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Unconfined Compressive Strength of Cement Stabilized Soil Using Industrial Wastes Including Optimization of Polypropylene Fiber

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A B S T R A C T

This Study is focused on suitability of industrial wastes in cement stabilized soil. The investigation is based on Unconfined compressive strength (UCS) tests. Experimental work is carried out to compare the UCS of cement stabilized soil specimens with different proportion of industrial wastes like Iron ore tailing, Quarry dust, Fly ash and Bagasse ash. The mix proportion is designed such that clay content is maintained at 10.5% for fine grained soil and density of 17.5 kN/m^3. It is observed that the mix comprising industrial wastes and fiber have improved the mechanical properties compared to cement stabilized soil. Fiber addition has improved post peak behavior of soil specimen. The Scanning Electron Microscopy (SEM) microstructure images depict soil particle flocculation, leading to an increase in compressive strength and Energy Dispersive X-ray Spectroscopy (EDS) studies suggest the use of industrial wastes with natural soil helps in strengthening of soil cement stabilization, as well as to minimize the environmental pollution.

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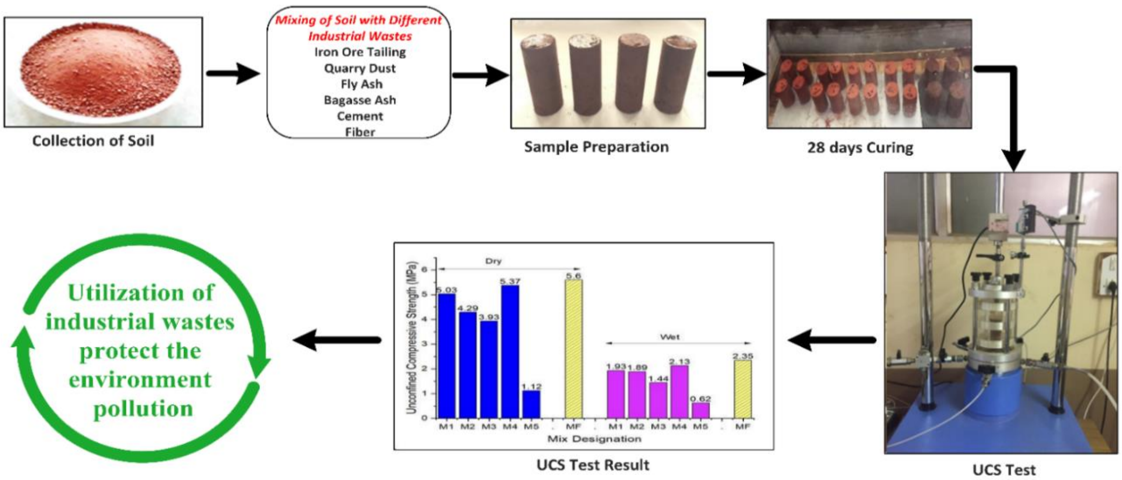
Graphical Abstract



1. INTRODUCTION

Earth is a modest, environmentally friendly and richly accessible building material. Around 30% of the world's present population still lives in earthen structures (1).

In civil engineering projects, the soil material modification can enhance the Geo-Technical properties of the soil (2) and soil being the main foundation medium and construction material to support all structures. Therefore, the soil modification plays an important role

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in geotechnical engineering design. Previous studies reported that combination of soils with additives like lime, cement, fly ash etc. resulting in increase in the strength of the soil (3). It was also reported that soil stabilization technique is very effective and eco-friendly method for improving the soil property in various geotechnical applications (3-5). The soil modification method being widely used, a feasible and most cost-effective method to improve the engineering performance (6, 7). The main properties of the soil which are important for the study are namely, the strength, stability, permeability, durability and compressibility (7-9).

Various methods of soil stabilization have been employed including stabilization using soft aggregates, mechanical stabilization, bituminous stabilization, cement stabilization, lime stabilization, thermal stabilization, chemical and electrical stabilization. Admixtures like, lime, fly-ash, cement, blast furnace slag, enzyme and calcium chloride were used in soil (10-12).

