Development of Light Weight Rubberised Geopolymer Concrete by Using Polystyrene and Recycled Crumb-Rubber Aggregates

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Abstract—***An environmentally friendly concrete is of high insert to develop because the production of pot land cement as the main binder of conventional concrete is associated with generating a large amount of carbondioxide. As a green and illegible alternative to conventional concrete geopolymer concrete (GC) has been invented and studied over the past 2 decades. This environmental study was aimed to take one step further by examine the possibility of developing light weight, rubberized and light weight rubberized geopolymer concrete. In the first step, a control mix was established for GC suitable to be cored at ambient temperature as it is necessary to promote its usage in the construction industry. Afterward, light weight geopolymer concrete (LWGC) was developed by replacing fine aggregates with expanded polystyrene beads (called BST) at 25%, 50%, 75% and100% ratios by volume. Then rubberized geopolymer concrete (RGC) was produced by 10% and 20% natural aggregates replacement by volume by width crumb-rubber (CR) aggregate, which is another pollution source to the global environment. Finally the possibility of developing lightweight rubberized geopolymer concrete (LWRGC) was examined using BST and CR aggregates. The performance of developed GCS and hence reduced the need for cement manufacture as well disposal of end life tires.***

Keywords—Carbon dioxide, GC, light weight rubberized, polystyrene beads, BST, RGC, CR, LWRGC, GCS, global

I. INTRODUCTION

The production process of ordinary Portland cement (OPC) not only consumes plenty of energy and natural resources, but also emits large quantities of carbon dioxide. A host of researchers have done abundant work in search of an environmentally friendly alternative binding material. Davidovits proposed new materials and techniques, named geopolymer and was treated as the most promising alternative materials to OPC. Geopolymers, generally made from materials such as metakaolin, fly ash, and ground granulated blast furnace slag (GGBFS), etc., are rich in silicon and aluminum compounds and will react under the stimulation of alkaline solution. These solid wastes can be utilized, reducing CO2 emissions by 20—50%, which, to some extent, can protect the environment. In addition, raw materials of geopolymer are mostly by-products of industrial products with abundant reserves and low prices. Compared with OPC, geopolymers have better mechanical, chemical, thermal properties, and durability. Based on the above-mentioned characteristics, geopolymer is a better option for the development of sustainable products such as building materials, fire-retardant coatings, fiber-reinforced composite materials, and fixed solutions for chemical and nuclear industrial wastes.

II. MATERIALS AND METHODS

A. Raw materials

A low calcium fly ash (Class F), GGBFS was used as the major ingredient.

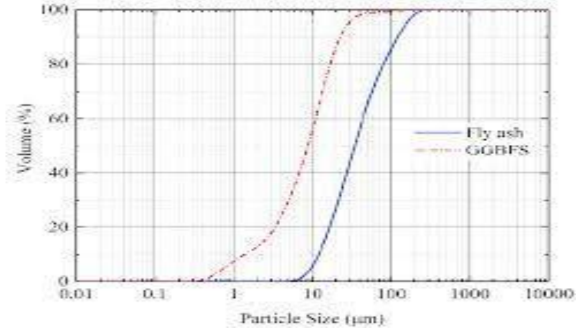


Figure 1. Initial particle distribution curves of FA and GGBFS

Table 1. Chemical components of fly ash (FA) and ground granulated blast furnace slag (GGBFS) by X-ray fluorescence (XRF) analysis.

Chemical Composition	Fly ash	GGBFS
SiO2	51.70	28.57
Al2O3	15.68	13.55
CaO	9.96	30.44
Fe2O3	19.06	2.92
MgO	1.48	9.80
Na2O	0.57	0.59
K2O	1.04	0.34
S	0.27	0
Other	0.24	13.79

Sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solution were selected as alkaline activators after comparing available activators. The modulus of sodium silicate was 3.306 with chemical composition of 26.65% SiO2, 8.32% Na2O, and 65.03% H2O. The NaOH solution was formulated with 60 g tap water and 28.80 g NaOH solid particles. The purity of sodium hydroxide pellet was more than 96%. The prepared concentration of sodium hydroxide solution remained constant at 12 mol/L in all mixtures.

The standard sand was obtained from an ISO Standard Sand Co., Ltd. Sodium tetraborate (Na2BO7·H2O) was used as retarder. The content of analytic pure sodium tetraborate was higher than 99.5%. A polycarboxylate based super plasticizer and an antifreeze agent were used in the samples. These additives were used to improve the workability of geopolymer mortar mixture.

