Production and Material Properties of Ceramic from Waste Glass Fiber Reinforced Plastic*


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Abstract
We produced porous glass fiber reinforced ceramic by mixing clay and crushed waste glass fiber reinforced plastic (GFRP) before firing the mixture. Sprues and runners, which are by-products from the manufacture of plastic merchandise by injection molding, were used as waste GFRP. By observing the ceramic microstructure and examining its strength, it was confirmed that porous ceramic reinforced by glass fiber could be produced. In addition, to examine the environmental suitability of the ceramic, the pH of immersion liquid was measured and acid resistance tests were carried out. The immersion solution of the ceramic was neutral or slightly alkaline, the mass loss of the ceramics in the acid resistance test was small and the reduction in bending strength after the tests was also very small. The ceramic is considered to be environmentally benign. The results suggest that the manufacture of porous glass fiber reinforced ceramic can be an effective means to recycle waste GFRP. It is expected that the ceramic could be used as a construction material because of its lightweight, high strength properties and environmental suitability.

Key words: Ceramic, Composite Materials, Recycling, Waste GFRP, Physical Properties, Chemical Properties, Glass Fiber

1. Introduction
Waste glass fiber reinforced plastic (GFRP) is the plastic that glass fiber is added to as reinforcement material to improve its specific stiffness, strength and incombustibility. GFRP has been used in various products. The disposal of large quantities of GFRP has become a social problem. Depending on the type of material, mechanical, thermal and chemical recycling technologies are applied to waste plastics. However, the recycling of waste GFRP is difficult because GFRP contains glass fiber in the plastic. Much of this waste is therefore buried underground as industrial waste. Fine glass fiber dust and leachates from this landfill may cause serious health and environmental damage and landfill sites may also become unavailable in future owing to space constraints.

This situation has led to the development of composite materials using natural fibers as...
an alternative GFPR reinforcement. Natural fibers such as hemp (4), sisal (5), jute (6), palm (7), kenaf (8) and bamboo (9) are used. Although the natural fibers are ecological materials, many have not been used frequently to date. In addition, it is difficult to enhance the incombustibility by adding plastic to the natural fibers. We must dispose of large used quantities of GFPR in an appropriate manner. Therefore, the development of an effective technique for disposing of waste GFPR without polluting the environment is strongly desirable (1) (3) (10).

Recycling of not only waste GFPR, but also various other composite materials has been attempted in many countries of the world (10) (11). For the recycling of waste GFPR, methods that add waste GFPR to mortars or concrete mixtures (12) (14) or into the cement kiln in the cement manufacturing process (2) (11) have been examined. The mechanical properties of the concrete improve marginally by these methods and although large amounts of waste GFPR can be disposed of, the high strength of the glass fiber is lost when placed into a cement kiln. To recycle the glass fiber in waste GFPR, the method of collecting glass fiber in plastic by decomposing GFPR using superheated steam (15) (16) was examined. This process has associated high costs, and the type and grade of the waste GFPR must be known. These various methods have their merits and demerits, but are not yet suitable for the recycling of various waste GFPRs.

To use waste GFPR effectively and to dispose of it without polluting, we have previously proposed a process that produces porous glass fiber reinforced ceramics by mixing clay and crushed waste GFPR before the mixture is fired (17) (18). This recycling technique has the following features.

1. The process enables various ceramic components to be produced by effectively recycling the glass fiber in the waste GFPR, as well as disposing of the waste GFPR.
2. GFPR with high glass fiber content that is not recycled currently can be used in this process, as this glass fiber is used to reinforce the ceramics. The ceramic strength is increased as the glass fiber content is higher.
3. This process is not selective towards the type of GFPR because the resins are decomposed thermally at lower temperature than the firing temperature of the clay (approximately 900–1200°C).
4. This process can minimize fine glass fiber dust generation by sintering clay and glass fiber, or sintering between glass fibers.

These promising features indicate that this may be an extremely useful process for disposing of waste GFPR. As the first step in this investigation previously, polyamide (PA) plastic pellets with glass fiber were used as waste GFPR. Several types of ceramic specimens (tiles) were then produced by changing the firing temperatures and mixing the ratio of clay and GFPR. From bending test results, specimen density and water absorption measurements, it was clarified that ceramics with high water absorption and strength could be produced in this process. However, the following areas require clarity to ensure practical application of this process.

