COMBINED UTILISATION OF INDUSTRIAL AND AGRICULTURAL WASTES IN CEMENT LESS CONCRETE CONSTRUCTION: ENVIRONMENTALLY FRIENDLY STRUCTURES

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Abstract: In this paper, the detailed experimental investigation was done to study the effect of partial replacement of cement by Fly Ash (FA) and Rice Husk Ash (RHA) in combine proportion started from 100%, 80%, 60%, 40% FA and 0%, 20%, 40%, 60% RHA mix together in concrete by replacement of cement with the gradual increase of RHA by 20% and simultaneously gradual decrease of FA by 20%. Last proportion was taken 40%FA and 60% RHA. The tests on hardened concrete were destructive in nature which includes compressive test on cube for size (100 x 100 x 100 mm) and split tensile strength on cylinder (100 mm ø x 200 mm) at 28 days of curing as per IS: 5816 1999. The work presented in this paper reports the effects on the behaviour of concrete produced from cement with combination of FA and RHA at different proportions on the mechanical properties of concrete such as compressive strength and split tensile strength. The fluid ratio (F_r= (Na_2SiO_3 / NaOH)) used in this study 2.4 and 2.5. The Partial replacement of FA and RHA reduces the environmental effects, produces economical and eco-friendly concrete.

Keywords: Fly Ash, Rice husk Ash, Compressive Strength, Split Tensile Strength, Eco-friendly concrete.

1. INTRODUCTION

The applications of concrete in the field of infrastructure and transportation have greatly influenced the growth rate of economic progress and their quality of life. Though Ordinary Portland Concrete (OPC) is widely used in construction industry for many decades. About 1.5 tons of raw materials are required in the production of every ton of Portland cement, on the other hand for about 0.883 ton of carbon dioxide is being released in to the environment, rich in green house increasing gasses like carbon dioxide (CO_2), carbon monoxide (CO) which are serious in increases the global warming.

Rice husks are the hard protective coverings of rice grains which are separated from the grains during milling process. Rice husk is an abundantly available waste material in all rice producing countries, and it contains about 30%–50% of organic carbon. In the course of a typical milling process, the husks are removed from the raw grain to reveal whole brown rice which upon further milling to remove the bran layer will yield white rice. Current rice production in the world is estimated to be 721 million tons. Sources of rice husk ash (RHA) will be in the rice growing regions of the world, as for example China, India, and the far-East countries. RHA is the product of incineration of rice husk.

Most of the evaporable components of rice husk are slowly lost during burning and the primary residues are the silicates. The characteristics of the ash are dependent on composition of the rice husks, burning temperature, and burning time. Every 100 kg of husks burnt in a boiler for example will yield about 26.8kg of RHA. In certain areas, rice husk is used as a fuel for parboiling paddy in rice mills, whereas in some places it is field-burnt as a local fuel. However, the combustion of rice husks in such cases is far from complete and the partial burning also contributes to air pollution.

2. CHEMICAL REACTION

Polymerization is a process which takes place in geo polymer concrete mix. The geo polymer can be characterized as three- dimensional inorganic polymer with a formula:

$M_n [-(Si-O)_z -Al-O]_n . w(H_2O)]$. Where n is degree of polymerization.

The performance of concrete is usually determined by its strength and durability. For getting better quality of concrete, parameters like reduction of water content, fine and coarse aggregates should be well graded. Strength depends up on not only on grading of properties but also on better curing technique like, steam curing, ambient. For Example, high alkaline solution content could significantly change the strength of the concrete in fly ash-based geo polymer concrete, aluminosilicate gel which is formed from sodium hydroxide and sodium silicate induces the silica and the alumina in the source materials. Physical and chemical properties of geo polymer concrete like strength , microstructure etc., differ with type of curing. The geo polymer concrete can be prepared by mixing fly ash using alkaline solution like Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate (Na_2SiO_3) or Potassium Silicate (K_2SiO_3) and forms a gel which binds the fine and coarse aggregates, which produces hard compacting bonding material. This material possesses good in engineering properties and durability in aggressive environments.

3. MATERIALS

3.1 Fly ash

In this study, low-calcium (ASTM Class F) dry fly ash from Mettur Thermal Power Station, Mettur was used. Low-calcium fly ash (1) could be successfully used to manufacture geopolymer concrete when the silicon and aluminum oxides constituted about 80 percent by mass, with the Si-to-Al ratio of about 2.