In modern times, waste-derived pozzolans like rice husk ash, fly ash, and slag are increasingly recognized as environmentally friendly alternatives to conventional cementitious materials. Recent research has demonstrated that using locally obtained soil stabilizing materials with fly ash and cement can reduce construction costs, especially for geotechnical engineering projects (12, 13). Natural or synthetic fibres such as coir, cotton, polypropylene, sisal, polyester and basalt may be used to enhance the mechanical characteristics of weak or soft soils (2, 14).

The soil improvement method is largely dependent on the characteristics of the soil. Soil stabilization using lime or cement is most popular method reported in the previous literature. It was also observed that using of the cement along with the soil resulting in the bonding of the particle since cementing material occupys the pore space between the soil particles which improves the strength (2, 15, 16).

Kalantari et al. (17) reported the mechanical behavior of the peat soil stabilized with cement and silica fume, under soaked and unsoaked conditions using unconfined compressive strength (UCS) and California bearing ratio (CBR). It was observed that the mechanical properties of peat soil increased by using the cement and silica fume (2, 18-20).

Boobathiraja et al. (20) investigated on mechanical properties of the stabilized peat soil using lime and cement. It was reported that addition of cement performed better as compared with lime. Whereas, several studies proved the improvement in the mechanical characteristics of soil by using various types of fibers (2, 20-24).

Kalantari et al. (25) examined the UCS and CBR values of peat soil stabilized with cement, steel fibres and polypropylene. It was observed that the CBR and UCS values of specimens containing 2% of steel fibres, 0.15% of polypropylene fibres and 5% of cement, increased by as high as 748.8% and 122.7%, respectively (2).

Numerous studies have explored the mechanical properties of soils using different materials like cementation agents and fibers, there has been few studies focusing on the mechanical behavior of stabilized soil with industrial waste and fiber (2).

Compacting in-situ soil mixed with cement is a widely used to improve the soil properties. Benefit of this procedure is that sufficient strength can be accomplished in a brief time frame. To rescue the natural soil can be replaced with modern waste materials, such as Fly ash, Bagasse ash, Quarry dust and Iron ore tailing have been in practice. Waste products are now seen to be environmentally acceptable materials that can take the place of conventional materials (26).

This practice has some influential factors, for example, water content, cement substance, curing condition, substitution proportion and compaction energy on the microstructure engineering characteristics of stabilized soil (27, 28).

This study aims to investigate the physical properties of soil, mix proportion of soil with different combinations of industrial wastes and to find out the unconfined compressive strength (UCS) of cement stabilized soil with industrial wastes and fiber.

Moreover, the validity of the test results were supported by performing Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) analysis on soil samples.

2. MATERIALS AND METHODS

2. 1. Materials: Soil (S) In this work the soil is collected from Halkurki, Bagalkot District, Karnataka. The soil is collected at a depth of 60 cm below the ground surface. Hydrometer test is conducted to get the particle size distribution of the soil. As per unified soil classification systen soil type is OL (Organic Soil of low plasticity) as per IS 1498 – 2007 (29).

Iron Ore Tailing (IOT): The mining industry considered for the investigation is M/S Doddannavar mining and manufacturing plant located near Kamatagi, Bagalkot District Karnataka. The industry produces daily around 1000 tonnes of iron mineral, which generates 3000 tonnes of tailing as industrial waste. Thus, the dumping of iron ore tailing has turned into a major problem, since it requires more space. The chemical composition of iron ore tailing is harmful to agricultural land which causes land and environmental pollution. **Quarry Dust (QD):** Quarry dust generated as a byproduct during the process of crushing of the boulders into aggregates. Around 20–25% is generated as quarry dust. The quarry dust is collected from Kolhar quarry, Vijayapur District, Karnataka.

Fly Ash (FA): Fly ash is a non-crystalline substance with pozzolanic properties and cementitious characteristics. It is industrial waste with environmental concerns, generated through the combustion of coal in thermal power plants. The annual production of fly ash has reached 95 million tonnes. Fly ash used in this experimental work is brought from National Thermal Power Corporation Limited, Kudagi, Karnataka.

