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Innovative Strategies for Eco-Friendly Thermal Insulation: Integrating Rice Straw and High-Volume Fly Ash in Foamed Concrete

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ABSTRACT

One of the most important challenges of future buildings is the reduction of energy consumptions in all their life phases, from construction to demolition. As a tropical country, India faces the serious issue of temperature rise and fall in most of the parts, which demands the need for thermal insulation in existing buildings. Insulation is a key component of sustainable building design. The present research work focuses on the development of a thermal insulation wall panel made from high volume fly-ash foam concrete with the inclusion of rice straw. Utilization of straws in building materials can not only save the raw materials, reduce the cost, use scrap material and protect the environment but also can be of great significance to achieve sustainable development. The rice straw was collected from the nearby village locality and it was allowed to dry under the sun for 15 days in order to get rid of its moisture and serve to be easy for chopping. These dried rice straws were then chopped into tiny pieces of 10 mm long pieces and treated with NaOH. NaOH removes extractives, waxes, oil and amorphous constituents such as hemicellulose and lignin from fiber surfaces and thus increases the overall roughness of the surface. Strength and insulation properties are studied by conducting thermal, strength and durability study it was found that 1% is the optimum percentage of rice straw that can be added. In the second trial, foam concrete with 20%,30%,40% and 50% foam volume was used. Also, 50% by weight of cement was replaced with class F fly ash by completely eliminating sand. In the third trial, in addition to the 50% fly ash replacement a further replacement of 15% of cement with silica fume is done which results in an increase in strength, but a slight increase in thermal conductivity. Considering the increase in the number of ingredients foam concrete mix with cement to fly ash ratio 1:1, foam volume of 20% to 25% and rice straw content range from 0.5 to 1.5 % by weight of cement was found to be optimum in terms of strength and functional property.

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1. INTRODUCTION

Due to expanding trends in eco-friendly and energy-saving building considerations, architects/constructors round the globe are emphasizing the usage of foamed concrete. A well-insulated home saves energy by staying warm in the winter and cool in the summer. Materials with relatively low thermal conductivities are recommended to reduce heat loss. The thermal resistance of foam concrete is widely known. It is a sort of lightweight concrete whose density ranges from 400kg/m3 to 800kg/m3. Because of its lighter weight, it requires less labour during construction and requires less shipping than ordinary concrete. Foam concrete has unique qualities such as low aggregate consumption, excellent flowability, high porosity, strong heat insulation, fire resistance, low self-weight, airborne sound insulation, suitable compressive strength, and so on.

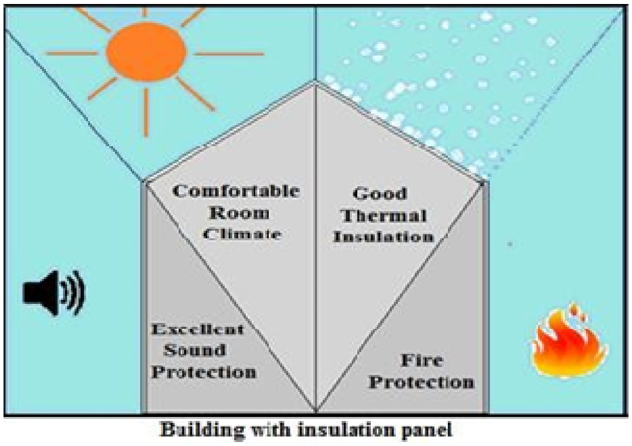

Figure Building with insulation

Pre-foaming or mixed foaming processes are used to create foam concrete. The foam is manufactured separately and combined with the base mix during the pre-foaming process. The foaming agent is directly introduced to the base mix during the mixed foaming process, and the foam is formed during the mixing.