Table 1 Chemical composition of fly ash

Sl.No.	Compound	Percentage (mass)
1.	SiO_2	52.54
2.	Al_2O_3	26.74
3.	Fe_2O_3	11.12
4.	CaO	1.28
5.	Na_2O	0.47
6.	K_2O	0.82
7.	TiO_2	1.57
8.	MgO	0.87
9.	P_2O_5	1.53
10.	SO_3	1.70
11.	*LoI	1.36

**LoI- Loss on Ignition*

3.2 Rice Husk Ash Classification and Chemical Composition

The rice husk ash possesses a chemical composition similar to many of the organic fibres. Rice husk ash consists of the following:

- Cellulose ($C_5H_{10}O_5$)
- Lignin ($C_7H_{10}O_3$)
- Hemicellulose
- SiO_2
- Holocellulose

These are compounds within them in common. The rice husk ash may vary depending upon the source as well as the type of treatment. Treatment in the sense the rice husk is burned to have proper properties. So, the method of heating can also bring changes in the overall chemical composition of the ash. The silicates are one of the primary components of the rice husk ash. During the burning process, the components that can evaporate are evaporated and the only component left are the silicates. The rice husk ash to be more precise have characteristics based on the components, the temperature of burning and the time of burning.

The chemical composition of rice husk ash, in general, is given in Table 2.

Table 2 Chemical Composition of Rice Husk Ash

Sl. No	Particulars	Proportion
1	Silicon Dioxide	86.94%
2	Aluminium Oxide	0.2%
3	Iron Oxide	0.1%
4	Calcium Oxide	0.3 – 2.25%
5	Magnesium Oxide	0.2 – 0.6%
6	Sodium Oxide	0.1 -0.8%
7	Potassium Oxide	2.15 – 2.30%

3.3 Aggregates

Locally available river sand with fineness modulus of 2.72 and specific gravity of 2.64 has been used. Crushed granite coarse aggregates of size ranging from 7 mm to 20 mm have been used at the saturated surface dry condition. The sieve analysis result for fine aggregate is shown in Table 3. The percentage of passing indicates that the fine aggregate confirms Zone-II as per IS 383-1970.

Table 3 Sieve Analysis for Fine Aggregate

Sl.No	Aperture size (mm)	Weight retained (gms)	Percentage of weight retained	Cumulative Percentage weight retained	Percentage of passing
1	80	0	0	0	100
2	40	0	0	0	100
3	20	0	0	0	100
4	10	0	0	0	100
5	4.75	6.5	0.65	0.65	99.35
6	2.36	8.5	0.85	1.50	98.50
7	1.18	53.5	5.35	6.85	93.15
8	600µ	408.5	40.85	47.7	52.3
9	300µ	371.5	37.15	84.85	15.15
10	150µ	141	14.1	98.95	1.05
11	75µ	15	1.5	100	0

The grading of fine aggregates, when determined as described in IS: 2386 (Part I)-1963 shall be within the limits and also described as fine aggregates, Grading Zones I, II, III and IV: Where the grading falls outside the limits of any particular grading zone of sieves other than 600-micron IS Sieve by a total amount not exceeding 5 percent, it shall be regarded as falling within that grading zone. The upper and lower limit specified for Zone-II as well as actual gradation Fine aggregate used and the percentage of passing coarse aggregate as per IS 383-1970 has been utilized in the experimental study.
The sieve analysis results of coarse aggregates are shown in Table 4.

Table 4 Sieve analysis for coarse aggregate:

Sl.No	Aperture size (mm)	Weight retained (gms)	Percentage of weight retained	Cumulative Percentage weight retained	Percentage of passing
1	80	0	0	0	100
2	40	0	0	0	100
3	20	0	0	0	100
4	12.5	485	16.17	16.17	83.83
5	10	1655	55.17	71.34	28.66
6	4.75	857	28.56	99.90	0.09
7	Below 4.75	3	0.1	100.00	0

As per IS 383 -1970, the size of coarse aggregate should fall between 10 mm to 12.5 mm. The gradation curves for percentage passing, percentage retained as per the above code and the aggregate used in this study. As per IS 2386-1963 (Part I to IV) the specific gravity of fine aggregates which lie in zone II ranges from 2.6 to 2.7 and also the coarse aggregates ranges from 2.7 to 3.1. Normally the water absorption of fine aggregate is less than 1 percent and the coarse aggregate is less than 2 percent. The properties of fine and coarse aggregates used in this study are determined as given in Table 5.

