UTILIZATION OF MARBLE DUST TO IMPROVE THE GEOMECHANICAL PROPERTIES OF A FINE GRAINED SOIL.

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Abstract

The current study aims to explore the potential of marble dust (MD) to improve the geotechnical features of Karewa soil. For this purpose, a comprehensive exper- imental programme was carried out, in which different percentages of marble dust (10%, 20%, 30%, 40% and 50%) by dry weight of soil were added to assess its impact on its geomechanical properties. The strength gain was evaluated by conducting direct shear tests (DST) and unconfined compressive strength tests (UCS) after curing of samples for 7, 14 and 28 days. The test results depicted an increase in the strength characteristics of marble dust treated samples, reduced strain at failure and changed the behaviour to a relatively brittle one. Test results revealed that the strength of Karewa soil improved upto 40% addition of marble dust to soil beyond which a drop in the strength was noticed. Further the strength improved with the curing time, irrespective of the marble dust concentration in the soil. The gain in strength is attributed to the formation of cementitious products due to hydration and other pozollanic reactions between calcium oxide (CaO) of the marble dust and the oxides of Karewa soil. Utilization of marble dust in the construction sector serves two benefits; first, it will eliminate of the environmental degradation due to its wide spread disposal and second, it will prove an economical means of soil improvement.

Keywords: Karewa soil. Marble dust. Soil stabilization. Geomechanical properties. Waste management.

Introduction

The construction industry continuously seeks innovative solutions to enhance the properties of soils used in various civil engineering projects. One of the promising approaches is incorporating industrial by-products into soils to improve their stability and performance [1–9]. Marble dust, a by-product of the marble industry, is an exam- ple of such a material. India generates millions of tons of marble dust annually due to its extensive marble processing industry. Specifically, about 6 million tons of marble waste, including dust, are produced each year from activities such as cutting, polish- ing, and grinding marble blocks [10]. This research focuses on evaluating the impact of marble dust on Karewa soils of J&K by adding it in different percentages (10%, 20%, 30%, 40%, and 50%). Utilization of marble dust in soil stabilization serves two key benefits: first, it helps to mitigate environmental issues by recycling industrial waste; and second, it improves soil characteristics in an economical manner.

Karewa soils are silt dominated soils and occupy more than half of the total land in Jammu and Kashmir, India. The engineering behaviour of these soils is unfavourable. They possess undesirable properties in terms of strength, compressibility and liquefaction susceptibility, particularly under saturated conditions [11–13]. These soils tend to have low shear strength, making them prone to deformation and failure under load. This characteristic poses challenges for construction, as it affects the stability of foundations and other structures. These soils exhibit high compressibility, leading to significant settlement when subjected to loads. This property can cause differential settlement in structures built on Karewa soils, resulting in structural damage. Karewa soils swell when wetted and shrink upon drying, which can lead to volume changes that affect the integrity of structures. This behavior is particularly problematic in regions with seasonal variations in moisture content. The plasticity of Karewa soils, influ- enced by their clay content, contributes to their undesirable engineering properties. High plasticity can lead to excessive deformation under load. Given these challenges, improving the engineering properties of Karewa soils is essential for safe and durable construction.

Saygili [14] focused on the use of waste marble dust for stabilizing clayey soil, demonstrating that marble dust enhances the unconfined compressive strength of the soil. The study reported that a 30% addition of marble dust provided the highest strength improvement, which is attributed to the pozzolanic activity of the calcium carbonate present in the marble dust. Okagbue and Onyeobi [15] explored the potential of marble dust to stabilize red tropical soils for road construction.

The reviewed studies consistently demonstrate that marble dust is an effective stabilizer for various soil types. Its high lime content facilitates pozollanic reactions, leading to improved compaction, increased strength, and enhanced load-bearing capacity. These benefits make marble dust a viable alternative to traditional soil stabilizers.

1 MATERIALS AND METHODS

1.1 MATERIALS

In this study, the following materials were used and tested in the laboratory following the standard codal procedures.