The increased use of cement in the creation of foam concrete causes plastic and drying shrinkage in the concrete, and the resulting fracture causes major durability concerns. The use of fibres into foam concrete is one method for reducing shrinkage cracks and improving its durability. In India, waste products from agriculture such as rice husk, straw bale, maize cob materials and sugarcane bagasse are abundant depending on location, and these can be used as green materials in the construction field. There has been very little research done employing these materials as thermal insulation. Straw is a byproduct of cereal production that is plentiful and inexpensive in India. Straw was one of the earliest materials used in green buildings, and there are many buildings all around the world that use this technology. Straw was used to build mud-brick houses in India's ancient past for the roofs and as reinforcement for the walls, which helped to keep the inside temperatures comfortable for people by lowering the temperature. Using rice straw in construction will be a practical substitute for extensive agricultural burning, and the farmers will also see a return on their investment in this waste product.

One of the industrial waste products that is difficult to dispose of is fly ash. Fly ash is recognized as a partial replacement for cement in concrete due to its pozzolanic feature, which can lower the cost of the building. As a result, lightweight foam concrete made from fly ash is regarded as a sustainable, environmentally friendly material that uses the least amount of energy to make. The density of fly ash-based cellular lightweight concrete can be significantly lowered without compromising strength with the right design mix. It is an effective sustainable construction material for future CO2 mitigation against global warming since it minimizes the need for cement in concrete.

The primary goal of the current study is to improve the thermal application of foam concrete by using some industrial and agricultural waste materials, such as fly ash and rice straw, without sacrificing the material's strength attributes.

2. OBJECTIVE OF THE STUDY

The objectives outlined in the current study are:

1. The creation of a high volume, cost-effective fly ash foam concrete wall cladding using rice straw and other environmentally friendly materials in various ratios.
2. Evaluating the built-in insulated panel's capacity for thermal insulation, mechanical strength, noise absorption, moisture absorption, acid resistance, shrinkage, and fire resistance.
3. Being aware of the optimal straw ratio based on test results for improved thermal insulation.

3. LITERATUREREVIEW

Youssef El Moussi et al (2022) In order to reduce the consumption of energy and the emissions of greenhouse gases and CO2 generated by the construction industry, bio-based concretes made of plant aggregates are increasingly used in the optimization of building envelopes, thanks to their good hygrothermal performances, their renewable origin, and biodegradability. The present study focuses on the effect of combining different proportions of rice straw (RS) with rice husks (RH) on mechanical hygric, and thermal properties of straw/husk concrete. The experimental investigation seeks to evaluate the thermal conductivity, moisture buffer value (MBV) and mechanical compressive properties of these concretes. The results clearly that it is interesting to associate these two residues. The thermal conductivity of the bio-based concretes slightly decreases with increasing rice straw content and rises almost linearly with concretes density. The MBV measurements reveal that rice straw confers to concretes an excellent moisture buffering capacity. Finally, the compression test results highlight that the addition of rice straw induces high deformability and enables concretes to store a high quantity of energy.

Balaji. K. et al (2021) Foam concrete is a lightweight concrete. It has high flowability, porosity, fire resistance, airborne sound insulation, good heat insulation, and a desirable compressive strength. The goal of this study is to produce thermal insulation foamed concrete cladding using cement, fly ash, and rice straw. Rice straw and fly ash were used to improve the thermal properties of foamed concrete. The present study analyses the thermal and strength properties of foam concrete. A numerical study to investigate the thermal insulation capacity using COMSOL software is also done. The w/s ratio of 0.55 and fly ash cement ratio of 1:1 is fixed for all the specimens. The result shows that the mix with 1% rice straw (by weight of cement), and 20% foam volume, is found to be optimum in terms of strength and thermal conductivity.

Amritha Raj et al (2021) The goal of this research is to develop a sustainable environment-friendly thermal insulation aerated concrete cladding using rice straw, silica fume, fly ash, and cement. Silica fume and rice straw were added to improve the strength and functional properties of aerated concrete. The strength and thermal properties of aerated concrete with various foam volumes are investigated in this study. A numerical analysis of thermal insulation capacity is also carried out using the COMSOL software. For all specimens, the w/s ratio is fixed to 0.55. The result shows that the mix with 20% foam volume is best in terms of desirable compressive strength and thermal conductivity.

