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Influence of alccofine and polypropylene fibers on stabilization of soil – An investigational study

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Abstract
In this experiment, the role of admixtures on the strength of red soil (RS) and black cotton soil (BCS) are studied. Many researchers have used different admixtures like cement, nanomaterials, bagasse ash, polypropylene fibers, palm oil, zeolites, bio-enzyme, Alccofine etc. to stabilize the soil. Each admixture has shown considerable enhancement in the strength of the soil. However, there was a lag in literature with a combination of Alccofine and polypropylene fibers and, comparison between two types of soil. Hence, identifying this research gap, the authors attempted to investigate the engineering properties of RS and BCS by adding an admixture like Alccofine and polypropylene fibers. Alccofine are added in varying percentages such as 0, 5, 10, 15, 20, 25, and 30% with fixed 1% of polypropylene fibers. The basic tests of soil such as specific gravity, sieve analysis, water content, Atterberg's limit tests are performed along with strength test. A standard compaction test is carried out to assess the ideal moisture content (MC) and the maximum dry density (MDD) of a soil. Unconfined compressive strength (UCS) test and California bearing ratio (CBR) test are conducted to determine the soil strength. Inclusion of these admixtures in the soil has improved the strength and stability of the soil against the absorption of moisture content. An increment in the strength with an increase of Alccofine content was observed. Maximum strength is found to be at 20% addition of Alccofine, there after we noticed a decline in the strength of soil. Also, the CBR value in both soaked and unsoaked conditions of both the soil has improved the strength by more than 20% compared to nominal soil strength value. Reduction in Atterberg limits has shown that a decrease in water absorption as Alccofine stabilizes the soil and results in a minimum water content requirement for soil. Finally, the test results are compared, and an optimum percentage of Alccofine with constant polypropylene fibers for obtaining maximum strength of soil is identified. Thus, the significance of using Alccofine and polypropylene fibers as an admixture to attain maximum strength is concluded, proving it as an economical and sustainable approach in improving the clayey soil strength.

Keywords
Alccofine, Atterberg's limit, Black cotton soil (BCS), California bearing ratio (CBR), Polypropylene fibers, Red soil (RS).

1.Introduction
Soils are the upper layer of the earth, which is formed by the weathering of rocks. Soils are thus the mixture of organic matter and inorganic constituents [1, 2]. The fine-grained natural soil composite of clay minerals are the clayey soils. In Southern part of India, the most common type of soil found is laterite soil composed of red soil (RS) and black cotton soil (BCS). Laterite soil is also called RS as it contains iron oxide, which gives color to it [3, 4]. These soil properties vary with the presence of moisture content (MC) as it absorbs water and holds within it [5, 6]. Also, BCS, which is rich in clay content called as expansive soil due to its swelling and shrinkage properties [7, 8]. These laterite soil possesses high compressibility, and high-volume changes due to high plasticity and increased permeability [9, 10]. Hence, these soil results in weaker strength and stiffness in the construction field causing a serious problem for the Geotechnical engineer to build any structures or pavement [11]. Thus, we need to stabilize the soil to have a better properties and strength of the soil. To improve the soil properties, many researchers are trying with different admixtures to enhance the strength characteristics of soil [12, 13]. The different admixtures used are cement, nano materials, ground granulated blast furnace slag

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(GGBS), alkali activated volcanic ash and slag, construction materials, solid waste, recycled gypsum, polymers, bagasse ash, polypropylene fibers (PPF), palm oil, zeolites, Alccofine, bio-enzyme, bitumen emulsions, and so on. Each admixture has shown considerable improvement in strength, stability, expansion, shrinkage, and many other properties of the soil. Cement particles help to bind the soil by absorbing moisture and by undergoing chemical reactions with the presence of water. Studies have shown that addition of cement and zeolite helps in obtaining maximum strength at 30% inhibition [14]. Also, it reduces the expansion and contraction of the soil when it is exposed to varying temperatures. This controlled behavior of cement mixed soil is due to hydrophilic minerals like illite and montmorillonite [15]. These minerals have a high specific area, high potential towards volume change, compressibility, and results in high strength of the soil [16].

If volume change is controlled in a soil, it can reduce the settlement of soil which may lead to damage of foundations, buildings, pavements, railways, and many other structures [1]. This chemical soil stabilization will impact on the environment causing greenhouse effect and by releasing carbon-dioxide. GGBS, fly ash, alkali activated volcanic ash and steel slag which are the industrial by-product has shown that soil can also be stabilized without causing harm to the environment [17]. These by-products have shown enormous potential in improving the soil properties and to become an alternate for cement. Interestingly, this industrial waste reduces the carbon footprint on the environment and reduces the waste disposal problem [12]. Solid waste such as tyre poses, tannery, sludge from sewage, refinery industries are also found to be an alternative to cementitious substances as a soil stabilizing agent. This benefits the developing countries as waste disposal is a major challenge concerning to people and the environment. Every solid waste requires some improvement before considering as an admixture in the soil [18]. Different waste impacts on different properties of soil. Hence, we need to identify the property of soil that must be improved and thus choose the corresponding alternative agent [19, 20]. Similarly, there are many other admixtures that can be incorporated to improve the soil properties [21–24]. But there were lag in literatures with a combination of Alccofine and PPF. Hence, identifying this research gap, the authors tried to study the engineering properties of RS and BCS by adding an admixture like Alccofine and PPF.

