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# Studies on mechanical properties of concrete containing waste glass aggregate

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**Abstract**

Quantities of waste glass have been on the rise in recent years due to an increase in industrialization and the rapid improvement in the standard of living. Unfortunately, the majority of waste glass is not being recycled but rather abandoned, and is therefore the cause of certain serious problems such as the waste of natural resources and environmental pollution. For these reasons, this study has been conducted through basic experimental research in order to analyze the possibilities of recycling waste glasses (crushed waste glasses from Korea such as amber, emerald green, flint, and mixed glass) as fine aggregates for concrete. Test results of fresh concrete show that both slump and compacting factors are decreased due to angular grain shape and that air content is increased due to the involvement of numerous small-sized particles that are found in waste glasses. In addition the compressive, tensile and flexural strengths of concrete have been shown to decrease when the content of waste glass is increased. In conclusion, the results of this study indicate that emerald green waste glass when used below 30% in mixing concrete is practical along with usage of 10% SBR latex. In addition, the content of waste glasses below 30% is practical along with usage of a pertinent admixture that is necessary to obtain workability and air content.



*Keywords:* Waste management; Alkali–aggregate reaction; Glass; Polymer; Concrete

## 1. Introduction

Glass in general is a highly transparent material formed by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperatures followed by cooling during which solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing [1].

The total annual domestic glass product usage is approximately 4.2 million tons, among which sheet glass for windows occupies about 36%; glass fiber products, 6%; and disposable glassware such as bottles, etc., 58% [2]. However, due to recent urbanization and industrialization, waste glass amounted to 613,000 tons in 1998, 692,000 tons in 1999, and has continued to demonstrate an increasing trend. This pattern has raised social and environmental concerns, and adequate management and recycling of waste glass is gathering social interest [2,3]. Foreign countries have long been taking much effort to recycle waste glass bottles. A bottle recovery system, through which empty bottles previously containing alcoholic beverages, refreshing beverages, condiments, milk, etc. are collected, washed, and reused, has already been established. In addition, broken bottles and bottles previously containing chemicals, cosmetics, etc. are melted down to be reused or crushed and turned into paving material, block material, glass marble, glass tile, glass fiber, lightweight blowing agents, etc. [4–10].

In Korea, empty used bottles are similarly reutilized in that they are collected, sorted, and crushed to be used mostly as a raw material for new bottles. However, only negligible proportions of the total used bottles are actually currently being recycled. Therefore, we have sought to evaluate the recyclability of domestic waste glass as a fine aggregate for concrete and other secondary processed construction materials.

## 2. Research significance

There is significant interest in the development of concrete with waste glass. Recycling waste glass as an aggre-

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Table 1
Conditions and variables of experiment

| Conditions | Variables |
|---|---|
| W/C (%) | 50 |
| S/A (%) | 47 |
| Replacement ratio of waste glass (%) | 0, 30, 50, 70 |
| Replacement ratio of SBR (%) | 0, 5, 10, 20 |
| Target slump | 150 mm |
| Target air content | 5% |
| Test items | |
| Waste glass | Specific gravity |
| | Sieve analysis |
| | Fineness modulus |
| | Chemical composition |
| | Unit weight |
| | Water absorption |
| | Absolute volume |
| Fresh concrete | Slump |
| | Air content |
| | Compacting factor |
| Hardened concrete | ASR test |
| | Compressive strength |
| | Tensile strength |
| | Flexural strength (age 1, 4, and 13 weeks) |

gate is effective for environmental conservation and economical advantage. Therefore, the most common flint, amber, and emerald green bottles were collected and crushed to be included in concrete as an aggregate, and a basic experimental study on the physical and mechanical properties of concrete containing waste glass was carried out.

## 3. Experimental outline

### 3.1. Experimental plan

As shown in Table 1, waste glass particles crushed to be used as a fine aggregate for concrete were analyzed in terms of physical and chemical properties such as specific gravity, particle size, water absorption, absolute volume, and chemical composition. Alkali–silica reaction (ASR) expansion was analyzed in terms of waste glass content. Following that, we prepared several concrete test pieces with water–cement ratio (W/C) 50%, sand–coarse aggregates ratio (S/C) 47%, and others by varying the content of waste glass aggregates to 30%, 50%, and 70% and analyzing the physical and mechanical properties of these concretes. Also, the mechanical properties of the concrete using emerald green waste glass was analyzed in terms of waste glass and polymer (SBR latex) content.

Table 3
Physical properties of aggregates

| Items | FM | Specific gravity | Absorption (%) | Unit weight (kg/m$^3$) |
|---|---|---|---|---|
| Fine | 2.68 | 2.65 | 1.40 | 1650 |
| Coarse | 7.08 | 2.70 | 1.32 | 1480 |

### 3.2. Materials

General Portland cement manufactured by domestic company “D” was used. Its chemical composition and physical properties are shown in Table 2. Fine and coarse aggregate sands from the upper stream of Gumkang were used as a fine aggregate, while crushed stones with a maximum diameter of 25 mm manufactured by company “H” in Chungnam Province were used as a coarse aggregate. Table 3 and Fig. 1 show their physical properties and grading distribution, respectively.

