Sustainable Concrete: Enhancing Strength With Rice Husk Ash And Fly Ash For Eco-Friendly Construction

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ABSTRACT

Concrete is the backbone of the construction industry, playing a crucial role in infrastructure development. However, the growing global demand for cement, which currently stands at approximately 4.1 billion metric tons annually, has led to excessive exploitation of natural resources and significant environmental concerns. Cement production is not only resource-intensive but also a major contributor to carbon emissions.

At the same time, industries generate vast amounts of waste by-products, such as fly ash, silica fume, mineral slag, and rice husk ash (RHA). Rice husk ash, an agricultural by-product obtained from rice mills, often goes unused or is burned at high temperatures in industrial processes, resulting in a lightweight material with potential applications in construction.

The research explores the feasibility of partially replacing cement with RHA and fly ash in varying proportions—ranging from 5% to 20%—to assess its impact on concrete performance. A series of experimental tests were conducted to evaluate compressive strength and split tensile strength of concrete samples cured for 7, 14, and 28 days.

The study presents promising results, demonstrating that an optimized blend of RHA and fly ash can enhance the strength and durability of concrete while reducing environmental impact. By integrating these industrial by-products into concrete, this project advocates for a sustainable, cost-effective, and eco-friendly alternative to traditional cement-based construction materials.

Key words: Split Tensile Strength , Carbon Emission Reduction, Industrial By-Products

1. INTRODUCTION

Concrete is an essential material in the construction industry, forming the backbone of modern infrastructure. However, its primary component—cement—has a significant environmental impact, contributing substantially to global carbon dioxide (CO_2) emissions. The production of cement is energy-intensive and is one of the major contributors to greenhouse gases, making it a pressing environmental concern. To address this challenge, researchers and engineers have been exploring sustainable alternatives to reduce the reliance on cement in concrete production.

One promising solution lies in Supplementary Cementitious Materials (SCMs), which include industrial by-products such as fly ash, silica fume, ground granulated blast furnace slag (GGBS), metakaolin, and agricultural waste like rice husk ash (RHA). These materials not only help in reducing cement usage but also improve concrete properties, enhance durability, and contribute to waste management by repurposing industrial and agricultural by-products that would otherwise go to waste.

Fly ash, a by-product of coal combustion in power plants, has been widely recognized for its ability to enhance concrete strength and durability. Similarly, rice husk ash, derived from burning rice husks, is an abundant agricultural waste product with high silica content, making it a highly effective pozzolanic material. When properly processed and incorporated into concrete, RHA reacts with calcium hydroxide, forming additional compounds that improve strength, reduce permeability, and enhance long-term performance.

Incorporating these SCMs into concrete not only reduces carbon emissions but also addresses critical environmental concerns such as waste disposal and resource depletion. Additionally, aerated concrete—an innovative lightweight material—has gained popularity due to its excellent thermal and acoustic insulation properties. Its porous structure helps reduce the overall weight of concrete while maintaining sufficient strength for various applications.
By integrating fly ash and rice husk ash as partial cement replacements in concrete, this research aims to explore their effects on mechanical properties such as compressive strength and split tensile strength over different curing periods. The findings will provide valuable insights into the potential of SCMs in sustainable construction, offering a cost-effective and eco-friendly alternative to traditional cement-based concrete.

