Recycling of Waste Concrete and Fixation of Carbon Dioxide by Micro Bubble Jet Flow

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(Received 22 December 2010; received in revised from 13 May 2011; accepted 5 June 2011)

Abstract
The severe problem of the disposal of various wastes continue to increase, one of which is waste concrete. In relation to global warming, reducing the generation and fixation of CO2 gas must also be solved.

This paper experimentally examines an efficient recycling system to reuse the sand in waste concrete whose mean size is about 0.3 mm. We found that the liquidation of Ca2+ with waste concrete in a hydrochloric acid water solution of pH ≈ 2.5 is optimum. Next, we show a new efficient CO2 gas fixation method by the reaction of carbonic acid with a micro bubble CO2 gas jet flow. Finally, a new process system to efficiently recycle waste concrete and to improve CO2 fixation and its performance is examined.

Key words
Waste Concrete, Recycle, Calcium Carbonate, CO2 Fixation, Micro Bubble Jet Flow

1. Introduction
Recently in the construction industry, disposing of the large amounts of waste concrete produced in building scrap and the lack of aggregate sand for making concrete have become more serious. The development of CO2 disposal technology concerned with global warming is another urgent issue that must be addressed.

Kamiya et al. studied CO2 fixation that contained Ca in waste concrete whose mean diameter was about 0.3 mm make an elute in water to which CO2 was added to make CaCO3. Moreover, we considered reusing the waste concrete that lost Ca an aggregate sand for making concrete and the produced CaCO3 as a raw material of cement. But since this CO2 fixation needs a long chemical reaction time it may be difficult in practical use because the charcoal oxidation reaction (COR) must be enhanced efficiently in its continuous treatment system.

In this research, an enhancement method of COR did the following : (1) it increased the extraction speed of Ca in water using an acid water solution; and (2) in the separation of CaCO3 and the fixation of CO2, it increased the dissolution speed by flowing CO2 as micro bubble jet in the solution for a remarkable increase in the interfacial area. We generate micro bubbles (MB) with a new MB generator that has a large shearing stress around the outside of the submerged high speed water jet.

The results of (1) were evaluated by a chemical experiment of Ca2+ density and the chemical analysis of the products or the sand. The results of (2) were also evaluated by the improvement of the dissolution speed of CO2 by a micro bubble jet (MBJ) experiment with CO2.

Finally, we proposed a new COR processing system that combined both elements and discussed total efficiency by evaluating its reaction efficiency and processing capacity.

2. Charcoal Oxidation Reaction and Evaluation Method
2.1 Test sample of waste concrete
The size distribution of the test sample made by Tokai Concrete Industries ranged from about 0.2 to 590μm and its mean diameter was 280μm. The greatest frequency of the size distribution was at 15 and 280μm, and the minimum frequency was 90μm.

Table 1 shows the ingredient analysis results of the test sample by a fluorescence X-ray fixed quantity measurement. The Ca content was 10.9 wt% and the Ca2+ concentration (see Section 2.2 below and 3.2.1) in the solution was 1090ppm if the Ca in the 10gr sample was dissolved entirely in 1000ml of water.

2.2 Charcoal oxidation reaction
In this research, the Ca ingredient in the test sample was dissolved in water as a positive ion and CaCO3 was produced after the chemical reaction of Ca2+ and CO2 in water. The theoretical equation of the chemical reaction is shown below:

\[
\text{Ca} + 2\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \quad (1)
\]

\[
\text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \quad (2)
\]

The reaction solution contains Ca2+, HCO3-, and CO32-, and CaCO3 is produced from the reaction solution with these ions. By this COR, CO2 gas is fixed as CaCO3.

2.3 Evaluation method
The efficiency was evaluated by Ca recovery and CO2 fixation rates.

\[
\delta = \frac{X \times 40}{100 \times 0.129} \times 100 \quad \% \quad (3)
\]

Table 1 Composition of waste concrete

<table>
<thead>
<tr>
<th>Component</th>
<th>Content [%]</th>
<th>Component</th>
<th>Content [%]</th>
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<tbody>
<tr>
<td>SiO2</td>
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<td>MgO</td>
<td>1.08</td>
</tr>
<tr>
<td>Al2O3</td>
<td>8.28</td>
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</tr>
<tr>
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<td>2.26</td>
<td>K2O</td>
<td>2.18</td>
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<tr>
<td>TiO2</td>
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<td>Lg. Loss</td>
<td>4.91</td>
</tr>
<tr>
<td>MnO</td>
<td>0.06</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>CaO</td>
<td>14.51</td>
<td>TotalL</td>
<td>100.00</td>
</tr>
</tbody>
</table>
3. Recycling of waste concrete (elution of Ca ingredient)

3.1 Experimental set-up and procedure

Figure 1 shows the schematic diagram of the experimental set-up for our model experiment. The 10g test sample was churned with 1000-ml of distilled water by a propeller type agitator at a constant 400rpm in a beaker. The CO₂ from the CO₂ cylinder flowed into the beaker from the bottom through a 1-mm inner diameter tube. The mean bubble size was about 3 to 4mm. The pH and water temperature variations were measured.

