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Research article

Experimental study on fire resistance of cellular light weight concrete block of rice husk ash

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ABSTRACT

This present study investigates the impact of agricultural waste Rice Husk in the form of ash (RHA) on the fire resistance of Cellular Light weighted Concrete (CLC) blocks. In this study, a comprehensive experimental approach was employed, involving the production of 63 CLC blocks with varying RHA content (ranging from 0% to 30%). These blocks underwent a 28-day curing period before being subjected to elevated temperatures of 300°C and 500°C, respectively, for 2 hours in a muffle electric furnace. The results reveal a remarkable impact of RHA on the fire resistance of CLC blocks. Following exposure to 300°C, the average strength was reduced from 6.57% to 3.3%. Similarly, exposure to 500°C resulted in an average strength reduction between 16.82% and 12.93%. The study underscores the significance of RHA content in shaping the fire-resistant properties of CLC blocks, providing insights for the development of construction materials with enhanced thermal performance.

1. Introduction

The growing global need for sustainable construction materials has led researchers to investigate alternative additives that can enhance both the structural performance and environmental friendliness of standard concrete. In this regard, the agricultural waste generated from rice husk in the form of ash (RHA – Rice Husk Ash) has been identified as a promising supplementary material, offering potential advantages such as enhanced strength, durability, and ecological sustainability. This paper conducts a parametric study to thoroughly examine the influence of varying proportions of RHA on concrete properties. As a by-product of rice milling, RHA is widely available and has demonstrated the ability to positively influence the characteristics of concrete when used in its mixtures. The study systematically adjusts the percentage of RHA in concrete mixes to evaluate its impact on key parameters like compressive strength, durability and workability. By performing an in-depth parametric analysis, the research aims to determine the optimal range of RHA content that achieves the desired improvements without compromising the overall performance of the concrete. This research is significant not only for addressing the environmental issues and waste management related to rice husk waste but also for enhancing the understanding of effective RHA incorporation into concrete mixtures. The important findings of this study are anticipated to yield critical insights for engineers, researchers, and construction industry professionals seeking sustainable solutions for concrete production. Through this parametric investigation, the study aims to contribute to the ongoing discussion on eco-friendly construction materials and promote the broader use of RHA in concrete applications.

In the dynamic landscape of structural engineering and construction, the development of fire-resistant materials stands as a pivotal pursuit, crucial for ensuring the safety and structural integrity of buildings. Concurrently, the drive towards sustainable construction practices has cast a spotlight on RHA as a compelling candidate for enhancing the fire resistance properties of concrete. This paper embarks on a meticulous parametric study, delving into the comprehensive exploration of the impact of varying proportions of RHA on the fire resistance capabilities of concrete. The incorporation of rice husk ash into concrete formulations has shown considerable promise, not only in efficiently utilizing an agricultural byproduct but also in potentially augmenting the

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material's performance under fire conditions. In this study, the percentage of RHA in concrete mixes is systematically varied to scrutinize its influence on critical parameters associated with fire resistance, encompassing thermal conductivity, structural integrity, and the overall material response in high-temperature environments.

Understanding the nuanced relationship between RHA content and the fire performance of concrete is imperative, especially considering the potentially devastating consequences of fire accidents. The current parametric study aims to provide valuable insights into the intricate dynamics governing the impact of RHA on concrete's fire resistance. The experimental findings of this study aspire to furnish engineers, researchers, and policymakers in the construction industry with critical knowledge, aiding in the development of concrete mixtures aligned with sustainable practices while fortifying structures against fire hazards. Notably, the research aligns with the definition of fire resistance, which entails the structural member's ability to withstand fire exposure without loss of load-bearing function or the capacity to act as a barrier against fire spread. Furthermore, we acknowledge that fire resistance in buildings can be effectively achieved by adopting materials inherently resistant to fire, coupled with strategic practices to delay fire propagation, ensuring occupants have ample time for a safe evacuation.