2. LITERATURE REVIEW

Saand et.al., (2019) studied the effect of partial replacement of cement with rice husk ash at different percentage i.e., 0%,2.5%,5%,7.5%,10%,12.5% and 15%. It was found that up to 10% replacement of cement with rice husk ash the compressive strength and split tensile strength will get increased but further increase in the percentage of rice husk ash beyond 10% the strength starts decreasing. The maximum value of compressive strength and split tensile strength for 10% of cement replacement with RHA obtained is 4.4MPa and 0.53MPa respectively. He et.al., (2019) used recycled wood fibre and rubber powder in AAC. Researchers used the different percentage of recycled wood fibre and rubber powder in AAC to improve its performance and reduce the negative environmental impact. It is found that 0.4% is optimal wood fibre content for the strength of AAC blocks. No effect is seen at 0.5% and 1% of rubber powder content. At 1% of rubber powder content and 0.4% of wood fibre, high-performance AAC can be obtained. Sukmana et.al., (2019) used the phosphogypsum in NAAC to study the effect on compressive strength. Taguchi method is used for experimental design. The result shows that the best composition for NAAC is Portland cement with a content of 34%, phosphogypsum 35% and quicklime 10% to achieve the best strength value 20.93 kg/cm2 having density 806 kg/m3. Fabien et.al., (2019) have done experimental work on the replacement of sand with recycling waste perlite and pure perlite. Pure perlite sand and waste perlite sand (30% +30%), which is used to replace sand is characterised by low density, which makes the concrete expand under non-autoclaved condition. The presence of these waste products reduces mechanical strength but improve thermal insulation. It is found that increasing the cement by 2%, we can increase the mechanical strength by 21%. A 100% expended material with thermal conductivity of 0.176w/. k was obtained. Therefore, non-autoclaved swelling solutions have promoted the development of thermal insulation material based on recycled product.

Kunchariyakun et.al., (2018) had done an experimental investigation on replacement of sand with two agricultural waste i.e., rice husk ash and bagasse ash in preparation of AAC blocks. These samples are autoclaved at different autoclaving temperature (140oc, 160oc and 180oc) and different time period (4h, 8h and 12h). It was found that the effect of the increase in autoclaving temperature and time is directly related to the increase in strength and microstructural properties. But at 180oc it was found that there is no significant increase in strength with increase in time. The reason for no significant increase in strength is because Si ions from the sand reach its maximum dissolution. Karolina R. And Muhammad F. (2017) concluded that fly ash and bottom ash can be used in the manufacturing of lightweight concrete to minimize the use of cement and sand. In normal NAAC lightweight concrete, the water absorption is found to be 5.66% which is greater absorption in the study and 2.76% is the smallest absorption by adding 30% fly ash in concrete. For normal NAAC the compressive strength is 8.891Mpa that is the lowest compressive strength in the study and the highest compressive strength is 12.687Mpa using fly ash. The researcher also concluded that the addition of 30% fly ash in concrete gives the highest tensile strength i.e., 1.540Mpa while NAAC gives the lowest tensile strength i.e., 0.801Mpa. Wahane A. (2017) compared the AAC blocks with red bricks. The researcher concluded that these blocks are more earthquake resistant and safer than red bricks because of the lightweight of AAC blocks. Compared with red bricks, the weight of AAC blocks is almost reduced by about 80% which will lead to reducing a dead load of the structure. Also, it is found that these blocks have an attractive appearance and are easy to adapt to any style of building. Shuisky A. et.al., (2017) studied the effect of additive i.e., sodium sulphate on NAAC. In this study, one sample was prepared using 1.54% of sodium sulphate and the extra swelling part is removed from the sample. This removed part is then used to prepare new sample. Three new samples were prepared using 20% off cut with a variation of sodium cement of 1.23%, 2.4% and 3.7%. After analysing these samples, they concluded that adding sodium sulphate in the amount of 1.23% and cut-off 20% will produce the best structural properties. Shrivastva and Tiwari (2017) utilize the different percentage of aluminium in the production of aerated concrete blocks having size 70.6mm*70.6mm*70.6mm. The percentage of aluminium used is 0%, 0.04%, 0.08%, 0.12% and 0.16% of dry weight of material. Researchers observed that with the increase in the percentage of aluminium powder concrete density decreases. It is observed that the compressive strength of sample S1 (when the percentage of aluminium powder used is 0.04%) and S2 (when the percentage of aluminium powder used is 0.08%) of NAAC block is 4.48N/mm2 and 3.75N/mm2 respectively which is greater than the third-class brick strength. Il'ina and Rakov., (2016) studied the effect of grinding of Portland cement clinker with silica, carbonate components and mineral additive on mechanical properties of NAAC. Additives used are wollastonite and diopside to check the compressive strength, thermal conductivity and density of NAAC. Adding additives to NAAC will reduce energy consumption in concrete. It is found that the hardness and elastic modulus of additives diopside is higher. Adding 5% of diopside gives 3.3Mpa compressive strength, 0.131W/m.oc thermal conductivity and 580 kg/cm3 avg. density. Kunchariyakun et.al., (2015) used rice husk ash as partial replacement of sand in autoclaved aerated concrete. Percentage of rice husk ash used for replacement of sand are 25%, 50%, 75%, and 100%. Researchers have checked the mechanical properties of the sample at autoclaving condition having temperature 180oc and pressure 12bar. Samples have been checked for two different time period i.e., 8 hours and 18 hours. The best replacement rate for replacement of sand with RHA is found at 75%. It is found that replacing sand with RHA increases water requirement which negatively impacts the compressive strength of AAC.

