Improving Soil Properties for Construction Usage with Fly Ash and Rice Husk Ash

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Abstract. Changes made to any soil property with the goal of improving the soil's engineering performance are collectively referred to as soil improvement. This might include enhancing groundwater conditions, decreasing compressibility, minimising permeability, or strengthening the structure's structural integrity. Soil enhancement might be a short-term solution to make building easier or a long-term strategy to improve the finished structure's performance over time. Expansive soils, especially black cotton soil, pose serious problems for the building sector because of their negative swelling and shrinking characteristics. The purpose of this study is to better understand how stabilizing substances like fly ash and rice husk ash (RHA) might help address these issues and enhance the qualities of soil suitable for building. To evaluate the efficacy of RHA and fly ash as swell reduction layers and to improve unconfined compressive strength (UCS) in highway construction, the materials will be added to natural soil in different percentages (RHA: 0%, 15%, and 30%; fly ash: 10%, 20%, and 30%). Nine different combinations were tested using UCS after the quantities were established using the Taguchi optimization approach. The results suggest that adding these waste items can greatly strengthen the soil, and that certain combinations work best for stabilizing the soil. The study highlights how soils in construction can be addressed by utilizing sustainable resources like fly ash and RHA.

Keywords-: Stabilization, Soil, FA, RHA, Regression Analysis.

1 Introduction

A standard procedure for almost every road development is soil stabilisation. In general, mechanical stabilisation and chemical stabilisation are the two categories into which all forms of soil stabilisation can be divided. A soil's grading can be altered in mechanical stabilisation by combining it with other soil types that have varying grades. Compacted soil mass can be obtained by doing this. Conversely, chemical stabilisation refers to the alteration of soil characteristics by the incorporation of chemically active substances. Understanding the characteristics of the materials in the combination and the result after mixing is crucial for soil stabilisation. Furthermore, it's critical to ascertain the material's performance following stabilisation. Their nature to be plastic and compressible contributes to their tendency to swell when wet and contract upon drying. Certain clays are particularly problematic due to their significant volume changes with moisture fluctuations, which is a highly undesirable trait. Under sustained loads, cohesive soils can exhibit gradual deformation, known as creep, particularly when the shear stress levels are near the soil's shear strength, leading to potential sliding incidents [2]. Additionally, clays are known to exert substantial lateral pressures and typically have low values of resilient modulus, making them unsuitable as foundation materials. Soil stabilization addresses these issues by enhancing or preserving soil stability, thereby improving its engineering properties. This process is crucial for the development of robust foundations for buildings and bridges, in addition to for toll road improvement. Replacing volatile soil with extra appropriate material is frequently impractical and highly-priced, increasing normal challenge costs [3]. Consequently, enhancing the properties of the prevailing soil for infrastructure initiatives is a greater viable solution.

Numerous studies had been carried out to explore the usage of waste substances for soil enhancement, which not best improves soil overall performance but additionally promotes environmental sustainability by way of repurposing waste in optimistic programs. The study conducted in [2] investigates the enhancement of expansive soil's properties using rice husk ash (RHA) and fly ash for potential application in highway construction. Strength assessments on clay remoulded with RHA and fly ash aimed to determine the mixture's effectiveness as a swelling reduction layer. A fee evaluation evaluating stabilized and unsterilized sub-base preparations found out that 25% fly ash and 12% RHA supplied surest soil enhancement, whilst a 15% fly ash content became deemed appropriate for swell reduction layers [2]. Another study sought to improve black cotton soil's performance by incorporating fly ash (5% to 25%) and RHA (10% to 30%) into the soil, with evaluations conducted after a curing period of 28 days [4]. The maximum favourable effects have been found at 12% FA and 9% RHA. Additional studies on the stabilisation of BCS with fly ash (5% to 15%) and RHA (3% to 15%) found out decreases in plasticity index and specific gravity while enhancing CBR and UCS [6].
In a consideration investigating the software of Rice Husk Ash and lime for stabilising clayey soil, it became found that 10% RHA and 20% lime significantly increased soil energy and reduced the PI, indicating the technique's excellent ability [5]. Much like this, including lime and RHA to clayey soil caused a lower inside the maximum dry density and an upward thrust in an appropriate water content, specifically after a 28-day curing time frame. This helped to determine the appropriate admixture ratio for greater strength over an extended curing period. Given that approximately 21.4% of the country's geographical area consists of expansive soils, the review emphasizes cost-effective stabilization with RHA and fly ash at various proportions (e.g., 5%, 10%, 15%, 20%) to improve soil properties and reduce costs [7].
Adjusting soil properties with locally available waste materials like RHA and fly ash has been shown to affect clay soil's compressibility, with optimal material percentages discussed for soil improvement [8]. Stabilizing black cotton soil with fly ash and RHA-based geopolymer was found to substantially enhance soil strength and reduce swelling and shrinkage, offering a sustainable alternative to traditional stabilizers [9]. Both FA and RHA were observed to decrease liquid limit, plasticity index, and free swell index, while improving the coefficient of permeability and reducing swelling pressure in expansive clay, contingent upon the additive content [10]. Finally, the application of RHA and lime sludge for clay stabilization in civil engineering projects was reviewed, suggesting that a mixture of 10% RHA and 15% lime sludge can effectively stabilize clay [11]. The table 1 describes the work of various researchers on composition of materials and their respective outcomes.