Bagasse Ash (BA): Is a waste generated from sugar Industry as a byproduct. It is a serious problem in developing countries like India. India alone generates approximately 90 million tons of Bagasse ash as a solid waste. The Bagasse ash is collected from GEM Sugar Industry Kundaragi, Bagalkot District Karnataka. **Cement (C):** Type of cement used shall be Ordinary Portland Cement, 43 grade conforming to IS: 8112 (2013) (30) code to prepare the UCS samples. In the present study cement content of 10% by mass is used. **Water (W):** available tap water shall be used for preparing UCS samples. The properties like textural composition was carried out using hydrometer analysis (31) for soil and industrial waste individually. Some physical properties are summarized in Table 1. A photograph of the soil and other industrial waste materials are as shown in Figure 1.

Physical characteristics like change in the microstructure of the individual materials was carried out to understand the coagulation of soil particles, which indeed enhances the strength characteristics, and this can be studied using the Scanning Electron Microscopy (SEM) technique are shown in Figure 2. Through Energy Dispersive X-ray Spectroscopy (EDS), we can analyze the chemical composition of the soil and other materials are as shown in Table 2. EDS spectrum is useful in understanding the changes in chemical composition by adding different industrial waste to the soil as well as to determine the chemical change to gain strength. SEM micrograph of different material is shown in Figure 2. **Fiber (F):** Polypropylene fiber is used as a reinforcing material for cement stabilized soil. Few researchers have studied strength characteristics of fiber reinforced soil-cement mixtures and they investigated maximum UCS for polypropylene fiber (25, 32, 33) Therefore, in the present study soil- cement is reinforced with polypropylene fiber. Physical properties of polypropylene fiber are listed in Table 3.

The hydrometer analysis is carried out to evaluate the particle size distribution for the soil and industrial wastes (31). The grain size analysis of soil with industrial waste are presented in Figure 3.

2. 2. Reconstituted Soil

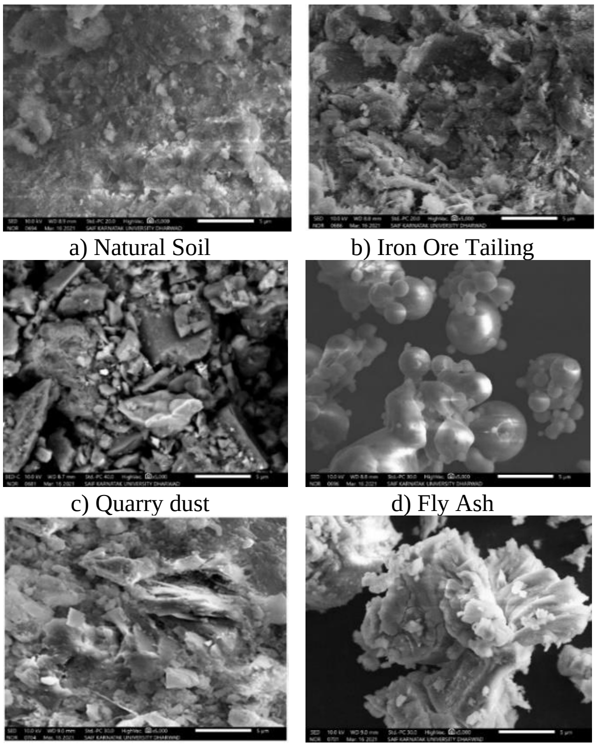
Reconstituted soil is a mixture of the soil, industrial waste, fiber and cement. The optimum clay content of 10.5% for Fine grained soil was achieved (27) in the present study. The density of specimens is kept constant and the respective optimum moisture content is obtained by standard proctor test (34).

TABLE 1. Properties of soil and industrial wastes

Sl. No.	Description of Properties		SOIL	IOT	FA	BA	QD
1	Textural Composition (% by Mass)	Sand (4.75–0.075mm)	57.08	15.42	19.87	36.03	79.97
		Silt (0.075-0.002mm)	33.56	65.56	75.99	57.74	17.01
		Clay (<0.002mm)s	09.36	19.05	4.14	6.23	3.02
2	Atterberg's Limit	Plastic Limit	28.48	17.80	15.15	-NP-	-NP-
		Liquid Limit	32.50	28.00	28.15	-NP-	-NP-
		Plasticity Index	4.02	10.20	13.00	-NP-	-NP-
3	Unified soil classification (USC)		OL	CL	CL	-	-
4	Compaction Properties (with cement)	MDD (kN/m^3)	17.50	-	-	-	
		OMC (%)	17.00				
5	Specific Gravity (G)	-	2.64	3.44	2.85	1.48	2.20
6	Chemical Property	pH value	7.05	8.05	9.50	7.34	9.19

