Properties of Unsaturated Polyester Mortars Using Crushed Waste Glass

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Abstract

The purpose of this study is to explore the use of crushed waste glass as an aggregate in unsaturated polyester (UP) mortar. The unsaturated polyester mortars using crushed waste glass are prepared with three types of fillers, UP-fine aggregate ratios and crushed waste glass replacements for fine aggregate, and tested for weight change, strengths, setting shrinkage and acid resistance. From the test results, the strengths and acid resistance of UP mortars are improved with an increase in the waste glass replacement for fine aggregate. The setting shrinkage of UP mortars has a minimum value of 21.25x10⁻⁴ at CWG replacement of 50% for fine aggregate. It is reduced by a factor of two or more compared with 0%. In this study, a UP mortar with fly ash as a filler, a UP-fine aggregate ratio of 15% and a waste glass replacement of 50% for fine aggregate is selected as an optimal mix proportion of UP mortar using crushed waste glass. This is enough to assure the use of the crushed waste glass as an aggregate for the production of UP mortar.

Keywords: Crushed waste glass; unsaturated polyester mortar; strengths; setting shrinkage; acid resistance

Introduction

Recently, the importance of countermeasures to deal with waste materials has been pointed out, because such materials continue to increase each and every year. Waste glass is also one of the waste materials used for recycling in construction sites. The crushed waste glass has been used to make a glass polymer composite that can be applied for sewer, storm drain pipes and interlocking blocks, etc.¹ In this study the possibility of recycling crushed waste glass as a substitute for fine aggregates is explored.

The purpose of this investigation is to ascertain the properties of the UP mortars using crushed waste glass. UP mortars using crushed waste glass are prepared with ground calcium carbonate, blast furnace slag and fly ash as filler,² the UP-fine aggregate ratios, crushed waste glass replacements for fine aggregate, and tested for unit weight, setting shrinkage, flexural and compressive strengths, weight change and acid resistance. From the test results, improvements in the properties of the UP mortars due to the crushed waste glass replacements for fine aggregate are discussed.

Materials

A commercially available orthophthalate-type unsaturated polyester resin (UP) was used as a binder. The unsaturated polyester resin consists of unsaturated polyester of 60 wt% and styrene of 40 wt%. Table 1 gives the properties of the unsaturated polyester resin.

Table 1. Properties of Unsaturated Polyester Resin.

| Acid Value | Specific Gravity (20°C) | Viscosity (20°C, mPa•s) | Styrene Content (%) |
|------------|-------------------------|-------------------------|--------------------|
| 23.0       | 1.12                    | 125                     | 40                 |

Methyl Ethyl Keton Peroxide(MEKPO) was used as a catalyst. Commercially available calcium carbonate, fly ash and blast furnace slag were used as fillers. The properties of fillers are given in Table 2. Crushed waste glass (FM: 3.76) and Jumunjin standard sand were used as fine aggregates. The properties of fine aggregates are given in Table 3.

Testing Procedures

According to JIS A 1181 (Method of Making Polyester Resin Concrete Specimens), polyester mortars were mixed with the mix proportions indicated in Table 4. The polyester mortar beams with dimensions of 40x40x160mm were molded, and then subjected to a three-day-20°C-60% R.H. dry cure. According to KS F 2475 (Method of Test for Unit Weight and Air Content of
Table 2. Properties of Fillers.

| Type of Filler | Specific Gravity (20°C) | Specific Surface Area (㎠/g) | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O |
|----------------|------------------------|----------------------------|-------|-------|-------|-----|-----|-----|------|------|
| Blast Furnace Slag | 2.90                  | 4,647                      | 33.1  | 13.8  | -     | 42.4| 6.1 | -   | 0.2  | 0.3  |
| Fly Ash          | 2.22                  | 3,613                      | 52.6  | 33.4  | 4.6   | 0.7 | 0.7 | 0.3 | 0.6  | 4.5  |
| Calcium Carbonate | 2.70                  | 2,500                      |       |       |       |     |     | CaCO₃ = 99% |

Table 3. Properties of Fine Aggregates.

