EXPERIMENTAL STUDY ON THE PERFORMANCE OF GEOPOLYMER CONCRETE WITH SURFACE MODIFIED RECYCLED CONCRETE AGGREGATES

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Abstract: In the present scenario, an increase in population and infrastructure development leads to the generation of lots of construction and demolition waste(C&D) and industrial waste products in to the environment. The Geo-polymer concrete (GPC) is an eco-friendly promising technology which eliminate the use of ordinary Portland cement (OPC) with the industrial waste or by-products as a binding material which is rich in alumina and silica. An attempt has been made in this study to investigate the behaviour of ground granulated blast furnace slag (GGBFS) based GPC incorporating surface modified recycled concrete aggregate(RCA) with pre-soaking technique. The sodium hydroxide (NaOH) and sodium silicate (Na_2Sio_3) was used as alkaline activators to replace the water. The molarity of NaOH varied from 8M to 14M.The alkaline solution to binder ratio was taken as 0.45 and 0.5 with Na_2Sio_3 to NaOH ratio as 2.5. An experimental results reveal that the compressive strength of GPC was maximum with recycled coarse aggregates pre-soaked with 30% mixture of GGBFS with water.

Keywords- Recycling of waste concrete, Global warming, Conservation of natural resources, geopolymer concrete.

1. INTRODUCTION

The Ordinary Portland cement concrete (OPC) is the one of the foremost construction material used in the construction sector worldwide. The demand for concrete is expected to grow to 18 billion tons a year globally by 2050 (Mehta et al. 2006). The production of constituents of concrete such as cement and aggregates results in negative impacts on the environmental sustainability. The cement industry is the second largest producer of the greenhouse gas. The production of concrete also consumes enormous quantity of freshwater (approximately 1 trillion L every year) for mixing and curing process raising a water shortage (Mehta 2001). The over exploitation of natural aggregates has also been increased. Meanwhile an enormous amount of construction and demolition waste (C&D) is generated due to structural flaws and natural disaster. These C&D waste are dumped into the land and water bodies. It causes choking of water bodies and shortage of land surfaces. The usage of recycled concrete aggregate (RCA) has gained momentum in construction sectors recently. The utilization of recycled concrete waste would benefit into two folds. First, it reduces the environmental pollution and second conserves the natural resources (Tam et al.2007, Akash Rao et al 2006).

The negative impacts due to the production of concrete and C&D waste on the environment can be minimized by replacing these materials by using geopolymer concrete (GPC). The term Geopolymer was invented by Joseph Davidovits in 1978. Geopolymer consists of two main components such as the source material rich in alumina and silica and alkaline activators. The source materials from natural materials and industrial by-products like metakaolin, fly ash, ground granulated blast furnace slag, red mud, mine waste etc can be used (Rahimah et al., 2015). The polymerization process involves a chemical reaction of alumina-silicate minerals under alkaline condition that results in a three dimensional polymeric chain it binds the aggregates together (Hardjito 2005,Davidovits 2008, Duxson et al 2007).

In geopolymerisation, alkaline activators play a vital role (Rangan 2008, Wallah et al 2006).The sodium or potassium based alkaline activators with soluble alkalis can be used. Sodium hydroxide (NaOH) in combination with sodium silicate (Na_2SiO_3) is the commonly used alkaline activator to develop GPC (Kong et al 2008).The use of geopolymer technology has several benefits. The Natural resources can be conserved by utilizing the RCA as a coarse aggregate and global warming due to CO_2 emission from the cement industry can be reduced to save our environment. The utilization of industrial waste products leads to conserve the land and water resources used for dumping.Geopolymers are potentially used to dispose a toxic waste and recycling a large variety of industrial wastes rich in alumino-silicate materials (Ahmari et al 2013).Geopolymers are gaining increased interest for its low CO2-emission in comparison to OPC (Yang et al 2013).