(a) (b) (c) (d) (e) (f) (g)

Figure 1. (a) Natural soil (b) Iron ore tailing (c) Quarry dust (d) Fly Ash e) Bagasse Ash (f) Cement (g) Polypropylene fiber



a) Natural Soil b) Iron Ore Tailing

c) Quarry dust d) Fly Ash

e) Bagasse Ash f) Cement

Figure 2. SEM micrography of all the materials at 5µ m magnification

TABLE 2. Chemical Composition (%) of Materials used in the experiments

Chemical Name	Cement	Natural Soil	IOT	Quarry Dust	Fly Ash	Bagasse Ash
CaO	42.27	0.78	-	7.47	0.42	2.53
SiO_2	15.52	39.99	10.75	39.81	19.92	69.27
Al_2O_3	1.97	19.02	11.31	15.65	17.85	8.30
FeO	1.59	14.09	61.84	14.42	0.47	5.10
MgO	1.36	-	-	2.67	2.12	2.96
CO_2	34.85	25.24	16.10	14.27	59.05	10.24
S	0.80	-	-	-	-	-
K_2O	0.36	0.88	0.00	0.00	0.16	1.50
TiO_2	-	-	-	1.83	-	-
Na_2O	1.27	-	-	3.89	-	0.98

TABLE 3. Properties of polypropylene fiber

Properties	Value
Specific gravity	0.91
Average diameter (mm)	0.048
Average length (mm)	12
Breaking tensile strength (MPa)	350
Modulus of elasticity (MPa)	3500
Fusion point (°C)	165
Burning point (°C)	590
Acid and alkali resistance	Very good

Table 4 represents the detailed mix proportion for reconstituted soil (26, 35).

2. 3. Testing Procedures The scope of this investigation is to study the effect of adding industrial waste and fiber content on strength characteristics. At beginning of the construction using better geomaterials, it is imperative to assess the strength of the stabilized soils (36). Tests were performed on soil specimens of 17.5 kN/m3 density and water content determined using the Standard proctor test. All the samples were tested in dry and wet conditions and post peak behavior was studied.

2. 3. 1. Specimen Preparation All samples tested in this investigation are 33.5 mm in diameter and 70.5 mm in height. The specimens were prepared for different types of soil mentioned in Table 3. Soil samples were prepared by thoroughly mixing soil with cement,

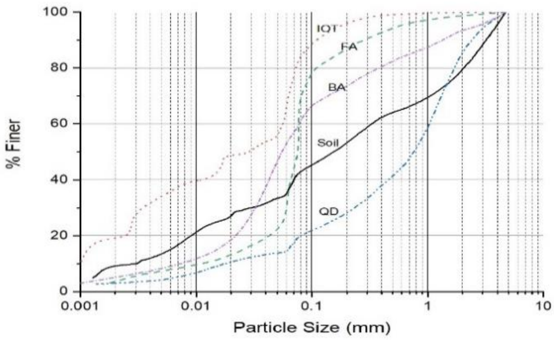


Figure 3. Grain size analysis of soil with industrial waste

TABLE 4. Details of Mix Proportion for reconstituted

Mix Designation	S	IOT	QD	FA	BA	C	W	F
M1	1	-	-	-	-	0.100	0.19	-
M2	1	0.28	-	-	-	0.128	0.27	-
M3	1	1	0.59	-	-	0.259	0.49	-
M4	1	1	-	0.58	-	0.258	0.45	-
M5	1	1	-	-	1.17	0.317	1.54	-
MF	1	-	-	-	-	0.100	0.19	0.0066

S= Soil, IOT= Iron Ore Tailing, QD= Quarry Dust , FA= Fly Ash, BA= Bagasse Ash, C= Cemenr, W= Water, F= Fiber industrial waste and fiber in dry condition,. The required quantity of water is added and mixed to give a uniform mixture. The known weight of wet mix is placed and compacted in threee layer to achive the required density. Specimens were kept in a mould for 24 hours with sealed plastic bag to arrest water evaporation. Specimens were demoulded (Figure 4) and soaked in water for 28 days for curing (Figure 5). After 28 days of curing specimens were allowed to dry in the laboratory for 14 days prior to testing. UCS test was performed in dry and wet conditions, to achieve the dry condition, the specimens were kept in the temperature-controlled oven at 500°C to attain constant weight (Figure 6). The wet condition of the specimens is achieved by soaking thesample in water for 72 hours prior to testing (Figure 7) (37, 38).

