Effect of Sustainable Glass Powder on the Properties of Reactive Powder Concrete with Polypropylene Fibers

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Abstract-Global warming and environmental damage have become major problems. The production of Portland cement releases large quantities of gas, which cause pollution to the atmosphere. This problem can be solved via the use of sustainable materials, such as glass powder. This study investigates the effect of partial replacement of cement with sustainable glass powder at various percentages (0, 15, 20, and 25%) by weight of cement on some mechanical properties (compressive strength, flexural strength, absorption, and dry density) of Reactive Powder Concrete (RPC) containing a percentage of Polypropylene fibers (PRPC) of 1% by weight. Furthermore, steam curing was performed for 5 hours at 90°C after hardening the sample directly. The RPC was designed using local cement, silica fume, and super plasticizer with a water/cement ratio of 0.2 to achieve a compressive strength of 96.3MPa at the age of 28 days, and it was tested at percentages of sustainable glass powder replacement of 0 and 20% by weight of cement. According to the study's findings, RPC's compressive strength rose up to 4.2% as a consequence of the use of sustainable glass powder replacement by 20%, flexural strength up to 15.3%, dry density up to 0.49%, and absorption reduction by 31.7% at the age of 28 days and in comparison with the reference mixture.

Keyword-reactive powder concrete; sustainable glass powder; polypropylene fiber; flexural strength; compressive strength

I. INTRODUCTION

The requirements for high strength and high performance of concrete are the main reason for the production of Reactive Powder Concrete (RPC) [1]. RPC is defined as a cementitious composite with very high strength and ductility [2]. The development of RPC is based on the idea that a material with a limited number of internal voids will have a larger load-carrying capacity and will exhibit superior structural overall performance [3]. In order to manufacture cement, a large amount of natural resources and energy must be used in its production. The production of 1 ton of cement from start to finish requires about 1.5 tons of raw materials. It is vital to hunt for alternative binders because of the necessity to minimize CO_2 emissions. The need for more cost-effective and environmentally friendly cement ingredients has fueled the interest in alternative materials that may partly replace Ordinary Portland Cement (OPC), which is the most widely utilized [4].

The majority of the recent work in Iraq's building sector has been devoted to determine the viability of local raw resources as substitutes for imported commodities that are required for certain practical uses [5]. Additionally to traditional mineral admixtures, other materials, such as glass powder, can be used. When glass is utilized as an aggregate, its high alkali content facilitates the formation of the pozzolanic reaction that occurs when it is crushed into fine powder and used as a partial substitute for cement. It has been shown that the inclusion of glass powder has a positive effect on the expansion caused by alkali silica reaction. Cracks in a concrete construction are unavoidable during the course of its life [6, 7]. Structures exposed to the external environment are more prone to cracking because they are impacted via shrinkage or expansion in weight and drying, as well as other environmental variables. These cracks have an impact on the mechanical characteristics and the durability of the structures reduces. Fibers may be used to solve this issue [8]. Polypropylene fibers are regarded to be an excellent substitute for cotton, because of their excellent chemical stability and hydrophobic nature [9, 10]. It was found that using polypropylene fibers to volume percentages up to 0.45% produced results that were comparable to those achieved with steel fibers [11]. Authors in [12] checked the mechanical and fresh properties of RPC. They produced RPC with a compressive strength of 130MPa under standard processing conditions at the age of 28 days. The strength obtained at 28 days of curing is equivalent to approximately 70% of the strength achieved at 7 days. The results show that the addition of fibers led to a significant improvement in compressive strength and bending compared to concrete without fibers [13].

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II. MATERIALS

A. Cement

OPC (Cem I 42.5R) was used in this study. The physical and chemical requirements comply with [14].

B. Silica Fume (SF)

Silica fume was employed to improve rheological properties via the lubrication effect caused by the spherical shape of the material. The chemical and physical properties as well as the strength activity index are in accordance with the [15] standard.

