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Utilizing Response Surface Methodology for Strength Prediction of Cementitious Green Hybrid Concrete for Low Volume Roads

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ABSTRACT

This study reveals how mechanical properties of concrete containing coarse aggregate , cement, fine aggregate is influenced by use of coconut shell, lime powder, rice husk ash respectively. Response surface methodology (RSM) is a systematic approach that combines experimental data and mathematical modelling to optimize concrete mix designs, improve performance, reduce costs, and ensure that desired properties are met. RSM is a powerful tool that can be used to explore the complex relationships between the input factors (e.g., cement content, water-to-cement ratio, aggregate type and size) and the output response (e.g., compressive strength, durability, workability). By understanding these relationships, engineers can develop concrete mixes that are tailored to specific performance requirements and cost constraints. This experimental program comprises forty concrete mixes. All the concrete mixes were created by partially replacing cement with lime, fine aggregate with rice husk ash, coarse aggregate with coconut shell by substituting various percentages. The M30 grade mix design was chosen for the study. Tests were conducted on hardened samples to ascertain their compressive and flexural strength after 14, 28 days of curing under water. The experimental observations indicate that use of RHA and lime powder concrete mixes improves the strength in comparison with that of coconut shell and lime powder based concrete mixes. It is observed that, partial substitution of RHA with fine aggregate increases strength in all the concrete mixes. The result indicates higher compressive and flexural strength at 20% partial replacement of fine aggregate with RHA. Strength decreases as percentage of coconut shell in the concrete increases. The maximum strength obtained for the specimens with 0% coconut shell.

Keywords: Response Surface Methodology, compressive strength, flexural strength, modelling, optimisation.

1. INTRODUCTION

1.1 Green Concrete:

Green concrete, also referred to as sustainable or eco-friendly concrete, is a variant of concrete engineered to minimize its environmental footprint in comparison to traditional concrete blends. It employs a range of techniques and materials to enhance its eco-friendliness across its entire life cycle, spanning from production through to utilization and disposal. Below are key aspects of green concrete and its attributes, including Alternative Cementitious Materials, Recycled Aggregates, Low-Carbon Cement, Optimized Mix Formulations, and Durability. In contrast to conventional concrete, green concrete boasts numerous applications, encompassing construction, low-impact building, infrastructure development, urban planning, historical preservation, and prefabricated components. The principal advantages of green concrete encompass reduced greenhouse gas emissions, the preservation of natural resources, enhanced indoor air quality within structures, and prolonged structural longevity. However, it is worth noting that the specific advantages and applications of green concrete can vary depending on regional factors, regulations, and the availability of materials and technologies. Green concrete constitutes an integral component of sustainable construction practices and contributes significantly to the broader endeavor of mitigating the environmental impact of the construction industry.

Figure 1: Green concrete

1.2 Design OF Experiments:

Design of experiments (DOE) is a crucial step in response surface methodology (RSM), which aims to efficiently and effectively explore the relationships between input factors and the response variable. DOE involves selecting a set of experiments that will provide enough data to build a robust response surface model, which is a reliable representation of the system dynamics. Here are the key steps in DOE for RSM:

1] Identify the factors that could influence the response variable.

2] Determine the range or levels at which each factor will be examined.

3] Choose a DOE approach. Common approaches include full factorial design, fractional factorial design, central composite design, and Box- Behnken design.

4] Determine the total number of experimental runs based on the factors, their levels, and the chosen design type.

5] Randomize the experimental runs to minimize the influence of uncontrolled variables.

6] Execute the experiments and measure the response variable for each run.

7] Analyze the data to construct the response surface model.

8] Validate the response surface model to ensure its accuracy and reliability.

9] Use the validated model for optimization, i.e., to identify the factor levels that maximize or minimize the response while satisfying any constraints.

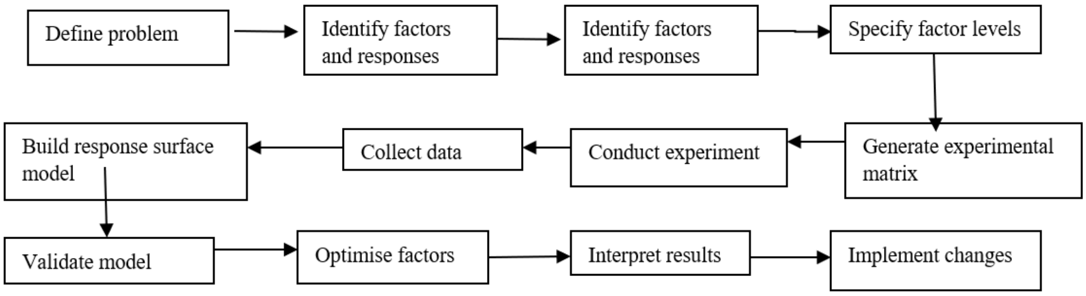
9] Interpret the results to gain insights into how the factors influence the response.

10] Implement the optimized settings in practical applications.

11] Monitor the results and make adjustments as needed.

12] DOE is an iterative process that can be used to achieve optimal outcomes in a wide range of fields.

13] DOE is a powerful tool that can be used to improve the quality of products and processes in a wide range of industries.



1.3 Central Composite Design:

Central Composite Design (CCD) is a widely adopted experimental design methodology within the framework of Response Surface Methodology (RSM). Its significance becomes particularly apparent when navigating the intricate interplay among multiple independent variables and a dependent response variable, all while minimizing the number of necessary experimental runs. CCD proves to be a versatile choice, proficient at investigating linear, quadratic, and interaction effects, making it invaluable for the optimization of processes and products. The overarching objective of CCD is to explore both the primary effects of factors and potential interactions among them. Additionally, it forms the basis for constructing a response surface model that can predict the response variable across various factor levels. This predictive model serves as the foundation for the pursuit of process or system optimization, shedding light on the optimal factor settings to maximize or minimize the response. Central to the CCD methodology are its fundamental components. First, the controllable variables of interest, known as factors, are identified. Specific levels or values for these factors are defined, typically encompassing low, medium (central), and high levels. Center points are crucial in estimating pure error and understanding the curvature of the response surface. Moreover, axial points, positioned at a specified distance from the center for each factor, enable the estimation of quadratic effects. To enhance precision, center point replicates are often included to accurately gauge experimental error. The CCD experimental matrix is a composite of factorial points, center points, and axial points, with the total number of runs determined by the number of factors and the chosen type of CCD. During the execution phase, experiments align with the CCD matrix, with factors set at their predefined levels, and responses meticulously recorded. This process culminates in the development of the response surface model, usually represented by a mathematical equation that relates factors to the response variable, encompassing linear, quadratic, and interaction terms. Model validation is a crucial step, often involving additional experiments or statistical techniques such as cross-validation to ensure an accurate representation of the actual system or process. Leveraging the validated response surface model, optimization becomes achievable, revealing the factor settings that best align with the desired objectives while adhering to any constraints or prerequisites. The results are subjected to interpretation, unveiling insights into how factors influence the response and guiding the path toward optimal performance. In essence, Central Composite Design serves as an indispensable tool within Response Surface Methodology, enabling the efficient exploration of intricate factor-response relationships. This, in turn, leads to improvements in processes, product optimization, and a deeper understanding of system dynamics.

1.4 Materials :

Lime powder: Lime powder, typically in the form of hydrated lime (calcium hydroxide, $Ca(OH)_2$) or quicklime (calcium oxide, CaO), can serve as an additional component in concrete, offering numerous advantageous properties and benefits when incorporated into concrete mixes:

Enhanced Workability: The inclusion of lime powder in concrete can elevate its workability, simplifying the mixing and placement processes. Lime functions as a plasticizer, facilitating improved flow and decreasing the need for excess water, resulting in more straightforward construction and finishing tasks. Decreased Permeability: Lime, when added to concrete, has the capacity to diminish its permeability, rendering it more resistant to water infiltration and corrosive chemicals. This property enhances the longevity of concrete structures, particularly in challenging environmental conditions. Augmented Chemical Resistance: Lime serves to augment the concrete's resistance to chemical assaults, such as those induced by sulfates or acids. This attribute proves particularly valuable in industrial settings, including wastewater treatment facilities. Enhanced Control Over Setting Time: Lime can be effectively employed to regulate the setting time of concrete. It acts as a retarder, postponing the initial setting of the concrete mixture. This feature is advantageous, especially in scenarios involving extensive or intricate concrete placements. Improved Surface Finish: The addition of lime can result in a superior surface finish for concrete, yielding a smoother and more uniform appearance. This is of paramount importance in applications involving architectural and decorative concrete. Mitigated Shrinkage Cracking: Lime can play a pivotal role in mitigating shrinkage cracking in concrete, a phenomenon that may occur as the concrete cures and undergoes contraction. This leads to a more crack-resistant concrete composition. Environmental Advantages: Incorporating lime into concrete offers environmental benefits by reducing the carbon footprint associated with concrete production. Lime partially replaces cement, a major contributor to carbon dioxide emissions, contributing to environmental sustainability.

Figure 2: lime powder

Rice Husk Ash: Rice husk ash (RHA) is an additional cementitious substance that finds application in the production of concrete. It is derived from the incineration of rice husks, the outer protective layer enveloping rice grains, which constitutes a byproduct of rice milling. When properly processed, rice husk ash can yield several benefits as a concrete component: Pozzolanic Characteristics: Rice husk ash is abundant in amorphous silica (SiO_2), granting it pozzolanic attributes. Upon interaction with calcium hydroxide ($Ca(OH)_2$) and water, it forms additional calcium silicate hydrates (C-S-H) gel. This pozzolanic reaction contributes significantly to the concrete's strength and durability. Enhanced Strength and Durability. The inclusion of rice husk ash in concrete has the potential to augment its compressive strength, particularly during later stages of curing. It also bolsters the concrete's resilience against chemical corrosion, thus extending its operational life in corrosive settings. Diminished Heat of Hydration: Rice husk ash can effectively lower the heat of hydration in concrete, rendering it suitable for applications involving massive concrete structures where the control of temperature rise is crucial to prevent cracking. Improved Workability: In certain instances, the incorporation of rice husk ash can enhance the workability of concrete mixtures, facilitating more straightforward placement and finishing processes. Environmental Advantages: The utilization of rice husk ash in concrete production embodies an environmentally conscious approach as it repurposes a waste material that would otherwise require disposal. This practice contributes to the reduction of the environmental footprint associated with concrete manufacturing. Cost-Efficiency: Depending on the local availability of rice husks and processing facilities, the utilization of rice husk ash can prove cost-effective compared to other supplementary cementitious materials.