Paul Awoyera et al (2021) In this study, the mechanical properties of concrete incorporating rice husk ash (RHA) and wheat straw ash (WSA) as a ternary cementitious material were investigated. The study examined various properties, including workability and hardened concrete properties. The findings revealed that as the content of the added cementitious materials increased, the slump value of the concrete mixes decreased. Additionally, the density and water absorption of the modified concrete samples were lower than those of the control mix after 28 days of curing. The compressive strength, splitting tensile strength, and flexural strength of the concrete increased with longer curing regimes, and the modified concrete showed higher strength development compared to the control mix. However, the strength slightly decreased when the content of supplementary cementitious materials exceeded 10%. Moreover, the drying shrinkage of the concrete decreased as the replacement of Portland cement with RHA and WSA increased. Overall, the concrete mix containing 5% RHA and 5% WSA exhibited the best performance in terms of both fresh and hardened state properties.

NR Aravind et al (2019) The major segment for energy consumption is found in the industry, transport, agricultural, residential, and commercial sectors. The main part of the energy consumption in residential and commercial buildings is due to the use of mechanical devices to maintain a comfortable indoor environment. The thermal conductivity of building materials is one of the factors that influence heat transfer in buildings. Thermal conductivity can be reduced using materials with low density. The present paper reports the development of a sustainable thermal insulating external wall panel and its mechanical, thermal, and durability properties. The wall panel was prepared using foam concrete and rice husk and replaced the cement by fly ash. The strength of the panel was tested by conducting an in-plane bending test and a compressive strength test. Thermal conductivity was tested using a guarded hot plate apparatus. Durability properties were tested by conducting water absorption tests, drying shrinkage, and acid resistance tests. The test results showed that the rice husk and fly ash content had a major influence on the thermal conductivity and durability properties of the developed wall panels.

2018 study, Gokul and Anandh discovered that water content was a further element that affected the flexural strength, with an excess of water reducing the flexural strength of foam concrete (with constant binder content).

Falliano et al. (2018) highlighted the fact that fiber reinforcement affects foamed concrete's tensile strength as well. It was claimed that using bidirectional glass-type grid reinforcement and 2% short polymer fibre content increased flexural strength. It was noted that after the interaction between the two degrees of reinforcement exceeded a specific point (5%) that strength also decreased noticeably. The mean failure load of foam concrete can be raised with the help of basalt grid and carbon grid.

According to Falliano et al. (2018), extrudable foam concrete has superior thermal resistance than aerated autoclaved concrete due to its smaller air bubble size.

Lim et al. (2017) investigated the feasibility of substituting quarry waste for river sand in light-weight foam concrete (LFC). For a given density of light weight concrete, the finer quarry dust reduces the need for foam volume while strengthening the connection between cement and quarry dust particles. As a result, enhanced compressive strength and thermal conductivity were attained.

According to Akhund et al. (2017), biomass aggregates can increase the strength of foam concrete. In comparison to regular sand in an indoor environment, they found that the biomass aggregate foam concrete acquired its greatest compressive strength at 91 days of air curing.

4. MATERIALUSED

Materials used

Fig. 3.1 displays the ingredients utilized in the study to prepare the foam concrete.

- ***Ordinary Portland cement*** **(OPC)** confirming to IS 8112 (1989) is used. Tables 3.1 and 3.2 show the corresponding physical and chemical properties of cement.

Table Physical Proerties of Cement

Specific gravity	Consistency	Fineness
3.15	33%	0.5%

Table Chemical composition of cement

Main oxides	Percentages
CaO	61.7
SiO_2	21.2
Al_2O_3	4.6
Fe_2O_3	1.8
Na_2O	0.1
K_2O	0.7
MgO	4.3
SO_3	2.0
Loss of Ignition	0.8

Figure Chemical composition of cement

- **Sand** which is finer than 300µm with a specific gravity of 2.65 is used. It helps to improve the stability of foam and increases the strength of foam concrete.
- **Water:** Fresh, clean, potable water is used for mixing purposes**.**
- **Micro Silica fume:** Pozzolanic material used to improve the strength property.