1.2 Karewa soil

In the present study, Karewa soil from Jammu and Kashmir, India was selected for MD stabilization. Soil sampling was carried out at the sides of National Highway NH-1 near the saffron fields of Pampore, Pulwama, at depth of 1.5m below the original ground level. The soil is fine- grained (silt-clay) and brownish in colour. The physical properties of Karewa soil are depicted in Table 1.

1.3 Marble Dust

The marble dust utilized in this study was sourced from Kartar Sanitary Store in Nowgam, Srinagar. This dust is produced as a by-product during the water jet cutting of marble blocks in the marble industry. It is a white powder with cementitious prop- erties. The chemical composition of the marble dust and Karewa soil was analyzed using X-ray fluorescence (XRF) technique, as detailed in Table 2. The primary oxides present in the marble dust are calcium oxide (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). The high concentration of CaO in the marble dust contributes to the hardening and strengthening of the Karewa soil samples treated with it.

1.4 TESTING METHODOLOGY

An extensive experimental program was conducted to test marble dust treated Karewa soil. The tests included gradation, specific gravity, chemical analysis, Proctor compaction tests, and shear strength tests. All samples were prepared and tested according to the relevant standards [16]. Karewa soil test specimens were treated with varying MD levels from 10% to 50% (in 10% increments by dry weight of soil) at $0.95\gamma_{\mathrm{dmax}}$ and optimum moisture content (OMC) as determined from standard Proctor tests. The moisture content corresponding to OMC is typically adequate to support compaction and cementitious reactions during soil stabilization. The MD-treated soil samples were preserved in a desiccator for moisture retention and subjected to DST and UCS tests for strength evaluation after 7, 14, and 28 days.

2 Physical and Engineering properties of untreated Karewa soil

Karewa soil under study is brownish in colour and is silt dominated. The particle size distribution of the soil is shown in Fig.1 . It depicts that 83% of particles by weight have a size less than 75μm. As per the Indian soil classification system (ISCS) [17], it is classified as silt with intermediate plasticity (CI). The oxide composition of the soil was determined using the X-ray fluorescence technique (XRF). The main oxides

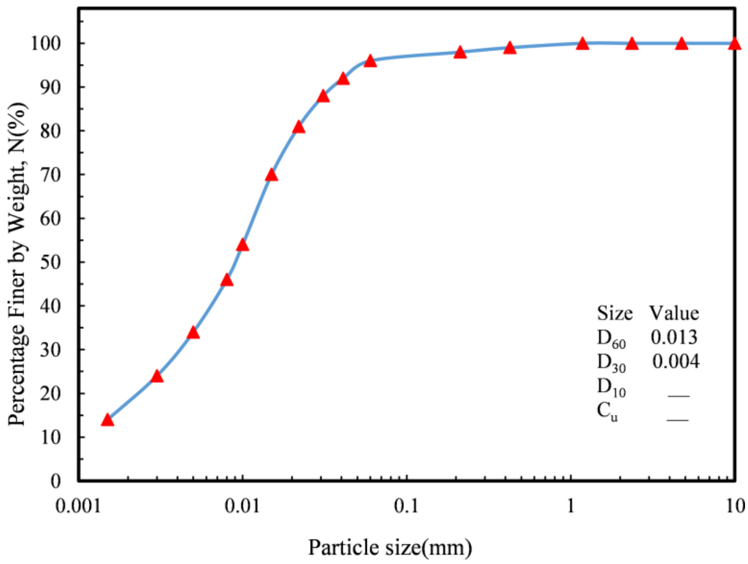

Fig. 1 Particle size distribution curve of karewa soil

of Karewa soil were found to be silica (as SiO_2), alumina (as Al_2O_3), iron oxide (as Fe_2O_3), and calcium oxide (as CaO). The (SiO_2 + Al_2O_3 + CaO + Fe_2O_3) fraction of soil is more than 85% of its total content and can be classified as a pozzolanic material. A similar oxide composition of Karewa soil has been reported in the literature [13].