Figure 3: Rice Husk Ash

Coconut Shell: Coconut shells offer a sustainable and eco-friendly option as a material in concrete production when appropriately processed and integrated into concrete mixes. The utilization of coconut shell aggregates presents several potential benefits: Compared to conventional aggregates such as gravel and crushed stone, coconut shell aggregates are lightweight. This characteristic results in lighter concrete, which proves advantageous for alleviating the dead load on structures, Employing coconut shells as a concrete component repurposes a natural byproduct that would otherwise be discarded. This contributes to sustainability efforts and diminishes the environmental impact associated with construction practices. Coconut shells possess inherent insulating qualities owing to the presence of air pockets within their structure. This feature can be beneficial in applications requiring thermal insulation, such as certain construction types and acoustic insulation. The incorporation of coconut shell aggregates can introduce a distinctive and visually appealing element to concrete surfaces. They can be utilized in decorative concrete applications to create visually engaging textures and patterns. Nevertheless, there are considerations and challenges associated with using coconut shells in concrete. Coconut shells do not exhibit the same level of strength and durability as traditional aggregates. Consequently, their use may be limited to non-structural or low-stress applications. Proper processing of coconut shells is essential to eliminate any remaining husk, fibers, or impurities. Failure to do so can compromise the quality and performance of the concrete. Coconut shells have a higher propensity to absorb water compared to traditional aggregates, potentially leading to workability issues in concrete mixtures. Adequate mix design is crucial to address this concern. The compatibility of coconut shells with cementitious materials must be carefully considered to ensure they do not adversely affect the setting time or overall performance of the concrete. It may be necessary to consult local building codes and standards to determine the suitability of coconut shell aggregates for use in construction projects.

3. LITERATURE REVIEW

1] Using glass sand and rice husk ash in concrete production offers several benefits. It not only conserves natural river sand resources and promotes waste recycling but also mitigates the alkali-silica reaction generated by glass sand and cement slurry through the pozzolanic effect of rice husk ash. To assess the feasibility of incorporating glass sand and rice husk ash into concrete, we conducted a series of experiments to evaluate the mechanical properties of both glass sand concrete and glass sand concrete with added rice husk ash. The experimental findings indicate that introducing glass sand into the concrete mixture decreases water absorption and the compressive strength of standard concrete. However, it enhances the splitting tensile strength, shear strength, and cyclic compression performance of standard concrete. Furthermore, the inclusion of rice husk ash significantly improves the later-stage compressive strength and splitting tensile strength of glass sand concrete. It's worth noting that the optimal replacement rate for rice husk ash is 15%, as replacement rates of 30% and 45% are not suitable for structural concrete. Additionally, while rice husk ash reduces the shear strength and cyclic compression performance of glass sand concrete, it effectively enhances the crack resistance of this type of concrete. The outcomes of this study provide valuable insights into the mechanical properties of rice husk ash glass sand concrete, serving as a reference for future research endeavors.

2] It has been well-established that Rice Husk Ash (RHA) contains a substantial amount of silica and poses environmental concerns if left to burn. Consequently, the primary objective of this study was to investigate the impact of partially substituting RHA for ordinary Portland cement (OPC) on changes in compressive strength, thermal conductivity, and structural characteristics. RHA was acquired through controlled burning, followed by grinding, and subsequently blended with OPC. Various percentages of RHA, ranging from 10% to 50% in incremental steps of 10%, were incorporated.

The properties of the resulting material were assessed after storing the samples for durations of 3, 7, 14, 21, 28, 56, and 90 days. The findings indicate that samples containing 10% RHA exhibited the highest compressive strength, reaching 2066.33 Psi, with a density of 2.65 g/cm3 after 28 days of curing. Beyond 28 days, due to elevated relative humidity and temperature, the strength showed a slight reduction compared to specimens preserved in water. Thermal conductivity measurements revealed that samples containing 50% RHA exhibited the lowest thermal conductivity at 0.81 Btu/ft2/hr/0F, while the highest thermal conductivity was observed when 10% RHA was used as a replacement. XRD analysis unveiled significant alterations in the phase composition and crystallinity of the mixture. The average crystallite size of pure RHA measured 2227.69 Å, whereas for the mixture, it was observed to be 712.2 Å and 162.77 Å when 10% and 40% RHA was employed, respectively. In summary, this study concludes that the partial substitution of RHA in OPC yields a cost-effective and thermally insulating construction material for the building industry.

3] This study explores the impact of partially substituting Portland cement with rice husk ash (RHA) on the mechanical characteristics and microstructure of recycled aggregate concrete (RAC). Various tests, including assessments of workability, compressive strength, and splitting tensile strength, were conducted on specimens containing different proportions of RHA (0%, 10%, 20%, and 30% of the binder) and various levels of recycled concrete coarse aggregate replacement (0%, 50%, and 100%). The findings indicate that the addition of RHA leads to improvements in the compressive strength of the concrete, albeit at the expense of workability and splitting tensile strength. Moreover, an in-depth analysis of the cement paste's microstructure was performed using techniques such as X-ray diffractometry (XRD), mercury intrusion porosimetry (MIP), and scanning electron microscopy (SEM). This analysis proposed a mechanism for the pozzolanic reaction of RHA particles, which involves the consumption of calcium hydroxide (CH) generated during cement hydration. This pozzolanic effect results in an increase in the content of calcium silicate hydrate (CSH) and leads to the refinement of the interface transition zone (ITZ) and the pore structure, ultimately creating a denser microstructure by optimizing pore distribution. The results also demonstrated that a concrete mix incorporating 100% recycled coarse aggregate and 30% RHA fulfills the requirements for engineering applications while significantly reducing concrete production costs and lowering carbon emissions.

4] Solid waste materials like rice husks (RH) and iron ore tailings (IOT) pose environmental concerns. Research has shown that rice husk ash (RHA), obtained by controlled incineration of RH at suitable temperatures, can exhibit pozzolanic properties, and IOT can potentially replace natural sand in concrete. This study aims to assess the combined impact of incorporating RHA and IOT into concrete. The study involved varying the replacement levels of cement with RHA (0%, 5%, 10%, and 15%) and natural sand with IOT (0%, 20%, 40%, and 60%). Compressive strength, flexural strength, the ratio of compressive strength to flexural strength, and frost resistance of the resulting RHA and IOT-mixed concrete (RIC) were analyzed and discussed. The findings showed that the inclusion of RHA and IOT had a significant positive effect on concrete performance. Notably, the concrete with 10% cement replaced by RHA and 40% natural sand replaced by IOT demonstrated the most substantial performance enhancement.

Additionally, microscopic comparisons involving scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), porosity analysis, and nanoindentation analysis were conducted between the control group and the RIC group, where 10% of cement was replaced by RHA and 40% of natural sand was replaced by IOT after a 90-day curing period. The control group, without RHA and IOT, exhibited more internal pores. Conversely, the concrete prepared by replacing 10% of cement with RHA and 40% of natural sand with IOT showed a substantial reduction in porosity and an increase in Ca elements. This was attributed to the pozzolanic activity of RHA and partial IOT, leading to secondary hydration reactions that produced an abundance of calcium silicate gel, enhancing aggregate bonding and effectively filling internal pores. Furthermore, the fine particles of RHA and IOT contributed to improved filling, and the rugged surface of IOT facilitated aggregate interlocking, thereby enhancing mechanical properties.

5] As infrastructure construction continues to surge, concerns regarding carbon emissions and environmental pollution have escalated. To foster sustainable development within the construction sector, there has been a growing interest in incorporating rice husk ash (RHA) into recycled aggregate concrete. This study seeks to examine the influence of partially replacing ordinary Portland cement (OPC) with RHA in equal mass proportions (0%, 10%, 20%, 30% of the binder) on the mechanical properties and freeze-thaw resistance of recycled concrete. The research involved assessing the workability, compressive strength, mass loss, and dynamic elastic modulus of recycled concrete. Additionally, the hydration products and microstructure were analyzed through scanning electron microscopy (SEM) tests. The study aimed to unveil the mechanism behind the deterioration of freeze-thaw damage in RHA-recycled aggregate concrete. The findings reveal that the introduction of RHA has a negative impact on the workability of fresh concrete. This is attributed to its high specific surface area, which provides numerous nucleation sites for hydration reactions. This refinement of the pore structure in the paste and enhancement of the pozzolanic reaction and filling effect within the matrix improve the compressive strength of the concrete by strengthening the weak bonding in the interfacial transition zone (ITZ). Furthermore, the porous structure of the mortar attached to the recycled aggregate, along with mesoporous RHA, absorbs a significant amount of water during freeze-thaw cycles. As expansion pressure accumulates, interior pores and cracks gradually expand and extend, resulting in more pronounced damage to the concrete. The extent of freeze-thaw damage deterioration increases with higher RHA replacement ratios.

6] In this research, an examination was conducted on the short-term and long-term mechanical characteristics of self-compacting concrete (SCC) using a blend of lime-cement binder, silica fume (SF), perlite powder (PP), and a combination of silica fume and perlite powder (SF-PP) as additives. The primary objective of this study was to explore the impacts of varying additive proportions on the fresh and mechanical properties of SCC. Furthermore, the study explored the replacement of the cement-lime binder with SF, PP, and SF-PP at different levels, specifically 0%, 5%, 10%, 15%, and 20%.

The optimal proportions were determined to be 17% for SF, 6% for PP, and 6% for SF-PP, both on the 28th and 90th days, in order to achieve the highest compressive strength. The outcomes revealed that an increase in silica fume (SF) content led to elevated water absorption, dry density, and 28-day compressive strength. The replacement of PP and SF-PP also had an impact on SCC properties, with SF-PP showing a more favorable effect on the concrete. The highest compressive strength for SCC was observed at 17% for SF, 6% for PP, and 6% for SF-PP, particularly on the 90th day. When 10%

lime powder was used instead of cement, the optimal SF utilization decreased to below 20%, contrasting with normal concrete where the ideal SF content is typically above 20%.

7] The substantial demand for concrete in construction, utilizing typical heavy aggregates like gravel and granite, has led to a significant depletion of natural stone resources, resulting in environmental damage and ecological imbalances. Therefore, it is imperative to explore alternative materials to replace natural stone. Notably, in India, the utilization of unconventional aggregates in concrete construction is not yet a common practice. India ranks as the world's third-largest producer of coconut products, with coconut trees being extensively cultivated in the southern states, particularly Kerala. The substitution of coconut shells for coarse aggregates in concrete has gained prominence, especially in this region, as it offers the potential to reduce environmental waste and provide a sustainable substitute for non-renewable natural stone aggregates. An experimental study was conducted to examine the concrete properties when crushed coconut shells replaced coarse aggregates in varying proportions of 25%, 50%, and 100%. The study assessed workability, compressive strength, flexural strength, and splitting tensile strength in comparison to regular concrete properties. The outcomes of this research are anticipated to encourage the adoption of coconut shells as a viable alternative to traditional coarse aggregates in concrete.

