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Fabrication and Testing of Advanced Concrete Made with Carbonized Bio Waste Available Locally: Special Consideration of Waste from Rajasthan

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Abstract

In today's world, the construction sector must contend with a number of challenges on account of factors such as increasing urbanization and diminishing natural resources. More ecologically friendly building materials are being produced by industry as a result of increased awareness of the effects of climate change. Among other possible substitutes, rice husk ash (RHA), sugarcane bagasse ash (SCBA), and bamboo leaf ash (BLA) are already being used in the production of eco-friendly building materials like BIO-BRICKS. This article takes a look at a product called Bio-Bricks, which is made out of agricultural waste. Brick and other types of masonry, environmentally friendly concrete, insulation, reinforcing materials, particleboard, and bio-based polymers are the materials that are employed. Key selection factors were how well it is known and how widely it is used in contemporary building applications. The primary focus of this research is on common materials, the continued use of which has a detrimental impact on the natural world. According to the findings of the study, the utilization of agro-waste in the production of sustainable building materials was successful due to the fact that the products satisfied the standards for buildings. Therefore, items made from agro-waste may be used in place of conventional building materials to achieve sustainability on several fronts, including the economic, environmental, and social.

Keywords: Sustainable bricks, EQUEST, ansys fluent, thermal comfort, building energy saving

INTRODUCTION

Concrete production is a key factor in greenhouse gas emissions. Estimates indicate it may account for as much as 8% of carbon dioxide emissions. This stark reality for more sustainable methods to produce concrete. There's an urgent need to lessen the environmental effects of the construction industry. A promising solution lies in using locally sourced bio waste materials in concrete production.

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Bio waste materials, including agricultural residues, food waste, and forestry byproducts, are readily available in many areas. Often, these materials are discarded or burned, leading to air pollution and greenhouse gas emissions, which is really unfortunate. Yet, they possess valuable carbon-based compounds that can be turned into innovative and sustainable construction materials. Recent studies have highlighted the potential of these bio waste materials for concrete production. One method involves carbonizing organic waste through pyrolysis. This process heats the waste without oxygen and creates biochar—a dense carbon substance. Biochar has several appealing properties. It can enhance compressive strength, improve durability & serve as a filler in concrete mixtures.

However, adopting biochar widely presents challenges. There's still a limited understanding of how various types of biochar work with different concrete mixtures. Optimizing these interactions is key to achieving desired outcomes. Additionally, how to source, process & use bio waste materials in a budget-friendly manner is still a concern. The agriculture sector produces large amounts of bio waste yearly—like crop residues & animal manure. If not handled properly, these wastes might contribute to greenhouse gas emissions & hurt water quality. But they also provide opportunities to create valuable products through carbonization. This conversion of organic material into biochar offers many benefits: it can help improve soil health, retain water & sequester carbon effectively. Moreover, biochar can have multiple applications—such as being a fuel source or filtration medium or even in building materials! Using biochar for concrete production could reduce the significant carbon dioxide emissions linked to traditional methods.

In addition to its role in concrete, agricultural waste-derived biochar can enhance soil health and fertility when used as a soil amendment. Farmers using it can boost water retention, minimize nutrient loss & increase crop yields. Such practices not only benefit rural economies but also lessen the environmental burdens of conventional farming methods. India's agricultural sector plays a vital role in its economy and generates considerable amounts of bio waste—especially in regions like Rajasthan. With around 58% of the population dependent on agriculture, there’s a significant opportunity to repurpose these residues into new products. This study taps into that potential by examining how agricultural waste can be used for producing insulating bricks—bringing sustainability into both agriculture & construction practices. By aligning with India's goals of enhancing agricultural income and improving rural livelihoods through innovative waste management solutions, this research addresses pressing challenges head-on. It looks at how carbonized bio waste can serve as raw materials for advanced concrete products from Rajasthan. The study will evaluate how different types of biochar affect concrete mixtures' properties and their suitability for bricks & insulating boards.