Owing to the fine-grained nature of soil particles, the density bottle method was used to determine the specific gravity of soil particles. Kerosene, being a better wetting agent, was used in place of distilled water to find the specific gravity of soil particles. The average specific gravity value of soil particles was found to be 2.67, which is in agreement with the standard value of specific gravity for Karewa soils. The standard Proctor compaction test was conducted on Karewa soil and the compaction curve is shown in Fig. 3. The maximum dry unit weight (MDU) of untreated Karewa soil was found to be 16.9 kN/m^3 and the optimum moisture content (OMC) was found to be 18.5%.

Unconfined compression strength tests was conducted on three untreated samples of soil and the average value of UCS was found to be 122 kN/m^2. Direct shear tests were carried out on three samples of untreated BKW prepared at 0.95 γ_{dmax} and optimum moisture content in a direct shear testing machine as per relevant codal procedures. The cohesion was found to be 41 kPa and the angle of internal friction was 17°. CBR tests were carried out on the remoulded and untreated soil samples as per the standard codal procedures [18] and the values of unsoaked and soaked CBR were found to be 6.8% and 3.1%, respectively.

3 Physical and Engineering properties of MD treated Karewa soil

3.1 Effect of MD stabilization on plasticity characteristics of Karewa soil

The basic parameters for defining the plasticity characteristics of a soil are the liquid limit (LL), plastic limit (PL), and plasticity index (PI). The impact of adding marble dust to Karewa soil on these parameters is illustrated in Fig.2. The liquid limit decreases from 37% to 30.5% with a 50% replacement of soil by marble dust. This reduction is mainly due to the coarser particles of marble dust compared to the silt and clay particles in Karewa soil. Similarly, the plastic limit drops from 25% to 22.5% with a 50% replacement by marble dust. As a result, both the LL and PL decrease with the increased proportion of marble dust, causing the plasticity index to reduce from 12% to 8.3% at 50% marble dust replacement. All the tests have been carried as per the relevant code of practice for determination of plasticity characteristics [19].

3.2 Effect of MD stabilization on compaction behaviour of Karewa soil

Compaction involves increasing the unit weight of a material by bringing its particles closer together, which reduces air content. This process decreases soil compressibility, enhances shear strength, and lowers permeability. The compacted unit weight is

Table 1 Physical and mechanical properties of Karewa soil

S.no	Property	Soil
1	Natural moisture content (%)	16.5
2	Field dry density (kN/m^3)	16.4
3	Gravel (%)	0
4	Sand (%)	3
5	Silt (%)	80
6	Clay (%)	17
7	Liquid limit (%)	37
8	Plastic limit (%)	24
9	Plasticity index (%)	13
10	Specific gravity, G	2.67
11	Colour	Brownish
12	Classification	**CI**
13	Std. Proctor, maximum dry unit weight (kN/m^3)	16.9
14	Optimum moisture content (%)	18.5
	DST parameters (remoulded) at OMC and 0.95γ_{dmax}	
15	Cohesion, c (kN/m^2)	38
16	Angle of internal friction, ϕ ()	16
17	Unconfined compressive strength, UCS (kN/m^2)	122
18	Unsoaked CBR (%)	3.1
19	Soaked CBR (%)	6.8

Table 2 Oxide composition of Karewa soil and MD

Composition (by wt. %)	Soil	MD
SiO_2	51.8	7.2
Al_2O_3	18.3	1.5
Fe_2O_3	8.71	0.8
CaO	9.37	53.2
MgO	5.46	4.3
K_2O	3.11	0.61
Na_2O	1.13	0.73
$CaSO_4$	-	-
SO_3	-	0.16
TiO_2	0.62	-
P_2O_5	0.22	-
LOI	1.28	31.5