C. Fine Aggregates

The utilized fine aggregates had a good gradation, were free from harmful substances that have an impact on the results of the examination, and passed through the 0.6mm sieve, and complied with the requirements of [16].

D. Polypropylene Fibers

Belgian Fibers polypropylenes fibers were used for reinforcement. The specifications and properties of the fibers used throughout the experimental work are illustrated in Table I and Figure 1.

TABLE I. POLYPROPYLENE FIBER PROPERTIES*

Description	Specifications
Length	6mm
Diameter	34μm
Aspect ratio	0.176
Density	0.91g/cm^3
Young modulus	3750MPa

*data sheet

Fig. 1. Polypropylene fibers used in this work.

E. Glass Powder

In this study, sustainable glass powder (Figure 2) resulting from shops selling window glasses was used. Because it was difficult to be disposed of, it was recycled and grounded to the required finesse according to the requirements of [17]. At first the grinding process was carried out with the use of an iron hammer that crushed the waste glass into small pieces. Then an industrial grinder was used. The chemical and physical properties and strength activity index comply with [18], as show in Table II.

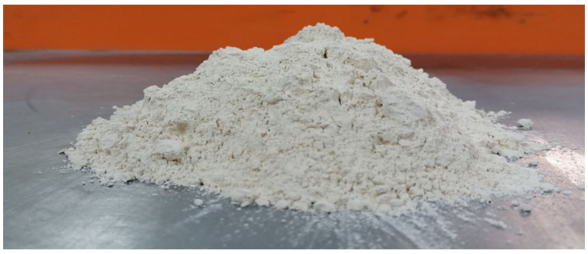

Fig. 2. Glass powder used in this work.

TABLE II. CHEMICAL AND PHYSICAL PROPERTIES OF GLASS POWDER

Oxide composition	Test result %	Limit of ASTM C618-15 class N specification requirements
Silicon Oxide (SiO2)	64.22	Min(70)
Aluminum oxide(AL_2O_3)	9.6 (79.02)	
Iron oxide(Fe_2O_3)	5.2	
Sulfur trioxide (SO_3)	2.1	Max(4)
Calcium oxide (CaO)	4.26	-----
Magnesium oxide (MgO)	1.65	-----
Loss of ignition	3.21	Max(10)
Percent retained on 45μm (NO.325)	32%	34%
Strength activity index % with OPC at 7 days.	101.4	Min (75)

F. Water

The water used in this study was clean and free from harmful substances, complying with [19].

G. Chemical Admixtures

Given that adding fibers to the mixture reduces mixture workability, therefore a superplasticizer was added to the mixture. This type G product, conforms to [20] and the manufacturer's suggested dose varied from 0.5 to 2.5lt per 100kg of cement.

III. REACTIVE POWDER CONCRETE DESIGN

For the purpose of obtaining RPC with the desirable properties, strength design of 95MPa was adopted [12]. Table III summarizes the mix design RPC containing polypropylene fibers by 1% vol. of concrete. The used dosage of superplasticizer was 1.8lt/100Kg of cement.

TABLE III. DETAILS OF RPC MIX PROPORTIONS FOR (Kg/m^3)

Mix type	OPC	Fine aggregates	Silica fume	Glass powder	Water weight	W/Cm
M.0%	950	1045	238	----	208	0.175
M.15%	807.5	1045	238	142.5	208	0.175
M.20%	760	1045	238	190	208	0.175
M.25%	712.5	1045	238	237.5	208	0.175

IV. CURING SAMPLES

After the samples were removed from the molds, they were placed in the steam curing device for 5 hours at a temperature of 90°C as shown in Figure 3. After that, the samples were outed from the steam curing device and were placed in the normal treatment tank for the age of test.

