23rd Australasian Conference on the Mechanics of Structures and Materials

2014

Pozzolanic reaction of glass powder and its influences on concrete properties

Hongjian Du
National University of Singapore

Hongchen Jacey Gao
National University of Singapore

Wei Li
National University of Singapore

Publication details

Du, H, Gao, HJ & Li, W 2014, 'Pozzolanic reaction of glass powder and its influences on concrete properties', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. I, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 267-272. ISBN: 9780994152008.

23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)
Byron Bay, Australia, 9-12 December 2014, S.T. Smith (Ed.)

POZZOLANIC REACTION OF GLASS POWDER AND ITS INFLUENCES ON CONCRETE PROPERTIES

Hongjian Du*
Department of Civil and Environmental Engineering, National University of Singapore
Engineering Drive 2, 117576, Singapore. ceedh@nus.edu.sg (Corresponding Author)

Hongchen Jacey Gao
Department of Civil and Environmental Engineering, National University of Singapore
Engineering Drive 2, 117576, Singapore. jacey.ghc@gmail.com

Wei Li
Department of Civil and Environmental Engineering, National University of Singapore
Engineering Drive 2, 117576, Singapore. ceeliw@nus.edu.sg

ABSTRACT

Waste glasses were finely ground to use as ordinary Portland cement (OPC) replacement in concrete. Its pozzolanic reactivity was evaluated at different replacement levels, including 15%, 30%, 45% and 60% by mass. The particle size distribution for glass powder is almost the same as that of OPC. It was found that the total hydration heat was greatly reduced due to the dilution effect of OPC, which results in a lower strength at early age. However, the pozzolanic reaction of glass powder became obvious with longer curing period, supported by the much improved strength for concrete with 15% and 30% glass powder. Calcium hydroxide content was determined at different ages for paste with various amount of glass powder and the results revealed that the calcium hydroxide drastically dropped with age, consumed by the pozzolanic reaction of glass powder. At 91 days, almost no calcium hydroxide was found in the paste with 60% glass powder, implying that the optimum replacement level should be less than 60%. Pore size distribution was also compared for OPC concrete and glass powder concrete, via mercury intrusion porosimetry (MIP) respectively.

KEYWORDS

Sustainable materials, waste glass, compressive strength, durability, pozzolanic reaction.

INTRODUCTION

Incorporating waste materials in concrete has been demonstrated to be an effective way to increase the sustainability of structures and infrastructures. Extensive research has been carried out to use fly ash, slag, rice husk ash and silica fume as cement replacement previously. Another promising material is municipal waste glass whose recycling rate is still low at 27.7% for US, 45% for Australia, and 20% for Singapore. Those unrecycled waste glasses are disposed in landfills. Jin et al. (2000) first proposed to use waste glass as fine aggregates in concrete and found its feasibility provided that alkali-silica reaction can be mitigated under the safe level. A few studies were following to investigate the influence of using waste glass as sand in concrete, including fresh, mechanical and durability properties (Tan and Du 2013; Du and Tan 2013; Du and Tan 2014a,b). Recently, it is found that the finely ground glass powder can be used as cement alternative because of the pozzolanic reaction of fine glass powder with cement hydration products (Shao et al. 2000; Shayan and Xu 2004; Shi and

Zheng 2007). This would further reduce the cement content in concrete and consequently the CO_2 emission during the cement production.

Previous literature focuses on the influence of glass powder pozzolanic reaction on the hydration process in paste as well as on the mechanical properties of cement mortar or concrete. The durability performances are rarely discussed. In this study, the pozzolanic reaction of glass powder and its effect on the hydration product and the microstructures of concrete would be determined. The results will be linked with the measured durability. Based on the results, the optimum cement replacement level will be provided.

EXPERIMENTAL PROGRAMS

Materials

Waste glass bottles were collected form a local plant and crushed into small particles. Further finely grinding was completed by using a ball-miller. The particle size distributions for both cement and glass powder are shown in Figure 1. XRD patterns of glass powder are displayed in Figure 2, from which it is noted that glass powder is amorphous. Daracem-100 was added as superplasticizer (SP) to adjust the workability of concrete.

