# The effect of waste material mixtures on the mechanical properties of clayey soils

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***Abstract*: Soil is one of the most important and primary media for any construction work. The strength and durability of any structure depends on the strength properties of soil. Nowadays, scarcity of good land for construction which is one of important problems for engineers using land increases demand for unsuitable soils. When the mechanical qualities of unsuitable soils are lower than those required, reinforcing can be an option to improve performance, notably in enhancing its strength. Use of waste material is alternative method as low-cost material for soil reinforcing applications. In this study, two waste material were used together at different content. The waste material mixtures obtained from marble dust and scrap tire rubber were used for the stabilization of clayey soil. Unstabilized and stabilized clayey soil samples subjected unconfined compressive strength tests to investigate the waste material mixtures on the strength properties of clayey soils. As a result, it is concluded that the waste material mixtures obtained from marble dust and scrap tire rubber can be successfully used for the reinforce of clayey soils in the geotechnical applications.**

***Keywords*— Clayey soil, waste material, marble dust, scrap tire rubber, soil stabilization**

## I. INTRODUCTION

The soil is one of the most important and primary media for any construction work. The strength and durability of any structure depends on the strength properties of soil (Nath et al., 2017). Clayey soil (CS) is generally classified as expansive soils and these soils are known to cause severe damage to structures resting on them. However, these soils are very important in geology, construction, and for environmental applications, due to their wide usage as impermeable and containment barriers in landfill areas and other environmentally related applications (Erguler and Ulusay, 2003; Harvey and Murray, 1997; Kayabali, 1997; Keith and Murray 1994; Murray, 2000; Sabtan, 2005; Kalkan and Akbulut, 2004; Kalkan et al., 2019; Indiramma et al., 2020).

Soil stabilization is the permanent physical and chemical alteration of soils to enhance their physical properties. In its broadest senses, it includes compaction, pre-consolidation, drainage, and many such processes. However, the term stabilization is generally restricted to the process which alters the soil material itself for improvement of its properties. It is the collective term for any physical, chemical or biological method or combination of such methods employed to improve certain properties of natural soil to make it serve for intended engineering purposes. Improvements include increasing the dry unit weight, bearing capabilities, volume changes, the performance of insitu subsoils, sands and other waste materials in order to strengthen road surfaces, and other geotechnical applications. It is required when the soil available for construction is not suitable for the intended purpose and mainly aimed at increasing resistance to softening by water through bonding the soil particles together, water proofing the particles, or combination of the two (Little et al., 1987; Winterkorn, 1991; Makusa, 2012; Firoozi et al., 2017; Arora, 2019; Mekonnen et al., 2020).

The improvement of soil properties is necessary to solve many engineering problems. Soil improvement techniques can be classified in various ways, for example, mechanical, chemical, and physical stabilization (Ingles and Metcalf, 1977; Lambe and Whitman, 1979; Naeini and Mahdavi, 2009). In the mechanical stabilization, the soil density is increased by the application of mechanical forces in the case of surface layer compaction. Chemical stabilization includes incorporation of additives such as natural soils, industrial by-products or waste materials, and cementitious and other chemicals. Physical stabilization includes changing the physical conditions of a soil by means of heating or freezing (Naeini and Sadjadi, 2008; Arab, 2019; Yarbaşı and Kalkan, 2019).

Several stabilization methods are available for stabilizing expansive soils. These methods include stabilization with chemical additives, rewetting, soil replacement, compaction control, moisture control, surcharge loading, and thermal methods (Chen, 1988; Nelson and Miller, 1992; Steinberg, 1998). All these methods may have the disadvantages of being ineffective and expensive. Therefore, new methods are still being researched to increase the strength properties and to reduce the swell behaviors of expansive soils (Puppala and Musenda, 2002). Many investigators have experienced on natural, fabricated, and by-product materials to use them as stabilizers for the modification of CSs (Aitcin et al., 1984; Sandra and Jeffrey, 1992; Kayabali, 1997; Asavasipit et al., 2001; Prabakar et al., 2004; Kalkan and Akbulut, 2004; Cetin et al., 2006; Kalkan, 2006; Akbulut et al., 2007; Kalkan3 2020; Kalkan et al., 2020; Yarbaşı and Kalkan, 2020).