To increase the speed of the Ca elution in the waste concrete into the solution, an acid water solution was used. A thin 33% hydrochloric acid concentration was dripped into the test beaker by Komaogame pipette, and the test water solution was churned under a constant pH of 1 to 5. The processing time was 60 minutes, and the Ca₂⁺ concentration was measured at \( t_1 = 5, 10, 20, 30, 45 \), and 60 minutes by sampling the test solution. The concentration was measured by an EDTA method, and after getting the total hardness of the water solution, it was converted to a Ca₂⁺ concentration.

To confirm the reuse characteristics of the waste concrete after the treatment of the elution processing of Ca the concrete powder was collected and dried. 150μm wassifled, and the residual substance’s mass was measured by an electronic balance.

We identified the test sample of the waste concrete using a test sample after extracting both Ca and the crystalline material of the product after COR by ingredient analysis by powder X-rays diffractionometry (XRD) using an X-ray diffraction device (Rigaku Co., PINT2500PC).

3.2 Experimental results and discussions

3.2.1 Collection of sand.

Concentration of Ca₂⁺, \( C_{ca} \) (Effects of pH)

\[
\gamma = \frac{X \times \frac{22.4}{100}}{Q \times t} \times 100 \%
\]

(4)

where, \( X \) is the quantity of generation, \( M_c \) is the quantity of the waste concrete, \( Q \) is the CO₂ flow rate, and \( t \) is time. The molecular weights of Ca and CaCO₃ are 40 and 100.

Figure 2 shows the pH effects of the solution on the concentration of Ca²⁺, \( C_{ca} \), during the elution process. \( C_{ca} \) increases with increasing time for every pH level, especially when pH decreases. When pH is unity \( C_{ca} \approx 1000ppm \) at \( t_1 = 20 \)min, and after that it does not increase. At \( t_1 = 20 \)min, every possible Ca was eluted.

3.2.2 Mass of test sample (effects of pH)

Figure 3 shows the relation between mass \( M_c \) of the test sample and pH after a 60 minute treatment. At the beginning \( M_c \) is 10g but the mass of sand SiO₂ decreases after treatment by an acid water solution. At pH=5, it decreases by 1.53g, and as the pH decreases more, it decreases rapidly and at pH=1 it decreases by 5.13g due to the elution of CaO in waste concrete and the remaining silicon oxide, which is hard to melt in an acid water solution. There is little variation of the mass when pH=1 and 2, but even if pH=2 after a 60minute churning processing the cement ingredient is almost eluted enough.

For all processing times, \( C_{ca} \) increases with decreasing pH and takes a maximum at pH=1. But, the effects of the processing times when the pHs equal 2, 3, and 4 are larger than when it is 1 or 5. Generally, if the elution time is long \( C_{ca} \) increases; but since at pH=1 almost all Ca elutes at \( t_1 = 10 \)min, and at pH=5 the elution ability is weak because of the sub-acidity if it takes a long processing time, a little Ca is eluted.

The XRD pattern results at pH=2 of the waste concrete show that after the extraction of Ca, the quartz peak appears at \( 2\theta \approx 26.6^\circ \), and comparing with the test sample of the waste concrete the crystal of the cal site disappears and the Ca ingredient is removed. At pH=3, the Ca ingredient was not removed perfectly.

The above results suggest that if the test sample of waste concrete is processed by 60min in a water solution of pH=2.5, almost all Ca ingredients will be eluted and the remaining sand with a 0.3-mm diameter can be reused as a reproduction aggregate.

4. Charcoal Oxidation Processing

4.1 Experimental apparatus and procedure

4.1.1 Collection of Ca ingredient

Next, we only collected the Ca ingredient in the above water solution (Table 1) to react it with CO₂ and to generate a CaCO₃ fixation of CO₂.

a. Absorption of Ca²⁺ to cation exchange resin
At the same time of the elution of Ca, we adsorbed Ca\(^{2+}\) by the cation exchange resin (Nippon Rensui Co., SK1B). To separate the test sample of waste concrete and the cation of the exchange resin, the sample was wrapped in a paper pack and set at the center bottom of the beaker. To check the effects of quantity \(I_r\) of the cation of exchange resin, the Ca\(^{2+}\) concentration was measured for \(I_r=0, 10, \) and 20g.

b. Substitution of Ca\(^{2+}\) at cation exchange resin

Since Ca\(^{2+}\) adhering to a cation exchange resin changes to a part of the chelate, it needs to elute Ca\(^{2+}\) after substituting it with other metal ions in another vessel. We substituted Na\(^+\) in salt water (NaCl) because CO\(_2\) is hardly affected by salt water.

