COMBINED EFFECT OF STEEL FIBERS AND GROUND GRANULATED BLAST FURNACE SLAG ON CLAYEY SOIL

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Abstract - *An important practical part of geotechnical engineering is the technical improvement of soil. Soil stabilization is a well-known method for the treatment of problematic soils. Its advantages over soil replacement include low cost and fast implementation. To improve the strength and stiffness various cementitious materials are adopted. The stabilizers include Portland cement, lime, quartz, fly ash, and GGBS. In the last few decades, green materials and their applications in the civil engineering infrastructure have been gaining significant attention Unfortunately, these mixtures do not perform well under tensile load because soil-cement materials are brittle. Ground granulated blast furnace slag (GGBFS) is a by-product of the manufacture of iron. GGBS material is also used as a substitute for cement in concrete mixtures and in soil stabilization. The Fiber inclusion in expansive clays shows significant enhancement in swell-shrink behaviour and in the prevention of tensile cracks in soil. The study aims to find the combined effect of steel Fibers and Ground Granulated Blast Furnace Slag (GGBS) on clayey soil. The effect of variation in the percentage content of steel fiber (0.5%, 0.75%, 1%) and different bend angles of steel fibers (90,120,150,180 degrees) and percentage of GGBS was experimentally investigated. The strength of the soil is tested at the 7th, 14th and 28th day using the Unconfined Compressive Strength Test (UCS) and Split tensile strength (STS) test. It was found that 30% GGBS content was the optimum content for the soil and as the fiber content and curing period increase the UCS and STS also increase. UCS and STS of Soil-GGBS-Steel fiber mix with Steel fiber having 120 degrees show maximum Strength compared with other fiber bend angles.*

Keywords: Steel Fiber, GGBS, Split tensile strength

1. INTRODUCTION

Ground improvement is a widely used technique for enhancing soil conditions. Soil stabilization involves modifying the physical and chemical properties of soil to increase its strength, durability, and overall performance. Soil stabilization aims to render the soil suitable for construction, especially in regions where the natural soil may not possess the required engineering characteristics. Various techniques are used for soil stabilization, including the incorporation of stabilizing agents such as lime, cement, fly ash, or ground granulated blast furnace slag (GGBS). These agents alter the soil's properties, enhancing its stability, reducing its susceptibility to erosion, and improving its load-bearing capacity. Soil stabilization is frequently employed in the construction of roads, embankments, foundations, and other civil engineering projects to ensure the long-term integrity of structures built on or with the stabilized soil. Ground granulated blast furnace slag (GGBS), a byproduct of the blast furnace, is mainly composed of silicate and aluminosilicate compounds formed from the molten calcium extracted during the furnace process. Industrial production generates approximately ten to twenty megatons of GGBS each year. Failure to properly utilize or dispose of this significant amount of GGBS can result in environmental pollution and degradation. GGBS serves as an effective soil stabilizing agent, improving soil characteristics. Its properties are similar to those of cement, making GGBS a popular alternative to traditional cement in modern applications. Being a by-product further adds to its appeal.

Soil exhibits inherent weakness in tension but possesses significant strength in compression, a fundamental characteristic influencing its behaviour in engineering applications. Similar to steel reinforcement in concrete, the addition of fibers offers tensile reinforcement to the soil, mitigating its inherent weakness and enhancing overall stability. In non-cementitious soils, strength is provided by the interaction between the soil and fiber surfaces. In cementitious soils, the cohesive properties of cementitious materials combined with surface fiber interactions play a role in soil strength. Integrating fibers into soil systems yields numerous advantages, including the reduction of tensile crack development, minimization of soil deformations, and enhancement of shear strength and bearing capacity. By strategically placing fibers within the soil matrix, the material gains resistance against tensile loads, thereby improving its overall structural integrity and performance. This study aims to analyse the combined effect of steel fibers and GGBS on soil strength characteristics.