Alccofine is the finest GGBS based cementitious material derived from Ambuja Cement Ltd, manufacture of various cement in India. The raw material composed of low calcium silicates which impart strength to the soil [11, 25]. Also, it acts as a good binding material reducing volume compressibility within the soil. Hence solve the problem of RS and the BCS. The combination of soil and Alccofine makes the soil brittle and does not yield significant tensile strength. So, authors are using PPF to enhance the ductile property of the soil. Polypropylene is a lightweight synthetic material that has good corrosion resistance and chemical attack. These fibers are treated with polyvinyl alcohol and montmorillonite. These fibers are used with cement to enhance the strength of concrete at different age of curing. Thus, expecting it can also bring noticeable changes in the properties of soil, we are attempting to use PPF in the soil at a constant rate and by varying the Alccofine percentage in relation to soil weight. Soil stabilization with these fibers enhances the soil strength and diminishes the volume change by decreasing porosity in the soil [26].

Thus, an attempt is conducted by mixing Alccofine at varying percentages 0, 5, 10, 15, 20, 25 and 30% and PPF of 1% at a fixed percentage in RS and BCS. As per the recent investigations in PPF, feasible percentage of addition of fibers is found to be 1%. These soils are tested for specific gravity, water absorption, Atterberg's limits, soil classification, relative density, standard proctor compaction (SPC), unconfined compressive strength (UCS), and California bearing ratio (CBR) tests. Later a comparative analysis is made between the properties of both the soils in the presence of admixtures. This research exhibits use of PPF as an additive reinforcement to enhance the properties of soil. The next section covers the literature review and gaps identified from the available research. Likewise, section 3 covers materials and methodology followed by test results, discussion, and conclusion in section 4, 5 and 6 respectively.

2.Literature review

As per the rising demand of the vertical structures and highway road network, the strength of the soil plays a major role in any construction. Due to rapid urbanization, there is a necessity to construct buildings, roads, other structures even on the undesirable soil. This also resulted in an increase cost of land. The majority of costs will be spent on the enhancement of the soil properties to make that soil as desirable for the construction activities [27]. In this concern many researchers trying to improve the soil by using industrial by-product, solid waste, construction waste, recycled materials, and many more [28–32]. Various alternative materials can affect the properties of soil such as its expansion, contraction, water absorption, and durability [33]. They can also improve the soil's Atterberg limits and dry density. There are different admixtures that increase the properties of soil when added in suitable proportions which the researchers have investigated through different trial mixes [34]. The different admixtures used are cement, nano materials, GGBS, bagasse ash, PPF, palm oil, zeolites, Alccofine, bio-enzyme and so on. Chenarboni et al. [1] (2021) examined the properties of the soil by using zeolite and cement as an admixture. They found that the soil dry density was increased, and optimum moisture content (OMC) was reduced. This is due to the fact of cement hydration which increases the binding nature by absorbing sufficient water content. Cement and zeolite content were varied in different proportions and basic tests were performed on the expansive soil. Maximum UCS is found at 30% addition of zeolite. Also, it has shown a high resistance against the volume change of the soil.

This zeolite reduced the brittle nature in turn improved the shear strength of the soil. Devarajan Parthiban et al. [20] (2022) considered a detailed review on industrial precursors to stabilize the weak soil with geopolymers. Geopolymer is used as an alkali activated solution as an alternative for soil stabilization [35]. Thereby minimizing the impact on the environment and improving the strength of the soil. An alternative material called geopolymer is a combination of various materials that can be used for construction projects [36]. Its properties can be enhanced through the development of a binding phase. Binding is achieved by the reaction of various materials such as steel, calcined clay and fly ash with a potassium-based alkaline solution. Solid waste, tannery and refinery products are also used to stabilize and enhance soil properties. This proves to be very efficient in the developing countries where the waste disposal is of major concern [37]. Singh [38] investigated the characterization and stability of BCS using cement kiln dust (10%, 15% & 20%) and terrazyme (2.5%) in varied proportions. The properties of soil such as maximum dry density (MDD), water absorption, Atterberg limits are improved by using these admixtures. The unconfined strength of soil can be enhanced by increasing the percentage of cement kiln dust and terrazyme [39].