The experiments were carried out using 1000ml of salt water in a beaker with salt concentrations \(C_N\) of 3.5, 10, and 20%. The cation exchange resin was set after processing the above elution at the center bottom of the beaker and churning it, and Ca\(^{2+}\) concentration was measured at times \(t=5, 10, 20, \) and 30 minutes.

c. Generation of CaCO\(_3\)

Next, we generate CaCO\(_3\) by adding CO\(_2\) to the salt water of the remaining Ca\(^{2+}\). At that time the flow rate of CO\(_2\) was \(Q_2=0.10 \, \text{l/min-const.}\) and it flows into the salt water after 30 minutes of churning with an agitator. The Ca\(^{2+}\) concentration was measured at times of \(t=5, 10, 20,\) and 30 minutes and the quantity of the reaction was calculated by the reduction rate of the Ca\(^{2+}\) concentration.

The continuing flow in with the CO\(_2\) of the solution’s pH decreased, the CaCO\(_3\) was dissolved, and the charcoal oxidation reaction was not generated because an ion form of CO\(_2\) does not exist as HCO\(_3\) and CO\(_3^{2-}\). The experiment was carried out under a range of pH=8~10, which was maintained by dripping an ammonia-alkaline water solution into the salt water by a Komagome pipette.

4.2 Experimental results

4.2.1 Effects of cation exchange resin on absorption and Substitution of Ca\(^{2+}\)

a. Absorption of Ca\(^{2+}\)

Figure 4 shows the effects of the quantity of cation exchange resin on \(C_{Ca}\) in the Ca elution process when pH=2.5. Without cation exchange resin \(I_r=0\), \(C_{Ca}\) increased rapidly with increasing time \(t\), but when a cation exchange resin was added, its rate of increase fell, and at \(I_r=20g\) it decreased after \(t=5\) min. Ca\(^{2+}\) increased by eluting Ca into the water solution but Ca\(^{2+}\) in the water solution simultaneously decreased by absorbing the cation exchange resin. The quantity of absorption increased as \(I_r\) became larger.

Figure 5 shows absorption rate \(\alpha\) of the cation exchange resin of Ca\(^{2+}\) to that eluted in the water solution. \(\alpha\) increases at almost the same rate until \(t=5\) min independently of \(I_r\). After it for \(I_r=10g\), it takes almost the same \(\alpha\) of 55%, and for \(I_r=20g\) it increases gradually until \(\alpha=90\%\) because for \(I_r=10g\), the absorption and elution quantities are almost the same. But by increasing \(I_r\), the absorption exceeds the elution. Ca\(^{2+}\) can apparently be absorbed effectively so that there is much cation exchange resin.

b. Substitution of Ca\(^{2+}\)

Figure 6 shows the effects of \(I_r\) on \(C_{Ca}\) in a substitution process of Ca\(^{2+}\) when pH=2.5 and \(C_N=10\%\) after \(t=60\) min. \(C_{Ca}\) increases rapidly with time independently of \(I_r\) until \(t>5\) min and then increases gradually. From this result the substitution of Ca\(^{2+}\) is finished in about five minutes. The quantity of the substitution rate of Ca\(^{2+}\) is different by \(I_r\) and the quantity for \(I_r=20g\) is larger.

Figure 7 shows \(C_{Ca}\) for flowing CO\(_2\) in a CaCO\(_3\) generation process. For \(I_r=0\), CO\(_2\) flowed into the water solution just after an elution process of Ca. \(C_{Ca}\) at \(t=0\) min and is different by \(I_r\), but \(C_{Ca}\) decreased rapidly at \(t<5\) min and then decreased gradually. A charcoal oxidation reaction was suddenly caused, and Ca\(^{2+}\) decreased in five minutes after CO\(_2\) was added to the water solution. CaCO\(_3\) generation was identified by a cloudy water solution after \(t>5\) min.

c. Quantity of generation of CaCO\(_3\)

Figure 8 shows the relation between quantity \(X\) of the generation of CaCO\(_3\) and flowing time \(t_2\) of CO\(_2\). Since the
4.2.2 Effects of salinity
(a) Substitution process of Ca$^{2+}$

