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EFFECT ON WORKABILITY, COMPRESSIVE, AND TENSILE STRENGTH OF GEOPOLYMER CONCRETE INCORPORATED WITH QUARRY ROCK DUST, FLY ASH, AND SLAG CURED AT AMBIENT AND ELEVATED TEMPERATURES

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Abstract-This paper presents the effect of ambient (27°C) and heat (100°C) curing on the properties viz. workability, compressive, and tensile strength of quarry rock dust (QRD) based geopolymer concrete (GPC) comprising fly-ash (FA), and slag (SG) as a binder. The SG was replaced with QRD up to 20% by weight to develop QRD-SG-FA based geopolymer concrete (QFS-GPC). A total of 12 types (6 cured at ambient and 6 cured at 100°C) of mixes were prepared and tested. The workability of the mixes was reduced by the replacement of SG with QRD. The ambient cured GPC-D27°C and oven-cured GPC-D100°C mixes with FA/SG contents of 50/35% and QRD of 15%, yielded the maximum compressive strength of 33.55MPa and 35.45MPa respectively. The strength properties i.e., compressive, and splitting tensile strengths of the above optimal mixtures have shown improved strength by curing at higher temperature and have depicted more strength than the control OPC concrete specimens.

Keywords- Ambient temperature curing, elevated temperature curing, geopolymer concrete, quarry rock dust.

1. Introduction

Nowadays, construction activities have been increasing to meet infrastructure demand. It can be observed that ordinary Portland cement (OPC) concrete is an essential and broadly used construction material in most construction activities. During the manufacturing process of OPC, a huge amount of carbon dioxide (CO_2) is released into the atmosphere through the transformation of raw material and fuel consumption. The second-largest source of production of greenhouse gases in the cement industry [1]. [2]. The manufacturing of OPC contributes about 5% of CO_2 emission globally [3]. Therefore, an alternative finding for OPC concrete has been a challenging task for researchers and environmentalists. It is essential to work on feasible and better solutions, which can utilize industrial solid wastes to yield alternative binder materials. Alkali activated geopolymer concrete (GPC) is a relatively new technique in the construction industry that has been becoming popular due to its mechanical properties and eco-friendly benefits. The geopolymers are good solutions to reduce and support the effective use of waste materials [4]. The geopolymers can play a significant role in reducing the low emission of CO_2 in comparison to OPC in the construction industry [5]. In general, the geopolymers are classified as alumino-silicate, an inorganic polymer manufactured from the alkaline activation of different aluminosilicate constituents of geological source or industrial by-product wastes like metakaolin, slag (SG) and, fly ash [6][7].

It is described that the production of GPC with low calcium FA at elevated temperature curing resulted in superior mechanical properties [8] which restricts its usage to precast structural members only. However, at ambient curing conditions, these results are comparatively less promising. It was due to the polymerization procedure which proficiently holds at elevated temperature and directs to the development of sodium aluminate silicate hydrate (NASH) calcium aluminate silicate hydrate (CASH) [9]. In few studies, by adding calcium-rich materials such as alcofine [9], SG [10], etc. the reactivity of low calcium FA was improved at ambient curing conditions. It has been remarked that SG and FA blended GPC mixes proved good resistance to high temperature [11] and displayed heightened shrinkage [12]. It is also described in experimental work that calcium comprising ingredients accelerate the rate of geopolymrization at ambient curing conditions, minimize the pore sizes in the mixture and produce the compressed composite with better mechanical properties [13][14].

The quarry rock dust (QRD) is a dumped residue and calcium-containing substance which can be utilized as a partial alternative to filler or binder material in GPC. This can assist in the reduction of land and environmental pollution by preventing its deposition at landfills. From the previous studies, it was noticed that mostly QRD has been utilized as a partial substitute of sand in geopolymer mortar [15] and cement concrete [16][17]. However, the research studies on QRD as a partial alternative of binding material in geopolymer concrete are rather limited. Therefore, the present research study investigates the effect of QRD as partial replacement of SG on fresh and mechanical properties of QRD-FA-SG based GPC (QFS-GPC) cured at ambient (27 °C) and elevated (100°C) temperature conditions. To accomplish this, a series of GPC mixes were planned by differing the amount of QRD (to partially substitute SG) in QFS-GPC as shown in Table 1. The tests were later performed to find an optimal mix considering workability and mechanical properties viz. compressive and splitting tensile strength.

