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MERMER TOZU İLE STABİLİZE EDİLMİŞ KİLLERİN MEKANİK ÖZELLİKLERİ

MECHANICAL PROPERTIES OF CLAYS STABILIZED WITH MARBLE DUST

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ÖZET

Atık malzemelerin toprak stabilizasyonunda kullanımı giderek yaygınlaşmıştır ve atık geri dönüşüm çabalarına ve çevresel kirliliğin azaltılmasına katkıda bulunmaktadır. Bu çalışma, mermer tozunun toprak stabilizasyonunda avantajlı uygulamalarını keşfetmeyi amaçlamaktadır. Mermer tozunun 5-20% oranlarında katıldığı kil toprak karışımlarında testler yapılmıştır. Mermer tozunun etkisini, yanı sıra iyileşme süresi ve kalıp su içeriği gibi çeşitli geoteknik parametreler olan serbest basınç dayanımı (qu), donma-çözülme direnci ve kayma dayanımı değerlendirilmiştir. Mermer tozunun eklenmesi, donma-çözülme döngüleri sonrasında tane kaybını azaltırken, artmış bir serbest basınç dayanımı ve donma-çözülme direncine yol açmıştır. Uzun iyileşme süresi, artan karışım dayanımı ve azalan tane kaybı ile ilişkilidir. Sonuç olarak, bu çalışma, mermer tozunun katılmasıyla kil toprağın jeoteknik özelliklerinin iyileştirildiğini göstermektedir. Mermer tozu ile iyileştirme, atık malzemenin kullanılmasını sağlayarak çevre dostu bir yöntemdir ve doğal kaynakların kullanımını azaltır. Ayrıca, yapıların güvenliği ve dayanıklılığını artırarak yapıların ömrüne katkıda bulunur. Bu yöntem, çeşitli endüstriyel ve altyapı projelerinde yaygın olarak kullanılabilir ve maliyet etkin bir çözüm sunar.

Anahtar Kelimeler: kil, mermer tozu, mekanik özellikler, zemin iyileştirme

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ABSTRACT

The utilization of waste materials for soil stabilization has become increasingly prevalent, contributing to waste recycling efforts and environmental pollution reduction. This study aims to explore the advantageous application of marble dust in soil stabilization. Tests were conducted on clay soil blends amended with marble dust (5-20%). Various geotechnical parameters such as unconfined compressive strength (qu), freeze-thaw resistance and shear strength, were evaluated to assess the impact of marble dust, as well as curing duration and molding water content. The addition of marble dust resulted in enhanced unconfined compressive strength, and freeze-thaw resistance while reducing grain loss post-freeze-thaw cycles. Prolonged curing duration correlated with increased mixture strength and decreased grain loss. Consequently, this investigation demonstrates that incorporating marble dust improves the geotechnical characteristics of clay soil. Remediation with marble powder is an environmentally friendly method because it enables the utilization of waste material and reduces the use of natural resources. Additionally, it contributes to the safety and longevity of structures by increasing the durability of clay soils. This method can be widely used in various industrial and infrastructure projects and provides a cost-effective solution.

Keywords: clay, marble dust, mechanical properties, soil stabiziation

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1. INTRODUCTION

Soils that exhibit significant variations in both volume and water content are known as expansive soils. When water is added, it swells; when it evaporates, it shrinks. The presence of extremely reactive clay minerals like smectite and montmorillonite is the cause of the swelling behavior. Light constructions constructed on this soil may move unevenly and fracture as a result of these variations in soil volume, which include swelling and shrinking. Cracking and breaking of light building foundations, pavements, roads, slab-on-grade members, channel linings, irrigation systems, gas pipelines, water pipelines, and sewer lines are examples of issues caused by expansive soil. The cost of damage was assessed by earlier studies because the damage caused by earthquakes, hurricanes, tornadoes, and floods combined is more than twice that of this soil [1, 2].