Table 1: Comparative analysis of literature survey

Study Reference	Materials Used	Soil Type	Optimal Content	Effects on Soil Properties	Application Area
[2]	RHA and Fly Ash	Expansive Soil	25% Fly Ash, 12% RHA	Enhanced subgrade soil, effective swell reduction	Highway construction swell reduction layer
[3]	Fly Ash and RHA	Black Cotton Soil	5% to 25% Fly Ash, 10% to 30% RHA	Improved soil performance after 28 days	Black cotton soil performance improvement
[4]	FA and RHA	Black Cotton Soil	12% FA, 9% RHA	Reduced plasticity index and specific gravity, increased CBR and UCS	Black cotton soil stabilization
[5]	RHA and Lime	Clayey Soil	10% RHA, 20% Lime	Improved soil strength, reduced plasticity index	Clayey soil stabilization
[7]	RHA and Fly Ash	Expansive Soil	5%, 10%, 15%, 20% proportions	Improved soil properties, cost reduction	General soil stabilization
[11]	RHA and Lime Sludge	Clay	10% RHA, 15% Lime Sludge	Effective stabilization of clay	Clay stabilization in civil engineering

The survey reveals that the output strength, tensile strength and plasticity are the factors contributing to the efficiency of polymer-based concrete which can be analysed using Taguchi methods [12]. The mechanical characteristics help in achieving the best possible composition of any substances [14]. The input parameters need to be so adjusted that the final product meets both technical requirements as well as environmental requirements [15]. The paper show cased how ANOVA and regression equations can be useful in achieving these outcomes based on loading conditions [16].

2. Materials and Methods

2.1 Materials

One of the byproducts of milling rice is rice husk ash (or RHA) which is environmentally beneficial substitute for the ultimate disposal is to employ it as a soil stabiliser as shown in Fig. 1. RHA is not self-cementitious, so in order to produce cements and increase the strength of the soil, it is also a hydraulic binder, such as lime, needs to be applied. Approximately

78% of the weight of the paddy grains is collected as rice, broken rice, and bran throughout the milling process [17]. Husk is derived from the remaining 22% of the weight of paddy. In order to produce steam for the parboiling procedure, this husk is employed as fuel in different mills. Approximately 75% of this husk's weight is made up of organic volatile matter, while the other 25% is turned into ash also referred to as rice husk ash throughout the burning process. Between 85% and 90% of this RHA is made up of amorphous silica. In many regions of the world, particularly in developing nations, rice husk is produced as a major agricultural byproduct by the rice processing industry. Only 20% of the 500 million tonnes of rice husk that are burned worldwide each year are converted to rice hull acid (RHA).