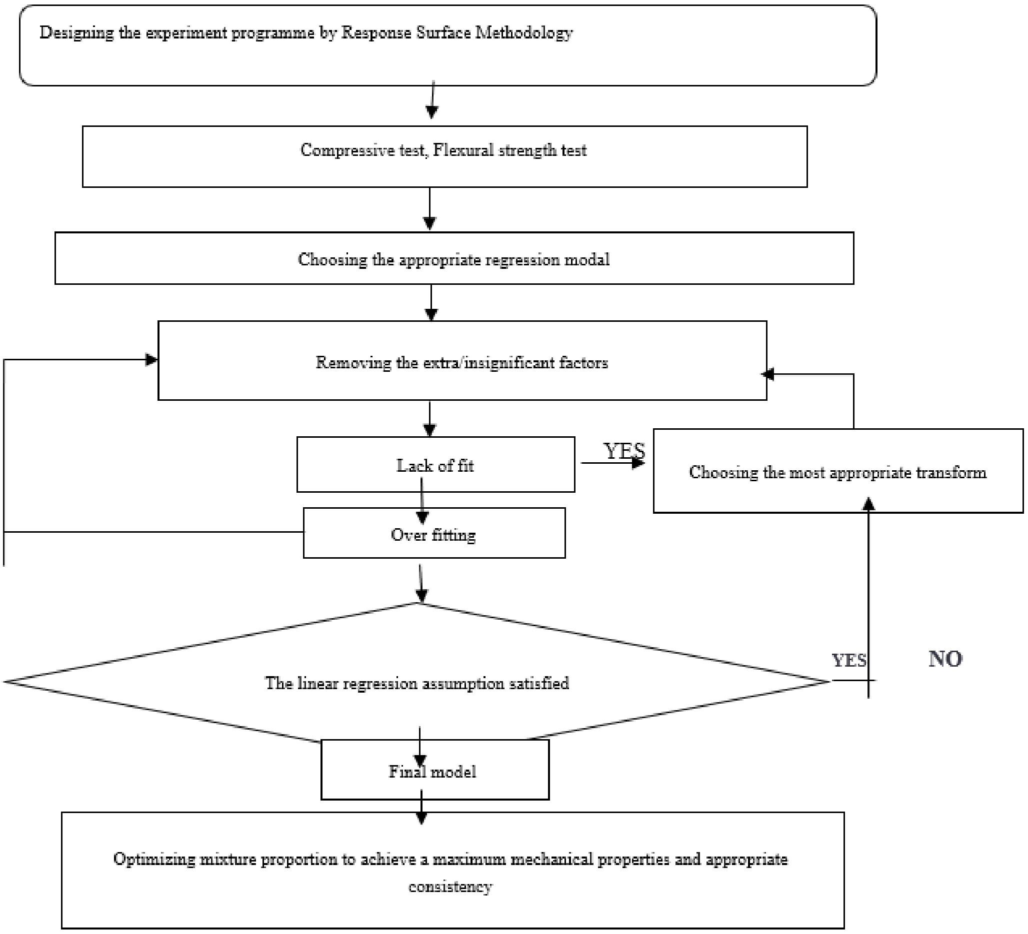
8] Ferrochrome ash (FA) is a by-product generated by the ferroalloy industry. This study aims to evaluate the potential of using FA in combination with lime as a partial substitute for cement in the production of concrete. To achieve this goal, various concrete properties such as workability, fresh density, compressive strength, flexural strength, bond strength, acid resistance, sulfate resistance, and sorptivity were thoroughly examined for concrete mixes that incorporated FA. The FA content in these mixes ranged from 10% to 40%, with increments of 10%, and included 7% lime. The results of the investigation demonstrated that the addition of FA and lime had a positive impact on the properties of the concrete. Remarkably, when the ordinary Portland cement (OPC) was replaced by 40% FA and supplemented with 7% lime, the concrete exhibited properties either equivalent to or even better than those of regular concrete. These findings were consistent across various tests, both destructive and non-destructive. Microstructural analysis, including assessments of gel condition and hydration degree, further confirmed these positive results. In summary, the investigation conclusively established the technical suitability of using FA in conjunction with lime as a supplementary cementitious material in concrete production.

9] The effect of rice husk ash (RHA) on concrete properties and durability was studied. To establish the suitable proportion of RHA for the partial replacement of cement, concrete mixtures with 0–30% RHA were produced and their mechanical properties were determined. The effect of RHA on the uniformity of concrete was also examined. The durability of the specimens exposed to aggressive environments (5% NaCl with wet-dry cycling) was evaluated for a total of eleven months. The degree of damage was studied by determining the percentage of reduction in compressive strength and chloride ions penetration as compared with control specimens that had cured normally. The results indicate that the partial replacement of cement by RHA improved durability and homogeneity but did not increase the early age compressive strength of concrete. However, concrete containing RHA showed higher compressive strength at the later ages. The scanning electron microscopy (SEM) studies of the microstructure of mortar specimens showed that the RHA filled up the pores and this explained the superior mechanical performance of the mortar with RHA.

10] This paper presents a comprehensive experimental investigation focused on examining the impact of partially substituting cement with Fly Ash (FA) and Rice Husk Ash (RHA) in concrete. The study commenced with a combination of 30% FA and 0% RHA replacing cement, and then gradually increased the RHA content by 2.5%, simultaneously decreasing the FA content by 2.5% in each step. The final composition consisted of 15% FA and 15% RHA. The evaluation involved destructive tests on hardened concrete, including compressive testing on 150 x 150 x 150 mm cubes at curing durations of 7, 14, 28, 56, and 90 days as per IS: 516—1959, flexural strength testing on 150 x 150 x 700 mm beams at 28 days of curing according to IS: 516—1959, and split tensile strength testing on 150 mm ø x 300 mm cylinders at 28 days of curing following IS: 5816—1999 guidelines. findings presented in this paper shed light on how the combination of FA and RHA at different proportions affects the mechanical properties of concrete, including compressive strength, flexural strength, and split tensile strength. The investigation revealed that, compared to the targeted strength, compressive strength increased by 30.15% but decreased by 8.73% compared to control concrete at 28 days. Additionally, flexural strength increased by 4.57% compared to control concrete at 28 days, while split tensile strength decreased by 9.58% compared to control concrete at 28 days. These results were observed with a combination of 22.5% FA and 7.5% RHA. The partial replacement of FA and RHA not only mitigates environmental impacts but also leads to the production of cost-effective and eco-friendly concrete.

METHODOLOGY

The methodology of the present work has been shown in the below figure



Step by step approach to achieve response surface approach and optimization

The present experimental programme is designed by using the response surface methodology which evaluates the effect and interaction of multiple variables on a dependent variable just like the taguachi method.. The experimental data is from the compressive test, flexural strength test. The appropriate regression model is chosen by most appropriate transform due to lack of fit or by removing the extra or insignificant factors due to over fitting. The final model is obtained when the linear regression assumptions are satisfied. Optimization is done for the mix proportions to achieve maximum mechanical properties and appropriate consistency.

4. RESULTS

Based on the predicted mechanical properties obtained from the Response Surface Methodology the results are presented.

Compressive strength:

Effect of lime powder on compressive strength:

In this present work researchfor enhancement of compressive strength of concrete with different percentage variation of lime powder in concrete mix. The addition of lime powder decreases compressive strength properties of the concrete as green concrete mixes incorporating lime at 0% to 35% by weight of cement and the variation in the compressive strength results are shown. Lime has the tendency to develop the concrete properties especially strength. It has been observed that there is an increment in the compressive strength results with the increase in the lime powder content. The compressive strength results were found to increase with increase in the lime powder content irrespective of rice husk ash and coconut shell. For instance the mixes which are not containing lime powder, rice husk ash, coconut shell are producing maximum strength than the mixes without lime powder.

Effect of rice husk ash on compressive strength:

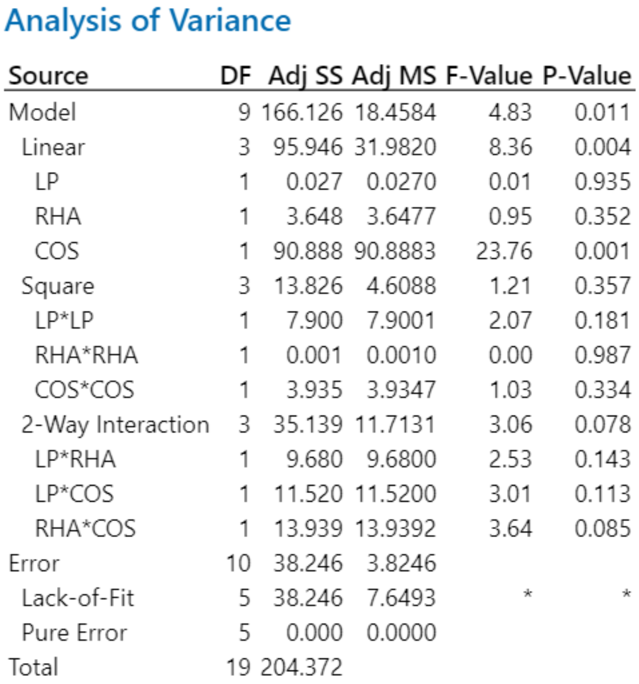
Rice husk ash is added in various percentages along with lime powder, coconut shell to enhance the compressive strength. The results of the experiments carried out with varying mixing volume of rice husk ash have shown that the compressive strength of concrete significantly increases with an increased volume of rice husk ash. The compressive strength results are found to be increases at 15% rice husk ash blended with lime powder and coconut shell.

For instance at 15% of rice husk ash, the compressive strength at 28 days, 14 days curing of the mixes producing the maximum strength which is containing 17.5% lime powder, 25% coconut shell.

Effect of coconut shell on compressive strength:

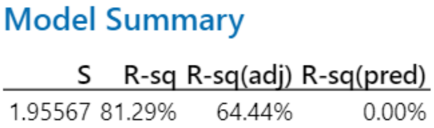
The compressive strength of concrete decreased with the addition of coconut shell into the concrete matrix. As coconut shells are organic materials, and they have a smooth surface and low surface energy. This makes it challenging for them to bond well with the cement matrix, leading to reduced adhesion and weaker overall strength. The present study revealed that the strength was decreased about 40% than the conventional concrete. The mixes which are not containing coconut shell are giving best results than those which are containing coconut shell. At 0% partial replacement of coconut shell with coarse aggregate the concrete is attaining its maximum strength.

