enhanced by the fact that RCW is a local resource, often available in regions where carpet production and consumption are high. This local sourcing reduces transportation costs and associated environmental impacts. Additionally, the economic viability of using RCW increases when considering the long-term savings related to the durability and improved properties of the stabilized soil. For example, the higher shear strength and compressive resistance observed in soils treated with small amounts of RCW can lead to reduced maintenance and repair costs for infrastructure and construction projects [40-43]. The durability of these soil mixtures enhances the overall lifecycle value of the project, contributing to further cost savings in the long run.

Furthermore, the adoption of sustainable building practices, such as the use of RCW, can improve the competitiveness of construction firms and attract environmentally conscious investors and clients. The growing demand for green building materials and sustainable infrastructure solutions makes RCW an attractive option for companies looking to enhance their reputation and marketability in an increasingly eco-conscious market.

#### 4.4.3.Challenges and Future Considerations

Despite the numerous environmental and economic advantages, there are challenges to the widespread implementation of RCW in geotechnical engineering. One of the primary concerns is the long-term performance and stability of RCW-treated soils under various environmental conditions. While preliminary studies show positive effects on soil strength and compaction, further research is needed to evaluate the behavior of these materials over time, especially in the face of temperature fluctuations, moisture variations, and mechanical stresses [44-47]. It is crucial to assess how the incorporation of RCW might impact the long-term durability and performance of infrastructure projects, particularly in regions with extreme climates.

Another challenge lies in the scaling up of this practice in the construction industry. While laboratory-scale studies demonstrate the feasibility and advantages of using RCW, practical implementation on a larger scale requires standardization, quality control, and regulatory frameworks to ensure the consistency and safety of the stabilized soils. This would involve cooperation between industry stakeholders, including carpet manufacturers, construction firms, and policymakers, to establish guidelines for the use of RCW in construction.

#### 4.4.4. Future Research Directions

For optimizing the use of RCW in soil stabilization, future research should focus on analyzing the long-term performance of these mixtures under various environmental conditions and loading scenarios. Additionally, conducting life cycle cost analysis to better assess the economic benefits and savings in the long run, as well as developing standards and regulatory frameworks for the safe application of RCW in large-scale projects, is crucial. Furthermore, exploring advanced carpet waste recycling technologies and new processing methods can enhance the quality and efficiency of this approach in construction.

## 5. Conclusion

The results of this study revealed that the incorporation of RCW has significant effects on the physical and mechanical properties of clayey soils. As the RCW percentage increased, the maximum dry unit weight decreased, and the optimum moisture content increased. These changes generally led to a reduction in the soil's compaction capacity. In the unconfined compressive strength (UCS) test, the highest increase in UCS was observed up to 24% at 1% RCW, but higher percentages led to a decrease in UCS. Similarly, in the secant modulus ($E_{50}$), a significant increase in stiffness and initial resistance to deformation was seen up to 1% RCW, but it decreased at higher percentages. In the direct shear test, maximum shear stress increased up to 1% RCW but decreased at higher percentages. Regarding shear properties, both cohesion and internal friction angle improved with RCW addition but declined at higher percentages. This indicates that a certain amount of RCW can improve the strength properties of the soil, but beyond a certain threshold, negative effects appear.

From an environmental perspective, using recycled carpet waste as a soil additive can significantly contribute to waste reduction and the conservation of natural resources. This approach not only enhances the engineering properties of soil but also represents a novel and practical solution for integrating industrial waste into geotechnical applications. By turning non-biodegradable waste into a functional material, this method introduces an innovative pathway for sustainable soil improvement, aligning with modern strategies for environmental protection and circular resource use.

Future research should focus on the long-term evaluation of these mixtures in real environmental conditions and their impacts under different climatic and geographical scenarios. Furthermore, a more detailed investigation into the effects of these materials on the performance of structures and infrastructure, and comparison with other methods as a sustainable solution, could facilitate broader use of carpet waste in geotechnical engineering and civil works. The environmental impacts, including biodegradability and natural recovery potential, also need to be thoroughly assessed for a complete understanding of this technology's potential.