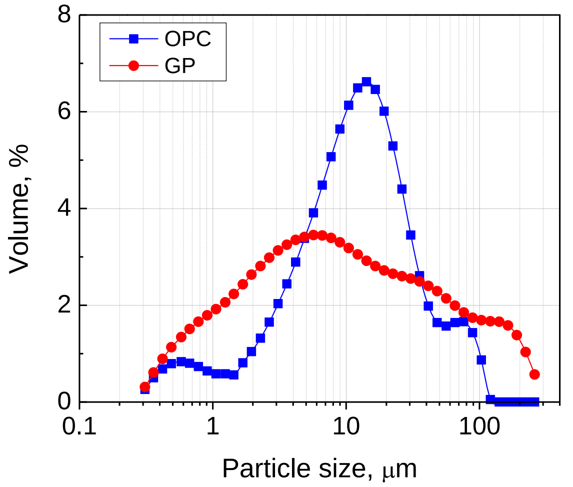

Figure 1. Particle size distribution of cement and glass powder

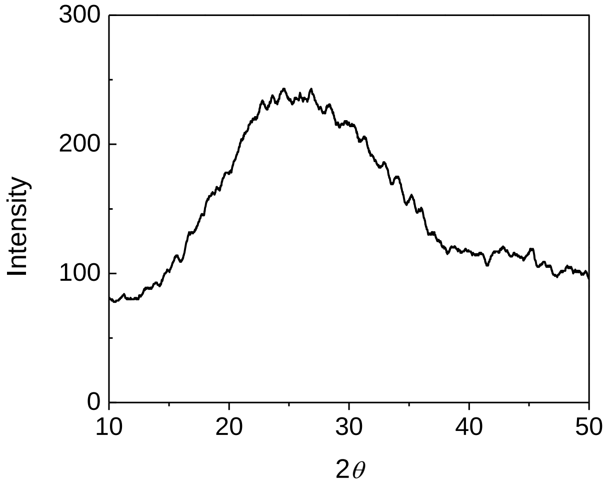

Figure 2. XRD patterns of glass powder

Mix Proportion

A reference concrete mix was selected with water-to-cement ratio of 0.485. Glass powder was used as cement substitute at replacement level of 15%, 30%, 45% and 60%, respectively. Paste samples were also prepared to determine the Portlandite content at different ages, for each glass powder replacement level.

Table 1. Mix proportions of concrete with glass powder

Mix No.	Content, kg/m^3					
	Water	Cement	GP	Coarse aggregate	Sand	SP
OPC	185	380	0	825	960	3.8
15GP	185	323	57	825	948	3.2
30GP	185	266	114	825	936	3.0
45GP	185	209	171	825	925	3.9
60GP	185	152	228	825	913	4.5

Test Methods and Specimens

The concrete mixtures were mixed in a pan mixer and compacted on a vibration table. All the concrete specimens were cured in water tank till the age of 28 days. Paste samples were cured in saturated lime water and thus oven-dried and finely ground at the age of 7, 28 and 91 days, respectively, to determine the Portlandite content by using thermogravimetric analysis (TGA). Compressive strength of concrete was determined based on three Ø100×200 mm cylinders, according to ASTM C 33. Water absorption and water accessible porosity were calculated from three Ø100×200 mm slices as per ASTM C 642. Water penetration depth was measured fro two Ø100×200 mm cylinders, in accordance with BS EN 12390-8. MIP was conducted by using micrometitics AutoPore III, with a maximum pressure of 412.5 MPa. Samples were collected from fractured surface of concrete after compression test.