2. Experimental Methodology

A total of ten types of mixes of QFS-GPC were designed as described in Table 1, with varying dosage (0%, 5%, 10%, 15%, and 20%) of QRD, partially substituting SG (by weight of binder), while maintaining all ingredients the same in all the mixes. For the sake of comparison, two OPC concrete mix types were also considered as control mixes to observe the differences and improvements, if any. Thus, a total of 12 mix types were prepared. The engineering properties (i.e., fresh, and mechanical) of control mix (OPC) and QFS-GPC mixes were evaluated by slump test, compressive, and splitting tensile strengths tests. According to ASTM standard C143/C143M-20 [26], the workability of fresh concrete was determined by performing a slump cone test. A universal testing machine (UTM) with a load capacity of 3000 KN was used for testing of cylinders and cubes at the rate of 8 KN/s after 7, 28, and 56 days of casting to determine split tensile and compressive strengths according to ASTM C496/C496M-17 [27] and BS EN 12390-5-2019 [28] respectively.

2.1. Materials specifications and mixing of ingredients.

In the present study, the type II OPC confirming to ASTM standard C-150/C150M-20 [18] for OPC concrete; and three binders i.e., QRD, FA, and SG were used in various proportions in the preparation of QFS-GPC mixes. The low calcium FA of class F (Grey color) confirming the requirements of ASTM C618-19 [19] was used. It is a preferred source over high calcium FA due to the high calcium effect on the polymerization process [19]. The grinded QRD was sieved through a 45μm sieve confirming the finess of particles used in the GPC production as a binder [20]. The off-white processed SG justifying the ASTM C989/C989M-18a was used [21].

In the present study, the alkaline solution was prepared by mixing sodium hydroxide (SH) and sodium silicate (SS). The molar solution of SH (12M) was prepared 24 hours before use, by gradually mixing 98% pure flakes in the potable water. The solution of SS was mixed with SH solution 30 minutes before its usage. The natural river sand obtained from Lawrancepur (near Attock) was used as fine aggregates. The coarse aggregates were supplied from Margallah hills crushers. The finess modulus of sand was verified to ASTM C136/C136M-19 [22] while the water absorption and specific gravity were according to ASTM C128-15 [23]. The specific gravity of coarse aggregates was as per recommendations of ASTM C127-15 [24]. The alkaline solution is generally viscous than water, hence its usage makes the GPC mixes stickier and more viscous than OPC concrete mixes. Therefore, to increase the workability of freshly GPC mixes, a Naphthalene Sulphonate grounded superplasticizer conforming ASTM C494/C494M-19 [25] was utilized in the present study. The mix proportion for 1 kg/m^3 of OPC and GPC is shown in Table 1.

Table 1. The composition and proportions of OPC and GPC mix used in the study.

Group. No.	Group ID	Curing Temperature (°C)	Mixture proportions								Concrete mixture quantity (kg/m^3)											
			Binder																			
			C %	FA %	SG %	QRD %	AAL/B Ratio	W/C Ratio	Molarity of SH (M)	SS/SH Ratio	B	C	FA	SG	QRD	SH	SS	S	CA (10 mm)	CA (20mm)	SP	Water
1	OPC-27 °C	27 °C	100	-	-	-	-	0.35	-	-	400	400	-	-	-	-	-	680	751	340	10	140
2	OPC-100 °C	100 °C	100	-	-	-	-	0.35	-	-	400	400	-	-	-	-	-	680	751	340	10	140
3	GPC-A 27 °C	27 °C	-	50	50	0	0.50	-	12	1.5	400	-	200	200	0	80	120	680	751	340	10	35
4	GPC-A 100 °C	100 °C	-	50	50	0	0.50	-	12	1.5	400	-	200	200	0	80	120	680	751	340	10	35
5	GPC-B 27 °C	27 °C	-	50	45	5	0.50	-	12	1.5	400	-	200	180	20	80	120	680	751	340	12	35
6	GPC-B 100 °C	100 °C	-	50	45	5	0.50	-	12	1.5	400	-	200	180	20	80	120	680	751	340	12	35
7	GPC-C 27 °C	27 °C	-	50	40	10	0.50	-	12	1.5	400	-	200	160	40	80	120	680	751	340	14	35
8	GPC-C 100 °C	100 °C	-	50	40	10	0.50	-	12	1.5	400	-	200	160	40	80	120	680	751	340	14	35
9	GPC-D 27 °C	27 °C	-	50	35	15	0.50	-	12	1.5	400	-	200	140	60	80	120	680	751	340	14.5	35
10	GPC-D 100 °C	100 °C	-	50	35	15	0.50	-	12	1.5	400	-	200	140	60	80	120	680	751	340	14.5	35
11	GPC-E 27 °C	27 °C	-	50	30	20	0.50	-	12	1.5	400	-	200	120	80	80	120	680	751	340	14.5	35
12	GPC-E 100 °C	100 °C	-	50	30	20	0.50	-	12	1.5	400	-	200	120	80	80	120	680	751	340	14.5	35