Table 5 Properties of fine and coarse aggregates

Sl. No.	Test Conducted	Aggregates	
		Fine	Coarse
1.	Specific gravity	2.64	2.72
2.	Fineness modulus	2.70	5.96
3.	Bulk density (gm/cc)	1.52	1.68
4.	Water absorption (Percentage)	0.60	1.10

3.4 Water

The Indian standards IS: 456-2000 specification accept water for making concrete if the pH value of water lies between 6.0 and 8.0 and the water is free from organic matter. Potable water has been used for the preparation of Alkali- activator solution (AAS) and preparation of normal concrete. The pH value of water has been determined using a pH meter and the value is 7.56.
As per ASTM C642-2013 the pH value of Alkali-Activator solution utilized in concrete normally ranges from 8.1 to 9.5. The pH value of AAS used in this study is 8.74.

3.5 Details of Alkali – Activator Solution

The sodium hydroxide with 97-98 percent purity, in flake or pellet form is commercially available. The properties of sodium hydroxide (NaOH) are shown in Table 6. The concentration of sodium hydroxide solution (2) can vary in the range between 8 Molar however, 8 Molar solution is adequate for most applications. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 8 Molar consists of 8x40 = 320 grams of NaOH solids per litre of the solution, where 40 is the molecular weight of NaOH. The solids must be dissolved in water to make a solution with the required concentration.

Table 6 Properties of NaOH

Sl.No.	Details	Contents
1.	Molecular formula	NaOH
2.	Molar mass	39.9971 g/mol
3.	Appearence	White solid
4.	Density	2.13 g/cm^3
5.	Melting point	318C,591K, 604F
6.	Boiling point	1388C,1661K,2350F
7.	Solubility in water	111 g/100ml
8.	Solubility in ethanol	13.9 g/100ml
9.	Solubility in methanol	23.8 g/100ml
10.	Solubility in glycerol	Soluble
11.	Acidity(pK$_a$)	13
12.	Refractive Index(n$_D$)	1.412

Source: Supplier

The properties of sodium silicate are listed in Table 7.

Table 7 Properties of $Na_2 SiO_3$

Sl.No.	Details	Contents
1.	pH value	Neutral
2.	Assay of Na_2O	7.5percent - 8.5percent
3.	Assay of SiO_2	25percent-28percent
4.	Free alkali	Passes test

Source: Supplier

A combination of sodium silicate solution and sodium hydroxide (NaOH) solution can be used as the alkaline liquid (Fig. 1). It is recommended by experts that the alkaline liquid is prepared by mixing both the solutions together, at least 24 hours prior to use.