## 6. References

[1] Abdel-Rahman, M.M. (2021). Review of Soil Improvement Techniques. Advancements in Geotechnical Engineering. Sustainable Civil Infrastructures. Springer, Cham, Switzerland. doi:10.1007/978-3-030-62908-3_14.

[2] Fondjo, A. A., Theron, E., & Ray, R. P. (2021). Stabilization of Expansive Soils Using Mechanical and Chemical Methods: A Comprehensive Review. Civil Engineering and Architecture, 9(5), 1289–1294. doi:10.13189/cea.2021.090503.

[3] Barman, D., & Dash, S. K. (2022). Stabilization of expansive soils using chemical additives: A review. Journal of Rock Mechanics and Geotechnical Engineering, 14(4), 1319–1342. doi:10.1016/j.jrmge.2022.02.011.

[4] Malik, P., & Mishra, S. K. (2023). A comprehensive review of soil strength improvement using geosynthetics. Materials Today: Proceedings. doi:10.1016/j.matpr.2023.05.710.

[5] Chatrabhuj, & Meshram, K. (2024). Use of geosynthetic materials as soil reinforcement: an alternative eco-friendly construction material. Discover Civil Engineering, 1(1), 41. doi:10.1007/s44290-024-00050-6.

[6] Umar, M., Kassim, K. A., & Ping Chiet, K. T. (2016). Biological process of soil improvement in civil engineering: A review. Journal of Rock Mechanics and Geotechnical Engineering, 8(5), 767–774. doi:10.1016/j.jrmge.2016.02.004.

[7] Wani, K. M. N. S., & Mir, B. A. (2020). Microbial geo-technology in ground improvement techniques: a comprehensive review. Innovative Infrastructure Solutions, 5(3), 82. doi:10.1007/s41062-020-00335-6.

[8] Zhang, N., & Wang, Z. (2017). Review of soil thermal conductivity and predictive models. International Journal of Thermal Sciences, 117, 172–183. doi:10.1016/j.ijthermalsci.2017.03.013.

[9] Gupta, S., & Kumar, S. (2023). A state-of-the-art review of the deep soil mixing technique for ground improvement. Innovative Infrastructure Solutions, 8(4), 129. doi:10.1007/s41062-023-01098-6.

[10] Huang, Y., & Wang, L. (2016). Experimental studies on nanomaterials for soil improvement: a review. Environmental Earth Sciences, 75(6), 1–10. doi:10.1007/s12665-015-5118-8.

[11] Onyelowe, K. C. (2019). Review on the role of solid waste materials in soft soils reengineering. Materials Science for Energy Technologies, 2(1), 46–51. doi:10.1016/j.mset.2018.10.004.

[12] Shinde, B., Sangale, A., Pranita, M., Sanagle, J., & Roham, C. (2024). Utilization of waste materials for soil stabilization: A comprehensive review. Progress in Engineering Science, 1(2–3), 100009. doi:10.1016/j.pes.2024.100009.

[13] Ahmad, A., Sutanto, M. H., Harahap, I. S. H., Al-Bared, M. A. M., & Khan, M. A. (2020). Feasibility of Demolished Concrete and Scraped Tires in Peat Stabilization - A Review on the Sustainable approach in Stabilization. 2020 2nd International Sustainability and Resilience Conference: Technology and Innovation in Building Designs, 1–5. doi:10.1109/IEEECONF51154.2020.9319953.

[14] Shaheen, S. M., Hooda, P. S., & Tsadilas, C. D. (2014). Opportunities and challenges in the use of coal fly ash for soil improvements - A review. Journal of Environmental Management, 145, 249–267. doi:10.1016/j.jenvman.2014.07.005.

[15] Iravanian, A., & Haider, A. B. (2020). Soil Stabilization Using Waste Plastic Bottles Fibers: A Review Paper. IOP Conference Series: Earth and Environmental Science, 614(1), 12082. doi:10.1088/1755-1315/614/1/012082.

[16] Kazmi, D., Williams, D. J., & Serati, M. (2020). Waste glass in civil engineering applications—A review. International Journal of Applied Ceramic Technology, 17(2), 529–554. doi:10.1111/ijac.13434.

