Strength and Chemical Durability of PC-Slag-RHA Ternary Blended Concrete Mixes

Swetha Ajith Mathew, M. Nazeer

Abstract— Concrete is an important and commonly used man made construction material, which can be considered to have better strength and durability characteristics. Nowadays, ternary blended concrete is achieving popularity by overcoming the disadvantages of binary blended concrete. The present work deals with study of fresh properties, strength and durability of ternary blended concrete with Ground Granulated Blast Furnace Slag (GGBS) and Rice Husk Ash (RHA). Concrete mix is designed for strength of 40MPa. The study is limited to ternary blended concrete with 50% replacement of cement with GGBS and remaining 50% of cement is replaced with 5%, 10% and 15% RHA in different mixes. The chloride penetration resistance of the concrete is assessed by rapid chloride permeability test. The observations were critically analysed and the different attributes of the various mixes were correlated with the RHA content in the mix.

Keywords— Ground Granulated Blast Furnace Slag, Rice Husk Ash, ternary blended concrete, strength, durability

I. INTRODUCTION

Compressive strength of concrete is an indexing property as other properties of concrete have direct relation with this property. Therefore, determining compressive strength property is the foremost priority while dealing with any type of concrete. In the recent years, it has been reported that gradual deterioration, caused by the lack of durability, makes concrete structures fail earlier than their specified service lives in ever increasing numbers. The main purpose of durability study on concrete is to record the durability performance of the concrete under different environment condition. The addition of supplementary cementitious materials (SCMs), such as Rice Husk Ash (RHA), Fly ash (FA) and Ground Granulated Blast Furnace Slag (GGBS), to cement generally improves the properties of concrete[1-10]. It is believed that SCM concrete performance varies significantly with the source and proportion of the cementitious materials (CMs). Concrete with SCM often displays slower hydration, accompanied by slower setting and lower early-age strength, especially under cold weather conditions. Most of the SCMs are industrial by-products. These materials are generally not used as cements by themselves, but when blended with OPC, they make a significant cementing contribution to the properties of hardened concrete through hydraulic and/or pozzolanic activity. SCMs are increasingly used in concrete because of the advantage that it reduces economic and environmental concerns by utilizing industrial wastes, reducing carbon dioxide emissions, And lowering energy requirements for OPC clinker production and also it helps improve the concrete properties, such as workability, impermeability, ultimate strength, and durability, including enhanced resistance to alkali-silica reactions, corrosion of steel, salt scaling, delayed ettringite formation and sulphate attack.

The molten slag from the blast furnace is water-quenched, resulting in the formation of a glassy granulate. This glassy granulate is dried and ground to the required fineness [11], which is known as ground granulated blast furnace slag (GGBS). The main advantages of using GGBS in concrete are its sustainability and improved durability. The chemical composition of slag is similar to that of cement. The material is considered as both pozzolanic and latent hydraulic due to relatively higher proportion of SiO_2 and CaO in their reactive form.

On burning, the rice-husk produces ash at an average of 18% by weight of the husks known as Rice husk ash (RHA). In 1973, Mehta published the first of several papers describing the effect of pyro processing parameters on the pozzolanic reactivity of RHA [12]. Studies have shown that RHA resulting from the burning of rice husks at control temperatures have physical and chemical properties that meet ASTM (American Society for Testing and Materials) Standard [13]. At burning temperatures of 550^0C – 800^0C, amorphous silica is formed, but at higher temperatures crystalline silica is produced. The silica content is between 90 and 96%. The reaction between RHA and $Ca(OH)_2$ solution yields Calcium Silica Hydrate (C–S–H) gel. This C–S–H gel has large specific area and is the main reason for improving the concrete properties with the addition of RHA [14]. In general, it is well evident that finely divided highly reactive pozzolan reacts with $Ca(OH)_2$ supply to early heat evolution, by accelerating the hydration of OPC and by rapidly reacting with $Ca(OH)_2$.

II. EXPERIMENTAL

A. Materials

Materials used in the present investigation was carefully selected and tested in the laboratory to assess the quality and suitability in making concrete of required strength.

Cement: Ordinary Portland Cement (OPC) confirming to **IS 12269** (53 Grade) [15] having specific gravity 3.15 and standard consistency 31.25% was used for the present experimental work. The reason for selecting high grade cement is that the replacement of cement with other supplementary cementitious materials should not cause undue reduction in strength at early ages. Other physical properties of cement used satisfy the requirements as per **IS 12269** [15].

***Ground Granulated Blast Furnace Slag*:** GGBS used in the present study was obtained from Jindal Steel Works. From

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the laboratory tests, the specific gravity was obtained as 3.03 and density as 994 kg/m^3.