2. 3. 2. Strength Test The strength test is measured in terms of UCS as per IS 4332 Part V (39) using digital triaxial system machine of 50 kN capacity. A test setup and schematic drawing is shown in Figure 8. The test was perfomed with loading rate of 0.003mm/s. Stress is calculated dividing the load by surface area of the specimen where as strain is calculated change in length of the specimen (Platen moment of equipment) to the original lenght (36).

3. RESULT AND DISCUSSION

3. 1. Unconfined Compressive Strength (UCS) The effect of UCS is investigated for a different combination of soil with industrial wastes as per mix design. The UCS results for both dry and wet conditions are illustrated in Figure 9. The UCS values for M1 type of Soil for dry and wet conditions were measured as 5.03 and 1.93 MPa, respectively. For M4 type of soil the values for dry and wet conditions were 5.37 and 2.13 MPa, respectively. It is observed that the strength is more for M4 type of soil because of the presence of fly ash similar results were reported in previous studies [12].

Figure 4. Specimen Sample

Figure 5. Samples soaked in water for 28 days

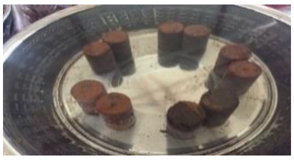


Figure 6. Specimens kept in a oven to test under dry condition

Figure 7. Specimens kept in a water to test under wet condition

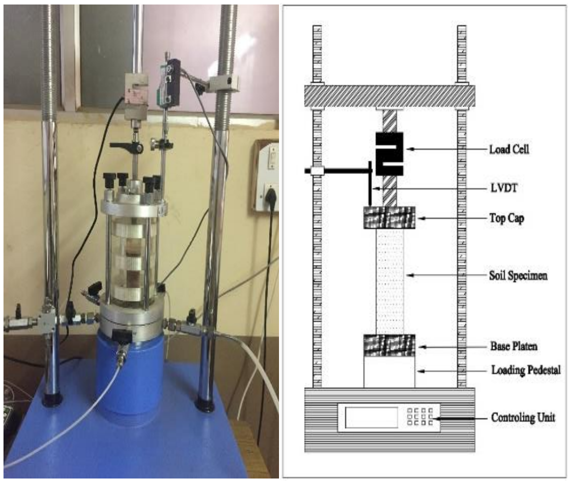


Figure 8. Unconfined compression test setup

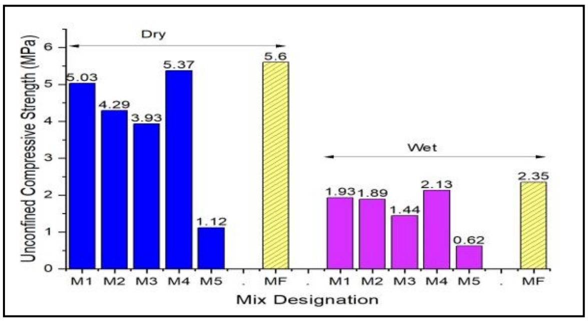


Figure 9. Unconfined Compressive Strength results both in dry and wet condition

The UCS results of M2 and M3 type soil for both dry and wet conditions were found to be 4.29 and 1.89 MPa, 3.93 and 1.44 MPa, respectively (40). The UCS results for M5 type of soil for dry and wet conditions were found to be 1.12 MPa and 0.62 MPa, irespectively. Except M5 type of soil, other type of soils has shown satisfying strength values as per IS 2110:2002 (41). The minimum permissible threshold for soil cement's compressive strength is 1.4 MPa in dry conditions and 0.7 MPa in wet conditions.

UCS results for MF type of soil is 5.6 MPa and 2.35 MPa in dry and wet conditions respectively. Randomly distributed fiber arrest cracks during loading which increses UCS values (25).

