Performance of Conventional Concrete Integrated with RHA and GGBS As a Cementitious Material

Yogesh Tambe and Pravin Nemade

Abstract Sustainable development becomes necessary to protect our existing environmental conditions. The agricultural and metal industry produces various residues which are having prospective tobe utilized as a supplementary for the cement. Rice husk ash (RHA) minimizes the carbon footprints emissions and achieves green effect in the existing environment. Ground Granulated Blast Furnace Slag (GGBS) is utilized as an alternative to the cement which helps in reducing CO_2 emissions and minimizes the consumption of non-renewable resources of lime stone. The corresponding study insights the usage of supplementary materials like GGBS and RHA into the production of concrete matrix. Also, the aim of this study is to achieve sustainable development incorporating the agricultural and industrial wastes into concrete industry, which can be beneficial for the nation and loss the effect on natural ingredients on convectional concrete. The present study is carried out to optimize percentages of RHA and GGBS after the replacement to the cement such as 0, 5, 10, 15, 20, 25 and, 30% interval. Also, to evaluate the compression and split-tensile strength of conventional concrete with different ages of 7 and 28 days under normal curing conditions. The prediction model for compression strength is prepared using statistical analysis.

Keywords RHA · GGBS · Compressive strength · Split tensile strength · Prediction model

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1 Introduction

The primary building material is concrete consumed in large quantity by the construction industry. In construction industry due to urbanization the need of concrete has been increased rapidly therefore, the new supplementary materials for cement should be developed for the manufacturing of conventional concrete. The concrete industry is continually in search of advanced supplementary materials consisting pozzolanic properties with the purpose of minimizing the residues disposal problems [1]. Concrete has basically consisted of ingredients as cement, sand, aggregate and water. Primarily, cement is crucial component of concrete mix design. During cement manufacturing severe environmental pollution caused and leads to carbon dioxide (CO_2) emissions up to almost 6–8% [2]. The various environmental issues are resulted from cement production has become a worldwide major concern today. To achieve a sustainable development it is encouraged to minimize the use of such construction materials that can affect the environment [3]. The residual waste disposal of materials are poses serious problems to the environment [4, 5]. Due to increasing worldwide consciousness of environmental pollution and, increasing residues disposal issues, it is now challenge for researchers to design and produce cementitious materials with less clinkers and incorporating them into concrete for sustainable development. The various researchers concluded that, the conventional concrete properties can be improved with various supplementary binders namely, fly ash (FA), waste paper sludge (WPS), metakaolin (MK), silica fume (SF), ground granulated blast furnace slag (GGBFS) and rice husk ash (RHA) in quantified percentages as a replacement to the cement [6]. The use of a steel industrial residue, GGBS is effectively accepted binder for various cementitious applications which attains durability including high sulphate attack resistance, penetration of chlorides and, protection in case of alkali-silica reaction [7]. Also, RHA is an agricultural residue which is produced annually in large quantity. The fineness of RHA is more than cement and contains large amount of silica percentage which indicates such material is having potential for pozzolanic actions [8]. Nearly, 1 tonne of CO_2 is evolved in the production of each tone of Portland cement, which is harmful for environment so for that, it becomes essential to find out alternative materials which attain properties similar to cement [9]. Therefore, to tackle with these problem effective materials such as GGBS and RHA adopted in this research. This study experimentally investigates, the influence of RHA and GGBS as a partially substituted with cement on mechanical behavior of conventional concrete at 7 and 28 days.

2 Ingredients of Conventional Concrete

The ingredients used in the production of conventional concrete were 53 grade OPC with a specific gravity of 3.15, specific gravity of F.A. and C.A. is 2.65 and 2.7 with zone III respectively, water, GGBS and, RHA. The Fig. 1a, b represents the