Rice Husk Ash: RHA was supplied by NK Enterprises, Orissa. From the laboratory tests, the specific gravity was obtained as 2.14 and density as 530 kg/m^3.

Fine aggregate: Manufactured sand having fineness modulus 3.06 and specific gravity 2.50 was used as fine aggregate.

Coarse aggregate: Crushed stone aggregate of size between 20mm and 4.75mm and specific gravity 2.80 and fineness modulus 7.09 was used as coarse aggregate.

Water: Clean drinking water available in the college water supply system was used for mixing and curing of concrete.

Superplasticizer: The superplasticizer used was Conplast SP430 supplied by M/s Fosroc Chemical (India) Pvt. Ltd.

B. Mix Proportion

The grade of concrete prepared for the experimental study was M40. The design basically involves the determination of water-binder ratio for a given compressive strength. After selecting the suitable water content, the cement requirement was determined. The coarse aggregate content was fixed depending on max aggregate size and fineness modulus of fine aggregate. The fine aggregate content was calculated on the absolute volume basis. In the design, the volume of entrapped air was assumed to be 2 percent. The final proportion was 1:1.94: 2.75 (cement: fine aggregate: coarse aggregate) with w/b of 0.42. The cement content in concrete was 400 kg/m^3. Five different mixes were prepared: conventional concrete mix, binary mix and three ternary mixes. The various mix designation is shown in **Table 1.** For all mixes other than conventional concrete, only the cementitious materials will change and the quantity of fine aggregate, coarse aggregate, water content and water to binder ratio remains constant. (Fine aggregate – 776 kg/m^3, Coarse aggregate – 1101 kg/m^3, Water – 169 kg/m^3).

Table 1. Mix Designation

Mix designation	Cement (%)	GGBS (%)	RHA (%)
C	100	0	0
R0	50	50	0
R5	45	50	5
R10	40	50	10
R15	35	50	15

C. Methods

Workability: The workability was assessed by determining the compacting factor as per the **IS 1199:1959** [16] specification.

Compressive strength: In the present study, compression tests were carried out on 100mm cube specimens at ages of 7, 28, 56 and 90 day as per **IS:516-1959** [17]**.** The reported strength values are average of three test results.

Rapid chloride permeability test: The rapid chloride permeability test (RCPT) was conducted as per **ASTM C 1202** [18] recommendations. The test was conducted on 100 mmΦ x 50 mm disc specimens at the ages of 56 and 90 days.

III. RESULTS AND DISCUSSIONS

The strength and durability studies were conducted on GGBS-RHA admixed concrete according to the procedures described in the previous session. The results obtained were tabulated and a detailed analysis and discussion on the results is presented in this session.

Workability: It is observed that R0 mix having 50% GGBS replacement has higher workability. This is probably due to the fact that the GGBS particles are less water absorptive than OPC particles. But the value of compacting factor decreased with increase of RHA replacement. An attempt has been made to correlate the decrease in workability of GGBS admixed concrete due to the addition of RHA. **Fig. 1.** represent this variation and there exist a polynomial relation between the compacting factor and RHA content in the mix in the follwing form;

$$CF_r = CF_0 - 0.012r + 0.0004r^2$$

where r - dosage of RHA in GGBS concrete (%) and *CF* – compacting factor

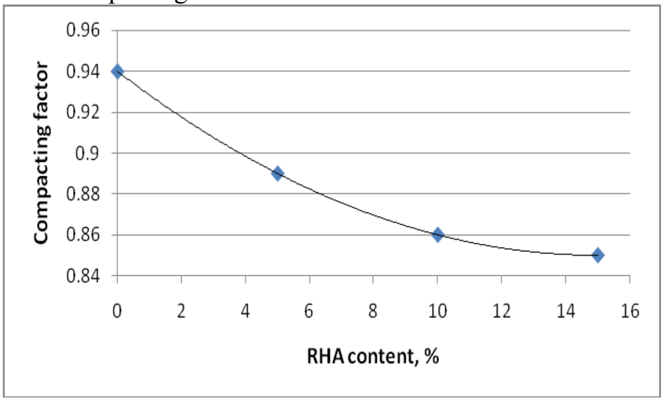

Fig. 1. Compacting factor variation with RHA content

Compressive Strength test: R0 mix with 50% GGBS replacement has lower strength at early ages but its long term strength is greater compared to the control mix. It may be due to the presence of higher proportion of strength enhancing calcium silicate hydrates (CSH) than the concrete made with OPC only. Compared to R0 mix, ternary blended concrete with RHA replacements of 5%, 10%, 15% showed lower compressive strengths. At 7 days and 28 days, RHA replaced concrete did not develop a compressive strength comparable to that of control mix and R0 mix. But it can be noticed that for RHA replaced concretes, it is possible to achieve strength more comparable to that of control mix and R0 mix at later ages (56 days and 90 days). **Fig. 2.** shows the variation for compressive strength for all the five mixes.