The construction industry is responsible for up to 38% of global greenhouse gas emissions—making sustainable materials essential now more than ever! Using agricultural waste—like crop residues or animal manure—to create construction products shows great promise. For example, straw and husks could be transformed into insulation services that offer better performance while being gentler on the environment. Furthermore, integrating agricultural byproducts like rice husks into concrete doesn’t just enhance strength and durability; it also lowers carbon emissions! This creative utilization helps diminish environmental impact while fostering rural economies by opening up new markets & reducing disposal expenses. When it comes to building insulation materials—they vary widely: from bulky fibers such as fiberglass and cellulose to rigid foam boards and reflective foils—all designed to slow down heat transfer within a building's structure. Common options include mineral wool alongside natural fibers while rigid foam boards like polystyrene trap air efficiently to limit heat flow. For cooling regions, radiant barriers utilizing reflective foils effectively deflect radiant heat! While less common materials like cementitious foams exist too but agricultural wastes—like straw and husks—are emerging as sustainable solutions for effective insulation production that’s good for the planet!

LITERATURE REVIEW

The existing literature on agricultural & industrial waste in construction materials shows great progress in making eco-friendly and sustainable building materials. This review brings together important findings from various studies that look at using biochar, bio-based aggregates, & waste products in concrete. It has been examined biochar from agricultural waste as a cement additive. They wanted to improve the mechanical & durability properties of concrete. Their results showed that adding 0.75-1.5 wt% biochar led to notable enhancements: compressive strength increased by 28-29%, while flexural strength grew by 16% compared to control samples. Additionally, concrete with biochar had high ultrasonic pulse velocity & low electrical resistivity, indicating better structural integrity with fewer internal flaws. A SWOT analysis revealed its performance advantages, effectiveness in harsh conditions, and potential for supporting a circular economy. Still, high production costs & technical difficulties in mixing biochar with concrete were significant challenges [1].

It has been investigated that how the amount of bio-based aggregate (BA) influences concrete's thermal & acoustic qualities. They swapped traditional dense aggregates for varying BA levels and found that BA lowered thermal conductivity while improving acoustic performance thanks to its lightweight & porous nature. Concrete with 50% BA still held enough strength for structural use, showing an average flexural strength of 6.5 MPa and compressive strength of 27.0 MPa [2]. It is also, focused on what affects the compressive strength & elastic modulus of lightweight concrete. Their research indicated that both lightweight aggregate properties and the water/binder ratio played crucial roles in determining concrete's strength and stiffness. Statistical analysis highlighted the importance of aggregate characteristics on the mechanical attributes of concrete [3]. Electric arc furnace steel slag (EAFS) works as a natural aggregate replacement in concrete. They found that using EAFS didn't greatly change the mechanical properties of concrete. Plus, EAFS helped produce sustainable concrete by cutting down energy use & emissions while reducing costs by about 20% [4].

Functionally graded concretes (FGC) that used steel fibers and recycled aggregates. They discovered improvements in mechanical performance and sustainability with FGCs compared to regular concrete, making them good choices for lower load applications like parking areas & bike lanes. The study even suggested equations to connect design factors with reinforced thickness and fiber content, making it easier to create cost-effective & eco-friendly FGCs [5]. It has been also investigated that adding recycled tire rubber, alkaline activation, and silica fume to enhance concrete's mechanical properties. They found that using recycled tire rubber slightly lowered compressive strength but resulted in a strong concrete mix at 48 MPa after 28 days when combined with alkaline-activated rubber and silica fume [6].

Industrial & agricultural by-products as alternatives for pozzolan and aggregates in lightweight concrete. Their findings showed that these by-products could lessen structural weight due to lower density & less thermal conductivity—though higher replacement levels could negatively affect fresh and hardened properties [7]. It is also, found that Palm Oil Fuel Ash (POFA) and bottom ash in non-autoclaved agricultural aerated concrete, results showed more POFA improved thermal insulation but weakened compressive strength while raising water absorption & porosity—suggesting POFA can enhance thermal insulation without losing acceptable mechanical properties[8]. It is also, examined waste plastics as aggregates in lightweight concrete, finding they significantly reduced thermal conductivity while also improving insulation—but could compromise mechanical properties if their content was too high, though still suitable for non-load-bearing structures [9].