Table 4: Analysis of variance table for 14 days compressive strength



Analysis of Variance

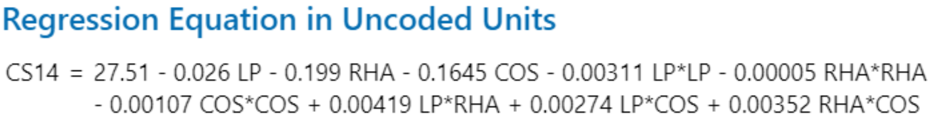
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	166.126	18.4584	4.83	0.011
Linear	3	95.946	31.9820	8.36	0.004
LP	1	0.027	0.0270	0.01	0.935
RHA	1	3.648	3.6477	0.95	0.352
COS	1	90.888	90.8883	23.76	0.001
Square	3	13.826	4.6088	1.21	0.357
LP*LP	1	7.900	7.9001	2.07	0.181
RHA*RHA	1	0.001	0.0010	0.00	0.987
COS*COS	1	3.935	3.9347	1.03	0.334
2-Way Interaction	3	35.139	11.7131	3.06	0.078
LP*RHA	1	9.680	9.6800	2.53	0.143
LP*COS	1	11.520	11.5200	3.01	0.113
RHA*COS	1	13.939	13.9392	3.64	0.085
Error	10	38.246	3.8246		
Lack-of-Fit	5	38.246	7.6493	*	*
Pure Error	5	0.000	0.0000		
Total	19	204.372			



Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.95567	81.29%	64.44%	0.00%

Figure 5



Regression Equation in Uncoded Units

CS14 = 27.51 - 0.026 LP - 0.199 RHA - 0.1645 COS - 0.00311 LP*LP - 0.00005 RHA*RHA
- 0.00107 COS*COS + 0.00419 LP*RHA + 0.00274 LP*COS + 0.00352 RHA*COS