Fig. 1 **a** GGBS and **b** RHA

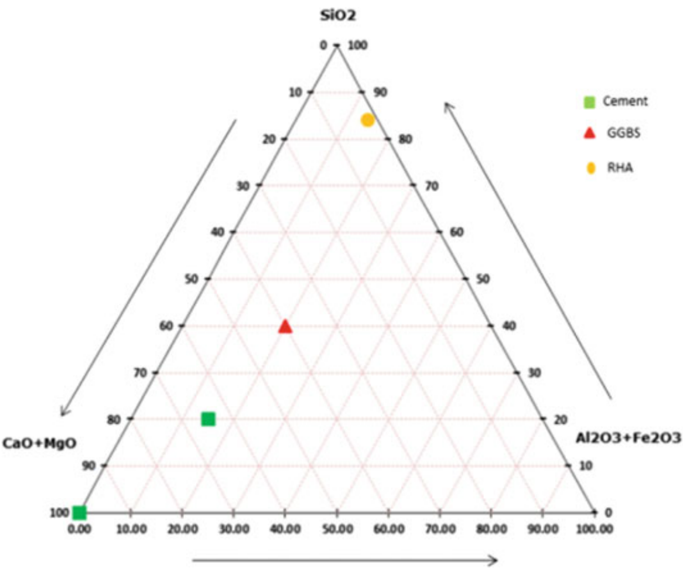

Fig. 2 Ternary diagram

residual waste materials adopted in this research. Figure 2 shows ternary diagram which represents the chemical compositions of the residual wastes utilised in concrete matrix. The chemical and physical properties of RHA and GGBS are represented in the following Tables 1 and 2.

3 Concrete Mixture Proportion

The IS code method (IS 10262-1982) has adopted for the trail mix designs. This method consists of determining the water content and fine aggregates percentage

Table 1 Comparison of chemical properties of RHA and GGBS with cement

Components	Cement	RHA	GGBS
SiO_2	±19.65	±83.87	±33.46
Al_2O_3	±5.25	±2.35	±15.19
Fe_2O_3	±3.68		
CaO	±62.9	±0.2	±25.08
MgO	±2.54	±0.52	±7.97
SO_3	±2.72	±0.11	±0.85
K_2O	±0.9	±0.13	±1.31
Na_2O	±0.25	±0.16	±1.32

Table 2 Comparison of physical characteristics of RHA and GGBS

Properties	RHA	GGBS
Colour	Blackish white	White
Shape	Irregular	Spherical
Specific gravity	2.1–2.33	2.6–2.77
Bulk density (kg/m^3)	22	1040–1090
Appearance	Powder form	Powder form

corresponding to nominal size of aggregate for the various values of workability w/c ratios and the grading of F.A. (Tables 3 and 4).

1. 28 days characteristic compressive strength = 20 MPa
2. Max. Agg size. = 20 mm

Table 3 Proportion of design mix for M-20 grade

Mix M-20	Water	Cement	F.A.	C.A.
By weight (kg/m^3)	186	413.33	674.6	1121.84
Proportion	0.45	1	1.63	2.71

Table 4 Mixes for different proportion of RHA/GGBS for 1 m^3

Replacement percentage (%)	OPC (kg)	RHA/GGBS (kg)	F.A. (kg)	C.A. (kg)	Water (l)
0	413.33	0	674.60	1121.84	186
5	392.64	20.69	674.60	1121.84	186
10	371.95	41.33	674.60	1121.84	186
15	351.26	62.02	674.60	1121.84	186
20	330.62	82.33	674.60	1121.84	186
25	309.93	103.02	674.60	1121.84	186
30	289.31	123.71	674.60	1121.84	186

3. Deg. of quality = Good
4. Condition = Mild exposure
5. Method of concrete mixing = Hand mixing
6. Sp. gravity OPC grade 53 = 3.15
7. Sp. gravity of C.A. = 2.7
8. Sp. gravity of F.A. = 2.65 (Zone-III)

Mix design calculations

1. Target mean strength—
   $F_t = F_{ck} + KS$
   $= 20 + 1.65 \times 4$
   $= 26.60$ N/mm^2
2. W/C ratio
   Based on experience and trials
   Select W/C = 0.45
   Max. W/C ratio = 0.55
   Selected W/C ratio = 0.45
3. Water content
   (Ref. T-5 IS456-2000 page no. 20)
   Degree of workability – compaction factor = 0.8
   Slump = 25
   Max. C.A. size = 20 mm
   Water quantity = 186 kg/m^3
4. Applying correction for water content
   Correct quantity of water = 191.5 kg/m^3
5. Cement quantity
   W/C ratio = 0.45
   Cement = 186/0.45 = 413.33 kg/m^3
   From IS recommendations, min. cement content = 220 kg/m^3 (mild exposure condition)
6. Proportion of volume of C.A. and F.A. for zone 3
   Ref. T-3 Page No. 3 IS 10262 – 2009
   Size of agg. 20 mm with zone 3 of C.A & F.A. = 0.62
   Vol. of C.A. per unit Vol. = 0.62
   Vol. of F.A. = 1 – 0.62 = 0.38

