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STRENGTH OF CONCRETE MORTAR PREPARED BY PARTIAL SUBSTITUTION OF CEMENT WITH RECYCLED GLASS POWDER

PRANSHOO SOLANKI and HARSH CHAUHAN

Dept of Technology, Illinois State University, Normal, USA

This experiment was conducted to determine the utility of substituting cement with the recycled glass powder (RGP) in mortar mixtures. A total of 21 mortar mixtures were produced using various RGP (FG) ratios (CG), and fly ash (FA) powders. The mortar mixtures were used to prepare cubes which were tested for 7- and 28-day compressive strength. The substitution of cement with FG and CG in mortar resulted in reduced 7- and 28-day compressive strength values. However, the amount and type of RGP substituted for cement plays a crucial role in the determination of mortar strength. Above contraction in compressive strength was observed at an initial maturity than at the final maturity. Further, replacement of cement with Fly Ash showed increase in compressive strength up to certain content. More research and testing for the optimal percentage and size of waste glass powder that can be used is required in flowable fill.

Keywords: Compressive strength, Fly ash, Finer glass, Cured.

1 INTRODUCTION

The need of construction materials continues to increase worldwide due to the construction of infrastructure for growing population. One of the construction materials is mortar, which is used for binding building blocks such as concrete masonry units, bricks, and stones. The ordinary Portland cement mortar is made by mixing Portland cement, fine aggregate (or sand), and water in a certain proportion. However, according to US Environmental Protection Agency (USEPA 2015, 2017), cement production is a major source of air pollution. Pozzolanic material is recognized as one of the methods of reducing emissions from Portland cement manufacturing by reducing the quantity of cement needed for a specific use (USEPA, 2010). Fly ash (FA) is one of the most widely used pozzolan in the construction industry (USEPA, 2010). However, with an increase in the awareness of the environment and shortages of FA, many transportation agencies and concrete producers are interested in pozzolan replacements for FA (AASHTO, 2016).

Literature review shows that few researchers used glass as a sand replacement in mortar. For instance, Bhandari and Tajne (2013) conducted a parametric experimental study for evaluating mechanical properties of mortar blocks using fine and coarse waste glass as sand substitute. The data collected showed a significant increase in the compression strength of the mortar blocks compared to the control sample due to the pozzolanic nature of fine glass due to the replacement of 20 percent fine aggregate with finer glass.

In a recent study, Huseien *et al.* (2020) studied alkali-activated mortars (AAMs) blended with glass bottles waste nano powder (BGWNP). The main aim of this research was to evaluate the feasibility of reusing BGWNP in place of blast furnace slag to produce AAMs. It was concluded that the proposed AAMs obtained using BGWNP offer definitive environmental benefits by minimizing global warming. AAMs workability was found to increase with increasing BGWNP content. The flexural, compressive and indirect tensile strength showed maximum improvement with AAMs containing 5% BGWNP as a slag substitute. It was also found that mixtures with BGWNP as a slag substitute resulted in longer initial and final setting times. Further, AAMs matrix containing BGWNP showed enhanced durability and reduced water absorption.

Further literature review revealed that few studies used various other solid wastes in mortar. For example, Gupta and Vyas (2018) replaced sand with wastes produced in mortar mixes from the cuts and completion of granite blocks. In concrete morter mixes, fine aggregates of 30 to 40 percent volume were replaced with waste granite powder. It was found that volume replacement in blended morter was reduced by 7 and 3 percent at 30 and 40 percent. Both tensile and compressive strength as well as adhesive strength were found to improve.

In a recent study, Oliveira *et al*. (2020) incorporated glass fiber embedded in epoxy resin in Portland cement mortar mixtures. Oliveira *et al*. (2020) obtained the solid waste from wind turbine blades manufacturer and converted it into a powder like that of sand by employing a turning process. It was concluded that the mortar produced with up to 15% of the sand replacement with wind turbine waste powder complied with relevant technological criteria, such as compression resistance (8 MPa). Further, utilization of wind turbine waste in mortars reduced the specific mass which could potentially be used in various construction projects.

