Strength analysis of concrete by partial replacement of cement with agricultural waste ash

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Abstract: This paper presents the studies conducted to know the strength characteristics of cement concrete made with Ordinary Portland Cement (OPC) and two agro wastes i.e. Rice Husk Ash (RHA) and Groundnut Husk Ash (GHA). Cubes were casted with percentage replacement of both ashes of 0, 2.5, 5, 7.5, 10 and 12.5%. The Chemical analysis was carried out to know pozzolana properties of GHA and RHA. It was observed that slump and density decreases from 70 mm to 27 mm and 2440 Kg/m^3 to 2237 Kg/m^3 respectively. Compressive strength also decreases with respect to control mix except for 10% replacement. Scanning Electron Microscopy (SEM) and Chemical analysis in micro areas Energy Dispersive X – ray Spectrometry (EDS) analysis was also done to track the phase changes and microstructure of mature concrete. It was found from the results and observations that 10% replacement of cement with GHA – RHA is suitable in concrete for construction.

Index Terms - **GHA – RHA, Scanning Electron Microscopy, Pozzolana, Cement, Energy Dispersive X – ray Spectrometry**

1. Introduction: The ever-increasing demand of cement-concrete in the construction field requires cheaper alternative materials in conventional construction methods. The environmental concerns also compel the designers to opt for green materials, feasible for use in construction. Research in the past brings out various green materials used like pozzolona as replacement of cement viz. fly ash, groundnut shell ash etc. The American Society of Testing Materials (ASTM) defines Pozzolana as Siliceous or Aluminous materials which possess little or no cementitious properties, which will react in the presence of moisture with lime [$Ca(OH)_2$] at ordinary temperature to form a Calcined material with pozzolana properties [ASTM 1981].

In India, more than 960 million tons of solid waste annually generates during the processes in industries, querying and in agricultural activities, which leads to an environmental problem of disposal. Several researches have been carried out on the use of agro waste ashes like Rice husk ash, oyster shell, groundnut shell, Corn Cob ash and Sunflower seed husk ash in concrete as partial replacement of fine aggregates and Cement [J.K Prusty et al, Raheem S B et al, N V Lakshami et al, M V Kumar et al, E N Ogork]. Such substitutions help to save energy, conserve natural resources and reduce cost of construction. The aim of present research is to introduce Groundnut and Rice husk Ash as Supplementary Cementitious Material in concrete.

2. Literature Survey

Latha et al. (2017) studied that the compressive strength and split – tensile strength by 10% replacement of cement with GHA and 15 % of Waste Marble Aggregate (WMA) with coarse aggregates is optimum. Lakshami et al. (2017) reported that mix design of 1:2:4 with w/c ratio of 0.6 and with 10% replacement showed the highest compressive strength and split tensile strength than flexural strength. Oseni et al. (2016) and Krishnan et al. (2016) concluded that GLSA could be used as partial replacement of OPC. Devinder Singh et al. (2016) compared the use of agro wastes and found that use of agro waste would be helpful in waste, pollution and cost reduction and increase the potential of natural resources. Mara Wazumtu et al. (2015) investigated that water absorption and workability decreased with increased GSA, but it increased the consistency and setting time of cement paste also therefore GSA would be used a retarder. Compressive strength and resistance increased up to 4% addition of GSA. Egbe – Ngu Ntui Ogork et al (2014) investigated the GHA could be used as retarder in hot weather in ready mix concrete. 10% GHA gave optimum structural strength for mortar and 20% and above could be used in non structural mortar while 15% replacement of cement with GHA – RHA concrete gives maximum strength while 10% RHA with GHA showed highest resistance against HCl and H_2So_4. Rao et al. (2014) studied and found that 5% replacement has highest compressive strength and flexural strength. Moulick et al (2015) investigated the Mix design for M10, M15, M20, M25 and M30 grade. Compressive strength and Cost analysis was also determined for these mixes. Jamil et al. (2013) determined the pozzolanic contribution of rice husk ash in cementitious system. Habeeb et al. (2009) studied the workability, fresh density, compressive strength and found RHA concrete showed improvement in strength for 10% replacement. Saraswathy et al. (2007) investigated the Corrosion performance of rice husk ash blended cement. By conducting compressive strength test , workability test and split tensile strength it was found that Strength of cement increased by addition of rice husk due to formation of calcium silicate hydrate (CSH) gel around the cement particle and it became dense.