In this study the mixtures of marble dust (MD) and scrap tire rubber (STR) as alternative low-cost stabilizer material. The main objectives of this research are to investigate the utilizability of waste material mixtures (WMMs) such as MD and STR for stabilization of CSs in geotechnical applications. Also, to test mechanical performance of CSs stabilized with WMMs. To accomplish these objectives, natural CS samples were stabilized by using different contents of WMMs. The stabilized CSs obtained by the compaction process were subjected the unconfined compression tests and the results obtained were compared with that of natural CSs.

## II. MATERIAL AND METHOD

### *2.1. Materials*

The CS has been supplied from the clay deposits of Oltu Oligocene sedimentary basin, Erzurum, Northeast Turkey. This soil has placed in plastic bags and transported to a soil mechanics laboratory. The CS is over-consolidated and it has clayey-rock characteristics in natural conditions. It is defined as a high plasticity soil (CH) according to the Unified Soil Classification System (Kalkan, 2003; Kalkan and Bayraktutan, 2008). The chemical composition and engineering properties of the CS are summarized Tables 1, and 2, respectively.

The waste MD was obtained in wet form as an industrial by-product directly from the deposits of marble factories, which forms during the sawing, shaping and polishing processes of marble in Afyon (Turkey) region. The wet marble sludge was dried up prior to the preparation of the samples. The dried material was sieved through a 0.25 mm sieve to remove the coarse particle (Kalkan and Yarbaşı, 2013). The chemical composition and physical properties of the MD used in this study are given in Table 1 and 2, respectively.

The STR fibers were supplied by local recapping truck tires producer in Erzurum, Northeast Turkey. When the tread on truck tires down, it is more economical to stave off the old tread and replace it than to purchase brand new tires. The tire is shaved off into 150 mm and smaller strips using a sharp rotating disc. These strips are then ground into scrap rubber (Pierce and Blackwell, 2003; Akbulut et al., 2007). The rubber fibers used in this study have three different lengths such as 1.18 mm, 2 mm and 3.15 mm. The engineering properties of STR were given in the Table 3.

Table 1. Chemical properties of CS and MD

| Components | CS | MD |
|---|---|---|
| $SiO_2$ | 46.83 | 0.36 |
| $Al_2O_3$ | 15.35 | 0.28 |
| $Fe_2O_3$ | 6.81 | 0.04 |
| CaO | 11.02 | 54.98 |
| MgO | 4.52 | 0.62 |
| $Na_2O_3$ | 0.92 | 0.03 |
| $K_2O$ | 1.23 | 0.07 |
| $TiO_2$ | 0.81 | |
| $SO_3$ | - | 0.06 |
| $CaO_2$ | - | 43.56 |

Table 2. Physical and mechanical properties of CS and MD

| Properties | CS | MD |
|---|---|---|
| Density, g $cm^{-3}$ | 2.63 | 2.75 |
| Sand (%) | 2 | - |
| Silty (%) | 66 | - |
| Clay (%) | 32 | - |
| Liquid limit ($L_L$, %) | 73 | - |
| Plastic limit ($P_L$, %) | 35 | - |
| Unit volume weight (g/$cm^3$) | 37 | - |
| Porosity (%) | - | 0.2 |

Table 3. Engineering properties of STR (Akbulut et al., 2007)

| Parameters | Value |
|---|---|
| Density (mg/$cm^3$) | 1.153-1.189 |
| Elastic modulus (MPa) | 1.97-22.96 |
| Tensile strength (MPa) | 28.1 |
| Extent at failure (%) | 44-55 |
| Softening temperature ($^o$C) | 175 |

### *2.2. Experimental Procedure*

The CS was dried in an oven at approximately 65 °C and then ground before using in the mixtures. First, the required amounts of CS and WMM were blended together under dry conditions. Then the CS-WMM mixtures were mixed with the required amount of water according to the optimum moisture content. The contents of WMM were selected as 5.5%, 6.0%, 7.0%, 10.5%, 11%, 12.0%, 15.5%, 16.0% and 17.0% by the total weight of stabilized samples. The proportion of dry weight of sand is considered as the percentage of fiber and denoted as below.

$$P_{WMM} = \frac{W_{WMM}}{W_{CS}} x100\% \qquad (1)$$

where PWMM is percentage of WMM, WWMM is of WMM and WCS is weight of dry CS.

For unconfined compression test, samples were prepared with static compaction method based on ASTM standards. Three-layered compaction was adopted to keep the uniformity of test samples with the 35 mm diameter and 70 mm height.

The unconfined compression tests were performed to obtain the unconfined compressive strength (UCS) values of tested samples were in accordance with ASTM D 2166. This test is widely used as a quick and economical method of obtaining the approximate UCS of the soils. The unconfined compression tests were carried out at the loading rate of 2.4mm/min until samples failed. The samples used experimental studies and the contents of all samples were summarized in the Table 4.