RESULTS AND DISCUSSIONS

Pozzolanic Reaction

Portlandite content for paste with 0%, 30% and 60% glass powder was shown in Figure 3, at different ages. OPC sample always shows the highest content of Portlandite and remains almost constant after 7 days, indicating that the cement hydration has been completed. However, paste with glass powder consistently exhibited a reduction in the Portlandite content with increasing curing age, particularly for paste with 60% glass powder. At early age, the decreased Portlandite content is due to the cement dilution effect. With longer curing period, the pozzolanic reaction of glass powder consumes Portlandite to form additional calcium-silicate-hydrates, leading to a more compact paste microstructure. At 91 days, the Portlandite content was 11.5% and 3.4% for paste containing 30% and 60% glass powder, respectively. This result revealed that beyond 60% replacement, there might be insufficient Portlandite to react with glass powder, to aid the further pozzolanic reaction.

Compressive Strength

Development of compressive strength of concrete containing varying contents of glass powder is shown in Figure 4. Plain concrete had the highest strength at early age of 7 days while exhibited the slowest strength gain rate till 91 days. Concrete with 15-45% glass powder demonstrated higher strength in comparison with the reference concrete. This trend is even more obvious at 91 days when all the concrete mixes with glass powder are superior to the plain concrete regarding compressive strength. This increase in compressive strength for concrete with glass powder is attributed to the pozzolanic reaction, which can improve the quality of cement paste, especially at the interface transition zone (ITZ) between aggregate particles and paste. In addition, it is noted that the highest strength occurred for concrete with 30% glass powder, followed by 45% and 15%.

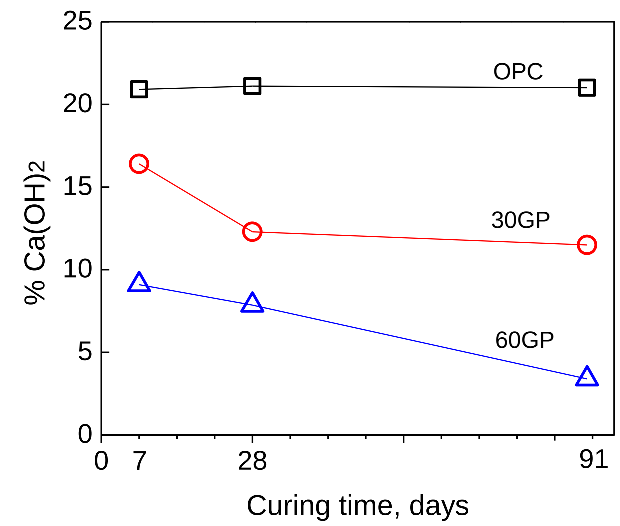

Figure 3. Development of Portlandite content in paste containing glass powder

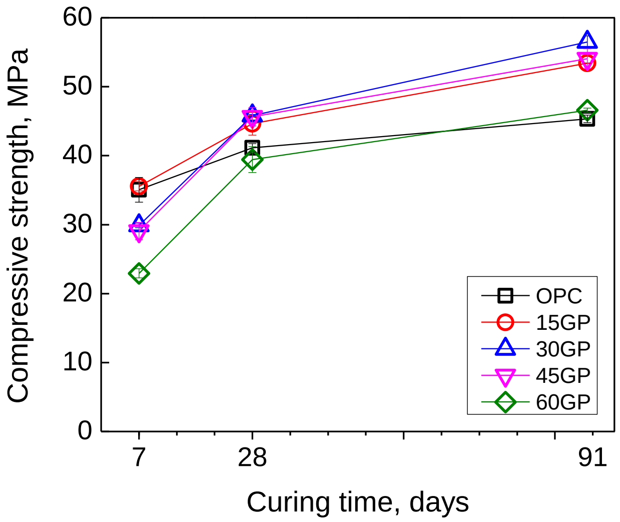

Figure 4. Development of compressive strength of concrete containing glass powder

Water Absorption and Water Accessible Porosity

At 28 days, the water absorption and water accessible porosity of concrete with glass powder are shown in Figure 5. Both parameters decreased with increasing glass powder content until 45% and afterwards increased slightly. This reduction in water absorption and water accessible porosity is attributed to the pozzolanic reaction of glass powder, which can refine the pore structures and decrease the connectivity. At the glass powder content reaches 60%, the pozzolanic reaction would be limited by Portlandite, the cement hydration products. This agrees well with the lowest compressive strength for concrete with 60% glass powder.