2.1 Objectives of Research

1. To find the optimum replacement level of Groundnut husk ash - Rice husk ash for obtaining maximum strength.
2. To determine the physical and chemical characteristic of concrete mix at various curing periods

3. MATERIALS AND METHOD

Materials used for this research include Ordinary Portland Cement (OPC), Groundnut Husk Ash (GHA) and Rice Husk Ash (RHA).

I. CEMENT

Ordinary Portland Cement (OPC 43) of Wonder Brand manufactured in India was used for entire research work. Cement having specific gravity 3.15 was used. The initial and final setting time of cement was found to be 190 minutes and 345 minutes respectively. 28 days compressive strength of cement was found to be 44.2 MPa.

II. AGGREGATES

River sand of zone – II was used as fine aggregate and machine crushed angular stone of 20mm nominal size was used as coarse aggregates. The specific gravity of fine aggregates and coarse aggregates were found to be 2.69 and 2.703 respectively. The Finesse modulus of fine and coarse aggregates was found to be 2.64 and 2.87 respectively. Moisture content of fine aggregates and coarse aggregates were found to be 1.647 and 1.377 respectively.

III. WATER

Potable ground water was used to prepare the concrete mix. The properties of water were tested as per Bureau of Indian Standard (BIS) code and all the parameters were within the limit of IS 456.

IV. GROUNDNUT HUSK ASH AND RICE HUSK ASH

Groundnut husk was collected from the field of Alwar in Rajasthan and sun dried for one week and burnt in Open Air Furnace at controlled temperature of 1000ºC. After cooling, ash was sieved through IS sieve of 150 micron.

Rice Husk Ash was collected in bags from the chemical industry, where it was used as fuel for boilers. RHA was in wet condition to cool down its temperature with water. Oven dried ash was used to pass through 150μ sieve.

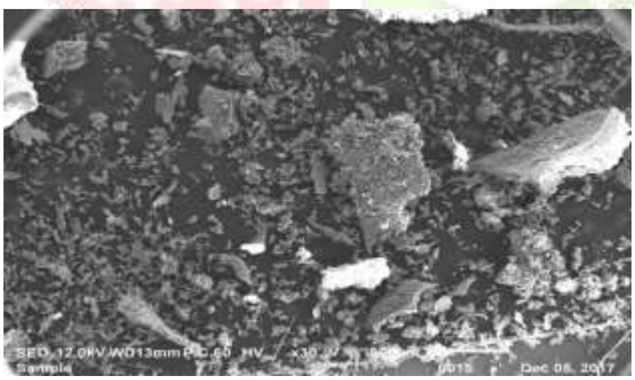


Fig. 3.1: SEM image of GHA at 1000ºC

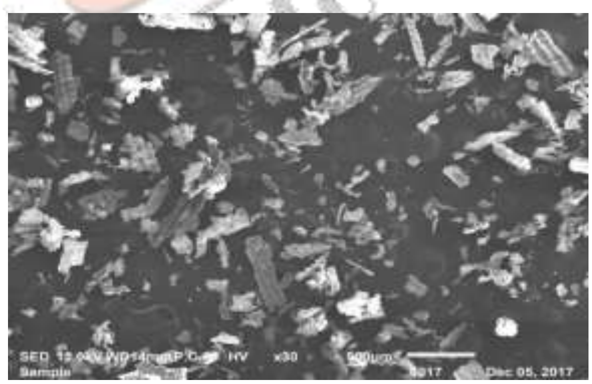


Fig. 3.2: SEM image of RHA at 1000ºC

Fig. 3.1 shows the SEM images of ungrounded groundnut husk ash calcined at 1000°C (GHA). The particles are in irregular shape and small pore are visible on the surface of large particle [K. Umamaheswaran et al. (2008)]. Fig. 3.2 is SEM image of rice husk calcined at 1200°C, ash contains flaky Cob shaped structure and cellulose of rice husk ash has been reduced at high temperature [Shu – Ting Liu et al. (2014) Hadipramana et al.(2016)].

