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Mechanical Behavior of Modified Reactive Powder Concrete with Waste Materials Powder Replacement

Mushtaq Sadiq Radhi[*1], Zainab M. R. Abdul Rasoul[1], Aymen J. Alsaad[1]

[1] Department of Civil Engineering, College of Engineering, University of Kerbala, 56001, Karbala, Iraq
[*] Corresponding author, e-mail: mushtaq.sadiq@uokerbala.edu.iq

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Abstract

Across the world, a huge amount of waste materials is deposited from different industrial or construction activities. Out of this massive waste quantity, a petite is recycled and remaining is dumped in vulnerable lands. This paper deals with the potential utilization of solid waste in reactive powder concrete, practically powdered glass originating from waste glass bottles and powdered ceramics tile from waste of construction process. First, the optimum ratio of waste pozzolanic material (ceramics to glass ratio) was obtained by pozzolinic activity test. Then, the optimal waste pozzolanic material was incorporated in reactive powder concrete at several substitution levels. The waste pozzolanic material in 5 %, 10 %, 15 %, 20 %, and 25 % were added in the reactive powder concrete mixes as fractional supplement of silica fume. Strength and water absorption of the modified reactive powder concrete were evaluated. A significant enhancement was observed in mechanical behavior of modified reactive powder concrete containing 15 % waste pozzolanic material. Results directed irrelevant raise in water absorption as increasing the waste replacement material.

Keywords

high strength concrete, mechanical performance, microsilica, sustainable, waste cementitious

1 Introduction

The incorporation of very fine ingredients such silica fume and other fine materials into the concrete matrix to improve pozzolanic activity and particles condensing, joined with a utilization of superplasticizer for reducing water to binder ratio have motivated the improvement of an inventive type of cement based materials identified as reactive powder concrete (RPC) [1].

The basics of reactive powder concrete were presented in a research by Richard and Cheyrezy [2]. Basically, reactive powder concrete has many advantages compared to conventional cement based materials, including increased particles size homogeneity and microstructure condensing owing to elimination of the coarse aggregate and usage of very fine sand (150–600 µm), reduced water to binder ratio lesser than 0.2 by utilization superplasticizer which noticeably increased reactive powder concrete mechanical behavior. Extremely, reducing the volume of the cement paste pores and increased reactivity due to the high fraction addition of silica fume accelerates the pozzolanic reaction to produce extra hydrate of calcium silicate. Adequately dispersed steel fibers serves as rigid constituents in the cementitious matrix for improving the mechanical behavior of reactive powder concrete, primarily elastic modulus, tensile strength, and ductility. Enhancing the microstructure by accelerating the hydration of cement as result of subjecting pressure at fresh stage and special curing regime [3–5].

Large quantities of waste materials like clay bricks, glass, concrete and mortar are produced from construction or demolition process. The use of these waste to manufacture recycled building materials is both an economical process of disposal and environmentally friendly.

Recycled powders are created from waste construction and demolition, and reused to manufacture green building materials by smashing, grinding, drying, and grading [6–12]. Many researchers have revealed that waste materials like glass or pottery clay has potential for using as building materials. Zhu et al. [13] inspected 10 %, 20 %, and 30 % cement replacement in the reactive powder concrete by powered clay bricks. It was found that the mechanical properties of recycled reactive powder concrete improved at first and then reduced as the replacement proportion increased. The 10 % replacement