The waste glasses used were from the soda–lime series that are widely used for bottles and glassware in Korea. Waste glasses were collected and sorted into three different colors—amber (A), emerald green (EG), and flint (F)—before they were crushed into fragments of 6–20 mm in size at the Korea Resources Recovery and Reutilization Corporation’s recycling factory in Hongsung, Chungnam Province. These fragments were then put into a small crusher to prepare waste glass aggregates of less than 5 mm in size. As an admixture, an AE reducing agent was used. Its properties are summarized in Table 4. A styrene butadiene rubber (SBR) latex manufactured by domestic company “C” was used as the polymer, and its physical properties are shown in Table 5.

### 3.3. Test method

To determine the applicability of the crushed waste glass as a fine aggregate for concrete, physical properties of the

Table 2
Chemical composition and physical properties of cement

| Chemical composition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | Loss on ignition | Total |
| 21.24 | 5.97 | 3.34 | 62.72 | 2.36 | 0.13 | 0.81 | 1.97 | 1.46 | 100 |

| Physical properties | | | | | |
|---|---|---|---|---|---|
| Specific gravity | Blaine (cm$^2$/g) | Stability (%) | Compressive strength (N/mm$^2$) | | |
| | | | 3 days | 7 days | 28 days |
| 3.14 | 3200 | 0.02 | 22 | 29 | 38 |

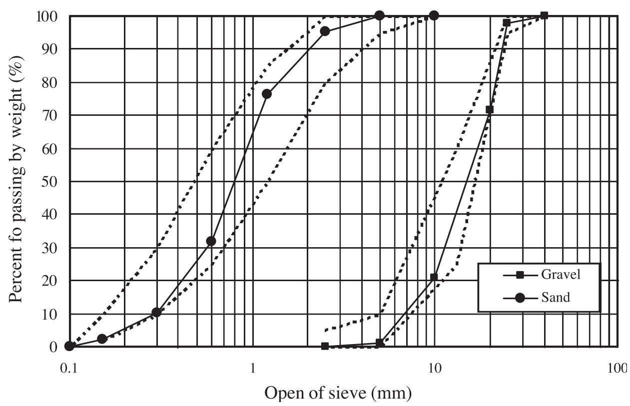


Fig. 1. Grading curves of aggregates.

waste glass fine aggregates were measured in accordance with the test method for each test item listed in Table 6.

Tests for evaluating the physical and mechanical properties of the concretes with waste glass aggregates were conducted in accordance with the methods listed in Table 7.

ASR test was conducted in accordance with ASTM C 1260 to check the recycling potential of the waste glass and to evaluate its influence on the ASR. Three test mortar bars were made for each mixing with W/C 0.47 and S/C 2.25. Normal procedure was to cure them for 24 h, immerse them in water for 24 h, and then store them in 1 N NaOH solution at 80 °C in a closed container. Changes in the length of the mortar bars were checked for the next 14 days after their surface was dried by using a comparator, a length-comparison measuring device with an accuracy less than 0.002 mm.

### 3.4. Compounding and mixing

In order to evaluate the recycling potential of waste glass as a fine aggregate for concrete, a proportioning plan was established for the color and content of the waste glass and the content of the waste glass and polymer as shown in Table 8. Ingredients such as coarse aggregate, cement, fine aggregate, and admixture with water, also it with polymer of 0, 5, 10, 20 percent for cement weight were fed in this order into a forced fan-type mixer having a capacity of 50-l, where they were mixed for 90 s. The mix proportions used to evaluate the ASR expansion characteristic were prepared in accordance with ASTM C 1260 shown in Table 9.

Table 4
Properties of admixture

| Type | Color | Main ingredient | Solid (%) | Specific gravity |
|---|---|---|---|---|
| AE reducing agent | Dark brown | Naphthalene | 33 | $1.15 \pm 0.05$ |

Table 5
Properties of polymer

| Type | Color | pH | Solid (%) | Density (g/cm$^2$) |
|---|---|---|---|---|
| SBR latex | White milky liquid | 10.5 | 50 | 0.97 |

Table 6
Test methods for waste glass

| Test items | Test method |
|---|---|
| Fineness modulus | KS F 2502 |
| Specific gravity | KS F 2504 |
| Water absorption | KS F 2504 |
| Absolute volume | KS F 2505 |
| Sieve analysis | KS F 2502 |
| Unit weight | KS F 2505 |
| Chemical composition | SEM and EDX |

### 3.5. Preparation of test specimens

To evaluate the mechanical properties of the concrete (compressive, tensile, and flexural strengths) by age and mixing ratio, concrete test specimens were made in accordance with KS F 2403. They were then air cured for 24 h, removed from their forms, and put through standard curing under water at 20 ± 3 °C until they reached the required age.