3.2 Methodology

Six mix proportions were prepared with a controlled mix with 100% Ordinary Portland cement and without any additive, and others with Groundnut husk Ash in proportion of Control mix, 2.5%, 5%, 7.5%, 10% and 12.5%. The replacement concentration selected for test were evaluated on 12 cube specimen of size 150mm x 150mm x 150mm. Tests were conducted to determine the slump on fresh concrete and density and compressive strength were determined in three set of specimens at curing age of 3, 7, 14 and 28 days at hardened state.

3.2.1 Microstructure study of sample

Scanning Electron Microscopy (SEM) images were obtained from JCM- IT 100 model at SED 12 KV at 50µm and 100µm depth. Samples of Groundnut husk ash , Rice husk ash and Crushed samples of GHA – RHA concrete from compressive strength tests were collected, labeled and stored for SEM to study the properties of ashes and effect of GHA – RHA on concrete. The control mix GR – 0 and GR-10 samples were used after the curing age of 7 and 28 days. EDS test was carried out for 7 days curing age samples.

3.2.2 Mix proportion of Concrete

Concrete mix of M20 grade was designed (1: 1.99: 3.41) for target mean strength 26.6 N/mm^2 with 0.55 water /cement ratio, Slump range of 50 – 75mm as per IS 10262: 2000. Six mixes control mix, GR-2.5, GR - 5, GR - 7.5, GR - 10 and GR - 12.5 were prepared and concrete composition is presented in Table 3.1 and 3.2.

Table 3.1: Amount of Cement and Other materials at different replacement levels.

Mix-No.	**% age replacement**	**Cement, Kg/m3**	**GHA , kg/m3**	**RHA kg/m3**	**Fine aggregates kg /m3**	**Coarse aggregates kg/m3**	**Water/ Cement ratio**
Control mix	0%	155.94	0	0	309.49	528.523	0.55
GR – 2.5	2.50%	152.042	1.945	1.945	309.49	528.523	0.55
GR – 5	5%	148.143	3.899	3.899	309.49	528.523	0.55
GR – 7.5	7.50%	144.244	5.848	5.848	309.49	528.523	0.55
GR – 10	10%	140.346	7.797	7.797	309.49	528.523	0.55
GR – 12.5	12.50%	136.448	9.747	9.747	309.49	528.523	0.55

Table 3.2: Mixture proportion of Concrete

Material/Mix	Control mix	GR- 2.5	GR- 5	GR- 7.5	GR- 10	GR- 12.5
Cement	1	1	1	1	1	1
GHA	0	1.27	2.63	4.05	5.56	7.14
RHA	0	1.27	2.63	4.05	5.56	7.14
Fine Aggregates	1.99	2.03	2.09	2.15	2.21	2.27
Coarse Aggregates	3.28	3.48	3.57	3.66	3.77	3.87
Water/cement ratio	0.55	0.56	0.57	0.59	0.61	0.63

3.2.3 Slump

The workability aims at compaction of freshly mixed concrete. The values of Slump (in mm) for different replacement levels of cement are given in Table 3.3. Results indicated that the suitability GHA & RHA in concrete leads to decrease in slump values by 35.7% with substitute of 12.5% of GHA & RHA. The decrease in slump was due to absorption of some quantity of water by RHA particles from the mix. Because of large surface area of RHA, more water molecules were attracted towards the surface of these particles [Krishna et al. 2016].

Table 3.3: Workability of Concrete and Density of cubes at different replacement level of cement

Mixture proportion	Control mix	GR- 2.5	GR- 5	GR- 7.5	GR- 10	GR- 12.5
Slump (mm)	70	65	60	53	50	45

