Research Article

Zainab Ali Hussain* and Nada Mahdi Fawzi Aljalawi

Behavior of reactive powder concrete containing recycled glass powder reinforced by steel fiber

https://doi.org/10.1515/jmbm-2022-0025
received February 28, 2022; accepted April 03, 2022

Abstract: Environmental sustainability is described as one that avoids the depletion or deterioration of natural resources, while also allowing for the preservation of long-term environmental quality. By practicing environmental sustainability, we may assist to guarantee that the requirements of today's population are satisfied without risking the capacity of future generations to meet their own needs in the future. Engineers in the field of concrete production are becoming increasingly interested in sustainable development, which includes the utilization of the locally available materials in addition to using the agricultural and industrial waste in construction industry as one of the possible solutions to the environmental and economic issues. This study investigated the effect of partial substitution of cement with recycled glass powder (0, 15, 20, and 25%) by weight of cement at various ages (on compressive strength) after determining the optimal ratio of replacement. This optimal ratio is used to study its effect on some mechanical properties (such as flexural strength, absorption, and dry density) of reactive powder concrete containing 1% micro steel fiber (SRPC), and furthermore, utilizing steam curing for 5 h at 90°C after hardening the sample directly. Reactive powder concrete (RPC) has been designed with the use of the local cement, silica fume, and super plasticizer with a water/cement ratio of 0.20 in order to achieve a compressive strength of 137.09 MPa at the age of 28 days. When recycled glass powder replacement (20%) was utilized, the findings revealed that the compressive strength of RPC improved by 4.2%, the flexural strength increased by 15.3%, the dry density increased by 0.61%, and the absorption was reduced by 32% at 28 days after the test results were compared to the reference mix.

Keywords: reactive powder concrete, recycled glass powder, micro steel fiber, flexural, compressive strength

*** Corresponding author: Zainab Ali Hussain,** Department of Civil Engineering, Baghdad University, Baghdad, Iraq,
e-mail: Zainab.hussain2001m@coeng.uobaghdad.edu.iq
Nada Mahdi Fawzi Aljalawi: Department of Civil Engineering, Baghdad University, Baghdad, Iraq,
e-mail: Nada.aljalawi@coeng.uobaghdad.edu.iq

1 Introduction

The reactive powder concrete (RPC) can be defined as one of the modern cement composite materials with high performance and good durability characteristics. Adding fiber to the RPC has resulted in the improvement of its compressive strength characteristics in comparison with the conventional concrete [1]. A major advancement has been made in the development of several types of concrete during the previous few years. In contrast to the conventional concretes, the RPC is characterized by technologies as a form of technological revolution. Steel fiber reinforced concrete (SFRC) and high strength concrete (HSC) are two forms of concrete produced that are particularly noteworthy. In addition to that, high-performance concrete (HPC) that is generated when strength is not the most critical feature may be utilized in many applications. This material, which has just recently been accessible, displays increased durability and strength qualities in comparison with the conventional or high-performance concrete, and is therefore classified as ultrahigh performance concrete (UHPC). RPC, as indicated *via* ref. [2], is the most important enhanced "High Tech" material.

In the creation of RPC, the objective was to use materials with a restricted amount of internal voids in order to increase their load-carrying capacity, while also exhibiting improved structural performance overall. This is accomplished by the use of fine sand rather than large pieces of coarse aggregate in the RPC mix, which also includes a high concentration of cement, SF, and a superplasticizer. Because of the absence of coarse aggregate, the heterogeneity between cement matrix and aggregate was reduced for RPC mix (increased adhesive), resulting in an improvement in both the microstructure and the performance of the concrete mix. Despite the fact that the matrix does not include coarse aggregate, RPC is often referred to as concrete rather than mortar in the industry because of the consistency of the material [3]. In order to make cement, which acts as the primary binder in concrete, a significant quantity of natural resources and energy must be utilized in the process of cement manufacturing. From start to end, the production of 1 t of cement necessitates the use of around 1.5 t of raw materials. Because of the need to reduce carbon dioxide emissions, it is critical to look for alternative binders to be utilize in concrete. This has sparked interest in alternate materials that may be utilized to partially replace Ordinary Portland Cement (OPC), which is now the most extensively utilized cement component due to the need for more cost-effective and environmentally friendly cement ingredients [4]. Iraq's construction industry has spent the better part of the last decade trying to figure out whether or not local raw materials can be utilized to replace imported commodities that are necessary for specific practical applications. While natural resources are getting more costly, the search for alternative sources of energy is becoming increasingly vital as a result [5].