Addition of biochar to Portland cement; it reduced paste weight but kept decent mechanical strength—making it a feasible substitute for cement in certain contexts [10]. The use of peach and apricot shells as lightweight aggregates has also been explored in previous studies, highlighting their potential to improve the thermal insulation properties of concrete while reducing overall density. peach & apricot shells as lightweight aggregates; their work showed these organic materials improved mechanical properties and creep characteristics when treated effectively. Overall, the literature suggests that using agricultural & industrial waste can lead to sustainable construction materials with better thermal insulation, acoustic performance, and adequate mechanical properties—helping reduce environmental impacts while promoting renewable resources & waste reduction.

Despite the significant strides made in utilizing agricultural & industrial waste for construction materials, research gaps still exist. First off—more studies are needed on long-term durability and performance of biochar-based concretes under different environmental conditions. Moreover, there is a lack of standardized methods for producing these materials which complicates widespread adoption efforts. Economic analyses assessing cost-effectiveness against traditional options are also limited—plus deeper research into environmental impacts is essential to fully understand sustainability potential & guide future use [11, 12].

This study investigates the mechanical behavior of concrete with partial replacement of tire retread fibers, aiming to assess their suitability as a sustainable alternative in concrete production. tensile strength peaks at 15% replacement, further investigation is warranted to ascertain long-term trends. Furthermore, the absorption by capillarity test reveals that fiber pores mitigate water absorption, offering potential for enhancing concrete properties and reducing structural weight [13].

The incorporation of waste materials into asphalt pavements has gained increasing attention as a sustainable and environmentally responsible approach to road construction and maintenance. Mechanical tests reveal that the asphalt rubber and quartzite waste mixture exhibit superior tensile strength and resilience modulus compared to reference mixtures, suggesting enhanced load-bearing capacity and resistance to deformation. This study underscores the versatility of utilizing materials like quartzite waste and rubber from scrap tires in road pavement applications, advocating for further exploration of their suitability, particularly in regions with extensive road networks and diverse environmental conditions[14].

Natural rubber (Hevea brasiliensis) is generally a product of tropical countries such as Thailand, Malaysia and Indonesia. Due to its excellent physical properties, it is a widely used material in various industries, including tyre automotive, construction and medical. Natural rubber is often manufactured in wet form and must be dried to remove excess moisture and improve its mechanical properties. Research is currently underway to study the effects of microwave drying on natural rubber properties, including the physical, mechanical, chemical and thermal properties of the material. In this context, the article aims to provide an overview of the natural rubber drying process, with a particular focus on microwave drying [15].

MATERIALS AND METHOD

The materials & methods section of this study centers on making and testing advanced concrete. This concrete uses carbonized bio-waste found locally, aiming to create sustainable bricks & insulating boards. Type-1 Ordinary Portland Cement (OPC) serves as the main binder in this project. The carbonized bio-waste comes from agricultural waste in Jaipur, Rajasthan. It consists of rice husk, wheat straw, & sugarcane bagasse. These materials are carbonized at a temperature of 500°C to improve their physical and chemical traits for use in concrete mixtures. This carbonization process is about partial combustion within an oxygen-limited space. The result? A charred substance that has better qualities, making it suitable for producing concrete. The study carefully outlines the properties of each material involved. These include specific gravity, moisture content, bulk density, & particle size distribution. Notably, the carbonized bio-waste shows a specific gravity of 0.23 g/cm³, a moisture content of 5.5%, a bulk density of 0.16 g/cm³, and particle sizes between 1 mm to 10 mm. Such properties suggest that carbonized bio-waste can effectively replace some OPC. This helps enhance the mechanical & thermal performance of concrete while lessening the environmental issues tied to agricultural waste disposal.

Concrete mixtures are prepared by replacing part of the OPC with carbonized bio-waste. The mixing method requires precise measurements & thorough quality checks to maintain consistency and reproducibility throughout the process. After mixing, this concrete is shaped into bricks and insulating boards which then undergo various tests. These tests evaluate their mechanical strength, thermal properties, & durability under different environmental conditions like weather changes or stress factors.