Preetham et al. [40] used an industrial waste of steel manufacturing industry called to enhance the geotechnical qualities of soft clay, GGBS was used as a stabiliser. Soft clay is substituted with granulated blast furnace slag (GBFS) in increasing proportions by weight (10%, 20%, 30%, 40%, and 50%) in this study, and the plasticity, density, and strength characteristics of the mix are investigated. With an increase in slag concentration in the soil, the plasticity index drops and the UCS increases, according to a detailed analysis [41]. In addition, there is a noticeable increase in the chemical interaction between free lime and soil with an increase of UCS value along with curing age. Maximum UCS value is obtained at 40% replacement of clay with GBFS and found to be optimum compared to other mix proportions. Gokul et al. [42] used GGBS and sodium hydroxide (NaOH) to study the Alkali activation in clayey soil. Results showed improved stability in the soil with GGBS and 12M NaOH. Throughout its experiment, Alkali Binder ratio (A/B) maintained is 0.4 and 0.6. GGBS is added in varied percentage of 6%, 12%,18% and 24% to the clayey soil. Increase in the amount of GGBS and curing ages can also help to raise the unconfined strength of soil. This method can help in determining the strength of subgrade soil and reduce the cost of construction. In this experimental work, Sudheer Ponnada et al. [43] used Fly ash, GGBS (up to 10%) and 5% NaOH with BCS collected from Dharmapuri, Andhra Pradesh. A test was conducted to see how mineral and chemical admixtures affected the Atterberg limits and pavement thickness. The results showed that the combination of these additives significantly increased the CBR by over 400% [44].

3.Materials and research methodology

3.1Materials

RS and BCS are collected from the northern and southern part of Karnataka. They are pulverized in the laboratory and dried under natural sun to remove the dampness in the soil. *Figure 1* indicates different the materials used in the study. *Table 1* indicates the engineering properties of both RS and BCS. PPF, a reinforcing material are added to soil at constant percentage by the weight of soil. Alccofine is the finest GGBS based cementitious material collected from Ambuja Cement Ltd. These Alccofine are considered at varied percentages like 0, 5, 10, 15, 20% by the weight of soil. *Table 2* and *Table 3* represents the physical and chemical properties of Alccofine respectively.

Figure 1 Materials used for experimental analysis

Table 1 Engineering characteristics of soil

Description	Red soil	Black cotton soil
USCS Classification	Grade 2 Well graded sand	Grade 1 Well graded sand
Liquid limit	52%	60%
Maximum dry density	1.87 g/cc	1.53 g/cc
Relative density	79%	58.45%
Specific gravity	2.82	2.57
Plastic limit	24%	28%
Optimum moisture content	26%	32%
CBR value without soaking	6.5%	4.5%
Plasticity index	28%	32%
Unconfined compressive strength	96.85 kN/m^2	82.26 kN/m^2
Shrinkage limit	18%	16%
CBR value with 4 days (96hours) soaking	5.62%	3.82%

Table 2 Physical characteristics of Alccofine 1101

Property	Test values
Grade	Alccofine 1101
color	Light grey
Specific gravity	2.63
Bulk density	700-900 kg/m^3
Fineness	>9000 cm^2/g

Table 3 Chemical properties of Alccofine 1101

Property	Percentage (%)
Calcium Oxide	33.78
Iron oxide	1.94
Magnesium oxide	9.42
Aluminum oxide	19.36
Sulphur trioxide	0.68
Silicon dioxide	34.82

3.2Methodology

Soil samples are procured into the laboratory for performing the tests. After the process of pulverization of soil, the basic tests are performed on RS and BCS as per the Indian standard. Sieve analysis is performed on the soil for its gradation. Specific gravity and water absorption tests are performed as per Indian standard IS 1124 (1974). To estimate the bulk and dry density of the soil, a relative density test is performed in accordance with IS 2720 (Part 14): 1983. To assess the liquid limit, plastic limit, and shrinkage limit of the soil, Atterberg limit tests are done according to IS: 2720 (Part 5) 1985. This test helps to determine the sensitivity of soil to water content fluctuations. According to Indian standard IS-2720-Part-7-1980, the standard compaction test is used to assess the soil's MDD and OMC. This test aids in determining the soil's compaction properties in relation to water content. UCS test is conducted as per IS 2720-10:1991 to assess the compressive strength of soil under laboratory conditions. Finally, according to IS-2720-PART-16-1987, a CBR test is done for unsoaked soil conditions. The entire structure of testing carried out in this study is depicted in *Figure 2*.