Water Penetration Depth

The influence of glass powder on the water penetration depth is shown in Figure 6. It is clear that the resistance of concrete against water penetration can be significantly reduced, with higher glass powder content, even up to 60%. Splitted specimens after 7 days of testing are shown in Figure 7, in which the waterfront was marked for each specimen. This better durability is consistent with the reduced water accessible porosity, as mentioned in the preceding section. However, the lowest water penetration depth was observed for concrete with 60% glass powder, which did not exhibit the lowest water accessible porosity. This is because the transport of water is governed by factors like pore connectivity and pore size distribution, other than water accessible porosity. Pore size distribution was characterized by MIP and shown in Figure 8. It is obvious that the cumulative curve shifted towards fine size ranges, indicating that pozzolanic reaction can refine the capillary pores and increase the tortuosity for water transport.

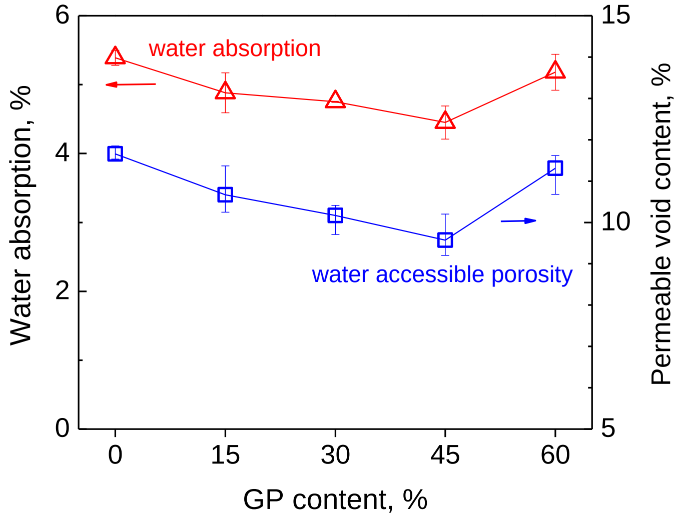

Figure 5. Development of compressive strength for concrete containing glass powder

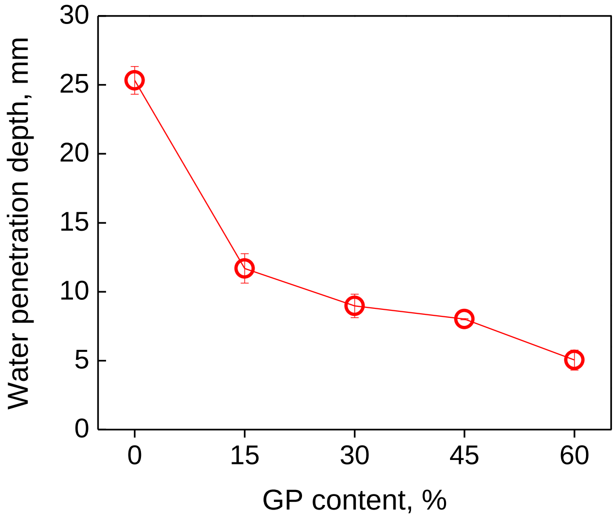

Figure 6. Water penetration depth into concrete with glass powder

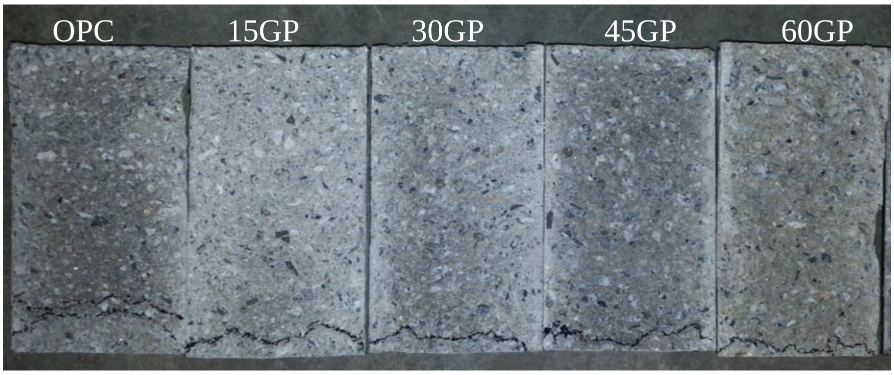

Figure 7. Test photos of water penetration depth into concrete containing glass powder