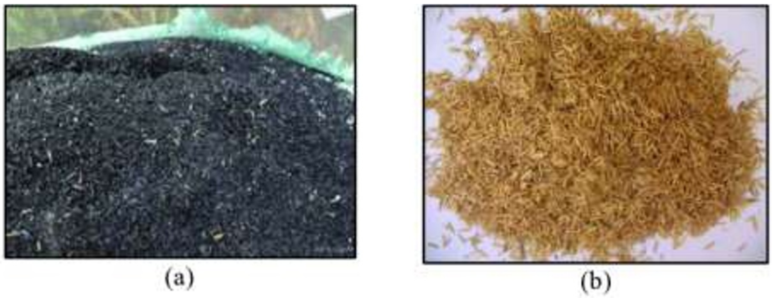


Fig. 1: (a) Rice Husk ash (b) Rice Husk

RHA is still not usefully applied, and it is typically disposed of in landfills or into streams, polluting the air, water, and soil. Utilising industrial and biogenic waste as supplemental cementing substance has become an essential component of the concrete building process due to increasing concerns regarding the environment and the need for preserving both resources and energy [18]. RHA is composed of no crystalline SiO_2 with high particular Surface area as well as high pozzolanic reactivity. Because pozzolanos are finer than cement particles, they can fill the spaces between them to create a finer porous structure, which increases strength. RHA is used during the manufacturing of concrete in two ways: first, as a Portland cement alternative to lower the cost of concrete as well as produce low-cost structural components; and second, as an additive to produce concrete with superior strength.
The permanent physical and chemical modification of soils to improve their physical characteristics is known as soil stabilization. Many chemical additions, such as fly ash as shown in Fig. 2, can be used to do this, presented that appropriate design and testing are carried out. The finely divided waste known as fly ash is carried out of the chamber of combustion by exhaust gases after coal has been ground and burned. Plants that generate steam and electricity using coal also produce fly ash. Usually, the boiler's combustion chamber is filled with crushed coal and air, which instantly ignites to produce heat and a molten mineral deposit [19]. Heat is extracted from the boiler via boiler tubes, which cools the flue gas and causes the molten mineral residue to solidify into ash. The more lightweight small ash particles, called fly ash, stay suspended within the exhaust gas, while the coarser ash particles, called bottom ash or slag, sink to the bottom of the chamber of combustion.

Fig. 2: Fly ash for soil stabilization

According to ASTM, both dry and wet sieving should be used to verify the fly ash's granularity. The proportion of fly ash remaining on a 45-micron sieve after a sample is sieved through it is used to determine the fineness of the material [20-24]. The Lech atelier technique and the Blaine Specific Surface approach are further techniques for measuring fineness. Fly ash has varying specific gravities; sub-bituminous ash has a low specific gravity of 1.90 and bituminous ash has a high specific gravity of 2.96. The fly ash has a particle size that varies between 10 to 100 microns because it is a very tiny substance. Its form is typically spherical.

2.2 Method

The Taguchi method is a Japanese engineering technique that aims to reduce noise and variance in order to improve the quality of processes and products [25-29]. It includes designing tolerances, parameters, and systems. To determine essential parameters, optimize the setting of parameters, and establish acceptable limits, the method makes use of statistical tools. It minimizes the susceptibility of the product to changes, enhancing quality, cutting expenses, and raising customer satisfaction. Engineering uses a variety of experimentation techniques to reduce trial runs and get dependable findings. These consist of the Taguchi method, the factorial approach, and the classical plan. For complicated processes without an analytical model, the classical plan is employed; for technically proven processes, the factorial technique minimizes work [20]. The Taguchi approach reduces the effect of noise changes on performance by establishing a strong link between performance and controllable variables. Taguchi specifies the signal to noise (S/N) ratio—which may be expressed as follows—as the measure of quality features.

$S/_N = -10\log((\frac{1}{n})\sum\frac{1}{y^2})$; For higher is better.