Narattha et.al., (2015) worked on partial replacement of cement with fly ash and silica fumes in NAAC. Thermogravimetric analysis of NAAC is done and it was found that calcium silicate hydrate ettringite, gehlenite, calcium hydroxide and calcium carbonate phases were detected in all mixes. Results showed that the use of silica fumes in NAAC has more compressive strength and thermal conductivity as compared to NAAC made up of fly ash. For silica fumes compressive strength is 23MPa and for fly ash it is 13Mpa. Also found that the specimen cured in water has more compressive strength than the specimen cured in air. Yang et.al., (2013) utilized the phosphor gypsum for the preparation of non-autoclaved aerated concrete. The result showed that with the increase in Na2SO4 the compressive strength increased with the increase in the percentage of Na2SO4 from 0 to 1.6% and decreased when the percentage of Na2SO4 exceeds from 1.6%. As the aluminium powder increased in the specimen the specimen density decreased.

The optimal mixing ratio for preparation of NAAC using phosphor gypsum are 15% cement, ground granulated blast furnace slag (GGBFS) 30%, phosphor gypsum 55%, quick lime 7%, NA2SO4 1.6%, Al powder 0.074% and w/c ratio 0.45. The optimal steam temperature for curing sample is 90°c. Xia Y. et.al., (2013) have done an experimental investigation on the use of circulating fluidized bed combustion fly ash (CFA) as a raw material in NAAC. The diameter of CFA particle ranges from 9.6μm to 23.9μm which is more suitable for making NAAC because of matching conditions of thickening rate of slurry and reaction rate of aluminium powder and water. Based on physical and mechanical test the optimal proportion of CNAAC was determined to be CFA 63.5 - 65.5%, cement 20-22%, lime 10%, PG 1.5%, Slag-3%. Both cement and lime in CNAAC affect the rheological properties of the paste. Greater the amount of cement, the reduction in relative yield stress is greater. However, relative yield stress and viscosity tend to increase as the number of lime increases. Li et.al., (2011) used de-sulphuration residues as aggregate in NAAC. Results showed that with the increase in de-sulphuration residue content the strength, as well as dry density of NAAC concrete, will get reduced. Gypsum based NAAC has compressive strength less than fly ash-based NAAC. Researchers found that the optimal amount of replacement determined as 50%, at this rate the compressive strength obtained is 2.83MPa and bulk density is 543 kg/m3. XRD pattern shows that the ettringite and calcium silicate hydrated is in such a way that they cover the incompletely reacted de-sulphuration residue and fly ash. Khalaf AL and Yusuf AT (1984) have investigated the effect of rick husk on pozzolanic behaviour of rice husk ash. They studied the actual range of temperature required to burn rice husk to get the desired pozzolanic product. They investigated that up to 40% replacement of cement with RHA can be made with no significant change in the compressive strength as compared to the controlled mix, if the rice husk is burnt under optimum temperature condition. They found replacement is more effective when fineness of RHA is within 50%.