CLC blocks emerge as exemplary fire-resistant materials, with their resistance hinging on parameters such as the type of aggregate used, void ratio, and density of CLC. The unique properties of CLC blocks, specifically the presence of voids created by the introduction of a foaming agent into the cement slurry, contribute to their thermal resistance. The entrapped air within these voids, being a poor conductor of heat, enhances the thermal resistance of CLC blocks (**Siram, 2012; Mydin, 2011)**. The composition of CLC blocks involves cement, fine sand, fly ash, and a crucial component, the foaming agent. The innovative production process results in the creation of millions of small voids within the block, reducing its density and, consequently, material and labor requirements. The lightweight nature of these blocks also alleviates the overall dead load on foundations (**Deepa, 2015**).

This research introduces the use of agricultural waste ash such as RHA as a partial replacement for cement, with a focus on RHA with rich silica content. Silica plays a crucial role in enhancing concrete strength, and RHA is further recognized for its good insulates properties, extending its potential applications to the construction of flat steel through continuous casting processes (**Siddika et al., 2017; Johnson et al., 2007**). Additionally, the application of fly ash in standard concrete is explored as a dual-benefit solution for concrete enhancement and environmental sustainability. The pozzolanic properties of fly ash, derived from its silica content, oppose the formation of microcracks induced by surplus lime during the cement hydrating process. This ongoing reaction enhances concrete strength and mitigates the deleterious effects of surplus lime (**NTPC 2007**).

In this holistic exploration, this study extend to assess the impact of agricultural waste ash on the fire resistance properties of CLC. Beyond the technical advancements, this research contributes to sustainable waste disposal practices, offering a potential solution for the management of agricultural waste such as rice husk ash. Moreover, the study endeavors to make construction processes eco-friendly by reducing reliance on traditional cement usage. Through this multifaceted approach, the aim of the study is to usher in a new era of fire-resistant, sustainable construction practices.

2. Materials and Methods

The materials used in the construction of sustainable concrete made up of agricultural and industrial waste in the present study are as follows:

Cement - The foam concrete utilized in this research was produced using Portland pozzolana cement following IS 1489 (1991), specifically the Mycem brand of fly ash. It has a specific gravity of 3.15. The initial setting time was recorded at 45 minutes, while the final setting time was 480 minutes. The compressive strength of the concrete after a curing period of 7 days and 28 days was found to be 26 N/mm^2 and 28 N/mm^2 respectively.

Sand - The river sand with a specific gravity of 2.5 was used in the concrete. The particle size of the sand lies between 1.18 mm to 300 mm, and the fineness modulus was 1.30 mm.

Fly ash – The industrial waste, in the form of fly ash, was taken from the Ghatampur Power Plant with a specific gravity of 2.5. The fly ash retained on the 45µm IS sieve was about 34%.

RHA – The agricultural waste in the form of rice husk ash was taken from the Lohiya industry with a specific gravity of 2.1. The 47% rice husk ash was retained on the 45µm IS sieve.

Foaming Agent – The protein-based foaming agent was taken from VAM consultants with a density of 1000 kg/m^3.

The current investigation delves into the influence of RHA on the characteristics of self-compacting concrete through the formulation of seven distinct mixes. These mixes involve the systematic replacement of Portland Pozzolana Cement (PPC) with RHA, varying from 0% to 30% by weight, resulting in the creation of a total of 84 meticulously crafted cubes. The study aims to distinguish the influence of different RHA percentages on the final concrete properties. To maintain uniformity across the mixes, a water/cement ratio of 0.9 was consistently applied during the mixing process. The essential foam, integral to self-compacting concrete, was generated with a Water/Foaming Agent ratio of 20. The methodology commenced with the meticulous preparation of a dry mix, amalgamating the various dry ingredients. Following this, water, adhering to the specified water/cement ratio, was incorporated into the dry mix. The foaming agent and water were subsequently blended in a specific proportions to create a homogeneous foam, which was then incorporated into the prepared cement slurry. The introduction of the foam agent into the cement slurry led to the development of numerous small bubbles, resulting in an expansion of the overall slurry volume. This unique mix, characterized by self-compacting properties, was then poured into molds without the requirement for external vibration. After a curing period of 48 hours, the molds were opened, and the concrete cubes were immersed in the containers full of water to undergo curing until the designated period of testing.