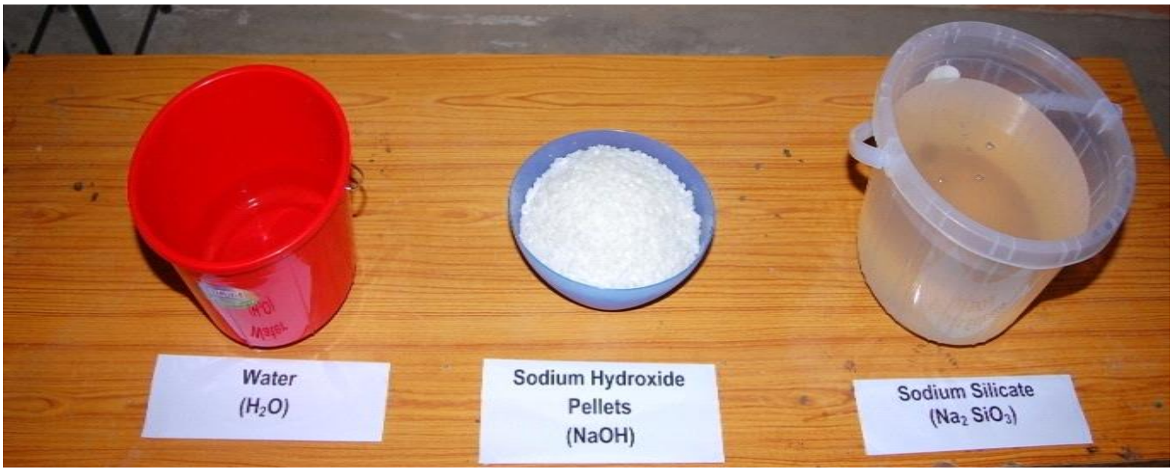

Fig.1 Preparation of Alkali-Activator Solution

4. MIX PROPORTIONS

A mix ratio of 1:1.4:3.2 (1= (varying percentages of FA &RHA): 1.4 fine aggregate: 3.2 coarse aggregate) with water cement ratio of 0.38 has been obtained for normal concrete for a cube compressive strength of 40 N/mm^2 (approximate) by adopting the mix design procedure given in IS 10262 - 2009.

The same mix ratio has been retained as a trial mix for Geopolymer concrete with the replacement of cement with fly ash and water cement ratio with Alkali –Activator Solution / Fly ash ratio. The constituent materials used in the mix for 8 molar solution is shown in Table 8. In this study, various concentrations of NaOH solution 8M, is used along with different Alkali – Activator Solution /fly ash (AAS/FA) ratios 0.40, 0.45, 0.50 and 0.55.

Table 8 Constituents of Geopolymer concrete (Per 1m^3)

Sl.No.	Mix ratio	Fly ash (kg)	Fine Agg. (kg)	Coarse Agg. (kg)	NaOH solution		Na_2SiO_3 (kg)	Na_2SiO_3 / NaOH	AAS/ FA
					Mass (kg)	Molarity			
1.	1:1.3:2.7	450	579.4	1211.9	51.45	8M	128.63	2.5	0.40
2.					57.88		144.68		0.45
3.					64.31		160.78		0.50
4.					70.74		176.85		0.55

4.1 PREPARATION OF SPECIMENS

The concrete batch was mixed using the following procedure:

i) The fly ash, rice husk ash taken with proper ratios and fine aggregate were mixed dry until the mixture is thoroughly blended and is uniform in colour.

ii) The coarse aggregate was added and mixed with the fly ash, rice husk ash and fine aggregate until the coarse aggregate was uniformly distributed throughout the batch. The aggregates were kept in saturated surface dry condition.

iii) The Alkali-Activator solution was added and the entire batch was mixed until the concrete appeared to be homogenous and get the desired consistency.

The solid constituents of the fly ash and rice husk ash based geopolymer concrete, the aggregates and the fly ash and rice husk ash were dry mixed using a Pan mixer for about three minutes. The wet mixing of Alkali-Activator solution was prepared earlier and dry mixture of aggregates usually continued for another four minutes. The wet mixing is usually in cohesive condition.

5. CUBE COMPRESSIVE STRENGTH

The cube compressive strength is compared in Table 9. The cube compressive strength increases with increase in the fluid ratio (Fr) (3) and at the same time decreases with the increase in Alkali-Activator Solution ratio (Sr).

Table 9 Comparison of Cube Compressive Strength Results

Sl. No.	**Mix Ratio &Molar**	**Fr &Sr**	% FA	% RHA	Compressive strength			
					0.40	0.45	0.50	0.55
1.	1:1.4:3.2, 8M	2.4	100	0	35.0	32.0	31.0	30.0
			80	20	32.0	30.0	29.0	28.0
			60	40	31.0	30.0	28.0	27.0
			40	60	25.0	23.0	22.0	20.0
2.		2.5	100	0	40.0	38.0	35.0	33.0
			80	20	35.0	33.0	30.0	28.0
			60	40	33.0	31.0	29.0	27.0
			40	60	30.0	28.0	26.0	24.0
3.	1:1.4:3.2	W/C=0.38			33.8			

Fr - Na_2SiO_3 / NaOH, Sr - AAS/FA

The design mix ratio 1: 1.4: 3.2 is utilized in this study. The cube specimen compressive strength with respect to various Sr values for different Fluid ratio (Fr) 2.4 and 2.5 are used. An alkaline liquid which contains soluble silicates increases the rate of reaction and also increases the adhesive property between the aggregates. At the Fluid ratio 2.5 the saturation is fully attained in bonding action, which facilitates increase in compressive strength.