2. LITERATURE REVIEW

Many authors have studied the various factors affects the physical, mechanical and durability properties of GPC with RCA and compared it with that of NA. Available literatures on GPC with RCA are summarised and discussed.
Anuar et al (2011) have studied the strength characteristics of GPC containing RCA. In this study Waste Paper Sludge Ash (WPSA) as a binder and alkaline liquid are being used to replaced the Portland cement to produce GPC.They concluded that GPC containing WPSA will set faster and rapidly hardened compare to GPC containing Fly Ash. It happens because of WPSA containing higher number of calcium in chemical composition compare to the fly ash. The higher concentration of NaOH

solution, higher compressive strength of GPC will produce because the higher concentration of NaOH will make the good bonding between aggregate and paste of the concrete.

Shi et al (2012) have analysed the mechanical properties and microstructures of GPC and compared with different RCA replacement ratios. The features of aggregates, paste and interfacial transition zone (ITZ) were compared and discussed. The Experimental results indicate that using alkali-activated fly ash GPC as replacement of OPC effectively improved the compressive strength. With increasing of RCA contents in both RAC and GRC, the compressive strength decreased gradually. The microstructure analysis shows that, on one hand, the presence of RCA weakens the strength of the aggregates and the structure of ITZs; on the other hand, due to the alkali-activated fly ash in GPC, the contents of Portlandite ($Ca(OH)_2$) and voids were reduced, as well as improved the matrix homogeneity. With more RCA, the compressive strengths of RAC and GRC are decreased.

Ridzuan et al (2015) carried out an investigation on the effect of NaOH concentration and curing condition to the strength and shrinkage performance of GPC with RCA. The authors have arrived at a conclusion stating that the molarities of NaOH influenced the strength of WPSA based GPC produced incorporating with increasing of RCA. The high concentration of NaOH solution will improve the compressive strength properties of GPC produced because the higher concentration of NaOH produced the good bonding between aggregate and paste of the concrete. The result also shows that the GPC undergoes very low shrinkage. Curing condition will also affect the strength of GPC produced.

Shaikh et al (2016) examined the effect of RCA on the mechanical and durability properties of fly ash based GPC. The results show that the inclusion of RCA as a partial replacement of NCA in GPC adversely affects its compressive and indirect tensile strengths and elastic modulus at 7 and 28days curing ages. The above properties decrease with an increase in the RCA contents. This study also shows that the current sustainable concrete containing a partial replacement of OPC with supplementary cementitious materials and RCA as a partial replacement of NCA can further be extended to OPC less sustainable concrete with 50% less NCA without sacrificing much of the properties of current sustainable concrete.

Nuaklong et al (2018) made an investigation on the effect of RA on strength of high calcium fly ash GPC with inclusion of OPC and nano-SiO_2. In this study, the use of ordinary Portland cement (OPC) and nano-SiO_2 (nS) to improve the mechanical and durability properties of recycled aggregate geopolymer concrete (RAGC) was evaluated. The results indicated that the inclusion of OPC enhanced the compressive strength and reduced the water absorption, porosity, as well as the penetration of chloride. It was found that the nano-SiO_2 has an adverse effect on other durability properties. The results clearly showed that the addition of nano-SiO_2 into RAGC was inferior for acid and chloride resistance; moreover, increasing nS addition leads to more deterioration from acid attack and increased chloride penetration.

Zhang et al (2018) experimentally studied the interfacial transition zone (ITZ) between geopolymer binder (GP) and RCA. The results reveal that the water to solid (W/S) ratio has an important effect on the bond strength of the different ITZs. Higher W/S ratio decreases the bond strength of the GP-based ITZs and the OPC-NA ITZ due to the more porous microstructure at higher water content.

Xie et al (2019) assessed the Physico-chemical properties of alkali activated GGBFS and fly ash geopolymeric recycled concrete (GRAC). They concluded that the combination of fly ash and GGBFS based geopolymer and RCA can provide an excellent compression resistance in concrete. GPC with RCA required more water than that with NA in order to maintain the equivalent workability. Pre-wetted RCA content had a slight impact on the workability of GRAC and a much shorter setting time than conventional concrete.

Wang et al (2020) studied the optimum initial curing condition for fly ash and GGBFS based geopolymer recycled aggregate concrete (GRAC). The results show that the initial curing under 80^{o} C for 12–24 h is the optimum curing condition, under which the GRAC had the highest compressive strength, elastic modulus and toughness, evidenced by more ettringite formed and a denser microstructure.