Equation 2

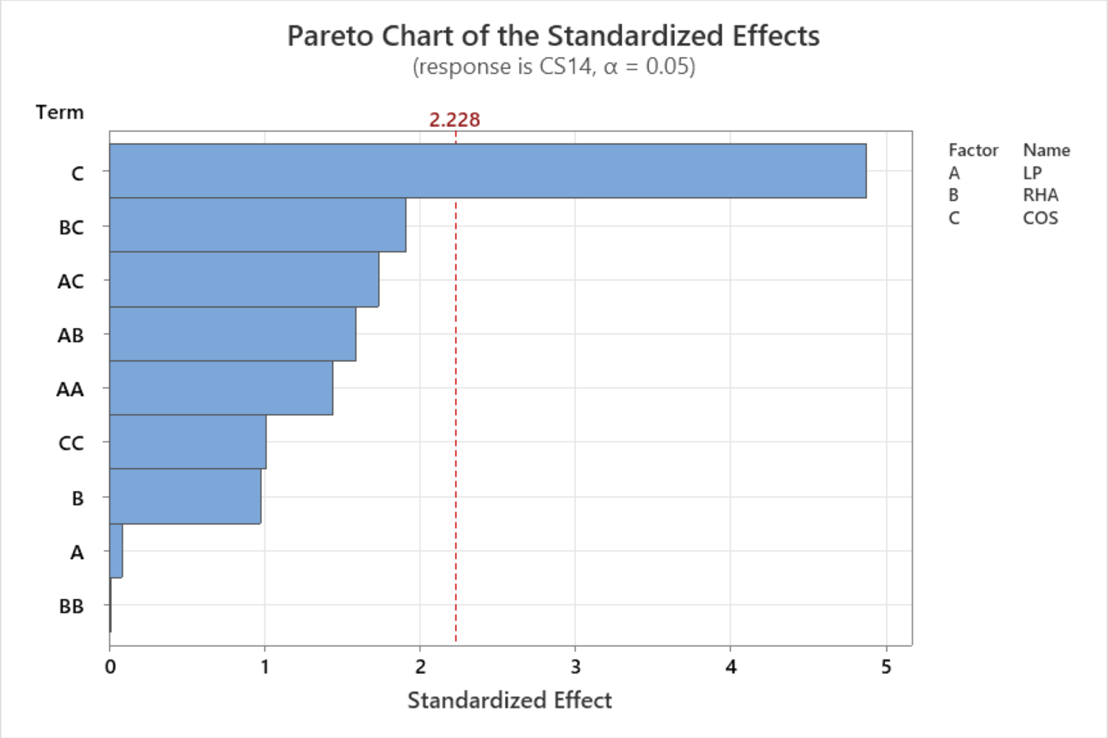


Figure 6

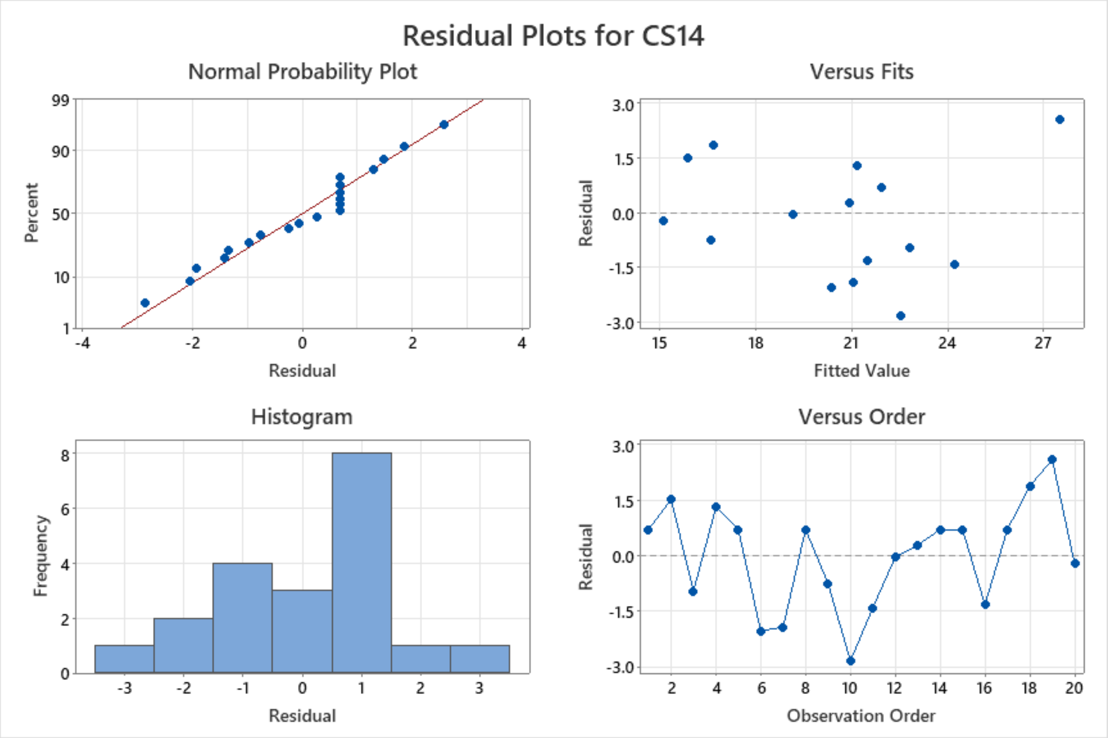


Figure 7

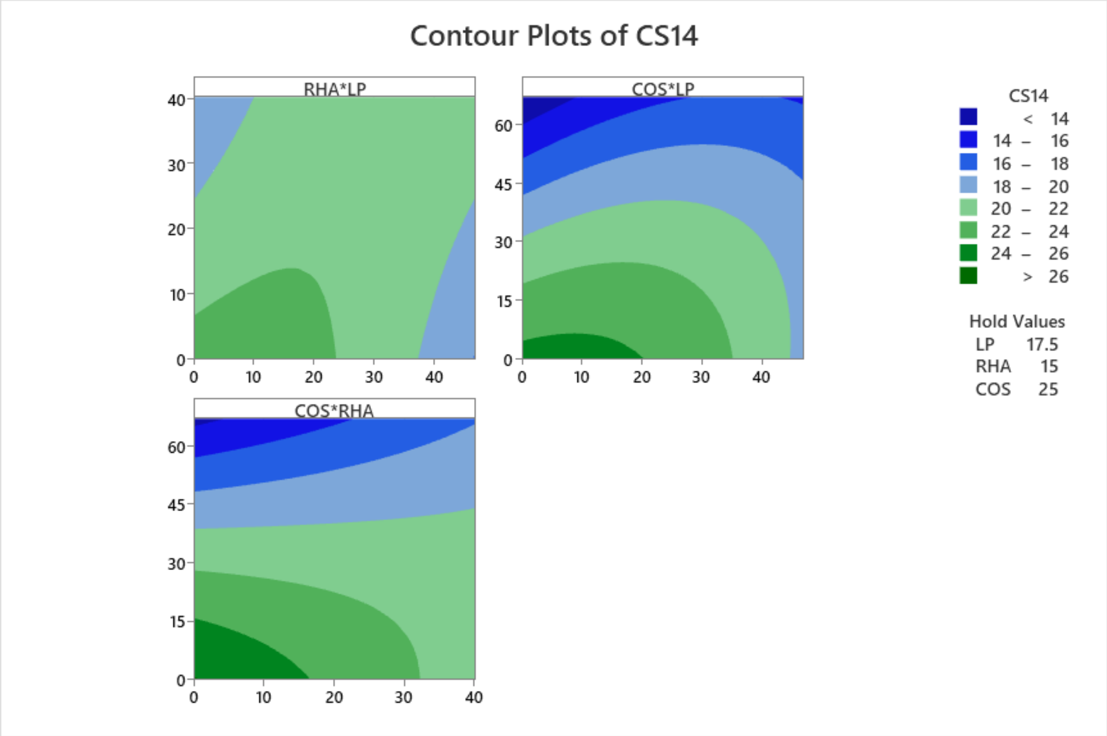


Figure 8

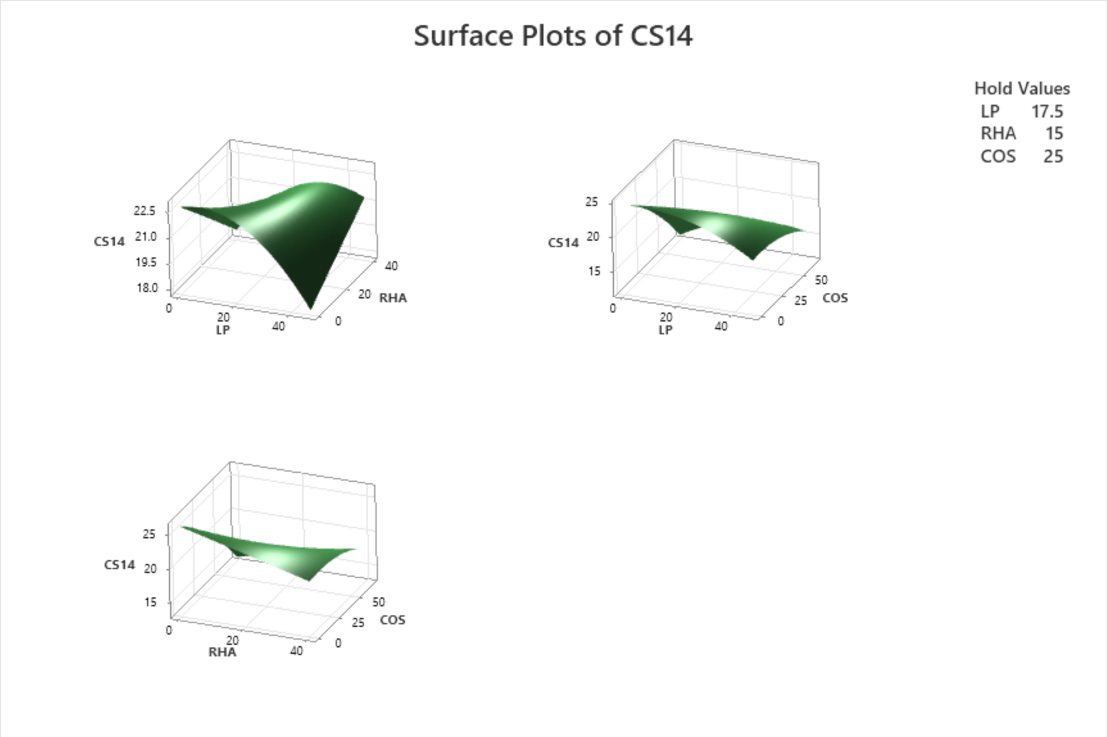
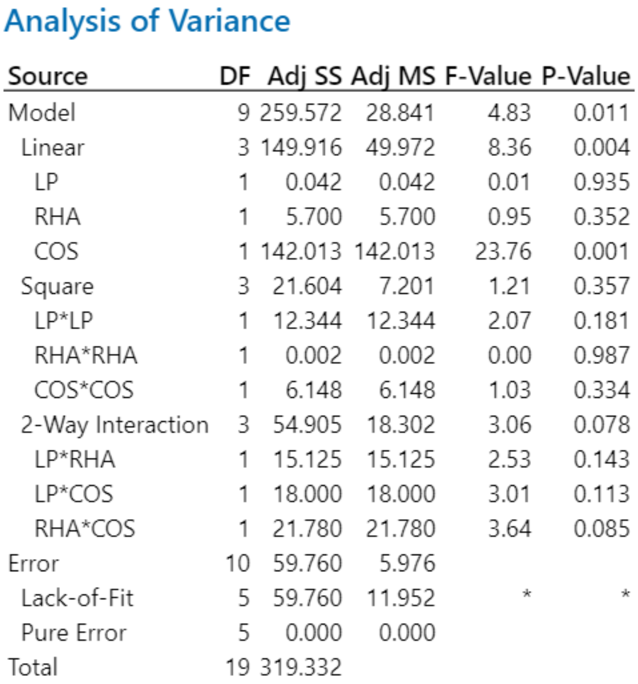


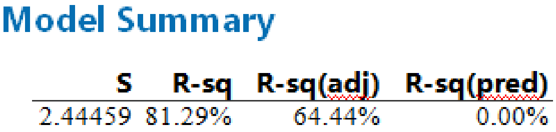
Figure 9

Table 5: Analysis of variance table for 28 days compressive strength



Analysis of Variance

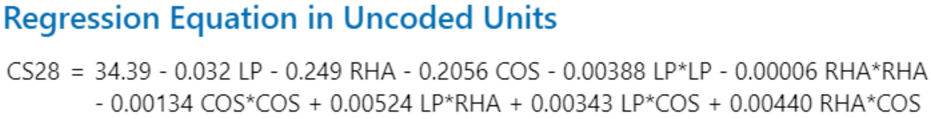
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	259.572	28.841	4.83	0.011
Linear	3	149.916	49.972	8.36	0.004
LP	1	0.042	0.042	0.01	0.935
RHA	1	5.700	5.700	0.95	0.352
COS	1	142.013	142.013	23.76	0.001
Square	3	21.604	7.201	1.21	0.357
LP*LP	1	12.344	12.344	2.07	0.181
RHA*RHA	1	0.002	0.002	0.00	0.987
COS*COS	1	6.148	6.148	1.03	0.334
2-Way Interaction	3	54.905	18.302	3.06	0.078
LP*RHA	1	15.125	15.125	2.53	0.143
LP*COS	1	18.000	18.000	3.01	0.113
RHA*COS	1	21.780	21.780	3.64	0.085
Error	10	59.760	5.976		
Lack-of-Fit	5	59.760	11.952	*	*
Pure Error	5	0.000	0.000		
Total	19	319.332			



Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.44459	81.29%	64.44%	0.00%

Figure 10



Regression Equation in Uncoded Units

CS28 = 34.39 - 0.032 LP - 0.249 RHA - 0.2056 COS - 0.00388 LP*LP - 0.00006 RHA*RHA
- 0.00134 COS*COS + 0.00524 LP*RHA + 0.00343 LP*COS + 0.00440 RHA*COS