[17] Rai, A. K., Singh, G., & Tiwari, A. K. (2020). Comparative study of soil stabilization with glass powder, plastic and e-waste: A review. Materials Today: Proceedings, 32, 771–776. doi:10.1016/j.matpr.2020.03.570.

[18] Mistry, M. K., Shukla, S. J., & Solanki, C. H. (2021). Reuse of waste tyre products as a soil reinforcing material: a critical review. Environmental Science and Pollution Research, 28(20), 24940–24971. doi:10.1007/s11356-021-13522-4.

[19] Sotayo, A., Green, S., & Turvey, G. (2015). Carpet recycling: A review of recycled carpets for structural composites. Environmental Technology & Innovation, 3, 97–107. doi:10.1016/j.eti.2015.02.004.

[20] Wang, Y. (1999). Utilization of recycled carpet waste fibers for reinforcement of concrete and soil. Polymer-Plastics Technology and Engineering, 38(3), 533–546. doi:10.1080/03602559909351598.

[21] Ghiassian, H., Poorebrahim, G., & Gray, D. H. (2004). Soil reinforcement with recycled carpet wastes. Waste Management & Research, 22(2), 108–114. doi:10.1177/0734242X04043938.

[22] Miraftab, M., & Lickfold, A. (2008). Utilization of carpet waste in reinforcement of substandard soils. Journal of Industrial Textiles, 38(2), 167–174. doi:10.1177/1528083708091064.

[23] Shahnazari Habib, Ghiasian H., Nourzad A., Shafiei A., Tabarsa A.R.*, J. R. (2009). Shear Modulus of Silty Sand Reinforced by Carpet Waste Strips. Journal of Seismology and Earthquake Engineering, 11(3), 133-142. https://www.jsee.ir/article_240594.html

[24] Mirzababaei, M., Miraftab, M., Mohamed, M., & McMahon, P. (2013). Unconfined Compression Strength of Reinforced Clays with Carpet Waste Fibers. Journal of Geotechnical and Geoenvironmental Engineering, 139(3), 483–493. doi:10.1061/(asce)gt.1943-5606.0000792.

[25] Mirzababaei, M., Miraftab, M., Mohamed, M., & McMahon, P. (2013). Impact of Carpet Waste Fibre Addition on Swelling Properties of Compacted Clays. Geotechnical and Geological Engineering, 31(1), 173–182. doi:10.1007/s10706-012-9578-2.

[26] Choobbasti, A. J., Samakoosh, M. A., & Kutanaei, S. S. (2019). Mechanical properties soil stabilized with nano calcium carbonate and reinforced with carpet waste fibers. Construction and Building Materials, 211, 1094–1104. doi:10.1016/j.conbuildmat.2019.03.306.

[27] Eshghi, P., & Shalkoohy, A. J. (2022). Laboratory evaluation of the effect of polymer carpet waste on geotechnical properties of Bandar Anzali sandy soil. Iranian Journal of Engineering Geology, 15(1), 131–134.

[28] Eshghi, P., Niri, H. G., & Pourdada, A. (2025). Assessing the impact of recycled carpet waste (RCW) on unconfined compressive strength (UCS) and ultrasonic pulse velocity (UPV) in cement-stabilized sandy soil: an experimental study. Journal of Building Pathology and Rehabilitation, 10(1), 1–13. doi:10.1007/s41024-025-00577-w.

[29] ASTM D422-63(2007). (2014). Standard Test Method for Particle-Size Analysis of Soils. ASTM International, Pennsylvania, United States. doi:10.1520/D0422-63R07.

[30] ASTM D2487-17e1. (2025). Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). ASTM International, Pennsylvania, United States. doi:10.1520/D2487-17E01.

[31] ASTM D854-14. (2023). Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

(Withdrawn 2023). ASTM International, Pennsylvania, United States. doi:10.1520/D0854-14.

[32] ASTM D4318-17e1. (2018). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, Pennsylvania, United States. doi:10.1520/D4318-17E01.

[33] ASTM D698-12e2. (2021). Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft$^3$ (600 kN-m/m$^3$)). ASTM International, Pennsylvania, United States. doi:10.1520/D0698-12E02.