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proportion was recommended. In an another study implemented by Kushartomo et al. [14] to examine the impact of 10 %, 20 %, 30 % of waste powdered glass, as pozzolanic replacement, on the performance of the reactive powder concrete. The outcomes showed that the maximum improvement in the mechanical performance can be achieved at 20 % replacement. Asteray et al. [15], Demiss et al. [16] and Asteray et al. [17] were performed studies to inspect the reactive powder concrete performance that adapted by incorporation different waste materials (fly ash, glass, and ceramic) as silica fume and sand replacement. The outcomes confirmed that the full replacing of the silica fume by combination of fly ash and powdered waste glass, 15 % replacing of sand by powdered ceramics waste is a promising line for construction sector because of the improvement of the mechanical properties of adjusted reactive powder concrete. Mao et al. [18] investigated the utilization of powdered demolition materials (clay bricks and concrete) to substitute cement in reactive powder concrete. Tests outcomes directed that reactive powder concrete with replacement proportion up to 30 % has adequate mechanical properties. Mohammed et al. [19] were produced recycled reactive powder concrete by incorporation crashed clay bricks as sand replacement up to 50 %. The experimental outcomes indicted that recycled reactive powder concrete properties were enhanced by replacement proportion up to 25 %. Islam and Yesmin [20] were implemented experimental research to examine the influence of use the waste materials (powdered glass, fly ash, and slag) as replacement from cement and silica fume in the reactive powder concrete. Test results showed that the mechanical properties slightly affected by replacement. Most recent study conducted by Liu et al. [21] to examine the employment of hazard waste materials (cathode ray tube glass) as sand replacement in reactive powder concrete. The findings of the study provided an operative alternative to reutilizing of this hazard waste without limitations on the replacement ratio and safety due to the satisfactory properties of the recycled reactive powder concrete.

The utilization of waste materials like waste clay bricks and waste glass as pozzolanic replacement in concrete or reactive powder concrete can diminish the quantity of these waste materials and increase the availability of locally pozzolanic materials. The main target of the present investigation was to examine the outcomes of co-utilization of two powdered waste materials (ceramics tiles and glass) as silica fume replacement on the mechanical behavior of reactive powder concrete. To achieve this objective, firstly, the optimal ratio between powdered waste glass and powdered recycled clay bricks was found. Then, new waste pozzolanic material was substituted from silica fume at different percentages. Lastly, the mechanical behavior of modified reactive powder concrete was measured.

2 Experimental work

2.1 Materials

2.1.1 Silica fume

A silica fume as cement replacement used to produce concrete with high performance properties. Micro silica fume with trademark Conmix was utilized in this study, which has activity index 140 % based on accelerated method at 7 days. The requirements of the silica fume complied to ASTM C-1240 [22].

2.1.2 Cement

The adopted cement in this study was type I Portland cement with trademark Karasta–Lafarage. This cement obeys to ASTM C-150 [23] in terms of chemical properties and physical properties.

2.1.3 Fine aggregate

Natural fine aggregate with maximum size particles 0.6 mm was unitized in this investigation. The grading of this fine aggregate comply with ASTM C-33 [24] grading.

2.1.4 Waste glass

A glass is amorphous solid with silica content ranged between 60 % to 80 % [25]. The adopted glass in this study was collected from waste glass bottles, which fabricated from soda- lime glass the most communal commercial glass. The typical chemical composition of this glass type is silica ranged between 70 % and 75 %, and the remaining constituents are sodium oxide, and lime.

2.1.5 Waste ceramic tiles

Ceramic tile compositions mainly comprise silica about 70 % and alumina about 20 %. This contents not fully crystalline and may present in amorphous state with pozzolanic activity [26]. The adopted ceramic waste was collected from waste materials of some building under construction.

2.1.6 Chemical admixture

A third generation super-plasticizer based on modified Polycarboxylates with trademark Sika Viscocrete 5930 was utilized in this study for increasing the flow of reactive powder concrete at a given water to binder ratio. This chemical admixture complies with requirements of ASTMC-494 (types F and G) [27].

2.1.7 Water

A potable water was used in this study for production and curing reactive powder concrete, that supplied from local city network.

2.2 Preparation of waste powder

Fineness of the pozzolanic material is key factor of its reactivity, as fineness increase the activity increased. To attain the required fineness at ASTM C-618 [28], the two waste materials (glass and ceramic tile) were individually prepared at three steps: first, manually crashed by hammer into small size. Then, these particles were grinded by loss angles machine for about 15 min. Finally, the powdered waste materials were grinded by high velocity electrical grinder for further finesses. To achieve the homogenous between the powdered glass and powdered ceramic tile, the two powdered of waste materials were additionally grinded together by electrical grinder for each powered ceramic tile to powdered waste glass ratio.

