Effect of Rice Husk Ash as Supplementary Cementitious Material for Rigid Pavement Construction

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ABSTRACT

The calorific value of the agricultural waste in the form of Rice Husk is very close to the calorific value of coal. Therefore it finds its use as fuel for boilers in cement production. This saves 5% of the country's coal which is the non-renewable resource of fuel. The resultant Rice Husk Ash (RHA) produced is mostly used in land filing which is an environmentally hazardous way to deposit this agro-industrial by product. Researchers have observed the RHA produced has high silica content which makes it a suitable Supplementary Cementitious Material (SCM). This not only reduces the use of coal but also reduces the cement manufacturing cost. The manuscript here is keen to achieve sustainability in industry as well as innovation and infrastructure by not only reducing the usage of non-renewable energy resources but also effectively addressing the environmental and economic concerns. In this study the properties of hydrated cements are investigated when mixed with the RHA. This not only improved the properties of the concrete but also made them sustainable for high grade concrete construction, conventionally used for the construction of rigid pavements. The activity of the RHA made variation in the mortar properties which was analyzed by X-Ray Diffraction (XRD). Experimental results confirmed increased compressive strength of high grade RHA mixed cement concrete by replacement up to 15% and 5% of Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) respectively by weight compared to high grade virgin cement concrete. The incorporation of RHA also reduced the pH value and consequently the Alkali Aggregate Reaction (AAR).

Keywords—Rice Husk Ash; Cement; Compressive Strength Test; XRD; AAR

I. INTRODUCTION

In India 63.73 lakh kilometers of road network exists, making it the 2nd largest road network in the world. The road network carries 87% passenger traffic and 60% freight transport (MoRTH, Year End Review 2022, 2023). 90% of these paved roads are bituminous and the remaining 10% are rigid pavement (MoRTH, Specifications for road bridge works 5th revision, 2013). This statistical data shows that the rigid pavements are less favourable, which is mainly due to its high initial construction cost (Mohod & Kadam, 2016). However their low maintenance cost in comparison to the flexible pavement have kept the researchers and engineers ever interested in their implementation whenever possible. In recent years the Government of India has started significant endeavors to implement all weather road connectivity to habitations in Left Wing Extremism (LWE) areas (PMGSY, 2017). This have once again opened up the opportunity of implementation of rigid pavement on a large scale. On the contrary, this project requires a huge quality of material, which is leading to a potential material crisis and utilizing the materials from the neighboring lands. Besides the growing production cost of Portland cement have made researchers interested in partially replacing it with SCM (Mehta & Pitt, 1976). On the other hand, a mounting increase in the amount of siliceous waste material like agricultural waste in the form of RHA has made researchers and industry professionals interested towards the replacement of cement with these (Nehdi, Duquette, & Damatty, 2003). The pozzolanic properties of RHA finds its utility in construction material as it enhances the structural sustainability and service life (Reddy, Jyothy, & Reddy, 2013). This further leads to recycling the RHA. This tackles the disposal issues and consequent environmental threats. It further reduces the cement content as well as reduces the energy consumption, non-renewable raw material consumption and consequent carbon dioxide emissions.

The aptness of utilizing RHA as SCM mainly depends upon its silica content and large surface area, which is due to the porous structure of the particles (Cook, Pama, & Damer, 1976). The reactive silica content of RHA along with its mineralogical properties depend upon the combustion time, temperature and turbulence during combustion (Deshmukh, Bhatt, Peshwe, & Pathak, 2012).

Investigators obtained rapid analytical method for determining the silica in RHA which is present in its amorphous phase. It is highly pozzolanic that can be used as SCM. Its reactivity depends on the temperature of incineration. The RHA becomes highly reactive as the temperature of incineration reaches 500°C (Zain, Islam, Mahmud, & Jamil, 2011). On increasing the temperature of incineration, the nature of RHA changes from amorphous to crystalline (Memon, Shaikh, & Akbar, 2011). It has been investigated that, the RHA mixed concrete produces satisfactory slump as well as setting time (Zhang, Lastra, & Malhotra, 1996). It also has excellent chloride ion penetration resistance, reduced surface scaling and excellent performance under freezing and thawing conditions (Givi, Rashid, Aziz, & Salleh, 2010). Researchers stated that, the pozzolanic reaction lowers the calcium hydroxide content in the RHA blended cement concrete as well as enhance its compressive strength and workability (Jaturapitakkul & Roongreung, 2003). Investigational works showed that, incorporating RHA in structural concrete is a good alternative of the concrete structure (Gastaldini, Isaia, Gomes, & Sperb, 2007). Although numerous research works have been done determining the different properties of the concrete using RHA, most of them have used Low Grade Concrete (M30).