Unconfined compressive strength characteristics of GGBS and lime was studied by Pai et al. [1] in 2019. UCS and CBR were done on different proportions of GGBS and lime content and it was found that, the UCS value of soil–binder mixes increased with higher binder content. The soil-GGBS-lime mix demonstrated greater strength compared to the soil-GGBS mix. Additionally, the CBR value of the soil-GGBS-lime mix was higher than that of the soil-GGBS mix.

Compaction characteristics and index properties of GGBS on clayey soil were studied by Anand et al. [1] in 2018. Varying proportions of GGBS content were studied and he found out that As the GGBS dosage percentage in soil increased, the maximum dry density value also increased. For clayey soil mixed with 16% GGBS, the liquid limit was 46%, the plastic limit was 30%, and the plasticity index was 16%. Noolu et al. [3] in 2018 studied the durability of GGBS-stabilized black cotton soil. It was found out that durability results for GGBS-based geopolymers showed a reduction in strength of about 10% after undergoing 12 wetting and drying cycles.

Kalhor et al. [3] in the year 2008 studied the effect of metal fibers on clayey soils. Varying percentages of fiber content and fiber length were studied and it was found that the use of metal Fibers caused an increase in the axial strength of clay soil and the peak point of axial strength is observed at 120 bend angles of fiber. Praveen et al. [3] in 2020 studied the improvement of CBR value for steel fibre-reinforced soil admixed with fly ash and cement. It was observed that the steel fiber reinforcement and cement modification of marginal soil can enhance its CBR value. Cement modification can transform marginal soil into non-plastic soil, leading to improved grain structure. When marginal soil is mixed with both cement and fly ash, there is a significant reduction in the plasticity index compared to untreated marginal soil. Alkali activation of clayey soil using GGBS and NaOH was studied by Steffi et al in the year 2020. it was found that for a higher alkali-to-binder ratio (A/B) typically results in increased compressive strength and Unconfined Compressive Strength (UCS) of stabilized soil tends to rise with higher percentages of GGBS. The compressive strength of the soil also increases as the curing period is extended.

2. MATERIALS AND EXPERIMENTAL SETUP

2.1. Soil

The soil used in this study was excavated 2m below the ground level. The soil was collected from Thonnakal, Thiruvananthapuram district. The properties of soil are summarized in Table 1. After testing the soil, it was found that the collected soil sample was Low plasticity clay (CL) according to IS Specifications.

Table – 1: Properties of soil

PROPERTY	VALUE
Initial Moisture content (%)	12.51
Specific Gravity, G	2.47
Clay (%)	42
Silt (%)	42
Sand (%)	16
OMC (%)	14.4
Liquid limit (%)	24.4
Plastic limit (%)	16.96
Maximum dry density (g/cc)	1.86
Unconfined compressive strength (kPa)	50.79
IS Classification	CL

2.2. GGBS

GGBS is collected from Astra Chemicals, Chennai. The properties of GGBS are shown in Table 2.

Table – 2: Properties of GGBS

Properties	Values
Fineness (m/Kg)	390
Specific gravity	2.85
Particle size (Cumulative %)	97.10
Insoluble Residue (%)	0.49
Magnesia content (%)	7.73
Sulphite content (%)	0.38
Moisture content (%)	0.10

2.3. Steel Fiber

Steel fiber is collected from the local market in Trivandrum. The properties of GGBS is shown in Table 3.

Table – 3: Properties of Steel fiber

Properties	Values
Length	20 mm
Diameter	0.5 mm
Aspect ratio	40
Carbon content (%)	0.002

2.4. Sodium Hydroxide

Sodium hydroxide pellets, also known as Caustic Soda, was purchased from Trivandrum Scientific Supplies Private Limited, Trivandrum. 1 Molar NaOH solution was used in the study.

3. EXPERIMENTAL PROGRAM

For the present study, the required materials were collected. 1 M NaOH solution is prepared by diluting it in the required amount of water. The soil sample is mixed with varying GGBS content (20%,30%,40% of dry weight of soil) and 1 M NaOH solution in 0.6 admixture to binder ratio (A/B). Mix the sample uniformly and place it in a UCS mould of diameter 3.8cm and height 7.2cm in 3 layers. The cylindrical specimen is then air-cured for 7, 14 and 28 days and then tested for the Unconfined Compressive Strength (UCS) test to find the optimum GGBS content.