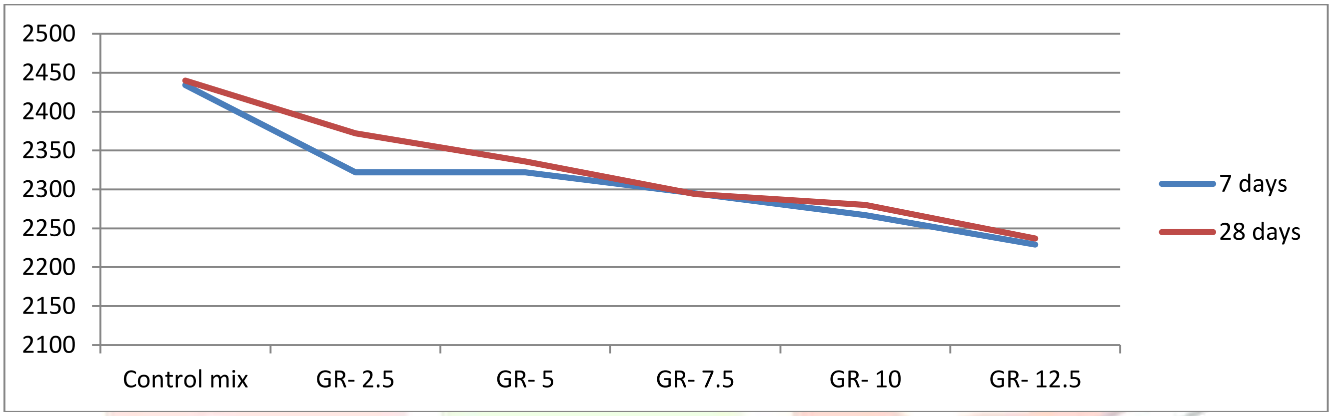
Density(Kg/m3)	2440	2372	2336	2294	2280	2237

Table 3.4: Density (kg/ m^3) of GHA – RHA concrete at different replacement level of cement

Replacement of cement	Control mix	GR- 2.5	GR- 5	GR- 7.5	GR- 10	GR- 12.5
3days	2431	2356	2316	2291	2267	2226
7 days	2434	2322	2322	2295	2267	2229
14 days	2436	2369	2333	2293	2268	2229
28 days	2440	2372	2336	2294	2280	2237

The density of control mix GR -0 was in range of 2431 to 2440 kg/m^3 are given in Table 3.4. Density of GHA – RHA concrete decreases as the replacement level increases. 28 days density for GR – 2.5 and GR – 12.5 are 2356 Kg/m^3 and 2237 Kg/m^3 due to low specific gravity of groundnut & Rice husk ash.

Graph 3.1: 7 days & 28 days Density (Kg/m^3) of GHA-RHA concrete at different replacement level.



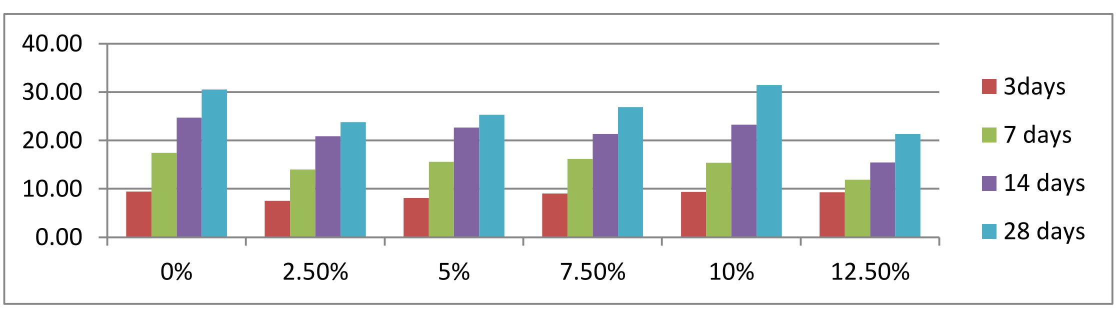
3.2.4 Compressive strength

Table 3.5: Compressive strength of cubes at various replacement levels

Replacement	Control mix	GR- 2.5	GR- 5	GR- 7.5	GR- 10	GR- 12.5
3days	9.44	7.52	8.10	9.04	9.37	9.30
7 days	17.45	14.00	15.60	16.20	15.40	11.85
14 days	20.44	20.90	22.67	21.34	23.25	15.44
28 days	27.51	23.76	25.28	26.90	27.01	21.33

From Table 3.5 it is found that there is no fixed pattern for development of compressive strength among the GHA – RHA concrete at various replacement levels, curing age and design compressive strength. It is observed that at three days curing age control mix and 12.5% replacement attains highest strength 9.44 N/mm^2 and 9.30 N/mm^2 respectively.