It is evident from the above that many researchers have studied the application of RCA in GPC. However the inferior quality of RCA has lowered the strength of GPC. It is already established that RCA is porous in nature due to the adhered mortar on it. In this study an attempt is made to utilize this porous characteristic of RCA for improving the surface by pre-soaking technique.

3. EXPERIMENTAL WORK

3.1 Surface Modification of RCA

The Crushed concrete cubes obtained from Pondicherry Engineering college laboratory was collected and crushed. The aggregate from the crushed specimen was used as a recycled concrete aggregates (RCA) is shown in Figure 1.The coarse RCA was pre-soaked into the mixture prepared with 10%, 20% and 30% of GGBFS mixed with the potable water for 24hrs is shown in Figure 2. After 24 hrs, the pre-soaked aggregates were dried as shown in Figure 3. The dried coarse aggregates were coated with GGBFS particles as shown in Figure 4. RCA is more porous compared to NA due to adhered mortar in RCA; it absorbs more amounts of GGBFS particles in the pores. It was evident in SEM images as shown in Figure 5.

Figure 1: Production of RCA from crushed concrete cubes

10% GGBFS mixture with water 20% GGBFS mixture with water 30% GGBFS mixture with water

Figure 2: Pre-soaking of RCA for 24hrs

10% GGBFS mixture with water 20% GGBFS mixture with water 30% GGBFS mixture with water

Figure 3: Drying of RCA for 24hrs.

10% GGBFS mixture with water 20% GGBFS mixture with water 30% GGBFS mixture with water

Figure 4: surface modified recycled concrete aggregate (RCA-SM) with GGBFS particles