II. INTRODUCTION

The RHA has been added to the cement in the form of SCM (0%, 2.5%, 5%, 7.5% and 10% by weight of PPC) and (0%, 5%, 10%, 15% and 20% by weight of OPC). Then 150 mm concrete cubes were casted using the blended cement, coarse aggregate, fine aggregate, water and admixture followed by compaction using needle vibrator. The mix proportion conformed to IS: 10262 (10262, 2009). After 24 hours, the casted cubes were taken out from the mould and subjected to curing before they were tested.

III. MATERIALS USED IN THIS INVESTIGATION

The materials used in this investigational work have been described as follows:

A. Rice Husk Ash

The RHA was procured from the Rice Mill of Burdwan, a district of West Bengal, India. It was produced by burning the Rice Husk for over 5 minutes at a temperature of 1000°C. This produced crystalline silica that is built by the repetition of silicon tetrahedron unit, oriented in a three dimensional network (Monteiro, Shomglin, & Wenk, 2001). The framework type structure is made up of quartz shown in Figure 1 which is found later in this study by performing the XRD analysis of the sample. The large silica content of the RHA represented in the Table 1 makes it suitable as a SCM. The physical properties of RHA is in Table 2.

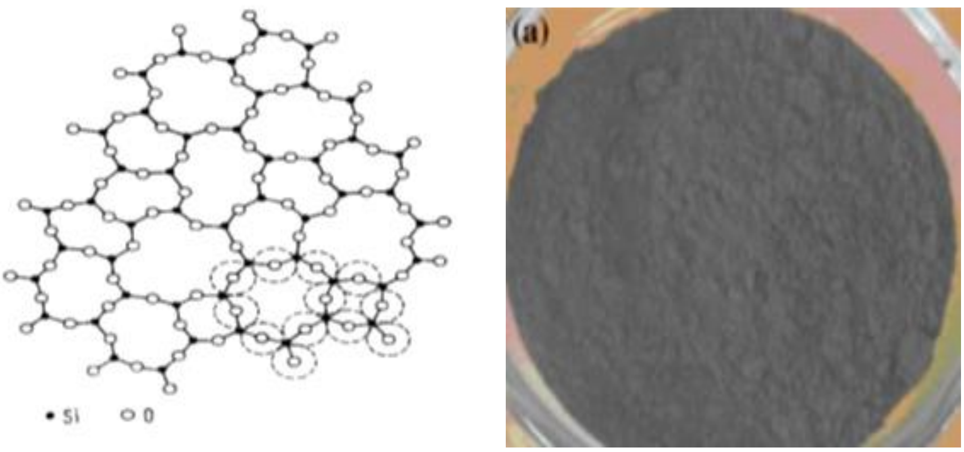

Figure 1. 2-Dimensional framework of SiO2 (Shomglin et al. 2001) present in RHA

Table 1. Chemical composition of RHA

Components of RHA	Percentage Present
Silica (SiO_2)	83.00%
Alumina (Al_2O_3)	12.00%
Ferric Oxide (Fe_2O_3)	0.50%
Titanium Oxide	Nil
Calcium Oxide (CaO)	1.35%
Magnesium Oxide (MgO)	0.70%
Sodium Oxide (Na_2O)	0.30%
Potash	0.20%
Loss on Ignition	1.95%

Table 2. Physical Properties of RHA

Physical Properties of RHA	Percentage Present
Plasticity	Non-Plastic
Optimum Moisture Content	86.95%
Maximum Dry Density	0.54 gm/cc
Specific Gravity	2.06
Soaked CBR	4.14%
Unsoaked CBR	8.36%
Moisture Content (by weight)	6.08%
Ash Content	23.39%
Bulk Density	90.0 kg/m^3

B. **Cement**

The OPC 43 Grade and the PPC used in the investigational work was supplied by the Ultra Tech Cement Limited.

C. **Super Plasticizer**

The super plasticizer used is of brand FOSROC made Auromix-400 shown in the Figure 2 was collected from local market, which mainly steadies the workability of the concrete mix keeping its strength intact. Auromix-400 used in the concrete mix is also a High Range Water Reducer (HRWR) having polycarboxylic base conforming IS: 9103 with specific gravity of 1.09.