Furthermore, in addition to these classic mineral admixtures, other components such as shattered glass in the form of glass powder have just lately been commercially accessible. In the case where the glass has been utilized as an aggregate, the high alkali content of the glass facilitates formation of an alkali-silica reaction, which can result in harmful stresses and cracking in the concrete. But when it is crushed into fine powder and utilized as a partial cement replacement, the pozzolanic reaction that happens has a positive effect on the fundamental properties of concrete and also has the additional benefit of limiting the expansion of concrete induced by the alkali-silica reaction (ASR). According to the findings of many studies, the presence of glass powder has a beneficial impact on the growth induced by ASR [6,7].

Cracks in a concrete construction are unavoidable during the course of its life. Structures exposed to the external environment are more prone to cracking because they are impacted via shrinkage or expansion in volume and drying, as well as other environmental variables and the overloading factor, in addition to other factors such as temperature fluctuations. These fractures have an impact on the structural strength of the structures via weakening them, and the mechanical characteristics and durability of the structures are lowered as a result of these cracks creating a conduit for damaging elements to get into the core of the structures. Fiber may be utilized to solve this issue [8]. Steel fiber (SF) is the most often utilized form of fiber for concrete reinforcement because of its strength and durability. Steel fibers are first utilized in the concrete industry for the prevention/control of the plastic and drying shrinkage. According to further research and development, adding steel fiber to concrete considerably enhances its flexural toughness, energy absorption capacity, ductile behavior prior to ultimate failure, decreased cracking, and overall durability [9]. The aim of this study is to reduce environmental pollution by reducing the amount of carbon dioxide (Co_2) released by the cement industry by replacing part of the cement with recycled materials, as well as recycling glass waste that is difficult to decompose and using it as a partial substitute for cement.

2 Materials to produce RPC

2.1 Cement

Cem I 42.5R, a kind of OPC, was employed in the present investigation, the physical and chemical requirement comply with the requirements of the (IQS 5, 2019) [10].

2.2 Silica fume

During this research, silica fume was employed as a mineral additive that was added to the RPC mixtures. The chemical and physical properties as well as the strength activity index are in accordance with (ASTM C1240) standard [11].

2.3 Fine aggregate (FA)

Fine aggregate should comply with requirements of the (IQS45, 1984) [12].

2.4 SFs

The SFs utilized in this study were a straight type, and have an average tensile strength of 2,600 MPa. The steel fiber properties utilized in this work are shown in Table 1, and in Figure 1, the utilized quantity was 1% by volume of concrete.

Table 1: Steel fiber properties

Description*	Specifications
Surface	Brass coated
Density	7,860 kg/m^3
Tensile strength	2,600 MPa
Form	Straight
Average length	13 (mm)
Diameter	0.2 (mm) ± 0.05 (mm)
Aspect ratio (L/D)	65

*Given by the manufacturer.

2.5 Glass powder (GP)

In the present study, the recycled glass powder available from shops selling window glass was utilized, and because it was difficult to dispose of it, was recycled and ground to the required finesse according to the requirements of (ASTM 311) [13]. The grinding process was carried out via utilizing an industrial grinder. The chemical and physical properties, and strength activity index comply with ref. [14], as shown in Figure 2 and Table 2.

2.6 Water

Water utilized in the mix and curing for this research should be clean and free from harmful and should satisfy the requirements of (IQS No. 1703/1992) [15].

2.7 Chemical admixtures

Given that adding fiber to the mixture reduces mixture workability and the need to increase water, this is undesirable because it reduces the strength. Therefore, a superplasticizer was added to the mixture to achieve the high strength. With low *w/c* ratio and high flowablity of the concrete mixtures, this product hyperplast PC600 type G conforms with (ASTM C494)[16], and the manufacturer's suggested dose varied from 0.50 to 2.50 lL/100 kg of cement, depending on the application.