## III. RESULTS AND DISCUSSION

### *3.1. Effects of WMM on the UCS of CS*

The unconfined compression tests were performed to investigate the effect of WMM on the UCS values of the samples. The results obtained from these tests were illustrated on the Figs. 1-3. The test results showed that WMM improved the UCS values of natural CS samples. In the stabilization of the CS with WMM, both of the MD and STR play a significant role. Both the lengths and contents of the STR is important in the development of UCS. It was observed that the increase in the UCS continues up to 0.5% content and 1.18 mm length and then start the decrease. In other words, optimum improvement was obtained by the 0.5% and 1.18 mm of STR in the stabilization of CS with WMM. The same results were obtained from some experimental studies carried out in the past (Ranjan et. al., 1996; Prabakar and Sridhar, 2002; Akbulut et al., 2007; Zaimoglu, 2010; Hejazi et al., 2012; Kalkan, 2013; Muntohar et al., 2013; Lv and Zhou, 2019; Benziane et al., 2019). The MD plays an important role in the improvement of mechanical properties of CS. It was observed that the UCS values of stabilized CS samples with WMM significantly increase with the addition of MD content. It was noted in literature that the addition of additive changed the composition, mineralogy and particle size distribution of clayey soil (Gillot, 1968; Ola, 1978; Kalkan and Akbulut, 2004). An increase in MD content in the CS made more brittle than the natural one. Clay particles are surrounded by a diffuse hydrous layer which is modified by the ion exchange of calcium. The cation exchange reaction is greater between lime and clay minerals (Osula, 1991). This modifies the density of the electrical charge around the clay particles and attracts them closer to each other to form flocculation. This implies stronger attraction forces between layers and a stacking of a greater number of layers (Grim, 1962). These reactions change the clay texture, giving thicker particles, reducing plasticity and increasing the soil strength (Basma and Tuncer, 1991; Al-Mukhtar et al., 2012; Kalkan and Yarbaşı, 2013).

### *3.2. Effects of Curing Time on the UCS of CS*

The UCS increased with length of curing time was explained in terms of the action of cementing gel material produced following pozzolanic reactions which take place over a period of time (Thompson, 1968; Okagbue and Onyeobi, 1999; Kalkan, 2013; Kalkan and Yarbaşı, 2013). When WMM is introduced in CS treatment, age hardening behavior occurs. Consequently, the mechanical resistance increases with curing time (Okyay and Dias, 2010). Among the different variables affecting the UCS of CS stabilized with WMM, curing time is of major importance. Its effect on UCS is a function of time, temperature and relative humidity (Mitchell and Hooper, 1961; Bell, 1996; Kalkan, 2013).

Table 4. CS, MD and STR ratio of stabilized CS samples

| No | Sample | CS (%) | MD (%) | STR | | | Total (%) |
|---|---|---|---|---|---|---|---|
| | | | | 1.18 mm (%) | 2.00 mm (%) | 3.15 mm (%) | |
| 1 | MIX1 | 100.00 | - | - | - | - | 100 |
| 2 | MIX2 | 94.50 | 5 | 0.50 | - | - | 100 |
| 3 | MIX3 | 94.00 | 5 | 1.00 | - | - | 100 |
| 4 | MIX4 | 93.00 | 5 | 2.00 | - | - | 100 |
| 5 | MIX5 | 89.50 | 10 | 0.50 | - | - | 100 |
| 6 | MIX6 | 89.00 | 10 | 1.00 | - | - | 100 |
| 7 | MIX7 | 88.00 | 10 | 2.00 | - | - | 100 |
| 8 | MIX8 | 84.50 | 15 | 0.50 | - | - | 100 |
| 9 | MIX9 | 84.00 | 15 | 1.00 | - | - | 100 |
| 10 | MIX10 | 83.00 | 15 | 2.00 | - | - | 100 |
| 11 | MIX11 | 94.50 | 5 | - | 0.50 | - | 100 |
| 12 | MIX12 | 94.00 | 5 | - | 1.00 | - | 100 |
| 13 | MIX13 | 93.00 | 5 | - | 2.00 | - | 100 |
| 14 | MIX14 | 89.50 | 10 | - | 0.50 | - | 100 |
| 15 | MIX15 | 89.00 | 10 | - | 1.00 | - | 100 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 16 | MIX16 | 88.00 | 10 | - | 2.00 | - | 100 |
| 17 | MIX17 | 84.50 | 15 | - | 0.50 | - | 100 |
| 18 | MIX18 | 84.00 | 15 | - | 1.00 | - | 100 |
| 19 | MIX19 | 83.00 | 15 | - | 2.00 | - | 100 |
| 20 | MIX20 | 94.50 | 5 | - | - | 0.50 | 100 |
| 21 | MIX21 | 94.00 | 5 | - | - | 1.00 | 100 |
| 22 | MIX22 | 93.00 | 5 | - | - | 2.00 | 100 |
| 23 | MIX23 | 89.50 | 10 | - | - | 0.50 | 100 |
| 24 | MIX24 | 89.00 | 10 | - | - | 1.00 | 100 |
| 25 | MIX25 | 88.00 | 10 | - | - | 2.00 | 100 |
| 26 | MIX26 | 84.50 | 15 | - | - | 0.50 | 100 |
| 27 | MIX27 | 84.00 | 15 | - | - | 1.00 | 100 |
| 28 | MIX28 | 83.00 | 15 | - | - | 2.00 | 100 |