1. The strength of ceramics produced in this process depends on the GFPR glass fiber content, as well as on the clay and GFPR mixing ratio. A number of types of GFPRs exist, and their glass fiber content is sometimes unknown. To obtain the target material strength, this content must be estimated in some way. In addition, the mixing ratio of clay and waste GFPR must be determined to obtain this target strength.
2. It is not easy to crush waste GFPR. It requires extensive processing time, as glass fiber is hard, while the resin enveloping it is soft. A means of crushing GFPR efficiently is therefore required.
3. The environmental suitability of ceramics produced by this process should be clarified by analyzing their chemical properties.

With these considerations in mind, in this study, a practical process for producing
ceramics using discarded GFRP is introduced and the resultant physical and chemical material properties are examined. From the results, the value of producing ceramics using waste GFRP can be assessed.

Firstly, the process whereby ceramics are produced using waste GFRP is introduced. The GFRP glass fiber content was estimated by performing an ignition loss test and component analysis of the inorganic substances present in the GFRP. A method to cool the waste GFRP using liquid nitrogen before crushing was investigated. Secondly, the strength of the specimens containing glass fiber made from clay and waste GFRP is compared with that of the specimens without glass fiber made from clay and resin. This is done to determine whether the porous ceramics reinforced by glass fiber can be produced when discarded GFRP is used as raw material. To determine the effect of glass fiber on ceramic strength and to investigate the strengthening mechanism, the strength of specimens made from clay and glass fiber was also examined. Thirdly, the proposed method for determining the mixing ratio of clay to GFRP for final target strength was evaluated for application to the ceramics produced using discarded GFRP. Finally, to examine the environmental suitability of the ceramic made from clay and GFRP, the pH of the immersion liquid was measured and acid resistance tests were carried out.

2. Materials and Methods

2.1 Manufacture of Ceramics Using Waste GFRP

2.1.1 Raw materials

Figure 1 shows the raw materials used for producing the specimens: the clay produced at Miyazaki Prefecture in Japan for use in bricks or tiles (Fig. 1(a)) and the sprue and runner waste GFRP containing glass fiber from PA and polybutylene terephthalate (PBT) (Figs 1(b) and (c)), respectively. Waste GFRP in the form of sprues and runners and produced in the manufacture of plastic merchandise, is discarded after injection molding in large quantities and is easy to collect. The sprues and runners are suitable to recycle as raw materials because the type and grade of waste GFRP is already known in most cases.

To examine the effect of glass fiber on the strength of ceramics produced from clay and GFRP, specimens that fired mixtures of clay and glass fiber were also produced. Amongst others, E, C and T glass fiber is used in reinforced plastics (19), where E glass is most typically used and is produced on a large scale. E glass fiber with diameter of approximately 200 µm was cut from lengths of a few meters or more into lengths 0.5 mm or less (see Fig. 1(d)). The mean bending strength of ten samples was 1.87 GPa. In addition, specimens without glass fiber were produced by mixing clay and PA resin (18).

2.1.2 Estimation of glass fiber content in waste GFRP

To estimate the GFRP glass fiber content, an ignition loss test and inorganic component analysis were carried out. The ignition loss test was carried out by firing samples in the furnace at 815°C. The inorganic component analysis was carried out using X-ray
fluorescence analysis (Simadz Corp., XRF-1700). Figure 2 shows the GFRP inorganic substance residue after firing. Table 1 shows the GFRP and clay inorganic chemical compositions after firing, and that of the E glass fiber. The ignition losses of the PA and PBT plastics with glass fiber were 68.5 and 70.5%, respectively. Both waste GFRPs contained fine substances. Little carbide remained after the ignition loss test. It is estimated that the waste GFRPs both contained 30% glass fiber and it was confirmed from the plastic grade data provided by the company that the estimation of the glass fiber content in the PA plastic was correct. The grade for the PBT plastic is unknown.

The glass fiber present in GFRP contained SiO₂, CaO and Al₂O₃ as its main components while the clay contains SiO₂ and Al₂O₃ as its main components. The CaO component ratio of the glass fiber is slightly larger than that of the clay. When the GFRP with 30% glass fiber is mixed with clay in a ratio from 10 to 30%, the resultant CaO component ratio of the produced ceramics will become a few percent more than that of ceramic made from only the clay. Although the chemical component ratio changes according to the type of glass fiber, most glass fibers contain SiO₂ as their main component (from 50 to 65%), with the other component ratios being very small. Therefore, it is considered that the ceramics made from clay and GFRP have similar chemical compositions.