This comprehensive methodology aims to yield valuable insights into the structural and mechanical properties of self-compacting concrete, specifically tailored to incorporate RHA. The study contributes to the evolving field of sustainable construction materials, shedding light on the potential of RHA to enrich and upgrade the structural behavior and performance of self-compacting concrete. The exact proportions of ingredients are given in the Table 1 below.

Table 1 Proportion of concrete mixture

⬇ Materials / ##RLC ➡	Replacement level of Cement by RHA						
	0%	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
Weight of Cement (g)	370	350	330	310	290	275	255
Weight of Sand (g)	540	540	540	540	540	540	540
Weight of Fly ash (g)	475	475	475	475	475	475	475
Weight of RHA (g)	0	20	40	60	80	95	115
Volume of WOS* (ml)	335	335	335	335	335	335	335
Volume of Fo. Ag. #(ml)	3	3	3	3	3	3	3
Volume of WOFA(ml)**	55	55	55	55	55	55	55

##RLC- Replacement level of Cement by RHA, ***WOS-** Water for slurry, ****WOFA-** Water for foaming Agent, **#Fo.Ag. -** Foaming Agent

2.1 Parametric Studies

The subsequent sections will unveil the findings of this parametric study, shedding light on how the varying proportions of Rice Husk Ash influence concrete's thermal conductivity, structural integrity, and overall response to elevated temperatures. By carefully analyzing these findings, we strive to offer meaningful insights to engineers, researchers, and professionals in the construction sector.

The prepared samples were tested for various parameters as discussed below:

2.1.1 **Block density test** –Three specimens from each sample were tested for block density after a 28-day curing period, and the reported result is the average of 3 samples. The density of each block is calculated as follows-

$$\textbf{Density} = \frac{\textit{mass of the block, in kg}}{\textit{volume of the block in } m^3}$$

2.1.2 Compressive strength test- The concrete cube specimens were constructed, as per code IS 2185, Part 4, and the compressive strength was determined after a curing period of 28 days. This test was carried out using the compressive testing machine. The reported results are an average of 3 samples from each mix proportion.

2.1.3 Thermal conductivity test- The thermal conductivity tests were carried out on 3 cube specimens from each sample of size 3.5×7×7 and were subjected to the TPS-500 Thermal Constant Thermal Analyzer after 28 days.

2.1.4 Fire resistance test- The fire resistance test was carried out using the Muffle Furnace for two temperature ranges, 300ºC, and 500ºC respectively. The specimens from each of the mixed proportions were selected and tested at each temperature and were kept in the muffle furnace for a duration of 2 hours. The concrete cube specimens were kept at room temperature for cooling afterward. The specimens were then tested for compressive strength and the results were compared with the strength of the block without burning.

3. Results and Discussions

The impact of the partial replacement of cement with rice husk ash in concrete properties is identified and the important findings of the present study are discussed below:

3.1 Effect of RHA on Void Ratio and Density

The effect of RHA on void ratio and density is represented in Figures 1 and 2 respectively. It is evident from Figures 1 and 2 that up to the 20% replacement level, the density of the block exhibits an inverse relationship, while the void ratio demonstrates a direct proportionality to the RHA content. The lower specific gravity of the RHA results in a decrease in block density in comparison to cement. Subsequently, when replacing cement with rice husk ash using a weight-based method, a larger volume of rice husk ash is required, leading to an overall reduction in block density and an increase in the number of voids within the block (**Siddika et al., 2017**).

However, it is noteworthy that the specific surface area of RHA surpasses that of cement. Consequently, rice husk ash possesses a greater water-absorbing capacity than cement. In the context of this research, where the water/binder ratio is maintained constant, this presents a challenge. The fixed water/binder ratio impacts the workability of the slurry. As the amount of RHA in the mixture increases, the workability of the cement solution was diminished. Once the proportion exceeds 20%, this decrease becomes notable and may jeopardize the foam's effectiveness by causing the foam bubbles to burst **(Rum et al., 2017).**

