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# IMPROVEMENT ON SUSTAINABLE CONSTRUCTION METHODS USING EPS AND RHA AS BIO COMPOSITES

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## ABSTRACT

*In this work, the combined effects of two waste materials—unprocessed rice husk ash (RHA) and expanded polystyrene (EPS)—on various concrete properties are assessed. Petrochemical sources are the source of polystyrene, which is frequently used in insulation and packaging before being discarded at the end of its useful life. However, RHA, a byproduct of milling rice, is an easily accessible agricultural waste item that is frequently underutilized throughout many locations. Because these materials have potential for recycling and repurposing, their disposal can have a smaller negative environmental impact, promoting sustainability. This study investigates the possibility of using rice husk ash (RHA) and expanded polystyrene (EPS) as bio composites to partially replace conventional building materials in concrete. The study looks into how they affect the final concrete mixtures' workability, water absorption properties, compressive, tensile, and flexural strength. A common building material, concrete is coming under more and more attention because of its large carbon footprint, which is mostly caused by the energy-intensive manufacturing of Ordinary Portland Cement (OPC). This study investigates the feasibility of partially substituting conventional components in concrete mixtures with expanded polystyrene (EPS) and rice husk ash (RHA) as sustainable alternatives in response to these environmental concerns. There are two different kinds of agro-waste materials: EPS and RHA. The results demonstrate how RHA and EPS, as bio composites, may support environmentally friendly building methods. But when it comes to the proportions of the concrete mix, accuracy and balance are crucial. Key factors for ecologically responsible building include managing water resistance issues, preserving workability, and striking a balance between sustainability and structural integrity. This study offers an environmentally favourable way ahead for sustainable construction practices by laying a solid foundation for the use of RHA and EPS in concrete manufacturing.*

**Keywords:** Bio Composites, Polystyrene, RHA, Concrete Behavior, Waste, Strength

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## INTRODUCTION

The construction industry stands as a cornerstone of modern society, providing the infrastructure and buildings upon which our lives depend. However, this industry has long faced the challenge of balancing the growing demand for construction materials with the imperative to reduce its environmental footprint. The relentless use of energy and resources in the manufacturing of concrete—mainly as a result of OPC—has sparked a search for environmentally friendly substitutes that can lessen the negative effects of this essential building material.

Concrete is celebrated for its structural versatility and durability, but its production accounts for a substantial share of global carbon emissions. This environmental dilemma has catalyzed research endeavors to explore alternative materials that can replace or supplement the conventional components of concrete. Notably, rice husk ash (RHA) and expanded polystyrene (EPS) have emerged as promising candidates for the partial replacement of cement and coarse aggregate, respectively, forming a bio composite known as RHA-Polystyrene concrete.

RHA is a plentiful and frequently unused byproduct of milling rice, which makes it a desirable resource for sustainable building methods. It has pozzolanic qualities and is rich in amorphous silica, both of which can increase the durability and strength of concrete. Moreover, EPS, a thermoplastic polymer that is lightweight and has well-established insulating qualities, has demonstrated the ability to improve concrete's thermal performance while simultaneously lowering its weight.

This study delves into the effects of incorporating RHA and EPS as partial replacements for cement and coarse aggregate in concrete, thereby creating a bio composite material. It scrutinizes three crucial aspects of concrete performance: compressive strength, workability, and water absorption. Through rigorous testing and analysis, we aim to shed light on the trade-offs between sustainability and structural integrity, the influence of varying percentages of RHA and EPS on workability, and the implications for water resistance in RHA-Polystyrene concrete.

As the global construction industry continues its shift towards more eco-conscious and sustainable practices, the findings of this research offer valuable insights into the potential of RHA and EPS to revolutionize the way concrete is produced. Striking a balance between sustainability and structural performance is imperative in this endeavor, and the outcomes of this study provide guidance for future efforts to foster greener construction practices and meet the demands of a rapidly evolving world.

We plan to add to the expanding body of knowledge on sustainable construction materials and methods by presenting the findings, discussing their consequences, and providing ideas for optimizing the use of RHA and EPS in concrete in the upcoming sections of this study.

According to a study by [1], adding RHA to concrete enhanced its workability, strengthened it relative to the control sample, and increased the amount of water needed. At 28 days, the figures for compressive strength were 38.4, 36.5, and 33 N/mm2, in contrast to the control, which had a compressive strength of 37 N/mm2. According to the results, adding RHA at a rate of 5–10% will increase strength, however adding RHA at a rate of 15–25% will cause strength to decrease by 15%. Furthermore, a decline in strength values is linked to an increase in RHA levels.

Research conducted by [2] revealed that approximately one-fifth of the 300 million metric tons of rice produced annually comprises rice husk, an agricultural waste. They concluded that to address the environmental issues caused by this waste, attempts are being made to burn the rice husk at a regulated temperature and use the ash as substitute cement.

RHA has a high content of amorphous silica, which is required for the effective addicting reaction in cement according to a study by Saad et al. [3]. RHA has been found to contain impurities that reduce concrete's compressive strength. However, when rice husk is treated with hydrochloric (HCL) acid before it is burnt, it improves the compressive strength of concrete when partially replaced with cement.

The sulphate resistance of concretes incorporating rice husk ash was studied in the works of [4]. Three RHA replacement levels were taken into account in their investigation. The samples were submerged in a solution of sodium sulphate and magnesium sulphate after curing. It was shown that the measurement of the concrete cubes' weight losses and compressive strength reduction had a significant influence on the degree. They came to the conclusion that replacing cement with RHA is known to slow down the migration of aggressive ions like sulphates.

Pozzolan reactivity is primarily influenced by amorphousness, more so than by any other pozzolan characteristic, according to [5]. Additionally, it concludes that the pozzolan's specific surface area determines the paste's water requirement, whereas its amorphousness determines the paste's strength. However, the chemical composition of the pozzolan has no discernible effect on either pozzolan strength or reactivity [6].

The study of [7] looked at using unprocessed fly ash, a byproduct of burning coal and unprocessed polystyrene, in place of some of the concrete's constituent parts. According to the study, high fly ash content in place of cement and polystyrene granules in place of coarse aggregate can be used to make lightweight, low-thermal conductivity bricks and blocks or for low-strength concrete applications like cycle paths, footpaths, and noise-reducing barriers.

The study by [8] focused on the rheological, thermo-mechanical, microstructural, and wetting aspects of cement mortars made with recycled expanded polystyrene (EPS). The testing results revealed that - EPS samples were found to be more fluid than the references, as evidenced by microstructural and prosimetra detections; in particular, the sample with EPS grains in the 50% and 50% bead size range of 2-4 mm (EPS3) was the most plastic. Along with good particle distribution, it also demonstrated high cohesiveness between the ligand and the organic aggregates. Because the EPS samples had a lower specific mass than the controls, their mechanical resistances were lower. Strengths increased for 45 days before stabilizing. The materials were stable under the conglomerates' particular water curing and conservation circumstances, as seen by the results, which showed no appreciable change after 60 days. Because of the smaller aggregate sizes and gaps at the EPS/cement paste interface, the EPS-based mortars displayed lower thermal conductivities and diffusivities as compared to the sand-based standards. Sand-EPS combinations showed intriguing findings in terms of low heat conductivity and strong mechanical resistances.