***Note*:** W (Water): B (Binder); C (Cement): OPC (Ordinary Portland Cement); AAL (Alkaline Activator Solution); QRD (Quarry Rock Dust); SG (Ground Granulated Blast Furnace Slag); FA (Fly Ash); SH (Sodium Hydroxide); SS (Sodium Silicate); M(molarity); SP (Superplasticizers); S (Sand); CA (Coarse Aggregates).

For the preparation of mixes, all the ingredients including aggregates (fine and coarse), and binders (OPC or QRD, FA, and SG) were dry mixed uniformly in the mechanical mixer having the capacity of 0.15m3 and speed of 20 rev/m for 2 minutes. Before the mixing, the saturated surface dry (SSD) condition of fine and coarse aggregates was obtained. The solution of SH was prepared 24 hours before its application [9] due to exothermic reaction produced during its preparation and mixed 30 min before with SS solution at a required ratio of 1.5 to enhance the reactivity of the solution [10]. Afterward, the premixed alkali-activated solution was added progressively, and mixing continued for another 2-3 minutes to ensure the uniformity of the mixture. Finally, the extra water and superplasticizer (SP) were added to the fresh mixture to achieve the required workability.

The moulds of cubes (150mm x 150mm x 150mm), and cylinders (150mm x 300mm) were filled in three layers with the freshly prepared concrete mix. A vibrator was used for compaction. The freshly casted specimens were placed in the laboratory at ambient and in an oven at 100°C temperature for 24 hours. After demoulding, the OPC and QFS-GPC specimens were kept in a water tank and direct sunlight for water and air curing respectively for 7, 28, and 56-days for testing. Three samples for any test of a mixed type were cast and the average value was used in the results.

3. Results and Discussions

The results of workability, compressive, and splitting tensile strengths are discussed in the following subsections.

3.1. Workability

The ease of positioning and placement of freshly made concrete is known as workability. The slump test on freshly prepared OPC and QFS-GPC mixes was performed according to ASTM standard C143/C143M-20 [26]. The values of the slump test are shown in Figure 1. The workability of QFS-GPC mixes was observed lower than OPC mixes due to the sticky and viscous properties of SH and SS solution [28]. In the present study, the target medium workability standard (50 to 89 mm) [29] was followed. The workability decreases by replacement SG with QRD in the QFS-GPC mixes due to the angular shape of QRD [15] than SG and FA particles that increase water requirement. The target medium workability standard was maintained by an equal amount of extra water for all QFS-GPC mixes and a varying amount of super-plasticizer [25]. The results of workability achieved for OPC and QFS-GPC mixes are shown in Figure 1.

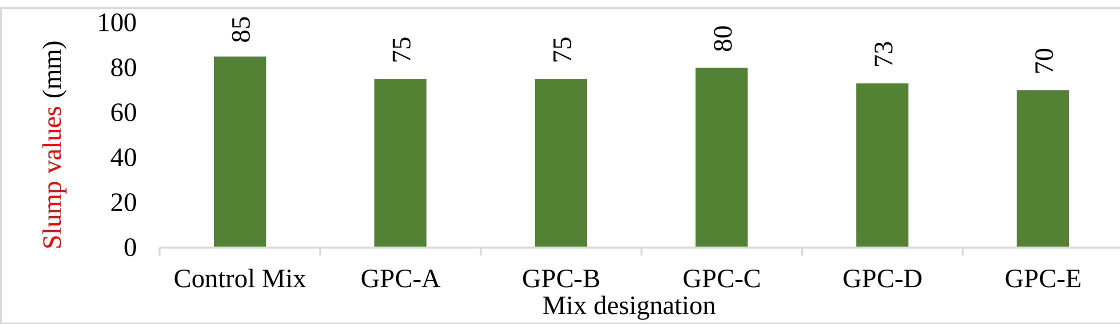

Figure 1: The slump values of control (OPC) and QFS-GPC mix to the target slump (medium workable) after supplementing varying quantities of SP.