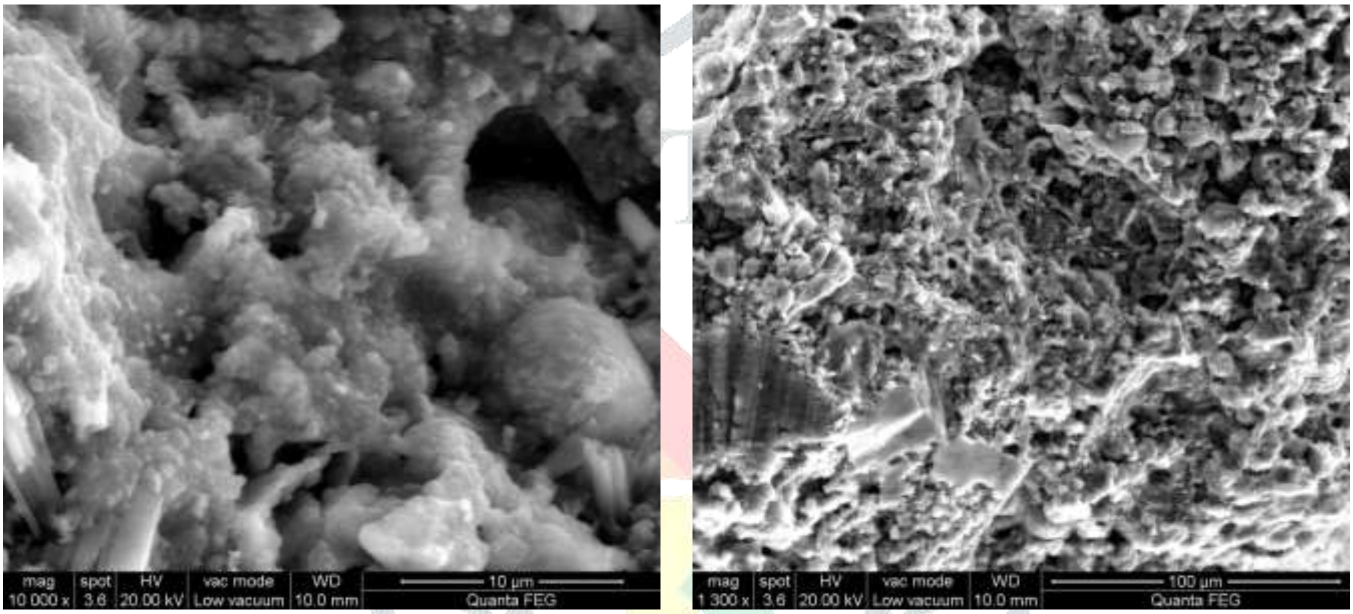

Figure 5: Microstructure of Surface modified RCA

3.2 Materials Used

The NA, RCA, and surface modified recycled concrete aggregate (RCA-SM) was used as a coarse aggregate. The coarse aggregates passing through 16mm and retained on 10mm and passing through 10mm and retained on 4.75mm sieves were used for this experimental work. The properties of NA and RCA are presented in Table 1. Locally available river sand passing through 4.75mm belongs to Zone I conforming to IS: 383-2016 was used as a fine aggregate. A Commercially available GGBFS was obtained from Astraa Chemicals, Chennai Tamil Nadu India was used as the main source of alumina-silicate material to replace OPC. The properties of GGBFS are presented in Table 2. Na_2Sio_3 solution with SiO_2 to Na_2O ratio by mass approx 2.0 (Na_2O = 14.7%, SiO2 = 29.4% and water = 55.9%) and the NaOH with 97-98% purity, in pellet form was used as a alkaline activators.

Table 1: Properties of coarse aggregates

S.No	Property	NA	RCA	RCA-SM
1	Specific gravity	2.73	2.28	2.42
2	Water absorption%	0.70	7.65	5.84
3	Bulk density kg/m^3	1506	1210	1320

Table 2: Properties of GGBFS

S.No	Properties	Value
Physical properties		
1	Colour	Off White
2	Specific Gravity	2.8
3	Shape	Spherical
Chemical properties		
4	Sio_2	32.84%
5	CaO	30.25%
6	MgO	32.75%
7	Al_2O_3	7.73%
8	Fe_2O_3	14.06%
9	LOI	2.85

3.3 Mixture Proportions

The alkaline solution to binder (AL/B) ratio was taken as 0.45 and 0.5. The Na_2Sio_3/ NaOH ratio was taken as 2.5. The molarity of NaOH was varied from 8M, 10M, 12M and 14M. The composition of designed mixture is presented in Table 3.

Table 3: Composition of designed mixture for Na_2Sio_3/ NaOH=2.5

Molarities of NaOH	GGBFS (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Mass of NaOH solids (kg/m^3)	Mass Water (kg/m^3)	Mass of Na_2Sio_3 solution (kg/m^3)
Alkaline/Binder=0.45						
8M	414	810	990	14	40	133
10M	414	810	990	17	37	133
12M	414	810	990	19	34	133
14M	414	810	990	22	32	133
Alkaline /Binder=0.5						
8M	400	810	990	15	43	143
10M	400	810	990	18	40	143
12M	400	810	990	21	37	143
14M	400	810	990	23	34	143

3.4 Specimen Preparation and Curing

A mixture of GGBFS with water was sufficiently prepared such that the required quantity of RCA was completely pre-soaked. The NaOH and Na_2Sio_3 of desired quantity were mixed together one day before the specimen preparation to minimize the heat from the NaOH solution. The GGBFS and aggregates were dry mixed thoroughly in the mixing pan. The premixed alkaline activator solution was then added gradually in to the mixer. Mixing was continued for 3–5 min to achieve a uniform mixing. As the fresh GPC mixture was not workable. In order to obtain a workable mixture 2% of naphthalene based super plasticiser and 10-15% of extra water were added. The Cubical concrete moulds were filled with concrete and compacted on a vibrating table. The specimens were kept under oven curing at 60^oC for 24hrs.

3.5 Testing of specimen

The oven cured GPC specimens were taken out and kept at ambient temperature before testing. These GPC specimens were crushed using compression testing machine with 1000KN capacity available in the laboratory.