Solid wastes are defined as wastes that are naturally solid and stay where they were removed. They can be divided into four categories according to where they were produced: (i) Fly ash, cement kiln dust, silica fume, copper slag, red mud, phosphogypsum, granulated blast furnace slag, ceramic dust, brick dust, and polyvinyl waste are examples of industrial solid wastes; (ii) home solid wastes include incinerator ash, waste tires, waste building and demolition materials, eggshell powder, grain storage dust, glass cullet), (iii) mineral waste materials (quarry dust, marble dust, baryte powder, pyroclastic dust, limestone dust, granite dust, and mine tailings), and (iv) agricultural solid wastes (rice husk, bagasse ash, ground nutshell, olive cake residue, and wheat husk). Environmental damage may result from discarding waste products into the environment. Because of this, recycling waste materials into sustainable civil engineering applications is crucial since there is a global need to find new ways to preserve natural resources and lessen the quantity of waste that ends up in landfills. To reduce waste's detrimental impacts on the environment and its economic contribution, recycling waste has emerged as a research issue. A large number of them fill up landfill space after being thrown in. Several nations are working to recycle and repurpose solid waste in applied science applications, such as the construction of concrete mixtures, which in turn leads to the production of bricks, decorative plastic coatings, ceramic tiles, cement, lime, activated carbonate, hollow blocks, wall tiles, and materials for filling embankments [3–7]. One method to enhance the engineering qualities of problematic soils and make them appropriate for building is stabilization using solid wastes [8–18].

Major engineering problems have emerged in the buildings erected on top of it. Therefore, the focus had to be on identifying appropriate techniques to use the local waste material to improve the quality of this soil. There have been some recent attempts to investigate the viability of recycling granite and marble powders for soil stabilization. Many studies have recommended marble dust powder, which contains a significant amount of lime, for extensive soil improvement. Several research [19–25] investigated how adding marble dust in varying quantities could improve expansive soils. They demonstrated the beneficial use of marble dust either by itself or in conjunction with waste stabilizers and chemicals like fly ash, cement, and lime to enhance the various characteristics of expansive soils.

Additionally, marble dust's larger particles and greater shear strength from its high internal friction can help expansive soil become more workable, flexible, and strong.

The effect of marble dust with different percentages ranging from 0% to 10% by weight of dry soil has been studied by Singh and Yadav [26]. The results of the test showed that the consistency limit of the samples containing marble dust varied significantly. The liquid limit dropped to 52.01% from 67.49%. The plasticity index dropped to 10.43% from 37.16%. Additionally, the differential free swell dropped from 60% to 14%, indicating a significant alteration in the behavior of swelling. The effects of marble powder and rice husk ash on expanding soil were investigated by Sabat and Nanda [27]. The results showed that the California bearing ratio and unconfined compression strength values increased with the addition of marble powder and rice husk to the soil. According to Saygılı [28], adding marble dust improves the parameters related to shear strength and decreases the expansive soil's capacity for swell. Marble dust's high calcium concentration also played a significant part in the hydration process. Additionally, adding marble dust to the clay samples will lower the cost of building on difficult soils and find new uses for waste marble dust, hence reducing environmental pollution. In addition, conserving resources and the economy will benefit greatly from the use of waste marble dust in troublesome areas. The impact of dolomitic marble powder (DMP) and calcite marble powder (CMP) on the geotechnical characteristics of cohesive soils was investigated by Sivrikaya et al. [29]. One-dimensional consolidation tests, Atterberg limits, linear shrinkage, expansion index, and treated samples containing 5, 10, 20, 30, and 50% waste CMP and DMP were performed on both untreated and treated samples. The findings of the laboratory tests demonstrated that the waste marble dusts were effective in stabilizing the soil by lowering the plasticity indices of the high-plasticity clay (CH) and high-plasticity silt (MH) samples, respectively, from 49 to 26% and 21 to 9%. The impact of marble dust on enhancing the geotechnical behavior of expanding soil was examined by Jain et al. [30]. A wide range of marble dust contents, up to 80%, has been used in comprehensive geotechnical tests (consistency limits, free swell index, compaction characteristics, one-dimensional consolidation tests, and unconfined compressive strength) to adjust the content of marble dust for soil stabilization and to understand its interactive behavior with soil. The primary findings showed that marble dust can be used to improve soil flexibility and regulate swell behavior.

This study aims to explore the advantageous application of marble dust in soil stabilization. Various tests were conducted on blends of clay soil and marble dust (5–20%). Several geotechnical parameters such as molding water content, curing duration, and the influence of marble dust were evaluated. Key assessments included unconfined compressive strength (qu), freeze-thaw durability, and shear strength.

2. MATERIALS AND METHODS

2.1 Soil

The clay soil utilized in the study was collected from Kyrenia- Northern Cyprus. Figure 1 shows the location where the soil was taken. Sieve and hydrometer analyses were used to identify the soil's index characteristics. The findings of the hydrometer and sieve analyses carried out in compliance with ASTM D422-63 and ASTM D140-17 standards [31] are displayed in Figure 2. The soil's composition was found to be 91.5% clay and 8.5% silt. According to Unified Soil Classification System [32], the soil type is CH. Table 1 displays the physical characteristics of the soil. Table 2 provides the soil's chemical composition.