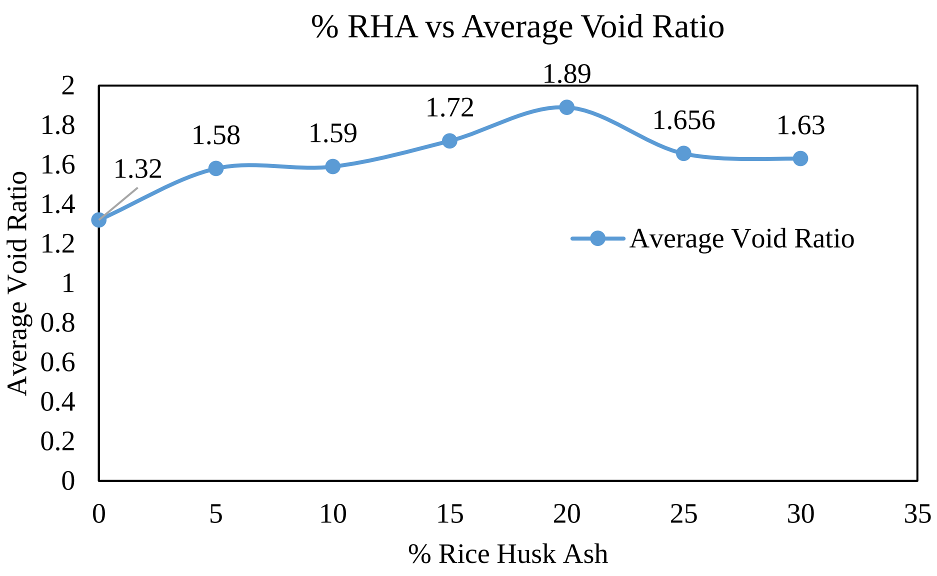

Fig. 1 Variation of Void ratio with the percentage replacement of RHA in concrete

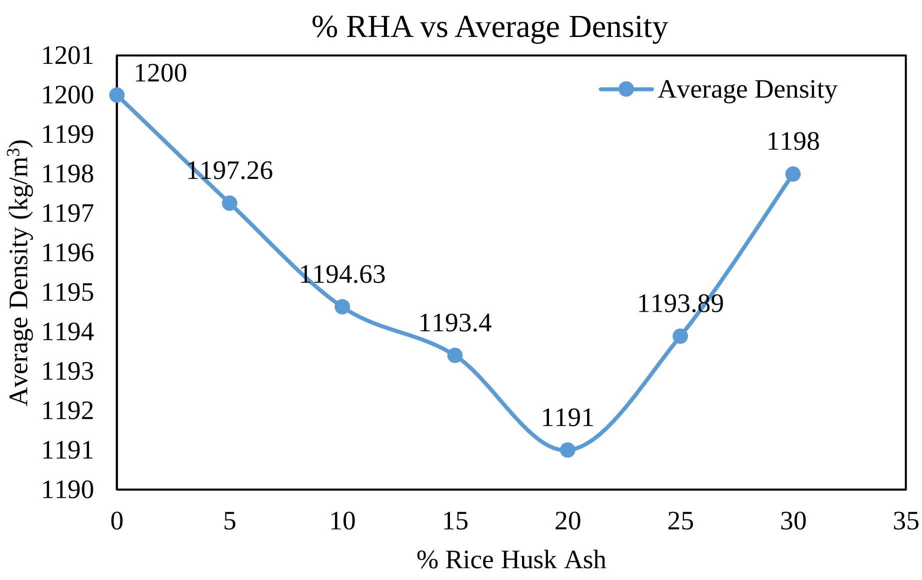

Fig. 2 Variation of Average Density with the percentage replacement of RHA in concrete

3.2 Effect of RHA on Characteristic strength of concrete

The compressive strength of the concrete with the percentage change in the RHA is presented in Fig. 3. It illustrates that, up to the 20% replacement level, the compressive strength exhibits a direct proportionality to the rice husk content. The presence of amorphous silica in RHA, a byproduct of controlled combustion, accounts for this phenomenon. The structural properties viz. strength and durability of concrete are improved with the formation of calcium silicate hydroxide when cement is combined with water. The formation of another compound of calcium hydroxide causes efflorescence in the concrete. Introducing RHA into the concrete mix leads to a reaction between the amorphous silica (SiO_2) in RHA and calcium hydroxide [Ca $(OH)_2$], resulting in the formation of amorphous nanostructure (C-S-H) calcium silicate hydrate. This reaction significantly augments the strength of the concrete, concurrently reducing the quantity of calcium hydroxide and mitigating efflorescence in the concrete **(Huang et al., 2017)**. However, beyond the 20% replacement level, the reduction in cement content reaches a point where it impedes the formation of a robust bond between cement and other aggregates or materials. Reducing the cement content negatively impacts the structural integrity and compressive strength of the concrete, highlighting the need for a balanced proportion to achieve optimal material performance.