Ismail M.D and Waliuddin (1996) had worked on effect of rice husk ash on high strength concrete. They studied the effect the rice husk ash (RHA) passing 200 and 325 micron sieves with 10-30% replacement of cement on strength HSC. Test result indicated that strength of HSC decreased when cement was partially replaced by RHA for maintaining same value of workability. They observed that optimum replacement of cement by RHA was 10-20%.

Ramezanianpour et al 2009, 2010 concluded that burning rice husk at temperature below 700°C produces rice husk ashes with high pozzolanic activity. Rice husk ash obtained from fair food overseas rice millkatni has been used in the analysis He also stated that with addition of 5% RHA content shows the best gain in compressive strength for curing duration of 7 and 28 days. Meheta H and Pitt A (1976) developed a process of converting rice husk in to energy and valuable industrial products. The x ray diffraction analysis they carried out showed that no crystalline phase of silica, the ash contains some residual carbon and a small amount if alkalis. They concluded that hydraulic cement with strength characteristics similar to OPC can be made from rice husk ash. They observed specific gravity to be within 1.8.

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Thorpe M (1977) compared the durability of OPC concrete to RHA concrete. Two cylinders, one of OPC concrete and other of RHA concrete were submerged continuously in a 5% HCL solution for a period of 63 days. He found that OPC concrete registered 35% weight loss during the test period, and RHA concrete showed only 8% weight loss. He found with 10% replacement the compressive strength was increased but with 20% and 30% replacement the compressive strength reduced significantly. Jain S and Pirtz D (1978) showed that for a 28 days period, with 30% weight replacement of OPC by RHA it is possible to reduce the temperature by approximately 20%. These mean that a considerable amount of money could be saved in two areas. One, the cement content is reduced and two the cooling cost of concrete is also reduced or eliminated, both of which would lead to considerable saving in mass concrete construction. Azam Abdul (1982) stated that the pozzolanic activity index depends very much on the fineness of RHA. It increases with increased fineness of the ash. For 75% and 85% fineness the pozzolanic activity index is lower than the minimum limits specified for ASTM class N, F and C pozzolana. For 85% to 95% fineness, it is higher than the ASTM minimum requirement for the three classes of pozzolana.

3. PROPOSED SYSTEM

The proposed system aims to develop a sustainable and eco-friendly concrete mix by incorporating Supplementary Cementitious Materials (SCMs) such as Fly Ash and Rice Husk Ash (RHA) as partial replacements for cement. This approach helps reduce the carbon footprint of concrete production, enhance its mechanical properties, and promote the efficient utilization of industrial and agricultural waste.

In this system, different concrete mix proportions with varying percentages of Fly Ash and RHA are tested to analyze their effects on compressive strength, split tensile strength, and durability. The concrete specimens are cured for 7, 14, and 28 days under controlled conditions, and their performance is evaluated through laboratory testing. The experimental results are used to determine the optimal mix design that offers improved strength, durability, and sustainability compared to conventional concrete.

Sustainability: Utilization of industrial and agricultural waste (Fly Ash and RHA) reduces cement consumption and environmental pollution.

Cost-Effectiveness: Replacement of cement with SCMs lowers the overall production cost of concrete.

Enhanced Concrete Properties: Improved mechanical properties such as increased compressive strength, reduced permeability, and better durability.

Waste Management: Provides an efficient way to repurpose industrial and agricultural by-products that would otherwise contribute to environmental degradation.

Eco-Friendly Construction: Reduces CO_2 emissions from cement production, contributing to greener construction practices.