To find the UCS and Split tensile strength (STS) for varying fiber content on soil-GGBS-Steel fiber mix. The optimum GGBS content found was mixed with the required soil content and 1 M NaOH solution at optimum moisture content and maximum dry density. Then varying steel fiber content of 0.5%, 0.75%and 1% is mixed uniformly with the soil-GGBS mix. And fill the UCS mould and air cure for 7,14 and 28 days. After the end of the curing period, the sample prepared is tested for the Unconfined compressive strength test and split tensile strength test.

To conduct the split tensile test, cylindrical specimens with a diameter of 3.8 cm and a length of 7.2 cm were prepared at the optimum moisture content and maximum dry density, following the same procedure used for unconfined compression tests. The soaked specimens were placed horizontally between the bearing blocks of the compression testing machine, which was adjusted to a strain rate of 1.00 mm/min. Mild steel strips, approximately 5 mm thick, 5 mm wide, and 50 mm long, were curved at the contact surface and placed on the upper and lower bearing elements of the cylinder to ensure uniform bearing pressure. The split tensile strength is obtained by the following equation:

Split tensile strength $= \frac{2P}{\pi d L}$,

where P=failure load; L=thickness or length of specimen; and d=diameter of the specimen

The UCS and split tensile strength for different bend angles of steel fiber that is for 90,120,150 and 180 degree is also tested for soil-GGBS-Steel fiber mix (Fig-1). For that 0.75% of steel fiber of different bend angles is mixed into the Soil-GGBS mix.

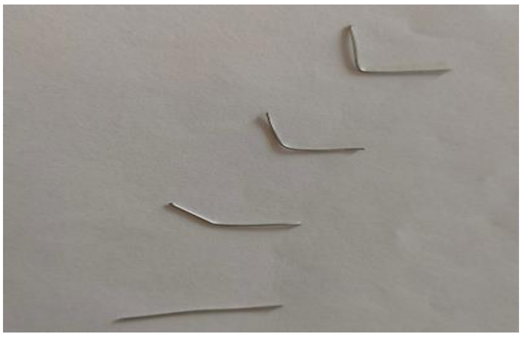


Fig – 1: Steel fibers bend at 90, 120,150 and 180 degrees.

4. RESULTS AND DISCUSSION

The unconfined compressive strength test and Split tensile strength tests were carried out following the IS procedure to analyse the soil-GGBS -Steel fiber mix.

The Unconfined compressive strength of soil-GGBS mix having varying GGBS content for different curing periods is shown in Fig. 2. Unconfined Compressive 28th day Strength of the Clayey soil for 20%, 30% and 40% GGBS are 284.78kPa, 630.58kPa and 355.97kPa respectively. UCS value increases at 30% GGBS content and then it decreases at 40% GGBS content. Therefore 30% GGBS content is taken as the optimum GGBS content for this soil. The addition of GGBS to the soil increases the unconfined compression strength over the curing period, demonstrating the time-dependent reactivity of the slag.