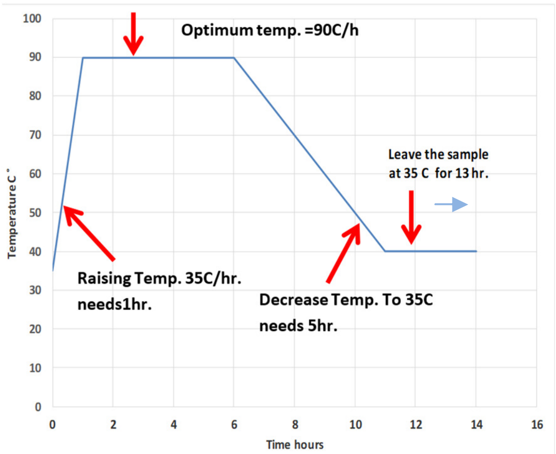

Fig. 3. The cycle of steam curing.

V. RESULTS AND DISCUSSION

A. *Flow Test*

Regarding the flow for PRPC samples, a minor increase was achieved with increased replacement percentage as shown in Figure 4. This occurred due to the small size of the glass powder particles in addition to the glassy texture and the spherical shape that makes them work as spherical bearings that lubricate the mix. Thus the glass powder acts as a superior plasticizer that increases workability and reduces the friction that occurs between the particles. This result agrees with the results of [21].

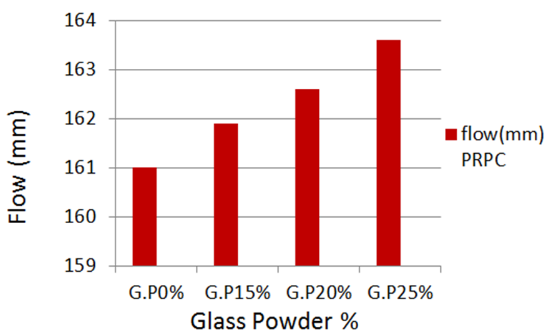

Fig. 4. Relationship between flow and flass powder percentage for PRPC.

B. *Compressive Strength*

The sustainable glass powder was utilized in 4 percentages (0, 15, 20, 25%) by weight of cement. We notice through the values shown in Figures 5-6 that the glass powder affects the chemical reactions in the cement. The highest value of compressive strength was obtained when the replacement ratio was 20%, due to the pozzolanic reaction caused by the glass powder in the RPC mixture being energetically triggered via the high temperature used for steam curing leading to the formation of a denser microstructure and a quicker development of strength. Finely dispersed glass powder acts as a supplementary cementitious material micro filler within the concrete matrix, causing the strength to increase. This result agrees with the results of [22, 24].

Fig. 5. Testing a prismatic concrete sample.

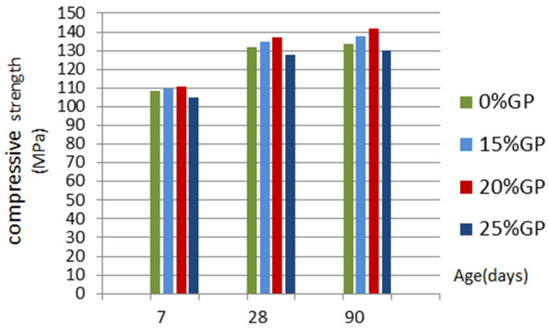

Fig. 6. Relationship between the compressive strength and age for PRPC.

C. *Flexural Strength*

The flexural strength values of the mixture with 20% replacement with glass powder were greater than the reference mixture's values as shown in Figure 7. This increase was caused by the great pozzolanic properties of the glass powder that play a micro filler function in the concrete matrix RPC mix. The flexural strength of PRPC was improved via extending the curing age due to the continued cement hydration as the curing age progressed. This result agrees with [25, 26].