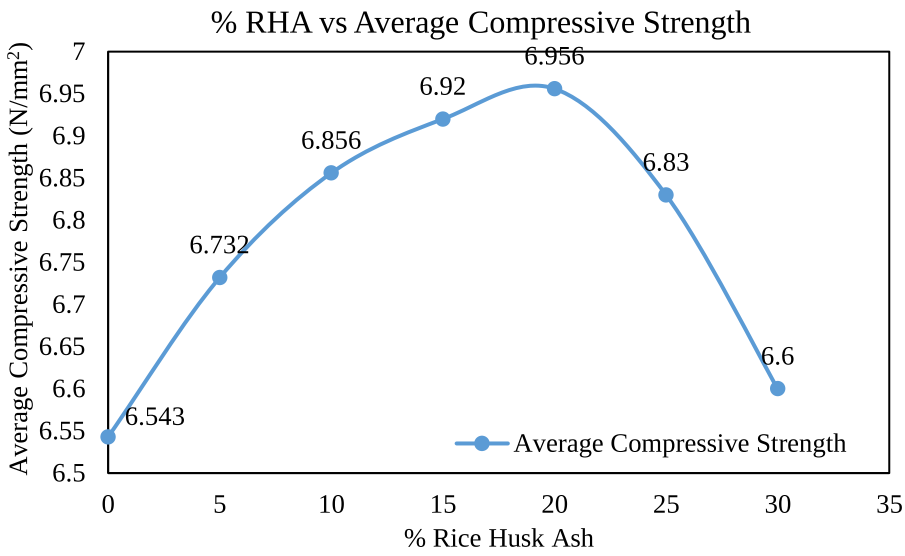

Fig. 3: Variation of Compressive strength with the percentage replacement of RHA

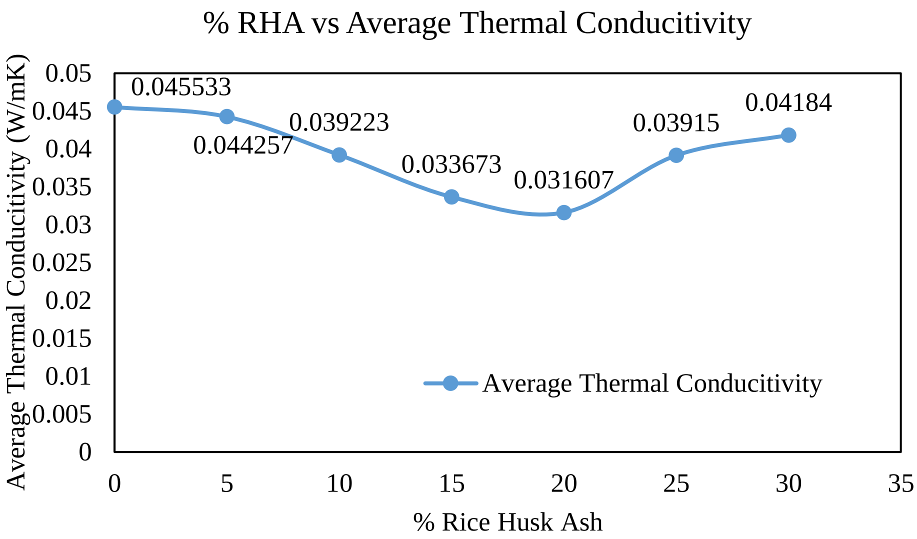

Fig. 4 Variation of Thermal conductivity with the percentage replacement of RHA

3.3 Effect of RHA on Thermal conductivity of concrete

The variation of thermal conductivity with the percentage replacement of rice husk ash in concrete is presented in Fig. 4. This figure presented the impact of RHA on the thermal conductivity of CLC. Up to a 20% replacement level, the thermal conductivity exhibits an inverse relationship with the RHA content. However, beyond this threshold, the thermal conductivity becomes directly proportional to the RHA content. The thermal conductivity of CLC is intrinsically linked to the number of voids present within the material. Voids, characterized by the presence of air, serve as poor conductors of heat. Consequently, an increase in the number of voids within the block corresponds to a decrease in thermal conductivity, while a reduction in voids increases thermal conductivity (**Mydin, 2011**). As previously discussed, the number of voids experiences continuous augmentation until the 20% replacement level. Post the 20% replacement level, there is a discernible shift, marked by a reduction in the number of voids. Consequently, the thermal conductivity of the blocks decreases until the 20% replacement level. As the number of voids decreases, the thermal conductivity of the concrete blocks increases. These findings highlight the complex relationship between RHA content, void formation, and thermal conductivity in CLC.

3.4 Effect of RHA on Fire Resistance