Comparing the above results obatined, the specimen with dry condition results in higher strength in comparison with wet condition. In dry condition, close bonding of the particle takes place. In wet condition, water penetrates through pores of the sample thereby reducing the bonding strength (42).

3. 2. Ucs Test To Find Out Optimum Fiber Content
To decide the optimum fiber content UCS test is conducted for M1 type of soil, specimen has been prepared according to IS 4332 part 5 (39). Fiber content differing at 0 % to 1 % with 0.1 % interval, test results are as shown in Figure 10. Unreinforced soil has taken considerable load. However, failed all of a sudden after the peak load is accomplished. This is not the same in the event of fiber reinforced specimen. As the fiber content is increased, load taken by specimen increases up to 0.6 % by dry weight of soil. Further, increase in the fiber content showed a decrease in UCS strength. The bridging of the fiber is seen as a failure in fiber reinforced specimen. The UCS results for M1 type of soil for 0.6 % fiber content for both in dry and wet condition were found to be 5.60 MPa and 2.03 MPa, respectively.

3. 3. Stress- Strain Behaviour Through studying the stress-strain response a better understanding can be developed as how to add industrial waste affects soil behavior. The effect of the additives on post peak strength strain is discussed in this section, Figures 11 and 12 present the stress strain response from dry and wet condition, respectively. The stress strain response presented in Figures 11 and 12 show addition of industrial waste improves the post-peak behavior of the specimens. The mix M4 will give more strength in contrast to other mixes this could be attributed to the presence of fly ash both in dry and wet conditions. The mix containing Bagasse Ash ie., M5 type of soil will not satisfying strength values as per IS 2110:2002 (41).

The UCS values of different mix proportion are lower for the wet specimen compared to those of dry specimen as shown in Figure 13. The incorporation of fiber in natural soil in conjunction with the cement will increase the post peak behaviour when compared with soil alone in dry and wet conditions (Figure 14). The stress and strain increased with inclusion of fiber content for M1 type of soil and the stress is found to be 5.03 MPa and 1.12 MPa both in dry and wet conditions, respectively. Soil with 0.6 % fiber content i.e., MF type of soil shows

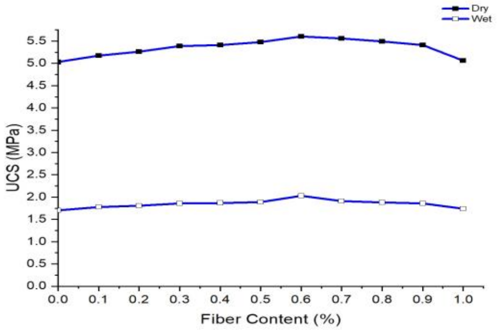


Figure 10. UCS results of M1 type of soil with fiber in dry and wet condition

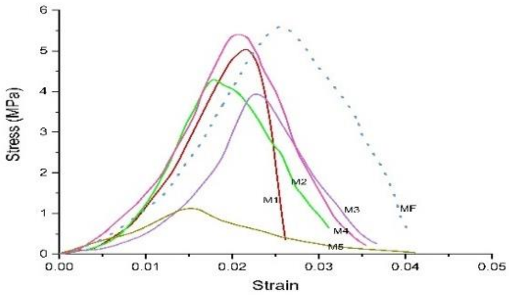


Figure 11. Stress-Strain response of soil with different industrial waste in Dry condition

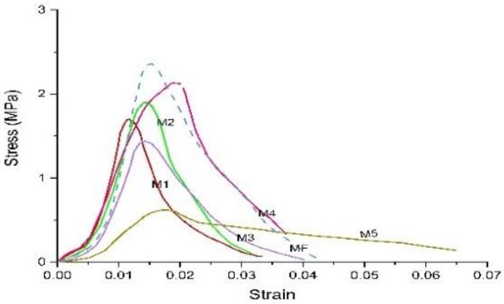


Figure 12. Stress-Strain response of soil with different industrial waste in Wet condition