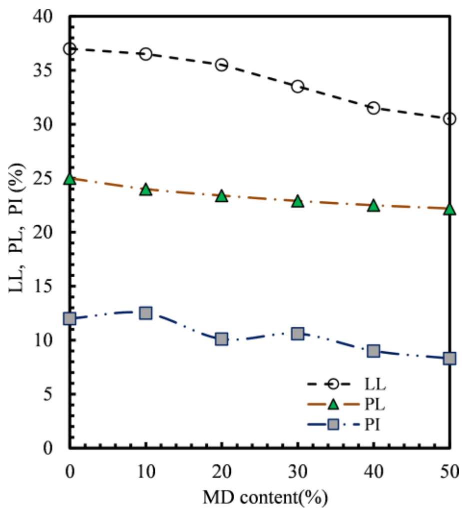

Fig. 2 Variation ol LL, PL and PI with marble dust(%)

influenced by factors such as soil type, compaction method, and water content during compaction. In this study, standard Proctor compaction tests were performed on Karewa soil treated with varying percentages of marble dust (10%, 20%, 30%, 40%, and 50%) by dry weight of soil as per the relevant code of practice [20]. The results, shown in Fig. 3a, illustrate the relationship between dry unit weight and water content of different soil and marble dust mixes. Fig. 3b presents the variation of optimum moisture Content (OMC) and maximum Dry Unit Weight (MDU) with different cement percentages.

It was observed that the MDU of marble dust-treated Karewa soil increases while the OMC decreases as the marble dust percentage rises from 10% to 50%, without showing an optimum value. This finding aligns with other researcher observations that

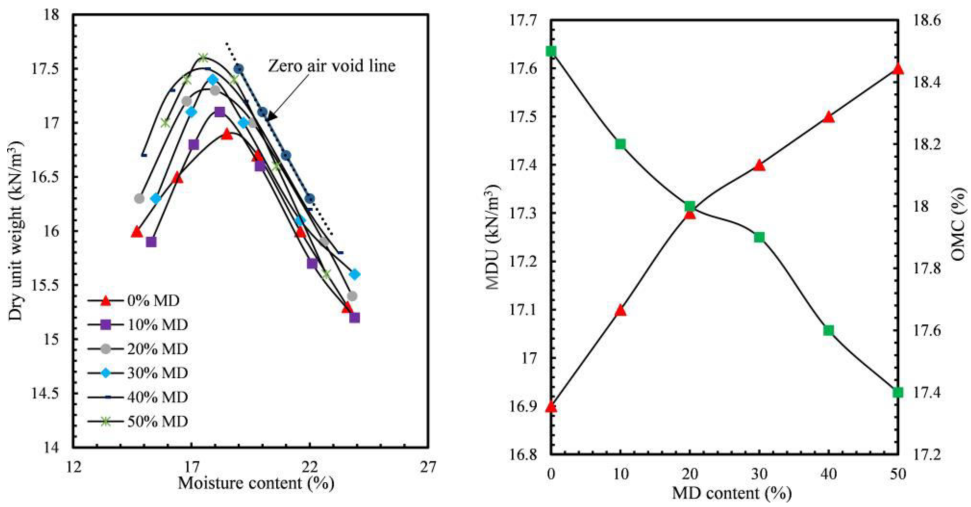

Fig. 3 (a) Compaction curves of soil-MD mixes. (b) Variation of OMC and MDU with MD(%)

marble dust addition significantly affects the compatibility of the soil-marble dust mixture. The increase in the unit weight of the mixture is attributed to the higher specific gravity of marble dust.

3.3 Effect of MD stabilization on UCS characteristics of Karewa soil

Evaluation of strength parameters of soil are prerequisite for its application in various civil engineering projects. In this study, unconfined compressive strength tests and direct shear tests were carried out to evaluate the impact of marble dust addition to the strength characteristics of Karewa soil. Cylindrical soil samples with 50mm diameter and 100mm height with different percentages of MD ranging from 10-50% were prepared using static compaction method at $0.95\gamma_{dmax}$ and optimum moisture content. The prepared samples were placed in the desiccator for subsequent UCS testing after 7, 14, and 28 days of curing as shown in Fig.4.

All the samples were tested for UCS strength as per the relevant code of practice [21]. The effect of MD addition to the UCS strength of Karewa soil with the curing time is shown in Fig.5(d).

From the test results of UCS shown in Fig.5 (a-c), it can be depicted that the elastic modulus and the peak strength of marble dust treated samples of Karewa soil improve significantly. The UCS strength of the samples improves further, as the samples were cured for 14 and 28 days as shown in Fig.5 (d). However, the stress-strain behaviour of cemented samples changes into a brittle one particularly at higher contents of marble dust.