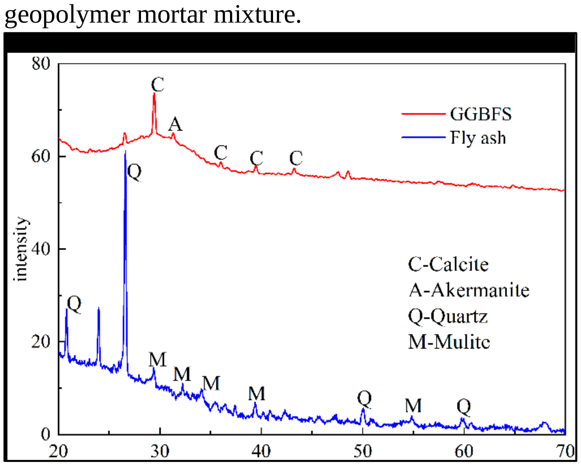


Fig.2 XRD patterns of FA and GGBFS

B. Mixture Proportions

Table 2. Details of geopolymer mortar mix proportions.

Mix	Fly ash (kg)	Fine sand (kg)	Activator (kg)		Added water (kg)
			Na_2SiO_3 (liquid)	NaOH (15 M)	
G7.5-0.75	0.523	1.440	0.128	0.101	0.082
G7.5-1.0	0.522	1.431	0.124	0.133	0.064
G7.5-1.25	0.521	1.438	0.167	0.046	0.108
G15-1	0.505	1.388	0.193	0.148	0.046
G15-1.25	0.500	1.376	0.255	0.117	0.033
G15-1.5	0.496	1.364	0.316	0.087	0.020

Quantities for kg/m^3

C. Mixing, Specimen Preparation, and Curing

The first step was activator solution preparation. The temperature of sodium hydroxide solution would increase due to the large amount of heat generated when sodium hydroxide solid particles were dissolved in water. Some research premixed the NaOH solutions until the solution reached room temperature within 24 h, and others considered that the activator mixed with sodium silicate and sodium hydroxide powder has more advantages than that in liquid form. In this study, the activator was still in the form of liquid solution. The purpose of this operation was to eliminate the unreliability of test results caused by heat originated from sodium hydroxide particles dissolving. The NaOH solution was premixed until its temperature reached room temperature.

The steel mold consisted of a horizontal groove, which can simultaneously form six specimens of 40 mm 40 mm 40 mm in size. Before the mortar was put into the mold, a thin layer of demolding agent was coated on the inner surface of the mold to facilitate demolding and ensure the smooth and intact surface of the samples. The complete process shown in fig.

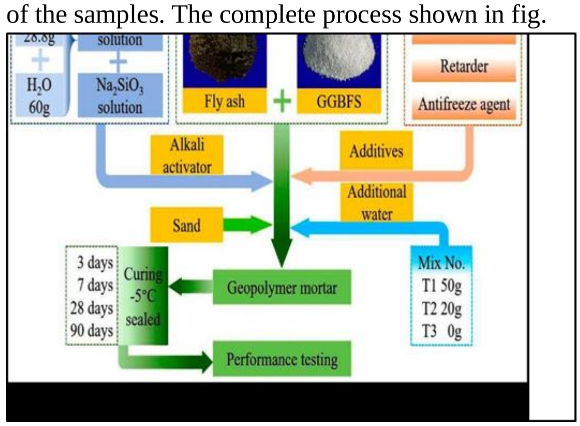


Figure 3 Complete process of samples preparation

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. *Compressive Strength*

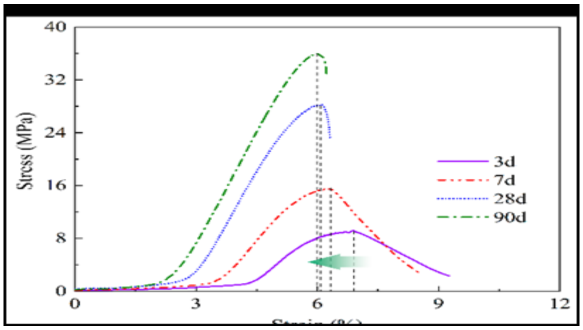
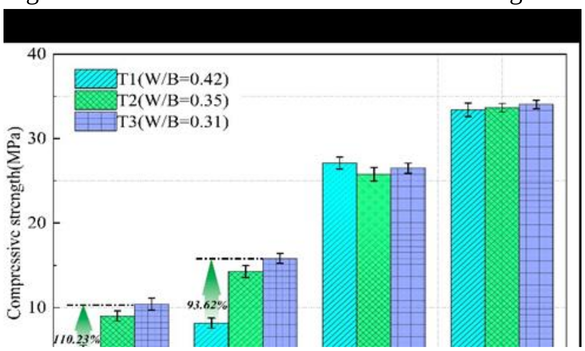


Figure 4. Stress-strain curves of T2 at different ages.