## 4. Test results and discussions

### 4.1. Physical and chemical properties of waste glass aggregates

The physical tests on the crushed waste glasses intended to be used as a fine aggregate for concrete provided the results shown in Table 10.

In summary, regardless of the color of the waste glasses, the fineness modulus (FM), specific gravity, water absorption rate, and absolute volume ratio ranged between 3.46–3.49, 2.50–2.52, 0.40–0.43%, and 60.90–62.60%, respectively. In addition, their unit weights measured a total of more than 1500 kg/m$^3$, demonstrating that the crushed waste glasses were suitable as a fine aggregate for concrete and other secondary construction materials.

Analysis by SEM and EDX of the grain shape and chemical composition of the waste glass aggregates provided the results shown in Table 11, where $SiO_2$ showed the highest composition (71.30–73.04%), followed by $Na_2O$

Table 7
Test methods for concrete

| Test items | Test method |
|---|---|
| *Fresh concrete* | |
| Slump | KS F 2402 |
| Air content | KS F 2421 |
| Compacting factor | BS 1881 |
| *Hardened concrete* | |
| ASR test | ASTM C 1260 |
| Compressive strength | KS F 2405 |
| Tensile strength | KS F 2423 |
| Flexural strength | KS F 2408 |

Table 8
Mix proportion of concrete containing waste glass

| Mix type | W/C (%) | S/A (%) | Content of waste glass (%) | Content of polymer (C × %) | Unit weight (kg/m$^3$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | C | P | W | G | S | WG | Ad. |
| *Plain* | | | | | | | | | | | |
| SBR0 | 50 | 47 | 0 | 0 | 380 | 0 | 190 | 914 | 796 | 0 | 3.8 |
| SBR5 | | | | 5 | | 19 | 180 | | | | |
| SBR10 | | | | 10 | | 38 | 170 | | | | |
| SBR20 | | | | 20 | | 76 | 151 | | | | |
| A30 | 50 | 47 | 30 | 0 | 380 | 0 | 190 | 914 | 557 | 227 | 3.8 |
| A50 | | | 50 | | | | | | 398 | 378 | 3.8 |
| A70 | | | 70 | | | | | | 239 | 530 | 3.8 |
| *EG30* | | | | | | | | | | | |
| SBR0 | 50 | 47 | 30 | 0 | 380 | 0 | 190 | 914 | 557 | 225 | 3.8 |
| SBR5 | | | | 5 | | 19 | 180 | | | | |
| SBR10 | | | | 10 | | 38 | 170 | | | | |
| SBR20 | | | | 20 | | 76 | 151 | | | | |
| *EG50* | | | | | | | | | | | |
| SBR0 | 50 | 47 | 50 | 0 | 380 | 0 | 190 | 914 | 398 | 375 | 3.8 |
| SBR5 | | | | 5 | | 19 | 180 | | | | |
| SBR10 | | | | 10 | | 38 | 170 | | | | |
| SBR20 | | | | 20 | | 76 | 151 | | | | |
| *EG70* | | | | | | | | | | | |
| SBR0 | 50 | 47 | 70 | 0 | 380 | 0 | 190 | 914 | 239 | 526 | 3.8 |
| SBR5 | | | | 5 | | 19 | 180 | | | | |
| SBR10 | | | | 10 | | 38 | 170 | | | | |
| SBR20 | | | | 20 | | 76 | 151 | | | | |
| F30 | 50 | 47 | 30 | 0 | 380 | 0 | 190 | 914 | 557 | 225 | 3.8 |
| F50 | | | 50 | | | | | | 398 | 375 | 3.8 |
| F70 | | | 70 | | | | | | 239 | 526 | 3.8 |

C: cement; P: polymer; W: water; G: gravel; S: sand; WG: waste glass; Ad: admixture.

and $K_2O$. A slight difference was noticed in the chemical composition of the various waste glasses depending on their color. Furthermore, the prevailing grain shape was angular regardless of color of the waste glasses—a factor that we believe severely affects their workability [11].

Table 9
Mixture proportions by ASTM C 1260

| Mix No. | W/C (%) | S/C | WG content (%) | C (g) | W (g) | S (g) | WG (g) |
|---|---|---|---|---|---|---|---|
| AC-0 | 47 | 2.25 | 0 | 440 | 206.8 | 990 | 0 |
| AC-1 | | | 10 | | | 891 | 99 |
| AC-2 | | | 20 | | | 792 | 198 |
| AC-3 | | | 30 | | | 693 | 297 |
| AC-4 | | | 50 | | | 495 | 495 |
| AC-5 | | | 100 | | | 0 | 990 |

C: cement; W: water; S: sand; WG: waste glass.