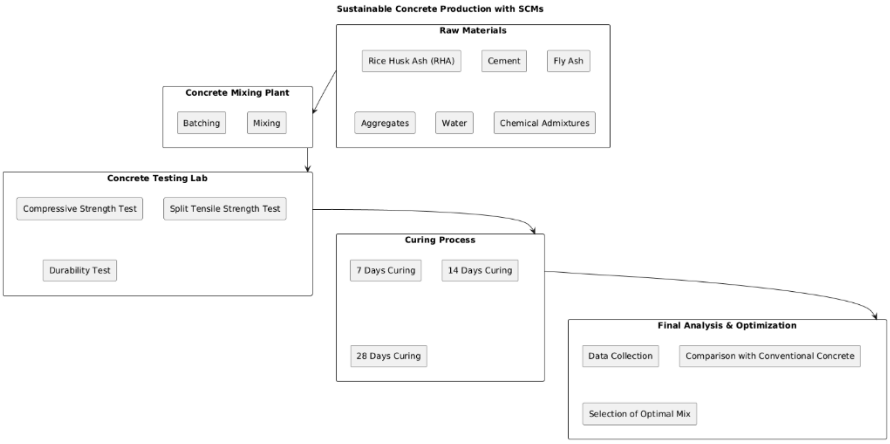

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

As per experimental programme results for different experiments were obtained. They are shown in table format and graph format, which is to be presented in this chapter.

4.1 Fresh properties of concrete (Workability Test)

4.1.1 Slump Test

The Slump test was performed on the Rice husk ash – Fly ash concrete to check the workability of it at different replacements viz. 0 % - 0%, 5% - 10%, 5% - 15%, 5% - 20%, 7.5% - 10%, 7.5% - 15%, 7.5% - 20%, 10% - 10%, 10% - 15%, 10% - 20% and the following results were obtained, according to which it can be concluded that with the increase in % of Rice husk ash – Fly ash from M1 to M10 , workability increases. The results obtained for Slump test are shown below in Table 4.1.

Table 4.1: Results of Slump test

Mix No	RHA % - FLYASH %	Slump (mm)
M1	0 - 0	90
M2	5 - 10	95
M3	5 – 15	97
M4	5 – 20	100
M5	7.5 - 10	101
M6	7.5 – 15	102
M7	7.5 – 20	105
M8	10 - 10	108
M9	10 – 15	110
M10	10 – 20	112

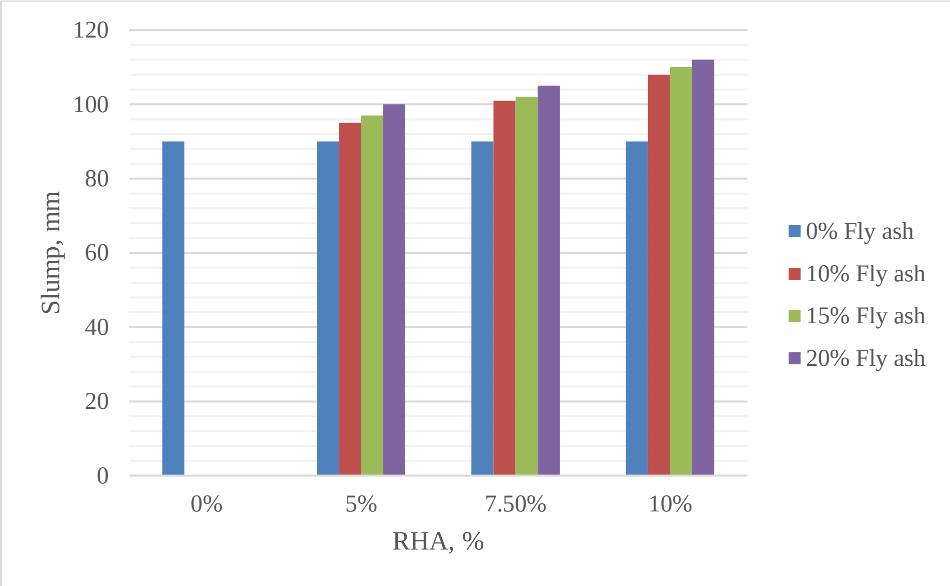

Fig 4.1 : Slump test results

The above figure 4.1 shows the slump results. It was observed that, the slumps increased from M1 to M10 mix with increased RHA – Fly ash in the mix. It was varied from Medium Workability to High workability.