The complete sequence of steps involved in this research is illustrated in the flow diagram presented in Figure 1. The process of making bricks and insulating boards includes several key steps: mould preparation, casting, & curing. First, moulds are prepared with great care to ensure everything is uniform. Then comes casting. This happens under controlled conditions. It helps in achieving the right shape and size. Next is the curing stage. This stage is crucial for strengthening concrete. Samples are immersed in water for a certain time. This allows the cementitious materials to hydrate properly. This research aims to tackle problems related to sustainable construction & environmental conservation. It does this by using locally available carbonized bio-waste in advanced construction materials. By detailing the experimental procedures and material properties, this study adds to the knowledge of sustainable materials. It also provides practical insights for creating eco-friendly infrastructure. The complete Carbonization process was show in Figure2.

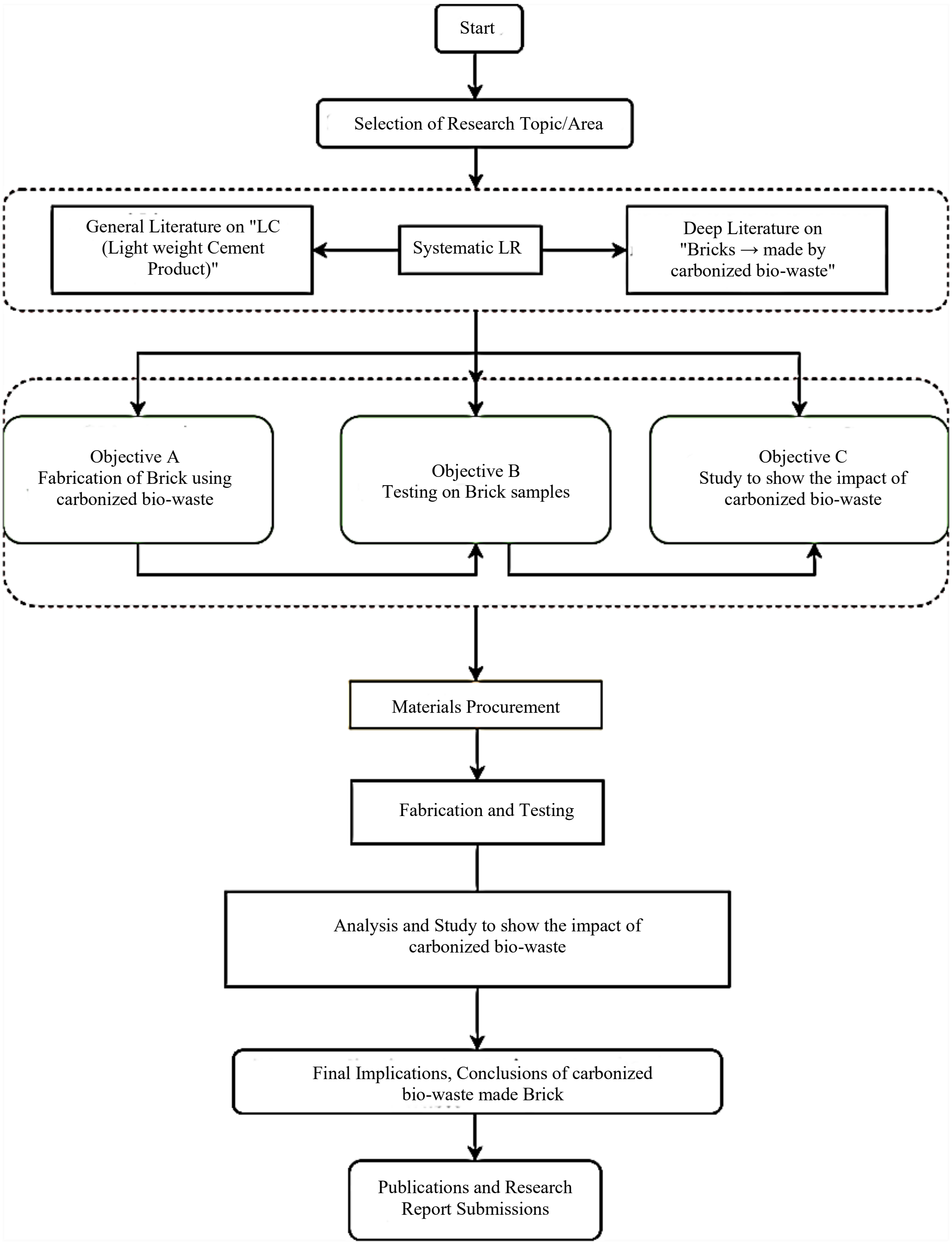

Figure 1. Research Flow diagram selected for present study.