6. CUBE TENSILE STRENGTH

Since there is no direct method for finding the tensile strength of fly ash and rice husk ash based geopolymer concrete (4), indirect method is adopted. In this method, the same compression testing machine is used for finding the tensile strength.

The concrete cubes were placed in the machine in such a manner that the load was applied on the diagonal edge surface of the cube as cast. The cube tensile strength is compared in Table 10. The cube tensile strength increases with increase in fly ash content and at the same time decreases with the increase in Rice husk ash content.

Table 10 Comparison of Cube Tensile Strength Results

Sl. No.	Mix Ratio &Molar	Fr & Sr	% FA	% RHA	Tensile strength			
					0.40	0.45	0.50	0.55
1.	1:1.4:3.2, 8M	2.4	100	0	6.02	5.75	5.18	4.76
			80	20	5.55	5.03	4.70	4.37
			60	40	4. 64	4.07	3.76	3.45
			40	60	4.30	3.95	3.34	3.12
		2.5	100	0	6.15	5.78	5.40	5.08
			80	20	5.85	5.45	5.02	4.80
			60	40	5.43	4.87	4.18	3.55
			40	60	4.70	4.26	3.66	3.28

Fr - Na_2SiO_3 / NaOH, Sr - AAS/FA

7. CYLINDER COMPRESSIVE STRENGTH

The cylinder compressive strength is compared in Table 10. The cylinder compressive strength increases with increase in the fluid ratio (Fr) and at the same time decreases with the increase in Alkali-Activator Solution ratio (Sr).

Table 10 Cylinder Compressive Strength Results

Sl.No.	Mix Ratio &Molar	Fr	% FA	% RHA	Compressive Strength (N/mm²)			
					0.40	**0.45**	**0.50**	**0.55**
1.	1:1.4:3.2 & 8M	2.4	100	0	22.0	20.2	18.8	16.8
			80	20	20.6	18.1	16.7	14.5
			60	40	18.5	16.9	14.4	12.9
			40	60	16.9	14.8	12.1	11.6
2.		2.5	100	0	25.0	23.2	21.8	19.8
			80	20	23.6	21.1	19.7	18.5
			60	40	22.4	20.9	18.4	16.9
			40	60	21.9	19.8	17.1	15.6
3.	CC 1:1.4:3.2	W/C = 0.40			24.6			

7. CYLINDER SPLIT TENSILE STRENGTH

The cylinders were placed with its longitudinal axis in horizontal position. The load was applied gradually till the specimens break down and no greater load was sustained. The cylinder tensile strength increases with increase in fly ash content and at the same time decreases with the increase in Rice husk ash content (5).

The split tensile strength in Fly ash and Rice husk ash based geopolymer concrete cylinders were obtained and are shown in Table 11.

Table 11 Split Tensile Strength of Cylinder Results

Sl.No.	Mix Ratio &Molar	Fr	% FA	% RHA	Split Tensile Strength (N/mm²)			
					0.40	0.45	0.50	0.55
1.	1:1.4:3.2 & 8M	2.4	100	0	4.7	4.2	3.6	3.2
			80	20	4.0	3.6	3.1	2.8
			60	40	3.6	3.2	2.8	2.4
			40	60	3.2	2.9	2.6	2.3
2.		2.5	100	0	5.2	4.8	4.3	3.7
			80	20	4.6	4.0	3.6	3.3
			60	40	4.0	3.8	3.4	3.1
			40	60	3.8	3.6	3.4	3.0
3.	CC 1:1.4:3.2	W/C = 0.40			4.75			

8. CONCLUSIONS

1. At the Fluid ratio 2.5 the saturation is fully attained in bonding action, which facilitates increase in compressive strength. Whereas at the Fluid ratio 2.4, the bonding actions gets delayed and also the compressive strength gets reduced by 3 to 4 percent in 8M.

2. A study of compressive strength for different Alkali-Activator Solution ratio (AAS/FA) reveals that when AAS/FA ratio, increases compressive strength decreases. The decrease in compressive strength is in the order of 6 to 10 percent for every 0.05 increase in AAS/FA. It shows that the dense solution create immediate polymerization reaction and increases the bonding action quickly between the aggregates.

3. The fly ash and Rice husk ash based geopolymer concrete cubes and cylinders strength slightly less strength than normal concrete but it is economical and environmentally friendly materials has been proved.

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