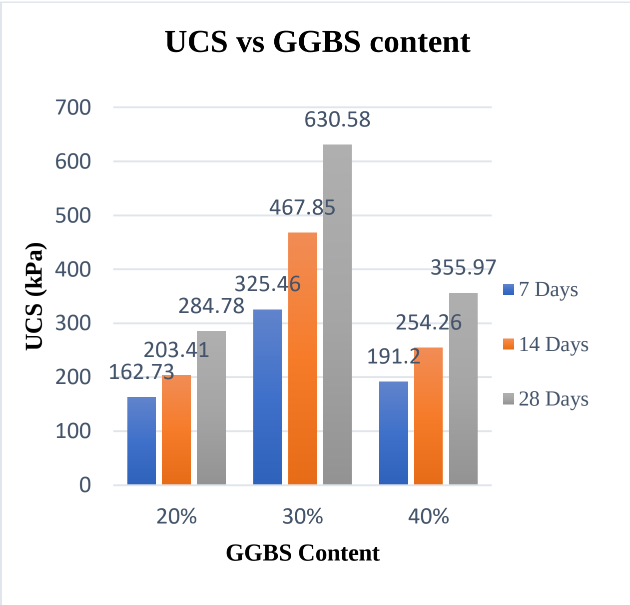


Fig- 2: Unconfined compressive strength of soil-GGBS mix having varying GGBS content

The concentration of the sodium hydroxide (NaOH) solution significantly influences the physical and mechanical properties of soil-stabilization-based geopolymers. This solution contains hydroxide ions (OH-

) and sodium ions (Na+), which trigger the reaction between the internal silicate (Si) and aluminate (Al) components, starting the dissolving process.

The results for Unconfined compressive strength and Split tensile strength of soil-GGBS- steel Fiber mix are shown in Fig. 3 and Fig. 4. For 0.5%, 0.75%, and 1% steel fiber on Soil-GGBS mixed soil the UCS were 630.58kPa, 1769.7kPa and 2603.7kPa respectively and split tensile strength were 124.1kPa, 156.34kPa and 236.5kPa respectively after 28 days of curing. It shows that as the fiber content and curing period increase the UCS and Split tensile strength of the Soil-GGBS -Steel fiber mix increases.

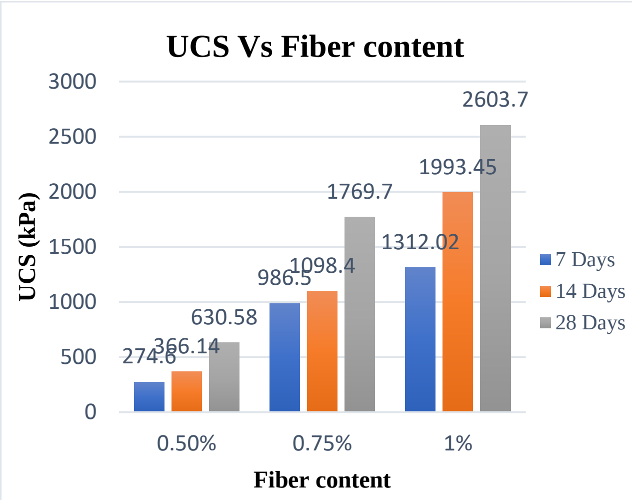


Fig- 3: Unconfined compressive strength of soil-GGBS-steel Fiber mix for varying fiber content for different curing periods.