Users' maintenance problems about the EPS components in housing are reported in [9]. It also determined the user's awareness of the EPS components in their houses and evaluated how satisfied they were with the attributes of EPS materials that are highly regarded in building construction. Despite its benefits, EPS has not yet been extensively adopted by the Nigerian building industry. A study found that only developers had used it for large-scale projects; there is no proof that it was used for private individuals' projects or for building massive housing developments. Similarly, user satisfaction with the created EPS attributes and maintenance issues are included in the study, along with the results of multiple laboratory tests on the material that validate the attributes assigned to it.

The study's findings encourage more developers to employ EPS material and raise awareness of its benefits in the construction sector, especially with regard to residential development. They said that the government should support the mass production of EPS and lower its cost for the general public in order to further promote its use.

The study by [10] discusses the use of expanded polystyrene (EPS) in building. It draws attention to the advantages that EPS may have for improving building design and structural integrity. Everyone agreed that expanded polystyrene (EPS) is a well-known insulating material that is utilized for a variety of purposes in construction, including panel applications, LWC, decorative moulding, and backfilling. Applications for flammable and non-flammable materials span a broad spectrum. Superior thermal insulation [11], impact resistance, low weight load bearing capability, complete water and vapor barrier, airtightness for regulated conditions, prolonged lifespan, low maintenance, and simple, quick assembly are just a few of the benefits of EPS foam, a lightweight yet rigid material. This article demonstrates the advantages and viability of using expanded polystyrene (EPS) as an insulator during the building design process that meets all insulation criteria, including fire safety. To address flammability and flame spread on the surface of EPS products and to comply with fire safety regulations, flame retardant grade EPS is required. As a result, while designing structures, EPS is blended with other fire-resistant materials [12].

A novel form of geo-polymer composite was reported to have been found [13]. It was created using two industrial wastes, red mud and rice husk ash, in different raw material mix ratios. The mechanical properties, microstructure, and geo-polymerization reactions of the final products were evaluated through X-ray diffraction, scanning electron microscopy, and mechanical compression testing. It was found that the primary component of this kind of composite final product is an amorphous geo-polymer binder, which is filled with both inherited and neo-formed crystalline phases. This results in a very complex composition of the composite and a wide range of mechanical properties. The practical application of RM-RHA based geopolymers as a construction material may be hindered by uncertainties regarding their composition, microstructure, level of RHA dissolution, and side reactions.

According to research by [14], RHA is thought to be a very effective pozzolan that is utilized in the construction of civil infrastructure. It not only degrades the environment but also improves concrete in a number of ways. According to their study's compressive strength and workability tests, RHA might replace OPC in the production of concrete by up to 25% without significantly compromising the material's strength or workability. It is reasonable to believe that the addition of RHA did not considerably boost the tensile strength based on the split tensile strength test findings. Flexural strength studies revealed a little increase at replacement levels of 10% to 25% RHA. Because of its many advantageous qualities, rice husk ash concrete is an excellent structural concrete that can be altered at a 10% rate in terms of both short- and long-term difficulties [15].

Again, adding RHA to concrete enhanced workability, strengthened it relative to the control specimen, and increased the amount of water used in the research [16] finished. At 28 days, the figures for compressive strength were 38.4, 36.5, and 33 N/mm2, in contrast to the control, which had a compressive strength of 37 N/mm2. According to the results, adding RHA at a rate of 5–10% will increase strength, however adding RHA at a rate of 15–25% will cause strength to decrease by 15%. Furthermore, a decline in strength values is linked to an increase in RHA levels.

Expanded Polystyrene Beads (EPS) and their effects on the mechanical characteristics of concrete were investigated by [17]. Based on the results and analysis of the research, it was discovered that as the volume of EPS integrated rose, the workability, compressive, and flexural strengths all decreased while the tensile strength varied (was not consistent).

Therefore, it is clear that concrete that uses expanded polystyrene in place of some coarse particles is weaker and should only be used for low-strength structural components, or those that require very little strength. The optimum applications for this type of polystyrene-based concrete are non-structural parts that do not require strong flexural and compressive strengths.

The benefits of EPS concrete's reduced weight and thermal insulation, however, are numerous. Thus, as stated by [18] and [19], investigating new concrete materials and examining modern structural materials are essential for practical engineering. For concrete walls inside frame buildings, lightweight concrete mixed with expanded polystyrene beads can be used, as the frame will support the building's dead and living loads. This method lowers expenses, improves thermal insulation, and lessens the dead load on the structure, among many other advantages [20].

## II MATERIALS AND METHODOLOGY

Expanded Polystyrene, or EPS (often referred to as cork in colloquial language), is extracted from various electronic packaging and physically broken into 6–15 mm granules. This is going to replace some of the coarse aggregate. The rice mill in Obubra, Cross River State, Nigeria, provides the RHA sample. The location of the rice mill is depicted in Fig. 1. Rice husk ash (RHA), the final result of the rice husk, was air dried.

OPC was acquired from the Lafarge cement factory located in the Nigerian state of Cross River, in the Akamkpa Local Government Area. For the experiment, coarse gravel with a size range of 15 to 22 mm will be obtained from a quarry owned by Faith Plant International Limited located in Akamkpa, Nigeria. For this investigation, naturally occurring fine aggregate from the Marina River will be used. In addition, this will sieve to make sure the sand is free of organic matter and to identify the grade zone for mix design purposes. Portable water that complied with the requirements set forth for water used in concrete mixtures was utilized for mixing and curing the concrete.

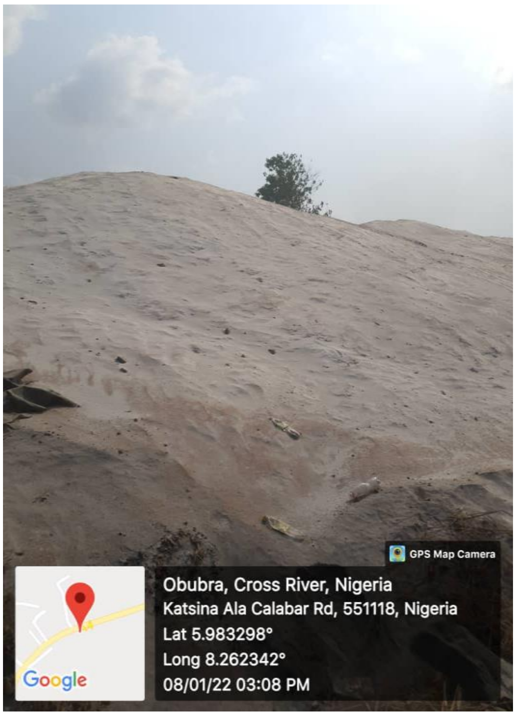

**Fig 1.** Heap of RHA

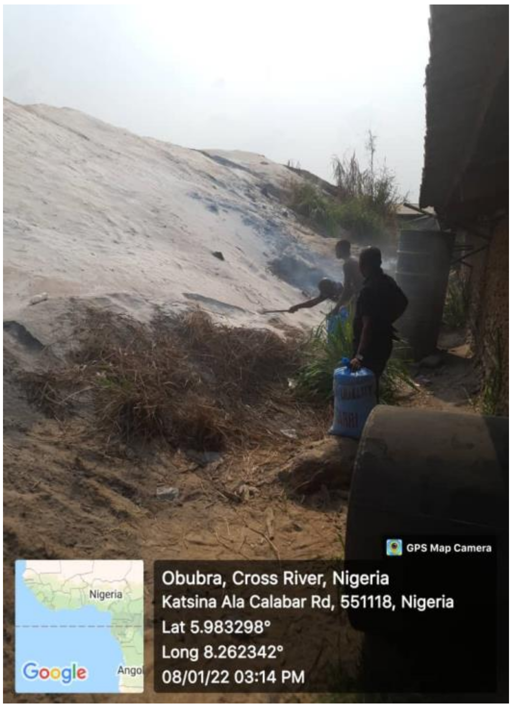

**Fig 2.** Sample of RHA being collected in sacks

The methods used involved firstly was preparation of materials, characterization of the materials, gradation of the aggregates used, characterization of materials and production of concrete samples according to the mixture proportions formulated.