The relationship for obtaining the unconfined compressive strength (UCS) as a function of MD content (m_d) and the curing time (t) has been obtained by performing the multiple regression analysis:

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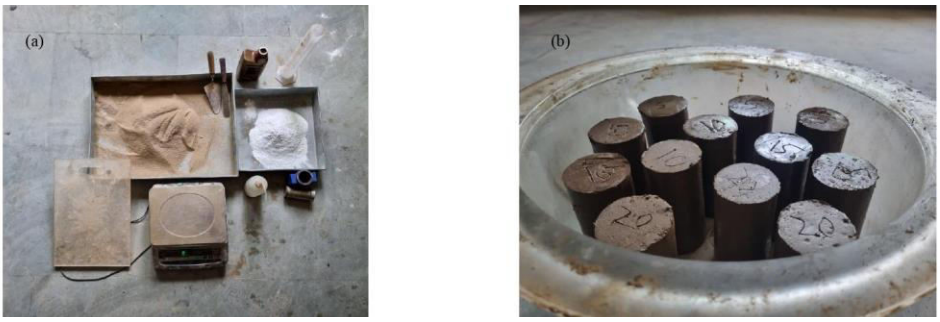

Fig. 4 (a) Sample preparation for UCS (b) UCS samples in desiccator for curing.

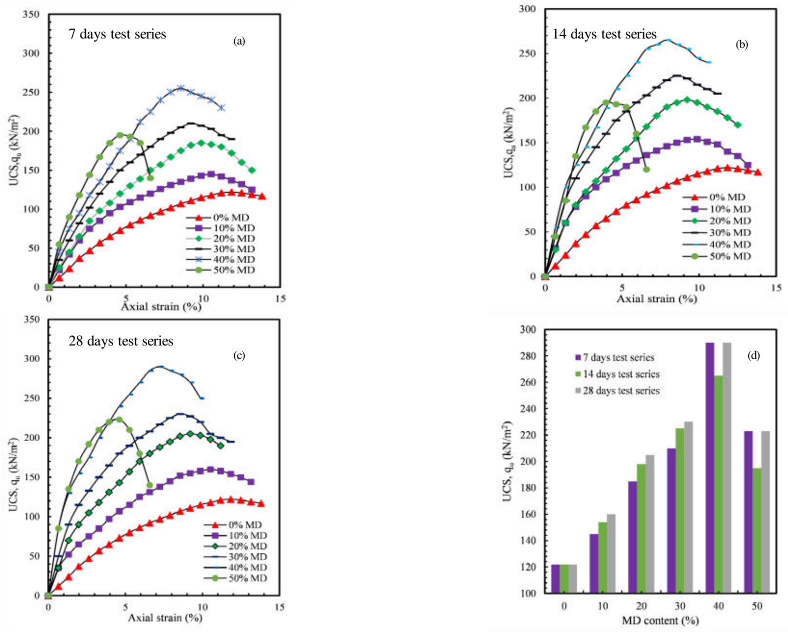

Fig. 5 (a-c) represent stress-strain plots of karewa soil treated with different %ages of MD. (d) shows variation of UCS with MD content after different curing times

$$\text{UCS} = K_0 + K_1(m_d) + K_2 \log(t) + K_3(m_d)^2 + K_4(m_d)^3 \quad (1)$$

Where,

- K_0 is the intercept (constant term).
- K_1 is the coefficient for marble dust percentage.
- K_2 is the coefficient for the logarithm of curing time (t in days).
- K_3 is the coefficient for the squared term of marble dust percentage.
- K_4 is the coefficient for the cubic term of marble dust percentage.

$$\text{UCS} = 108.12 - 0.62(m_d) + 6.61 \log(t) + 0.31(m_d)^2 - 0.005(m_d)^3 \quad (2)$$