This is a byproduct of the manufacture of silicon or ferrosilicon industry.

- **Rice straw**: Chopped and treated rice straw of length 1-2cm is used as a randomdiscrete additive to reduce the shrinkage and to improve the thermal efficiency.
- **A protein-based foaming agent** was used for this study. Its chemical characterization is Ethoxylate of vegetable protein extract and physical and chemical properties are given in Table 3.4.
- **Superplasticizer:** Poly master glenium SKY 8233, a high-performance superplasticizer based on Poly carboxylic ether, is used to improve workability.

Table Properties of foaming agent

Physical State	Highly viscous liquid
Appearance/Odour	Hazy yellow-pink liquid with a slight odour
pH	7.5
Vapour Pressure, Vapour Density, Evaporation Rate Boiling Point	≈ Water
Solubility in Water	Complete
Specific Gravity	1.075
Viscosity	>600 CPS
% Volatiles (g/L)	(21°C) ~ 65 (As Water)
Chemical Stability	Stable

Test methodologies.

The methodology includes the following tasks.

Task.1. Fix the mix design for foam concrete. Casting of specimens with different percentages of rice straw and different percentages of foam volume.

Task.2. Investigate the strength properties like compressive strength and flexural strength, durability properties like water absorption and acid resistance, and functional properties like fire resistance.

Task.3. Finding the optimum mix that gives good insulation properties anddesirable strength properties.

Task.4. Comparison of the properties of the panel with the commercially availableinsulating panels.

5. RESULTS AND DISCUSSIONS

A. Mix proportions.

In this case, rice straw at 1%, 3%, and 5% by weight of cement was added to alter the properties of the mix. The percentage foam volume is taken as 20, 30, 40 and 50%. The mix proportions used are shown in Table 4.1.

Table Mix Proportion

Mix	Cement	Sand	Water	Foam	Rice Straw
CR0	100.8	23.8	12.8	20%	0%
CR1	100.8	23.8	12.8	20%	1%
CR3	100.8	23.8	12.8	20%	3%
CR5	100.8	23.8	12.8	20%	5%
20FCR0	100.8	23.8	12.8	20%	0%
30FCR0	157.5	29.8	20	30%	0%
40FCR0	135.4	25.3	17	40%	0%
50FCR0	113.4	20.9	14	50%	0%
20FCR1	100.8	23.8	12.8	20%	1%
30FCR1	157.5	29.8	20	30%	1%
40FCR1	135.4	25.3	17	40%	1%
50FCR	113.4	20.9	14	50%	1%

Compressive strength

The compressive strength of foamed concrete is a crucial parameter in determining its suitability for various applications, such as lightweight structural elements, thermal insulation, and backfilling. It provides valuable information about the material's structural integrity, load-bearing capacity, and overall performance. Engineers and researchers utilize compressive strength data to assess and optimize the design, construction, and durability of foamed concrete structures.

Table Compressive strength

Mix	14-day strength (MPa)	28-day strength (MPa)
CR0	16.80	30
CR1	18.66	33.33
CR3	16.92	31.92
CR5	12.46	26.25
20FCR0	16.80	30
30FCR0	15.57	27.8
40FCR0	14.20	26.1
50FCR0	12.66	24.75
20FCR1	18.66	33.33
30FCR1	16.57	28.2
40FCR1	15.82	26.99
50FCR1	14.16	25.25