In another recent study, Raini *et al*. (2020) studied the use of waste material coming out of civil engineering labs combined with brick waste as an aggregate substitute in cement mortars. Mortar specimens were prepared by replacing 0%, 15%, 30%, 45% and 90% by weight of natural fine aggregate with recycled fine aggregates. The laboratory testing of mortar specimens showed that the incorporation of these recycled fine aggregate at 15% showed no destructive effects on the mechanical properties of mortar specimens.

As noted from the aforementioned literature review most of the studies used glass or other solid waste as an aggregate substitute or supplementary cementitious material. However, glass is in theory pozzolanic or even cementitious in nature due to relatively large quantities of silicon and calcium. According to Dyer and Dhir (2001), use of glass as a cement substitute is more valuable from energy efficiency standpoint. Consequently, the primary objective of this study was to evaluate the feasibility of recycled glass powder (RGP) as a partial cement substitute in concrete mortar. Results from this research will increase the confidence for use of recycled glass in concrete products and will encourage the recycling sector to pursue sustainable growth in construction activities.

2 MATERIALS AND METHODS

2.1 Materials

The materials used in this study are: ordinary Portland cement Type 1 which complies with ASTM C150, standard sand conforming to the ASTM C144 standard, class C fly ash (FA) which complies with ASTM C618, and recycled glass powder or RGP. In this study, fine RGP (called as FG) and coarse RGP (called as CG), were used. FG is a fine powder with a fineness of 90% passing 0.044 mm and CG is coarser 0.21 to 0.60 mm powder with fineness of 98% passing 0.600 mm. The chemical composition of cement, sand, fly ash, and RGP are presented in Table 1 for comparison purpose.

Table 1. Chemical composition of cement, sand, fly ash and recycled glass powder.

Chemical	Cement (%)	Sand (%)	FA (%)	RGP (%)
SiO_2	20	97.8	37.7	69
CaO	62	0.14	24.4	16.1
Al_2O_3	5.3	1.17	17.3	2.9
Na_2O	0.23	0.06	1.1	9.3
K_2O	0.55	0.445	1.1	<1
Fe_2O_3	4.6	0.05	5.8	<1
MgO	0.6	-	5.1	1.4
SO_3	2.6	-	1.2	<0.5
TiO_2	-	0.05	-	<0.1
LOI	2.0	0.25	1.2	<0.1

2.2 Specimen Preparation and Testing

A total of 22 mixtures including 21 containing RGP and one control were designed in accordance with ASTM C109 test procedure (Table 2). As shown in Table 2, seven mortar mixtures were prepared to evaluate the influence of FG on compressive strength by replacing 10%, 20%, 30%, 40%, 50%, 60%, and 70% of mass of the cement in control mixture with FG powder. Further, seven mortar mixtures were prepared to evaluate the influence of CG on compressive strength by replacing 10%, 20%, 30%, 40%, 50%, 60%, and 70% of mass of the cement in control mixture with CG powder. Additionally, for comparison with fly ash, seven mortar mixtures were prepared to evaluate the influence of class C fly ash on compressive strength by replacing 10%, 20%, 30%, 40%, 50%, 60%, and 70% of mass of the cement in control mixture with FA powder. Overall, a total of 132 cube specimens were prepared in this study. Specifically, six mortar cubes of 50 mm x 50 mm x 50 mm (2 in. by 2 in. by 2 in. size) were molded for each mixture using plastic split molds (total of 132 cubes); three were tested after 7 days of curing and remaining three were tested after 28 days of curing in accordance with ASTM C511 test method. The ASTM C 109 test method was used for determining compressive strength of specimens.

Table 2. Mortar proportions.