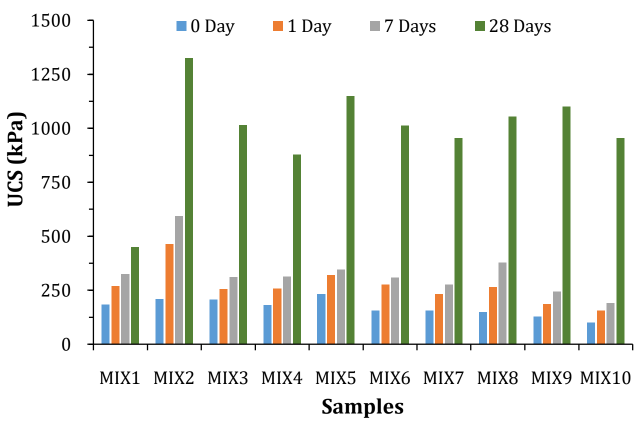


Fig. 1. The effects of WMM on the UCS values of natural CS

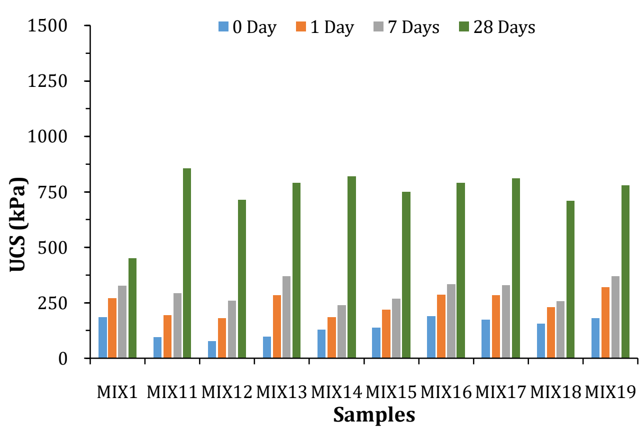


Fig. 2. The effects of WMM on the UCS values of natural CS

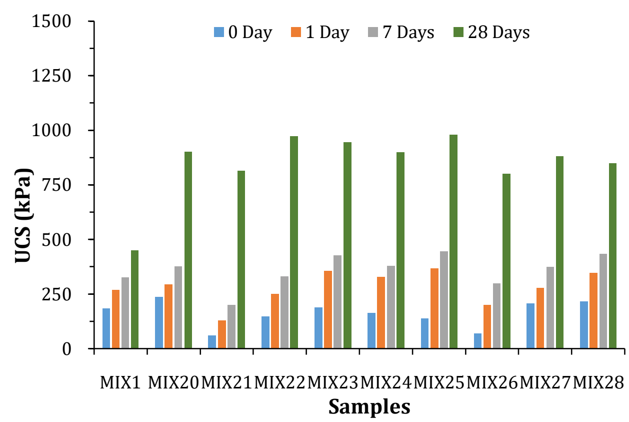


Fig. 3. The effects of WMM on the UCS values of natural CS

## IV. CONCLUSIONS

In this study, the effects of WMM on the UCS values of CS samples stabilized with WMM was investigated. According to the test results, WMM improved the unconfined compressive strength of CS. Also, the curing time play a significant role on the improvement of mechanical properties of WMM-stabilized CS. As a result, the WMM can be used as an alternative waste material for the stabilization of the CS in the geotechnical applications.

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