2.1.3 GFRP crushing

To crush GFRP finely in a short period of time, the waste GFRP was cooled using liquid nitrogen before crushing was attempted. The waste GFRP (PA plastic) shown in Fig. 1(b) was cut to approximately 10 mm in size or less using a wire cutter, before masses of 100 g were soaked in liquid nitrogen for 30 seconds (the liquid nitrogen temperature was approximately -196°C). These were then crushed immediately using a rotary mill (Osaka Chemical Co., Ltd., Japan, ABS-W). Figure 3(a) shows the relationship between crushing time and mass crushed to a size of 1 mm or less for the cooled and uncooled GFRP. Fig. 3(b) shows the relationship between the crushing time and temperature of the crushed GFRP. The crushed mass increased significantly when the GFRP is cooled using liquid nitrogen. However, the crushed mass decreases gradually with crushing time. This is because the temperature of the crushed GFRP rises with crushing time. From Figs 3(a) and (b), when the crushing times for cooled and uncooled GFRP are 90 and 30s, respectively, the GFRPs can hardly be crushed. This temperature is near the glass transition temperature of resin (PA). It is believed that the GFRP is largely deformed without fracturing because its flexibility recovers with rise in temperature. It should be noted that liquid nitrogen should be handled with caution for safety reasons.

Table 1 Chemical compositions of inorganic substance contained in clay, PA and PBT plastic with glass fiber and E glass fiber

<table>
<thead>
<tr>
<th>Component</th>
<th>Clay</th>
<th>PA plastic with glass fiber</th>
<th>PBT plastic with glass fiber</th>
<th>E glass fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>51.1</td>
<td>48.2</td>
<td>53.8</td>
<td>54.9</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>18.2</td>
<td>12.9</td>
<td>14.7</td>
<td>16.3</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.6</td>
<td>0.7</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.8</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>MgO</td>
<td>1.3</td>
<td>2.3</td>
<td>1.8</td>
<td>-</td>
</tr>
<tr>
<td>CaO</td>
<td>1.1</td>
<td>29.9</td>
<td>27.0</td>
<td>26.7</td>
</tr>
<tr>
<td>Sb₂O₃</td>
<td>-</td>
<td>4.1</td>
<td>0.2</td>
<td>-</td>
</tr>
</tbody>
</table>
2.1.4 Ceramic production

Table 2 shows the types of specimens and the mixture ratio of each specimen’s raw material. Specimens A and B were made from clay and PA and PBT, respectively, and each contained 30% glass fiber. Specimen C was made from clay and glass fiber. For specimens A and B, the crushed GFRP of 10 to 30% total mass was mixed with the clay. For specimen C, 0 to 60% E glass fiber was mixed with clay. The specimens were produced using the following procedures.

(1) Clay, GFRP and E glass fiber were crushed using a rotary mill, and then screened using a 0.5 mm mesh screen. Figure 4 shows images of each GFRP after screening. The fine-screened GFRP had the thickness of 0.5 mm or less and a maximum length of approximately 2 mm.

(2) The clay and crushed GFRP or E glass fiber were mixed in ratios as shown in Table 2. Each total mixture mass was 15.0 g.

(3) The mixtures were solidified by pressing into a mold under a pressure of 9.8 MPa. The molded specimens had a length of 70 mm, width of 20 mm and thickness of approximately 5 to 8 mm.

(4) The molded specimens were fired in an oxidizing atmosphere at 100°C/h using an electric furnace (Kyoei Electric Kilns Co., Ltd., Japan, KY-4N). The specimens were held at the 1000°C firing temperature for one hour and then cooled to room temperature in the furnace.
2.2 Experimental Procedure

To examine the specimen physical properties, bending tests and water absorption measurements were conducted. Similarly, to evaluate their chemical properties, a component analysis, pH measurement of the immersion liquid and acid resistance test were carried out.

2.2.1 Strength test

To examine the specimen strength, four-point bending tests were carried out. The tests were performed using a universal testing machine (Shimadzu Corp., AG-X50kN) at a crosshead speed of 0.5 mm/min. The maximum bending stress was calculated using the following equation from the measured maximum load:

\[
\sigma_f = \frac{3P(L-a)}{2bh^2}
\]  

(1)

where \(P\) is the maximum load, \(L\) is the 26 mm distance between the lower supporting points, \(a\) is the 10 mm distance between the upper loading points and \(b\) and \(h\) are the specimen’s rectangular cross sectional width and depth, respectively.