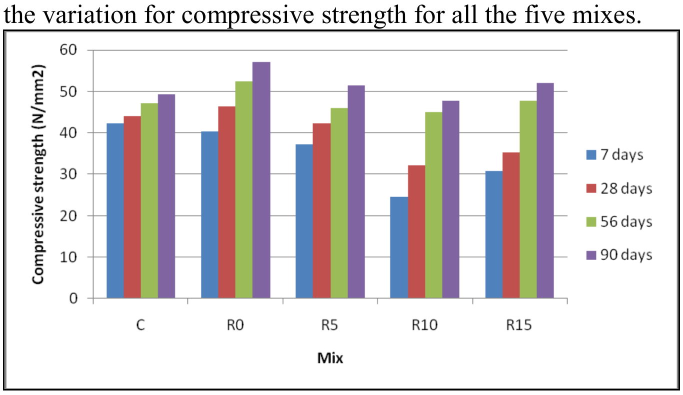

Fig. 2. Compressive strength variation for different mixes

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The values of compressive strength determined are used to calculate the cement efficiency factor (MPa/kg) for individual mixes. The factor is calculated as the ratio of compressive strength at designated age to the content of Portland cement in the mix. It may be observed from **Table 2** that for a particular age of test, the cement efficiency factor increases with the RHA content in the mix. The tabulated values corresponding to Portland cement is an indication of the development of compressive strength. Comparing the increase in the cement efficiency factor of various mixes at age 28 days and beyond, with that at the age of 7 days, the increase is as high as 95% for R10 mix at 90 days age against 41% for OPC-GGBS binary blend at the same age. This clearly indicates that there is a guaranteed improvement in the strength of concrete due to pozzolanic reaction of RHA. Further comparing the cement efficiency factor of OPC concrete and GGBS binary blend, there is a continuous increase in the value, about 90% at 7 days to 130% at 90 days.

Table 2 Cement efficiency factor for different mixes

Mix	Cement efficiency factor (MPa/kg)			
	7 days	28 days	56 days	90 days
C	0.1058	0.1100	0.1180	0.1232
R0	0.2017	0.2317	0.2617	0.2850
R5	0.2067	0.2352	0.2556	0.2852
R10	0.1529	0.2004	0.2812	0.2979
R15	0.2195	0.2524	0.3405	0.3714

Rapid Chloride Permeability Test (RCPT): The details of charge passed through different concrete mixes were assessed. It is to be noted that the highest total charge passed in plain concrete specimen and the lowest charge passed in R10 specimen, which represented highest chloride ion penetration resistance. This is probably due to the effective hydration/pozzolanic reaction products make the micro-structure of R10 mix more denser and refine the pore system in concrete. Another observation is that the charge passed decreases as the test age increases, which indicate better résistance to the penetration of chloride ions. Maximum resistance to chloride ion penetration was reported for R10 specimens. Therefore it is clear that by the increasing the duration of water curing the chloride penetration resistance was found to be increasing. Also from the results it is evident that by the addition of mineral admixtures such as GGBS and RHA, resistance to chloride penetration can be increased. The total charge passed in 6 hours is calculated from the experimental data and is presented in **Fig. 3**.

One of the disadvantages of RCPT is the longer test duration. In the present investigation an attempt is made to correlate the total charge passed through the specimen with the initial current observed during the commencement of the test. It was observed that there exists a linear relationship between total charge passed with the initial current (**Fig. 4.**). The relationship was in the form,

$$Q = p\, I_o$$

Where, p is a factor depending on the test voltage. The above relation has a value of p=28.045 with a correlation coefficient R^2=0.9988 (for ten observations). This relationship could be used to estimate the total charge passed without conducting experiments for the specified test durations (6h).