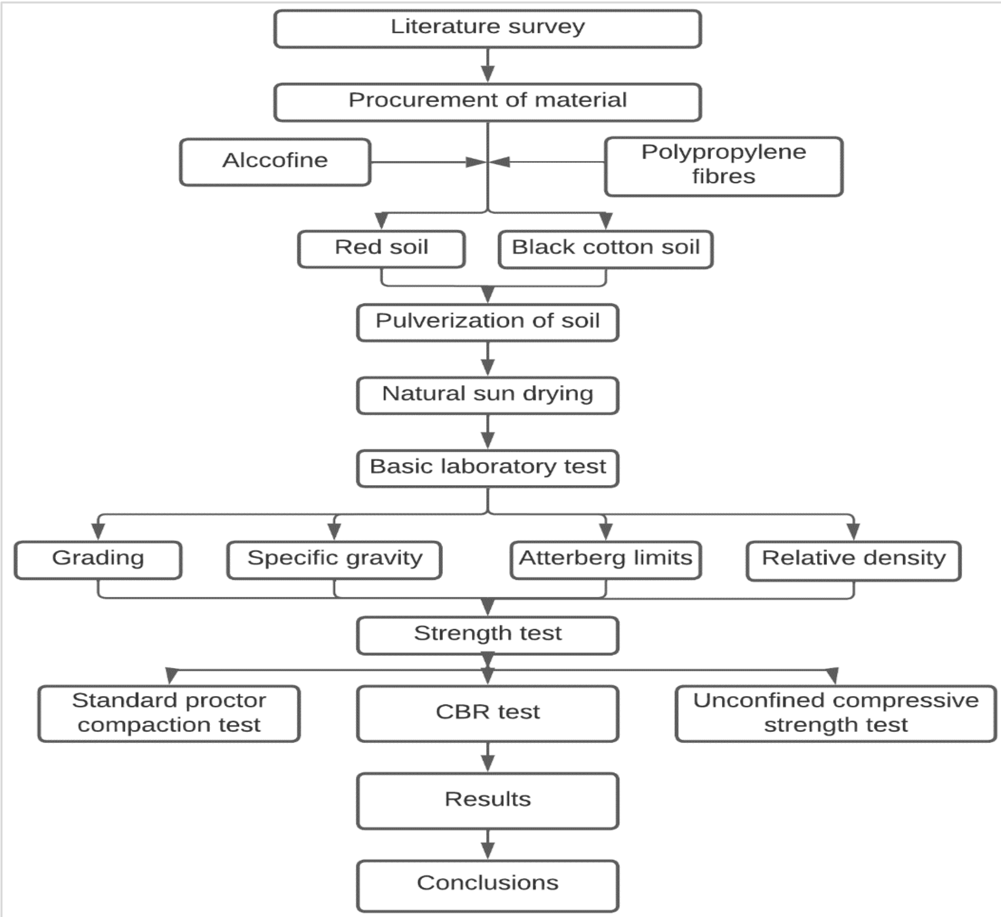

Figure 2 Research methodology

4.Test results

4.1Engineering properties of soil

The basic tests on two types of soil are performed and the results are indicated in *Table 1*. The RS and BCS are classified as Grade 2 and Grade 1 well graded gravel under UCS classification. MDD of RS and the BCS is found to be 1.87g/cc and 1.53g/cc with an OMC of 26% and 32% respectively. An UCS is the fastest and easiest method used to measure the soil's shear strength. At zero confining stress, UCS is the greatest axial compressive stress that a cohesive soil can withstand. The soil specimens RS and BCS possesses an UCS value of 96.85 kN/m2 and 82.26 kN/m2 respectively. Also, CBR value is found to be 6.5% and 4.5% under unsoaked conditions for RS and BCS respectively. Similarly, after 4days (96 hours) of curing or soaking, CBR value is found to be 5.62% and 3.82% for RS and BCS respectively. RS shows superior qualities compared to BCS as it undergoes more expansion on exposed to moisture. And the large number of voids present in the BCS results in the decreased MDD & less strength in terms of UCS & CBR value.

4.2Atterberg limits of the soil

The consistency of the soil is also determined by the Atterberg limits, which are the various properties of the soil that are represented by its plastic, liquid, and shrinkage limits. The influence of various additives on these limits is studied. *Figure 3* to *Figure 6* represents the variation of Atterberg limits & plasticity index with respect to Alccofine and fixed PPF for both RS and the BCS. There is a considerable decrease with an increase of Alccofine percentage.