[34] ASTM D2166/D2166M-13. (2016). Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. ASTM International, Pennsylvania, United States. doi:10.1520/D2166_D2166M-13.

[35] ASTM D3080/D3080M-11. (2020). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions (Withdrawn 2020). doi:10.1520/D3080_D3080M-11.

[36] Sim, J., & Prabhu, V. (2018). The life cycle assessment of energy and carbon emissions on wool and nylon carpets in the United States. Journal of Cleaner Production, 170, 1231–1243. doi:10.1016/j.jclepro.2017.09.203.

[37] Simon, A., Tripathi, A., Surehali, S., & Neithalath, N. (2023). Carpet fiber recycling in regular-use concrete mixtures and associated life cycle analysis. Waste Management Bulletin, 1(3), 103–114. doi:10.1016/j.wmb.2023.07.005.

[38] Ryłko-Polak, I., Komala, W., & Białowiec, A. (2022). The Reuse of Biomass and Industrial Waste in Biocomposite Construction Materials for Decreasing Natural Resource Use and Mitigating the Environmental Impact of the Construction Industry: A Review. Materials, 15(12), 4078. doi:10.3390/ma15124078.

[39] Maitlo, G., Ali, I., Maitlo, H. A., Ali, S., Unar, I. N., Ahmad, M. B., Bhutto, D. K., Karmani, R. K., Naich, S. ur R., Sajjad, R. U., Ali, S., & Afridi, M. N. (2022). Plastic Waste Recycling, Applications, and Future Prospects for a Sustainable Environment. Sustainability (Switzerland), 14(18), 11637. doi:10.3390/su141811637.

[40] Parvaresh, F., & Amini, M. H. (2024). Application of circular economy for sustainable waste management in the carpet industry. International Journal of Research in Industrial Engineering, 13(2), 188–206. doi:10.22105/riej.2024.426147.1405.

[41] Zaman, A. U. (2016). A comprehensive study of the environmental and economic benefits of resource recovery from global waste management systems. Journal of Cleaner Production, 124, 41–50. doi:10.1016/j.jclepro.2016.02.086.

[42] Peng, X., Jiang, Y., Chen, Z., Osman, A. I., Farghali, M., Rooney, D. W., & Yap, P. S. (2023). Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: a review. Environmental Chemistry Letters, 21(2), 765–801. doi:10.1007/s10311-022-01551-5.

[43] Chen, L., Yang, M., Chen, Z., Xie, Z., Huang, L., Osman, A. I., Farghali, M., Sandanayake, M., Liu, E., Ahn, Y. H., Al-Muhtaseb, A. H., Rooney, D. W., & Yap, P.-S. (2024). Conversion of waste into sustainable construction materials: A review of recent developments and prospects. Materials Today Sustainability, 27, 100930. doi:10.1016/j.mtsust.2024.100930.

[44] Wang, M., He, X., & Yang, K. (2023). Mechanical Properties and Damage Characteristics of Coal-Based Solid Waste Paste Filling Materials with Different Moisture Content. Sustainability (Switzerland), 15(2), 1523. doi:10.3390/su15021523.

[45] Abdulkareem, O. A., Mustafa Al Bakri, A. M., Kamarudin, H., Khairul Nizar, I., & Saif, A. A. (2014). Effects of elevated temperatures on the thermal behavior and mechanical performance of fly ash geopolymer paste, mortar and lightweight concrete. Construction and Building Materials, 50, 377–387. doi:10.1016/j.conbuildmat.2013.09.047.

[46] Xuan, W., Chen, X., Yang, G., Dai, F., & Chen, Y. (2018). Impact behavior and microstructure of cement mortar incorporating waste carpet fibers after exposure to high temperatures. Journal of Cleaner Production, 187, 222–236. doi:10.1016/j.jclepro.2018.03.183.

[47] Mohammadhosseini, H., Lim, N. H. A. S., Sam, A. R. M., & Samadi, M. (2018). Effects of Elevated Temperatures on Residual Properties of Concrete Reinforced with Waste Polypropylene Carpet Fibres. Arabian Journal for Science and Engineering, 43(4), 1673–1686. doi:10.1007/s13369-017-2681-1.