Figure 1: Steel fibers utilized in this work.

Figure 2: Glass powder utilized in this work.

3 Experimental methods

3.1 RPC design

For the purpose of obtaining RPC with desirable and appropriate properties, a group of the experimental mixes was prepared based upon a group of previous studies and research [17], with a strength of 130 MPa. Table 3 summarized the mix design of RPC containing micro steel fiber of 1% by volume of concrete and utilized dosage superplasticizer (1.8) L/100kg of cement.

3.2 Mixing process

1. All raw materials were combined in their dry state prior to 2 min.
2. 80% of the mixing water was added while continuously mixing for another 15 min.
3. 15% from the water mix with 70% superplasticizer was added to the mix and mixed again for 3 min.
4. The mixing was stopped for 1 min.
5. The remaining water and superplasticizer were added and mixed for 4 min, then micro steel fibers were added and mixed for 1 min to ensure that the fiber is uniformly distributed, so the total time required for mixing is 14 min.

Table 2: Physical and chemical properties of glass powder

Oxide composition	Test result (%)	Limit of specification requirement ASTM C618-15 class N
Silicon oxide (SiO_2)	64.22 } (79.02)	Min (70)
Aluminum oxide (Al_2O_3)	9.6	
Iron oxide (Fe_2O_3)	5.2	
SO_3	2.1	Max (4)
Calcium oxide (CaO)	4.26	—
Magnesium oxide (MgO)	1.65	—
Loss of ignition	3.21	Max (10)
% Retained on 45 μm (no. 325), max variation, % age point from average	32%	34%
Strength activity index with Portland cement at 7 days (%)	101.4	Min (75)

Table 3: Details of mix proportion for SRPC

Mix type	OPC (kg/m^3)	Fine aggregate (kg/m^3)	SF (kg/m^3)	Glass powder (kg/m^3)	Water (kg/m^3)	*w* (cm)
M.0%	950	1,045	237.5	—	208	0.175
M.15%	807.5	1,045	237.5	142.5	208	0.175
M.20%	760	1,045	237.5	190	208	0.175
M.25%	712.5	1,045	237.5	237.5	208	0.175

3.3 Casting sample

For the purpose of casting samples, the molds were prepared and cleaned, the inner surface was coated with a thin oil layer to prevent the concrete from sticking to the walls of mold according to (ASTM C192/C192M) [18], at the end, the samples were covered with polythene sheet for 24 h.

3.4 Curing sample

After taking out the samples from the molds, they were placed in a steam curing device for 5 h at a temperature of 90°C as shows in Figure 3. After that the samples were taken out from the steam curing device and placed in a normal treatment tank for the age of test.

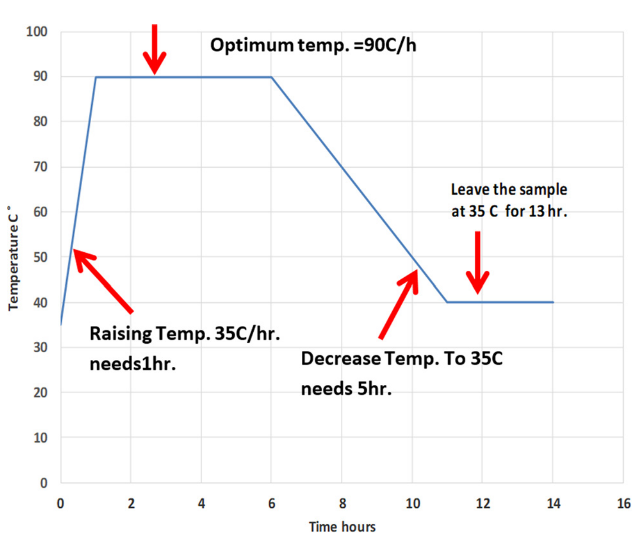

Figure 3: Cycle of steam curing.