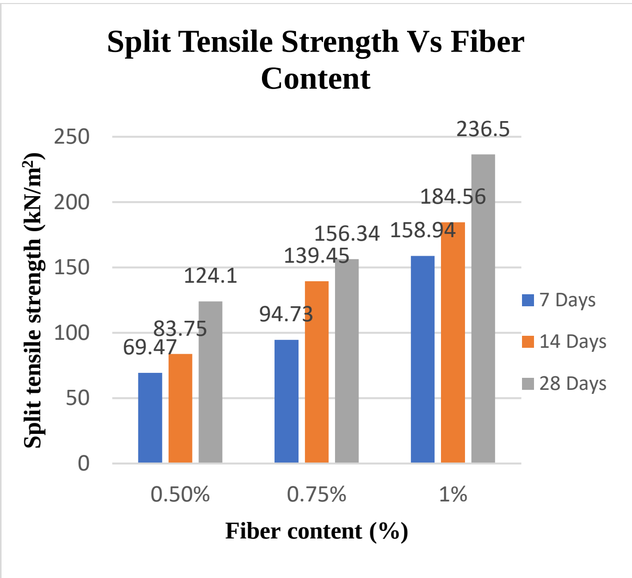
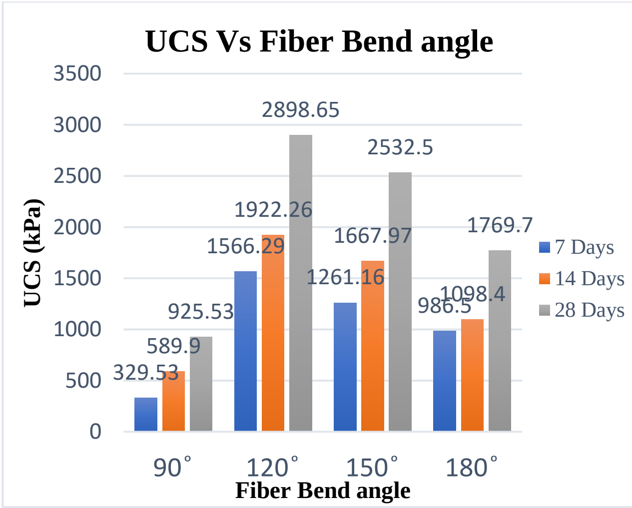
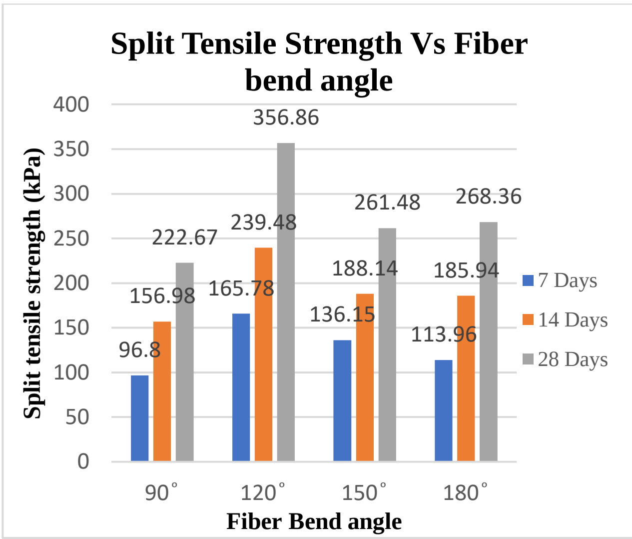


Fig- 4: Variation of split-tensile strength (STS) of soil with varying % of steel fiber, for soil mixed with 30% of GGBS for different curing periods.

The Variation of UCS and STS of soil with different bend angles of steel fiber (0.75%), for soil mixed with 30% of GGBS for different curing periods is shown in Fig. 5 and Fig. 6. The soil mixture contains Fiber with a bend angle of 120˚ shows maximum UCS and STS value followed by 150˚ bend angle and 90˚ bend angle shows the least strength compared to others. This shows that the fiber bend angle also influences the strength of the Soil-GGBS-Steel fiber mix. This indicates that the maximum bond between the Soil-GGBS mix and steel fiber occurs at a 120° bend angle of the fiber. These findings suggest that the Soil-GGBS-Steel fiber blend could potentially replace OPC for soil stabilization applications, such as deep mixing for ground improvement, which could lower the costs of both soil stabilization and landfilling.



Fig– 5: Variation of UCS of soil mix with different bend angles of steel fiber, for soil mixed with 30% of GGBS for different curing periods.



Fig– 6: Variation of Split Tensile strength of the soil mix with different fiber bend angles for different curing periods

5. CONCLUSIONS

The study has been conducted to assess the potential of the combined effect of GGBFS and Steel fiber for the stabilization of the soil. Unconfined compressive strength and Split tensile strength were tested. Several observations were drawn from the study:

– 30% GGBS content has been found out as the optimum content for the soil.
– Beyond the optimum content, GGBS content increases UCS of the soil decreases.
– As the fiber content increases the UCS and STS of the soil-GGBS-Steel fiber mix increases.
– For different bend angles of steel fibers, 120° bend angle shows maximum UCS and STS.
– As the curing period increases the strength of the soil-GGBS-Steel fiber mix also increases.

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