Figure 9 shows the effects of the salinity on $C_{Ca}$ with a Ca$^{2+}$ concentration in the water solution under the substitution process of Ca$^{2+}$ in the cation exchange resin. In this case, a cation exchange resin of $I_e=10g$ was used after a 60-min elution process of Ca at pH=2.5. For $C_N=3.5\%$, seawater was used. $C_{Ca}$ increased with increasing $C_N$ and the quantity of the substitution with Na$^+$ increases. Since $C_{Ca}$ increases up to 420 ppm when $C_N=20\%$, 90% of the absorbed Ca$^{2+}$, which is the absorption quantity at 468 mg, may be substituted and then the loss of the cation exchange resin will be small.

(b) Generation process of CaCO$\_3$

Figure 10 shows the $C_{Ca}$ for salinity $C_N$ in the production process of CaCO$\_3$. $C_{Ca}$ at $t_3=0$ is different for each case because $C_{Ca}$ is larger for larger $C_N$ in the substitution process of Ca$^{2+}$, but in every case it decreased rapidly until $t_3=5$ min and then decreased gradually. Until $t_3=5$ min, the charcoal oxidation reaction actively occurred. After $t_3=5$ min for larger $C_N$ the $C_{Ca}$ became smaller.

When a large amount of electrolyte is melted in a water solution, its solubility falls; this is extraction by the salting effect. Much carbonic acid apparition crop is generated in the water solution.

(c) Quantity of generation of CaCO$\_3$

Figure 11 shows the relation between generation quantity $X$ of CaCO$\_3$ obtained by charcoal oxidation reaction and flowing time $t_3$ of CO$\_2$. $X$ increased rapidly for every $C_N$ until $t_3=5$ min and then decreased gradually. $X$ is larger for larger $C_N$ and the efficiency of the charcoal oxidation reaction is improved.

4.2.3 Recovery

For charcoal oxidation reaction recovery $\delta$ of Ca, the above results for the charcoal estimate the use of Ca in the waste concrete, and fixation rate $\gamma$ of CO$\_2$ may be calculated. This section discusses the effects of $I_e$ and salinity on the recovery of Ca.
a. Effects of quantity of cation exchange resin

Figure 12 shows the relation between $\delta$ and $t_1$ for each $I_r$. $C_N$ is 10%. $\delta$ for $I_r=0g$ increased rapidly until $t_1\approx5min$, and $\delta$ for $I_r=10$ and 20g increased rapidly until $t_1\approx5min$, and after those, $\delta$ decreased gradually for every case. $\delta$ is larger when $I_r$ is larger, and it reached $\delta\approx35\%$ for $I_r=20g$. For $I_r=0g$, $\delta$ increased more and reached $\delta\approx60\%$. Loss by absorption or substitution did not occur because the substitution process of $Ca^{2+}$ from the cation exchange resin was not needed.

Figure 13 shows the relation between fixation rate $\gamma$ of $CO_2$ and $t_1$ for each $I_r$. $C_N$ is 10%. For every $I_r$, $\gamma$ takes a maximum at $t_1\approx5min$ and then decreased rapidly because a charcoal oxidation reaction suddenly occurred before $t_1\approx5min$, when almost all the $CO_2$ that flowed in was used for charcoal oxidation. But after $t_1\approx5min$, when the charcoal oxidation reaction rate became small, the $CO_2$ which was not used for the charcoal oxidation, increased and dissolved in the water or was released into the atmosphere.

Considering only fixation rate $\gamma$ of $CO_2$, the most efficient reaction time to stop the generation process of $CaCO_3$ is at $t_1\approx5min$. For $I_r=20$ and 0g, the maximum of $\gamma$ is $\gamma_{max}\approx40\%$ and $\gamma_{max}\approx70\%$.

b. Effects of salinity

Figure 14 shows the relation between $\delta$ and $t_1$ for various $C_N$s. $I_r$ is $I_r=10g$. As shown in Fig.12, $\delta$ increased rapidly until $t_1\approx5min$ and then decreased gradually. $\delta$ increased to about 32% at $C_N=20\%$. Since $\delta$ increased with increasing $C_N$, it is effective to use the salt water of the high density in the operation to substitute $Ca^{2+}$ for the cation exchange resin.

Figure 15 shows fixation rate $\gamma$ of $CO_2$ and $t_1$. $I_r$ is 10g. $\gamma$ shows almost the same profile as Fig.13 and increased rapidly until $t_1\approx5min$ and then decreased gradually. Since $\gamma$ and $C_N$ are generally large, using salt water is effective in high density. The maximum of $\gamma$ is $\gamma_{max}\approx38\%$.