The activity index, according to ASTM C-311 [29], for waste pozzolanic materials was performed at different mixes of ceramic to glass (CG0, CG20, CG 40, CG60, and CG80) with fractions of ceramic to glass are (0 %, 20 %, 40 %, 60 %, 80 %), respectively, to attain an optimum mixing ratio for the proposed pozzolanic material. The pozzolanic activity outcomes revealed that mix with 20 % powdered waste ceramic and 80 % powdered waste glass (CG20) has the greatest index from the other mixes, as shown in Fig. 1.

2.3 Mix proportion

Control mix and five mixes are approved in the experimental plan of the research. The optimum proposed pozzolanic material (CG20) was utilized as partial volumetric replacement from silica fume content at fractions of (5 %, 10 %, 15 %, 20 %, and 25 %). The proportion mix of control mix was stand on earlier local studies mixes [30–35]. The quantities of ingredients for mixes in this study are itemized in Table 1.

2.4 Specimens preparation

The preparation process of the modified reactive powder concrete was as the same as that clarified in reference [36]. First, the dry ingredients were mixed for 1 min in mortar mixer at low speed. Then, the water and super-plasticizer were added to mixer and mixed at high speed until achieve the required consistency. The well stirred mixtures were poured into steel molds (cubes and cylinders). Next, the filled molds were vibrated on the vibrating table, and then covered by nylon for 24 hr. Later, the molds were extracted and the specimens were water cured at temperature of 35 ± 3°C till test.

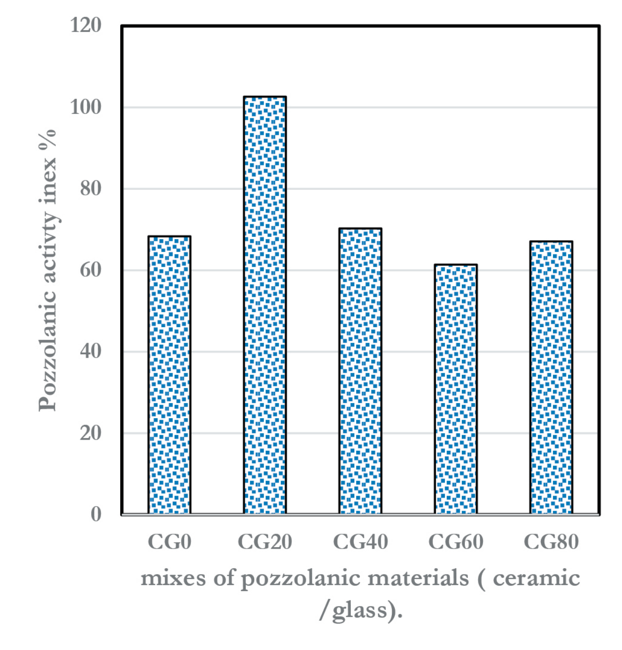

Fig. 1 Pozzolanic activity results for different ratio of waste ceramics to waste glass

Table 1 The proportion of all mixes

Material kg/m^3	MIX00	MIX05	MIX10	MIX15	MIX20	MIX25
Cement	880	880	880	880	880	880
Sand	970	970	970	970	970	970
S.F.	220	209	198	187	176	165
W.P(CG20)	0	11	22	33	44	55
Water	154	154	154	154	154	154
SP.%	3.2	3.4	3.7	3.9	4.1	4.4

- S.F., silica fume, W.P. waste powdered (CG20)
- SP. super-plasticizer

2.5 Measurement of mechanical behavior

The mechanical behavior of modified reactive powder concrete was measured by compressive strength according to ASTM C-109 [37], and splitting strength according to ASTM C-496 [38]. 50 mm cubes were adopted for compressive test at ages 7, 28, 56 days (three cubes at each age test). Cylinders with 100 mm height and diameter were adopted for splitting test at ages 7, 28, 56 days (three cylinders at each age test). Also, water absorption for all mixes was conducted according to ASTM C-642 [39].