The average residual strengths of concrete before and after burning are presented in Fig. 5 and 6, respectively. The presented figures delineate the impact of elevated temperatures on concrete. Upon subjecting the blocks to a temperature of 300°C, the average residual strength ranged from 93.43% to 96.70%. The overall strength loss at this temperature was observed to be between 6.58% to 3.3%. Notably, the 20% replacement level demonstrated the least loss of strength at this temperature. The average residual strength of concrete ranged from 83.79% to 87.07% upon exposure to a temperature of 500° C, resulting in an overall strength loss between 16.21% to 12.93%. Strikingly, the 20% replacement level once again exhibited the maximum residual strength for both temperature ranges. This observation is attributed to the optimal combination of maximum voids and minimum thermal conductivity at the 20% replacement level. Beyond this level, the residual strength experienced a gradual decline. It's notable that, apart from the number of voids, the thermal insulation properties of RHA also contribute significantly to the fire resistance of the blocks (**Umasabor and Ojo, 2018**). As the temperature surpasses 600°C, a notable transformation occurs with the dehydration of calcium carbonate and the formation of lime and water. This drastic change in chemical composition is anticipated to have a substantial impact on the concrete's strength (**Umasabor and Ojo, 2018**). These findings underscore the intricate interplay between temperature, material composition, and structural integrity, offering valuable insights into the nuanced behavior of concrete under varying thermal conditions. Table 2 presents the effects of RHA on various properties of the CLC blocks.