Equation 3

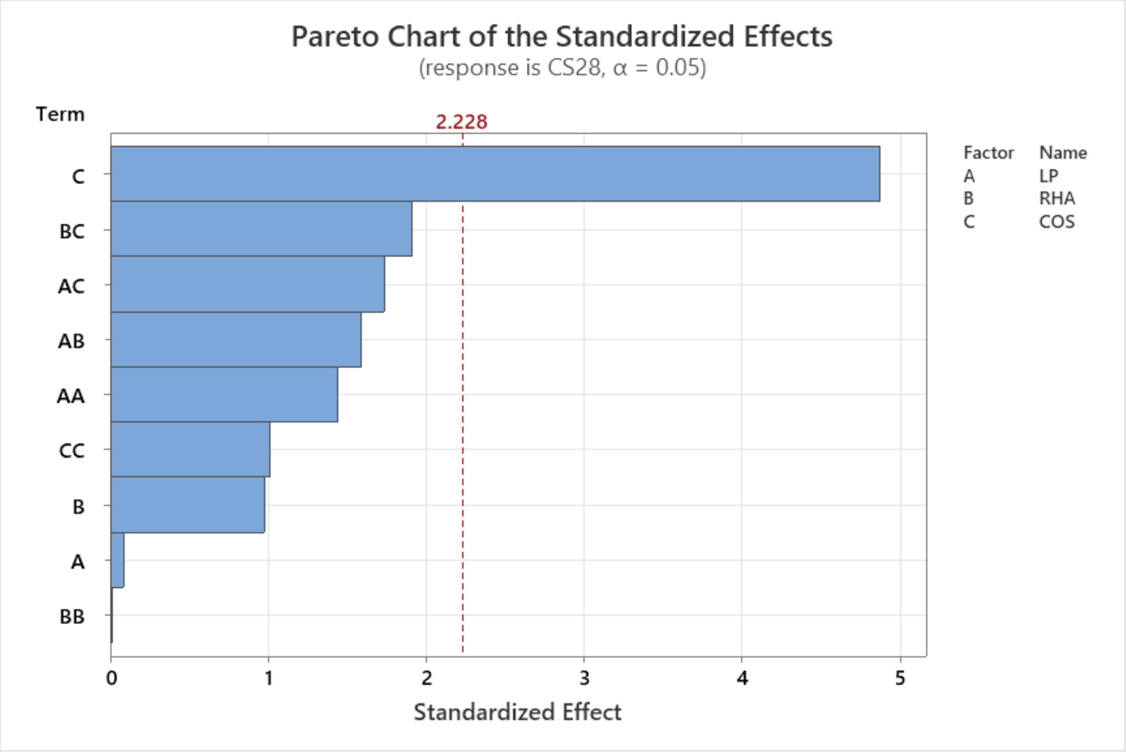


Figure 11

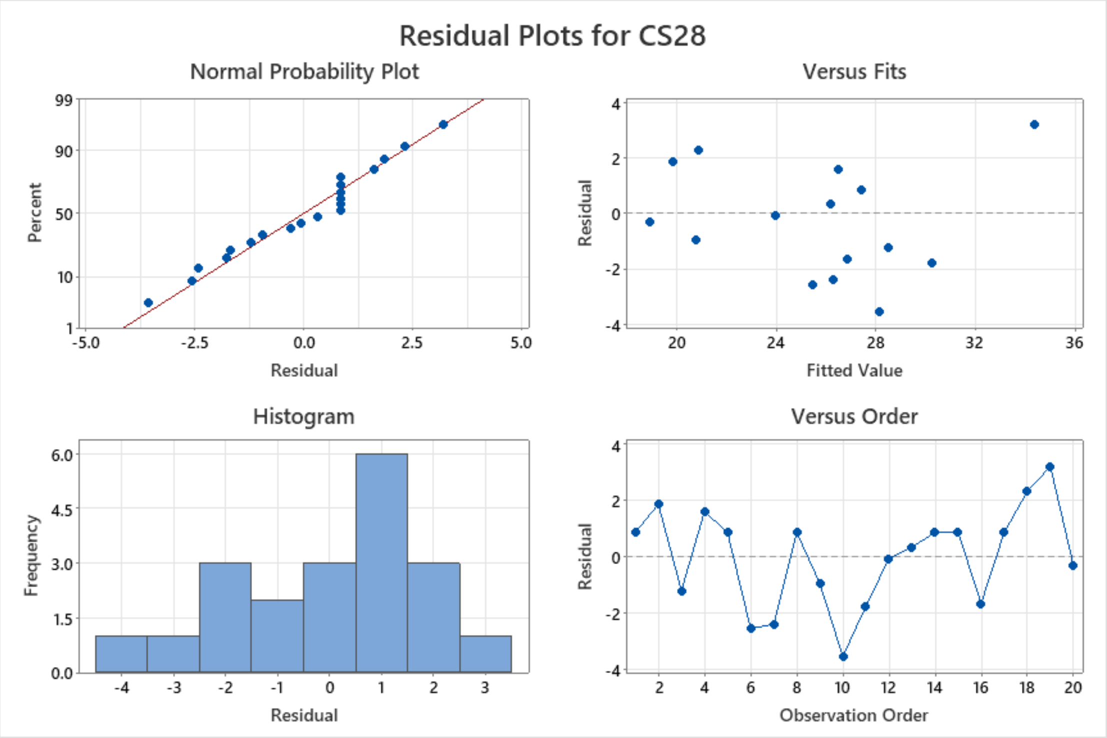


Figure 12

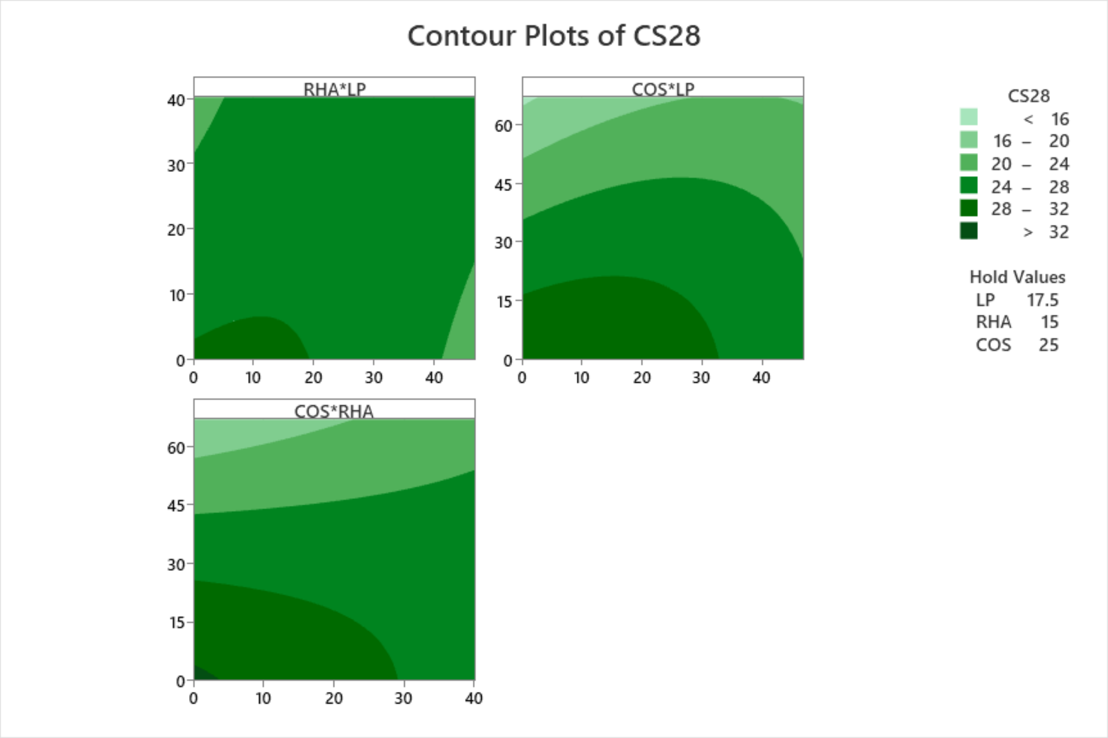


Figure 13

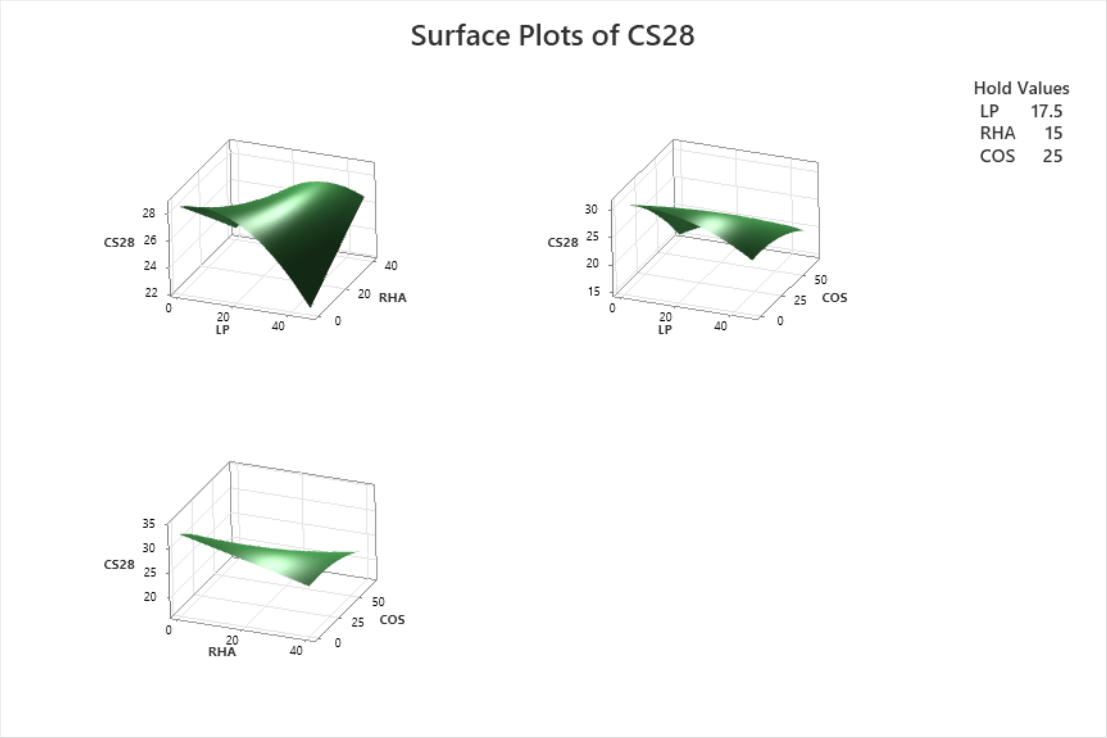


Figure 14

Flexural strength:

Effect of lime powder on flexural strength:

In this present work research for enhancement of flexural strength of concrete with different percentage variation of lime powder in concrete mix. The addition of lime powder increases flexural strength properties of the concrete as green concrete mixes incorporating lime at 0% to 35% by weight of cement and the variation in the flexural strength results are shown. Lime has the tendency to develop the concrete properties especially strength. It has been observed that there is an increment in the flexural strength results with the increase in the lime powder content. The flexural strength results were found to increase with increase in the lime powder content irrespective of rice husk ash and coconut shell. For instance the mixes which are not containing lime powder, rice husk ash, coconut shell are producing maximum strength than the mixes without lime powder.

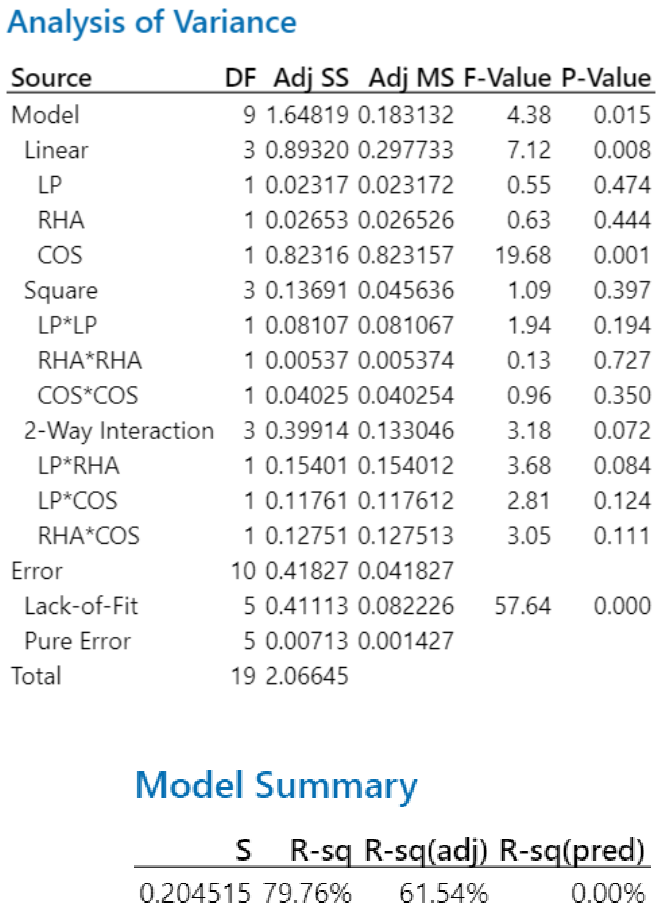
Effect of rice husk ash on flexural strength:

Rice husk ash is added in various percentages along with lime powder, coconut shell to enhance the flexural strength. The results of the experiments carried out with varying mixing volume of rice husk ash have shown that the flexural strength of concrete significantly increases with an increased volume of rice husk ash. The flexural strength results are found to be increases at 15% rice husk ash blended with lime powder and coconut shell. For instance at 15% of rice husk ash, the flexural strength at 28 days, 14 days curing of the mixes producing the maximum strength which is containing 17.5% lime powder, 25% coconut shell.

Effect of coconut shell on flexural strength:

The flexural strength of concrete decreased with the addition of coconut shell into the concrete matrix. As coconut shells are organic materials, and they have a smooth surface and low surface energy. This makes it challenging for them to bond well with the cement matrix, leading to reduced adhesion and weaker overall strength. The present study revealed that the strength was decreased about 40% than the conventional concrete. The mixes which are not containing coconut shell are giving best results than those which are containing coconut shell. At 0% partial replacement of coconut shell with coarse aggregate the concrete is attaining its maximum strength.