(a) Vol. of concrete = 1 m^3
(b) Vol. of cement = 413.33/3.15 $\times$ 1000 = 0.13 m^3
(c) Vol. of water = 186/1 $\times$ 1000 = 0.186 m^3
(d) Vol. of [C.A. + F.A.] = a – [b + c] = 1 – [0.1312 + 0.186] = 0.6828 m^3
(e) Mass of C.A. = 0.6828 $\times$ 2.65 $\times$ 0.62 $\times$ 1000 = 1121.84 kg
(f) Mass of F.A. = 0.6828 $\times$ 2.7 $\times$ 0.38 $\times$ 1000 = 674.60 kg

Fig. 3 Compression test on cube

4 Experimental Procedure

4.1 Compressive Strength of Concrete

The investigation was carried out for concrete grade of M-20 mix proportion with 0, 5, 10, 15, 20, 25, 30% of cement partially replaced with RHA and GGBS. The 78 number of cubic samples of size 150 mm were casted and tested using CTM to estimate the strength of matrix in compression at 7 and 28 days. To achieve uniform consistency all the concrete ingredients thoroughly mixed in concrete mixer. The cube specimen was compacted layer by layer properly while filling in mould. The casted specimens were separated from the mould after 24 h and kept in the water tank for the period of 7 and 28 days for curing under normal temperature. The compression testing was performed using CTM having 2000 KN capacity refer Fig. 3. The gradually uniform loading was applied on the specimen until the failure takes place. The testing specimen was kept horizontal in between loading planes of the CTM and the application of loading is uniform without causing disturbance until the failure occurs.

4.2 Split-Tensile Strength of Concrete

The cylinder specimens 78 in number of size 150 mm in diameter and 300 mm height with M-20 grade of concrete were casted to evaluate the split-tensile strength

Fig. 4 Testing on cylindrical sample

of conventional concrete. In a concrete mixer uniform consistency of concrete is achieved by thoroughly mixing of concrete ingredients. During casting of cylinder specimens properly compaction of concrete was carried out and specimens removed from the mould after 24 h of casting. For curing purpose the casted cylindrical samples were kept in water under normal temperature for a period of 7 and 28 days. The sample was kept horizontal in between the surfaces of loading of the CTM along with wooden strips placed at top and bottom of the specimen shown in Fig. 4. The application of loading was gradual without vibrations until the failure of the sample takes place.

5 Result and Discussion

The mechanical properties of conventional concrete in hardened state were discussed in accordance with compressive strength and split-tensile strength for the period of 7 and 28 days. The detailed discussion on compressive and split-tensile strength of concrete matrix is as follows.

5.1 Compressive Strength

The most crucial characteristic of concrete matrix is strength in compression which measures the amount of load sustained by the concrete structure before failure. The following figures show that, the compression strength of concrete cube specimens at the age of 7 and 28 days with respect to replacement percentage of cement 5, 10, 15, 20, 25, and 30% of RHA and GGBS mix proportion. The trend line equations for 7 and 28 days compressive strength represent better performance with the values of R^2 nearly equal to 0.98 as a regression coefficient.

The compressive strength testing results were shown in Figs. 5 and 6. The obtained results conclude that, the increment in the RHA percentage as replacement to the cement causes reduction in compression strength of concrete matrix. Figures 5 and 6 shows that, the RHA of 10% as a replacement to the cement is optimum and appreciable in terms of compressive strength. In case of RHA as the age of concrete increases, the compressive strength is reduced up to nearly 15%. But in case of GGBS the results are different, which shows increasing percent of GGBS as replacement to