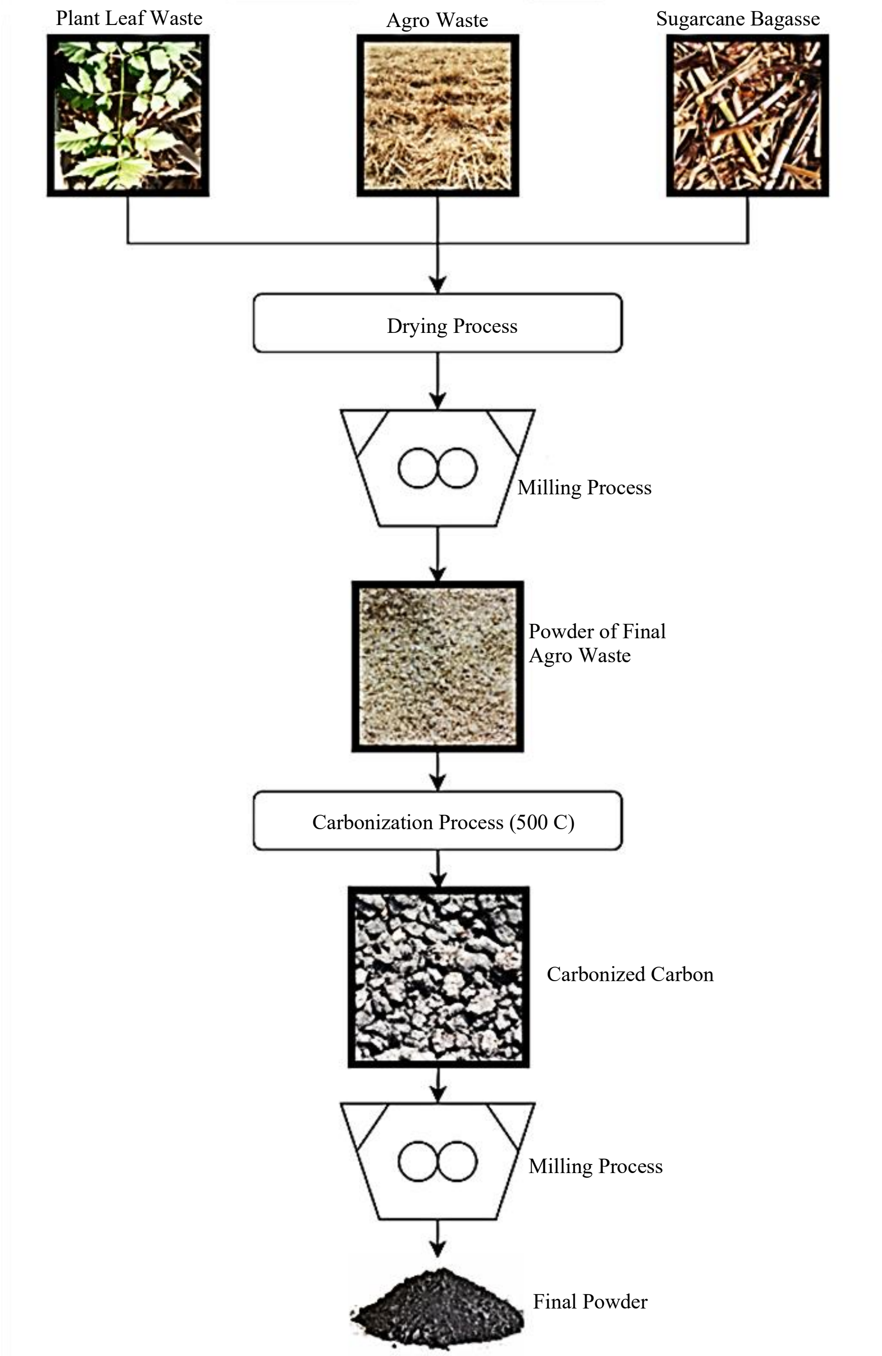

Figure 2. Carbonization process used in present study.