Figure 1: The location of the soil.

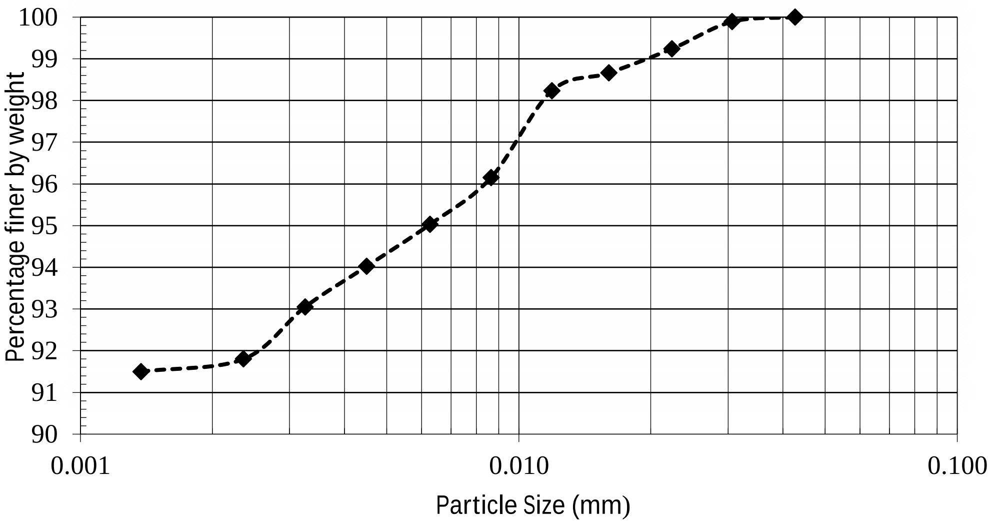

Figure 2: Particle size distribution of soil.

Table 1: Physical properties of soil.

Specific Gravity, (G_s)	2.63	ASTM D 854
Liquid Limit, (%)	84.5	ASTM D 4318
Plastic Limit, (%)	39.2	ASTM D 4318
Plasticity Index	45.3	ASTM D 4318
Optimum Water Content, W_{opt} (%)	23.5	ASTM D 698
Maximum Dry Density, (g/cm^3)	1.40	ASTM D 698

Table 2: Chemical composition of the soil.

Chemical Composition	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	P_2O_5	Sulphur as SO_3
Ratio (%)	52.4	10.7	13.0	5.01	0.16	1.04	6.74	0.23	0.07	0.61

2.2 Marble Dust

The marble dust used in the investigation was obtained from the Haspolat-Nicosia. Furthermore, the chemical composition of the marble dust used in the tests is given in Table 3. Various proportions of marble dust were employed as mix design parameters in this study. Marble dust concentrations of 5, 10, 15, and 20 % by weight were examined in earlier studies and left to cure for 7 and 28 days [33,35].

Table 3: Chemical composition of the marble dust.

Chemical Composition	SiO_2	Al_2O_3	CaO	MgO	SO_3	K_2O	MnO	TiO_2	Fe_2O_3	LOI
Ratio (%)	3.96	0.51	72.26	0.27	-	0.08	-	0.17	1.19	21.56

2.3 Lime

The lime used in the investigation was obtained from the Haspolat. The chemical composition of the lime used in the tests is given in Table 4. Similar in the previous research, 3% lime was also added to ensure clay soil stabilization and increase pozzolanic activity.

Table 4: Chemical composition of the lime.

Chemical Composition	SiO_2	Al_2O_3	CaO	MgO	SO_3	Fe_2O_3	LOI
Ratio (%)	0.90	0.05	54.53	0.18	0.04	0.15	43.68

2.4 Sample Preparation

Different marble dust ratios were used as mix design factors in this experiment. 5, 10, 15, and 20 % marble dust were used. An additional 3% of lime was added to the pozzolanic activity to ensure the stabilization of clay soil. 5, 10, 15, and 20 wt.% marble dust was blended, and the soil was treated for a maximum of 7 and 28 days according to standards.

Samples are subjected to compression, freeze-thaw resistance and direct shear testing. Samples were preserved in the curing room for 7 and 28 days. At the end of each curing day, 3 samples of each mix were subjected to experimental testing. The mix ratios are listed in Table 5.

Table 5: Mix proportions.