With the exception of using RHA and EPS in certain amounts to partially replace OPC and coarse aggregate, respectively, the process for making RHA-Polystyrene concrete was carried out just like regular concrete manufacture. For this study, a concrete mix ratio of 1:1.5:3 was used. To account for OPC and RHA, the binder part of the concrete mix ratio was divided. For every sample, the RHA was changed in part at 5, 10, 15, and 20% for OPC. In order to accept granite and EPS at partial replacement levels of 5, 10, 15, and 20%, the coarse aggregate fraction was also divided. Using a calibrated container, the volume of these percentages was determined. Five (5) separate batches of concrete total—normal concrete with 100% OPC was also created to act as the baseline for comparison.

The concrete's workability, percentage of water absorption, and compressive, tensile, and flexural strengths were all evaluated by testing. Slump tests were performed on new mixes of test and normal concrete in compliance with BS EN 12350-2:2009 to verify workability. Following setting, the fresh concrete was weighed, demoulded, and placed in 100 m3 moulds to determine the percentage of water absorption. The moulds were then placed in a curing tank. To get an average value, each batch of concrete had 12 cubes cast, 3 cubes for each of the four curing ages. The durations of the cures were 7, 14, 21, and 28 days. In order to determine whether concrete is susceptible to corrosion and deterioration from water or other hazardous fluids, water absorption tests are employed as a durability check on the material. It is the variation in the concrete cubes' dry and wet weights prior to and just after curing. The most crucial aspect of concrete, according to many, is its compressive strength. Compressive strength testing is a useful technique for figuring out how a material will respond to a compression force. Three replicate concrete samples were created in 100 x 100 x 100 mm moulds for each of the twelve (12) mix ratios. The interiors of the moulds were cleaned and lubricated before layers of freshly mixed concrete, about 50 mm thick, were added. A tamping rod of 16 mm in diameter, 60 cm in length, and bullet-pointed at the bottom end was used to crush each layer 35 times. Before letting the concrete set, its top surface was always levelled with a trowel. After a day, the concrete samples were demoulded, put in a water bath to cure, and then evaluated using a Universal Testing Machine (UTM) at 7, 14, 21, and 28 days to see how they responded in terms of compressive strength. Each sample was progressively loaded at a rate of 140 kg/cm$^3$ per minute until it failed. Each cube sample's compressive strength was determined using;

Compressive strength (kN/mm$^2$) $F_{cu} = W_f / A_p$

Where $W_f$ is the maximum applied load (N) and $A_p$ is the cross-sectional area of cube mould, (mm$^2$).

The split tensile test is done by placing nixture in cylindrical molds of 100mm diameter and 200mm height The samples are removed from the mold after a day and place in a water bath with a control temperature of 23-25$^o$C. This is to ascertain the tensile strength of the mixture at curing age of 7, 14, 21, and 28 days using a crushing machine. The splitting tensile strength of the specimen shall be calculated as follows:

$$\mathbf{T = 2P/\pi LD}$$

**T** = Splitting tensile strength

**P** = Maximum applied load

**L** = Length, m

**D** = Diameter

The flexural test is determined by placing mixture in prismatic molds of 100mm x 100mm x 500mm. The samples are removed from the mold after a day and place in a water bath with a control temperature of 23-25°C. This is to ascertain the flexural strength of the mixture at curing age of 7, 14, 21, and 28 days using a crushing machine. Suryakanta (2016) gave the flexural Strength or modulus of rupture (**$f_b$**) as

**$f_b = pl/bd^2$** (when **l** > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen)

b = width of specimen (cm)
d = failure point depth (cm)
l = supported length (cm)
p = max. Load (kg)

## III RESULTS AND DISCUSSION

The laboratory responses for the mixtures are as follows

### WORKABILTY

The results of the slump tests are shown in the Table 1 below:

**Table 1**: Results of Slump test showing varying percentages of OPC/RHA and GRANITE/EPS

| S/No | W/C RATIO | % OPC | % RHA | % SAND | % GRANITE | % EPS | SLUMP (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 0.45 | 100 | 0 | 100 | 100 | 0 | 96 |
| 2 | 0.45 | 95 | 5 | 100 | 95 | 5 | 85 |
| 3 | 0.5 | 90 | 10 | 100 | 90 | 10 | 78 |
| 4 | 0.6 | 85 | 15 | 100 | 85 | 15 | 70 |
| 5 | 0.6 | 80 | 20 | 100 | 80 | 20 | 62 |

The result of the slump test shows slight difference of 11mm of slump height between the control value (0% RHA, 0% EPS) and the first test value (95% OPC, 5% RHA, 5% EPS). Increase in percentage of partial replacement of OPC and granite with RHA and EPS respectively shows to have stiffening effect on the concrete with gradual increase EPS content. The slump results in table 4.1 shows that 5-15% EPS and slump ranging from 85-70mm, workability is high. And for 20% EPS with height of 62mm, the workability is low. These show that the workability of RHA-Polystyrene concrete is increased with gradual increase in RHA and EPS. Fig. 2 shows chart of variation of RHA-EPS concrete workability for the different mix batches.