Fabrication of Bricks and Insulating Boards

The fabrication of bricks and insulating boards involved meticulous preparation and casting procedures to ensure high-quality construction materials. Moulds made from steel sheets were cut and welded into rectangular or square shapes, coated with petroleum jelly to prevent adhesion during casting. The concrete mixture, comprising Type-1 OPC cement, carbonized bio-waste powder, sand, and coarse aggregate in a ratio of 1:0.5:2.5:3.5 by weight, was poured into these moulds. The compositions prepared for the present study, including the addition of carbonized bio-waste powder, are presented in Table 1.

Here CBW represent Carbonized Bio Waste and 1000 represent the particle size of CBW

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Each layer of the mixture got compacted on a vibrating table. This helped to get rid of air pockets & to create an even distribution. After all moulds were filled & compacted, a trowel was used to smooth the surface. Then, we covered the moulds with plastic sheets to keep the moisture in. The curing took place in a moist chamber held at 27°C with 90% relative humidity for 28 days. This special environment helped the concrete achieve its needed strength and durability. Once curing was done, we took out the moulds. The bricks & insulating boards were carefully demoulded. After that, these samples went through several tests to check their mechanical and thermal properties. Paying close attention during mould preparation, casting, & curing was super important for making bricks & insulating boards of high quality. With enhanced strength, less water absorption, and better thermal conductivity, this method shines a light on how using carbonized bio-waste can lead to sustainable building materials. The fabrication process of bricks and insulating boards used as test samples is illustrated in Figure 3.

RESULTS AND DISCUSSION

This research explores the innovative application of Design of Experiments, or DOE specifically using the Taguchi method. looks into how three main factors affect concrete. These factors include the percentage of carbonized biowaste (CBW), lime content, & the type of bonding materials used. The study carries out nine carefully structured experiments. It thoroughly examines how changes in these factors affect the compressive strength of concrete. The research aims to solve two big challenges at once: improving concrete technology while promoting environmental sustainability. By utilizing locally sourced carbonized biowaste from Rajasthan, this study seeks to lessen dependence on traditional raw materials. It also provides practical solutions for handling agricultural residues.

Table 1. Composition made for present study (CBW-1000micro m).

Specimen	OPC	Sand	Gravel	Bio Carbon
Simple-OPC	485.6	710	1204	-
OPC+1%	485.6	710	1204	3.4
OPC+1.5%	485.6	710	1204	3.4
OPC+2.0%	485.6	710	1204	3.4
OPC+2.5%	485.6	710	1204	3.4

Figure 3. Fabrication of test samples.

This approach not only aims to improve the mechanical properties of concrete but also helps reduce the carbon footprint linked with construction activities. Table 2 summarizes the factors and levels considered in this study, specifically focusing on the proportions of carbonized bio-waste powder, lime, and bonding agents.

Through the Taguchi method, which is renowned for its efficiency in optimizing processes and reducing variability, the study systematically evaluates the optimal combinations of CBW percentage, lime content, and bonding materials. Each factor's influence on the compressive strength of concrete is carefully scrutinized to identify the most effective mix proportions. Such findings are pivotal for advancing the practical applications of sustainable construction materials, especially in regions abundant with agricultural by-products. The research holds broader implications for the construction industry, advocating for environmentally friendly practices that align with global sustainability goals.

By showcasing the potential of carbonized biowaste as a supplementary material in concrete production, the study sets a precedent for leveraging local resources to foster innovation in construction materials. Ultimately, the paper not only contributes valuable insights to academic discourse but also offers practical solutions for sustainable development in Rajasthan and beyond. Total nine experiments were developed using Taguchi method which were present in Table 3.

The signal to noise ratio analysis of the compressive strength (CS) was present in Table 4 and Figure 4. To solve the signal to noise ratio “larger is better” option was selected for the present study.

