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ARTICLE

Significance of Stone Waste in Strength Improvement of Soil

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ABSTRACT

The evolution of industries is essential for the economic growth of any country; however, this growth often comes with exploitation of natural resources and generation of wastes. The safe disposal and utilisation of industrial wastes has become essential for sustainable development. A possible approach would be to utilize these wastes in construction industries. The stone industry is one such flawed industries that generates waste in dust or slurry form; this leads harmful impacts on human beings, animals, and surrounding areas which, in turn, can lead to soil infertility. In the present study, stone waste was examined for its influence on maximum dry density (MDD), optimum water content (OMC) and unconfined compressive strength (UCS) of soil experimentally. Stone waste was used at 0%, 4%, 8%, 12%, 16% and 20% by weight of soil and UCS tests were conducted at maturing periods of 7, 14 and 21 days. Test results reported that the incorporation of stone waste improved the compressive strength value significantly. Maximum dry density was enhanced; however, optimum water content was reduced with the use of stone waste in soil due to its fine particles. Linear regression equations were also derived for various properties.

1. Introduction

Industrialization promotes the generation of industrial by-products along with the usable final products. These wastes may be in solid, liquid and gaseous form. Nowadays, finished stone is an important building material used at various parts of a household. The stones generally are of different types, such as granite, marble, limestone, Kota stone etc. The stone can be used in the construction following a dimensioning process, which makes it more suitable for use as required. During the cutting and polishing process of stone blocks, a continuous stream of water is sent over the saw-blade to cool down the machine. The waste water, along with very fine particles of stone, comes out as slurry, which is dumped into surrounding area.

Within the overall production of stone waste of approximately 80 lakh metric tonne (MT) per year, about 12 lakh MT is produced as fine dust waste, and from which 4-5 lakh MT is disposed nearby mine sites, and rest of them disposed directly to the lands and water courses.

Safe disposal of the industrial wastes has become a serious threat to humans. Direct disposal of wastes to the land or water courses is not a mere nuisance; it also unbalancing the ecosystem. Stone industry also produces waste in the form of block pieces, slurry or dust that originates during the dimensioning of stones. The waste produced from the stone industry is non-biodegradable and direct dumping in open land may cause soil infertility

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by clogging the soil pores. If this waste contaminates water sources, flora and fauna dependent on these water sources may experience other serious problems and even death. Dry stone powder is very dangerous to both humans and animals, as its direct exposure may give rise to respiratory problems, eye and throat diseases too. Considering its severity, a safe and manageable disposal is needed[1]. Road construction industries may utilise the stone waste as a raw material or soil stabiliser. As the stone waste is available free of cost, weak geological formation may be stabilised by using stone waste. In the past, many investigators have used the stone waste as an additive or stabiliser for weak soil and found better results against loading and weathering conditions. Replacing the marble powder in marble bricks with Kota stone powder improved the compressive strength[2]. Intrusion of Kota stone in clayey subgrade has shown appreciable changes in California Bearing Ratio (CBR) value and compressibility characteristics[3]. Stone slurry waste was also found effective for soil stabilisation in terms of compaction, strength and CBR properties of soil[4]. Improvements in soil properties were also observed in highly compressible soil like black cotton soil (BCS) with other additives such as sawdust and fibres. The improvement was noted from 26% to 35% and higher content of fibres may reduce the dry density of soil due to its low density as compared to soil[5][6]. Replacing marble slurry with Kota stone sludge revealed better results[7]. Kota stone slurry was found to be a good stabiliser for BCS subgrade. The treated soil showed remarkable changes in UCS and CBR values[8]. Calcium-based additive i.e. eggshell powder was found as a good waste material to improve the strength characteristics of silty soil, as observed through physicochemical tests[9].

In the present study, stone waste was used to improve the compaction and strength characteristics of a clayey soil. As the stone waste mainly contains calcium content, so it may be effective for the treatment of clayey soil. In addition, utilization of stone waste in the soil stabilization reduces its disposal-related problem and other associated issues. For the rationalisation of the results, linear regression equations were also utilised. The objective of study was to utilize stone waste in soil to minimize its consequences to the ecosystem, along with improvement in soil properties.

2. Materials and Methodology

To realize the objectives, the whole procedure commenced in two phases. The first phase comprised of the determination of MDD and OMC of parent and treated soil using standard proctor test method as per IS: 2720 (VII) 1974, and strength test by performing unconfined strength test referring IS: 2720 (X) 1991[10][11]. During the second phase, analysis of results was done to generate linear regression equations for the compaction and strength parameters.

2.1 Materials

The soil was procured from the potholes of a construction site at Kurukshetra, India. Before digging the potholes, the vegetation must be peeled off to avoid all alien objects. Indian Standard Classification System (ISC) confirmed the subjected soil as the CL type according to plasticity chart method and other necessary index properties of soil (tabulated in Table 1). Granulometric curve of the soil is shown in Figure 1. Stone slurry, a waste material obtained from Kota stone, from Rajasthan, India, generated during the processing of stones, was dried and grinded to powder to use as an additive. The stone powder was sieved through a 425μm sieve before use. The idea behind sieving was to maintain the uniformity of the size of material. Usually, stone waste is white in color, with chemical properties as per Table 2. The scanning electron micrograph and energy dispersive X-ray spectrogram of stone waste are shown in Figures 2a and 2b[12]. The laboratory's available tap water supply was used during whole course of experimentation.