Table 10
Physical properties of waste glass

| Type | Test | | | | |
|---|---|---|---|---|---|
| | FM | Specific gravity | Water absorption (%) | Absolute volume (%) | Unit weight (kg/m$^3$) |
| Amber | 3.49 | 2.52 | 0.40 | 61.93 | 1559 |
| Emerald green | 3.48 | 2.50 | 0.41 | 61.78 | 1543 |
| Flint | 3.48 | 2.50 | 0.43 | 62.60 | 1551 |

### 4.2. Mechanical properties of concrete containing waste glass aggregate

Slump, air content, and compacting factor were measured under the same conditions as above in order to examine the property of fresh concrete containing waste glass aggregates of different colors and mixing ratios.

#### 4.2.1. Slump

The slump test outcome for the concretes with waste glass fine aggregates of different colors and mixing ratios are shown in Fig. 2. These results demonstrate a tendency

Table 11
Chemical composition of waste glass

| Type | Chemical composition | | |
|---|---|---|---|
| | Emerald green glass (%) | Amber glass (%) | Flint glass (%) |
| $SiO_2$ | 71.30 | 72.10 | 73.04 |
| $Al_2SO_3$ | 2.18 | 1.74 | 1.81 |
| $Na_2O + K_2O$ | 13.07 | 14.11 | 13.94 |
| $CaO + MgO$ | 12.18 | 11.52 | 10.75 |
| $SO_3$ | 0.053 | 0.13 | 0.22 |
| $Fe_2O_3$ | 0.596 | 0.31 | 0.04 |
| $Cr_2O_3$ | 0.44 | 0.01 | – |
| Grain shape | Angular | Angular | Angular |

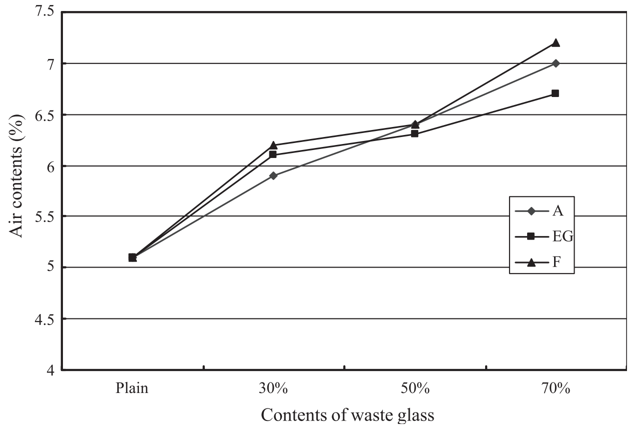


Fig. 2. Results of slump.

for the slump to decrease as the mixing ratio of waste glass aggregate increased; that is, regardless of their color, the slump decreased by 19.6–26.9%, 30.1–34.6%, and 38.5–44.3% as the mixing ratios of waste glass aggregates dropped by 30%, 50%, and 70%, respectively, compared to the plain concrete containing no waste glass.

We believe that this tendency may be due to the following: (1) as the mixing ratio of waste glass aggregate increased, additional cement paste attached to the surface of the waste glass, which thus resulted in less available cement paste necessary for the fluidity of the concrete; (2) waste glass aggregates had sharper and more angular grain shapes and were larger than sands, which resulted in less fluidity. However, the color of waste glass aggregates did not severely affect the slump. Therefore, an adequate amount of admixture was found in order to secure the necessary fluidity needed to prevent a decrease in the slump.

### 4.2.2. Air content

The results from the air content testing on concretes containing waste glass aggregates of diverse colors and mixing ratios are shown in Fig. 3. The concretes containing waste glass aggregates, regardless of their color, with an input ratio of 30%, 50%, and 70%, recorded 12.2–21.6%, 23.71–30.4%, and 30.6–41.4% increase in air content,

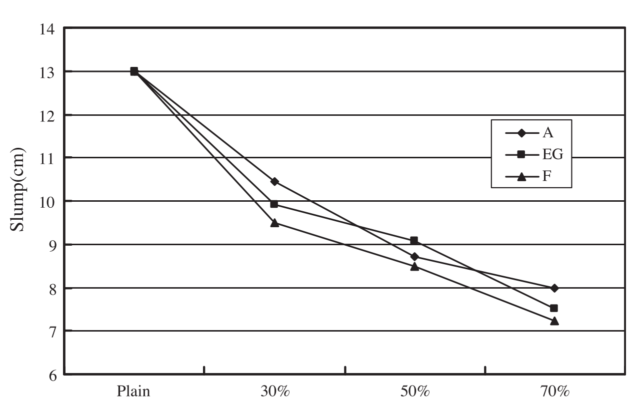


Fig. 3. Results of air content.