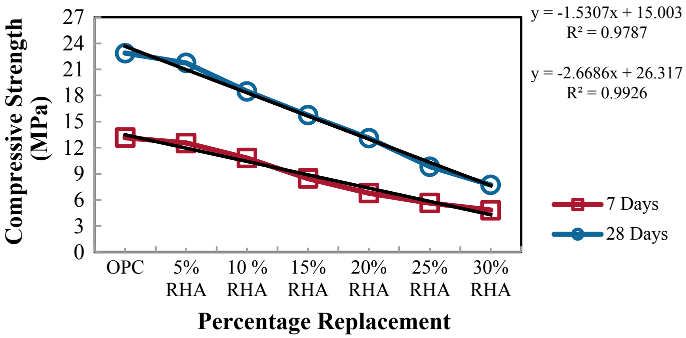

Fig. 5 Compressive strength versus Percentage replacement with RHA

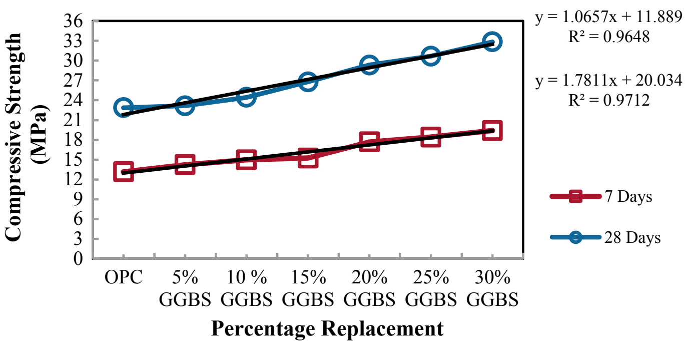

Fig. 6 Compressive strength versus Percentage replacement with GGBS

the cement increases strength of concrete in compression. The cement replacement up to 30% with GGBS is optimum and acceptable with respect to concrete compression strength. The compression strength is nearly increased up to 6–7% with increase in the age of concrete matrix. The developed model is used for the prediction of the concrete matrix compression strength containing supplementary cementitious materials (SCM) provides a useful design tool and, promotes environmental friendly concrete.

5.1.1 Binder Reactivity Effects with SCM on Strength of Concrete Matrix in Compression

The ordinary Portland cement and SCMs consists varying chemical compositions because of variation in their sources and types [10]. The above ternary diagram represents the chemical composition range based on percentage weight ratio for various types of binders. The diagram compares the chemical composition of SCMs with OPC and highlights the difference between compositions. When modeling the mechanical properties or proportioning design mix for conventional concrete, it becomes necessary to study the reactivity of binder materials. Practically, based on the experimental studies it can be observed that, the oxides of CaO, SiO_2, Al_2O_3, and Fe_2O_3 mainly contributes in the process of hydration for OPC [11–14]. The GGBS consists of comparable chemical composition with OPC and primarily contains CaO, SiO_2, Al_2O_3, and Fe_2O_3 oxides allowing GGBS with its self-binding properties [15].

5.1.2 Reactivity Assessment for SCMs

The reactivity for single SCM was effectively quantified considering following indices: Reactivity Modulus (RM), Silica Modulus (SM) and, Alumina Modulus (AM) represented in the following Eqs. (1), (2) and (3) respectively [15–18].

$$RM = \frac{[CaO + MgO + Al_2O_3]}{SiO_2} \tag{1}$$

$$SM = \frac{SiO_2}{[Al_2O_3 + Fe_2O_3]} \tag{2}$$

$$AM = \frac{Al_2O_3}{Fe_2O_3} \tag{3}$$

It can be noted that, the index RM evaluates the self-binding characteristics and AM and SM characterizes the pozzolanic reactivity of SCMs. The compressive strength of concrete (Fc) increases with an increase in the binder reactivity and minimizes with rise in the w/b ratio utilizes for the mix. The reactivity modulus of overall binder estimated by using following Eqs. (4)–(6);

Table 5 Results of compressive strength

SCM	Average compressive strength (28 days)	
	Experiment	Model
RHA	15.64	14.62
GGBS	27.15	26.13

$$RM = \frac{\sum_{k=1}^{n} [RM_k w]}{100} \tag{4}$$

$$SM = \frac{\sum_{k=1}^{n} [SM_K w]}{100} \tag{5}$$

$$AM = \frac{\sum_{k=1}^{n} [AM_K w]}{100} \tag{6}$$

where, RM_k and w is the modulus of hydration for each binder and, its weight. The combination of modulus showing pozzolanic and hydraulic behavior with *w/b* factor represents reactivity index (γ) as follows:

$$\gamma = \frac{[W_1 RM + W_2 AM + W_3 SM]}{(w/b)} \tag{7}$$

where, W_1, W_2 and W_3 are empirical constants with values 1.796, 0.002 and, 0.011 respectively. Depending on statistical analysis, the correlation uniting reactivity indices and the strength of concrete in compression including SCMs shown below [18];

$$F_c = U \cdot \gamma^V \tag{8}$$

The values of U and V are considered as empirical constants used in the above Eq. (8).

$U_{RHA} = 14.1$ and $V_{RHA} = -1.2$ and $U_{GGBS} = 5.3$ and $V_{GGBS} = 1$. The present study concludes that, the strength of concrete matrix in compression incorporated with SCMs is not only dependent on *w/b* factor of mix but also, based on their binder's reactivity (Table 5).