The compressive strength values of the prepared samples were obtained by uniaxial compression tests. The stress-strain curves of T2 at different ages are plotted in Figure 5. It can be seen that the compressive strength increases and failure strain decreases gradually with the increasing age. The brittle failure of samples is becoming increasingly evident. T1 and T3 present the same trend, which are not shown repeatedly here. Figure 6 shows the stress-strain curves of each group at age of 7 days. The greater W/B ratio, the lower strength, the failure strain corresponding to peak strength increases gradually, and plastic deformation characteristics become more and more prominent.

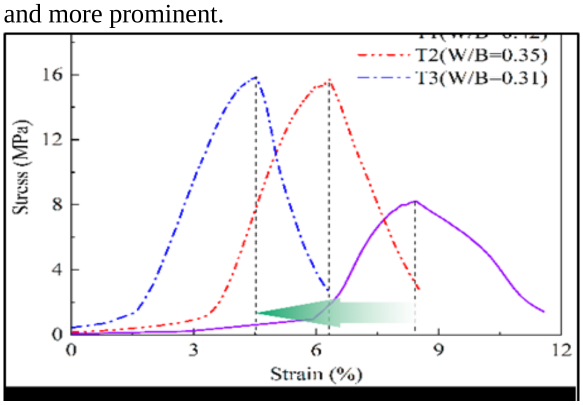


Figure 5. Stress-strain curves of mortars with different Water-to-Binder (W/B ratios at 7 days.

The compressive strength of mortar samples with different W/B ratios was tested at different ages. Three identical samples were tested each time. The mean values are given in Figure 7. The compressive strength of mortar increases gradually with the decrease of W/B ratio at early age (3 d, 7 d). At the age of 3 days and 7 days, the compressive strength increases by 82.13% and 74.63%, respectively, when the W/B ratio decreases from 0.42 to 0.35; when the W/B ratio decreases from 0.42 to 0.31, it increases by 110.23% and 93.62%, respectively, but when the W/B ratio decreases from 0.35 to 0.31, it increases slightly, 15.43% and 10.87%, respectively.

At the age of 28 days, the compressive strength of each group is basically maintained at the level of 25.78 MPa—27.10 MPa. The compressive strength reached 33.4 MPa—34.04 MPa at the age of 90 days, and the values are very close. The mechanism of the influence of water content on the strength of geopolymer is discussed based on the above experimental results. It can be clearly observed that, on the prerequisite of satisfying the workability of mortar, reducing the water consumption is beneficial to improving the early strength of mortar under negative temperature conditions. In fact, adding extra different amounts of water has changed the initial molar concentration of NaOH solution, which is no longer a fixed value of 12 mol/L, but less than 12 mol/L. The ultimate concentration of NaOH solution of T1, T2, and T3 was 3.83 mol/L, 4.56 mol/L, and 5.22 mol/L, respectively. It can be concluded that different water content has little influence on long-term The higher the water content is, the smaller the molar concentration is. The addition of extra water changes the excitation ability.

Higher initial molar concentration of NaOH solution promotes the dissolution of aluminosilicate and forms and tetrahedral units in the early age, leading to the augment of strength at the early stage [30]. Within a certain range, the increased NaOH concentration helps to improve the compressive strength of concrete [27,31,32], which is consistent with the results in this paper. different W/B ratios at different ages. At the age of 28 days, the compressive strength of each group is basically maintained at the level of 25.78 MPa—27.10 MPa.

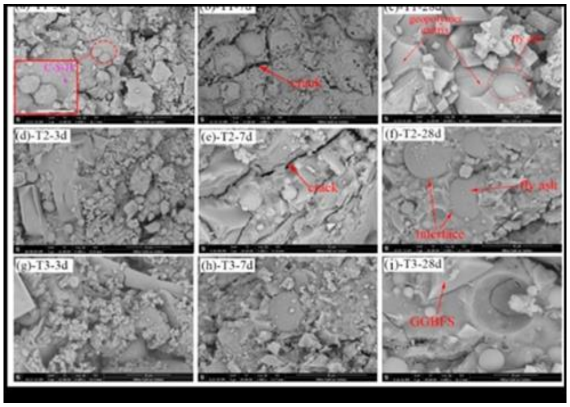


Figure 6. Compressive strengths of mortars with different W/B ratios at different ages.

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Within a certain range, the increased NaOH concentration helps to improve the compressive strength of concrete, which is consistent with the results in this paper. However, when the concentration of NaOH solution exceeds a certain limit, the polycondensation process was hindered and the compressive strength would be reduced from the results of this study, the initial concentration of NaOH solution did not exceed the limit value, and the strength value monotonously increased with the increasing concentrate.