4 Results and discussion

4.1 Flow test

Increased percentage replacement resulted in a little rise in mortar flow. As seen in Figure 4, the rising inflow as a result of the small size of the recycled glass powder particles, besides glassy texture and spherical shape, cause increase in the workability and reduce the friction that

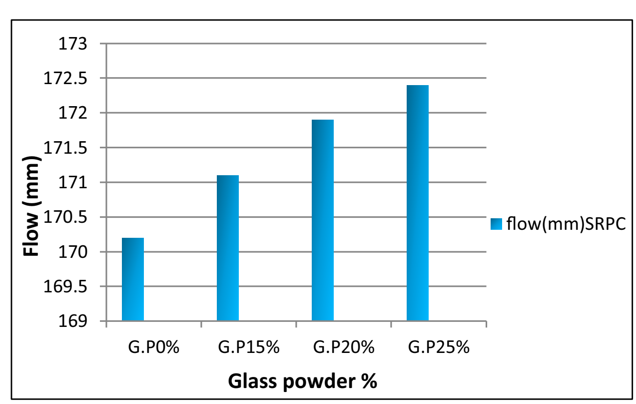

Figure 4: Relationship between the flow and glass powder % for SRPC.

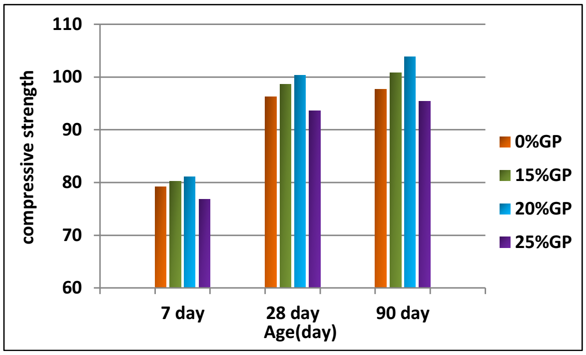

Figure 5: Relationship between compressive strength (MPa) and age (day) for SRPC.

occurs between the particles. The reasons for the increase are in agreement with ref. [19].

4.2 Compressive strength

The compressive strength values of RPC, at the replacement ratio of 20% recycled glass powder, were higher than the values of the reference mixture (0%) and also higher than the values of the replacement ratio of 15 and 25%. As shown in Figure 5, the reason for the increase in strength at the replacement ratio of 20% by weight of the cement is the pozzolanic reactions caused via the recycled glass powder in the RPC mixture being energetically triggered via the high temperature used for steam curing. This leads to the formation 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 and this caused the increase in strength. The reasons for the increase are in agreement with refs. [20–22].

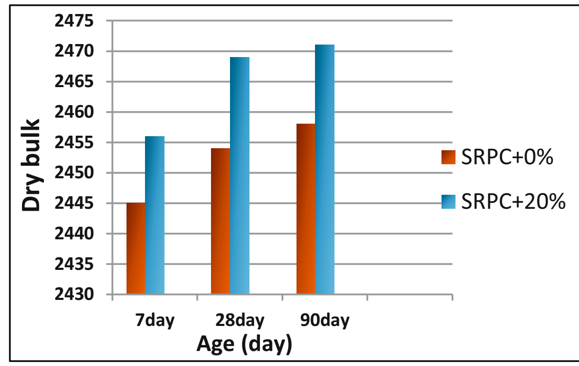

Figure 7: Relationship between the dry bulk density (kg/m^3) and age (day) for SRPC.

4.3 Flexural strength

The flexural strength values of RPC, at the replacement ratio of 20% recycled glass powder, were higher than the values of the reference mixture (0%). This increase is due to the recycled glass powder having great pozzolanic additives that may play a micro filler function in the concrete matrix RPC mix, and also, the reason for this improvement is to extend the life of the treatment, which causes continued cement hydration as the curing age progressed. The reasons for the increase are in agreement with refs. [23,24]. The results are listed in Figure 6.