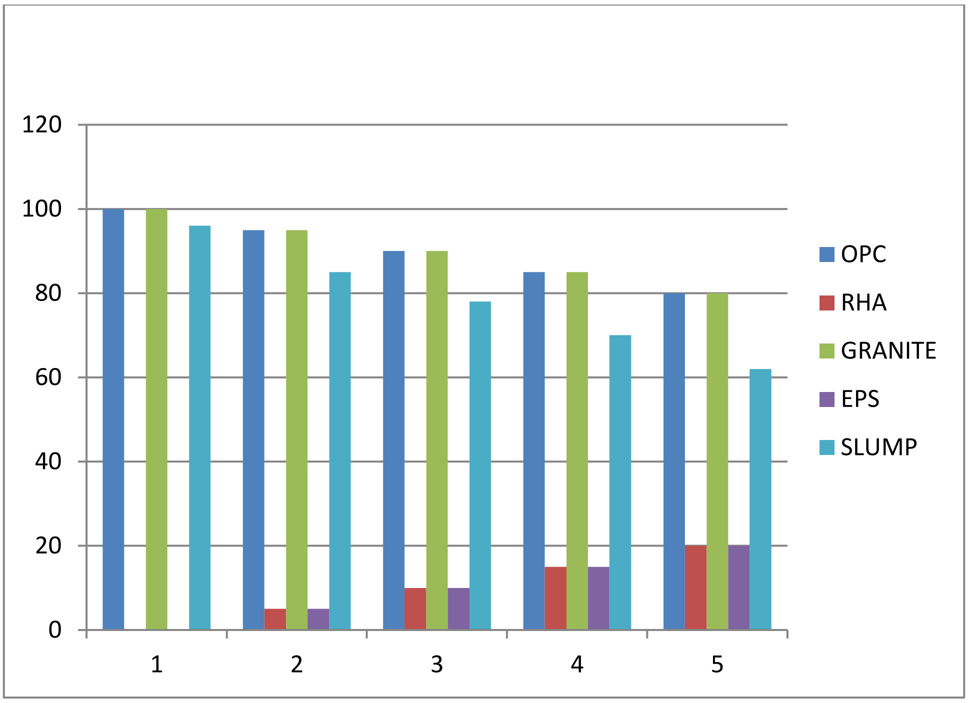

**Fig 3**: Chart of Variation of RHA-EPS Concrete Workability

## WATER ABSORPTION TEST

The results of the water absorption test are as shown from table 2-6. Moisture absorption is a critical property in determining the durability and susceptibility of concrete to environmental conditions. 0.36% was obtained for 0% RHA, 0% EPS - Control Mix and this value serves as the baseline for moisture absorption. The low moisture absorption indicates that the conventional concrete mix without RHA and EPS has relatively good resistance to moisture penetration. 0.94% was obtained for 5% RHA and 5% EPS mix. The increase in moisture absorption compared to the control mix suggests that the inclusion of 5% RHA and 5% EPS has a notable impact on the moisture absorption characteristics of the concrete. This increase could be attributed to the porous nature of both RHA and EPS, which might allow more water absorption. 1.09% was obtained for 10% RHA and 10% EPS mix. This further increase in moisture absorption at this mixture indicates that the inclusion of 10% EPS contributes to higher moisture absorption. The lightweight nature of EPS might result in additional voids within the concrete, providing pathways for water ingress. 1.17% obtained at 15% RHA, 15% EPS mix shows the additional increase in moisture absorption at this mixture suggests that, beyond a certain point, the lightweight nature of EPS starts to dominate over the positive effects introduced by RHA in terms of reducing moisture absorption. 1.28% obtained at 20% RHA, 20% EPS mix shows the moisture absorption at this mixture suggests a further increase which emphasizes the need for careful consideration of the proportions of RHA and EPS to achieve a balance between moisture resistance and the desired properties introduced by these materials. The graph of durability base on water absorption is shown in fig. 3 which indicates decreased durability with increase in EPS percentages.

**Table 2**: Results of moisture absorption test with 0% RHA and 0% EPS

| Curing Age | wet weight(g) | dry weight(g) | Avg dry weight(g) | Moisture absorption (%) | Avg Moisture absorption (%) |
|---|---|---|---|---|---|
| 7 days | 2822 | 2791 | 2798 | 0.31 | 0.28 |
| | 2801 | 2774 | | 0.27 | |
| | 2855 | 2830 | | 0.25 | |
| 14 days | 2657 | 2613 | 2728 | 0.44 | 0.37 |
| | 2801 | 2782 | | 0.19 | |
| | 2837 | 2789 | | 0.48 | |
| 21 days | 2848 | 2810 | 2773 | 0.38 | 0.43 |
| | 2781 | 2723 | | 0.58 | |
| | 2817 | 2785 | | 0.32 | |
| 28 days | 2801 | 2759 | 2787 | 0.42 | 0.36 |
| | 2821 | 2792 | | 0.29 | |
| | 2846 | 2810 | | 0.36 | |

**Table 3**: Results of moisture absorption test with 5% RHA and 5% EPS

| Curing Age | wet weight(g) | dry weight(g) | Avg dry weight(g) | Moisture absorption (%) | Avg Moisture absorption (%) |
|---|---|---|---|---|---|
| 7 days | 2581 | 2540 | 2536 | 0.41 | 0.47 |
| | 2678 | 2633 | | 0.45 | |
| | 2489 | 2434 | | 0.55 | |
| 14 days | 2469 | 2401 | 2468 | 0.68 | 0.62 |
| | 2523 | 2465 | | 0.58 | |
| | 2596 | 2537 | | 0.59 | |
| 21 days | 2407 | 2320 | 2442 | 0.87 | 0.85 |
| | 2694 | 2605 | | 0.89 | |
| | 2481 | 2402 | | 0.79 | |
| 28 days | 2626 | 2530 | 2563 | 0.96 | 0.94 |
| | 2697 | 2609 | | 0.88 | |
| | 2648 | 2550 | | 0.98 | |

**Table 4**: Results of moisture absorption test with 10% RHA and 10% EPS

| **Curing Age** | **wet weight(g)** | **dry weight(g)** | **Avg dry weight(g)** | **Moisture absorption (%)** | **Avg Moisture absorption (%)** |
|---|---|---|---|---|---|
| 7 days | 2528 | 2440 | 2467 | 0.88 | 0.81 |
| | 2551 | 2484 | | 0.67 | |
| | 2563 | 2476 | | 0.87 | |
| 14 days | 2401 | 2302 | 2278 | 0.99 | 0.95 |
| | 2332 | 2235 | | 0.97 | |
| | 2386 | 2297 | | 0.89 | |
| 21 days | 2411 | 2306 | 2343 | 1.05 | 0.99 |
| | 2481 | 2357 | | 1.24 | |
| | 2432 | 2365 | | 0.67 | |
| 28 days | 2510 | 2408 | 2423 | 1.02 | 1.09 |
| | 2537 | 2428 | | 1.09 | |
| | 2548 | 2432 | | 1.16 | |

**Table 5**: Results of moisture absorption test with 15% RHA and 15% EPS

| **Curing Age** | **wet weight(g)** | **dry weight(g)** | **Avg dry weight(g)** | **Moisture absorption (%)** | **Avg Moisture absorption (%)** |
|---|---|---|---|---|---|
| 7 days | 2385 | 2280 | 2287 | 1.05 | 0.97 |
| | 2441 | 2365 | | 0.76 | |
| | 2328 | 2217 | | 1.11 | |
| 14 days | 2306 | 2214 | 2266 | 0.92 | 0.99 |
| | 2413 | 2289 | | 1.24 | |
| | 2378 | 2296 | | 0.82 | |
| 21 days | 2388 | 2285 | 2217 | 1.03 | 1.12 |
| | 2453 | 2341 | | 1.12 | |
| | 2147 | 2026 | | 1.21 | |
| 28 days | 2513 | 2409 | 2340 | 1.04 | 1.17 |
| | 2441 | 2295 | | 1.46 | |
| | 2417 | 2315 | | 1.02 | |

**Table 6**: Results of moisture absorption test with 20% RHA and 20% EPS

| Curing Age | wet weight(g) | dry weight(g) | Avg dry weight(g) | Moisture absorption (%) | Avg Moisture absorption (%) |
|---|---|---|---|---|---|
| 7 days | 2296 | 2195 | 2226 | 1.01 | 1.02 |
| | 2351 | 2296 | | 0.55 | |
| | 2338 | 2187 | | 1.51 | |
| 14 days | 2321 | 2212 | 2203 | 1.09 | 1.14 |
| | 2323 | 2192 | | 1.31 | |
| | 2307 | 2204 | | 1.03 | |
| 21 days | 2233 | 2126 | 2133 | 1.07 | 1.06 |
| | 2197 | 2096 | | 1.01 | |
| | 2289 | 2178 | | 1.11 | |
| 28 days | 2119 | 2016 | 1998 | 1.03 | 1.28 |
| | 2154 | 1991 | | 1.63 | |
| | 2103 | 1986 | | 1.17 | |