2.2.2 Measurement of water absorption

The specimens were dried in a furnace at 40°C for over 24 h before being weighed. They were then soaked in water at 20°C for over 24 h and weighed again. The water absorption was calculated from:

\[
\text{Absorption} = \frac{m - m_0}{m_0} \times 100 \quad \text{(\%)}
\]  

(2)

where \(m_0\) is the dried specimen mass and \(m\) is mass of specimen containing absorbed water.
2.2.3 pH measurement of immersion liquid
The specimens were dried in a furnace and crushed to approximately 1 mm or less. The specimen powders were immersed in distilled water with a mass five times that of the powder for over 30 minutes before the solution pH was measured\(^\text{\textsuperscript{20}.}\)

2.2.4 Acid resistance test
Each specimen was immersed in 1 L 1 vol. % H\(_2\)SO\(_4\) solution at 90°C for 24 h and the mass loss per unit area was calculated from\(^\text{\textsuperscript{21}.}\):

\[
C = \frac{W_p - W_0}{A} \times 100 \quad (\text{kg/m}^2)
\]  

where \(W_p\) is the specimen mass after the acid resistance test, \(W_0\) is the specimen mass before the test, \(A\) is the specimen surface area before the test and \(C\) is the mass loss per unit area.

3. Results and Discussions

3.1 Physical Properties

3.1.1 Bending strength
Figure 5(a) shows examples of specimens made from clay and crushed GFRP. The specimens displayed rough surfaces as the mixing ratio of GFRP increased because they contained more voids in their structure. Their densities ranged from 1.2×10\(^3\) to 1.8×10\(^3\) kg/m\(^3\). The brick densities ranged from 1.6×10\(^3\) to 3.7×10\(^3\) kg/m\(^3\) and that of the concrete was approximately 2.4×10\(^3\) kg/m\(^3\)\(^\text{\textsuperscript{22}.}\). The specimens made from clay and crushed GFRP were very light. Fig. 5(b) shows the specimen surfaces observed by optical microscope. From aspects of the glass fibers present in the clay structure of the specimens made from clay and GFRP, it can be seen that the fine glass fibers contained in the GFRP were sintered and formed larger agglomerates.

![Examples of specimens](image1)

(a) Examples of specimens  
(b) Specimen surfaces

Fig. 5 (a) Examples of specimens made from clay and waste GFRP and (b) specimen surfaces

Figures 6(a) and (b) show the bending strength of specimens A and B made from clay and GFRP. In the diagrams, the bending strength of the porous specimens without glass fiber made from clay and resin is shown together with that of specimens A and B. The plotted points express the average values of the bending strength of five specimens and the error bars show the standard deviation. The x-axis expresses the mixing ratio of resin to compare the strength of specimens A and B with that of the porous specimen without glass fiber. The bending strength of specimens A and B decreased as the mixing ratio of resin increased because the void space increased. Compared with the bending strength of the
porous specimens without glass fiber, the bending strength of specimens A and B containing glass fiber was relatively high. The result showed that porous ceramics made from clay and waste GFRP were reinforced by glass fiber. The bending strength of specimen A made from clay and PA plastic was approximately equal to that of specimen B made from clay and PBT plastic. For this reason, it is considered that both PA and PBT plastic had the same glass fiber content and the resin was decomposed with only the glass fiber remaining in the matrix after firing. This result suggests that the strength of specimens made from clay and waste GFRP does not depend on resin type. Fig. 6(c) shows the bending strength of specimen C made from clay and E glass fiber. Specimens were produced to examine the effect of glass fiber on the strength of specimens made from clay and GFRP. The bending strength of specimen C increased with increasing mixing ratio of glass fiber. The strength increment was small in the case where the mixing ratio of the glass fiber was 40% or less.

![Fig. 6 Bending strength of specimen (a) A, (b) B and (c) C](image)

3.1.2 Strengthening mechanism of ceramics by glass fiber

The specimens made from clay and waste GFRP contained only 10% glass fiber or less, whereas their strength increased considerably in comparison with that of the specimens made from clay and resin without glass fiber. These results indicate that the strength of ceramics made from clay and GFRP cannot be estimated on the basis of the strength of a composite material made from clay and glass fiber. The strengthening mechanism caused by the glass fiber for the ceramics made from clay and GFRP is explained as follows.