Graph 3.2: Compressive strength of cubes



4. ANALYSIS AND RESULT DISCUSSION

Table 4.1: Chemical Composition of GHA and RHA

S.No	Parameters	By Mass (%) 1000ºC GHA	By Mass (%) above 1000^{O}C RHA
1	Silica (SiO_2)	26.92	82.10
2	Alumina (Al_2O_3)	6.43	0.95
3	Lime (Cao)	24.27	0.89
4	Iron Oxide (Fe_2O_3)	0.63	0.93
5	Magnesia (MgO)	2.09	0.53
6	Sodium Oxide (Na_2O)	0.61	0.80
7	Potassium Oxide (K_2O)	4.42	0.89
8	Sulphate (SO_3)	1.21	0.61
9	Loss of Ignition	28.99	12.17

4.1 Chemical analysis of GHA and RHA

The chemical composition of GHA & RHA is shown in Table 4.1. The analysis shows that high silica contents are responsible for the pozzolanic activity of RHA which belongs to class "F" but GHA belongs to class "C". The CaO in GHA was found to be 24.27% and is responsible for cementing properties. [Egbe-Ngu Ntui Ogork,et.al (2014)]. The MgO and K_2O content are 2.09% and 4.42% respectively in GHA which is higher than the maximum prescribed limit of 1.5%. These may be origin of disruption in cement and concrete matrix [Wazumtu et al. (2015) and Akinyele et. al. (2016)]. The Loss of ignition value of GHA and RHA are 28.99% and 12.17% respectively. These values are exceeding the maximum of 6%.

4.1.1GHA – RHA Concrete reactions

By adding GHA – RHA in concrete hydration of cement starts and Tricalcium silicate (C_3S) cement mineral hydrates and produces Calcium silicate hydrate (C-S-H) [CSH –I]gel and calcium hydroxide (Portladite). This reaction takes place during first few days and gain strength and reduces capillary porosity. Hydration of Dicalcium silicate (C_2S) produce same mineral and provide strength in later stage due its slow hydration rate. Calcium hydroxide reacts with silica oxide (SiO_2) present in GHA & RHA and form Calcium silicate hydrate -II [CSH-II] which has same properties of Calcium silicate hydrate gel. Potassium oxide hinders complete combination of lime and c magnesium silicate ($MgSiO_3$) acts as a retarder cause the delay of setting of GHA – RHA concrete.

Hydration reactions in GHA – RHA concrete [Wazumtu et al. (2015) and Srinivasreddy et al.(2013)]

$2\,C_3S + 6H \longrightarrow C_3S_2H_3 + 3\,Ca\,(OH)_2$ [CSH – I]

$2\,C_2S + 4H \longrightarrow C_3S_2H_3 + Ca\,(OH)_2$

$Ca\,(OH)_2 + SiO_2 \longrightarrow CaSiO_3.H_2O$ [CSH – II]