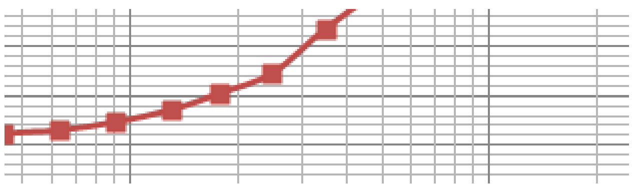

Figure 1. Grain Size Distribution Curve of Soil

Table 1. Properties of Soil

Physical Parameter	Value
Liquid limit	29%
Plastic limit	20%
Plasticity index	9%
Soil type	CL
Υ_d max	1.72g/cc
OMC	14.5%

Table 2. Typical Chemical Composition of Stone Waste

Chemical Constituent	Chemical Composition (%)
Calcium oxide	49.78
Silica	17.01
Aluminium Oxide	2.92
Magnesium oxide	0.61

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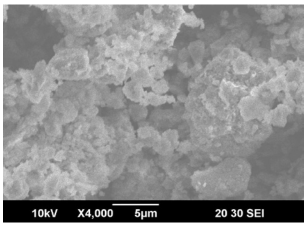

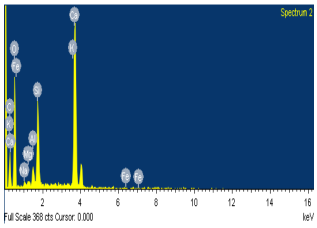

Figure 2a. SEM of SSP **Figure 2b.** EDS of SSP

1.2 Test Procedure

2.2.1 Standard Proctor Test

A series of tests was conducted to determine OMC and MDD of parent and treated soil, confirming to IS: 2720-1974 (Part VII)[10]. Stone waste was taken by dry weight of soil, and was mixed and dried during whole testing. After every layer of soil was scratched with a brush to improve its bond with the proceeding layer, the proctor mould was filled up to the attached collar in 3 layers using the lightweight compaction procedure. The stone waste was used at different percentages. The designated mixes have been given in Table 3.

Table 3. Mix Designation for Experimentation

Mix Number	Stone waste (%)
S1	0
S2	4
S3	8
S4	12
S5	16
S6	20

1.1.2 Unconfined Compressive Strength

The samples were prepared in the cylindrical mould confirming to IS: 2720-1991 (Part X)[11]. The wet homogenous mixture was placed inside the specimen mould in seven layers using a spoon, levelled and gently tap-compacted by 1cm diameter mild steel ram. The sample was kept under static load for at least 10 minutes in order to account for any deformation occurring due to moisture change. The sample was then removed from the mould with the help of the sample extruder and measured for its dimension. To maintain the consistency of the sampling, each sample was prepared for 38 mm diameter and 76 mm in length. To maintain the repeatability of the results, samples were prepared in triplicity and mean of the results of each sample was taken for the calculation.

2.2.3 Statistical Analysis

After performing the laboratory tests, the results were analyzed to create linear regression equations.

3. Results and Discussion

3.1 Optimum Moisture Content and Maximum Dry Density

The consequences of stone waste on maximum dry density and optimum moisture content were investigated experimentally, and results of MDD and OMC have been shown in Figures 3a and 3b respectively. Figure 3a showed that the increase in stone waste content in soil enhanced the maximum dry density. The increase in MDD may be due to finer particles of the stone waste.

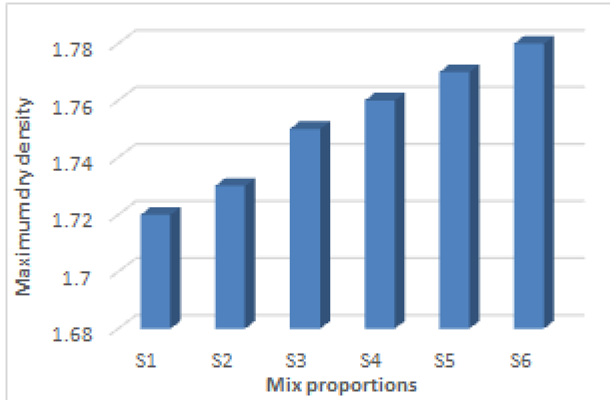

Figure 3a. Variation in MDD

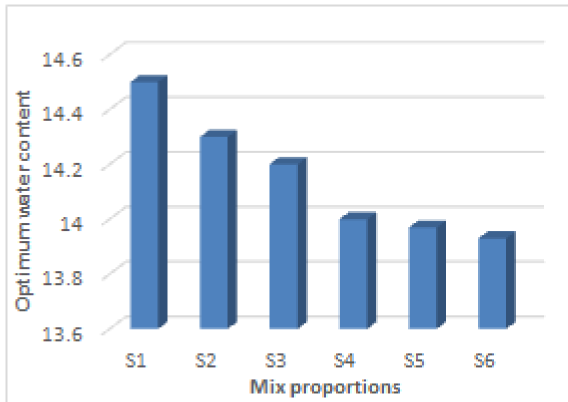

Figure 3b. Variation in OMC of Soil Using Stone Waste

The use of stone waste in soil had reduced the moisture content as shown in Figure 3b. The very fine particles of stone waste were responsible for the reduction in moisture content of soil. The similar trend of MDD and OMC was also observed in other related studies[13][14].