Figure 7(a) shows the microstructures of specimens A and B observed by optical microscope. The glass fiber is seen to exist in the clay structure voids because the resin that enveloped the glass fiber is decomposed by firing. It is assumed that the glass fiber present in the voids lies in the hole and bridges the circumference. It is assumed that the void circumference is reinforced by the presence of the glass fiber.

Fig. 7(b) shows the fractured surfaces after bending tests for specimens A and B made from clay and GFRP, specimen C made from clay and E glass fiber and the specimen without glass fiber made from clay and resin. Specimens A and B had very rough surfaces in comparison with those of the specimen without glass fiber. It seems that the glass fiber became separated from the matrix and many impressions were made on the fractured surface. From these results, the mechanism by which the glass fiber strengthens ceramics made from clay and GFRP is considered to be as follows. The crack extension resistance increases because the glass fiber lying in the voids bridges the stress field in the vicinity of the crack tip and prevents crack extension. On the fractured surfaces of specimen C, it can be seen that the thin E glass fiber was cut or pulled out of the matrix and the crack extension resistance for specimen C is believed to have increased slightly.
3.1.3 Estimation of strength of ceramics made from clay and waste GFRP

In this process, we produced a porous ceramic reinforced by glass fiber by mixing clay and crushed waste GFRP. The ceramic strength versus mixing ratio of clay and GFRP can be estimated as follows.

As shown in Fig. 6, the strength of the porous ceramic produced by firing the mixture of clay and crushed GFRP tends to decrease exponentially as the resin mixing ratio increases. It is assumed that the ceramic strength can be expressed by the following equation (18)

$$\sigma_b = \sigma_0 \exp(\alpha \rho)$$  \hspace{1cm} (4)

where $\sigma_b$ is the bending strength of the porous ceramic containing glass fiber, $\alpha$ is a constant, $\rho$ is the resin mixing ratio and $\sigma_0$ is the strength of the ceramic made from only clay where $\rho = 0$.

Figure 8 shows the logarithm of bending strength versus resin mixing ratio for specimens A and B made from clay and waste GFRP. The plotted points express the logarithm of bending strength, while the lines show a regression of the plotted points. In Fig. 8(a), the logarithm of bending strength of the specimens lacking glass fiber made from clay and resin is also shown. It is found that the specimens exhibit a linear relationship between the logarithm of the bending strength and the resin mixing ratio. Therefore, if the value of $\alpha$ is obtained, the bending strength of specimens containing glass fiber can be determined from the bending strength of the ceramics made from only the clay and the resin mixing ratio. The value of $\alpha$ is negative, meaning that the decrease in bending strength becomes large as the absolute value of $\alpha$ becomes large. The value of $\alpha$ can be calculated from the strength of a specimen made from only the clay and that of a few specimens made from clay.
and GFRP. The values of $\alpha$ for specimens A and B were -10.9 and -9.6, respectively. The resin content in the GFRP can be determined from its ignition loss test as mentioned earlier. As an example, if we hope to obtain a bending strength of 7 MPa and higher when PA and PBT plastics with 30% glass fiber are used as raw material, respectively, the mixing ratio of GFRP to total raw material becomes less than 7%. Table 3 shows the bending strength of specimens A and B when 7% GFRP was mixed with clay. From the results, it is found that the target bending strength is obtained. It was confirmed that the strength of ceramics versus mixing ratio of clay and GFRP could be estimated.

![Logarithm of bending strength versus resin mixing ratio for specimens A and B](image1)

![Water absorption of specimens made from clay and GFRP](image2)

3.1.4 Water Absorption

Figure 9 shows the water absorption of specimens A and B made from clay and GFRP. Water absorption of the specimens increased as the mixing ratio of GFRP increased because of the increase in void space. These specimens also displayed a high water absorption because the water absorption of the common brick is less than 15% (Japanese Industrial Standards R 1250).
3.2 Chemical Properties

3.2.1 pH measurement of immersion liquid of specimens

Table 4 shows the pH of the immersion liquid of specimens A and B. The pH of the immersion liquid of a specimen made from only the clay was neutral, that of specimen B was also neutral, while that of specimen A was slightly alkaline. From the chemical compositions of the specimens shown in Table 5, specimen A is shown to contain antimony. The antimony compound is possibly used to enhance plastic incombustibility. It is believed that this compound reacted with water to generate hydroxide ions of the form $\text{Sb(OH)}_6^{2-}$.