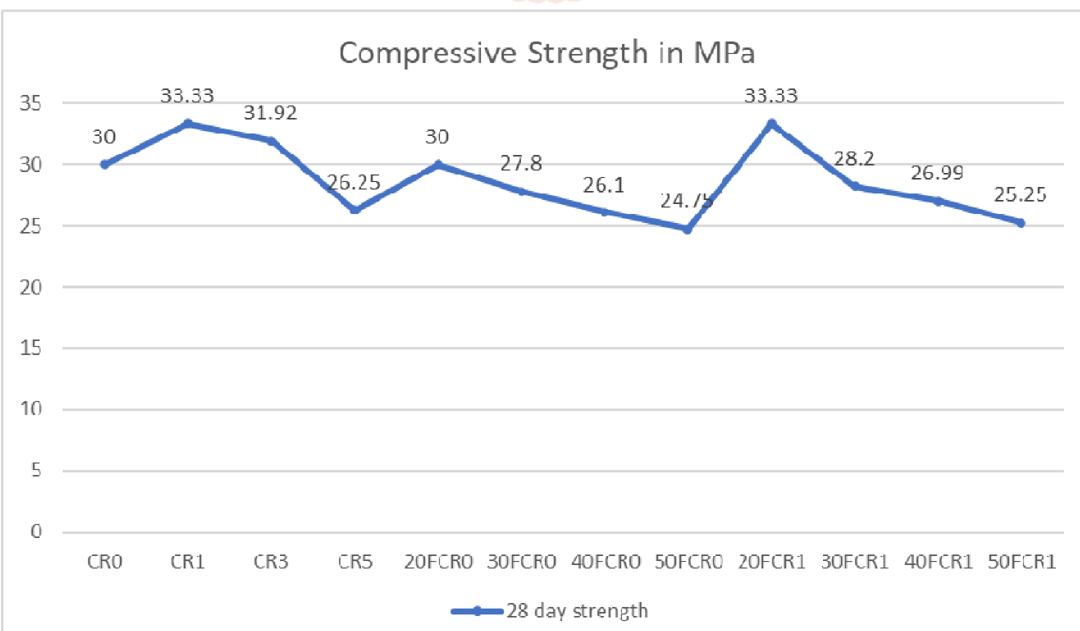

Figure Variation in Compressive strength 28days

Inference: Rice straw fibers can improve the cohesion of the concrete mix, enhancing the bond between the aggregates and the cement paste. This improved cohesion can contribute to increased compressive strength. But up to a certain limit i.e. after 3% the strength of concrete declines with further addition of rice straw.

The increase in 28-day strength was found to be maximum in the case of 1% RS and 20% foam volume. At 3% RS also strength is increased than the conventional mix, but the increase is lesser than with 1% RS content. At 5% RS content the strength is decreased. Also, excessive foam volumes can lead to a significant reduction in compressive strength. As inferred from the table and graph above the strength is decreased when foam volume is increased beyond 20%. It is essential to balance the foam volume with other factors such as the type and grading of aggregates, cement content, and curing methods to maintain adequate strength.

THE Breaking strength and modulus of rupture

The Breaking strength, also known as tensile strength, measures the maximum tensile stress that foamed concrete can withstand before it ruptures or breaks. Foamed concrete is generally weaker in tension compared to compression due to its brittle nature and lack of traditional reinforcement. The breaking strength is determined by subjecting cylindrical or prismatic samples to a tensile load until failure occurs. The maximum load sustained by the sample is recorded and used to calculate the breaking strength.

Modulus of rupture, also known as flexural strength, evaluates the ability of foamed concrete to resist bending or flexural stresses without fracturing. It represents the maximum stress that the concrete can withstand in a bending or flexural test before it breaks. The modulus of rupture is determined by applying a load to a prismatic or beam-like sample supported on two points and measuring the load required to cause failure. It is calculated using the dimensions of the sample and the maximum load sustained.