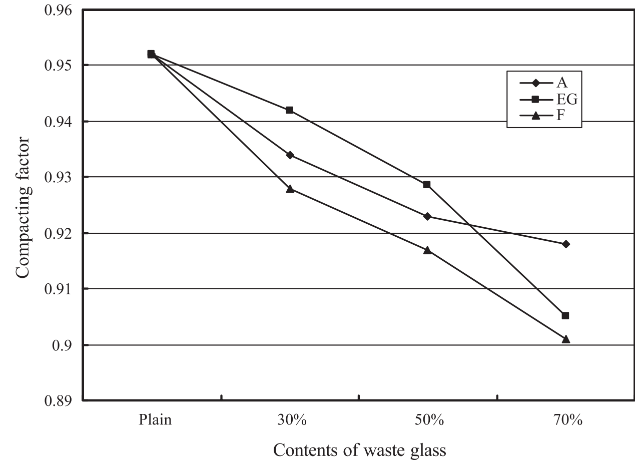


Fig. 4. Results of compacting factor.

respectively, compared to the plain concrete containing no waste glass. This tendency of air content increase may be because there were more waste glass aggregates that were larger than 0.6 mm in particle size than sands and also that they had an irregular shape, which resulted in a larger relative surface area that maintained more air.

### 4.2.3. Compacting factor

The results from compacting factor testing on concretes containing waste glass aggregates of different colors and mixing ratios are shown in Fig. 4. The concretes containing waste glass aggregates, regardless of their color, with an input ratio of 30%, 50%, and 70%, recorded 1.1–2%, 2.5–3.7%, and 3.6–5.4% decrease in compacting factor, respectively, compared to the plain concrete containing no waste glass. One reason for this tendency of compacting factor decrease may be because the grain shape of the waste glass aggregates were irregularly angled, which resulted in a fluidity drop parallel with an increase in the amount of the waste glass aggregate and subsequent decrease in compacting factor of the concretes.

Fig. 5 illustrates the relationship between slump and compacting factor. A linear regression analysis confirmed that there is a close correlation between the two with the correlation equation and the determining coefficient: Slump = 101.05 × compacting factor + 84.33 and 0.879, respectively.

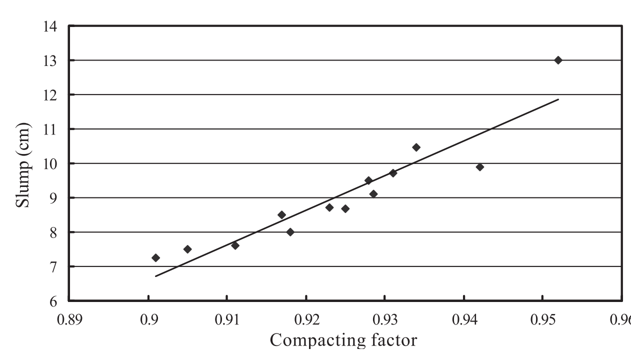


Fig. 5. Relationship between slump and compacting factor.

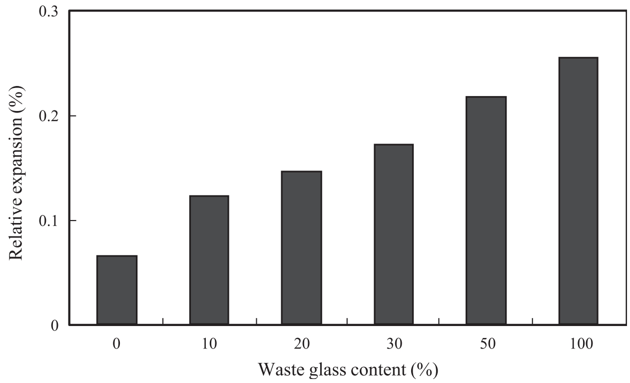


Fig. 6. Relative expansion for mortar bars.

### 4.3. Analysis of expansion characteristic of mortar containing waste glass

The relative expansion rate made by the measurements complying with ASTM C 1260 in terms of the content of green waste glass (0–100%) are shown in Fig. 6. Mortar bars with waste glass mixed in display a relatively higher expansion rate than plain bars with no waste glass mixed in. The bars containing green waste glass showed an expansion rate within 0.2% up to 30% of its content. The expansion rates noticeably increased in accordance with an increase in content. The bars containing green glass showed an expansion rate of 1.8–3.9 times that of plain mortar bars. In this ASTM C 1260 test, no pessimum was generated, as the expansion rate continued to increase along with an increase of the amount of mixing waste glass. This may be due to the unlimited supply of alkali in the 1 N NaOH solution when ASTM C 1260 test is applied.

