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Sustainable Use of Steel Slag and Polypropylene Fibers for Soil Improvement

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Abstract - The sustainable management of industrial by-products and the improvement of weak soils are two major challenges in modern geotechnical engineering. The present study explores the combined utilization of steel slag and polypropylene fibers for improving the engineering performance of soil while promoting the beneficial reuse of waste materials. Steel slag, generated in large quantities during steel production, has the potential to act as a granular stabilizing material because of its hard, angular, and durable particles. Polypropylene fibers, on the other hand, can provide additional reinforcement by improving interparticle bonding and restricting the development of cracks and deformation within the soil matrix. In this investigation, steel slag is incorporated into the soil at 10%, 15%, and 20%, while polypropylene fibers are added at 0.50%, 0.75%, and 1.00% by dry weight of soil. The stabilized soil mixtures will be systematically evaluated to examine the influence of individual and combined additions on their engineering behavior. The experimental programme will include Atterberg limits, standard Proctor compaction, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) tests. The results will be analyzed to identify the optimum combination of steel slag and polypropylene fiber that provides the most favorable improvement in strength and load-bearing characteristics. The steel slag is anticipated to enhance the soil's stiffness and frictional resistance, whereas the polypropylene fibers are expected to contribute tensile reinforcement and improve resistance to cracking and deformation. The study aims to demonstrate that the appropriate combination of steel slag and polypropylene fibers can provide a cost-effective, durable, and sustainable approach to soil improvement. Furthermore, the utilization of steel slag can reduce the environmental problems associated with industrial waste disposal and minimize the dependence on conventional stabilization materials, contributing to more resource-efficient and environmentally responsible geotechnical construction practices.

***Key Words*:** Compaction test, CBR, UCS, Polypropylene Fibers, Steel Slag

INTRODUCTION

The foundation for any land-based structure is the most important part of the entire structure. The strength of the foundation is determined by the soil around it. To improve soil strength, we must first have a thorough understanding of its properties and the elements that govern its behavior. Soil stabilization is a powerful tool for improving soil properties. Increase in population, consumerism and development led to very rapid increase in accumulation of plastic waste. There day to day uses contribute to a huge increase in volume of wastes. It is commonly known that the planet Earth is confronting environmental issues, including a waste disposal dilemma. These issues arise as a result of garbage, and one of the most commonly produced wastes is plastic, which accounts for 12.3% of total waste produced. This creates the need for encouraging the use of plastic waste in geotechnical engineering is necessary to keep the development path sustainable. Modernization raises demand for fuels and construction materials, resulting in scarcity and price increases. With rising population and a scarcity of land with good engineering properties, it is vital to investigate cost-effective stabilization methods. Various conventional methods of stabilization such as mechanical, chemical and reinforcing by steel or other admixtures are very costly so for both economical and preventing ecological hazards by reducing plastic waste by using it for improving soil properties. The majority of recent discoveries and approaches have been polymer-based in nature, such as processed polymer fiber or waste products such as polythene bags, plastic bottles, and recycled plastic pins. These new polymers and compounds have a number of important advantages to mechanical methods, including being less expensive and more effective in

general, as well as being substantially less hazardous to the environment than conventional chemical solutions. The term "soil stabilization" refers to the use of controlled compaction, proportioning, or the addition of a suitable admixture or stabilizer to improve the stability or bearing power of soil. Methods of soil stabilization are:

Mechanical method: Soil of different gradations are mixed and compacted to reduce the voids and achieve required density. Cohesion less soil by vibratory roller and cohesive soil by sheep foot roller.

Chemical Method: Certain additives are added in proper quantities to enhance the engineering properties of the soil. Some of the chemical additives are- cement, lime, bitumen, fly ash etc.

Polymer method: To improve the physical qualities of soil, polymers are added. Various polymers have been found to promote water retention and prevent erosion, as well as boost soil shear strength and structure, at very low concentrations within soils. According to the previous studies, polypropylene fiber as a soil reinforcement increases direct shear strength parameters (cohesion and angle of internal friction), unconfined compressive strength, and the soil's California Bearing ratio. In this study soil stabilization using randomly distributed polypropylene fibers in varying percentages obtained from waste sources and results obtained are studied to get the maximum enhancement in properties sub-bases.

The combined use of steel slag and polypropylene fiber offers a promising approach to soil stabilization by utilizing the granular characteristics of steel slag and the reinforcing properties of polypropylene fibers. Steel slag may improve soil packing and stiffness, whereas polypropylene fibers can enhance ductility and resistance to cracking. Therefore, the present study investigates the effects of steel slag and polypropylene fiber on the geotechnical properties of clayey soil through laboratory tests such as the Standard Proctor compaction test, unconfined compressive strength (UCS) test, and California Bearing Ratio (CBR) test. The study aims to identify suitable proportions of both additives for improving soil performance and exploring their potential applications in pavement subgrades and other geotechnical works.

2. Literature Review

Shantanu Paul et al (2026)

Expansive clays undergo moisture-induced swelling and shrinkage that can cause serviceability loss in lightly loaded structures and pavements. In Bangladesh, stabilization of such clay is a geotechnical concern, while steel slag generated from local steel industries remains an underutilized calcium-rich by-product. Although lime is a well-established calcium-based stabilizer, its energy-intensive production motivates evaluation of steel slag as a complementary stabilizing agent. Additives were mixed at 3%–15% by dry soil mass. UCS and one-dimensional swell specimens were compacted at the untreated soil's optimum moisture content and maximum dry density, sealed, and cured at 25°C□2°C; FSI was measured separately on uncured oven-dried mixtures after 24himmersion. SEM showed densification, aggregation, pore filling, and gel-like products morphologically consistent with ce-mentitious bonding. Lime most consistently reduced FSI at high dosage, steel slag minimized long-term swell pressure, and optimized blends provided balanced performance.