3.2. Compressive strength

The compressive strength results of OPC and QFS-GPC mixes cured at ambient (27°C) and elevated temperature (100°C) are shown in Figure 2. From the Figure 2, it can be observed that the 56- days cured OPC, GPC-A, GPC-B, GPC-C, GPC-D and GPC-E specimens at elevated temperatures have 7.97%, 14.45%, 4.27%, 7.76%, 5.67%, and 19.82% respectively better compressive strengths than at ambient cured specimens. It is also observed that the compressive strength of QFS-GPC mixes increases as the replacement levels of QRD contents increase but up to 15%, after which it decreased. It can be due to the increasing quantity of calcium-rich materials which hasten the rate of the polymerization process at room temperature (ambient) as well as at elevated temperature (100°C) and lessen the pore sizes. The specimens cured at elevated temperatures have higher strength due to better polymerization than the ones cured at ambient temperature. The effect of calcium-rich materials on the strength properties has also been described by other researchers at ambient [10,13-14] and elevated temperatures [8,11]. The increase in compressive strength is due to higher calcium oxide contents (in QRD) [13]. When the QRD contents increased from 15% to 20% (as in GPC-E27°C and GPC-E100°C), the QFS-GPC mix becomes least workable. The decrease in compressive strength can be due to excess lime quantity and an incomplete polymerization process [30]. The maximum strength was achieved by the GPC-D mix with 50% FA, 35% SG, and 15% QRD contents. After 56-day testing, the optimal mix GPC-D27°C and GPC-D100°C has 11.35% and 8.9% more compressive strength than the control mix (OPC mix) cured at ambient (27°C) and elevated (100°C) temperature respectively due to better polymerization process.

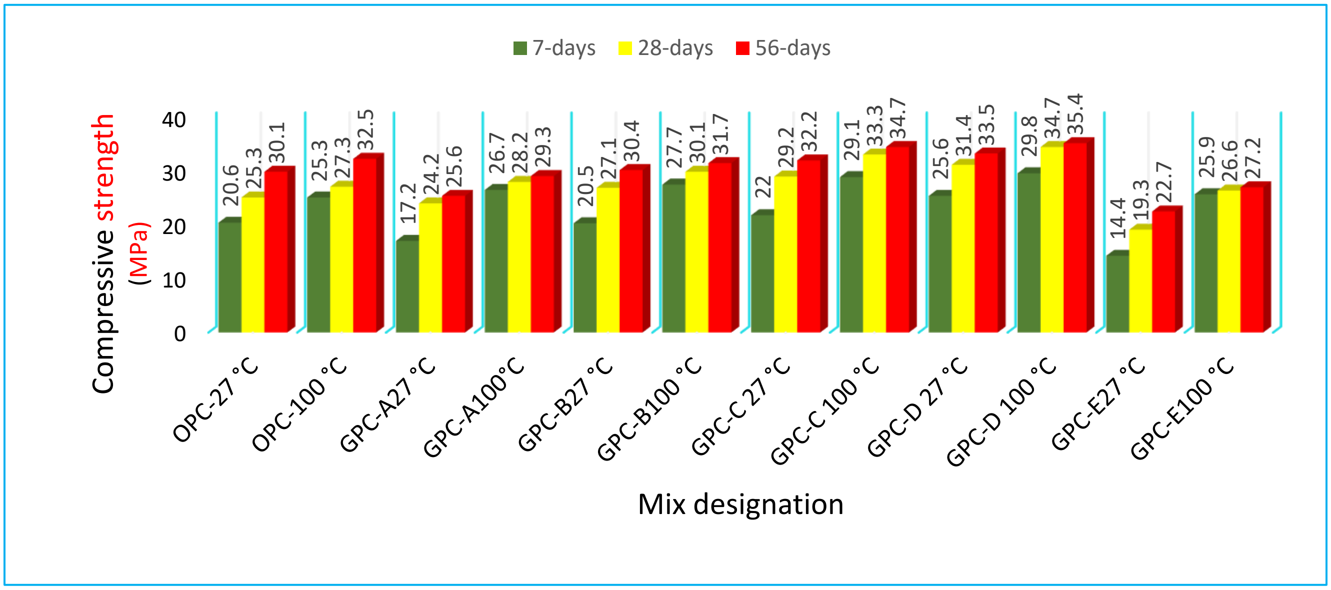

Figure 2: The compressive strength results of OPC and QFS-GPC mix at ambient and elevated temperatures