Mix	Classification
Soil	S
Soil-3%Lime	S-L
Soil-3%Lime-5%Marble Dust	S-L-5MD
Soil-3%Lime-10%Marble Dust	S-L-10MD
Soil-3%Lime-15%Marble Dust	S-L-15MD
Soil-3%Lime-20%Marble Dust	S-L-20MD

3. RESULTS AND DISCUSSION

3.1 Freeze-Thaw Resistance Test Results

This study used the closed-system FT cycle for freeze-thaw tests. This approach can be used to illustrate the requirement that the in-situ moisture content should not vary significantly throughout the year. Meanwhile, frost penetration occurs at a far higher rate than moisture transportation due to clay's limited permeability. It makes sense to use the closed FT type in this case.

The automatic refrigerator with internal temperature sensors (accuracy ±0.5°C) was used for the full FT cycle tests. To stop moisture exchange, a preservative film was placed over the prepared specimens. The samples were first frozen for 12 hours at -18°C, and then they were thawed for another 12 hours at 20°C. One FT cycle incorporated the two procedures, and so forth. In this study, specimens were subjected to freeze-thaw (FT) cycles numbered as follows: 0, 2, 5, and 10. Subsequently, the specimens were tested under compression after completing the designated FT cycles.

3.2 Influence of the Freeze-Thaw Cycles on the Unconfined Compressive Strength Test Results

Figure 3 displays samples used for the unconfined compressive strength test. All mix groups were evaluated for unconfined compressive strength according to ASTM D2166 [33], and the outcomes are depicted in Figure 4. The highest strength was observed in the sample containing 15% marble dust (MD) and 3% lime. Incorporating up to 15% marble dust enhanced the compressive strength. This improvement can be attributed to the interaction between marble dust, lime, and the clay minerals. Improved gradation likely contributed to the increased strength of MD-stabilized expansive soil, while reduced porosity and enhanced inter-particle interaction between soil and MD contributed to the densification of the soil matrix.

Additionally, the fine powder acts to fill pores. As mentioned earlier, this powder serves as an inert additive resembling ultrafine aggregates used for space filling. The correlation between unconfined compressive strength (UCS) and the varying percentages of marble dust (MD) added to the expansive soil is depicted in Figure 4. Across all treated samples tested over seven and twenty-eight-day curing periods, a consistent linear increase in UCS values with higher MD content is evident.

Figure 3: Unconfined compressive strength samples.

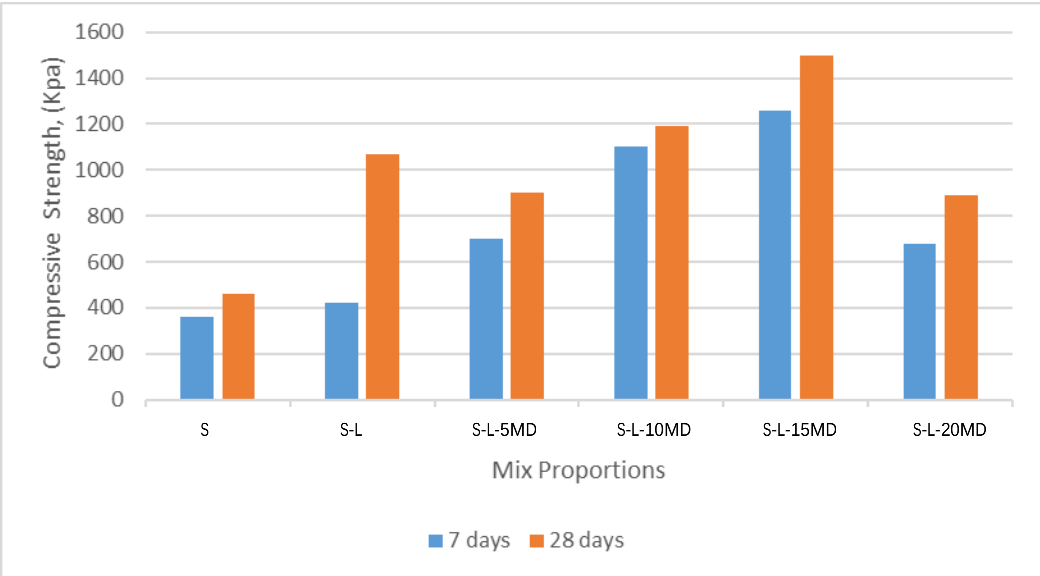

Figure 4: Unconfined compressive strength test results for mix proportions.