Figure 2. The Super Plasticizer AURAMIX-400 used for the study

D. **Coarse Aggregate**

In this study the coarse aggregate used is of Pakur variety with sizes ranging 10 mm to 20 mm.

E. **Fine Aggregate**

Fine aggregate is collected from local market with maximum aggregate size passing 2.36 mm sieve. The sand is thoroughly washed and dried for removing any organic matters present.

F. **Water**

Potable water is used for preparing the concrete mix samples. The water should be free from any organic substances.

G. **Measurement of Classical Prpperties of Blended Cement**

Classical properties of the cement used in this study has been evaluated in order to identify their grade and quality. The test methods are presented in a tabulated form in Table 3 along with their standard code.

Table 3. Various Test methods with standard

Name of the Test	Standard Code
Fineness of cement by Specific Surface Method	IS:269-1080
Consistency of Cement used	IS:4031 (Part IV)
Compressive Strength test	IS:516-1959

H. **Determination of the Nature of R.H.A**

X-Ray Diffraction (XRD) analysis was carried out on 4 gm of RHA sample by a Philips PW 1830 Diffractometer in the department of Metallurgy and Material Science, IIEST Shibpur. 35 kW, 25 mA power supply was used for this shown in figure 3. The procedure included a filament made out of copper, which is being pelted by electrons for characteristic Cu-Kα X-Ray generation. These rays after passing through a Beryllium monochromatic filter, was radiated towards the sample at an incident angle (ϴ) from 2.5°-40° (2ϴ=5°-80°) (Vayghan, Khaloo, & Rajabipour, 2013). Specific values of ϴ were found as peak intensities as the XRD pattern revealed constructive interference. According to Bragg's Law, the inter-atomic spacing (d) of the crystals formed in the sample is related to the value at each peak. Although the peaks of crystalline materials are very sharp and prominent, the amorphous materials gives very broad peaks without an identifiable ϴ value (Vayghan, Khaloo, Nasiri, & Rajabipour, 2012).

Figure 3. The X-Ray Diffraction Instrument in IIEST Shibpur

I. **Mixing, Casting and Testing of Concrete Cubes**

Design mix of M40 grade of concrete was prepared conforming to IS: 10262-2009. The ingredients were mixed thoroughly by hand-mixing in surface dry condition. Water and admixture in designed amount were mixed to it as represented by the Table 4 and Table 5. Needle vibrator was used to cast the cubes as shown in the figure 4. Design mix of RHA blended cement samples were also prepared identically. Curing of the samples was done, and the compressive strength of the cubes were tested after 7 days and 28 days of curing in the highway engineering laboratory of IIEST Shibpur.

Table 4. The Mix Proportion for the trial PPC Concrete Mix

Ingredients	Mix Proportions
Cement	370 kg/m^3
Rice Husk Ash (R.H.A)	0%, 2.5%, 5%, 7.5% & 10% to the total weight of PPC
Water	150 l/m^3
Fine Aggregate	858 kg/m^3
Coarse Aggregate	1090 kg/m^3
Chemical Admixture (Super plasticizer)	7 kg/m^3 (1.85% by weight of Cement)

Table 5. The Mix Proportion for the trial OPC Concrete Mix

Ingredients	Mix Proportions
Cement	348 kg/m^3
Rice Husk Ash (R.H.A)	0%, 5%, 10%, 15% and 20% to the total weight of OPC
Water	140 l/m^3
Fine Aggregate	894 kg/m^3
Coarse Aggregate	1137 kg/m^3
Chemical Admixture (Super plasticizer)	7 kg/m^3 (2.10% by weight of Cement)

Figure 4. Cement Concrete Cube casting by compaction with Needle Vibrator

IV. RESULTS AND DISCUSSIONS

Interpretations of the experimental results along with their respective discussions have been done in the article as follows:

A. Evaluation of Classical Properties of Tested Modified Cement

The consistency of the cement samples after adding RHA in the proportions of 0%, 2.5%, 5%, 7.5% and 10% to the PPC and 0%, 5%, 10%, 15% and 20% to the OPC have been evaluated and furnished in the Table 6 and Table 7 respectively. The test results showed increasing trend of consistency for increasing proportion of RHA blended with PPC and OPC. Increasing percentage of porous RHA which is shown in the figure 5 as determined by the Scanning Electron Microscopy (SEM) test, makes the blended mix porous, increasing its water absorption (Marthong, 2012). The change in the workability of the OPC and PPC after addition of RHA has been represented graphically by Figure 6.