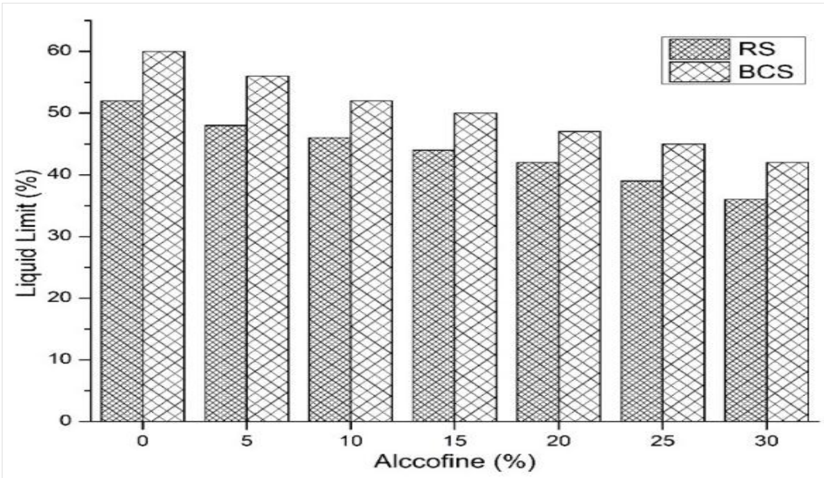

Figure 3 Fluctuation of liquid limit (%) with respect to Alccofine

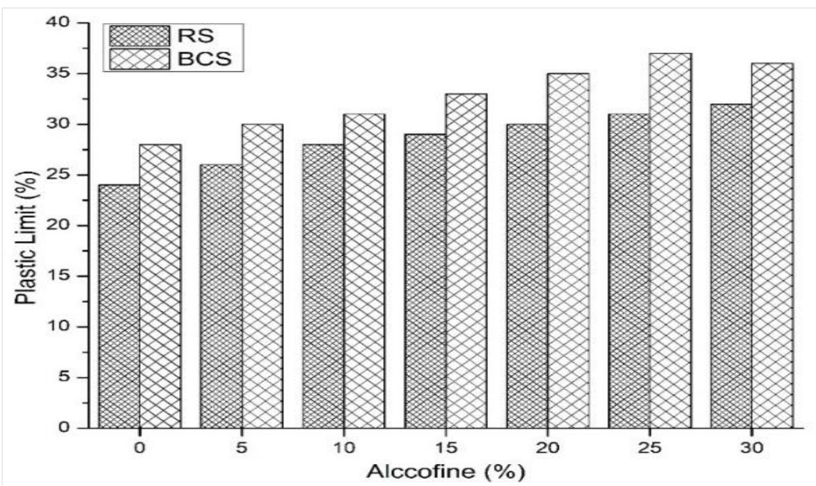

Figure 4 Fluctuation of plastic limit (%) with respect to Alccofine

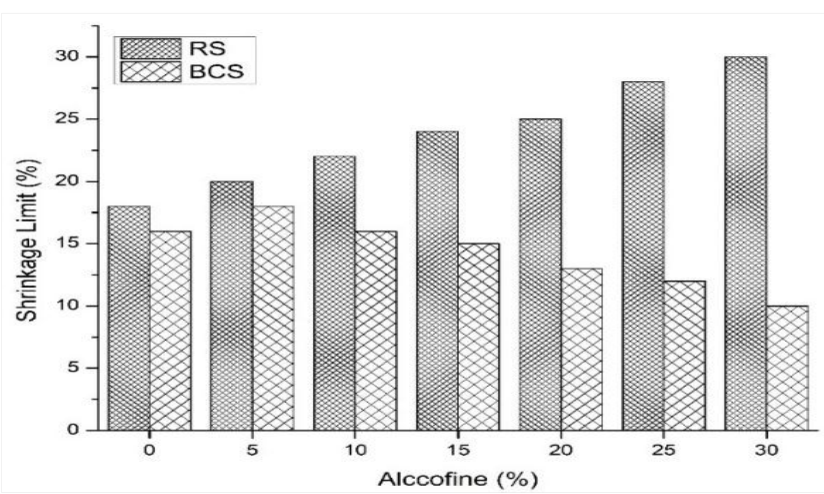

Figure 5 Variation of shrinkage limit (%) with respect to Alccofine

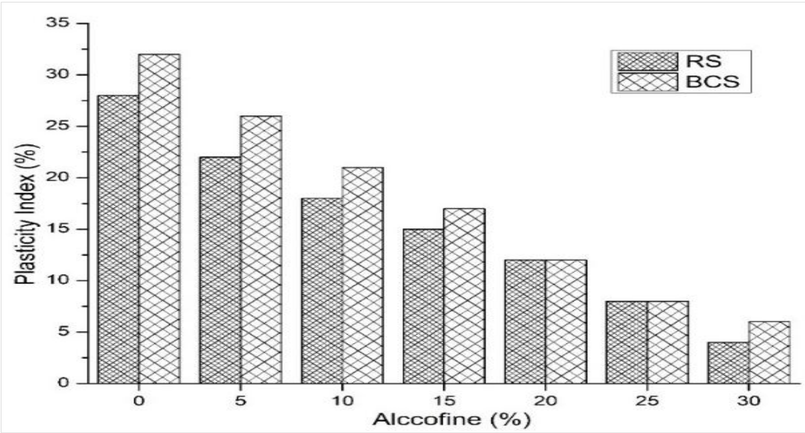

Figure 6 Variation of plasticity index (%) with respect to Alccofine

4.3Standard proctor compaction test

This test's objective is to determine the ideal MC and MDD of the soil for construction. The high value of dry density indicates the stability against settlements of the soil. Variation of MDD in g/cc, MC in % and UCS in kN/m2 with respect to Alccofine and fixed modified polypropylene fibers (MPPF). *Figure 7* and *Figure 8* represent the graphical variation of MDD in g/cc and OMC with respect to Alccofine and fixed MPPF.