Table 6: Analysis of variance table for 14 days flexural strength



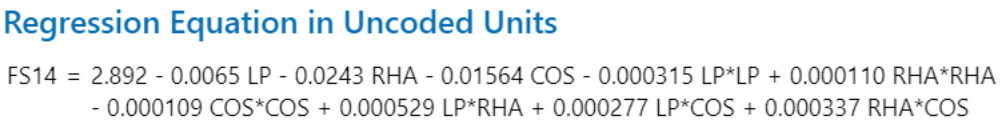
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1.64819	0.183132	4.38	0.015
Linear	3	0.89320	0.297733	7.12	0.008
LP	1	0.02317	0.023172	0.55	0.474
RHA	1	0.02653	0.026526	0.63	0.444
COS	1	0.82316	0.823157	19.68	0.001
Square	3	0.13691	0.045636	1.09	0.397
LP*LP	1	0.08107	0.081067	1.94	0.194
RHA*RHA	1	0.00537	0.005374	0.13	0.727
COS*COS	1	0.04025	0.040254	0.96	0.350
2-Way Interaction	3	0.39914	0.133046	3.18	0.072
LP*RHA	1	0.15401	0.154012	3.68	0.084
LP*COS	1	0.11761	0.117612	2.81	0.124
RHA*COS	1	0.12751	0.127513	3.05	0.111
Error	10	0.41827	0.041827		
Lack-of-Fit	5	0.41113	0.082226	57.64	0.000
Pure Error	5	0.00713	0.001427		
Total	19	2.06645			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.204515	79.76%	61.54%	0.00%

Figure 15



Regression Equation in Uncoded Units

FS14 = 2.892 - 0.0065 LP - 0.0243 RHA - 0.01564 COS - 0.000315 LP*LP + 0.000110 RHA*RHA
- 0.000109 COS*COS + 0.000529 LP*RHA + 0.000277 LP*COS + 0.000337 RHA*COS

Equation 4

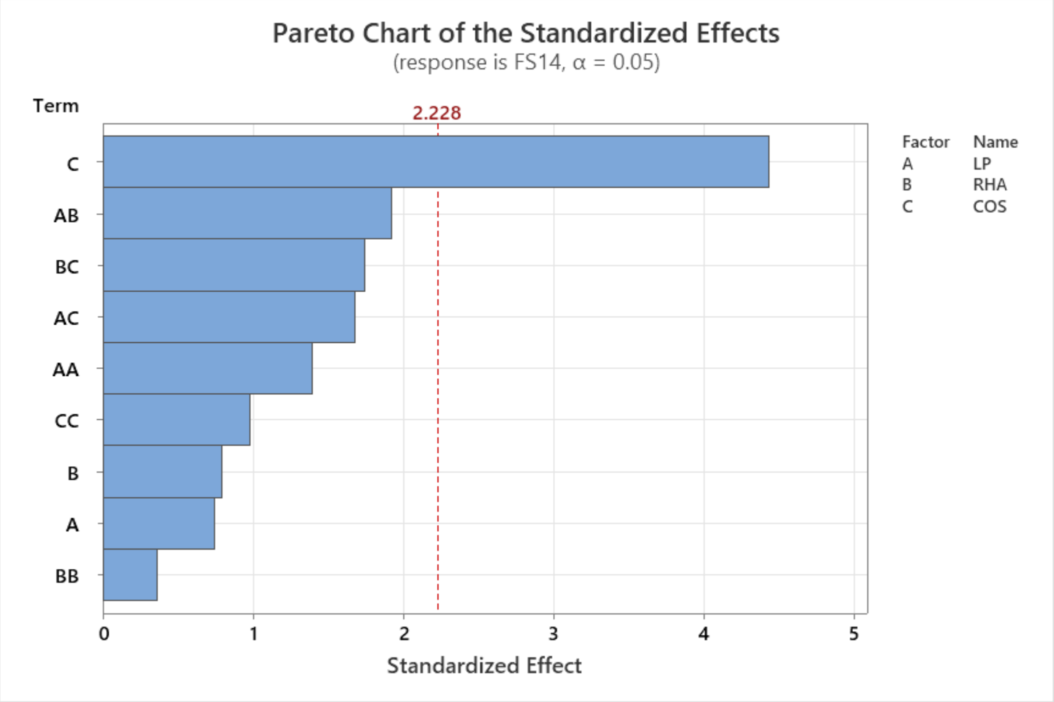


Figure 16

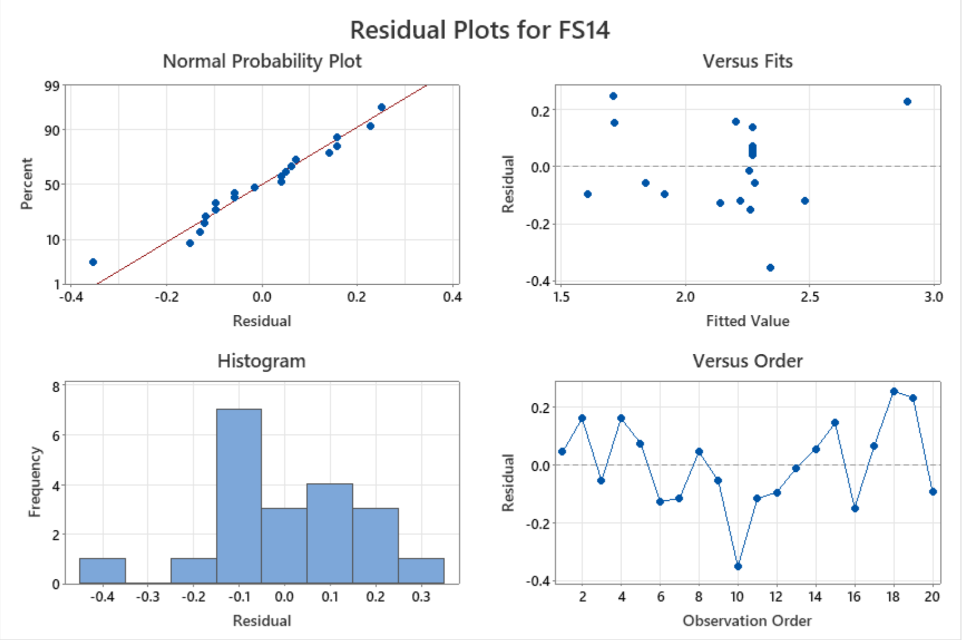


Figure 17

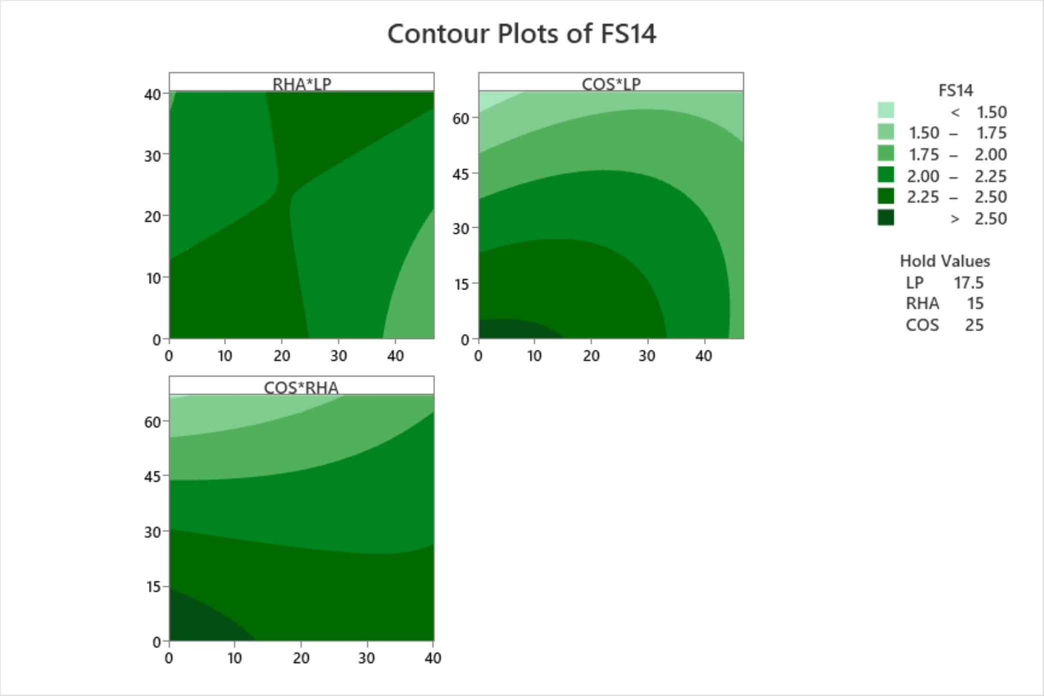


Figure 18

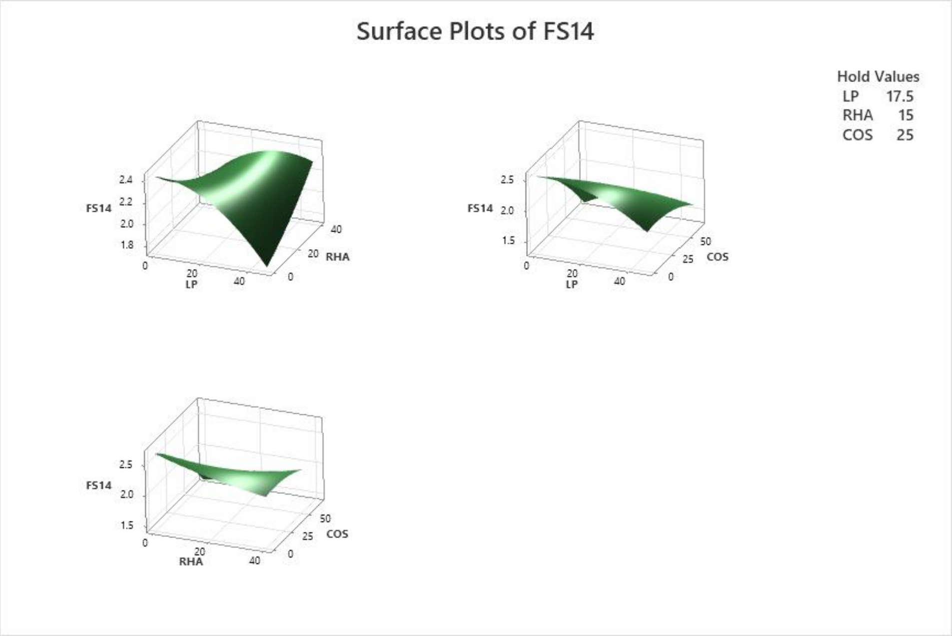


Figure 19

Table 7: Analysis of variance table for 28 days flexural strength

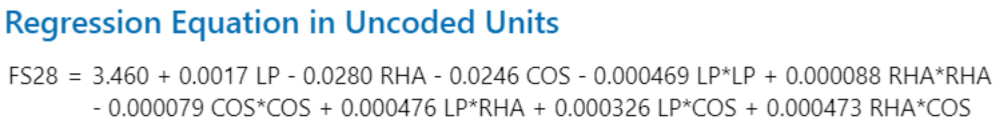
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2.72880	0.30320	4.26	0.017
Linear	3	1.71131	0.57044	8.01	0.005
LP	1	0.00098	0.00098	0.01	0.909
RHA	1	0.06318	0.06318	0.89	0.368
COS	1	1.62764	1.62764	22.87	0.001
Square	3	0.21905	0.07302	1.03	0.422
LP*LP	1	0.17990	0.17990	2.53	0.143
RHA*RHA	1	0.00344	0.00344	0.05	0.831
COS*COS	1	0.02107	0.02107	0.30	0.598
2-Way Interaction	3	0.53950	0.17983	2.53	0.117
LP*RHA	1	0.12500	0.12500	1.76	0.215
LP*COS	1	0.16245	0.16245	2.28	0.162
RHA*COS	1	0.25205	0.25205	3.54	0.089
Error	10	0.71180	0.07118		
Lack-of-Fit	5	0.65345	0.13069	11.20	0.010
Pure Error	5	0.05835	0.01167		
Total	19	3.44060			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.266795	79.31%	60.69%	0.00%