Degou Cai et al. (2025)

In order to create stabilized soil, three waste materials—rice husk ash (RHA), steel slag (SS), and iron tailing (IT) powder—were chosen and used in concert with cement. The microstructure, degree of hydration, and mechanical strength of the stabilized soil samples were assessed. According to the experimental findings, samples' mechanical qualities improved as the cement content increased. In particular, samples mixed with RHA exhibited the lowest strengths as compared to samples combined with SS and IT, suggesting that RHA has no effect on strength improvement. Additionally, compared to the reference batch, SS and IT demonstrated a significantly greater impact on enhancing the mechanical strength of the stabilized soil samples, with strength increasing rates as high as 60%. Additionally, the benefits of cement and waste materials on enhancing the performance of stabilized soil samples have been further demonstrated by the microstructure analysis results. Waste materials have been shown to improve the hydration reaction and pore structure. With a high usage of specific common wastes, the current work provides an insight into ecologically responsible road construction.

Sher Shah et al. (2025)

Using glass powder and steel slags as industrial wastes, the current study aims to explore various soil properties, including California bearing ratio, unconfined compressive strength, plasticity index, and maximum dry density. Steel slags and glass powder both significantly alter the various soil properties of the two soil samples. When glass powder and steel slag were added, the PI values of soil samples dropped from 13.7% to 10.1% and from 13.1% to 8.3%, respectively. Combining both with the specified percentage content significantly reduced the PI, with the largest decrease of 1.4% at 10% GP and 20% SS. In a similar vein, the MDD rose as the SS and GP contents increased; the highest increases were noted for 10% SS (1.92 g/cc) and 10% GP (1.96 g/cc), respectively. However, combining 10% GP and 20% SS with glass powder and steel slag produced the highest growth of 2.21 g/cc. Glass powder and steel slag both raised the CBR value. 10% SS (8.7%) and 10% GP (9.6%) showed the biggest increases. The blend of 10% G.P. and 20% SS with steel slag and glass powder showed the greatest increase of 17.6%. The number increased by over 183.8% from its initial value. Consequently, one popular and economical way to enhance soil qualities for stabilization is to utilize glass powder and steel slag.

Haojie Li et al. (2023)

A high-performance geopolymer cementing substance, mostly composed of green steel slag and fly ash, was formulated and activated using sodium silicate alkalinity to address the geological risk posed by unstable loess slopes susceptible to collapse and landslides. The investigation examined the mechanical characteristics and microstructural alterations of loess subjected to varying amounts of steel slag-fly ash geopolymers and different curing durations through a range of experiments, including unconfined compressive strength, direct shear, disintegration, scanning electron microscopy, and X-ray diffraction. The findings indicate that the utilization of geopolymers significantly enhances the internal friction angle, cohesiveness, and unconfined compressive strength of loess, while simultaneously reducing the quantity and speed of disintegration of stabilized soil. The consolidated soil blended with 20% geopolymer and cured for 28 days exhibited an internal friction angle of 31.12°, a cohesiveness of 81.09 kPa, and an unconfined compressive strength of 570.86 kPa. These figures are 1.62, 1.76, and 3.36 times more than the corresponding values of loess, respectively. Moreover, the degradation of consolidated soil within 1800 seconds is minimal, merely 1.97%. The efficacy of curing is significantly influenced by the age of the hardened soil. The duration of curing may be extended to substantially enhance the mechanical characteristics of the solidified soil. When the geopolymer content is 20% and the curing duration is prolonged to 28 days, the internal friction angle, cohesiveness, and unconfined compressive strength enhance by approximately 0.23, 0.48, and 1.61 times, respectively, in comparison to a curing period of 7 days. The SEM and XRD examinations indicated that the cementitious substances of C-S-H and C-A-S-H generated from the hydration of steel slag-fly ash geopolymer may proficiently occupy the voids among soil particles and enhance the mechanical characteristics of solidified soil. The findings of this research may offer a conceptual foundation for the enhancement of loess subgrade with steel slag-fly ash geopolymer.

Choudhary et al. (2022)

The main objective of this project is to investigate the effect of waste polypropylene fiber as a reinforcement by conducting compaction characteristics, Unconfined compressive strength, Direct shear test, and California bearing ratio for soil with randomly distributed small percentages (0%, 0.10%. 0.20%, 0.30%, 0.40% & 0.50%) of fiber. There is a rapid increase in plastic waste generation all over the world and the correct manner of disposing is very challenging as it is non-biodegradable and have very low recycling ratio ultimately causing ecological hazards. Soil stabilization by conventional methods using cement, lime fly ash as an

Admixture is not economical in recent years, so there is a need to look after for an alternative such as plastic. Fiber reinforcement emerged as an important method for improving the properties of soil. So, in this study we use waste polypropylene fiber and conducted various experiments to find optimum amount which will give the maximum enhancement in the strength of soil.

Pawar et al. (2022)

Employing steel slag for the stabilization of soil represents a contemporary utilization of this material. This research primarily aims to examine the influence

of steel slag on the strength properties of clay soil. Steel slag is mixed with clayey soil in proportions of 10%, 15%, 20%, 25%, and 30% of its dry weight. In our research, the ideal proportion of steel slag was established by evaluating the peak unconfined compressive strength. A sequence of additional laboratory examinations has been conducted on this ideal mixture to assess its appropriateness as a stabilizing agent. The examination was similarly performed with traditional stabilizing agents, including 10% fly ash and 5% cement with clayey soil, and the optimal mixture was identified. Subsequently, the outcomes are evaluated in accordance. The aforementioned investigation indicates that including steel slag markedly enhances strength parameters relative to fly ash, although exhibits inferior strength when compared to cement.