Table Breaking strength and modulus of rupture

Mix	Breaking Load (N)	Modulus of Rupture (MPa)
CR0	85	1.78
CR1	86	1.80
CR3	85.22	1.78
CR5	84.46	1.55
20FCR0	85	1.78
30FCR0	83.5	1.7
40FCR0	82	1.6
50FCR0	75	1.5
20FCR1	86	1.80
30FCR1	84	1.58
40FCR1	83	1.51
50FCR1	81	1.44

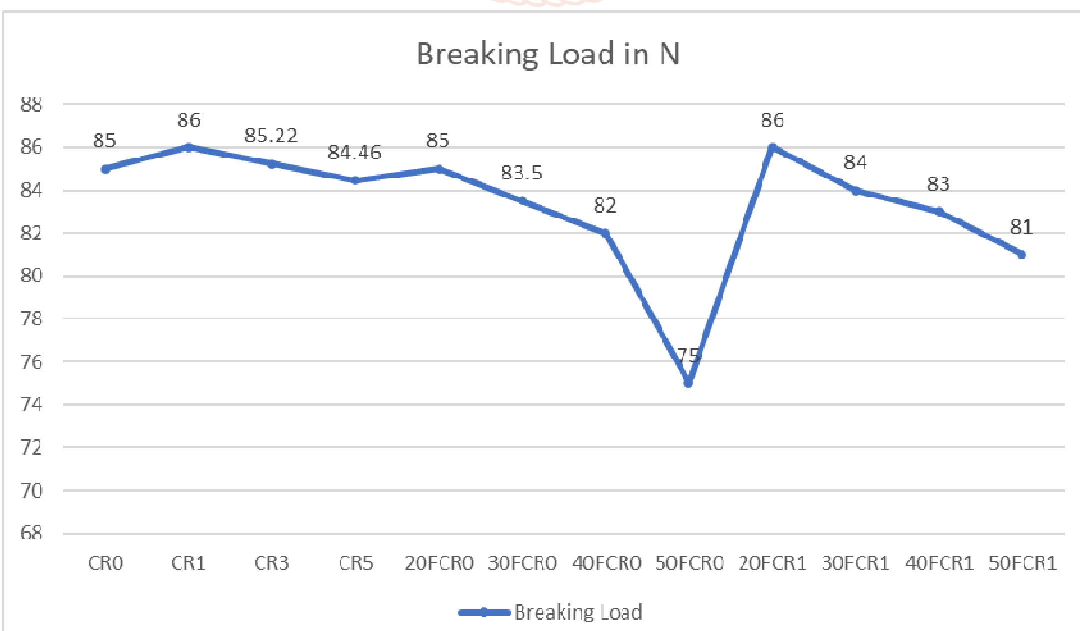

Figure Variation in breaking strength

Inference: Variations of breaking strength with percentage rice straw and foam volume are presented in Fig. Above foam concrete panel was tested after 28 days of curing. The breaking strength of foam concrete without rice straw (CR0) was observed to be 85N. Furthermore, when the RS content was increased breaking strength increases, but the increase is significant up to 1% RS content. At 3% RS also strength is increased than the conventional mix, but the increase is lesser than with 1% RS content. At 5% RS content the strength is decreased. Also, excessive foam volumes can lead to a significant reduction in compressive strength. As inferred from the table and graph above the strength is decreased when foam volume is increased beyond 20%.