Figure 20



Regression Equation in Uncoded Units

FS28 = 3.460 + 0.0017 LP - 0.0280 RHA - 0.0246 COS - 0.000469 LP*LP + 0.000088 RHA*RHA
- 0.000079 COS*COS + 0.000476 LP*RHA + 0.000326 LP*COS + 0.000473 RHA*COS

Figure 21

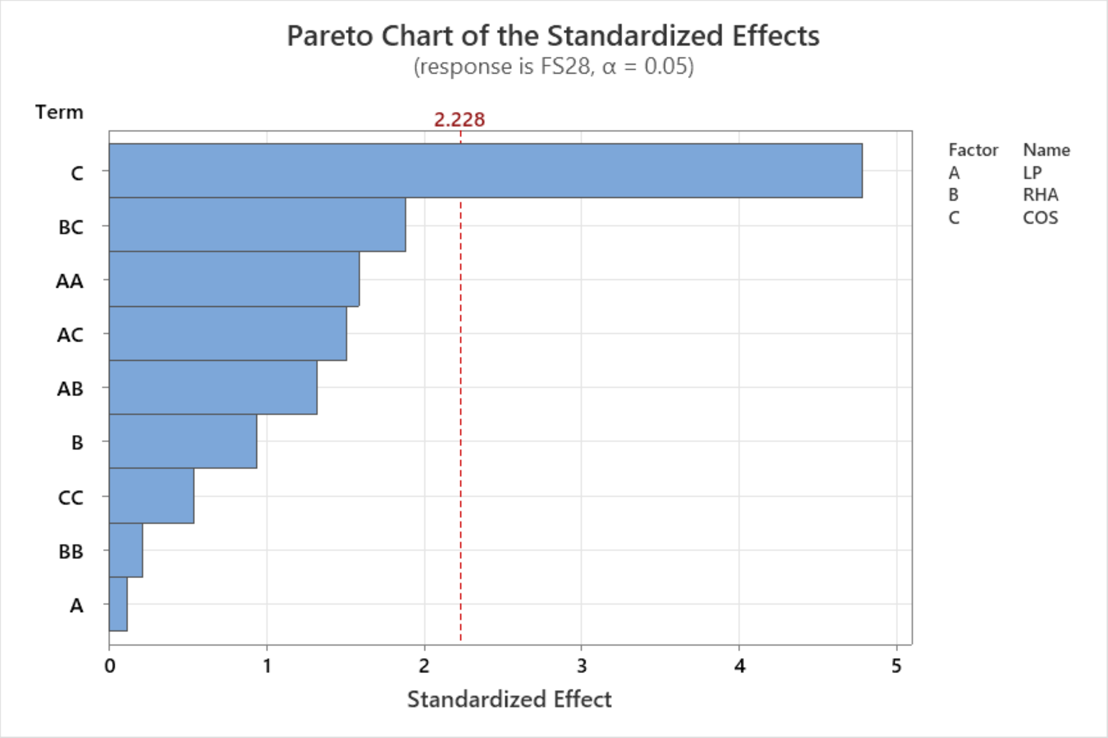


Figure 22

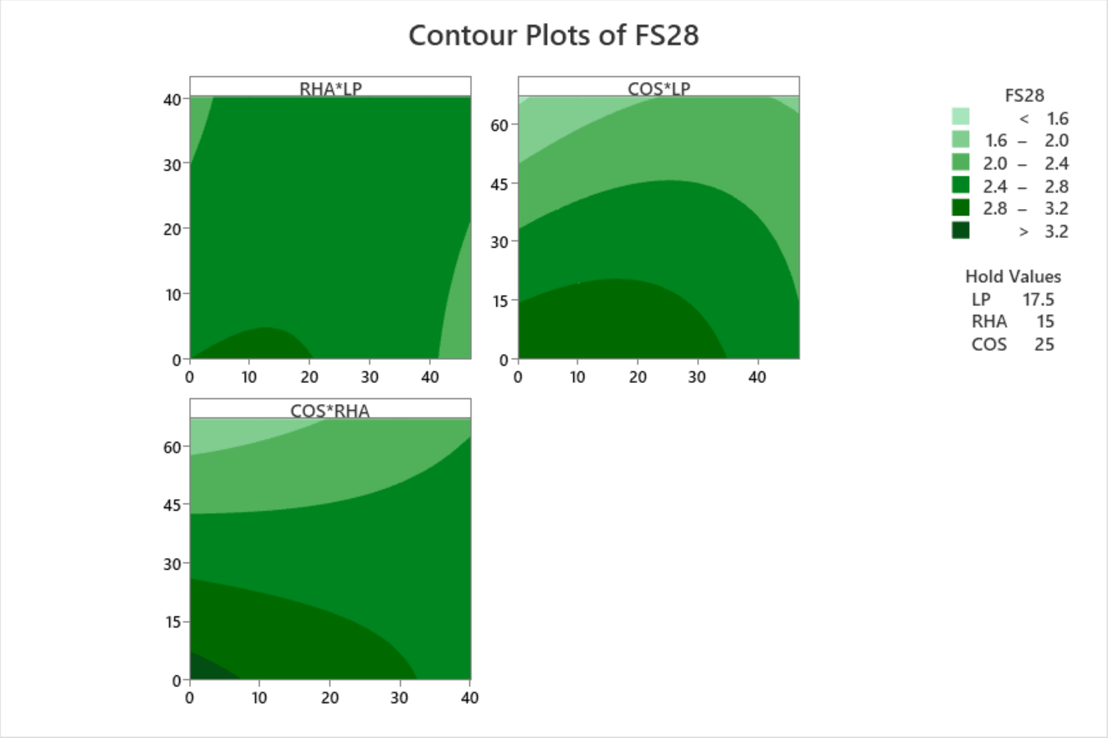


Figure 23

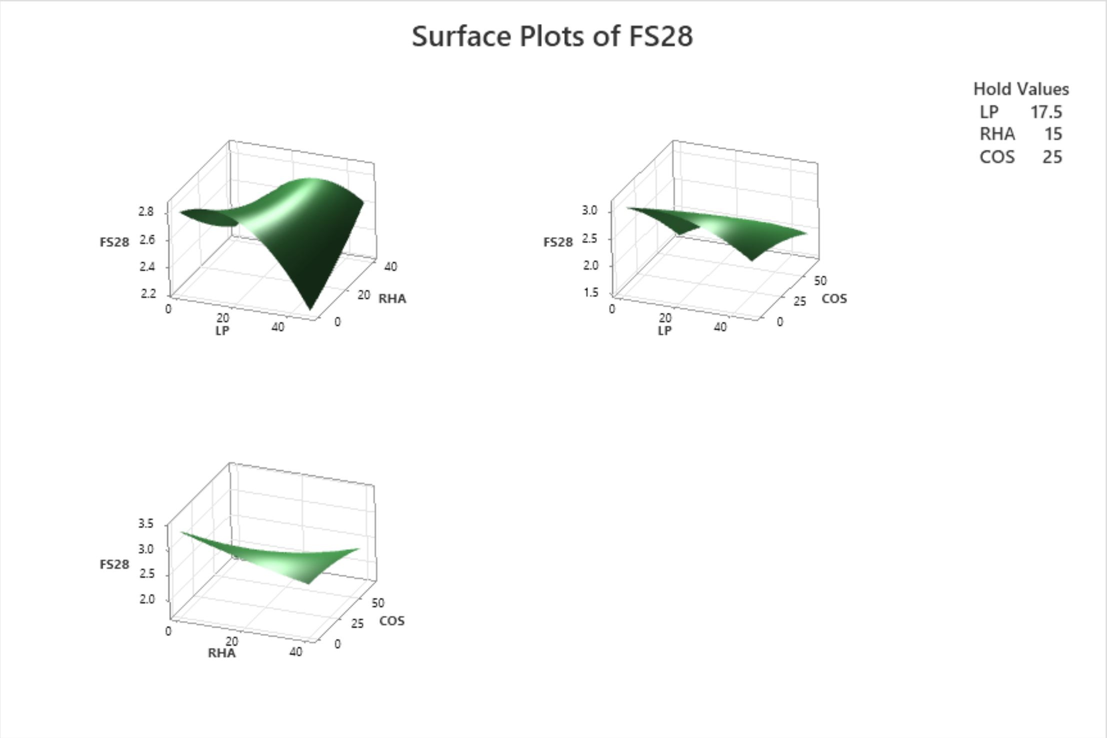


Figure 24

CONCLUSION

Based on the results obtained from prediction of mechanical properties on green concrete for following concluding remarks are made:

- The present work explores the usage of lime powder, rice husk ash and coconut shell as an additional material in concrete to improve its strength.
- Compressive strength and flexural strength tests were done on the cubes and prisms respectively by partially replacing cement with lime, fine aggregate with rice husk ash and coarse aggregate with coconut shell for various proportions.
- Experimental values of compressive strength and flexural strength are taken to predict the mechanical properties of green concrete through Response Surface Methodology.
- From the results, the optimum values for compressive, flexural strengths were observed at 17.5% lime powder, 15% rice husk ash and 25% coconut shell.
- Conventional concrete sample obtained maximum strength than any other sample.

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3] Chao Liu et.al “Recycled aggregate concrete with the incorporation of rice husk ash: Mechanical properties and microstructure” (2022)

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5] Wei Zhang et.al “Impact of Rice Husk Ash on the Mechanical Characteristics and Freeze–Thaw Resistance of Recycled Aggregate Concrete” (2022)

6] Chao Liu et.al “A compressive strength prediction model based on the hydration reaction of cement paste by rice husk ash” (2022)

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8] Mohith gupta et.al “Effect of Rice Husk Ash, silica fume & GGBFS on compressive strength of performance based concrete”(2021)

9] Ranjitha B“Strength characteristics of concrete using coconut shell as a coarse aggregate – A sustainable approach” (2021)