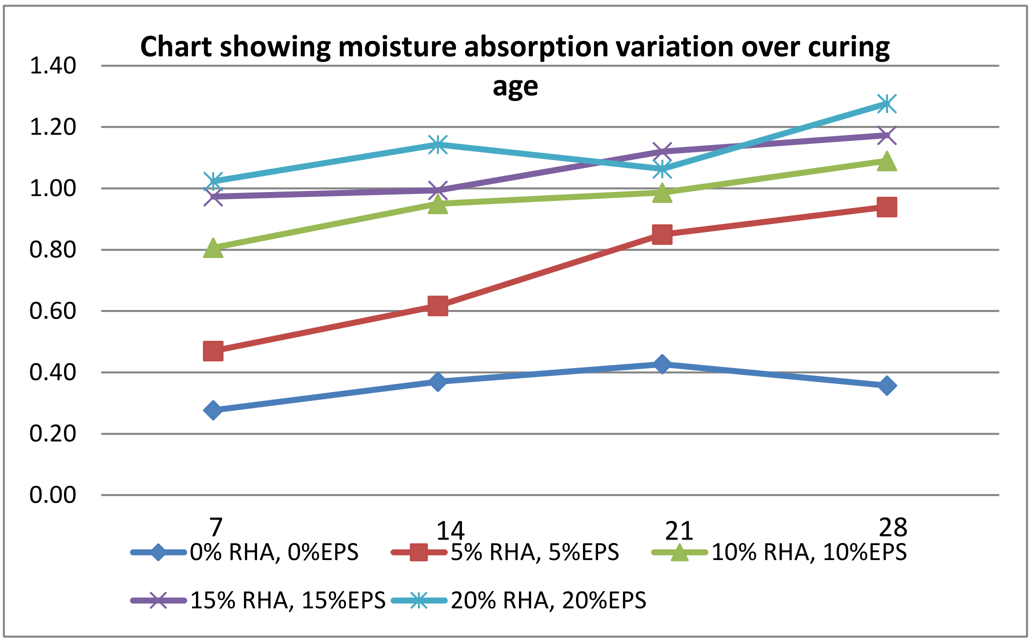

**Fig 4:** Graph of Durability Base on Water Absorption

## COMPRESSIVE STRENGTH

One of the many important parameters that is altered by the addition of RHA and EPS is the concrete's compressive strength. The concrete's mechanical qualities are significantly impacted, as evidenced by the observed fall in compressive strength as the amount of RHA increases. Compressive strength increased by 37.46 KN/mm$^2$ in comparison to the control mix, indicating that adding 5% RHA and 5% EPS had a positive impact. Even if RHA's pozzolanic reaction aids in the development of strength, it may be sufficient to offset the reduction brought on by EPS's low weight. Generally speaking, the density of concrete has an inverse relationship with its compressive strength. Concrete's compressive strength is affected when lightweight components like EPS are added since they lower the material's overall density. The control mix's reduction in compressive strength suggests that 10% RHA and 10% EPS have a considerable effect.

Because EPS is lightweight, the concrete's overall density is decreased, which lowers the concrete's compressive strength. This emphasizes the trade-off between preserving higher compressive strength and obtaining lower density (taking use of EPS's lightweight characteristic). The further decrease in compressive strength of 27.41 KN/mm² at 15% RHA and 15% EPS implies that, after a given amount of time, the pozzolanic reaction of RHA may not be as important due to EPS's lightweight nature. It suggests that in order to obtain the required strength properties, RHA and EPS must be carefully balanced. The findings of the compressive strength tests performed on the various batches of RHA-EPS concrete mixes are displayed in Tables 7 through 11. Figure 4 displays the chart that illustrates how RHA-EPS concrete's compressive strength varies with curing age.

**Table 7**: Results of compressive strength of control mixture

| | **crushing load(kN)** | **crushing load(kN)** | **fcu (N/mm$^2$)** | **Avg fcu (N/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 167.82 | 164.1567 | 16.782 | 16.42 |
| | 165.91 | | 16.591 | |
| | 158.74 | | 15.874 | |
| 14 days | 213.87 | 223.6433 | 21.387 | 22.36 |
| | 226.21 | | 22.621 | |
| | 230.85 | | 23.085 | |
| 21 days | 302.63 | 310.4767 | 30.263 | 31.05 |
| | 310.44 | | 31.044 | |
| | 318.36 | | 31.836 | |
| 28 days | 334.12 | 357.69 | 33.412 | 35.77 |
| | 355.91 | | 35.591 | |
| | 383.04 | | 38.304 | |

**Table 8**: Results of compressive strength with 5% RHA and 5% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **fcu (kN/mm$^2$)** | **Avg fcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 182.92 | 183.82 | 18.29 | 18.38 |
| | 183.07 | | 18.31 | |
| | 185.46 | | 18.55 | |
| 14 days | 253.16 | 251.67 | 25.32 | 25.17 |
| | 272.47 | | 27.25 | |
| | 229.38 | | 22.94 | |
| 21 days | 307.34 | 312.7667 | 30.73 | 31.28 |
| | 311.32 | | 31.13 | |
| | 319.64 | | 31.96 | |
| 28 days | 362.72 | 374.6433 | 36.27 | 37.46 |
| | 382.47 | | 38.25 | |
| | 378.74 | | 37.87 | |

**Table 9**: Results of compressive strength with 10% RHA and 10% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **fcu (kN/mm$^2$)** | **Avg fcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 164.88 | 163.85 | 16.49 | 16.39 |
| | 161.37 | | 16.14 | |
| | 165.31 | | 16.53 | |
| 14 days | 214.73 | 219.1533 | 21.47 | 21.92 |
| | 212.84 | | 21.28 | |
| | 229.89 | | 22.99 | |
| 21 days | 291.96 | 305.4933 | 29.20 | 30.55 |
| | 305.85 | | 30.59 | |
| | 318.67 | | 31.87 | |
| 28 days | 336.84 | 343.7067 | 33.68 | 34.37 |
| | 341.97 | | 34.20 | |
| | 352.31 | | 35.23 | |

**Table 10**: Results of compressive strength with 15% RHA and 15% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **fcu (kN/mm$^2$)** | **Avg fcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 144.14 | 143.80 | 14.41 | 14.38 |
| | 141.31 | | 14.13 | |
| | 145.94 | | 14.59 | |
| 14 days | 172.23 | 179.9867 | 17.22 | 18.00 |
| | 180.47 | | 18.05 | |
| | 187.26 | | 18.73 | |
| 21 days | 226.61 | 237.04 | 22.66 | 23.70 |
| | 238.84 | | 23.88 | |
| | 245.67 | | 24.57 | |
| 28 days | 261.88 | 274.0967 | 26.19 | 27.41 |
| | 272.07 | | 27.21 | |
| | 288.34 | | 28.83 | |

**Table 11**: Results of compressive strength with 20% RHA and 20% EPS

|  | crushing load(kN) | Av crushing load(kN) | fcu (kN/mm$^2$) | Avg fcu (kN/mm$^2$) |
|---|---|---|---|---|
| 7 days | 123.21 | 132.03 | 12.32 | 13.20 |
|  | 135.37 |  | 13.54 |  |
|  | 137.52 |  | 13.75 |  |
| 14 days | 176.18 | 173.5133 | 17.62 | 17.35 |
|  | 188.15 |  | 18.82 |  |
|  | 156.21 |  | 15.62 |  |
| 21 days | 191.84 | 190.17 | 19.18 | 19.02 |
|  | 180.19 |  | 18.02 |  |
|  | 198.48 |  | 19.85 |  |
| 28 days | 221.11 | 224.5433 | 22.11 | 22.45 |
|  | 217.37 |  | 21.74 |  |
|  | 235.15 |  | 23.52 |  |