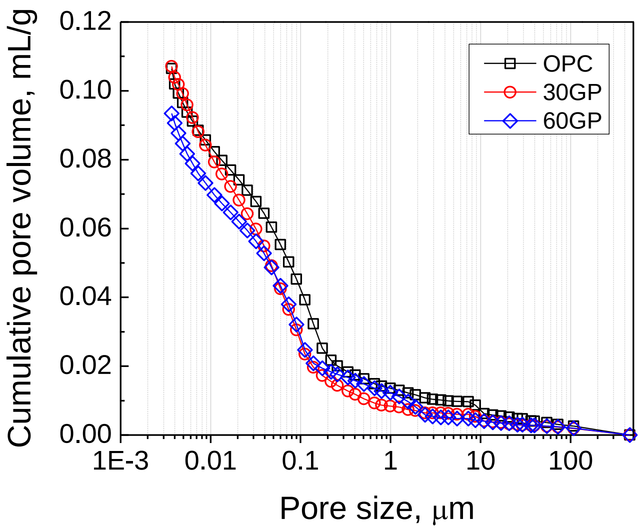

Figure 8. MIP curves for concrete containing glass powder

CONCLUSIONS

This study carried out experiments to determine the pozzolanic reaction of glass powder in cement paste and its influences on mechanical and durability properties of concrete. Results indicated that the Portlandite continuously decreased with more glass powder replacement. The highest compressive strength was observed to occur with concrete containing 30% glass powder. At higher content, glass powder seems to be overwhelming for the cement hydration products to react with. However, water permeability could be consistently reduced with increasing glass powder content because of the reduced water accessible porosity as well as the refined capillary pore systems.

REFERENCES

Du, H. and Tan, K.H. (2013) "Use of waste glass as sand in mortar: Part II- alkali-silica reaction and mitigation methods", *Cement and Concrete Composites*, Vol. 35, No. 1, pp. 118-126.

Du, H. and Tan, K.H. (2014a) "Concrete with recycled glass as fine aggregates", *ACI Materials Journal*, Vol. 111, No. 1, pp. 47-58.

Du, H. and Tan, K.H. (2014b) "Effect of particle size on alkali-silica reaction in recycled glass mortar", *Construction and Building Materials*, Vol. 66, pp. 275-285.

Jin, W., Meyer, C. and Baxter, S. (2000) "Glascrete-concrete with glass aggregate", ACI Materials Journal, Vol. 97, No. 2, pp. 208-213.

NEA. (2014) *Waste Statistics and Recycling Rate for 2013*, National Environment Agency, Singapore.

NRRS. (2013) *Paper Packaging, Glass Containers, Steel Cans and Aluminium Packaging*, IndustryEdge Pty Ltd and Equilibrium OMG Pty Ltd.

Shao, Y., Lefort, T., Moras, S. and Rodriguez, D. (2000) "Studies on concrete containing ground waste glass", *Cement and Concrete Research*, Vol. 30, No. 1, pp. 91-100.

Shayan, A. and Xu, A. (2004) "Value-added utilization of waste glass in concrete", Cement and Concrete Research, Vol. 34, No. 1, pp. 81-89.

Shi, C. and Zheng, K. (2007) "A review on the use of waste glasses in the production of cement and concrete", *Resources, Conservation and Recycling*, Vol. 52, No. 2, pp. 234-247.

Tan, K.H. and Du, H. (2013) "Use of waste glass as sand in mortar: Part I- fresh, mechanical and durability properties", *Cement and Concrete Composites*, Vol. 35, No. 1, pp. 109-117.

US EPA. (2014) *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2012*, United Sates Environmental Protection Agency, EPA530-F-14-001, Washington, DC.