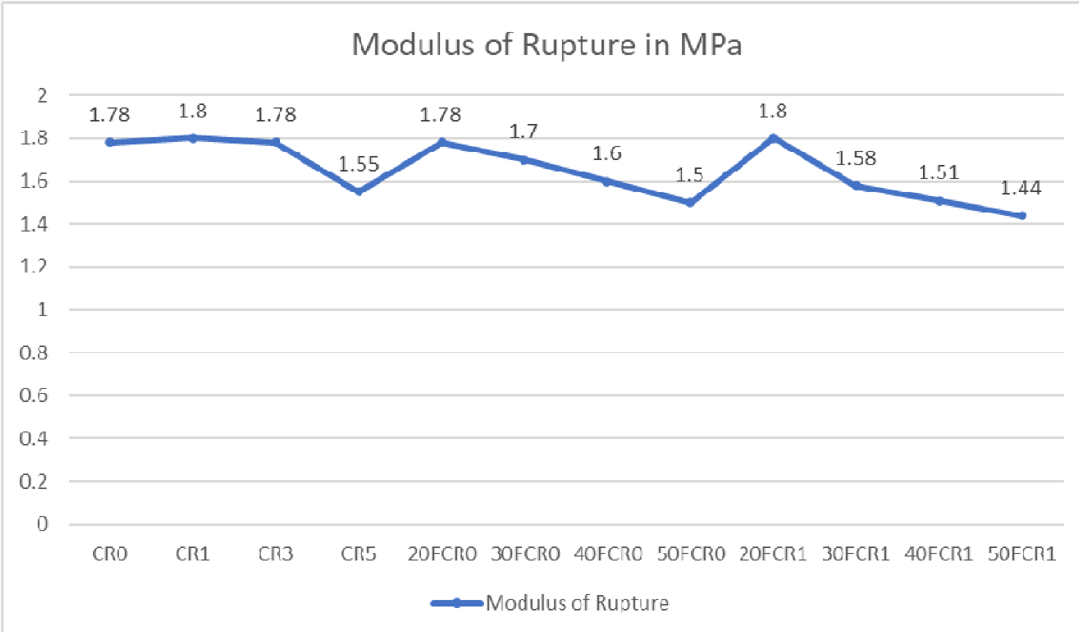

Figure Variation in modulus of rupture with % Rice straw

Inference: Variations of Modulus of Rupture with percentage rice straw and foam volume are presented in Fig. above foam concrete panel was tested after 28 days of curing. The modulus of Rupture of foam concrete without rice straw (CR0) was observed to be 1.78MPa Furthermore, when the RS content was increased Modulus of Rupture increased, but the increase is significant up to 1% RS content. At 3% RS also Modulus of Rupture is increased than the conventional mix, but the increase is lesser than with 1% RS content. At 5% RS content the Modulus of Rupture is decreased. Also, excessive foam volumes can lead to a significant reduction in the Modulus of Rupture. As inferred from the table and graph above the Modulus of Rupture is decreased when foam volume is increased beyond 20%.

Durability properties

Rate of water absorption

The main factors that influence water absorption are foam volume, paste content,pores, and voids. Voids and pore formation are different for different percentages of rice straw inclusion. Both fibres and voids influence the rate of water absorption. Rice straw itself is porous, and it accelerates the flowability of the fluid molecule. So, water absorption increased with an increase in the percentage of rice straw content. Foam concrete wit 1%, 3%, and 5% rice straw does not show a higher percentage of water absorption compared to the control specimen, which can be attributed to the NaOH treatment of the straw. But the increase in foam volume increased the water absorption when compared to the base mix. This variation can be due to the presence of higher capillarity pores resulting from a higher paste content.

Table Rate of water absorption

Mix	Water absorption in gm/100cm2		
	15min	60min	240min
CR0	38	42	55
CR1	40	43	57
CR3	50	54	75
CR5	55	61	89
20FCR0	38	42	55
30FCR0	40	44	58