4.4 Dry bulk density

The results of the oven-dry density of hardened test for replacement ratio of 20% recycled glass powder at ages of 7, 28, and 90 days are higher when compared with reference mixtures. The results listed in Figure 7 indicated that the use of pozzolanic material such as glass powder

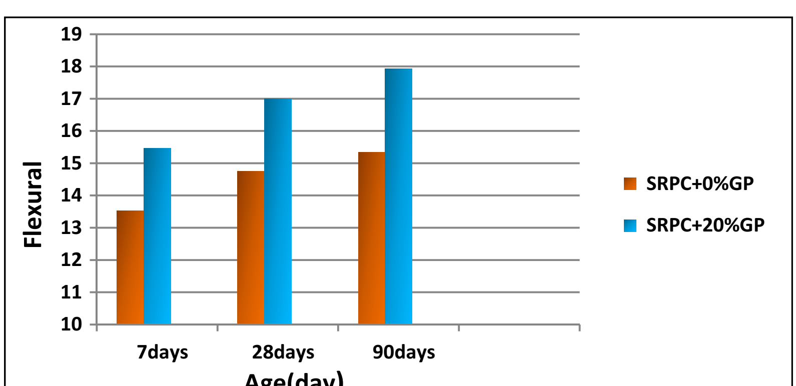

Figure 6: Relationship between the flexural strength (MPa) and age (day) for SRPC.

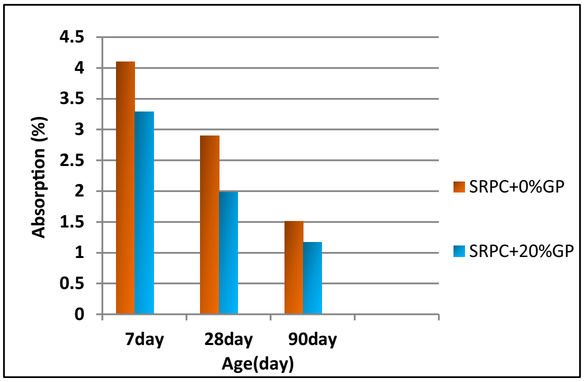

Figure 8: Relationship between the absorption (%) and age (day) for SRPC.

increases the dry density when compared with reference mixtures. This increase due to glass powder has the potential to react with calcium oxide generated from cement hydration and lead to the formation of additional binder material, which is calcium silicate hydrate gel, which contributes to the increase in the density of the mortar via filling the space between cement paste and fine aggregate. The reasons for the increase are in agreement with refs. [25,26].

4.5 Water absorption

The findings of the absorption test revealed that the amount of recycled glass powder present is inversely proportional to the amount of absorption present. In those cases when a drop in the values of the absorption ratio for the replacement ratio of 20% was seen when compared to reference mixes, the reason was due to recycled glass powder acting as supplementary cementitious materials and forming of larger amounts of C–S–H gel, that can fill the spaces in the concrete matrix that would be filled with water. The reasons for the decrease in the rate of absorption are compatible with ref. [21]. The results are listed in Figure 8.

5 Conclusion

After conducting experiments in the laboratory and comparing, the values of the reference mixture for RPC with a replacement ratio of 0% of recycled glass powder with mixtures with a replacement ratio of 15, 20, and 25% via weight of cement, it was concluded that:

- The compressive strength at recycled glass powder replacement at 20% increases about 2.4, 4.2, and 6.2% in ages of 7, 28, and 90 days, respectively.
- At recycled glass powder replacement at 20% by weight of cement, the flexural strength is increased by about 15.3% at age of 28 days.
- Water absorption is lowered by 32% approximately compared with the reference mixture at age 28 days at replacement ratio of 20%.
- When 20% of the cement has been substituted with recycled glass powder, the dry density of SRPC increased somewhat at all ages when compared with reference samples, and the SRPC density attained by this substitution rate was of 2,456, 2,469, and 2,471 kg/m^3 at 7, 28, and 90 days, respectively.
- In this research, recycled glass powder is particularly effective in improving the mechanical characteristics in the presence of micro steel fibers with an optimal replacement percentage of 20%.

Funding information: The authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: Authors state no conflict of interest.