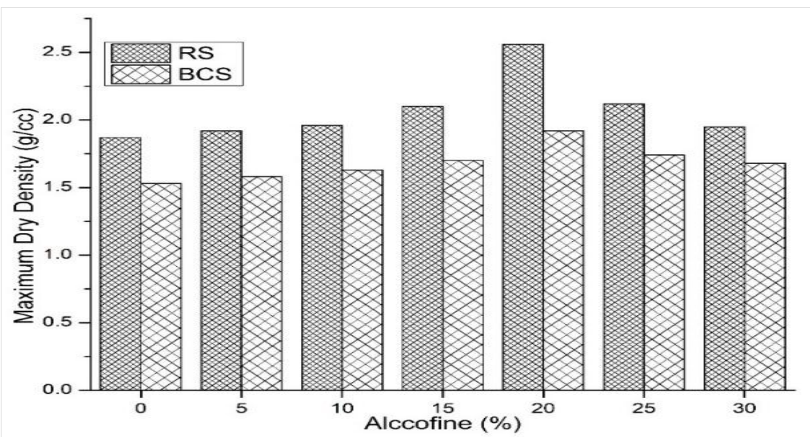

Figure 7 Variation of MDD (g/cc) with respect to Alccofine

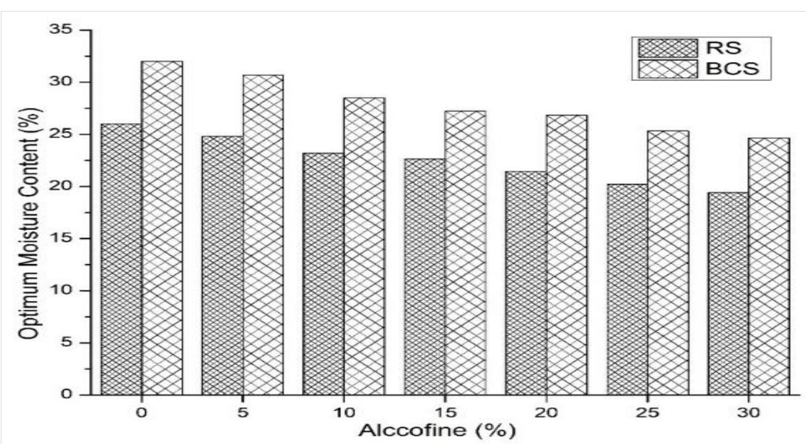

Figure 8 Fluctuation of Optimum Moisture Content (%) with respect to Alccofine

4.4Unconfined compressive strength (UCS)

The UCS test is performed to assess the strength of the soil under laboratory conditions. It can be performed on various types of soil such as red and black cotton. Based experimental results, we can notice that UCS increases up to 20% addition of Alccofine admixture and beyond that strength starts decreasing. Maximum UCS at 20% Alccofine is found to be 132.64 kN/m2 and 106.87 kN/m2 in RS and BCS respectively. *Figure 9* shows the graphical variation of UCS (kN/m2) with respect to Alccofine and fixed MPPF.

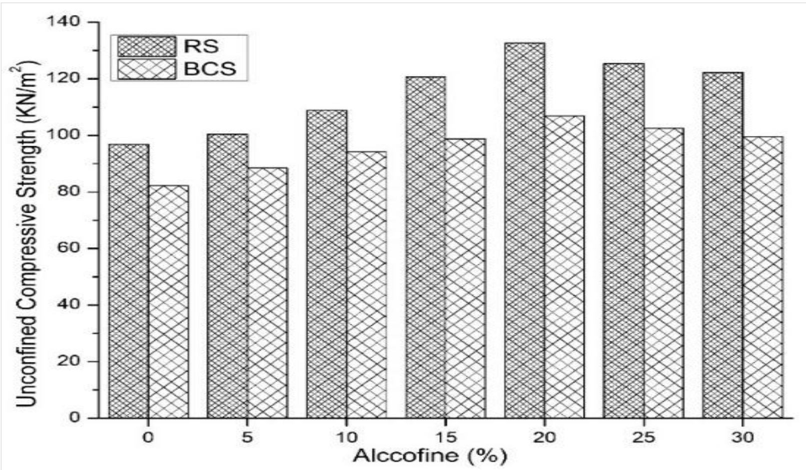

Figure 9 Fluctuation of unconfined compressive strength (kN/m2) with respect to Alccofine