| Type of Aggregate | Size (mm) | Specific Gravity (20°C) | Water Content (%) | Organic Impurities |
|-------------------|-----------|-------------------------|-------------------|--------------------|
| Jumunjin Standard Sand | 0.3-0.6 | 2.63                    | 0.1               | Nil                |
| Crushed Waste Glass | <5      | 3.38                    | 0.1               | Nil                |

Fresh Polymer-Modified Mortar), the unit weight of polymer mortars was measured. According to KS F 2482 (Method of Test for Flexural Strength of Polyester Resin Concrete) and KS F 2483 (Method of Test for Compressive Strength of Polyester Resin Concrete Using Portions of Beams Broken in Flexure), strengths of polymer mortars were measured. Setting shrinkage was measured by use of 8cmx10cmx40cm mold equipped dial gauges at the center of both ends. According to the drafted JCI [Japan Concrete Institute] (Method of Test for Chemical Resistance of Polymer-Modified Mortar), the cured beam specimens were immersed in test solutions at 20°C for 28 and 91 days for acid attack. The test solution used is 10% sulfuric acid (H₂SO₄). After 28-day and 91-day immersion, the attacked portions of the beam specimens were cleaned. Their weight was then determined, and its change calculated as follows:

\[
\text{Weight change} (%) = \left[ \frac{(W_1-W_0)}{W_0} \right] \times 100
\]  (1)

where \( W_0 \) and \( W_1 \) are the weights (g) of the beam specimens before and after immersion, respectively.

After that, the beam specimens were tested for compressive and flexural strengths in accordance with KS F 2481 (Method of Test for Compressive Strength of Polyester Resin Concrete) and KS F 2482 (Method of Test for Flexural Strength of Polyester Resin Concrete) respectively, and their relative compressive strength calculated as follows:

Relative flexural strength (%) = \( \frac{\sigma_f}{\sigma_{f0}} \times 100 \)  (2)

Relative compressive strength (%) = \( \frac{\sigma_c}{\sigma_{c0}} \times 100 \)  (3)

where \( \sigma_{f0} \) and \( \sigma_f \) are the flexural strength (MPa) of the beam specimens before and after immersion, respectively. And \( \sigma_{c0} \) and \( \sigma_c \) are the compressive strength (MPa) of the beam specimens before and after immersion, respectively.

Table 4. Mix Proportions of Unsaturated Polyester Mortars Using Crushed Waste Glass.

| UP-Fine Aggregate Ratio, UP/FA(%) | Crushed Waste Glass Replacement for Fine Aggregate, CWG/FA(%) | F/B | MEKPO/UP (%) |
|----------------------------------|-------------------------------------------------------------|-----|--------------|
| 0                               | 0                                                          | 1.0 | 1.0          |
| 1.0                             | 0                                                          | 1.0 | 1.0          |
| 12                              | 20                                                         | 50  | 100          |
| 13                              | 20                                                         | 50  | 100          |
| 14                              | 20                                                         | 50  | 100          |
| 15                              | 20                                                         | 50  | 100          |

Results and Discussion

Fig. 1 shows the unit weight of UP mortars using crushed waste glass with CaCO₃ as a filler. With increasing CWG replacement, the unit weight of the UP mortars increases sharply at CWG replacement for standard sand up to 100% owing to the difference of specific gravity by fine aggregates. Also, the unit weight of the UP mortars increases with an increase in the UP/FA ratios.
Fig. 1. Weight of Unit Volume of UP Mortars with Crushed Waste Glass.

Fig. 2 shows the setting shrinkage of UP mortars using crushed waste glass with CaCO$_3$ as a filler and UP/FA ratio of 15%. On the whole, the setting shrinkage of the UP mortars increases with additional curing time, and tends to become nearly constant within eight hours, irrespective of CWG replacements for standard sand. In general, the setting shrinkage of the UP mortars decreases with an increase in the crushed waste glass replacements for fine aggregate. This is attributed to the fact that more crushed waste glass (<5mm) used in this study has continuous grading than standard sand. The setting shrinkage of the UP mortars has a minimum value of 2.125x10$^{-4}$ at CWG replacement of 50% for fine aggregate. It is reduced by a factor of two or more compared with 0%.