3 Results and discussion

3.1 Compressive strength

Compressive strength outcomes for all mixes in this study at different ages are presented in Fig. 2. The magnitude of compressive strength for all mixes with waste powdered replacement (80 % glass + 20 % ceramics) were found higher than to that of reference mix (without waste powdered replacement). Maximum strength was achieved for (MIX15) at all ages, which was 19.3 %, 14.4 %, and 9.5 % auxiliary than reference mix at ages 7, 28, and 56 days respectively. Variation pattern of compressive strength with the level of waste powdered replacement for 7, 28, and 56 days are directed in Fig. 3.

The increment of compressive strength for waste powdered as volumetric replacement from silica fume at 28 days are 8.1 %, 10.2 %, 14.4 %, 8.3 %, and 2.3 % for MIX05, MIX10, MIX15, MIX20, and MIX25, respectively. This trend somewhat was reported by earlier authors [40].

3.2 Splitting strength

Splitting strength outcomes for all mixes in this study at different ages are presented in Fig. 4. Similarity to compressive strength trend, the magnitude of splitting strength for all mixes with waste powdered replacement (80 % glass + 20 % ceramics) were found higher than to that of reference mix (without waste powdered replacement). Maximum strength was achieved for (MIX15) at all ages, which was 30.8 %, 14.8 %, and 20.3 % auxiliary than reference mix at ages 7, 28, and 56 days respectively. Variation pattern of splitting strength with the level of waste powdered replacement for 7, 28 and 56 days are directed in Fig. 5.

The increment of splitting strength for waste powdered as volumetric replacement from silica fume at 28 days are 5.2 %, 9.8 %, 14.8 %, 11.7 %, and 10.8 % for MIX05, MIX10, MIX15, MIX20, and MIX25, respectively.

3.3 Water absorption

Water absorption outcomes for all mixes in this study at different ages are presented in Fig. 6 the results demonstrate that value of water absorption increases as the waste powdered materials replacement from silica fume increase. The increment percentage at age 7 days was 1.25 %, 2.5 %, 4.4 %, 6.9 %, and 10.7 % for MIX05, MIX10, MIX15, MIX20, and MIX25 as compared to references mix