Mix#	Specimen Label	Cement (%)	Finer RGP (PFG) (%)	Coarser RGP (PCG) (%)	Fly Ash (PFA) (%)
1	Control	100	0	0	0
2	C-90 FG-10	90	10	0	0
3	C-80 FG-20	80	20	0	0
4	C-70 FG-30	70	30	0	0
5	C-60 FG-40	60	40	0	0
6	C-50 FG-50	50	50	0	0
7	C-40 FG-60	40	60	0	0
8	C-30 FG-70	30	70	0	0
9	C-90 CG-10	90	0	10	0
10	C-80 CG-20	80	0	20	0
11	C-70 CG-30	70	0	30	0
12	C-60 CG-40	60	0	40	0
13	C-50 CG-50	50	0	50	0
14	C-40 CG-60	40	0	60	0
15	C-30 CG-70	30	0	70	0
16	C-90 FA-10	90	0	0	10
17	C-80 FA-20	80	0	0	20
18	C-70 FA-30	70	0	0	30

Table 2. Mortar proportions (contd.).

19	C-60 FA-40	60	0	0	40
20	C-50 FA-50	50	0	0	50
21	C-40 FA-60	40	0	0	60
22	C-30 FA-70	30	0	0	70

3 RESULTS

Figures 1 through 3 show compressive strength of mortar specimens versus percent fine glass (PFG), percent coarse glass (PCG) and percent fly ash (PFA) substitution. Further effect of FG, CG and FA on compressive strength of mortar mixtures is discussed in subsequent sections.

3.1 Effect of PFG on Strength

It is evident from Figure 1 that the compressive strength of specimens improved with age, as expected. However, strength was found to decreased with increase in the fine glass powder content for both 7- and 28-day mortar specimens. The lowest value was obtained at 70% PFG. Higher reduction in compressive strength was observed at an early age than at the later age. Specifically, replacing 10%, 20%, 30%, 40%, 50%, 60%, and 70% of mass of the cement in control mixture with FG powder reduced compressive strength by 13.9%, 29.7%, 34%, 35.4%, 44.4%, 66.2%, and 79.1%, respectively, at 7 days. Further, replacing 10%, 20%, 30%, 40%, 50%, 60%, and 70% of mass of the cement in control mixture with FG powder reduced compressive strength by 10.4%, 17.1%, 23.3%, 33.8%, 41.7%, 48.7%, and 60.1%, respectively, at 28 days. This behavior of reduction or early age strength could be attributed to long-term pozzolanic reactions. Literature review suggests that with longer curing time, the amorphous silica in glass dissolves in the alkaline environment to form C-S-H (calcium-silicate-hydrate) gel (Du and Tan 2017, Nahi *et al.* 2020).

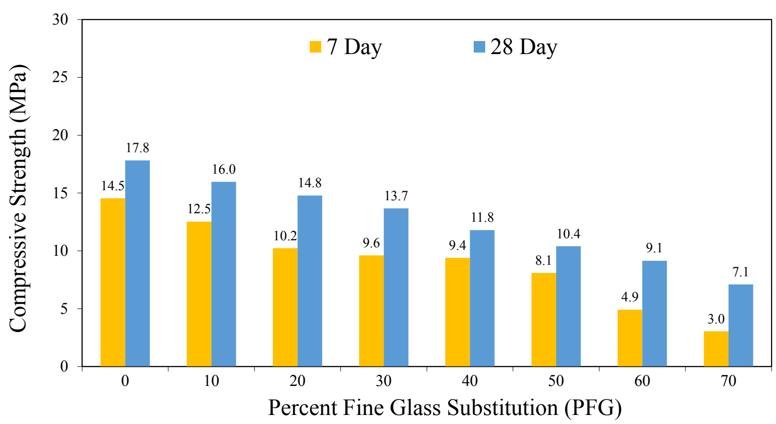

Figure 1. Effect of percent fine glass substitution (PFG) on compressive strength at 7 and 28 days.