Additionally, the rate of rise is higher up to 15% MD; it thereafter decreases. Jalal et al. [34] observed a similar improvement in UCS of expansive soil stabilized with MD after conducting an experimental investigation in which various percentages (0%, 2%, 4%, 6%, 8%, and 10%) of marble industry waste (MIW) were used to stabilize expansive soil. The findings showed that MIW is a useful additive for raising the tested clay soils' unconfined compressive strength and that 10% is the ideal MIW concentration. They ascribed this to the soil-lime reaction, and at 3 and 7 days, respectively, there is a 300% and 154% increase in the unconfined compressive strength.

3.3 Direct Shear Test Results

By ASTM C496 [35], six different mix designs were taken into consideration when executing the direct shear test. Samples for the shear strength test and results are shown in Figure 5 and Figure 6, respectively. As in unconfined compressive strength test results, the mixture containing 15% marble dust caused the maximum shear strength.

Figure 5: Direct shear strength samples.

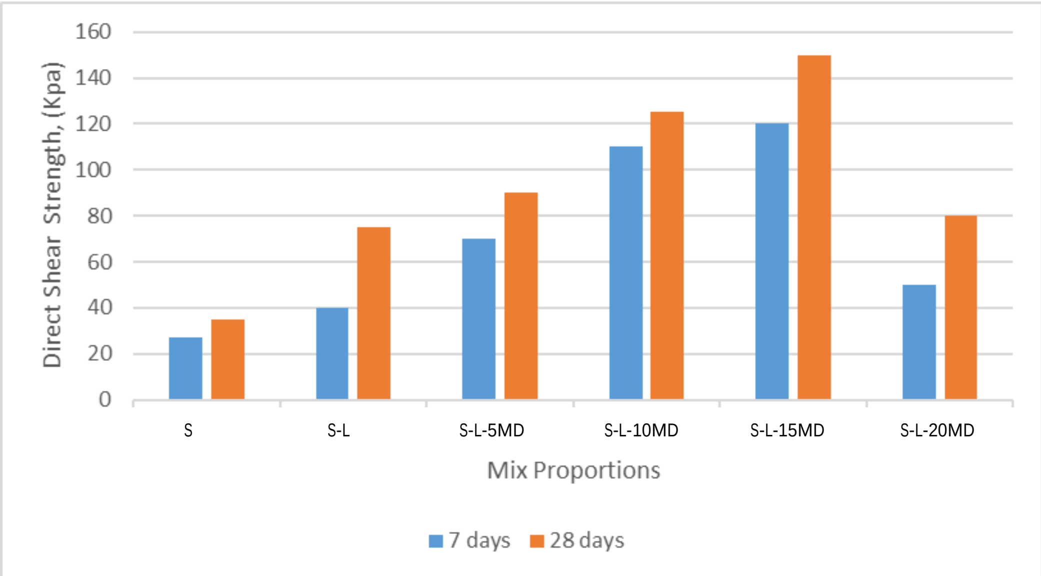

Figure 6: Direct shear strength test results for mix proportions.

S-L-15MD combination ratio yielded a result that was roughly 328% of the control sample. The augmentation in MD strength improved gradation can be linked to stabilized expansive soil, whereas decreased porosity and improved inter-particle interaction between the soil and MD are responsible for the soil matrix's increased compactness. Moreover, the way that fine powder fills pores.

3.4 Conclusions and Recommendations

The main objective of improvements to the soil is to improve the mechanical performance and durability of the soil. To properly remediate problem soil, several considerations must be made, such as the type of soil, treatment depth, application methods, phases and patterns of treatment, expected level of remediation, costs, and environmental impact. These factors are all included in the planning and assessment process to determine the level of improvement that is required.

The research has led to the recommendation of an effective method for stabilizing soft high plastic clay soil: a lime and marble dust mixture that is also environmentally beneficial. One of the limitations of the study is the use of marble dust mixed with 3% lime for stabilizing extremely flexible clay soil. It was found that the results of related research showed similar behavior. The results of the research and recommendations are summarized as follows:

1. The addition of marble dust, and lime increased the unconfined compressive and direct shear strengths of problematic soil samples. Comparing the optimum design mixture to the control samples, an increase of 226% in compressive strength and 328% in direct shear strength was observed. While decreasing grain loss following freeze-thaw cycles, the addition of marble dust increased unconfined compressive strength and freeze-thaw resistance.
2. Because of the action of fine powder filling pores, a rise in unconfined compressive and direct shear strengths has been noted as the curing period increases. It has been shown that the inclusion of marble dust reduces pore structures. In addition, it was found that the results of related research showed similar behavior [34].
3. Research on the permeability characteristics of mixtures is required to assess the marble dust effect.

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LIST OF ABBREVATIONS

SYMBOL	EXPLANATION
S	Soil
L	Lime
MD	Marble Dust