Figures 3a and 3b also show that stone waste increased the dry density. The increase in dry density was 0.58% to 3.49% as compared to the parent soil. A possible reason for the improvement in maximum dry density upon the inclusion of stone waste is the fineness of stone waste that fills the voids of the soil and helps to create a denser material. A decrease in optimum moisture content was also observed. Stone waste contains an appreciable amount of lime. As long as lime present in the mix, more water is required to react. As a result, this reaction, known as the pozzolanic reaction, results in the greater consumption of

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water in the mix.

3.2 Unconfined Compressive Strength

Figure 4 shows the effect of stone waste on the unconfined compressive strength (UCS) of the soil at various curing ages i.e. 7, 14 and 21 days. From Figure 4, it has been observed that UCS varied proportionally to increases in stone waste percent and curing ages. The enhancement in UCS may be due to addition of fine particles of stone waste. The maximum strength gain was obtained at 20% intrusion of stone waste for all the curing ages. The similar results also reported in related studies[15].

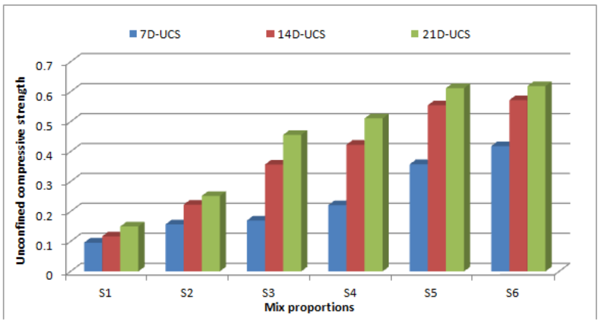

Figure 4. Variation of UCS at Varied Curing Age

Stone waste increased the UCS linearly and was found to be very effective in increasing the UCS of the subjected soil. The percentage increase in UCS varied from 0.58% to 3.49% after incluusion of stone waste from 4% to 20%.

3.3. Regression Analysis

To check the rationalization of the presented study, a regression analysis of the responses was also carried out. Linear regression analysis of MDD, OMC and UCS was done and has been shown in Figures 5a, 5b and 5c respectively.

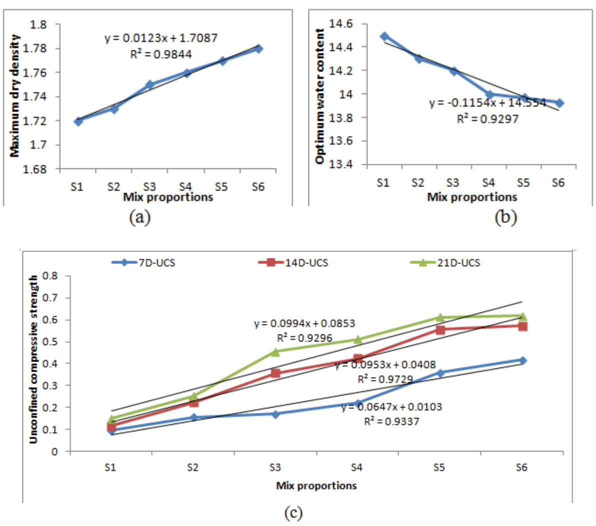

Figure 5. Regression Analysis for (a) MDD; (b) OMC; and (c) UCS at 7, 14 and 21 Days

From Figures 5 (a), (b) and (c), it can be seen that regression equations showed good results in terms of R-squared i.e. near to unity. As such, these regression equations can be used in future to predict the compaction and strength characteristics of such type of low compressible soils.

4. Conclusion

Present study represents the occurrence of stone waste inclusion in plastic soil. Stone waste was introduced in soil at varied percentages and the effect on compaction and strength characteristics was researched. For viability of the results, regression equations were also obtained using responses of the experiments under laboratory conditions. The following conclusions can be drawn from the present study:

1. Maximum dry density increased and optimum moisture content decreased linearly with the increase in stone waste.

2. Fine particles of stone waste filled the voids and helped to increase the dry density of soil.

3. Available calcium of stone waste reacted with clay minerals and started pozzolanic reaction, which helped for the attainment of long-term strength.

4. Linear regression equations showed reliability of the results.

In the present study, utilisation of stone waste in soil works resulted in improvement of soil parameters. So, freely available stone waste can be utilized to stabilize the subgrade of pavement and make it cheaper for practitioners and engineers. As a wise step to make environment safe and eco-friendly always appreciated.

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