IV. MICROSTRUCTURAL PROPERTIES

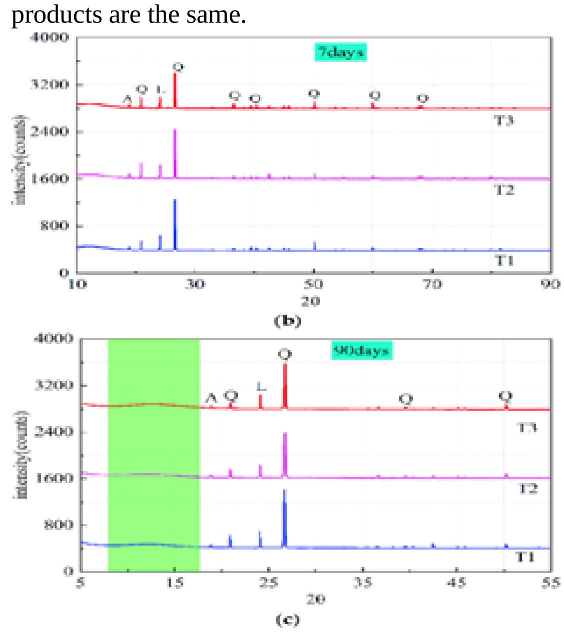
A. SEM Observation

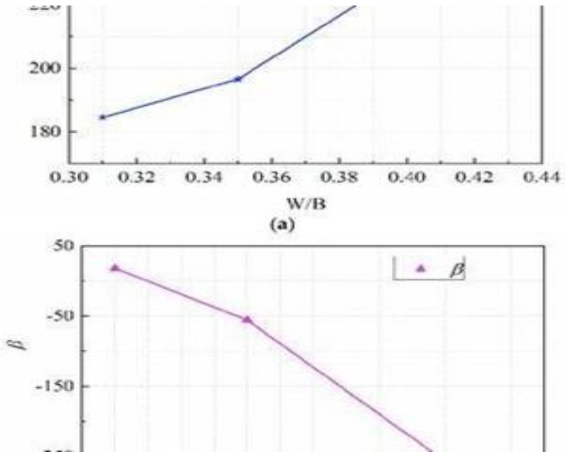
In this section, the influence of water content on the microstructure of geopolymer is discussed. The micrographs of samples have been obtained using SEM as shown in Figure 8. All images clearly show the presence of fly ash cenosphere and slag particles that have completely or partially undergone geopolymer reactions and been embedded in a continuous matrix. The usual trend is that with the same water content, the structure becomes more and more dense for increasing of age.

It can be concluded that water content has a certain influence on the microstructure of geopolymer in early age. The smaller the water content is, the less unreacted components are, denser the structure is and the higher the strength is. In addition, the long-term microstructure of geopolymer is not affected by water content. This will explain in terms of microstructure why the geopolymer mortar has low water content but high strength at an early age. At the same time, the reason why the strength increases with curing time is explained.

B. XRD Analysis

XRD patterns for all mixtures at different ages are shown in Figure 9a—c. Presence of quartz, lazurite, and amarillite ($NaFe3+(SO4)2\cdot 6H2O$) can be observed in all samples and the patterns are quite similar. This shows that different water content only affects the hydration process, and the final hydration products are the same.





The complex composition of lazurite (Na,Ca,K)7—8Si6Al6O24(SO4, S, Cl)2·nH2O) belongs to the sodalite group [35], and the molecular structure indicates the formation of sodium aluminosilicate hydrate(N-A-S-H) gel and calcium aluminosilicate hydrate (C-A-S-H) gel. Sodalite framework is a typical geopolymeric structure. Lazurite mineral crystal has zeolite-like structure. The trisulfur (S3−) is trapped into a cage of the zeolitic sodalite, which results in the sample manifesting a blue or green color. The studies showed that the specific color of exterior surface turned to gray or white when the concrete or mortar contacted with air. This conclusion is proved by the fact that the surface color of the damaged specimen is grey, and the interior is green.

A broad hump between 10° and 20° (2θ) can be observed on the XRD patterns in Figure 9c, which usually represents the existence of amorphous phase. Compared with geopolymer cured at room temperature [38], the hump height is lower. The lower hump height means that the amorphous gel Figure 9. XRD patterns of samples (T1, T2, T3) at di erent ages (Q-quartz, A-amarillite, L-lazurite): (a)3 days; (b) 7 days; (c) 90 days.

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V. CONCLUSIONS

The influence of water content on the properties of fly ash and GBBFS-based geopolymer mortars cured at −5 °C was investigated. Several interesting conclusions can be drawn from the results presented thus far:

- Water content has an impact on compressive strength of geopolymer mortar at the age of 3 days and 7 days. At the age of 28 days, the compressive strength of each group is basically maintained. at 25.78 MPa—27.10 MPa. The compressive strength reached about 33.4 MPa at the age of 90 days.
- Higher molar concentration of NaOH solution promotes the dissolution of aluminosilicate in early age, which leads to the increase of strength in early stage. Lower water content is beneficial to improving the early strength of mortar under negative temperature conditions, however, water content has little effect on long-term strength.

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