Ghanbari, M et al. (2021)

Waste generated by steel industry cases environmental and economic problems. Therefore, it becomes very important to utilize steel industrial waste material in a proper manner. One promising use for this huge amount of industrial waste is soil improvement. In this work, Unconfined Compressive Strength (UCS) tests were conducted to study the influence of steel slag on the mechanical characteristics of cement-stabilized sand. The UCS tests were conducted on the compacted specimens which prepared in the laboratory at their Optimum Moisture Content (OMC) and modified proctor Maximum Dry Density (MDD). The results indicate that use of steel slag powder as a partial replacement of chemical stabilizer such as cement in soil stabilization has advantages from economic, environmental and technical points of view. The highest value of UCS was observed in the sample containing 7.2% cement and 0.8% steel slag powder. Beyond optimum steel slag powder dosage, the UCS value decreased. The addition of polypropylene fiber into the specimens treated with cement or steel slag powder improves significantly the mechanical behavior of specimens and significantly increases the UCS and strain corresponding to the maximum compressive strength. The specimen containing 0.2% of polypropylene fiber, 6.4% of cement and 1.6% steel slag exhibits the highest UCS value when the sum of the amounts of cement and steel slag was 8%. The failure pattern of specimen indicates a transition from ductile to brittle behavior with addition of cement and steel slag. However, the addition of polypropylene fiber changes the brittle response of treated specimens to a more ductile behavior.

Samin et al. (2021)

In this study, PE and PP have been used in the form of fibres. The effect of the stabilisation was evaluated through carrying out standard laboratory tests. These tests have been conducted on natural and stabilised soils with four fibre contents (1%, 2%, 3%, and 4%) of the soil weight. The tests included the standard compaction test, unconfined compressive strength (UCS) test, California Bearing Ratio (CBR) test, and resilient modulus (Mr) tests. In addition, there was a significant improvement in the UCS of soils by 76.4 and 96.6% for both lengths of PE fibres and 57.4% and 73.0% for both lengths of PP fibres, respectively. Results of the CBR tests demonstrated that the inclusion of plastic fibres in clayey soils improves the strength and deformation behaviour of the soil especially with 4% fibre content for both lengths 1.0 cm and 2.0 cm, respectively, to a figure of 185 to 150% for PE and PP, respectively.

Hussein et al. (2019)

Current research main aim is to study the effect of adding polypropylene fiber (PPF) on the behavior of expansive soil to reduce the swelling as percentage (0.5, 1 and 2%) of the weight of dry soil. Expansive soil used in this research was prepared artificially by mixing Ca-based bentonite from geological survey and mining company with sandy soil brought from Karbala city as percentage 80% bentonite to 20% sand of dry weight. Multiple laboratory tests have been carried are (Unconfined Compression Test, One-Dimensional Consolidation Test, Swelling Test, Sieve Analysis and Cycle Swell Shrink Test). A conventional odometer cell was modified to allow the study of swell- shrink cycle test to be carried out under controlled temperatures and surcharge pressure. The results showed that the increase in percentage of (PPF) led to decrease the swelling and to increase the unconfined compression strength. The wetting and drying results of (PPF) showed that with continuous cycles the effect of (PPF) keeps on reducing the swelling and the 2% of (PPF) produces less ratio of swell - shrink, which has obtained higher than 57 % in the improvement factor of swell and shrink.

Mishra et al. (2019) In India, a major portion of total land area is covered by clayey soil. Of this, a large proportion is expansive soil. Structures constructed

over this expansive soil may be severely damaged due to its high swell-shrinkage behavior. So such soils need to be stabilized to increase its strength, durability and to prevent erosion. Various studies have been carried out on expansive soils to improve its properties. Soil stabilization is one of the promising techniques used to improve the geotechnical properties of soil and has become the major practice in construction engineering. This project aims to conduct a study to check the improvements in properties of clayey soil analysing physical properties of soil stabilized with surkhi and polypropylene such as Atterberg Limits, Compaction Curve (O.M.C. and M.D.D.),California bearing ratio, unconfined compression strength test. The tests were conducted in three phases. In first phase, the physical properties of pure soil were determined. In the second phase, various tests were performed on the soil with varying percentage of surkhi. In third phase varying percentage of polypropylene fiber was added to the optimum value of surkhi and soil mix determined in second phase.

Singh et al. (2019) The main motive of this research is to investigate the optimal combination of Nano-Silica and Polypropylene fiber with clay soil. The engineering properties such as liquid limit, plastic limit, maximum dry density and unconfined compressive Strength (UCS) are analyzed with virgin soil, the soil with Nano-Silica and combination of soil with Nano-Silica and polypropylene fiber. The Durability test is performed to understand the durability of stabilized soil by analyzing wetting–drying cycles Also, Scanning Electron Microscopy (SEM) test is carried out and images are obtained to understand micro-structural modification towards mixture of Nano-SiO2 and PPF. Four different combinations of Nano-Silica at different percentages 1%, 3%, 5% and 7% are used in integration with polypropylene fiber is used in different percentages such as, 0.1%, 0.4%, 0.7%, 1%, and 1.3%. From these experiments, it has been analyzed that with the increase of PPF content in addition to Nano-Silica, the UCS increases and maximum value of UCS is obtained at 7% of Nano-Silica with 0.7% of PPF. The intermixing of PP fiber with the soil acts as a reinforcing material in binding the soil particles and the ‘bridge effect’ of fiber reinforcement in soil impedes the further development of tension cracks.

Sharma et al. (2019) In the present study, therefore we have investigated the influence of waste polypropylene fibers on the resilient modulus of clay soil. Under this investigation, several cyclic CBR tests were performed on soil specimens by reinforcing the clay soil with polypropylene fibers which were added in different percentages i.e. 0.3%, 0.4%, 0.5%, 0.6% by weight of soil. The outcomes show that the experimented technique is very effective to improve the resilient modulus of clay soil. It is found that for the best results, optimum percentage of waste polypropylene fibers to be added is 0.4 % by weight of soil. Finally, it has been concluded that reinforcing the clay soil with polypropylene fibers provides positive influence on resilient modulus of the soil.