Figs. 3 and 4 represent the flexural and compressive strengths of UP mortars using crushed waste glass with CaCO$_3$ as a filler. In the case of the ordinary cement mortar, the strength decreases with CWG replacements for fine aggregate. While on the contrary, the flexural and compressive strengths of the UP mortars increase with an increase in the crushed waste glass replacements for fine aggregate. The strengths increase sharply at CWG replacement for standard sand up to 50% and become nearly constant or increase slowly over 50%. At a CWG replacement of 100% for standard sand, the strengths of flexure and compression are 2.5-3.0 times and 2.6-2.8 times compared with 0%, respectively. It is thought that the extent of the strength improvement is influenced by the physical union rather than chemical union. This is because crushed waste glass with abundant acute angles has more adhesion on the surface than sand. Also, like normal polymer mortars and concretes, the strength of UP mortars using crushed waste glass increases with an increase in the UP content.

Fig. 5 gives the weight change of UP mortars using crushed waste glass after being immersed in H$_2$SO$_4$ 10% solution. In general, the weight change of the UP mortars increases with increased immersion period, however, it decreases remarkably with an increase in the UP content and CWG replacements for sand. Particularly, the weight change of the UP mortars with a UP/FA ratio of 15% and a CWG replacement of 100% for sand is less than 0.1%. Accordingly, the weight change is almost unrecognizable. This can be induced by the fact that watertightness was obtained by reduced internal void when the UP content and CWG replacement increased.

Figs. 6 and 7 exhibit the flexural and compressive strengths of UP mortars using crushed waste glass immersed in 10% H$_2$SO$_4$ for 0, 28, and 91 days. At an immersion period of 28 days, each strength of flexure and compression are 2.5-3.0 times and 2.6-2.8 times compared with 0%, respectively. It is thought that the extent of the strength improvement is influenced by the physical union rather than chemical union. This is because crushed waste glass with abundant acute angles has more adhesion on the surface than sand. Also, like normal polymer mortars and concretes, the strength of UP mortars using crushed waste glass increases with an increase in the UP content.
compression decreases to 4-65% and 5-42%. Thus, it is considered that the effect of strength reduction is marked by calcium carbonate rather than UP resin, sand and crushed waste glass. Therefore it is revealed that the bigger CWG replacements for sand; the smaller the relative strength, and the bigger the UP/FA ratio, the bigger the reduction of relative strength, due to the increased quantity of filler. This is, just like the inferred result in weight changes, because denser structure in UP mortars is formed with an increase in the CWG replacements for sand and UP/FA ratio. Also, at an immersion period of 91 days, 8-67% in flexural strength and 6-55% in compressive strength decline and subsequently show a similar trend in an immersion of period of 28 days.

Figs. 8 and 9 show the flexural and compressive strengths of UP mortars using crushed waste glass with three types of fillers such as CaCO₃, blast furnace slag and fly ash. The flexural and compressive strengths of the UP mortars increase sharply with an increase in the UP/FA ratio and CWG replacements for standard sand. While the strengths of UP mortars with fly ash as filler are larger than those of the UP mortar using other types of fillers.

Fig. 10 represents the weight change of UP mortars using crushed waste glass with three types of filler. The weights of the UP mortars are inclined to increase with the lapse of the immersion period. In general, this trend is similar to the water absorption of unmodified mortar or polymer-modified mortars. Regardless of the UP/FA ratio,
the weight change of the UP mortars using fly ash as a filler is smaller than that of the UP mortars using CaCO₃ and blast furnace slag as fillers. In other words, this means that the CaCO₃ and blast furnace slag show large absorption of H₂SO₄ solution compared to fly ash in the UP mortars. On the other hand, the weight change of the UP mortars decreases sharply with an increase in the UP/FA ratio and CWG replacements for fine aggregate. The weight loss of the UP mortar in H₂SO₄ 10% solution is not recognized when CWG replacement for standard sand is 50%.