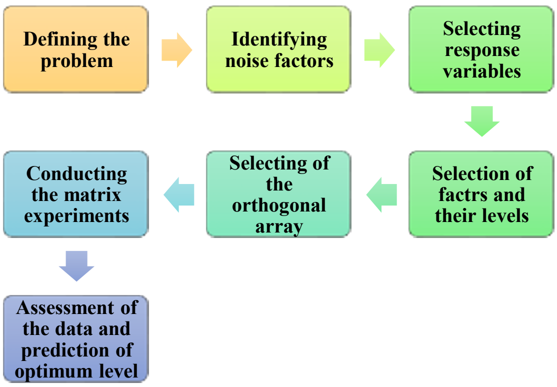


Fig. 3: Steps involved in Taguchi Method

The Taguchi technique is a way to stabilize black cotton soil by maximizing the effects of fly ash and RHA together. Fig. 3 shows the steps involved in the Taguchi method, it entails setting an objective, figuring out the levels and contributing elements, choosing an orthogonal array, running experiments, evaluating the response variable, assessing the outcomes, choosing the best combination, and validating the findings. The objective is to increase compressive strength. Soil samples are used for experiments, and the response variable is observed and recorded. Next, the best combination is identified, and validated by the combination.

3. Experimental Procedure

In an effort to assess the efficacy of Rice Husk Ash (RHA) and Fly Ash as soil stabilizers, they were incorporated into natural soil in various proportions. Fly Ash was added in increments of 10%, 20%, and 30%, while RHA was mixed in at 0%, 15%, and 30%. The specific mix ratios were determined using the Taguchi optimization technique within the Minitab Software, which produced an L-9 orthogonal array as shown in Table 2, outlining the outcomes of the Taguchi Design of Experiments (DOE). Based on the Taguchi analysis, nine samples labelled S1 to S9 were systematically prepared, following which their unconfined compressive strength was measured. Subsequent regression analysis was conducted to verify whether the identified optimized values indeed represented the most effective proportioning for soil stabilization.

Table 2: Design of experiment for sample preparation

Sample	RHA (%)	Fly Ash (%)	UCS (MPa)
S1	0	10	5.8
S2	0	20	6.2
S3	0	30	6.5
S4	15	10	7.2
S5	15	20	7.6
S6	15	30	8.2
S7	30	10	7.5
S8	30	20	7.6
S9	30	30	7.3

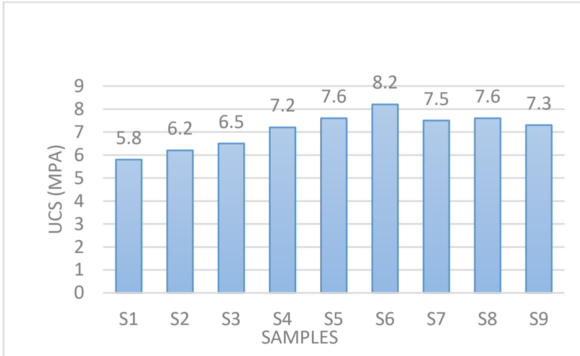


Fig. 4: Uncompressed strengths of prepared samples

The results of an experiment evaluating the impact of varying percentages of Rice Husk Ash (RHA) and Fly Ash on the Unconfined Compressive Strength (UCS) of soil samples shown in fig. 4. Samples S1 to S3, with no RHA, show a progressive increase in UCS as the percentage of Fly Ash increases from 10% to 30%, indicating that Fly Ash alone can enhance soil strength. Samples S4 to S6, which include 15% RHA, exhibit a further increase in strength across all Fly Ash proportions, with the highest UCS of 8.2 MPa at 30% Fly Ash. In contrast, samples S7 to S9 with 30% RHA display a peak UCS of 7.6 MPa at 20% Fly Ash, but a decrease in strength at 30% Fly Ash, suggesting an optimal RHA and Fly Ash combination exists for maximizing soil strength.