Sharana Kumar et al. (2018) The objective of study is intended to decide the strengthening impact of haphazardly disseminated short polypropylene filaments on the California bearing ratio test and unconfined compressive strength of black cotton soil. The expansion of polypropylene stands brought about increment in Ideal dampness substance and decline in most extreme dry thickness. Copper slag is one of the waste materials that are being used broadly in the structure outline improvement. In this paper the stabilization is done to determine the effect of both polypropylene fiber and copper slag on engineering properties of black cotton soil. Here the dry density, CBR value and unified compression test were carried out. The proportions of copper slag used are (6%, 12%.18% and 24 %,) with respect to dry weight of the soil and also the proportion of polypropylene fiber used are (0.5%.1%, 1.5% and 2 %.) with the dry weight of the dirt. Then by mixing both polypropylene fiber and copper slag with proportion 0.5%, 1%, 1.5%, 2%, And 3%.6%, 9%, 12%, respectively with the dry weight of the soil.

Joshi et al. (2018) The incorporation of steel slag enhances the load-bearing ability and fortitude of black cotton soil, hence indirectly reducing construction expenses. Various proportions of 5%, 10%, 15%, and 20% steel slag have been employed to enhance the stability of black cotton soil and to assess its viability as a construction material for roadways. The steel slag obtained from Kalika Steel in Jalna and the black cotton soil sourced from Himayatbaugh in Aurangabad. The entire software was executed in two stages. In the initial step, essential tests including Atterberg limit, C.B.R, and standard proctor compaction test on unadulterated soil were conducted to evaluate the maximum dry density and optimum moisture content. The black cotton soil was combined

with 5%, 10%, 15%, and 20% of steel slag in two stages.

Shubham more et al., (2018) The issue of industrial waste disposal is escalating in contemporary times. Hazardous waste is impacting both the environment and the land. In order to safeguard the land and ecosystem from industrial refuse, we repurposed that refuse for construction activities. At present, the global yearly output of steel slag is approximated to be between 90 and 135 million metric tons. Consequently, steel slag is utilized for the stabilization of black cotton soil and for reducing waste. The incorporation of steel slag enhances the load-bearing ability and fortitude of black cotton soil, hence indirectly reducing construction expenses. Various proportions of 5%, 10%, 15%, and 20% steel slag have been employed to enhance the stability of black cotton soil and to assess its viability as a construction material for roadways. The steel slag obtained from Kalika Steel in Jalna and the black cotton soil sourced from Himayatbaugh in Aurangabad. The entire software was executed in two stages. During the initial phase, essential tests including Atterberg limit, C.B.R, and standard proctor compaction test on unadulterated soil were conducted to evaluate the maximum dry density and optimum moisture content. In the second phase, the black cotton soil was combined with 5%, 10%, 15%, and 20% of steel slag.

Madurwar et al. (2018) In Indian economy the infrastructure is the major sector in which overall development is going on. The expensive soils are causing number of damages to the structures as compare to other natural hazards. Thus, worldwide these soils are considered to be problematic soil so, as to utilized these soil in effective way, proper treatment to the soil is required, with the same intention, an attempt is made to modify engineering properties of black cotton soil by using fly ash and various percentage of polypropylene fibres. The Atterdberg's limit, California Bearing Ratio (C.B.R.), Unconfined Compressive Strength (U.C.S.) tests were carried out on the samples of soil with fly ash and polypropylene fibre and the samples are tested after 3days, 7 days and 14 days. Fly ash added to the soil in dry state in constant percentage (by weight) 15% and polypropylene fibres in 0%, 0.5%, 1.0%, 1.5 %. Comparisons of these admixtures are done on the basis of test results obtained.

Jhanvi P et al. (2018) As the population increases there will be reduction in the available land, development of buildings are usually implement on weak soil. Weak soil has poor shear strength, high swelling and high shrinkage. So such kind of soil requires ground improvement techniques to enhance the reliability of construction. Among weak soils major portion will be black cotton soil. Expansive soil or black cotton soil severely damaged because of shrinkage and Swelling behavior.. Soil stabilization is the major technique to enhance the geotechnical properties of soil and it is one of the major practicing techniques in construction engineering. This study aims to check the improvements in black cotton soil by using steel slag and polypropylene fibers. Steel slag were added in percentages of 3%, 6%, 9%, 12%, 15% and Polypropylene fibers were added in the percentages of 1%, 2%, 3%. Steel fibers are industrial waste which reduce the clay content and increases the strength whereas Polypropylene fibers having increase in tensile strength. These stabilizers were added to enhance the strength properties and make them more suitable to use and noted that there will be Change in various soil properties such as plastic limit, liquid limit, Shrinkage limit, Maximum dry density, Optimum Moisture Content, Un Confined Compression Strength, California Bearing Ratio, Permeability of soil, Triaxial Shear strength of soil were studied.

Chand et al. (2017)

Soil is a naturally occurring substance utilized in the building of all layers of pavements except for the surface layers (i.e., concrete and asphalt) and is subjected to classification tests to ascertain its engineering properties. A significant area of Central India and a section of South India is enveloped in black cotton soils. These soils exhibit significant swelling and shrinkage properties, along with an exceedingly low California Bearing Ratio and shear strength. Consequently, enhancement of these attributes is necessary. The current research seeks to ascertain the characteristics of black cotton soil augmented by Steel slag and Copper slag in a stochastic fashion. The soil utilized is a variety of black cotton soil sourced from Vempalle, Kadapa District, at a depth of 1.5 meters from the natural ground surface. The soil specimens were formed with four varying proportions of Steel slag (5%, 10%, 15%, and 20% by weight of soil), while maintaining a constant 20% of Copper slag. The unconfined

compression test is performed following 0, 7, and 14 days of cure. CBR assessment conducted over a soaking duration of four days for both treated and untreated soil specimens.