4.5California bearing ratio (CBR) test

CBR test determines the strength of subgrade soil and helps in designing the pavement with minimum thickness and least construction cost. For both the unsoaked and soaked conditions, CBR test is performed to determine the changes. The combination of Alccofine and MPPF enhanced the CBR value in both RS and the BCS, according to the test findings. The graphical fluctuation of CBR value about Alccofine and fixed MPPF is shown in *Figure 10.*

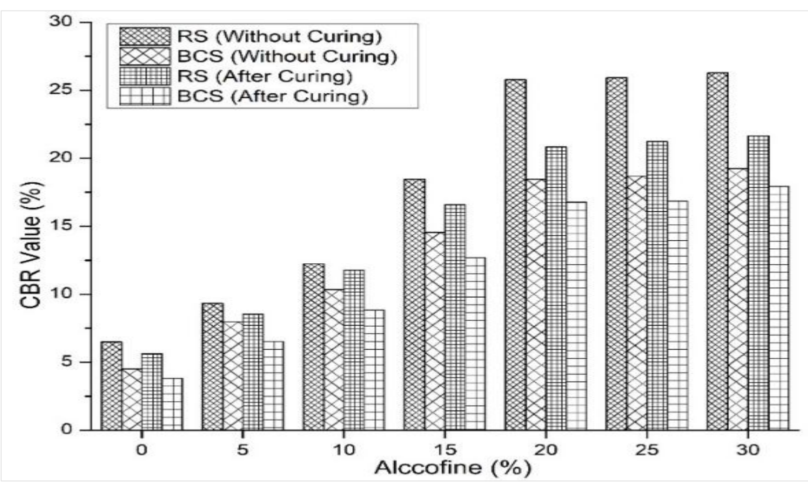

Figure 10 Variation of CBR Value (%) with respect to Alccofine

5.Discussion

5.1Atterberg limits of the soil

We can see from the test results that as the amount of Alccofine increases, the plasticity index drops. This signifies that an addition of these admixtures improves the expansive nature by controlling it in both soils. Thus, admixtures prove to be beneficial in yielding stable soil against moisture content. *Figure 3, 4, 5* and *Figure 6* represents the graphical variation of Liquid Limit, Plastic limit, Shrinkage limit and

Plasticity index in % with respect to Alccofine and fixed MPPF for RS and BCS respectively. There is a gradual reduction in absorption of water or moisture with an increase in Alccofine. Alccofine being a finer material absorbs the water and binds uniformly with the soil making. It is consistent and stable against cracks and brittle nature. This is because Alccofine having cementitious material, undergoes a chemical reaction when it gets contact with water. Calcium-silicate-hydrate (C-S-H) gel formation helps in proper binding of the material resulting in an increase of strength and reduces water absorption by reducing the volume of voids. Also, modified PPF improves tensile strength and improves the stability of soil against failure.

5.2Standard proctor compaction test

The addition of admixtures improves the density of both the soil. *Figure 8* represents the variation of OMC (%) with respect to Alccofine and fixed MPPF.As we can notice that density increases with an increase in percentage of Alccofine. As Alccofine contains cementitious compounds, binds well with the soil, leading to an increase in compactness of the soil with an admixture. This admixture has high potential to resist the volume change and compressibility. A desirable percentage of Alccofine results in MDD and after that MDD decreases slightly. From the results, MDD is obtained at 20% addition of Alccofine with 1% fixed PPF and there after it starts decreasing slightly with increase in Alccofine percentage. A similar trend is noticed in both RS and the BCS. As all the air voids get filled with the moisture, maximum density is obtained beyond which an increase in moisture leads to decrease in soil particle bonding. Thus, OMC decreases with an increase in percentage of Alccofine as like liquid limit. At MDD, an OMC is found to be 21.45% and 26.84% for RS and BCS respectively. From these observations, we can say that addition of Alccofine and PPF improves the properties of RS as well as the BCS. Also, BCS results show an improvement in its results because of Alccofine finer binding particles & its cementitious properties.

5.3Unconfined compressive strength (UCS)

The UCS value increases with an increase in percentage of Alccofine in both RS and the BCS. An industrial by-product containing lime and cementitious substance which helps in proper binding of soil ingredients. The brittle nature of the soil is converted into the stiffened soil by having a proper chemical reaction between soil and moisture. Inclusion of PPF enhances the tensile and shear strength. This has been proved from our experimental investigation that UCS increases with an enhancement of Alccofine up to 20%, thereafter strength decreases slightly but greater than the normal soil. Admixture shows an increase of UCS by 36.95% and 29.91% in RS and BCS proving to be an optimum mix proportion. *Figure 9* shows the graphical variation of UCS (kN/m2) with respect to Alccofine and fixed MPPF. With the use of Alccofine, there is a consistent rise in strength. Also, 20% of Alccofine is found to be optimum dosage as a cementitious material, even in the preparation of concrete. High quantity of Alccofine results in declining of UCS due to incomplete reactions in cementitious properties.