The interaction plot for the three factors selected for the present study was shown in Figure 5 for all three factors.

Table 2. Factor and levels selected for preset study.

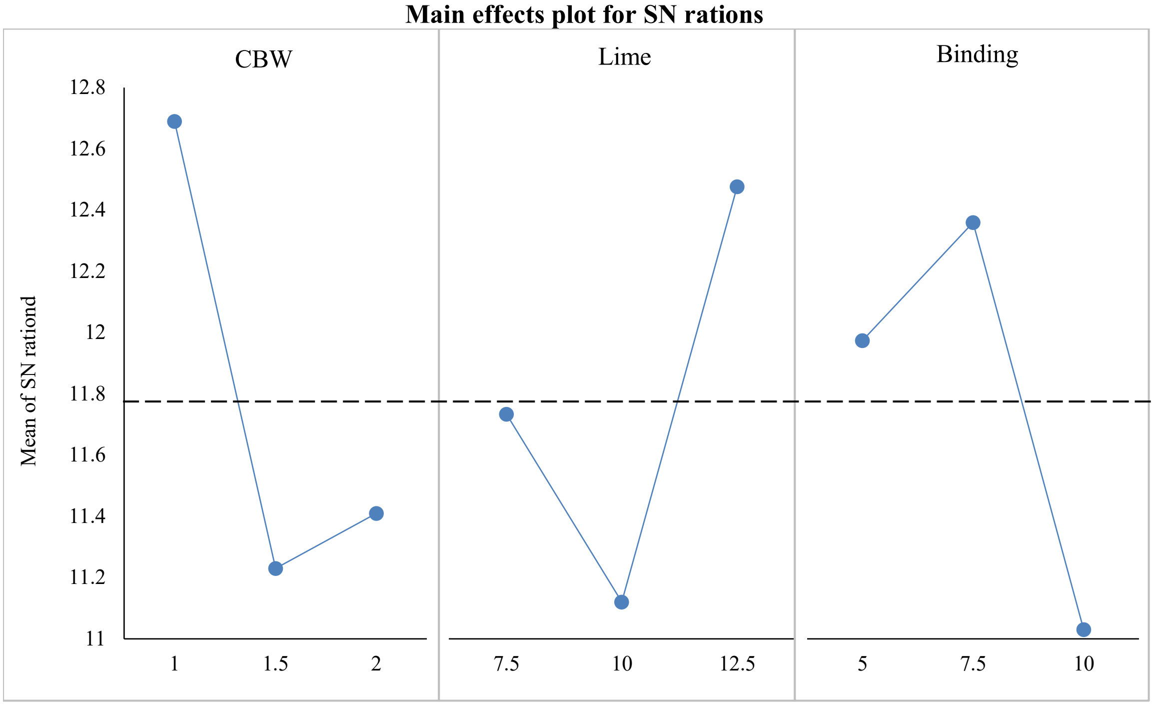
Factors/Levels	CBW	Lime	Bonding
1	1.0	7.5	5.0
2	1.5	10.0	7.5
3	2.0	12.5	10.0

Table 3. Orthogonal array developed using Taguchi method.

Run	CBW	Lime	Binding	CS
1	1	7.5	5	4.4
2	1	10	7.5	4.6
3	1	12.5	10	4.0
4	1.5	7.5	7.5	3.6
5	1.5	10	10	3.1
6	1.5	12.5	5	4.4
7	2	7.5	10	3.7
8	2	10	5	3.3
9	2	12.5	7.5	4.3

Table 4. Rank identification for factors (response compressive strength).

Level	CBW	Lime	Binding
1	12.69	11.73	11.96
2	11.23	11.12	12.34
3	11.41	12.47	11.03
Delta	1.47	1.35	1.31
Rank	1	2	3



Signal-to-noise: Large is better

Figure 4. Signal to noise ratio analysis for compressive strength.