Shalabi et al. (2017)

Elevated water content in these soils will result in significant expansion and a decrease in shear strength and foundation carrying capacity. The engineering characteristics of various soil types can be enhanced through the application of additives and chemical stabilizers. This study utilized by-product steel slag to enhance the engineering characteristics of clay soils. Laboratory and field experimental initiatives were established to examine the influence of incorporating varying proportions of steel slag on the plasticity, swelling, compressibility, shear strength, compaction, and California bearing ratio (CBR) of the modified materials. The findings from the clay soil tests indicated that with an increase in steel slag content, the dry density, plasticity, swelling potential, and cohesion intercept of the soil diminished, but the angle of internal friction augmented. The test outcomes indicated that the CBR value escalated with a rise in slag content.

Hattamleh et al. (2017)

This research aimed to investigate the efficacy of fine steel slag aggregate (FSSA) in enhancing the geotechnical characteristics of high plasticity subgrade soil. The mechanical and engineering characteristics of initial soil and fine steel slag were assessed. Subsequently, fine steel slag (FSSA) was incorporated into the prepared soil samples at dry weight percentages of 0%, 5%, 10%, 15%, 20%, and 25%. The efficacy of the FSSA was evaluated based on enhancements in consistency limits, compaction, free swell, unconfined compressive strength, and California bearing ratio (CBR). The test findings indicate that 20% FSSA additions will decrease the plasticity index and free swell by 26.3% and 58.3%, respectively. Additionally, the incorporation of 20% FSSA additives will enhance the unconfined compressive strength, maximum dry density, and CBR value by 100%, 6.9%, and 154%, respectively. In summary, FSSA positively influenced the geotechnical attributes of the soil and can serve as an additive to enhance the geotechnical properties of subgrade soil, while also addressing waste disposal issues.

Tiwari et al. (2016)

Black cotton soils have the tendency to swell or shrink depending on its moisture content. Due to such expansive characteristics of soil, the structures constructed over this may develop some cracks in due course of time. It is there for essential to stabilize such soils, prior to any construction work carried out on this to improve its engineering properties. At present waste materials like stone dust from crushers, fly ash from industry and plastic waste are in abundance at various parts of our country. These wastes not only create health problems but also its disposal is a great problem for our society. This paper deals with a feasibility study carried out to find the suitability of using waste material i.e. stone dust and polypropylene fibers as stabilizing material for improving the engineering properties of black cotton soil. Various tests like CBR, UCS were performed on the soil samples prepared by using stone dust and Polypropylene fibers mixed with black cotton soil at different percentages. On the basis of the results obtained from these tests, it may be concluded that the strength of black cotton soil can be substantially improved by mixing with stone dust and polypropylene fibers as stabilized materials.

Ajit kumar et al. (2016)

The study is an experimental investigation on the use of HDPE (High Density Polyethylene) mixed with a CL-ML soil. The HDPE sheets were cut into 5mm wide strips and then into three aspect ratios as 1, 2 and 3. Such strips were then randomly mixed in the soil in different proportions (0.5%, 1.0%, 1.5% and 2%) by dry weight of soil. The paper reports results obtained on dry density and CBR behaviour of the soil. A decrease in the dry density of soil with increasing aspect ratio as well as percentage of HDPE content was obtained. On the other hand, CBR value is found to increase with increase in aspect ratio, the maximum CBR value obtained at 1.5% HDPE content. Increasing HDPE to 2% resulted in reduction of CBR.

2.2 RESEARCH GAP

The utilization of steel slag and polypropylene fibers offers a potential alternative for improving the engineering performance of weak clayey soil. However, the combined contribution of these two materials to soil behavior needs further systematic assessment, particularly because steel slag modifies the granular composition of the soil, while polypropylene fibers provide internal reinforcement

against deformation and failure. A key research gap lies in understanding how variations in steel slag content and polypropylene fiber dosage influence the compaction characteristics, compressive strength, and bearing capacity of clayey soil when both additives are used together. The relationship between mixture composition and the resulting engineering performance also requires evaluation to identify a suitable combination for practical applications. Accordingly, the present investigation focuses on the combined incorporation of steel slag and polypropylene fibers into clayey soil. Laboratory experiments will be conducted to evaluate changes in maximum dry density, optimum moisture content, unconfined compressive strength and California Bearing Ratio. The findings are intended to establish the effectiveness of this combined stabilization approach and assess its potential for more resource-efficient geotechnical construction.

2.3 OBJECTIVES OF THE STUDY

The objectives of the research work are:

- To evaluate Atterberg's limits and specific gravity of the virgin soil.
- To determine the compaction characteristics, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of soil mixed with Steel Slag and Polypropylene Fiber.
- To evaluate the combined effect of Steel Slag and Polypropylene Fiber on Unconfined Compressive Strength (UCS).
- To assess California bearing ratio (CBR) values at different proportions of Steel Slag and Polypropylene Fiber mix with clayey soil.
- To determine the optimum mix proportion of Steel Slag and Polypropylene Fiber for maximum strength.

3. Materials

This study's main objective is to use various geotechnical lab experiments to examine how the behavior of the soil changed when clayey soil was mixed with Steel Slag and Polypropylene Fiber at varying percentages.