Example Calculation:
For a sample with 20% marble dust cured for 10 days:

$$UCS = 108.12 - 0.62(20) + 6.61\log(10) + 0.31(20^2) - 0.005(20^3)$$
$$= 108.12 - 12.4 + 6.61\log(10) + 0.31(400) - 0.005(8000)$$
$$= 108.12 - 12.4 + 6.61 \times 1 + 124 - 40$$
$$= 191.94 \text{ kPa}$$

3.4 Effect of MD stabilization on direct shear parameters of Karewa soil

Shear strength parameters were evaluated by conducting a series of direct shear tests on various samples of soil, treated with different percentages of MD (10%, 20%, 30%, 40% and 50%) as per the relevant code of practice [22]. The MD treated samples of size (60 × 60 × 25) mm were prepared at $0.95\gamma_{dmax}$ and corresponding optimum moisture content in DST samplers. Three identical samples for each series of testing were placed in direct shear box, one by one and subjected to normal stress values of 50 kPa, 100 kPa, and 150 kPa. The samples were sheared in a strain-controlled manner and the rate of shearing was fixed at 1.25 mm/minute.

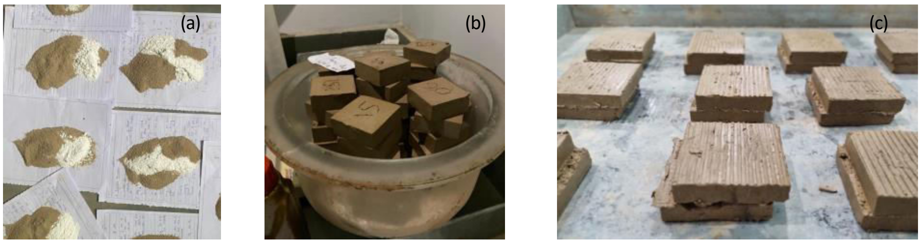

Fig. 6 (a,b) preparation of DST samples (c) Failed DST samples of karewa soil treated with MD.

The Mohr Coulomb strength envelope of MD treated with different percentages of MD (10%, 20%, 30%, 40% and 50%) and after curing of 7, 14 and 28 days of curing are shown in Fig. 7(a-c). From the results of the direct shear test, it was observed that the addition of MD to Karewa soil increased the shear strength of samples, and the strength further improved with the curing time. The early gain in strength is a consequence of the formation of cementitious products due to the hydration reaction of marble dust, and the latter part of strength is due to the secondary pozollanic reaction between the oxides of Karewa soil and the hydrated calcium hydroxide available in the mix. This gain in strength was found to increase up to 40% of MD replacement,