40FCR0	40	45	60
50FCR0	85	112	120
20FCR1	40	43	57
30FCR1	57	80	86
40FCR1	60	85	90
50FCR1	110	120	125

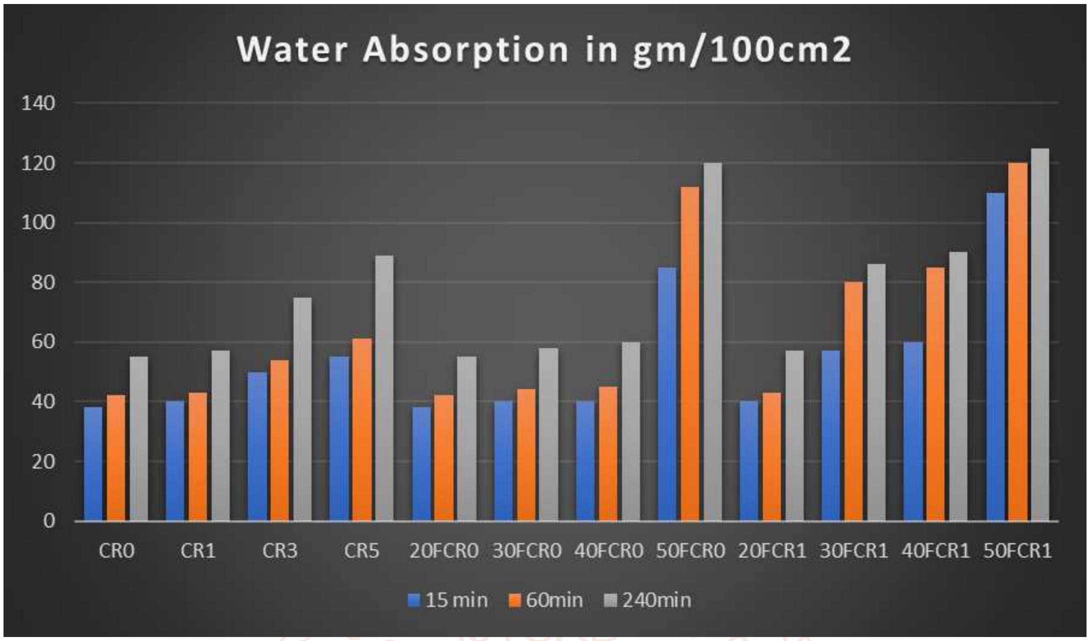

Figure Variation in water absorption with time

Acid resistance

When concrete is exposed to an acidic atmosphere acidic reaction will occur. All the specimens preserved in sulphuric acid showed a reduced strength compared to the control specimen due to deterioration. It is a surface phenomenon that started at the surface of the concrete and progressed inwards. Foam concrete with fly ash showed a markable increase in compressive strength when cured in water for up to 90 days due to a pozzolanic reaction. Up to 1% rice straw, the foam concrete specimen showed higher compressive strength compared to the control mix. Beyond 1% rice straw, the compressive strength was found to be reduced. The reduction in compressive strength is quite visible in all the rice straw added specimens subjected to acid attack. This is due to the decay of rice straw in acid, which made the concrete more porous and hence more ingression of acid into the specimen. Howeverthe reduction in strength is not significant in water-cured specimens due to the efficiency of the NaOH treatment provided to the rice straw.

6. CONCLUSION

1. **Compressive Strength** Rice straw fibers improved the cohesion of the foamed concrete mix, enhancing the bond between aggregates and cement paste, leading to increased compressive strength. However, the strength began to decline after 3% rice straw content. Excessive foam volumes also had a detrimental effect on compressive strength. Therefore, it is important to balance the rice straw content and foam volume to maintain adequate compressive strength.
2. **Breaking Strength and Modulus of Rupture:** The inclusion of rice straw generally increased both breaking strength (tensile strength) and modulus of rupture (flexural strength) of foamed concrete. The maximum increase was observed at 1% rice straw content. However, at 5% rice straw content, the strength decreased. Excessive foam volumes also led to a reduction in these properties. Therefore, the optimal rice straw content and foam volume should be carefully considered to achieve the desired breaking strength and modulus of rupture.
3. **Water Absorption:** The rate of water absorption in foamed concrete was influenced by foam volume, paste content, voids, and the presence of rice straw. Higher foam volumes and paste content increased water absorption, while rice straw inclusion did not significantly affect it.
4. **Acid Resistance:** Foamed concrete specimens exposed to an acidic atmosphere exhibited reduced compressive strength compared to the control mix. Rice straw content beyond 1%

further decreased the strength due to the decay of rice straw in acid, which increased the porosity of the concrete.

Overall, the addition of rice straw can enhance certain properties of foamed concrete, such as compressive strength, breaking strength, and modulus of rupture. However, there are limits to the optimal rice straw content, and excessive foam volumes should be avoided to maintain adequate strength. **The best results were achieved with 20% foam volume and 1% rice straw addition, indicating this as the optimum content for the tested properties.**

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