3.3. Splitting tensile strength

The results of split tensile strength are shown in Figure 3. From the figure, it can be noticed that the trend of increase in split tensile strength behavior is the same as was observed for the compressive strength results. The split tensile strength has improved as QRD contents increased in the QFS-GPC mixes up to 15%. The replacement level of SG with QRD beyond 15% has caused the reduction of split tensile strength. The increase of calcium-carrying blends (mostly CaO with an increase in QRD up to 15%)in the binders has caused improvement in the strength of QFS-GPC specimens at all ages which produced a reaction product for both FA and SG [32].The replacement levels of QRD beyond 15% have caused the reduction of tensile strength due to the deficient polymerization process [14]. After 56-day testing, the ambient cured GPC-D27°C and elevated temperature cured GPC-D100°C mix have slightly more i.e., 1.43% and 1.89% tensile strengths than the control mix specimens respectively. The mix GPC-D27°C and GPC-D100°C with the tensile strength of 2.12 MPa and 2.15 MPa were considered as the optimal QFS-GPC mixes cured at ambient and elevated temperatures respectively.

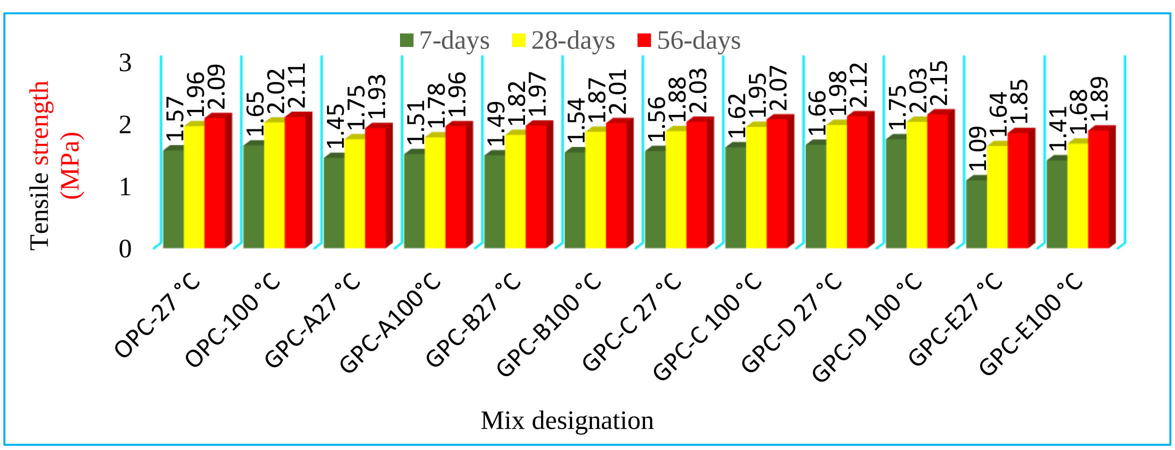

Figure 3: The splitting tensile strength results of OPC and QFS-GPC mix at ambient and elevated temperatures

4. Practical Applications

In general, GPC has restricted field applications due to heat curing for accomplishing a superior and better strength. Due to this reason generally, the precast structural units of GPC have been manufactured and applied in field applications. However, with the inclusions of calcium-rich materials (binders) like QRD, SG, and lime, the production of GPC at ambient curing conditions with better strength properties has become possible. The ambient curing conditions also lessen the energy consumed and costs related to heat curing.

5. Conclusions

The following conclusions can be drawn from the present study:

- The workability of QFS-GPC mixes decreases as the incorporation of QRD contents increases.
- The mechanical properties of QFS-GPC mixtures usually increased by incorporating the QRD content from 0% to 15% and beyond this replacing level i.e., 20% with SG, strength was reduced.
- The optimum (maximum) strength properties i.e., compressive, and split tensile strength of specimens cured at 27°C and 100°C were obtained by GPC-D27°C and GPC-D100°C with 15% QRD contents by weight of total binder respectively.

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