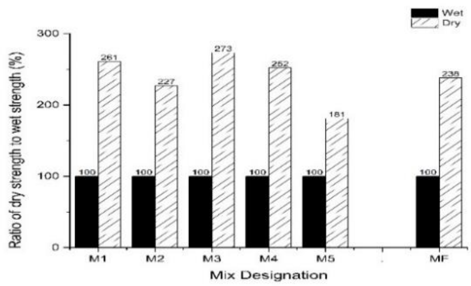


Figure 13. Variation of strength in Dry and wet condition

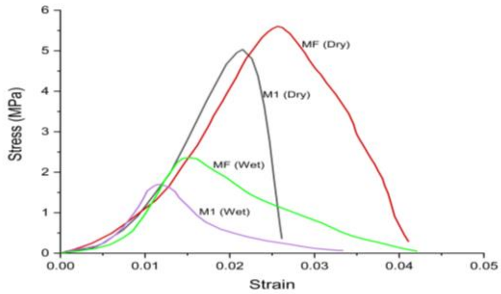


Figure 14. Stress-Strain response of soil with fiber in dry and wet condition

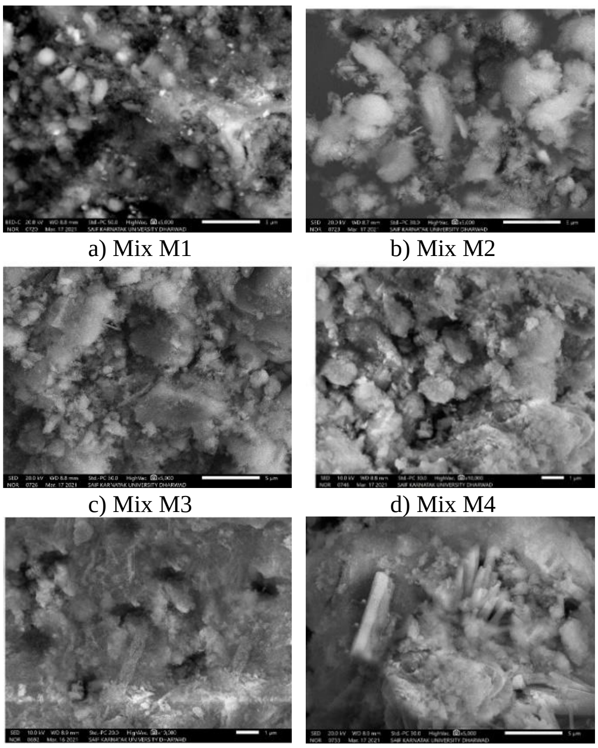
increase in the stress and strain content is 5.6 MPa and 2.35 MPa both in dry and wet conditions, respectively.

3. 4. Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) Study

The results of EDS and SEM for different mixes, denoted by their mix designations after 28 days curing, are shown in Figure 15. The SEM, an advanced technique that aids in understanding the soil structure's behavior when combined with various industrial waste materials and fibers. This method enables a detailed examination of how the soil responds to different mixtures (43).

TABLE 5. Chemical Composition (%) of different Mix

Chemical Name	M1	M2	M3	M4	M5	MF
CaO	7.42	1.12	7.31	15.27	10.17	15.55
SiO_2	23.36	21.06	15.70	30.83	30.83	21.27
Al_2O_3	15.91	2.60	11.50	16.84	6.18	15.41
FeO	8.73	5.41	32.05	11.56	4.98	19.09
MgO	0.42	-	-	0.64	3.58	-
CO_2	42.29	69.82	33.44	23.21	38.76	26.23
S	-	-	-	0.94	0.32	-
K2O	0.66	-	-	0.70	3.35	1.00
TiO_2	1.22	-	-	-	-	1.44
Na_2O	-	-	-	-	0.71	-



a) Mix M1 b) Mix M2

c) Mix M3 d) Mix M4

e) Mix M5 f) Mix M5

Figure 15. SEM Images of soil with different mix

The SEM image distinctly reveals the presence of crystalline particles, which illustrates the flocculation of soil and reduction of voids. The particle size has been enlarged compared to the original natural soil, indicating effective bonding between soil grains, industrial waste, and fiber interactions. CaO, SiO_2 and Al_2O_3 were three important minerals contributing significantly to the development of structural strength (as shown in Table 5) (44). The phenomenon was probably due to the chemical reactions of cement, with industrial wastes and soil to form cement and pozzolanic gels consisting of calcium silicate hydrate (CSH) (12, 45) gel and calcium aluminate hydrate (CAH) gel. The EDS analysis, the dominant elements namely, Si, Ca, Al, O, Mg and Fe are accountable for the enhancement in the stabilization of the soil sample. A similar trend was observed in literature (46-48).