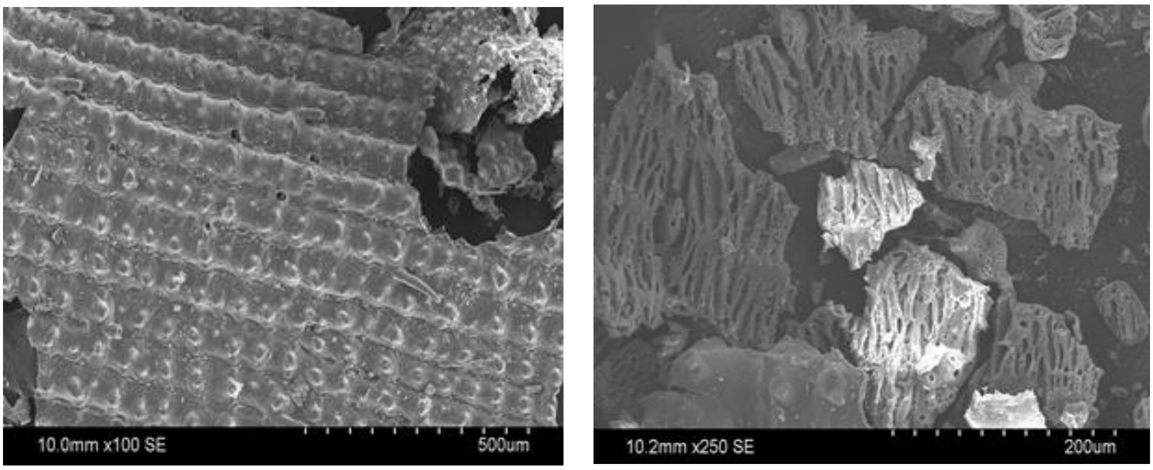

Figure 5. Porous Multi-layered structure of RHA seen under SEM.

Table 6. Consistency of PPC blended with RHA

Percentage of RHA as SCM	Consistency Values
0%	32.0%
2.5%	34.5%
5.0%	36.5%
7.5%	37.5%
10.0%	39.5%

Table 7. Consistency of OPC blended with RHA

Percentage of RHA as SCM	Consistency Values
0%	28.5%
5.0%	29.0%
10.0%	32.5%
15.0%	38.6%
20.0%	44.0%

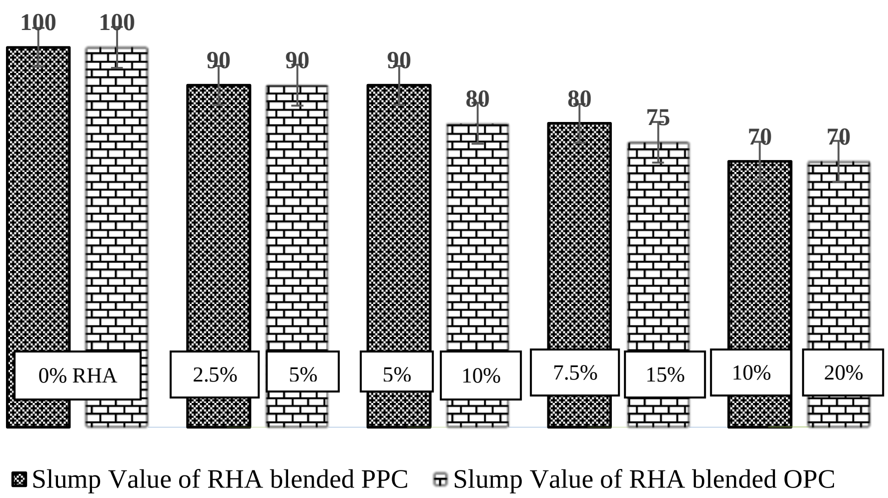

Figure 6. Graphical representation of the workability of concretes when mixed with the RHA.