4.2 Harden properties of concrete

4.2.1 Compressive Strength Test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the compressive strength of RHA -Fly ash based concrete and the results obtained are given in Table 4.2.

Table 4.2: Results of compressive strength test

Mix No	RHA % - FLYASH %	Compressive strength of cubes (N/mm^2)		
		7 days	14 days	28 days
M1	0 - 0	15.6	21.4	25
M2	5 - 10	18	24.8	28
M3	5 – 15	19.2	27	30.4
M4	5 – 20	15.6	23.5	26.1
M5	7.5 - 10	21.35	31.5	35
M6	7.5 – 15	25	37	40.2
M7	7.5 – 20	23	34.68	37.7
M8	10 - 10	19	29	32
M9	10 – 15	18.2	26.5	33.3
M10	10 – 20	16	24.3	27

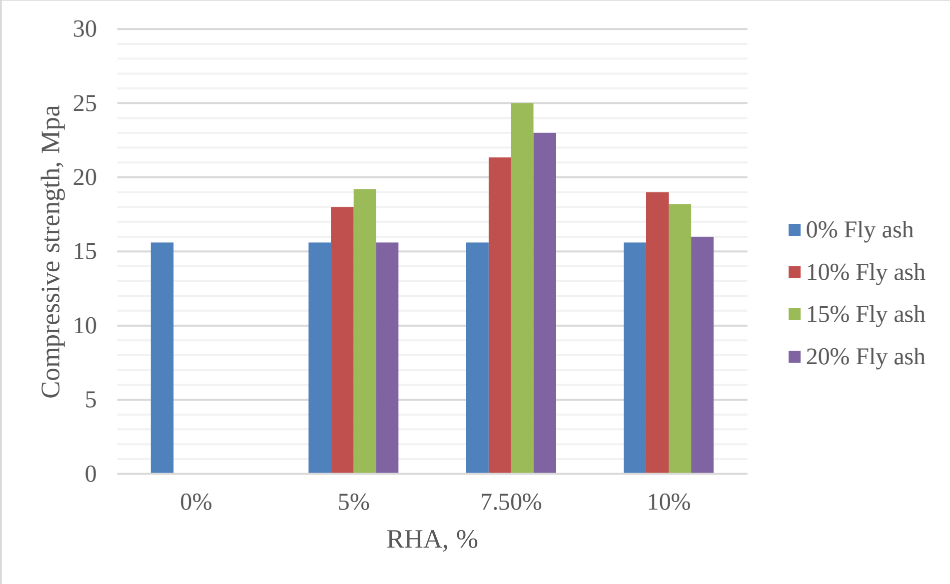

Fig 4.2: 7days Compressive strength test result graph

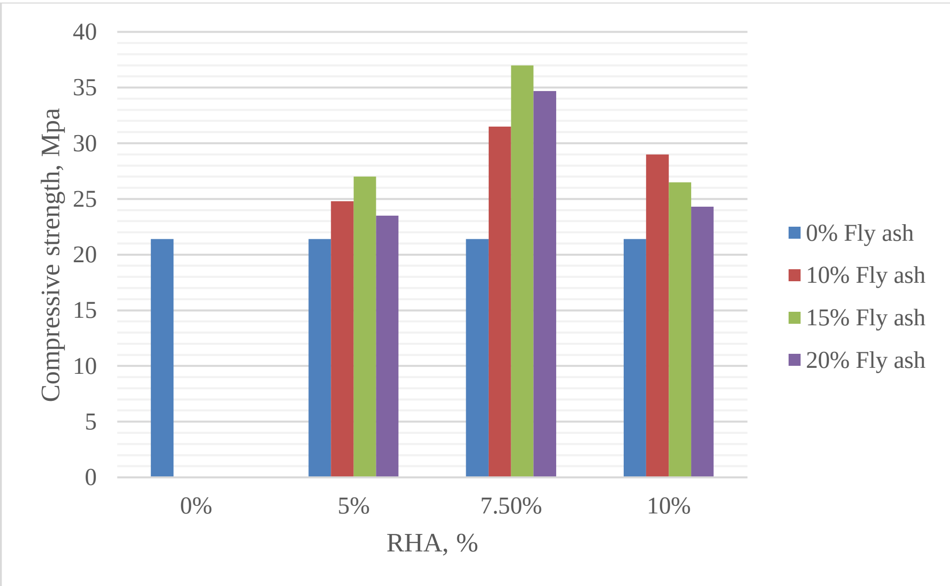