Table 4 pH values of immersion liquid of specimens made from clay and waste GFRP

<table>
<thead>
<tr>
<th>Mixing ratio of GFRP</th>
<th>Specimen A</th>
<th>Specimen B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>10%</td>
<td>7.8</td>
<td>6.9</td>
</tr>
<tr>
<td>20%</td>
<td>7.6</td>
<td>7.1</td>
</tr>
<tr>
<td>30%</td>
<td>8.1</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Table 5 Chemical compositions of specimens made from clay and waste GFRP

<table>
<thead>
<tr>
<th>Component</th>
<th>Specimen made from clay only</th>
<th>Specimen A (made from clay and PA plastic with 30% glass fiber and 30% PA mixing ratio)</th>
<th>Specimen B (made from clay and PBT plastic with 30% glass fiber and 30% PBT mixing ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>51.1</td>
<td>63.7</td>
<td>66.1</td>
</tr>
<tr>
<td>Al2O3</td>
<td>18.2</td>
<td>18.9</td>
<td>19.5</td>
</tr>
<tr>
<td>CaO</td>
<td>1.1</td>
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<td>4.0</td>
</tr>
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<td>Fe2O3</td>
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<td>3.6</td>
</tr>
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</tr>
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<td>Na2O</td>
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<tr>
<td>Sb2O3</td>
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</tr>
<tr>
<td>TiO2</td>
<td>-</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

3.2.2 Acid resistance

Figure 10 shows results from the acid resistance tests for specimens A and B made from clay and GFRP. The longitudinal axis of the graph expresses a mass loss per unit area for each specimen. Their mass losses were slightly larger than that of the specimen made from clay and these increased as the GFRP mixing ratio increased; i.e. their acid resistance decreased as the GFRP mixing ratio increased. It is believed that the CaO and Sb2O3 components reacted with $\text{H}_2\text{SO}_4$ to generate $\text{CaSO}_4$ and poly-antimonic acid, respectively, on specimen A and that CaO reacted with $\text{H}_2\text{SO}_4$ to generate $\text{CaSO}_4$ on specimen B.

Figure 11 shows the bending strength of the specimens before and after acid resistance tests. The heights of the bar graphs express the average values of the bending strength of the three specimens, respectively. The bending strength of the specimens after acid resistance tests tends to decrease slightly.

The immersion liquids of the specimens made from clay and GFRP were therefore found to be neither strongly acidic nor alkaline. Their pH values were in the range of general soil pH (approximately 6–8). For the acid resistance, although the specimen mass loss was slightly larger than that of a specimen made from clay only, the degree was small. For the chemical compositions of specimens made from clay and GFRP, specified toxic
substances were not detected. These chemical properties suggest that the ceramic made from clay and waste GFRP would not have a significant load on the environment.

![Graph](image)

Fig. 10 Acid resistance of specimens made from clay and waste GFRP

![Graph](image)

Fig. 11 Bending strength of specimens before and after acid resistance tests

4. Conclusions

To demonstrate the usefulness and promote a process that produces porous glass fiber reinforced ceramics by mixing clay and crushed waste GFRP before firing the mixture, a practical process for producing ceramics using actual waste GFRP was proposed and the properties of the resultant ceramics examined.

Ceramics were produced using waste GFRP in the form of sprues and runners (by-products from injection molding). The glass fiber content in the waste GFRP was estimated by performing an ignition loss test and inorganic component analysis. Next, the physical and chemical properties of ceramics made from clay and waste GFRP were examined with the following results.

1. It was confirmed that porous ceramics reinforced by glass fiber could be produced using actual waste GFRP. The strengthening mechanism of the ceramics by glass fiber was explained by the void circumference being reinforced by the bridging of glass fiber in the void. This increased the ceramic crack extension resistance.
2. By approximating the strength of ceramics using Eq. (4), it was confirmed that the strength of ceramics versus mixing ratio of clay and GFRP could be estimated.
3. The immersion solution of the ceramics was neutral or slightly alkaline. The mass loss of the ceramics in the acid resistance test was small, although it was slightly larger than
that of the ceramic made from only the clay. It is believed that the leachates from the ceramics will not cause significant damage to the environment.

From the results above, the usefulness of producing ceramics using waste GFRP was demonstrated. These ceramics show potential as a means to recycle waste GFRP. It is expected that they could be used as materials in civil engineering and architecture because of their light weight and high strength properties.

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