Fig. 11 exhibits the relative flexural strength of UP mortars using crushed waste glass immersed in 10% H₂SO₄ for 28 days. The relative flexural strength of the UP mortars with fly ash as a filler is somewhat larger than that of the UP mortars using CaCO₃ and blast furnace slag at the respective waste glass replacement for fine aggregate. Therefore, the relative flexural strength of the UP mortars with CaCO₃ and blast furnace slag is found to be somewhat inferior to that of the UP mortars using fly ash. In general, the relative flexural strength of the UP mortars using fly ash as a filler is more than 60%.

Fig. 12 shows the relative compressive strength of UP mortars using crushed waste glass immersed in 10% H₂SO₄ for 28 days. Like the relative flexural strength of the UP mortars, the relative compressive strength of the UP mortars increases with an increase in the waste glass replacements for fine aggregate. Regardless of the type of filler and UP/FA ratio, the relative compressive strength of the UP mortars has a good acid resistance at a CWG replacement of 50% for fine aggregate. The relative compressive strength of the UP mortars with fly ash as a filler is more than 60%.

UP mortars with a waste glass replacement of 50% for fine aggregate especially have a high relative flexural strength of more than 90% at UP-fine aggregate ratios of 14 and 15%.
filler is almost equal to that of the UP mortars using CaCO₃. Especially, it has a high relative strength of more than 90% at a waste-aggregate ratio of 50% and UP contents of 14 or 15%. Also, UP mortar with a waste glass replacement of 50% for fine aggregate at an immersion period of 91 days sustains relative flexural and compressive strengths of more than 60% at UP/FA ratios of 14 and 15%. In conclusion, the UP mortar with fly ash as a filler, a UP/FA ratio of 15% and a CWG replacement of 50% for standard sand is recommended as an optimal mix proportion.

**Conclusions**

The conclusions obtained from the test results are summarized as follows:

1. In general, the setting shrinkage of UP mortars using crushed waste glass decreases with an increase in the crushed waste glass replacements for fine aggregate. The setting shrinkage of the UP mortars has minimum value of 21.25x10⁻⁴ at CWG replacement of 50% for fine aggregate. It is reduced by a factor of two or more compared with 0%.

2. The flexural and compressive strengths of UP mortars increase sharply at CWG replacement for standard sand up to 50% and become nearly constant or increase slowly over 50%. At a CWG replacement of 100% for standard sand, the strengths of flexure and compression are 2.5-3 times and 2.6-2.8 times compared with 0%, respectively.

3. Weight loss of UP mortar in H₂SO₄ 10% solution is not recognized. In general, the weight change of the UP mortars using fly ash as a filler is smaller than that of the UP mortars using CaCO₃ and blast furnace slag as fillers.

4. The relative flexural strength of UP mortars using CaCO₃ and blast furnace slag as fillers is found to be somewhat inferior to that of the UP mortars using fly ash as a filler.

5. Regardless of the type of filler and UP-fine aggregate ratio, the relative flexural and compressive strengths of the UP mortars have good acid resistance at a waste glass replacement of 50% for fine aggregate.

6. In this study, a UP mortar with fly ash as a filler, a UP-fine aggregate ratio of 15% and a waste glass replacement of 50% for standard sand is recommended as an optimal mix proportion of UP mortar. From this study, it is enough to assure the use of the crushed waste glass as an aggregate for the production of UP mortar.

**References**

1. Fontana, Jack J. (1991) Waste Encapsulation and/or Solidification in Polymer Concretes, ICPIC Working Papers, International Congress on Polymers in Concrete, San Francisco, 1-10.

2. Soh et al (1997) Effect of Filler on the Mechanical Properties of Unsaturated Polyester Resin Mortar, Proceeding of the Second East Asia Symposium on Polymers in Concrete, E&FN Spon, London, 67-74.

3. Bae et al (1998) An Experimental Study on the Properties of Mortar Containing Recycled Glass, Proceedings of the Korea Concrete Institute, 10 (2), 36-41.

4. Ohama et al (1980) Effects of Styrene- Unsaturated Polyester Ratio on Properties of Polyester Resin Concrete, Japan Society of Materials Science, 29 (318), 60-65.