B. **Detetmination of the Nature of RHA using XRD**

XRD analysis was performed on the RHA sample to understand the nature of RHA. According to the analysis as represented by Figure 7 the RHA sample showed crystalline nature. The crystalline nature of the RHA is for the presence of Silica in the form of Cristobalite (Pavia, Lampman, Kriz, & Vyvyan, 2014) and is indicated by the sharp peaks and the identifiable ϴ values. This lowers the reactivity of the RHA with the cement.

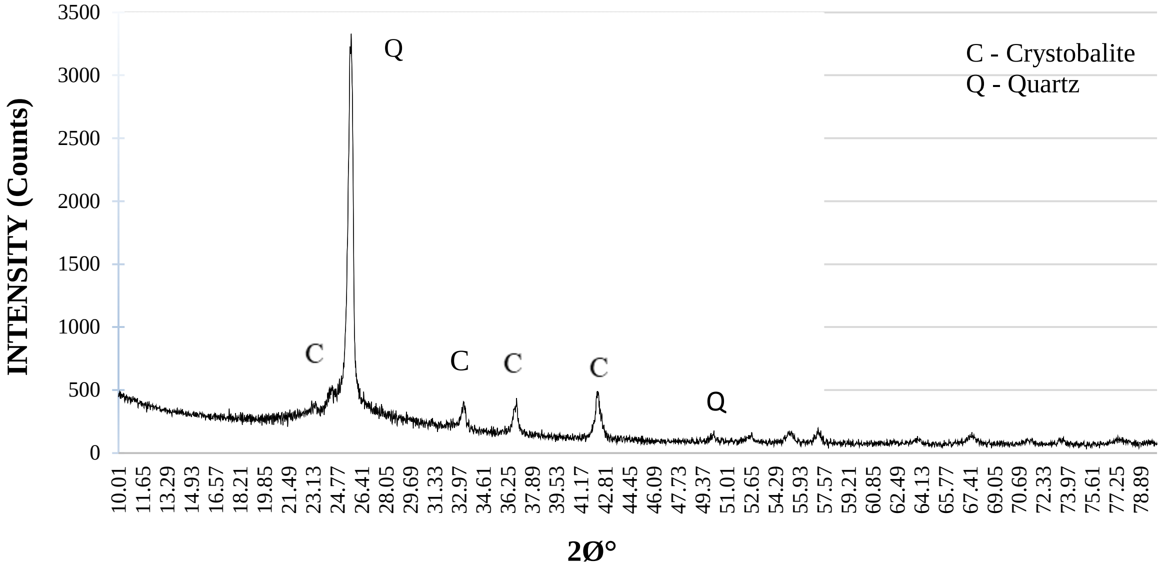

Figure 7. Mineral Phase detection of RHA using XRD analysis

C. **Evaluation of Compressive Strength of RHA Mixed Concrete**

The compressive strength of concrete prepared by varying the ratio of RHA, 0%, 2.5%, 5%, 7.5% and 10% for PPC and 0%, 5%, 10%, 15% and 20% for OPC have been determined for 7 days and 28 days of curing and represented by Table 8, Table 9 and Figure 8, Figure 9 respectively. The compressive strength test machine is shown in Figure 10. Every mortar's compressive strength datum was calculated using the average results of two samples. The test results clearly indicates that with the increase in the content of RHA as SCM the compressive strength also increases initially. However, for both the types of blended cement the value drops after reaching an optimum percentage of SCM, which is 5% for PPC and 15% for OPC. Better results for compressive strength test is observed for RHA blended OPC compared to RHA blended PPC all throughout the curing period. The results confirmed the pozzolanic nature of RHA. The high fineness of the RHA further contributes towards the strength development of the blended concrete (Rajput, Yadav, & Chandak, 2013).

Table 8. Compressive strength of concrete samples prepared by RHA blended PPC

Percentage of RHA as SCM	**Compressive Strength (MPa)**	
	7 days	28 days
0%	20	28
2.5%	22	36
5.0%	34	49
7.5%	30	44
10.0%	28	40