4. CONCLUSIONS AND RECOMMENDATIONS

Earth is a modest, environmentally friendly and richly accessible building material. Compacting in-situ soil mixed with cement is a widely used to improve the soil properties. To rescue the natural soil can be replaced with modern waste materials, such as Fly ash, Bagasse ash, Quarry dust and Iron ore tailing have been in practice to enhance the geotechnical qualities of soils. In the present study, physical properties of the soil, optimization of fiber content and unconfined compressive strength (UCS) was studied. Based on the experimental research work the following important results are emphasized with reference to the addition of industrial waste to natural soil and use of fiber may be drawn.

UCS results for M1, M2 and M3 type of soil is found to be within permissible limit (1.40 MPa for dry condition and 0.7 MPa for wet condition) as per IS 2110-2002.

UCS values for different combination soil with industrial wastes was found to be largest for soil type M4, in both dry (5.37 MPa) and wet (2.13 MPa) conditions. The increase in the strength of M4 type of soil is 6.76 % in dry condition and 10.36 % in wet condition in comparison with natural soil. This may be due to the presence of fly ash which contains CaO and SiO_2 are major component contribute to increase in the strength.

Based upon the UCS values for the soil type M5 provides lowest values in both dry (1.12 MPa) and wet (0.62 MPa) conditions. This could be attributed to the weak bonding of the particles with cement stabilized soil. The strength of this mix is less than the permissible limit as per IS 2110-2002.

The use of polypropylene fiber (MF type of soil) provides larger values of UCS in dry (5.60 MPa) condition and wet (2.35 MPa) condition. The relative strength gain for MF type of soil is found to be 11.33 %

and 21.76 % respectively for dry and wet conditions in comparison with natural soil.

The UCS values of M1 type of soil improves due to fiber addition. The maximum strength was achieved for an optimum fiber content of 0.6 %.

The SEM microstructure images depict soil particle flocculation, leading to an increase in compressive strength. The EDS analysis reveals alterations in chemical composition, specifically Si, Ca, Al, O, Mg and Fe, contributing to the enhanced stabilization of the soil. EDS studies suggest the use of industrial wastes with natural soil that helped in strengthening of soil cement stabilization.

From the test results, addition of cement, fiber and industrial waste to the soil as per the mix designation will increase the geotechnical properties of soil which can be used for civil engineering projects. Since disposing of industrial waste is major problem now a day's which harms the environment and fertile land. Utilization of industrial wastes not only provides the strength but also protect the environment pollution.

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Persian Abstract

چکیده

این مطالعه بر مناسب بودن پسماندهای صنعتی در خاک تثبیت شده با سیمان متمرکز شده است .این تحقیق بر اساس آزمایشات مقاومت فشاری نامحدود (UCS) است .کار آزمایشی برای مقایسه UCS نمونه های خاک تثبیت شده با سیمان با نسبت های مختلف ضایعات صنعتی مانند باطله سنگ آهن، گرد و غبار معدن، خاکستر بادی و خاکستر باگاس انجام شده است .نسبت مخلوط به گونه‌ای طراحی شده است که میزان رس در خاک ریزدانه و چگالی 17.5 کیلونیوتن بر متر مکعب 10.5درصد حفظ شود .مشاهده می شود که مخلوطی که شامل ضایعات صنعتی و الیاف است، خواص مکانیکی را در مقایسه با خاک تثبیت شده با سیمان بهبود بخشیده است .افزودن فیبر باعث بهبود رفتار پس از پیک نمونه خاک شده است .تصاویر ریزساختار میکروسکوپ الکترونی روبشی (SEM) لخته سازی ذرات خاک را نشان می دهد که منجر به افزایش مقاومت فشاری و مطالعات طیف سنجی پرتو ایکس پراکنده انرژی (EDS) می شود که استفاده از زباله های صنعتی با خاک طبیعی به تقویت تثبیت سیمان خاک کمک می کند .و همچنین به حداقل رساندن آلودگی محیط زیست.