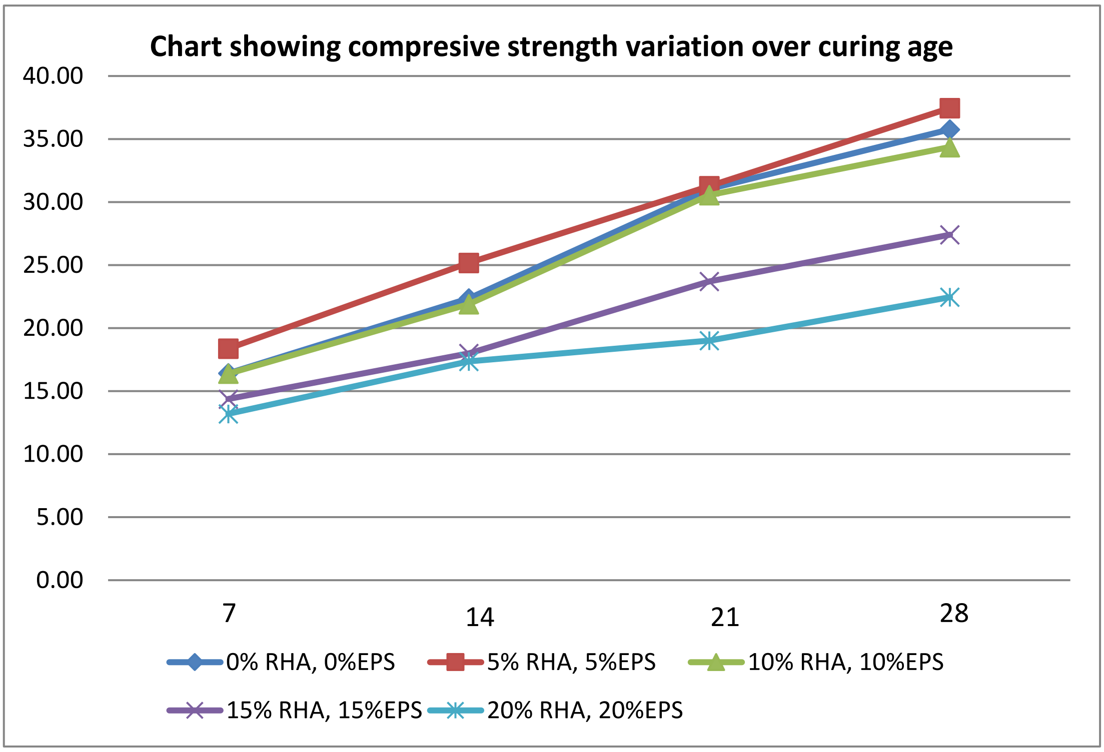

**Fig 5**: Chart Showing Variation of Compressive Strength Variation over Curing Age

## TENSILE STRENGTH

Tensile strength is a critical parameter in understanding a material's ability to withstand tensile (pulling) forces. The control mix had a value of 2.30 kN/mm² which serves as the baseline tensile strength. 2.44 kN/mm² was gotten for 5% RHA and 5% EPS mix. The increase in tensile strength compared to the control mix suggests that the inclusion of 5% RHA and 5% EPS has a positive effect on tensile strength. 2.13 kN/mm² was gotten for 10% RHA and 10% EPS. 1.55 kN/mm² was obtained for 15% RHA and 15% EPS mix.

The decrease in tensile strength at this mixture indicates that, beyond a certain point, the lightweight nature of EPS may start to dominate over the positive effects introduced by RHA. This highlights the need for a balanced approach in determining the optimal ratio of RHA and EPS to achieve the desired tensile strength. 1.41 kN/mm² was obtained for 20% RH and 20% EPS mix. The tensile strength at this mixture suggests that, with an increase in EPS content, there is a corresponding decrease in tensile strength. This reinforces the need for careful consideration of the proportions of RHA and EPS to achieve a balance between tensile strength and the desired properties introduced by these materials. The result of the tensile strength is shown in table 12 to 16. The combination of RHA and EPS in concrete mixes shows a complex interaction, similar to what was observed in compressive strength as shown in the chart in fig 5.

**Table 12**: Results of Tensile strength with 0% RHA and 0% EPS

| | **crushing load(kN)** | **crushing load(kN)** | **fcu (kN/mm$^2$)** | **Avg fcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 48.01 | 48.35 | 1.53 | 1.54 |
| | 46.93 | | 1.49 | |
| | 50.11 | | 1.59 | |
| 14 days | 55.13 | 55.93 | 1.75 | 1.78 |
| | 58.31 | | 1.86 | |
| | 54.35 | | 1.73 | |
| 21 days | 65.23 | 64.75333 | 2.08 | 2.06 |
| | 65.79 | | 2.09 | |
| | 63.24 | | 2.01 | |
| 28 days | 70.39 | 72.23 | 2.24 | 2.30 |
| | 72.36 | | 2.30 | |
| | 73.94 | | 2.35 | |

**Table 13**: Results of Tensile strength with 5% RHA and 5% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **Tcu (kN/mm$^2$)** | **Avg Tcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 46.96 | 48.02 | 1.49 | 1.53 |
| | 49.47 | | 1.57 | |
| | 47.63 | | 1.52 | |
| 14 days | 58.82 | 58.61333 | 1.87 | 1.87 |
| | 59.16 | | 1.88 | |
| | 57.86 | | 1.84 | |
| 21 days | 68.61 | 65.52333 | 2.18 | 2.09 |
| | 64.05 | | 2.04 | |
| | 63.91 | | 2.03 | |
| 28 days | 76.58 | 76.75333 | 2.44 | 2.44 |
| | 74.93 | | 2.38 | |
| | 78.75 | | 2.51 | |

**Table 14**: Results of Tensile strength with 10% RHA and 10% EPS

| | **crushing load(kN)** | **crushing load(kN)** | **fcu ($kN/mm^2$)** | **Avg fcu ($kN/mm^2$)** |
|---|---|---|---|---|
| 7 days | 51.96 | 49.23 | 1.65 | 1.57 |
| | 48.35 | | 1.54 | |
| | 47.38 | | 1.51 | |
| 14 days | 52.09 | 51.65 | 1.66 | 1.64 |
| | 51.83 | | 1.65 | |
| | 51.03 | | 1.62 | |
| 21 days | 53.69 | 52.19 | 1.71 | 1.66 |
| | 52.78 | | 1.68 | |
| | 50.11 | | 1.59 | |
| 28 days | 67.03 | 67.00 | 2.13 | 2.13 |
| | 65.68 | | 2.09 | |
| | 68.28 | | 2.17 | |

**Table 15**: Results of Tensile strength with 15% RHA and 15% EPS

| | **crushing load(kN)** | **crushing load(kN)** | **fcu ($kN/mm^2$)** | **Avg fcu ($kN/mm^2$)** |
|---|---|---|---|---|
| 7 days | 35.42 | 34.24333 | 1.13 | 1.09 |
| | 34.84 | | 1.11 | |
| | 32.47 | | 1.03 | |
| 14 days | 37.18 | 37.26333 | 1.18 | 1.19 |
| | 36.68 | | 1.17 | |
| | 37.93 | | 1.21 | |
| 21 days | 40.21 | 39.55 | 1.28 | 1.26 |
| | 38.89 | | 1.24 | |
| | 39.56 | | 1.26 | |
| 28 days | 51.66 | 48.85 | 1.64 | 1.55 |
| | 45.21 | | 1.44 | |
| | 49.68 | | 1.58 | |