5.2 *Split Tensile Strength*

The split-tensile strength is an important property of conventional concrete because concrete structures are highly vulnerable to tensile cracking due to various kinds of effects and applied loading. The following graphs shows that, the split-tension strength for cubes at 7 and 28 days strength with respect to 0, 5, 10, 15, 20, 25, 30% of RHA and GGBS mix proportion. The trend line equations for 7 and 28 days split-tensile strength represent better performance with the values of R^2 nearly equal to 0.96 as a regression coefficient.

The obtained results of split-tension test on concrete samples with RHA and GGBS as partially replaced with cement were shown in Figs. 7 and 8. The split tensile strength of conventional concrete whose cement is replaced by GGBS reduces with rise in percentage GGBS for 28 days, while in case of 7 days for concrete matrix the spilt tensile strength attains maximum values with rise in replacement percentages of GGBS. In case of RHA, as the age of concrete increases the split tensile strength is reduced consistently. The concrete becomes harsh with increase in percentage replacement of cement using RHA and GGBS. Based on the experimental investigations, it was concluded that, to maintain concrete strength and workability the most optimized percentages as replacement to the cement by GGBS is 30% and in case of RHA is 10%.

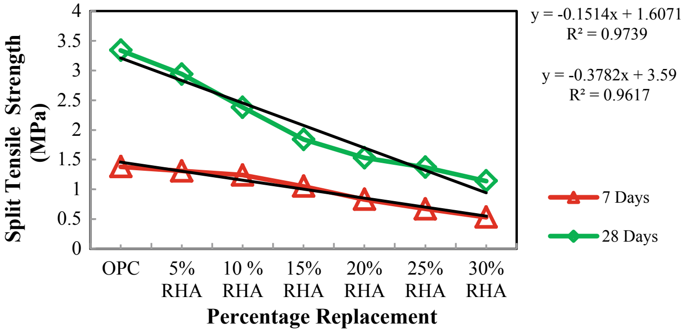

Fig. 7 Split-tensile strength versus Percentage replacement with RHA

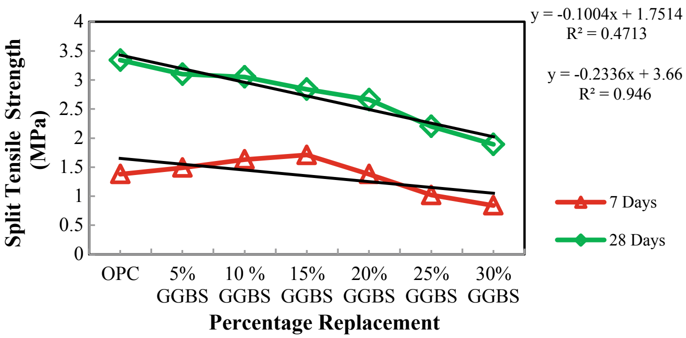

Fig. 8 Split-tensile strength versus Percentage replacement with GGBS

6 Conclusions

Depending on the experimental study on conventional concrete with RHA and GGBS, the notable conclusions are reported that, the GGBS and RHA are the appropriate cement replacement materials in order to safeguard environment from bitter effects of cement manufacturing process. The cement replacement using GGBS not only accelerates the compression strength but also, reduces the cement content which diminishes emission of CO_2. The strength of concrete in compression attains higher values with the addition of GGBS up to certain extent but in case of addition of RHA, it is discovered that, compressive strength of concrete decreases. The performance of the concrete is exceptionally magnificent in case of compressive and split tensile strength of concrete. However, beyond 30% of replacement of GGBS and 10% of replacement of RHA the strength decreases as well as performance of concrete dwindles. The experimental study represents that, most optimized percentages of replacement for cement by GGBS as 30% and in case of RHA, it is found to be 10%. Therefore, the partially replacement of ordinary Portland cement using GGBS &RHA is not only economical but also, makes provision for environmental friendly disposal of agricultural and an industrial residue which attains sustainable development in concrete industry. Thus, the incorporation of RHA and GGBS in concrete matrix proved suitable for sustainable development, as a result solving the adverse impacts during cement preparation like emission of CO_2, consumption of resources, economy and, problems regarding waste disposal for agricultural and industrial wastes to a certain limit. The developed model is used for the prediction of the concrete matrix compression strength containing supplementary cementitious materials (SCM) provides a useful design tool and, promotes green concrete applications and contributing to experimental friendliness.

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