3.2 Effect of PCG on Strength

Figure 2 reveals a gradual decrease in compressive strength of mortar specimens with the increase in PCG content. The lowest value was obtained at 70% PFG. Higher reduction in compressive strength was observed at an early age than at the later age. However, decrease in compressive strength was more enhanced with the replacement of cement with CG compared to FG. For instance, replacing 10%, 20%, 30%, 40%, 50%, 60%, and 70% of mass of the cement in control mixture with CG powder reduced compressive strength by 28.5%, 41.2%, 57.1%, 65.7%, 78.6%, 89%, and 94.6%, respectively, at 7 days. This behavior of improvement in strength of FG containing mixtures could be attributed to smaller size of the FG particles than CG particles.

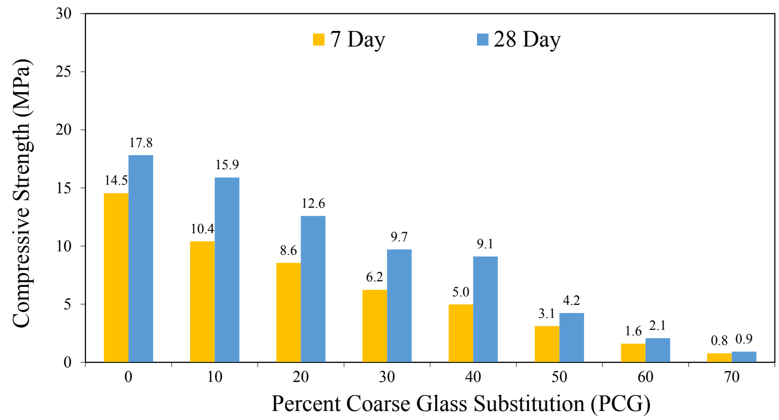

Figure 2. Effect of percent coarse glass substitution (PCG) on compressive strength at 7 and 28 days.

3.3 Effect of PFA on Strength

Figure 3 shows effect of PFA content on compressive strength. At 7 days, an increase in compressive strength was found up to 20% PFA content beyond which a constant decrease of compressive strength was observed. At 28 days, an increase in compressive strength was found up to 30% PFA content beyond which a constant decrease of compressive strength was observed. Optimum 7-day strength of 19.2 MPa and 28-day strength of 24.5 MPa was obtained with PFA content of 20% and 30%, respectively. Literature review shows similar results (Mehta 1985, Jaturapitakkul *et al*. 1999).

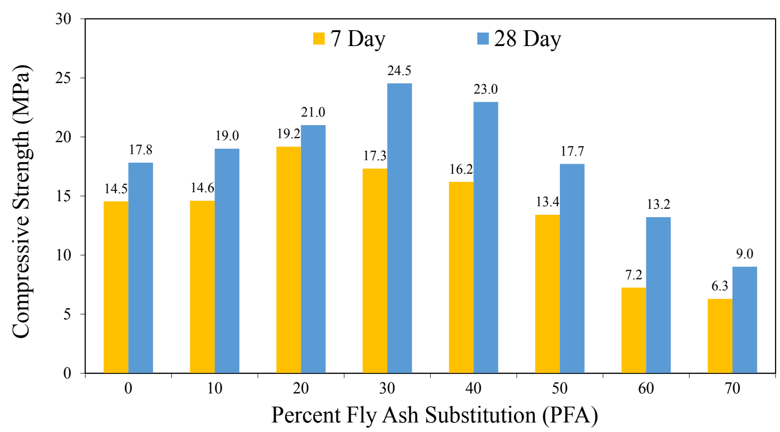

Figure 3. Effect of percent fly ash substitution (PFA) on compressive strength at 7 and 28 days.

4 CONCLUSIONS

In this study, recycled glass powder was investigated as partial substitute of cement in mortar mixtures. The replacement of cement with FG and CG in mortar was found resulted in reduced 7- and 28-day compressive strength values. However, the degree of reduction in strength was more due to substitution of cement with CG compared to FG powder. Higher reduction in compressive strength was observed at an early age than at the later age. On the contrary, replacement of cement with fly ash showed increase in compressive strength up to fly ash content of 20% and 30% for 7- and 28-day cured specimens, respectively.

Acknowledgments

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