**Table 16**: Results of Tensile strength with 20% RHA and 20% EPS

| | crushing load(kN) | crushing load(kN) | fcu (kN/mm$^2$) | Avg fcu (kN/mm$^2$) |
|---|---|---|---|---|
| 7 days | 38.65 | 37.16667 | 1.23 | 1.18 |
| | 37.67 | | 1.20 | |
| | 35.18 | | 1.12 | |
| 14 days | 40.17 | 40.50667 | 1.28 | 1.29 |
| | 38.73 | | 1.23 | |
| | 42.62 | | 1.36 | |
| 21 days | 42.3 | 42.19 | 1.35 | 1.34 |
| | 42.87 | | 1.36 | |
| | 41.39 | | 1.32 | |
| 28 days | 43.75 | 44.42 | 1.39 | 1.41 |
| | 45.58 | | 1.45 | |
| | 43.93 | | 1.40 | |

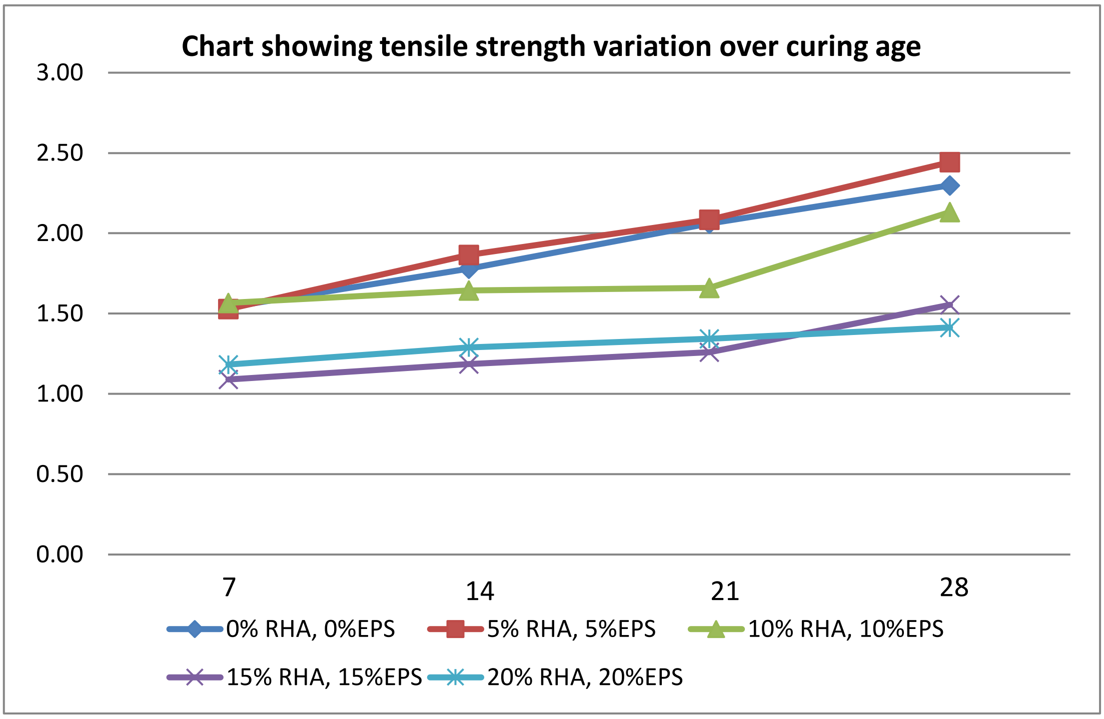

**Fig 6**: Chart Showing Variation of Tensile Strength Variation over Curing Age

## FLEXURAL STRENGTH

4.04 kN/mm² was obtained for the control mix to represent the baseline or control flexural strength. 3.94kN/mm² was obtained for 5% RHA and 5% EPS mix. The decrease in flexural strength compared to the control mix suggests that the inclusion of 5% RHA and 5% EPS has a diminishing effect. The pozzolanic reaction of RHA might not fully compensate for the reduction induced by the lightweight nature of EPS in terms of flexural strength. 3.29kN/mm² was obtained for 10% RHA and 10% EPS. The further decrease in flexural strength compared to the 5% RHA, 5% EPS mix indicates that the inclusion of 8% EPS has a negative impact.

This suggests that the lightweight characteristics of EPS can affect the concrete's ability to resist bending forces. 2.91kN/mm² was obtained for 15% RHA and 15% EPS mix. The additional decrease in flexural strength at this mixture indicates that, beyond a certain point, the lightweight nature of EPS dominates over the positive effects introduced by RHA, leading to a more significant reduction in flexural strength. 1.76 kN/mm² was obtained for 20% RHA and 20% EPS mix. The flexural strength at this mixture suggests a substantial decrease. This emphasizes the importance of balancing the proportions of RHA and EPS to achieve a flexural strength that meets the desired specifications. The result of the flexural strength is shown in table 17 to 21. Fig 6 shows the chart of variation of flexural strength of the different mixes over curing age.

**Table 17**: Results of Flexural strength with 0% RHA and 0% EPS

| | **crushing load(kN)** | **crushing load(kN)** | **fb (kN/mm$^2$)** | **Avg fb (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 478.9 | 480.55 | 3.59 | 3.61 |
| | 482.6 | | 3.62 | |
| | 480.15 | | 3.61 | |
| 14 days | 490.93 | 493.4967 | 3.68 | 3.70 |
| | 495.73 | | 3.72 | |
| | 493.83 | | 3.70 | |
| 21 days | 511.2 | 511.3033 | 3.83 | 3.83 |
| | 503.95 | | 3.78 | |
| | 518.76 | | 3.89 | |
| 28 days | 528.74 | 539.2733 | 3.97 | 4.04 |
| | 556.17 | | 4.17 | |
| | 532.91 | | 4.00 | |

**Table 18**: Results of Flexural strength with 5% RHA and 5% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **Tcu (kN/mm$^2$)** | **Avg Tcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 470.92 | 470.53 | 3.532 | 3.53 |
| | 472.57 | | 3.55 | |
| | 468.1 | | 3.51 | |
| 14 days | 479.24 | 482.40 | 3.5943 | 3.62 |
| | 482.14 | | 3.616 | |
| | 485.81 | | 3.64 | |
| 21 days | 492.16 | 493.54 | 3.69 | 3.70 |
| | 496.34 | | 3.72 | |
| | 492.13 | | 3.691 | |
| 28 days | 510.87 | 524.48 | 3.83 | 3.94 |
| | 521.84 | | 3.92 | |
| | 540.73 | | 4.06 | |

**Table 19**: Results of Flexural strength with 10% RHA and 10% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **Tcu (kN/mm$^2$)** | **Avg Tcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 365.54 | 370.21 | 2.74 | 2.78 |
| | 372.16 | | 2.79 | |
| | 372.93 | | 2.80 | |
| 14 days | 385.62 | 391.39 | 2.89 | 2.94 |
| | 391.71 | | 2.94 | |
| | 396.84 | | 2.98 | |
| 21 days | 418.76 | 418.85 | 3.14 | 3.14 |
| | 421.95 | | 3.17 | |
| | 415.83 | | 3.12 | |
| 28 days | 435.23 | 439.29 | 3.26 | 3.29 |
| | 440.18 | | 3.30 | |
| | 442.47 | | 3.32 | |