### 4.4. Properties of hardened concrete

#### 4.4.1. Compressive strength

The compressive strength test results for the concretes containing waste glass fine aggregates of different colors according to their age are very similar to each other. Thus,

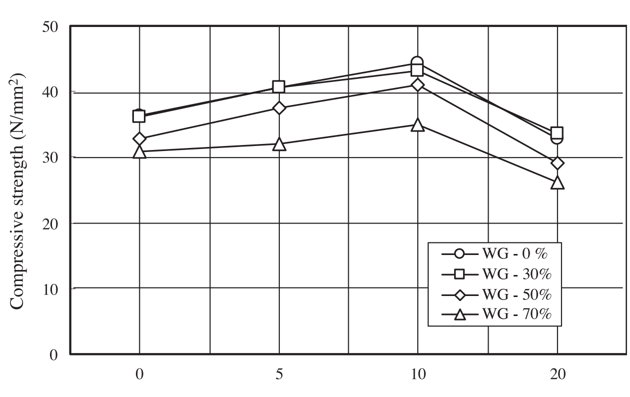


Fig. 7. Compressive strength of concrete containing emerald green waste glass.

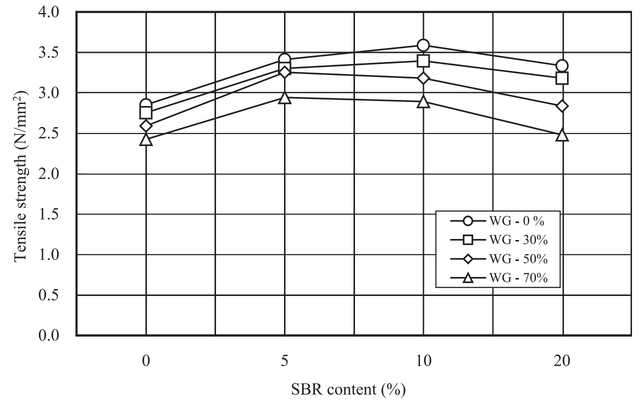


Fig. 8. Compressive strength of concrete containing emerald green waste glass and SBR.

results are presented in Fig. 7 for emerald green waste glass, representatively. Four-week-old concretes containing emerald green waste glass fine aggregates, regardless of their color, and with mixing ratios of 30%, 50%, and 70%, displayed a reduction in compressive strength, each showing 99.4%, 90.2%, and 86.4% compressive strength of the plain concrete, respectively. This tendency towards a decrease in compressive strength with an increase in mixing ratio was repeated for concretes 13 weeks of age. This inclination may be due to the decrease in adhesive strength between the surface of the waste glass aggregates and the cement paste as well as the increase in FM of the fine aggregates and the decrease in compacting factor in accordance with the increase in the mixing ratio of the waste glasses [12]. In any case, the color of the waste glass fine aggregates did not have any notable effect on the compressive strength of the concrete.

Fig. 8 shows the test result of the compressive strength depending on the changes in the mixing rate of the waste glass and polymer (SBR latex). It was observed that with increase of waste glass content, the strength of the concrete decreased. For each mixing rate of the waste glass (0%, 30%, 50%, and 70%), as the mixing rate of the polymer increased by 5–10%, the compressive strength increased by 12.1–22.3%, 12.7–19.5%, 14.4–25.4%, and 4.8–13.6%, respectively.

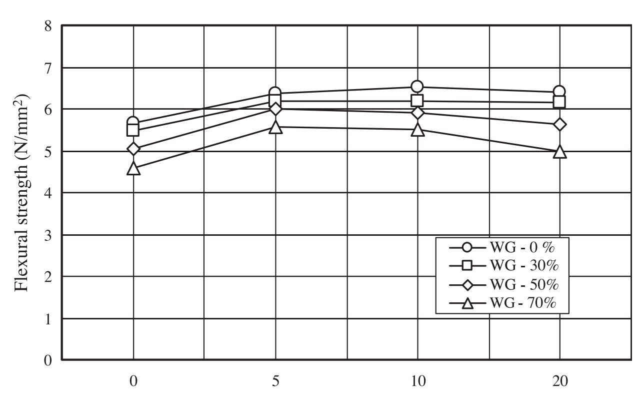


Fig. 9. Tensile strength of concrete containing emerald green waste glass.

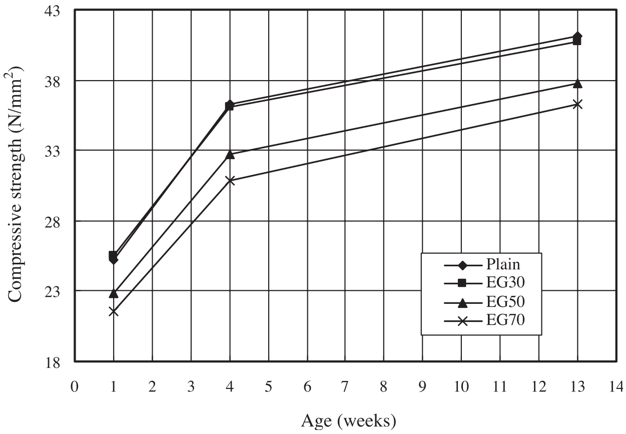


Fig. 10. Relationship between compressive strength and tensile strength.