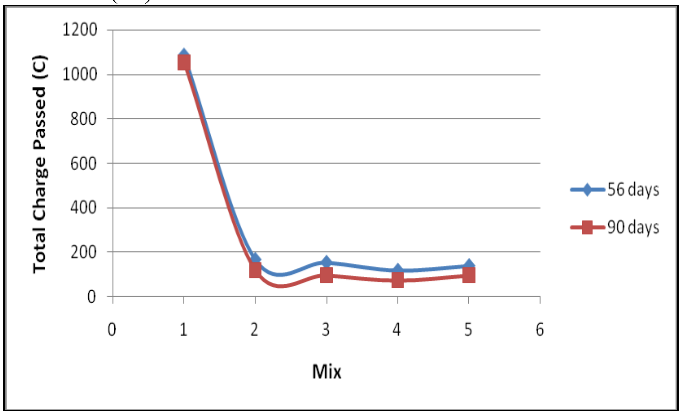

Fig.3. Total Charge Passed vs. Mix

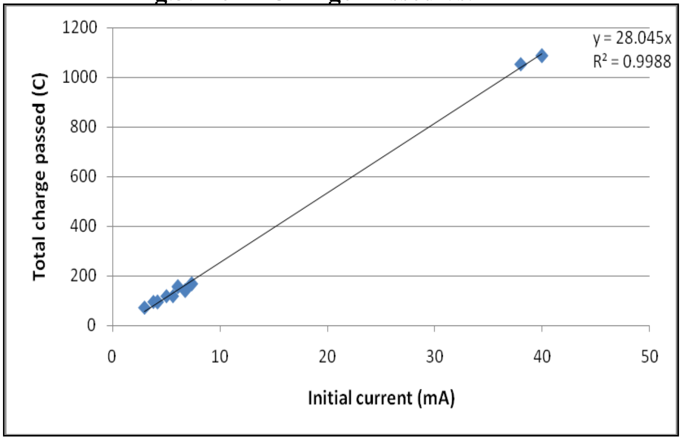

Fig. 4. Charge passed vs. Initial Current (56day and 90 day)

Figure 5 illustrate the variation of total charge passed in RCPT against the RHA content in the mix. It indicate that the charge passed through the specimen continuously decreases with increase in the RHA content. For both test ages (56 days and 90 days) there exist a polynomial correlation between the charge passed and the RHA content. The equations are as follows;

56 days : $Q_r = Q_0 - 6.633r + 0.299r^2$ with R^2 =0.75

90 days : $Q_r = Q_0 - 8.307r + 0.436r^2$ with R^2 =0.89

where r - dosage of RHA in GGBS concrete (%) and Q – total charge passed.

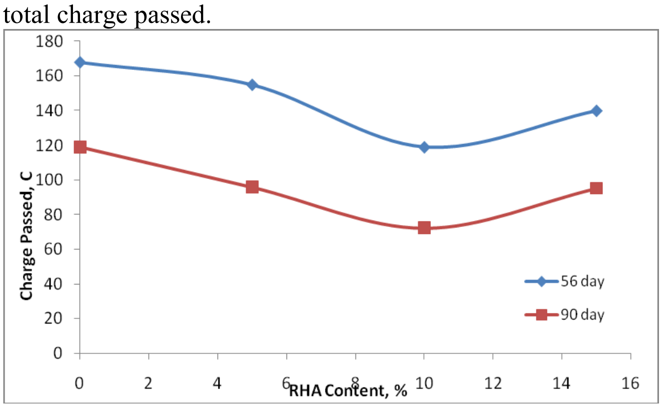

Fig. 5. Variation of charge passed for different RHA content

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IV. CONCLUSIONS

From the limited period observations on a few ternary blends and the comparable binary blend on workability, strength and durability performance of a medium strength concrete, following conclusions could be drawn:

- GGBS binary blend showed maximum workability. The workability of concrete had been found to decrease with increase of RHA content in concrete. The polynomial relation suggested can be used to evaluate the compacting factor of concrete with 50% GGBS and RHA up to 15%.
- GGBS binary blend (R0) showed maximum compressive strength at later ages. RHA replaced concrete did not develop a compressive strength comparable to that of control mix and R0 mix. But for RHA replaced concretes it is possible to achieve strength more comparable to that of control mix and R0 mix at later ages.
- Cement efficiency factor increased with age for all mixes. At 90 days the factor showed an increase of 95% for R10 mix against 41% increase of GGBS binary blend. Thus there is an improvement in compressive strength with addition of RHA. This may be due to the later age pozzolanic activity of RHA.
- Addition of SCMs in concrete causes a reduction of chloride permeability rating up to two order as per the ASTM rating. Maximum resistance to chloride ion penetration was reported for R10 specimens. A linear relationship was established between total charge passed with the initial current and could be used to estimate the probable total charge passed without conducting experiments for the specified test duration. Also for both test ages (56 days and 90 days) a polynomial correlation was established between the charge passed and the RHA content.

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