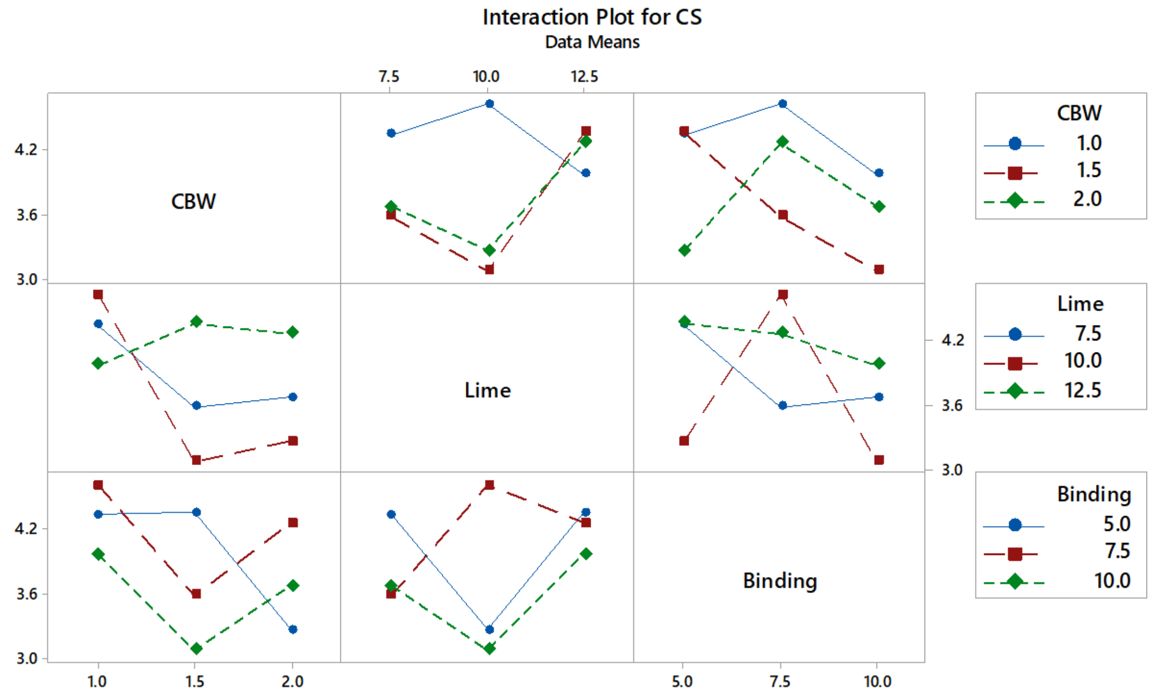


Figure 5. Interaction plot for all three factors and response compressive strength.

CONCLUSIONS

After analyzing the data from experiments that used the Taguchi method, some important conclusions can be drawn. These relate to making & testing advanced created with carbonized biowaste CBW sourced from Rajasthan. The results for compressive strength (CS) showed notable differences due to various combinations of CBW percentage, lime content, & types of binding materials. Clearly, these factors interact in ways that affect the mechanical properties of the concrete. The experiment recorded the highest compressive strength at 4.6 MPa. This was achieved with a mixture of 1% CBW, 10% lime, and 7.5% binding material. On the other hand, the lowest compressive strength noted was 3.1 MPa, found when using 1.5% CBW, 10% lime, & 10% binding material. This shows just how critical it is to optimize these parameters to get the right performance for concrete. Another point of interest is the Signal-to-Noise Ratio (SNR) analysis which gave insights into how robust & sensitive each experimental setup was. When SNR values are higher, it means better performance & reliability in achieving the required compressive strength targets. For example, experiment 2 had an SNR of 13.3 and showed a stronger performance than experiment 5 with an SNR of just 9.8. The Taguchi method worked well for systematically evaluating and optimizing the experimental factors. It proved useful in practical applications for shaping concrete formulas. By pinpointing the best combinations of CBW percentage, lime content, & binding materials, this method promotes sustainable practices that make efficient use of local biowaste resources. This study highlights the value of integrating carbonized biowaste from Rajasthan into concrete production as a sustainable option. By carefully refining mixture proportions through thorough testing & analysis, it's possible to make significant progress toward improving both environmental sustainability and mechanical efficiency in concrete materials. Looking ahead, future studies could investigate other parameters or utilize different sources of biowaste to broaden this method’s application and effectiveness in construction practices.

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