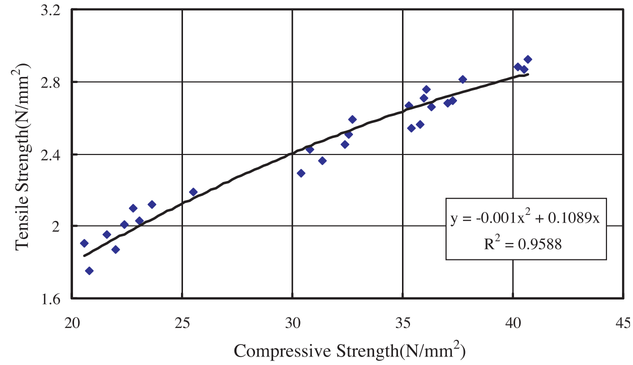


Fig. 12. Flexural strength of concrete containing emerald green waste glass.

### 4.4.2. Tensile strength

The tensile strength test results for the concretes containing waste glass aggregates of varying colors according to their age are very similar to each other, like compressive strength test results. Results are presented in Fig. 9 for emerald green waste glass, as an example. Four-week-old concretes containing emerald green waste glass fine aggregates at a 30% mixing ratio showed a slight decrease in the tensile strength, while the plain concrete showed 96.6% increase in tensile strength, respectively. The concretes containing emerald green waste glass aggregates displayed a slight decrease in tensile strength when their mixing ratio was increased to 50% and 70%, each showing 90.8% and 85.0% decrease in tensile strength of the plain concrete, respectively. A similar tendency towards decreasing compressive strength with increasing mixing ratio was noticed for the 13-week-old concretes. Similar to the case of the compressive strength test, this tendency may be due to the decrease in adhesive strength between the surface of the waste glass aggregates and cement paste as well as the increase in FM of fine aggregates and the decrease in the compacting factor in accordance with the increase in the mixing ratio of the waste glasses. Likewise, the color of the waste glass fine aggregate did not have any significant effect on the tensile strength. Fig. 10 details the relationship between the compressive strength and the tensile strength of the concretes containing the waste glass aggregates. The tensile strength rated about 1/14–1/10 of the compressive strength.

Fig. 11 show the test result of the tensile strength depending on the changes in the mixing rate of the waste glass and polymer (SBR latex). It was observed that with the increase of waste glass content the strength of the concrete decreased. For each mixing rate of the waste glass (0%, 30%, 50%, and 70%), as the mixing rate of the polymer increased by 5–10%, the tensile strength increased by 16.1–20.8%, 16.6–18.6%, 20–18.7%, and 18.6–17.2%, respectively.

### 4.4.3. Flexural strength

The flexural strength test results for the curing concretes with waste glass aggregates of different colors according to their age are presented in Fig. 12 for the emerald green waste glass, representatively, because the results were very similar to each other like the compressive and tensile strength test results. The concretes of 4 weeks of age containing emerald green waste glass fine aggregates at a 30% mixing ratio showed a slight decrease in the flexural strength while also showing a 96.8% decrease in the flexural

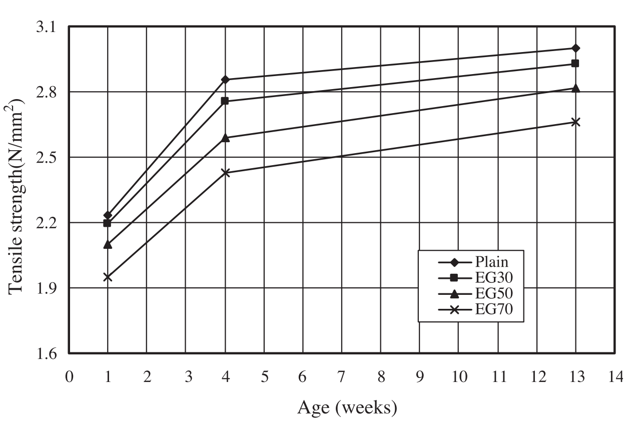


Fig. 11. Tensile strength of concrete containing emerald green waste glass and SBR.

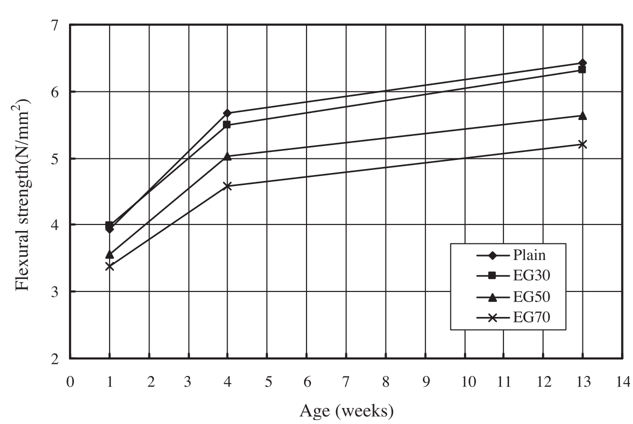


Fig. 13. Relationship between compressive strength and flexural strength.