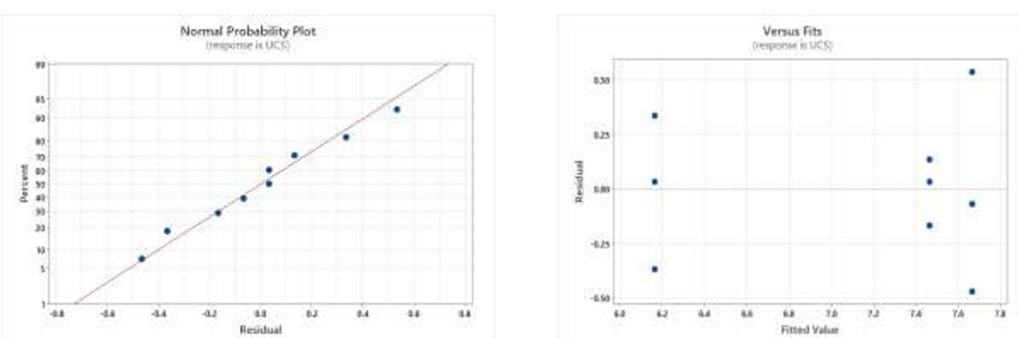
4 Regression Analysis

Regression analysis produces the regression equation, which is a crucial product that is utilized to forecast and comprehend the relationship between variables. In this study regression analysis is conducted for both RHA and Fly Ash. Regression analysis gives three residual plots, which support the hypothesis that the residuals are regularly distributed. By plotting the residuals against a hypothetical normal distribution, the "Normal Probability Plot" illustrates normality. Plotting the residuals versus fitted values, or "Versus Fits" plot, indicates consistent variance. The residuals' independence is evaluated in relation to the sequence of data collection using the "Versus Order" graph. The "UCS" response variable seems to have been modeled in a way that upholds the normality criteria. However, this evaluation is basically an estimate that utilizes no experiments or measurements.

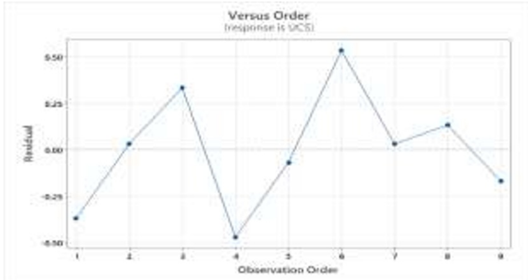
4.1 Regression Equation for RHA

The formula uses three distinct levels of rice husk ash (RHA) to predict unconfined compressive strength (UCS). It is a linear model. When all RHA factors are at their baseline level, the intercept is "7.100". "-0.933", "0.567", and "0.367" are the coefficients that indicate the anticipated variation in UCS in relation to the RHA baseline. Positive coefficients for "rha_15" and "rha_30" show an increase in UCS, whereas negative coefficients for "rha_0" suggest a decreasing trend.

$$UCS = 7.100 - 0.933\ rha\_0 + 0.567\ rha\_15 + 0.367\ rha\_30$$



(a) (b)



(c)

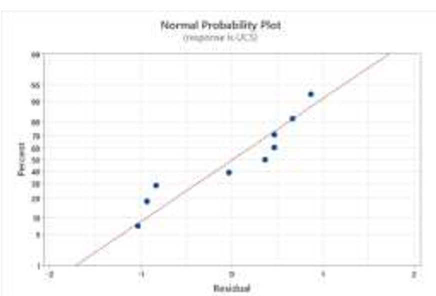
Fig. 5: Plots for RHA (a) Normal Probability plot for UCS (b) Versus fit for UCS (c) Versus Orders for UCS

The figure 5 (a) describes the normal probability distribution plot for UCS when RHA is used in different percentages. The residuals are distributed close to the line The figure 5 (b) shows the residul vs fits graphs where there is uniform distribution accros the zero line. The figure 5 (c) is the reisdual vs order plot for the UCS with RHA which depicts that the distirbution is random and therefore the data is reasonable.

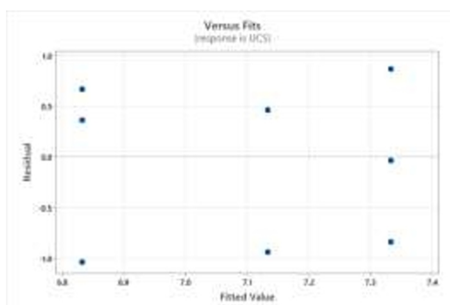
4.2 Regression Equation for Fly Ash

Unconfined Compressive Strength (UCS) is predicted by the equation, which is a linear regression model, depending on the amount of flyash injected to the material. When there is no fly ash added or when all fly ash factors are at their reference level, the intercept shows the predicted value of UCS. The predicted change in UCS for every rise in flyash percentage is shown by the coefficients for each flyash term. For instance, adding 10% flyash results in a 0.267-unit decrease in UCS, 20% flyash in a 0.033-unit rise, and 30% flyash in a 0.233-unit increase. With this model, UCS predictions determined by flyash percentages are feasible.