5.4California bearing ratio (CBR) test

Unsoaked condition of CBR value showed maximum value 26.28% and 19.24% with an increased Alccofine percentage in RS and BCS respectively. Similarly, after 96 hours of curing maximum value obtained is 21.65% and 17.93% for 30% Alccofine inclusion in RS and BCS respectively. Results have shown an excellent increase in CBR value both in soaked and unsoaked condition for both the soil. Unsoaked CBR value, has shown an incremental increase with an addition of Alccofine and in soaked condition, there is a slight decrease in CBR value but higher than conventional soil. *Figure 10* shows the test results and graphical variation of CBR Value (%) with regard to Alccofine and fixed MPPF respectively. Test result has proven that increase of Alccofine increases CBR value under both conditions of soil.

5.5Limitations of the study

- Increase in Alccofine beyond 20% reduces the UCS of soil and this may be due to insufficient hydration process or poor bonding between soil and Alccofine.
- Microstructural analysis of the soil is not explored, and it can be considered as future study by conducting X-ray diffraction (XRD), scanning electron microscope (SEM) analysis.
- Properties of soil are not studied with respect to variation of temperature.
- Deformation of the soil is not investigated which can be considered as future scope.
- Mathematical relation between strength, CBR, and other properties can be explored in future study.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion

This experimental work describes that the usage of Alccofine and PPF in soil for its Stabilization. Alccofine-1101 is added in different proportions such as 0%, 5%, 10%, 15%, 20%,25%, and 30% by weight of soil and modified polypropylene fiber at a constant 1% for RS, and BCS. Experimental investigation is performed to assess the engineering properties of soil and the UCS, CBR tests are performed to determine the shear properties of soil. From the results, we can observe that the inclusion of admixtures has enhanced all the soil properties and has given better results. Atterberg limit test results have proved that an increase in the quantity of admixtures reduces the water content. An industrial waste containing lime and cementitious components enhances the chemical reactivity with soil and water. Thereby increases the bonding between soil particles, reducing brittle nature of the soil. This chemical reaction absorbs the MC and undergoes hydration process leading to reduction in Atterberg limits and OMC. SPC strength tests showed that MDD had shown a consistent increase in its value with an increase in admixtures. Also, OMC has decreased with an increase in admixtures proving a reduction in water absorption. Addition of Alccofine enhances the stiffness and stability of soil. Thus, improving strength of the soil and controls the volume change considerably. UCS has improved with an increase in the admixture quantity. Maximum UCS at 20% Alccofine is found to be 132.64 kN/m2 and 106.87 kN/m2 in RS and BCS respectively. CBR test results also shown the increment in its value with an increase in admixtures. Soaked CBR test results after 4days have given a higher value than the unsoaked CBR test. Unsoaked condition of CBR value showed maximum value 26.28% and 19.24% with an increased Alccofine percentage in RS and BCS respectively. Similarly, after 96hours of curing maximum value obtained is 21.65% and 17.93% for 30% Alccofine inclusion in RS and BCS respectively. Results have shown an excellent increase in CBR value both in soaked and unsoaked condition for both the soil. We can say that in both the soil 20% Alccofine has given the highest strength, and beyond 20% strength decreases slightly. As a result, we may conclude that the optimum proportion of Alccofine admixture for soil stability is 20%. A study of microstructural properties of soil, deformation and influence or effect of the temperature on the soil can be considered as future study. Also, resistance of soil for seismic vibration can also be explored further to solve the settlement problem and thereby we can avoid the damage or failure of the structures during disaster activities.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Reshma T V: Conceptualization, methodology, investigation, writing - original draft. **Chandan Kumar Patnaikuni**: Supervision, data curation. **Manjunatha M:** Supervision, validation. **Bharath A**: Writing - review & editing. **Ranjitha B Tangadagi:** Investigation, data curation.

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Appendix I

S. No.	Abbreviation	Description
1	A/B	Alkali Binder Ratio
2	BCS	Black Cotton Soil
3	CBR	California Bearing Ratio
4	cm^2/g	Square Centimeter Per Gram
5	C-S-H	Calcium-Silicate-Hydrate
6	GBFS	Granulated Blast Furnace Slag
7	GGBS	Granulated Blast Furnace Slag
8	g/cc, g/cm^3	Gram Per Cubic Centimeter
9	KN/m^2	Kilo Newton Per Square Meter
10	MDD	Maximum Dry Density
11	MC	Moisture Content
12	MPa	Mega Pascal
13	MPPF	Modified Polypropylene Fibers
14	NaOH	Sodium Hydroxide
15	OMC	Optimum Moisture Content
16	PPF	Polypropylene Fibers
17	RS	Red Soil
18	SEM	Scanning Electron Microscope
19	UCS	Unconfined Compressive Strength
20	XRD	X-Ray Diffraction