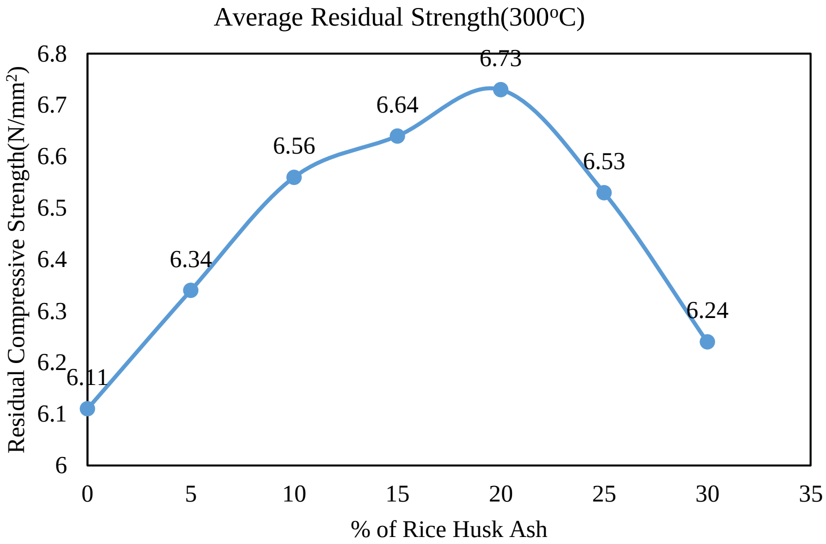

Fig. 5 Residual compressive strength after burning at 300°C

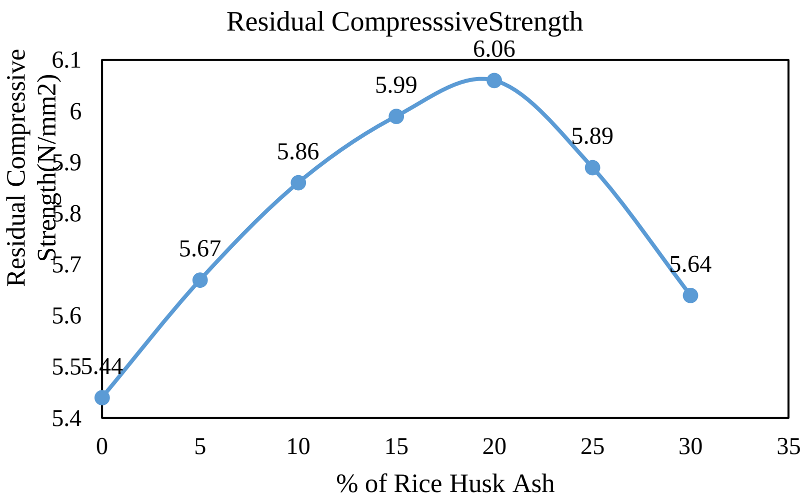

Fig. 6 Residual compressive strength after burning at 500°C

Table 2 Effect of RHA on void ratio, density, compressive strength, thermal conductivity, and Residual Compressive strength after burning for 300 ^{0}C and 500 ^{0}C

RHA %	Void ratio	Average Density of Concrete (kg/m^3)	Average Compressive Strength of Concrete (N/mm^2)	Average thermal conductivity (W/mK)	Residual compressive strength at 300^{0}C (N/mm^2)	Residual compressive strength at 500^{0}C (N/mm^2)
0	1.320	1200.00	6.54	0.045533	6.11	5.44
5	1.580	1197.26	6.73	0.044257	6.34	5.67
10	1.590	1194.63	6.86	0.039223	6.56	5.86
15	1.720	1193.40	6.92	0.033673	6.64	5.99
20	1.890	1191.00	6.96	0.031607	6.73	6.06
25	1.656	1193.89	6.83	0.039150	6.53	5.89
30	1.630	1198.00	6.60	0.041840	6.24	5.64

4. Conclusions

The important qualitative and quantitative findings of the study are summarized below: – The overall strength of the concrete was enhanced with the formation of amorphous silica in the ash when rice husk is burned at temperatures between 600°C and 900°C, depicting the pozzolanic properties of the concrete. The partial replacement of cement with rice husk ash about 20%, exhibits maximum voids, increased compressive strength, and residual compressive strength. Beyond this level, these properties progressively decrease. Most properties of Cellular Lightweight Concrete (CLC) blocks correlate with the number of voids, which decreased as slurry workability was decreased. The number of voids peaks at the 20% replacement level, decreasing thereafter. The density and thermal conductivity of CLC blocks reach a minimum at the 20% replacement level. Subsequently, both properties start increasing with higher replacement levels. The performance of CLC blocks is optimal at the 20% replacement level, representing a balance in various key properties. Compressive strength increases until the 20% replacement level due to the presence of amorphous silica. Beyond 20%, insufficient cement quantity hampers proper bonding. Thermal conductivity is influenced by the number of air voids, with larger particle sizes potentially puncturing air bubbles or increasing block denseness. Subjecting blocks to 300°C results in a strength reduction of 6.57% to 3.30%, and at 500°C, the reduction is 16.82% to 12.93%. The 20% replacement level exhibits the minimum strength reduction for both temperature ranges. The rate of strength was decreased with an increasing replacement levels, reaching a minimum of 20%. This is attributed to the increment in voids and the thermal resistance of rice husk ash. However, as voids decrease, thermal resistivity diminishes. These broad conclusions encapsulate the nuanced findings from the study, providing insights into the multifaceted impact of Agricultural Ash (RHA) on various properties of CLC blocks.

Author Contributions

- **Tarun Raj Singh:** Conceptualization, Methodology, Investigation, Writing – Original Draft.
- **Dr. Kavita Tandon:** Supervision, Validation, Writing – Review & Editing.

Conflict of Interest

The authors declare no conflict of interest in the present study.

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