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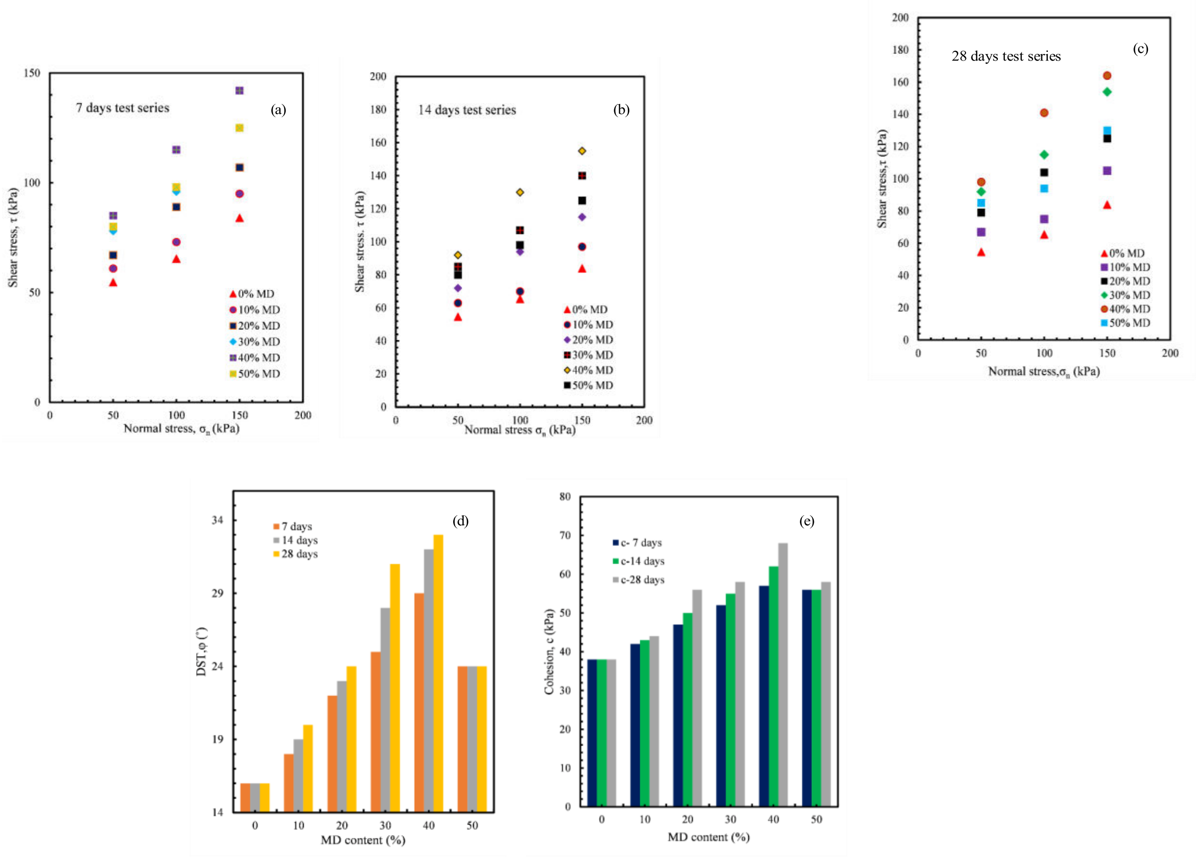

Fig. 7 (a-c) Mohr Coulomb envelopes for Karewa soil treated with different percentages of MD after 7,14 and 28 days of curing. (d,e) represent variation of c and ϕ with MD percentage and curing times.

beyond which a drop in the strength was observed. The variation of cohesion and the angle of internal friction with the different percentages of MD and curing times of 7, 14, and 28 days are shown in Fig. 7(d,e). The decrease in the strength beyond 40% addition of MD could be attributed to the fact that high marble dust content in BKW results in a brittle failure. Marble dust stabilization improved the cohesion value of Karewa soil from 38 to 68 kN/m^2 and the angle of internal friction from 16° to 33° at 40% MD addition and after 28 days of curing. It is further observed from the test results that the improvement in both the cohesion and the angle of internal friction is maximum during the initial 7 days of curing.

Some previous studies have also shown that the shear strength parameters, i.e., cohesion and angle of internal friction, increase with cement addition, and the improvement is influenced by the curing times.

CONCLUSION

In this study, the influence of marble dust addition to Karewa soil was investigated in order to improve its performance for use in various applications of geotechnical engineering. Based on the test results, the broad findings of this study are summarized below:

- The addition of marble dust to Karewa soil proved to be an effective means of improving its strength characteristics. The gain in strength was mainly found to depend on MD content and the curing period.
- Marble dust addition of 50% in standard Proctor tests resulted in the increase of MDU of Karewa soil from 15.2 kN/m^3 to 15.9 kN/m^3 and a decrease in OMC from 23.2% to 26.2%.
- The unconfined compressive strength of Karewa soil was found to increase up to 40% of MD addition, beyond which the UCS strength dropped. The value of UCS at 40% MD treatment to silty soil was found to be equal to 643 kPa.
- The shear strength parameters in DST showed a significant gain. There was an increase in the value of cohesion (c) from 14.63 kN/m^2 to 62.66 kN/m^2 and angle of internal friction from 35.37° to 48.49° at 40% MD addition to soil.
- The UCS strength and elastic modulus of MD treated soil are higher, but the stress-strain behaviour represents brittle failure, especially at higher MD content. For researchers, it is suggested to improve the ductility behaviour of MD treated soil by introducing fibres into it. Further, cyclic triaxial testing needs to be carried out to understand the susceptibility of MD treated silty soil to liquefaction.

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