3.1 CLAYEY SOIL

The lumps of the collected soil of the site were broken up with a wooden hammer, and then left to dry in the open air beneath cover. It was thoroughly mixed and sieved through 2.35mm IS sieve. The amount of dirt required for each test was drained from polythene bags and dried in oven for 24 hours at 105°C/5°C. The dirt was cooled to room temperature. The virgin soil used has the following different properties:

Table no. 1 Properties of soil used in the study

S. No.	Properties	Result
1.	Liquid limit (%)	39
2.	Plastic limit (%)	23
3.	Plasticity Index (%)	16
4.	Specific Gravity	2.58
5.	Free Swell Index (%)	38
6.	Maximum Dry Density (KN/m³)	17.20
7.	Optimum Moisture Content (%)	14.50
8.	Soil Classification	CI (Intermediate Compressive Clay)
9.	CBR (%) (soaked)	2.4
10.	CBR (%) (Unsoaked)	3.7
11.	UCS (7days) (kPa)	240
12.	UCS (14days) (kPa)	312
13.	UCS (28days) (kPa)	360

3.2 POLYPROPYLENE FIBER

The Polypropylene fiber used in this study was obtained from Amritsar. Polypropylene fiber is a natural fiber having greater tensile strength and can be used as an effective reinforcing material in soil stabilization. The properties and composition of Polypropylene fiber are discussed in table no. 2

Table 2: The properties of Polypropylene Fiber are given below;

S. No	Property	Value
1	Colour	White
2	Specific Gravity (Kg/m^3)	910
3	Water Absorption (%)	110
4	Length of fibre (mm)	12
5	Diameter of propylene fibre (mm)	0.034
6	Tensile Strength(MPa)	350
7	Modulus of elasticity (GPa)	3500

3.3 STEEL SLAG

Steel slag was obtained from Jalandhar (Dhunna Steel Casting) for this research. The steel slag underwent crushing to achieve finer granules and was sorted to the required size. The dry soil sample received the steel slag in assorted weight proportions. The smaller fraction of steel slag was identified as a non-plastic substance. The chemical makeup of steel slag is illustrated in Table 3 below.

Table 3 Chemical composition of Steel Slag

S.No	Compound	Composition (%)
1	Sio_2	10-19
2	Al_2O_3	1-3
3	FeO	10-40
4	CaO	40-52
5	MgO	5-10
6	MnO	5-8
7	P_2O_5	0.5-1

3.4 RESEARCH METHODOLOGY:

1. Soil Sampling & Preparation

- Collect disturbed clayey soil from site
- Air-dry, pulverize, and sieve through 4.75 mm sieve

2. Initial Soil Testing

Determine:

- Atterberg limits
- Specific gravity

3. Material Characterization

- Steel slag:
- Physical properties
- Chemical composition
- PP fibers:
- Length, diameter,

4. Mix Design

- Steel slag: 10%, 15%, and 20% by dry weight of soil
- PP fibers: 0.5%, 0.75%, and 1.0%

5. Compaction Test

- Conduct Standard Proctor Test
- Determine MDD and OMC

6. Sample Preparation

- Mix soil + slag + fibers uniformly
- Add water at OMC
- Prepare specimens

7. Curing

- Cure samples for 7, 14 and 28 days

8. Testing

- UCS test
- CBR test (soaked & unsoaked)
- Atterberg limits

9. Analysis

- Compare results with natural soil
- Determine optimum mix

10. Sustainability Assessment

- Waste utilization efficiency
- Cost and environmental benefits

11. Conclusion & Recommendations

- Identify best-performing mix
- Suggest practical applications in:

1. Road Subgrade
2. Embankments
3. Foundation soils

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

The present chapter examines the changes in the engineering behavior of clayey soil resulting from the incorporation of Steel Slag and Polypropylene Fibers. The laboratory investigation focuses on determining how these materials influence soil compaction, compressive strength, and load-bearing capacity. The performance of the treated soil is compared with that of untreated soil to assess the effectiveness of the proposed stabilization method. Particular attention is given to the variations caused by different additive proportions and the identification of a suitable mixture for geotechnical applications.

4.1 Mix Proportion Used

Table no. 4.0: Various Mix proportions of Soil, Steel Slag and Polypropylene Fibers

S.N.	Nomenclature	Description of the additives added with the soil		
		Soil (%)	Steel Slag by (%) of weight of soil	Polypropylene Fibers by (%) of weight of soil
1.	S	100	0	0
2.	S1	90	10	0
3.	S2	85	15	0
4.	S3	80	20	0
5.	S4	84.5	15	0.5
6.	S5	84.25	15	0.75
7.	S6	84.0	15	1.0
8.	S7	79.5	20	0.5
9.	S8	79.25	20	0.75
10.	S9	79.0	20	1.0

4.1 STANDARD PROCTOR TEST

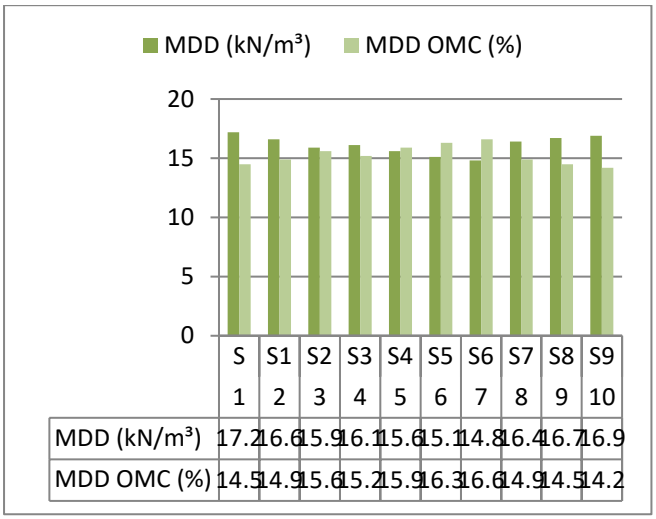
The laboratory test analysis employs various combinations of 15% and 20% Steel Slag as a constant alongside 0.5%, 0.75%, and 1.0% of Polypropylene Fibers. The numbers listed below demonstrate the fluctuation of optimum moisture content and dry density in relation to the proportion of Polypropylene Fibers and steel slag. The primary factors influencing the strength and longevity of pavements built on subgrades are the compaction properties of the soil. Any subgrade soil can be engineered at optimal moisture content (OMC) to achieve and sustain adequate stability under the influence of different load types for the necessary duration. Figure 1 and Table 4.1 illustrate that the compaction criteria are crucial for achieving the necessary sustainability of the pavement.