References

[1] Muhsin ZF, Fawzi NM. Effect of fly ash on some properties of reactive powder concrete. J Eng. 2021 Nov 1;27(11):32–46.
[2] Collepardi M. Innovative concretes for civil engineering structures: SCC, HPC and RPC. Workshop on New Technologies and Materials in Civil Engineering: Proc Milan; 2003. p. 1–8.
[3] Collepardi S, Coppola L, Troli R, Collepardi M. Mechanical properties of modified reactive powder concrete. ACI Spec Publ. 1997 Sep 1;173:1–22.
[4] Alsaedy SM, Aljalawi N. The effect of nanomaterials on the properties of limestone dust green concrete. Eng Technol Appl Sci Res. 2021 Oct 12;11(5):7619–23.
[5] Ali AW, Fawzi NM. Production of light weight foam concrete with sustainable materials. Eng Technol Appl Sci Res. 2021 Oct 12;11(5):7647–52.
[6] Shayan A, Xu A. Value-added utilisation of waste glass in concrete. Cem Concr Res. 2004 Jan 1;34(1):81–9.
[7] Yost P. C&D/wood debris management trends. Resour Recycl. 1998 Nov;17:22–8.
[8] Abd Al Kareem S, Ahmed IF. Impact resistance of bendable concrete reinforced with grids and containing PVA solution. Eng Technol Appl Sci Res. 2021 Oct 12;11(5):7709–13.

[9] Altun F, Haktanir T, Ari K. Effects of steel fiber addition on mechanical properties of concrete and RC beams. Constr Build Mater. 2007 Mar 1;21(3):654–61.
[10] Iraqi Standard. Portland cement. The Central Organization for Standardization and Quality Control. No. 5; 2019.
[11] ASTM C1240. Standard specification for use of silica fume as a mineral admixtures in hydraulic-cement concrete, mortar and grout. Annual Book of ASTM Standards, American Society for Testing and Materials; 2015. p. 1–8.
[12] Iraqi Specification. Aggregate from natural sources for concrete and construction. No 45; 1984.
[13] ASTM C311. Standard test methods for sampling and testing fly ash or natural Pozzolans for use in Portland-cement concrete; 2016.
[14] ASTM C618. Standard specification for coal fly ash and raw or calcined natural Pozzolan for use in concrete; 2015.
[15] Specification I. No. 1703: water used in concrete. Baghdad, Iraq: Central Organization for Standardization and Quality Control; 1992.
[16] ASTM C494. Standard specification for chemical admixtures for concrete; 2005.
[17] Sarika S. A study on properties of reactive powder concrete. Literatures. 2015;3:5.
[18] ASTM C192. Standard practice for making and curing concrete test specimens; 2016.
[19] Rashad AM. Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement. Constr Build Mater. 2014 Dec 15;72:340–57.
[20] Fawzi NM. Production of high-performance concrete using different types of local pozzolana. J Eng. 2009 March;15:1.
[21] Setina J, Gabrene A, Juhnevica I. Effect of pozzolanic additives on structure and chemical durability of concrete. Procedia Eng. 2013 Jan 1;57:1005–12.
[22] Kushartomo W, Bali I, Sulaiman B. Mechanical behavior of reactive powder concrete with glass powder substitute. Procedia Eng. 2015 Jan 1;125:617–22.
[23] Fawzi NM, AL-Awadi AY. Enhancing performance of self–compacting concrete with internal curing using thermostone chips. J Eng Univ Baghdad. 2017 Jun 30;23(7):1–3.
[24] Demiss BA, Oyawa WO, Shitote SM. Mechanical and microstructural properties of recycled reactive powder concrete containing waste glass powder and fly ash at standard curing. Cogent Eng. 2018 Jan 1;5(1):1464877.
[25] Oey T, Kumar A, Bullard JW, Neithalath N, Sant G. The filler effect: the influence of filler content and surface area on cementitious reaction rates. J Am Ceram Soc. 2013 Jun;96(6):1978–90.
[26] Juenger MC, Siddique R. Recent advances in understanding the role of supplementary cementitious materials in concrete. Cem Concr Res. 2015 Dec 1;78:71–80.