Fig 4.3: 14days Compressive strength test result graph

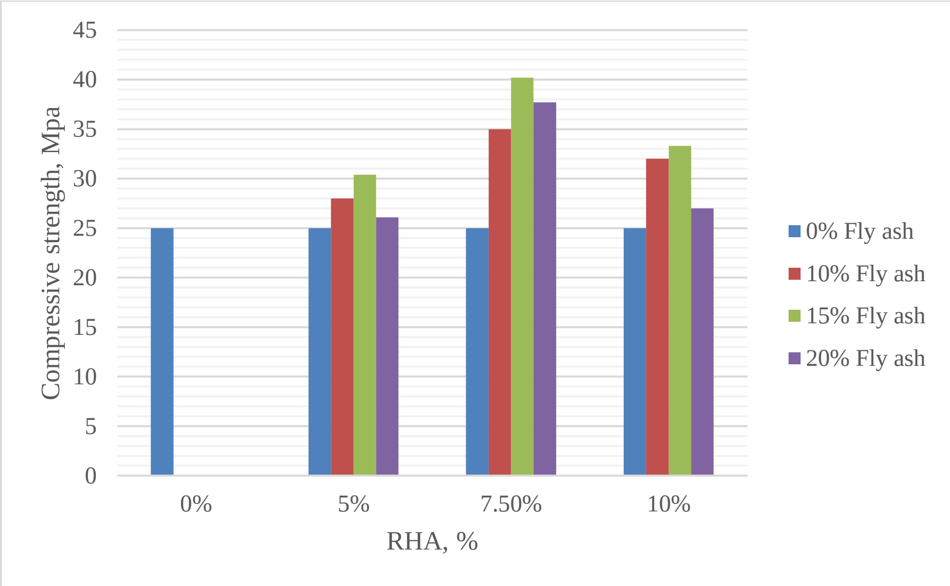

Fig 4.4: 28days Compressive strength test result graph

From the above results it was observed that with the increase in percentage of RHA – fly ash from M2 to M10 in concrete the compressive strength more than control mix M1. The highest compressive strength gained for 7.5% RHA – 15% Fly ash replacing with cement in the preparation of concrete. The optimum dosage suggested from this study was 7.5% RHA – 15% Fly ash.

4.2.2 Tensile Strength Test

The Tensile test was performed on the beams of size 300mm height x 150 diameter mm to check the Tensile strength of the concrete and the results obtained while performing the Tensile test on CTM are given in Table 4.3.