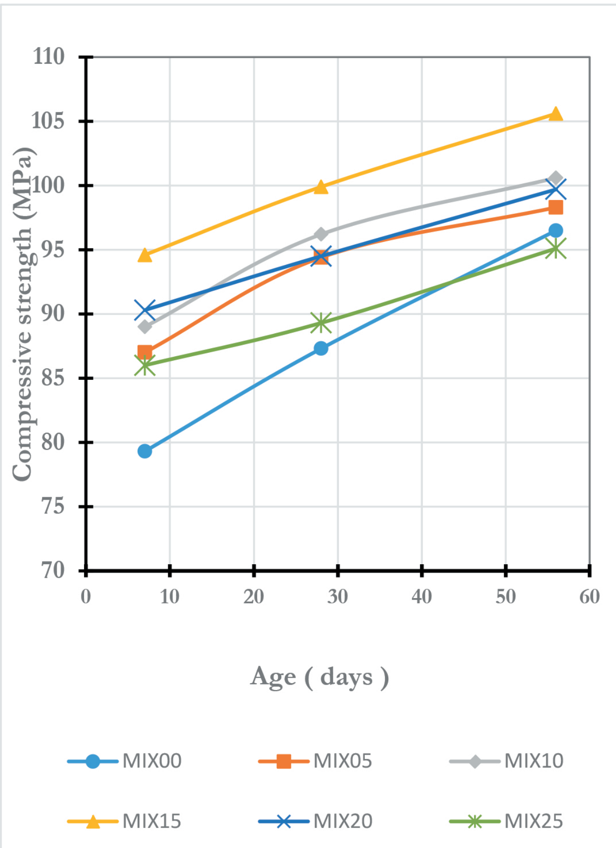

Fig. 2 Compressive strength results of reactive powder concrete at various ages

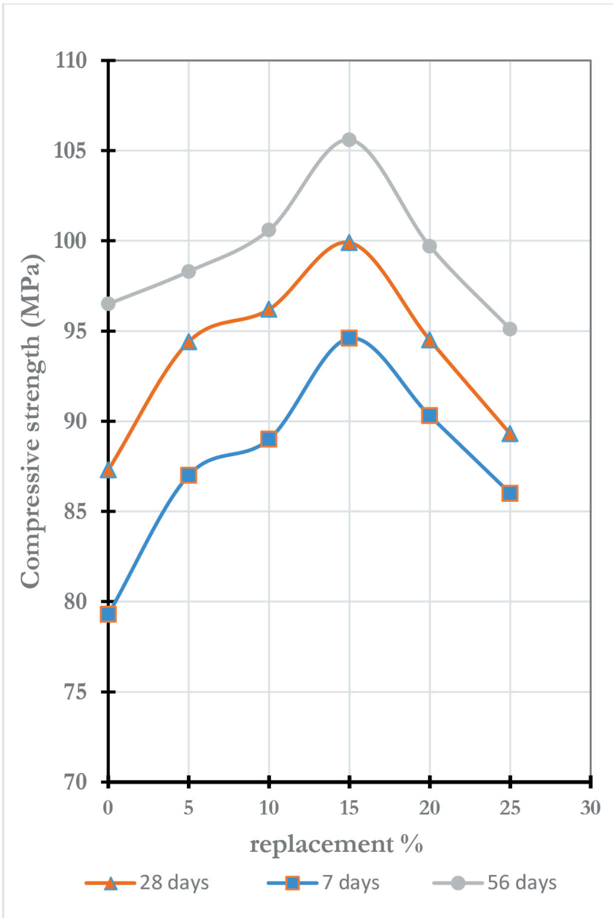

Fig. 3 Relationship between the compressive strength and replacement level at different ages