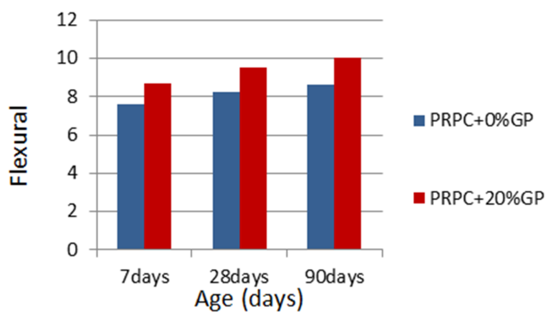

Fig. 7. Relationship between the flexural strength and age for PRPC.

D. *Dry Bulk Density*

The results of the oven-dry density of hardened test for replacement ratio of 20% sustainable glass powder at the age of

7, 28, and 90 days was higher than the reference mixtures (Figure 9). This increase was caused by the fact that the glass powder has the potential to react with the CaO generated from the cement hydration leading to the formation of additional binder material, which is a calcium silicate hydrate gel, which contributes to the increase in the density of the mortar by filling the spaces between the cement paste and fine aggregates. This result agrees [27, 28].

Fig. 8. Testing a cubic concrete sample.

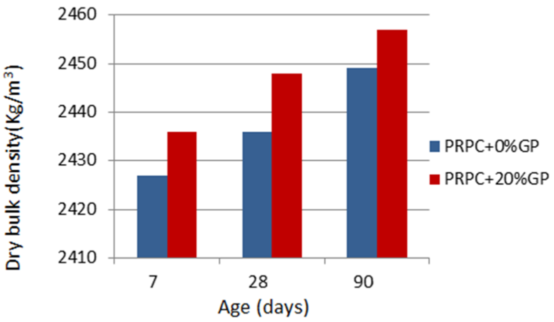

Fig. 9. Relationship between dry bulk density and age for PRPC.

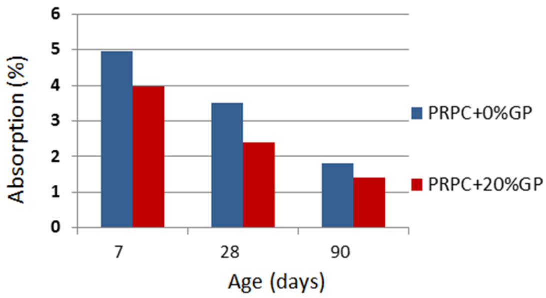

Fig. 10. Relationship between absorption (%) and age for PRPC.

E. Water Absorption

The findings of the absorption test revealed that the amount of sustainable glass powder present is inversely proportional to the amount of absorption (Figure 10). The sustainable glass powder can act as a supplementary cementitious material and form larger amounts of C-S-H gel that can fill the spaces in the concrete matrix that would be filled with water. This result agrees with the findings in [24].

VI. CONCLUSION

After experimenting in the laboratory and comparing the values of the reference RPC mixture with the mixtures of replacement ratios of 15, 20, and 25% by weight of cement, it is concluded that:

- The compressive strength at 15% replacement increased by about 1.39% at the age of 7 days, 2.39% at the age of 28 days, and by 3% at 90 days. At 20% replacement, the increase was about 2.39, 4.2, and 6.1% at 7, 28, and 90 days respectively. At 25% replacement ratio, the opposite occurred. The compressive strength was less than that of the reference mixture by about 3% at 7 days, but in later ages (28, 90 days) there was a decline in the decrease to 2.8 and 2.5%.
- The highest flexural strength of 9.53MPa was achieved at 28 days at 20% replacement.
- The water absorption of the 20% replacement mixture was less than the reference mixture's by 31.7% at the age of 28 days.
- The dry density of PRPC showed slight increases when the cement was replaced by 20% by sustainable glass powder at all ages. The PRPC density achieved by this replacement rate was 2436, 2448, and 2457kg/m^3 at 7, 28, and 90 days.
- The utilized in this study sustainable glass powder is very good in improving the mechanical properties of concrete in the presence of polypropylene fibers.

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