Table 4.1: Results of OMC and MDD for mix proportions of Soil, Polypropylene Fibers and Steel Slag

S No.	Soil Sample	MDD (kN/m^3)	OMC (%)
1.	S	17.20	14.50
2.	S1	16.60	14.90
3.	S2	15.90	15.60

4.	S3	16.10	15.20
5.	S4	15.60	15.90
6.	S5	15.10	16.30
7.	S6	14.80	16.60
8.	S7	16.40	14.90
9.	S8	16.70	14.50
10.	S9	16.90	14.20

Fig: 1 Variations b/w MDD and OMC of Polypropylene Fibers, Steel Slag & soil with different Ratios



- The Standard Proctor test results indicate that the maximum dry density (MDD) decreases from 17.20 to 15.90 when 10% and 15% steel slag are added, respectively, and then increases slightly to 16.10 at 20% steel slag. In contrast, the optimum moisture content (OMC) increases from 14.50% to 15.60% with an increase in steel slag content from 10% to 15%, followed by a decrease to 15.20% at 20% steel slag. The initial reduction in MDD may be attributed to changes in particle packing and the formation of a less compact soil–slag mixture. The increase in OMC up to 15% steel slag may be associated with changes in the mixture's water requirements. At 20% steel slag, the slight increase in MDD and decrease in OMC suggest improved particle arrangement and compaction characteristics compared with the 15% mixture. However, the optimum steel slag content should be determined by considering other geotechnical test results as well.
- With the steel slag content fixed at 15%, polypropylene fiber was added at 0.5%, 0.75%, and 1.0%. The maximum dry density (MDD) decreased from 15.60 to 14.80, whereas the optimum moisture content (OMC) increased from 15.90% to 16.60%. The decrease in MDD may be attributed to the lower specific gravity of polypropylene fibers compared with the soil–slag mixture and the disruption of close particle packing. The increase in OMC may be due to changes in the soil–fiber arrangement and the additional moisture required achieving effective compaction. These results indicate that increasing the polypropylene fiber content reduces the dry density and increases the moisture requirement of the stabilized soil.
- With the steel slag content fixed at 20%, the addition of polypropylene fibers at 0.5%, 0.75%, and 1.0% results in an increase in maximum dry density (MDD) from 16.40 to 16.90, while the optimum moisture content (OMC) decreases from 14.90% to 14.20%. The increase in MDD may be attributed to improved particle arrangement and packing within the soil–slag–fiber mixture. The decrease in OMC indicates that lower moisture content is required to achieve maximum compaction as the fiber content increases. These trends suggest that the interaction between steel slag and polypropylene fibers at 20% slag content may improve the compaction characteristics of the soil. However, the observed changes should be interpreted in relation to the experimental data and confirmed through repeat tests.

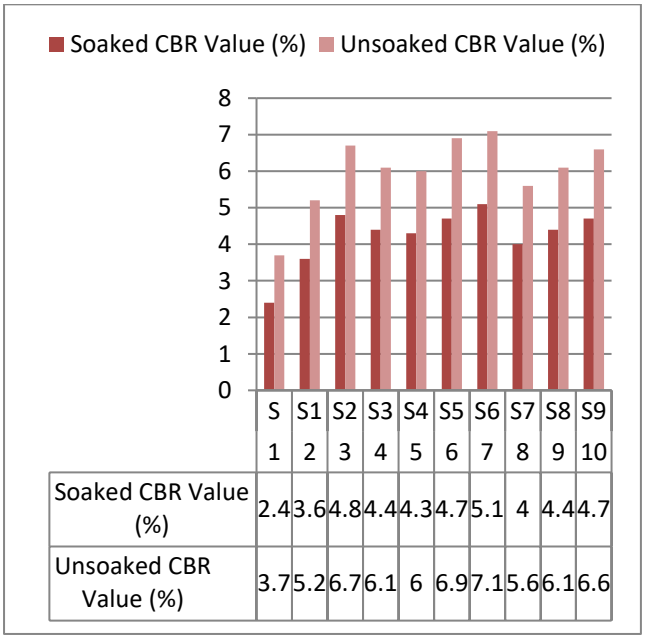
4.2 CALIFORNIA BEARING RATIO TEST

For the laboratory test analysis, the various combinations of 15% and 20% Steel Slag as a constant and 0.5%, 0.75%, and 1.0% of Polypropylene Fibers are utilized. The sub grade's California bearing ratio (CBR) is an important strength characteristic for predicting the thickness of the pavement's subgrade. According to IS: 2720 (Part 16) – 1987 the CBR values for clay sub grades are low. Different admixtures must be used to enhance the CBR of the clay subgrade. The California bearing ratio test was engaged for both soaked and unsoaked states for standard compaction results with the proportions of constant15% and 20% Steel Slag as a constant and 04, 06% and 08% of Polypropylene Fibers content as shown in figure 2 and tabulated in table 4.2.

Table 4.2: Results of CBR of Polypropylene Fibers and Steel Slag Mix with Clayey Soil

S No.	Soil Sample	Soaked CBR Value (%)	Unsoaked CBR Value (%)
1.	S	2.4	3.7
2.	S1	3.6	5.2
3.	S2	4.8	6.7
4.	S3	4.4	6.1
5.	S4	4.3	6.0
6.	S5	4.7	6.9
7.	S6	5.1	7.1
8.	S7	4.0	5.6
9.	S8	4.4	6.1
10.	S9	4.7	6.6

Fig: 2 Variations CBR values of Polypropylene Fibers, Steel Slag & soil with different Ratios



- The CBR test results indicate that the virgin soil has a soaked CBR value of 2.4% and an unsoaked CBR value of 3.7%. After stabilization with 15% steel slag and 1.0% polypropylene fiber, the maximum soaked and unsoaked CBR values increase to 5.1% and 7.1%, respectively.
- This improvement may be attributed to better particle interlocking provided by steel slag and the reinforcing effect of polypropylene fibers within the soil matrix. The fibers help resist deformation and improve the load-bearing capacity of the soil, while steel slag contributes to the formation of a stronger soil mixture.
- Overall, the increase in CBR values demonstrates the potential of combining steel slag and polypropylene fibers to improve the bearing capacity of clayey soil for geotechnical applications.