UCS = 7.100 - 0.267 flyash_10 + 0.033 flyash_20 + 0.233 flyash_30



(a)

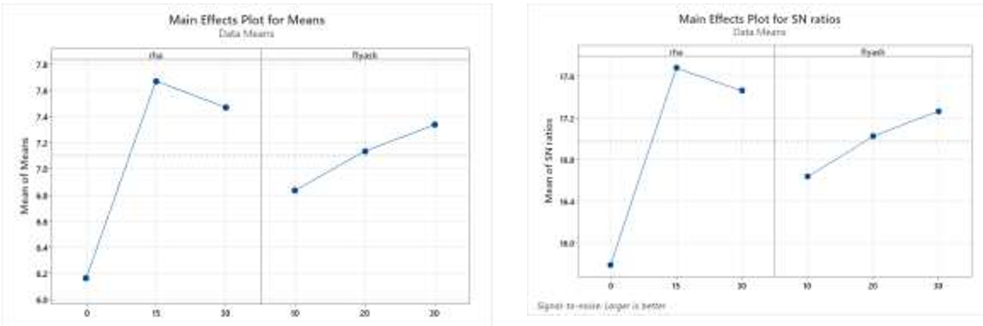


(b)

(c)

Fig. 6: Plots for Fly Ash (a) Normal Probability plot for UCS (b) Versus fit for UCS (c) Versus Orders for UCS

The figure 6 (a) describes the normal probability distribution plot for UCS when fly ash is used in different percentages. The residuals are distributed close to the line. The figure 6 (b) shows the residul vs fits graphs where there is uniform distribution accros the zero line. The figure 6 (c) is the reisdual vs order plot for the UCS which depicts that the distirbution is random and therefore the data is reasonable.



(a) (b)

Fig. 7: Plots for means and S./N ratio (a) Main Effect plot of RHA and Fly Ash for Means (b) Main Effect plot of RHA and Fly Ash for signal to noise ratio

This study investigates the effects of fly ash and rice husk ash on signal-to-noise (S/N) ratios and unconfined compressive strength (UCS). The first plot in Fig. 7(a) demonstrates how RHA rises UCS at first, reaching a peak at 15%, and then falls at 30%. The fly ash trend in the second plot in Fig. 7(b) is linear, with greater percentages indicating a positive correlation. While fly ash consistently improves S/N ratios and UCS, the data indicate that there is an optimal amount of RHA for boosting UCS. This shows that large quantities of fly ash usually result in better power and standard outcomes.

5 Conclusion

Research on the stabilization of expansive soils the use of fly ash and rice husk ash has proven promise for enhancing the difficult soils' engineering traits. The outcomes display a wonderful trend of stronger soil following the addition of fly ash and RHA, it also indicates that these materials can alleviate the bad effects of moisture on expansive soils.

a) In order to increase soil power, a mixture of 15% RHA to 30% fly ash determined to be the only adequate, demonstrating the capacity of these waste products to provide extra sturdy and solid building foundations. Regression analysis showed the effectiveness of the results and highlighted the methodological approach that the Taguchi optimization method presented in figuring out the top-rated blend ratios.
b) A mixture of 15% RHA and 30% fly ash is suitable for substantial foundations for systems. The regression technique substantiates the efficacy of the effects. The Taguchi optimization technique offers a methodical method to determine a appropriate aggregate of RHA and fly ash.
c) Making use of fly ash and rice husk ash to stabilize soils this study proves that mixing fly ash and rice husk ash with soils improves the engineering features of soils. These additions lower the effect of moisture content material via stabilizing the soil.

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