Table 5.3: Result of Tensile strength

Mix No	RHA % - FLYASH %	Tensile Strength for 28 days (N/mm^2)
M1	0 - 0	2.92
M2	5 - 10	3.27
M3	5 – 15	3.56
M4	5 – 20	3.05
M5	7.5 - 10	4
M6	7.5 – 15	4.7
M7	7.5 – 20	4.42
M8	10 - 10	3.71
M9	10 – 15	3.85
M10	10 – 20	3.12

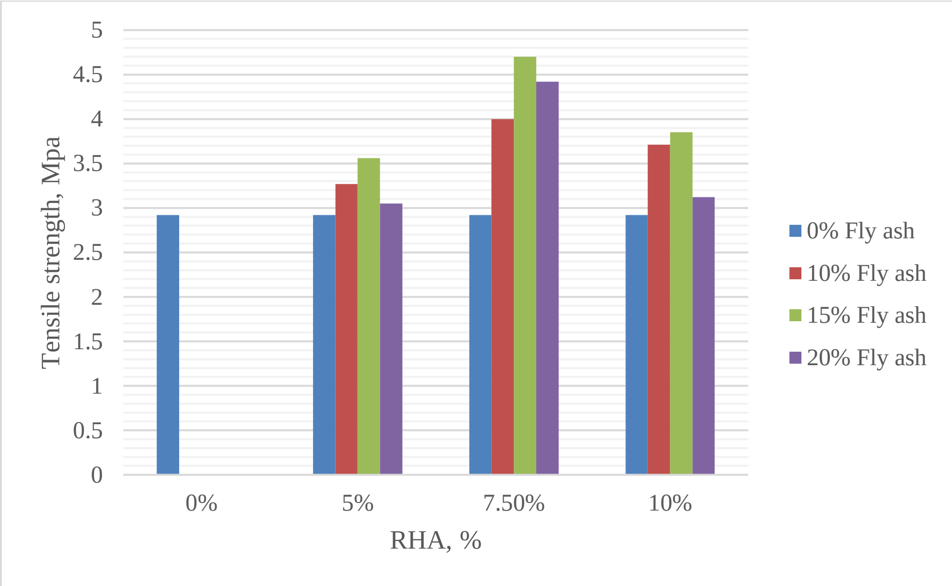

Fig 4.5: Tensile strength graph

From the above results it was observed that with the increase in percentage of RHA – Fly ash from M2 to M10 in concrete the tensile strength more than the control mix M1. The highest tensile strength gained for 7.5% RHA – 15% Fly ash replacing with cement in the preparation of concrete. The optimum dosage suggested from this study was 7.5% RHA – 15% Fly ash.

4.3 Discussions

The workability was increasing with increasing RHA – Fly ash replacement in the cement. The compressive and tensile strengths for RHA – Fly ash replacement in the cement, was more than control mix. The strength increment percentages were mentioned below Table 5.4. The maximum or highest strength was gained for 7.5% RHA – 15% Fly ash replacing with cement.

Table 4.4: Comparison of strengths

Mix	RHA % - FLYASH %	28days compressive strength (Mpa)	Increment (%)	28days Tensile strength (Mpa)	Increment (%)
M1	0 – 0	25	-	2.92	-
M3	5 – 15	30.4	21.6	3.56	21.9
M6	7.5 – 15	40.2	60.8	4.7	60.96
M9	10 - 15	33.3	33.2	3.85	31.85

5. CONCLUSIONS

The experimental study demonstrates the effectiveness of incorporating Rice Husk Ash (RHA) and Fly Ash as supplementary cementitious materials in concrete, leading to significant improvements in both workability and strength. The results indicate that increasing the proportion of these materials enhances the ease of mixing and placement. Among the tested combinations, the most substantial gains in compressive and tensile strength were achieved with a mix containing 7.5% RHA and varying Fly Ash contents (10%, 15%, and 20%). Notably, the optimal blend—7.5% RHA with 15% Fly Ash—exhibited a remarkable **60.8%** increase in compressive strength and **60.96%** in tensile strength compared to conventional concrete. Beyond performance enhancement, this sustainable approach reduces cement consumption, thereby lowering construction costs while addressing environmental concerns associated with the disposal of industrial and agricultural waste. The study underscores the potential of these innovative material replacements in fostering a more durable, cost-effective, and eco-friendly construction industry.

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