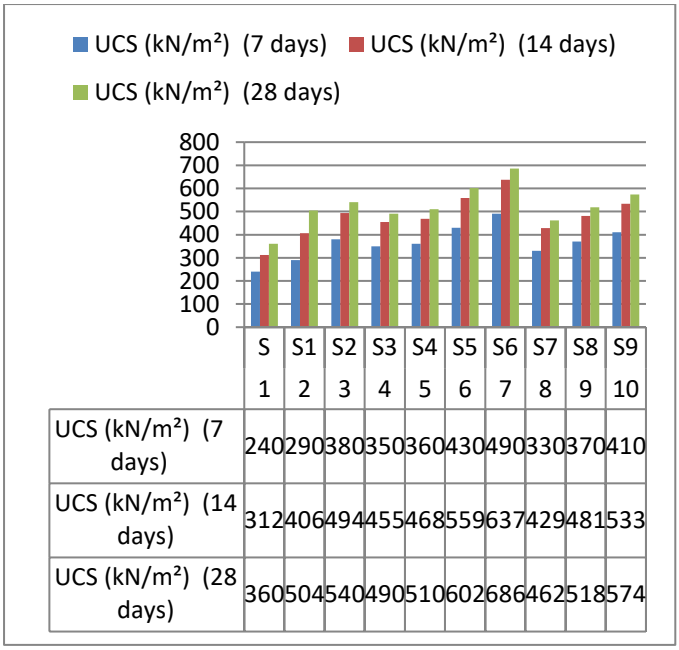
4.3 UNCONFINED COMPRESSION STRENGTH TEST

For the laboratory test analysis, the various combinations of 15% and 20% Steel Slag as a constant and 0.5%, 0.75%, and 1.0% of Polypropylene Fibers are utilized. As per IS: 2720 (part-10), the UCS test was performed on 7 days curing period, 14 days curing period and 28 days curing period specimen samples at a constant strain of 0.125mm/minute. The results of the unconfined compressive strength parameters of various combinations are being tested under a compressive force and final values are shown in Figure 3 and tabulated in table 4.3.

Table 4.3: Results of UCS of 7, 14 & 28 days Polypropylene Fibers and Steel Slag Mix with Clayey Soil

S No.	Soil Sample	UCS (kN/m²) (7 days)	UCS (kN/m²) (14 days)	UCS (kN/m²) (28 days)
1.	S	240	312	360
2.	S1	290	406	504
3.	S2	380	494	540
4.	S3	350	455	490
5.	S4	360	468	510
6.	S5	430	559	602
7.	S6	490	637	686
8.	S7	330	429	462
9.	S8	370	481	518
10.	S9	410	533	574

Fig: 3 Variations UCS values of 7, 14 & 28 days curing period of Polypropylene Fibers, Steel Slag & soil with different Ratios



- The UCS test results show that the virgin soil exhibits compressive strengths of 240, 312 and 360 kN/m² after 7, 14 and 28 days of curing respectively. The maximum UCS values are obtained with the addition of 15% steel slag and 1.0% polypropylene fiber reaching 490, 637 and 686 kN/m² for the corresponding curing periods.
- The improvement in strength may be attributed to enhanced particle interlocking due to steel slag and the reinforcing action of polypropylene fibers, which help resist deformation and crack development within the soil matrix. The increase in UCS with curing time indicates the development of stronger soil–stabilizer interactions over time. Overall, the combined addition of steel slag and polypropylene fibers significantly improves the compressive strength of the clayey soil.

5. CONCLUSIONS

The experimental study on stabilization of clay soil using Steel Slag and Polypropylene Fibers has resulted in the following conclusions:

1. The combined use of Steel Slag and Polypropylene (PP) fibers improved the geotechnical properties of clayey soil, demonstrating their potential for soil stabilization applications.
2. The Standard Proctor test showed that the addition of steel slag and PP fibers influenced the maximum dry density (MDD) and optimum moisture content (OMC). At a fixed steel slag content of 15%, increasing Polypropylene (PP) fiber content from 0.5% to 1.0% resulted in a decrease in MDD from 15.60 to 14.80 and an increase in OMC from 15.90% to 16.60%. At a fixed steel slag content of 20%, increasing PP fiber content from 0.5% to 1.0% increased MDD from 16.40 to 16.90 and reduced OMC from 14.90% to 14.20%.
3. The results indicate that the effect of PP fibers on compaction characteristics depends on the Steel Slag content. At 15% steel slag, MDD decreased and OMC increased, whereas at 20% steel slag, MDD increased and OMC decreased.
4. The UCS value increased from 240kN/m² to 490kN/m² after 7 days of curing, from 312 kN/m² to 637 kN/m² after 14 days, and from 360kN/m² to 686kN/m² after 28 days when 15% steel slag and 1.0% PP fiber were used.
5. The soaked CBR value increased from 2.4% for virgin soil to 5.1% with 15% steel slag and 1.0%

PP fiber, indicating improved resistance to penetration under soaked conditions. The unsoaked CBR value increased from 3.7% to 7.1% at the same combination, demonstrating enhanced bearing capacity compared with untreated soil.

6. Based on the tested combinations, 15% steel slag with 1.0% PP fiber produced the maximum reported CBR and UCS values. This combination appears promising for improving the engineering performance of clayey soil.

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