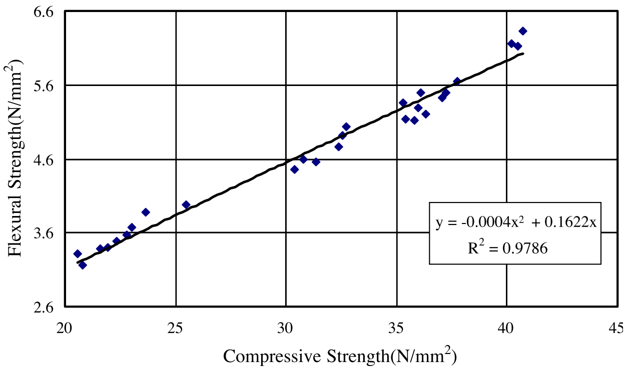


Fig. 14. Flexural strength of concrete containing emerald green waste glass and SBR.

strength of the plain concrete. Obvious differences in the strength depending on the color of the waste glass aggregates were not noticed. Moreover, the concretes containing waste glass aggregates, when applying mixing ratios of 50% and 70%, demonstrated 88.7% and 81.9% decrease in flexural strength of the plain concrete, respectively. This tendency towards decreasing flexural strength with increasing mixing ratio was also repeated for the 13-week-old concretes. This tendency may also be due to the decrease in adhesive strength between the surface of the waste glass aggregates and the cement paste as well as the increase in FM of the fine aggregates and decrease in compacting factor in accordance with the increase in the mixing ratio of the waste glass. Fig. 13 shows the relationship between the compressive strength and the flexural strength of the concretes with waste glass aggregates. The flexural strength rated about 1/7.0–1/6.0 of the compressive strength.

Fig. 14 shows the test results of the flexural strength depending on the changes in the mixing rate of the waste glass and polymer (SBR latex). It was observed that with the increase of waste glass content, the strength of the concrete decreased. For each mixing rate of the waste glass (0%, 30%, 50%, and 70%), as the mixing rate of the polymer increased by 5–10%, the flexural strength increased by 12.3–14.9%, 12.8–12.9%, 17.2–19.2%, and 20.0–21.5%, respectively.

## 5. Conclusions

The aim of this study was to evaluate the recyclability of domestic crushed waste glass as a fine aggregate for concrete and other secondary construction materials such as wall tiles and interlocking blocks. A basic experimental study on the physical and mechanical properties of concretes containing recycled waste glass as an aggregate provided the following results.

1. The physical analysis of crushed waste glass aggregates gave the values of 3.46–3.49 in FM, 2.48–2.52% in specific gravity, 0.40–0.43% in water absorption, 60.90–62.60% in absolute volume, and 1500 kg/m3 or more in unit volumetric weight, which we believe qualify the recycled waste glass as a feasible fine aggregate for concrete. However, the crushed waste glass aggregates have both an edged and an angular grain shape and contain a significant proportion of grains larger than 0.6 mm in diameter, which are considered to severely affect their workability.
2. The slump and compacting factor of the concretes containing the waste glass aggregates showed a decreasing tendency with an increase in the content of the waste glass aggregates, which is believed to be influenced by the grain shape and FM of the waste glass aggregates. In addition, the air content increased along with an increase in the content of the waste glass aggregates, which may be because the waste glass fine aggregates have both edged and angular grain shapes and contain a significant proportion of grains larger than 0.6 mm in diameter.
3. The expansion rate by ASR in accordance with ASTM C 1260 showed an increasing tendency with increasing content of emerald green waste glass. The bars containing emerald green waste glass showed an expansion rate within 0.2% up to 30% of its content.
4. The compressive, tensile, and flexural strengths of concretes containing the waste glass aggregates demonstrated a decreasing tendency along with an increase in the mixing ratio of the waste glass aggregates. The concrete containing waste glass aggregates of 30% mixing ratio gave the highest strength properties. Additionally, the mechanical properties of the concretes did not display any notable differences depending on color of the waste glass aggregates.
5. The mixture with SBR latex 10% added was found to be most effective for strength enforcement, and the appropriate inclusion rate of waste glass and SBR latex is thought to be 30% and 10%, respectively.
6. Therefore, it is advantageous to have the mixing ratio of the crushed waste glass aggregate at less than 30% and to use an adequate admixture in order to secure fluidity when mixing the waste glass aggregates. The most satisfactory characteristics of the strength were observed when the mixing rate of the polymer was 10%.

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