$MgO + H_2O \longrightarrow Mg\,(OH)_2.H_2O$

$Mg\,(OH)_2 + SiO_2 \longrightarrow MgSiO_3.\,H_2O$

$K_2O + H_2O \longrightarrow 2KOH$

$2KOH + SiO_2 \longrightarrow K_2SiO_3 + H_2O$

4.2 Microstructure analysis of concrete

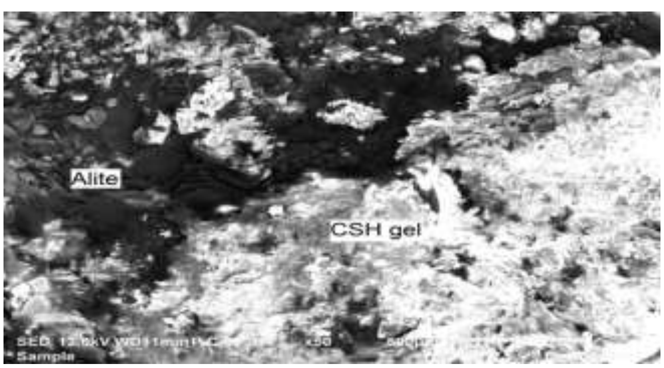


Fig.: 4.1- SEM image of Concrete mix of 7 days age

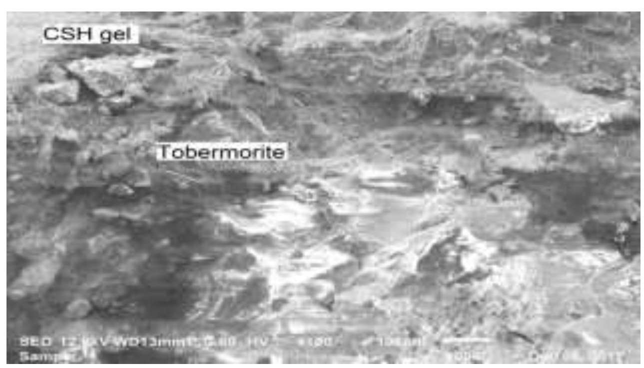


Fig. : 4.2 - SEM image of Concrete mix of 28 days age

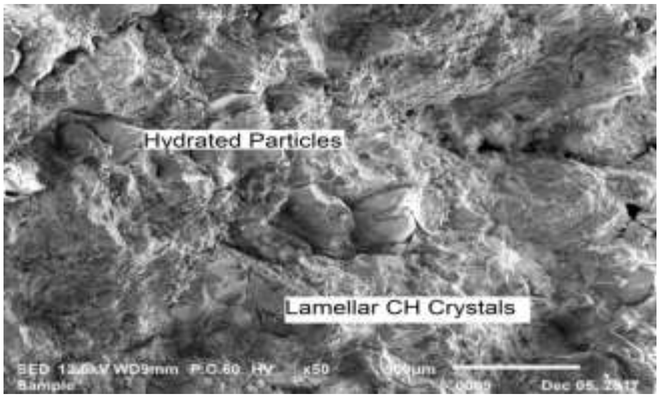


Fig. 4.3: SEM image of GHA – 10% concrete for 7 days

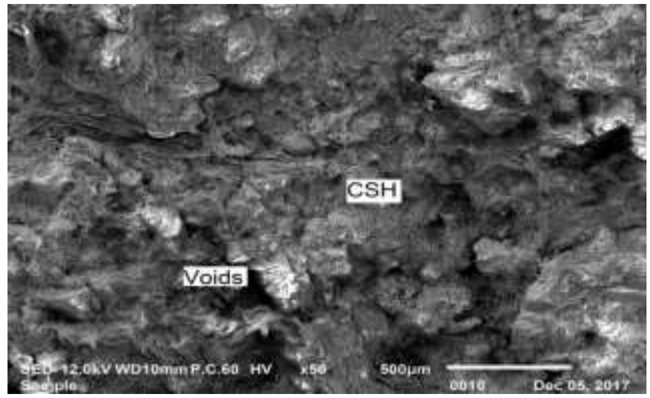


Fig. 4.4: SEM image of GHA 10% concrete for 28 days

In Fig. 4.1the image shows the presence of flakes of Calcium Hydroxide (Alite) in layers and Hexagonal crystals of Calcium Silicate Hydrate gel which has covered 50 -60% of total volume. Some cracks are also present there due to heat during hydration at 7days curing [Silva et al. (2017), Kunal et al. (2014) and Junpeng Mei et al. (2017)]. At 28 days curing Fig. 4.2 shows that small needle like structures are ettringite of elongated crystal with circular habit. This goes in the form of mesh like Honeycomb. At next stage the structure gets more and more dense which provide strength to concrete [Franus et al. (2015)]. In Fig. 4.3, by adding GHA – RHA, Lamellar CH Crystals reduces and hydrated particles of cement are present [Hongbo Tan et al.(2017)] . Formation of "Honeycomb" structure is found which has covered the entire solid phase due to transformation of CSH gel and some cracks are also present there [Jumate Elena et al. (2012)]. In Fig. 4.4after 28 days, CH crystals become dense, compact matrix of strength with non – hydrated belites.