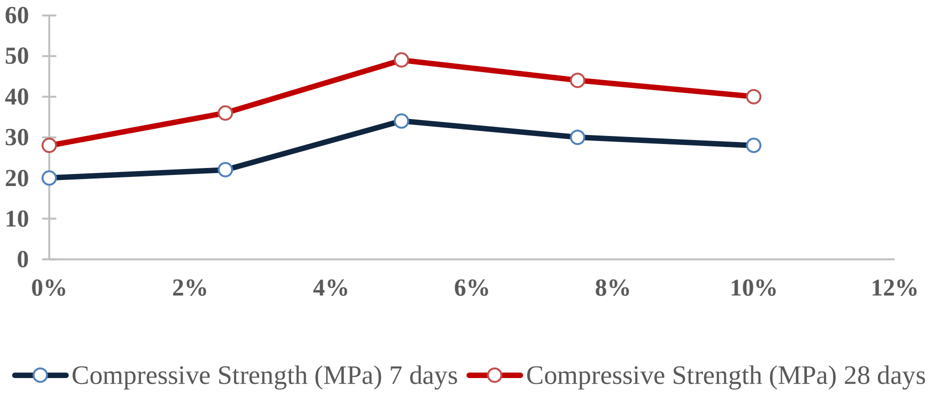

Figure 8. Graphical representation of compressive strength of concrete samples prepared by RHA blended PPC

Table 9. Compressive strength of concrete samples prepared by RHA blended OPC

Percentage of RHA as SCM	Compressive Strength (MPa)	
	7 days	28 days
0%	35	48
5.0%	50	62
10.0%	47	60
15.0%	46	59
20.0%	34	47
25.0%	32	45

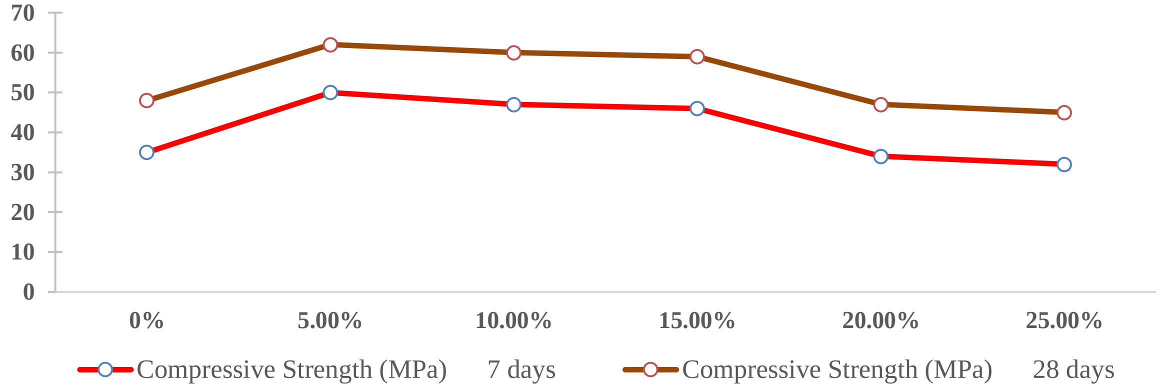

Figure 9. Graphical representation of compressive strength of concrete samples prepared by RHA blended OPC

Figure 10. Compressive Strength Test being conducted.

D. **pH Analysis of Blended Cement Concrete**

The pH determination as shown in figure 11 of the blended OPC with optimum RHA content of 15% and blended PPC with optimum RHA content of 5% after 7 days of curing showed pH reading of 11.20 and 11.68 respectively. This value is substantially lower than the pH value of sound concrete having pore-water pH of 13-13.50 (Dutta, Rakib, Hossain, & Rashid, 2020). RHA consists of silica which is an acidic oxide. On further reaction with water it gives Silicic Acid (H_4SiO_4) having pH 9.02 (Iier, 1979). The lower pH value considerably reduces the concrete brought on by Alkali Aggregate Reaction (AAR) which occurs at higher pH levels. The obtained pH values also reduces the rate of corrosion of the reinforcements in the concrete.

Figure 11. pH value determination of RHA blended OPC and PPC

V. CONCLUSION

The above investigational work shows that RHA can be used to replace 15% of OPC by weight. This can be used as SCM for construction of High Grade Concrete (HGC) that is used in Rigid Pavement construction as it gives satisfactory compressive strength. However, the percentage replacement decreases to 5% for PPC which already comes with the Fly Ash mixed in it. Nevertheless, both the blended cement concrete provides satisfactory strength of 49 MPa for PPC with RHA replacement 5% by weight of the cement and 59 MPa for OPC with RHA replacement 15% by weight of the cement, that is required for HGC for roadway rigid pavement. Besides, the utilization of the agricultural by-products not only provides an effective way out towards their disposal but also decreases the construction cost. This further provides a certain amount of advancement towards the sustainable agricultural waste management.

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