Figure 6: Oven curing of specimens at 60°C for 24 hrs

Figure 7: Compression testing machine

4. RESULTS AND DISCUSSION

4.1 Compressive strength

Compressive strength of different GPC mixtures was determined after 24hrs of oven curing at 60°C.The test results are shown in Figure 8 and 9.It is evident from these figures that the compressive strength of GPC prepared with NA was higher compared to GPC with RCA and RCA-SM. The compressive strength of GPC with RCA without surface modification was lesser compared to GPC with NA and RCA-SM. On comparing the compressive strength of GPC mixtures it is observed that, similar trend of results are observed at all molarities of NaOH. The compressive strength of GPC with 10% pre-soaked RCA-SM was lesser compared to 20 and 30%. The compressive strength of GPC with 20% pre-soaked RCA-SM was higher compared to 10% and lesser than 30%. The compressive strength of GPC with 30% pre-soaked RCA-SM was higher compared to 10% and 20%.

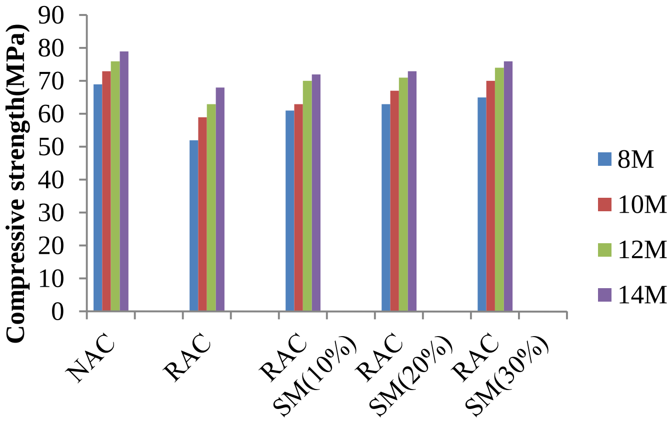

Figure 8: The effect of compressive strength GPC prepared with aggregates(NA,RCA, RCA-SM pre-soaked in 10 %,20% and 30% of mixture of GGBFS with water) AL/B=0.45, Na_2Sio_3/ NaOH=2.5

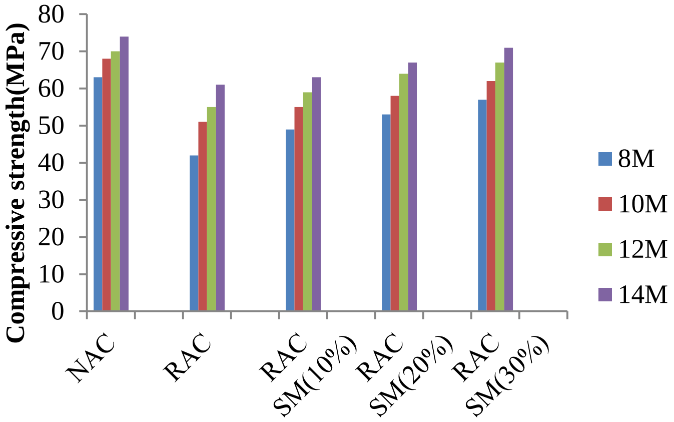

Figure 9: The effect of compressive strength GPC prepared with aggregates(NA,RCA, RCA-SM pre-soaked in 10 %,20% and 30% of mixture of GGBFS with water) AL/B=0.5, Na_2Sio_3/ NaOH=2.5

5. CONCLUSIONS

An experimental study was conducted to investigate the effects of surface modification technique on fresh and hardened properties of GGBFS based GPC with RCA as a coarse aggregate. The following salient conclusions are drawn from this experimental study.

1. The specific gravity of RCA is considerably lesser than that of NA, whereas the water absorption of RCA is much higher than that of NA due to the presence of adhered mortar contained on it. Surface modification by means of pre-soaking is contributing towards the improved quality of RCA.
2. Compressive strength was increased with increase in molarities of NaOH.
3. The concentration of GGBFS plays an important role in the surface modification technique. However with the increased concentration (above 30%) the uniform dispersion of GGBFS not guaranteed. This leading to the settlement of GGBFS at the bottom of the mixture. Therefore the maximum of 30% of GGBFS quantity in the mixture is advisable for efficient surface modification.
4. The compressive strength of GPC with 10% pre-soaked RCA-SM was lesser compared to 20 and 30%. The compressive strength of GPC with 20% pre-soaked RCA-SM was higher compared to 10% and lesser than 30%. The compressive strength of GPC with 30% pre-soaked RCA-SM was higher compared to 10% and 20%.

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