4.3 Energy Dispersive X – ray Spectrometry (EDS)

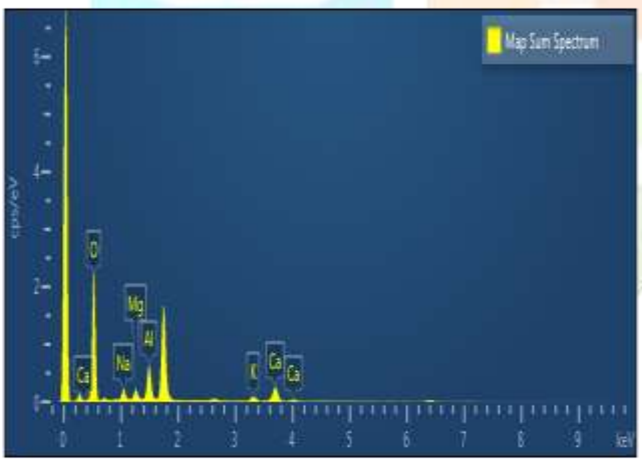


Fig. 4.5: EDS of Control Mix at 7 days curing.

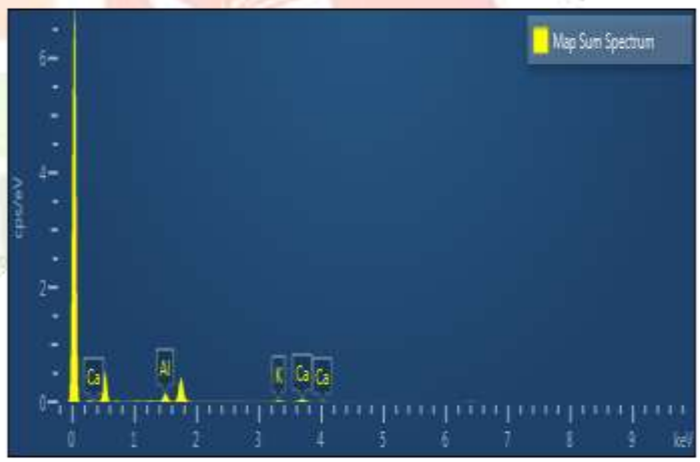


Fig. 4.6: EDS of GHA – RHA Concrete (GR-10%) at 7 days curing.

Table 4.1: Element by weight %age in Control Mix- 7 days

Element	Weight %
O	48.71
Si	18.16
Al	6.07
Ca	7.42
Na	2.23
Mg	1.79
K	2.01
Fe	5.21
Cl	0.54

Table 4.2: Element by weight %age in GR – 10% Concrete

Element	Weight %
Si	49.07
Ca	15.42
K	6.91
Fe	14.31
Al	14.28
Total	100.00

C	7.86
Total	100.00

By comparing and analyzing Fig. 4.5 & 4.6 and Table 4.1 & 4.2 - 7 days EDS (K series) of control mix and GHA – RHA concrete it was found that control mix contains O, Si, C, Ca, Al and Fe 48.6, 18.6, 7.86, 6.07 and 5.21% respectively by weight. While 7 days GHA – RHA concrete consists of Si , Ca, Fe, Al and K 49.07, 15.54 14.31, 14.28 and 6.91 % by weight respectively. All the major elements Si, Ca, Fe, Al and K are present in large amount in GHA – RHA concrete due to rice husk ash which contains 82% SiO_2.

CONCLUSION

Groundnut Husk Ash - Rice Husk Ash are found a good supplementary cementations material. Rice Husk used in this research is efficient pozzolana than the groundnut husk ash. Use of GHA-RHA concrete helps to minimize environmental pollution during manufacturing of cement and disposal of ash. Partial replacement of cement with GHA – RHA ash reduces the cost of concrete. It can be concluded that the groundnut husk Ash and Rice Husk Ash can be used as partial replacement of cement in concrete to obtain satisfactory compressive strength. Water requirement increases with increase in amount of ash. The compressive strength for control mix and GHA – RHA concrete is same. The threshold limit of replacement level is 10% with 50% GHA – 50% RHA by weight.

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