**Table 20**: Results of Flexural strength with 15% RHA and 15% EPS

| | **crushing load(kN)** | **Av crushing load(kN)** | **Tcu (kN/mm$^2$)** | **Avg Tcu (kN/mm$^2$)** |
|---|---|---|---|---|
| 7 days | 255.72 | 260.59 | 1.92 | 1.95 |
| | 267.42 | | 2.00 | |
| | 258.64 | | 1.94 | |
| 14 days | 285.62 | 289.4733 | 2.14 | 2.17 |
| | 289.04 | | 2.17 | |
| | 293.76 | | 2.20 | |
| 21 days | 328.07 | 334.32 | 2.46 | 2.51 |
| | 335.17 | | 2.51 | |
| | 339.72 | | 2.55 | |
| 28 days | 381.643 | 387.56 | 2.86 | 2.91 |
| | 393.48 | | 2.95 | |
| | 387.56 | | 2.91 | |

**Table 21**: Results of Flexural strength with 20% RHA and 20% EPS

| | crushing load(kN) | Av crushing load(kN) | Tcu (kN/mm$^2$) | Avg Tcu (kN/mm$^2$) |
|---|---|---|---|---|
| 7 days | 176.51 | 181.39 | 1.32 | 1.36 |
| | 182.19 | | 1.37 | |
| | 185.46 | | 1.39 | |
| 14 days | 192.62 | 195.66 | 1.44 | 1.46 |
| | 195.72 | | 1.46 | |
| | 198.64 | | 1.48 | |
| 21 days | 218.38 | 222.71 | 1.64 | 1.67 |
| | 225.78 | | 1.69 | |
| | 223.96 | | 1.68 | |
| 28 days | 232.44 | 234.48 | 1.74 | 1.76 |
| | 236.86 | | 1.78 | |
| | 234.14 | | 1.76 | |

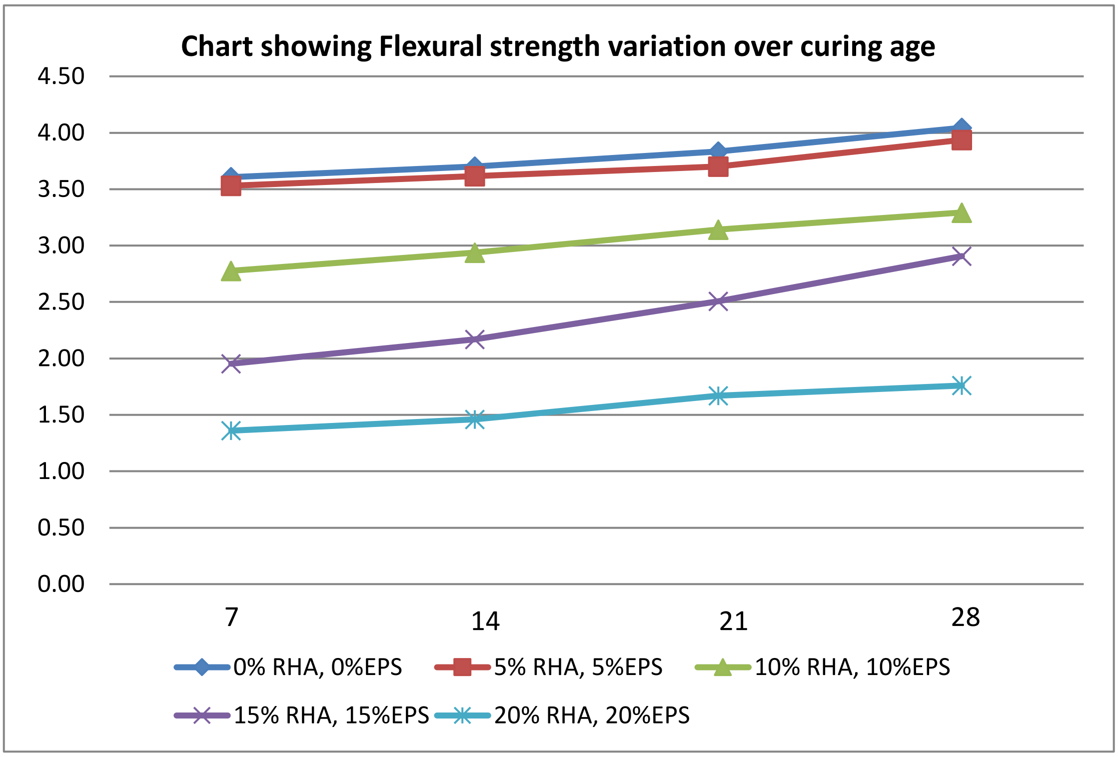

**Fig 7**: Chart Showing Variation of Flexural Strength Variation over Curing Age

## IV CONCLUSIONS

Based on the results of this research, it's evident that the introduction of rice husk ash (RHA) and expanded polystyrene (EPS) as partial replacements for cement and coarse aggregate has a significant impact on the compressive, tensile, and flexural strength, workability, and water absorption characteristics of the concrete and can serve as bio composite in the mixture. Here are some key observations and conclusions:

### 1. Compressive, Tensile and Flexural Strength:

- The control sample with 100% Ordinary Portland Cement (OPC) recorded compressive strength at 35.77 KN/mm² while the highest was seen in 5%RHA 5%EPS concrete at 37.46 KN/mm². This same trend was noticed in the tensile and flexural strength with values of 2.3 KN/mm² and 4.04kN/mm² respectively for the control sample and values for 5%RHA 5%EPS concrete being 2.44 KN/mm² and 3.94kN/mm² for tensile and flexural strength respectively.
- As the percentage of RHA and EPS increased, there was a noticeable decrease in compressive, tensile and flexural strength. This indicates that the replacement of OPC and coarse aggregate with RHA and EPS results in lower compressive, tensile and flexural strength.

### 2. Workability:

The slump test results indicate that the workability of the concrete is influenced by the percentage of RHA and EPS used.

Workability remains relatively high when using 5-15% EPS with slump heights ranging from 80-70mm.

However, when 20% EPS is introduced, the workability decreases significantly, with a slump height of 62mm. This suggests that a higher percentage of EPS leads to reduced workability.

### 3. Water Absorption:

The water absorption test results demonstrate that the introduction of EPS materials increases the water absorption of RHA-EPS concrete.

As the percentage of EPS increases, the water absorption exceeds what is obtained with 0% RHA and 0% EPS, indicating a potential drawback in terms of water resistance.

## RECOMMENDATIONS

### 1. Compressive, Tensile and Flexural Strength:

- It is crucial to find a balance between reducing the environmental impact through partial replacement and maintaining adequate compressive, tensile and flexural strength. Further research might focus on optimizing the mix proportions to enhance the strength of RHA-EPS concrete.

### 2. Workability:

- For applications where workability is critical, consider using lower percentages of EPS (5-15%) to maintain high workability. It may also be beneficial to explore additives or admixtures that could enhance workability without compromising other properties.

### 3. Water Absorption:

- If the concrete's resistance to water absorption is a priority, it's important to be cautious about higher percentages of EPS. Alternative methods or materials may need to be explored to reduce water absorption in RHA-EPS concrete.

In conclusion, this research shows that RHA and EPS can be viable partial replacements for cement and coarse aggregate as bio composites, but careful consideration of the specific requirements of the construction project is needed when deciding on the percentage replacements to achieve the desired balance between environmental sustainability, strength, workability, and water resistance. Further studies may be necessary to fine-tune these mixtures for various applications.

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