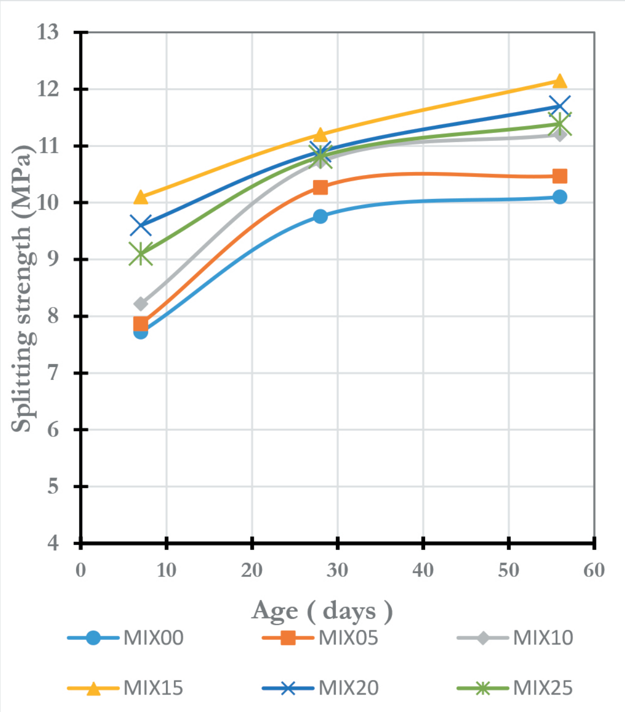

Fig. 4 Splitting strength results of reactive powder concrete at various ages

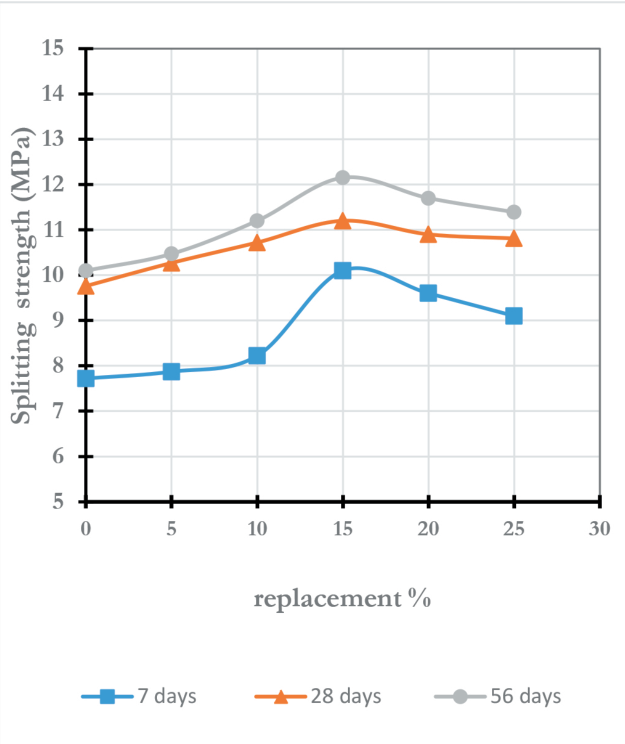

Fig.5 Relationship between the splitting strength and replacement level at different ages

without any replacement, respectively. The increment percentage at age 28 days was 1.6 %, 2.9 %, 4.5 %, 6.4 %, and 10.5 % for MIX05, MIX10, MIX15, MIX20, and MIX25

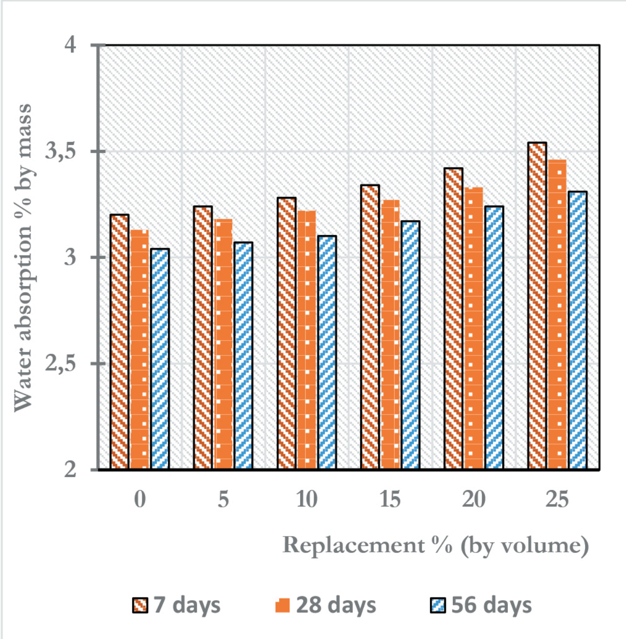

Fig. 6 Water absorption results of reactive powder concrete at various ages

as compared to references mix without any replacement, respectively. The increment percentage at age 56 days was 1.0 %, 1.9 %, 4.3 %, 6.6 %, and 8.9 % for MIX05, MIX10, MIX15, MIX20, and MIX25 as compared to references mix without any replacement, respectively.

4 Conclusions

After initiation the experimental work on simultaneously replacing of waste powdered materials (waste glass and waste ceramics tile) as partial of silica fume in modified reactive powder concrete and their detailed exploration, succeeding points could be concluded:

1. Powdered waste glass and powdered waste ceramics tile can be together utilized as pozzolanizc material in concrete replacement. The optimum mixing ratio for this pozzolanic material 80 % glass and 20 ceramics.
2. The compressive strength of modified reactive powder concrete containing waste powdered material up to 25 % replacement from silica fume higher than reference mix.
3. The splitting strength of modified reactive powder concrete containing waste powdered material up to 25 % replacement from silica fume higher than reference mix at all ages.
4. The water absorption of modified reactive powder concrete increases as the content of waste powdered material increase.

5. The optimum percent of replacement of waste powdered material from silica fume in reactive powder concrete is 15 %, due to the greatest enhancement in the compressive and splitting strengths of modified reactive powder concrete.
6. There is opportunity for recycling waste materials like glass and ceramics tiles as partially replacement from silica fume for producing modified reactive powder concrete.

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