5. Charcoal Oxidation Reaction and $CO_2$ Micro-Bubble Jet Flow

Based on the above results concerning the carbonic acid reaction of waste concrete, an effective method to improve the efficiency is using the MB of $CO_2$ to elutes the $Ca$ ingredient in an acid water solution or to produce $CaCO_3$ in a Ca water solution because the interfacial area will be increased remarkably and then the dissolution to the Ca water can be promoted.

For the micro bubble generation of $CO_2$, we used a new micro bubble generator for the large shearing stress of a high speed submerged water jet [1][3].

5.1 Experimental apparatus and procedure

Figure 16 shows a schematic diagram of a waste concrete processor that is comprised of two loops: Loop 1 for the recycle system of waste concrete after extracting the Ca ingredient under water and Loop 2 for the separation of $CaCO_3$ by the reaction of $Ca^{2+}$ in the water solution where $CO_2$ flowed into the water solution by MB. Loop 1 is a Ca extraction process, and Loop 2 is the $Ca^{2+}$ substitution and $CaCO_3$ separation processes.

In Loop 1 the water from the tank (1), whose pondage is nozzle (5) by pump (2) after adjusting the flow rate ($Q_{in}=W=15$ lit and $pH=2$, flows into I in Loop 1 through 5.0 l/min) by a valve (3) and flow meter (4). $M_c=20g$ of waste concrete is thrown into I from the upper opening of pipe II by a vibration feeder and the water that rises in pipe II’
returns to the tank after passing through the area whose cation exchange resin is set at $I_T=120g$.

Because the 5.0mm diameter water nozzle was inclined 30° for a pipe, the flow has a turning style and stays while the subsiding particle follows a flow in the fast neighborhood of the turning speed and turns. The test sample was collected from the bottom of the device with the water solution after processing and drying.

In Loop 2 the salt water from the tank (2), whose pondage is $W_2=15$ lit. and $C_{Na}=20wt\%$, flowed into III in Loop 2 through micro bubble generation nozzle (8) by pump (7) after passing through the area of the cation exchange resin in the pipe II and adjusting the flow rate ($Q_{se}=3.0$ l/min) by a valve and a flow meter (4). CO$_2$ gas was supplied from a carbon dioxide cylinder and issued from the micro bubble generation nozzle (8) after passing through the flow meter (7). A gas-liquid two-phase flow including a micro bubble rises in the vertical pipe III and returned to the tank (1) from the exit at the upper part. After processing, the waste concrete and the provided product was collected by a filter and a vacuum pump (10).

Figure 17 shows the details of the micro bubble generation nozzle. Its 1.0mm diameter air nozzle was set 3.0mm from the center of the water orifice nozzle whose exit diameter was $d_{in}=2.0mm$ and whose contraction area ratio was 0.16. The edge angle of the orifice nozzle was 30°. The induced air by a high speed submerged water jet became thin with a large shearing force depending on the large velocity gradient around the outside of the water jet [20]. The flow characteristics of the micro bubble water jet were examined by flow visualization and observation, and bubble size and velocity distributions were measured by Laser Doppler Velocimetry (LDV).

5.2 Experimental results

5.2.1 Flow characteristics of CO$_2$ micro-bubble jet flow

Figure 18 shows the flow pattern of the micro bubble jet flow when the flow rate of the water jet was $Q_{se}=3.0$ l/min, the nozzle exit mean velocity was $u_{se}=15.9m/s$, and the flow rate of air or CO$_2$ was $Q_{g}=0.1$ l/min. The white colored part is the bubble swarm, and the spread of the CO$_2$ micro bubble jet flow is smaller than that for the micro bubble air jet flow.

The bubble size distribution on the upside of $x/d=30$ from the nozzle exit was measured using a photograph of the visualized flow. The air flow had many bubbles smaller than 200μm, and the mean diameter was $D_m=140μm$. However for CO$_2$ that exceeds 80%, the bubbles were smaller than $D_m=100μm$ and $D_m=66μm$ and smaller than the air and much smaller than the former results of $D_m=3$ ~4mm in Section 3.1.

5.2.2 Processor of waste concrete

Figure 19 shows $C_{Ca}$, which is the Ca$^{2+}$ density in the Ca extraction process in Loop 1. $C_{Ca}$ increases with time until a certain constant but after that it hardly changes. In the case of $I_T=120g$ the increment rate of $C_{Ca}$ is smaller than $I_T=0g$, and this difference is the quantity of the absorption of Ca$^{2+}$. Here, the absorption is 82ppm at $t=30min$. Ingredient analysis by XRD and powder X-rays diffractometry of the test sample after processing confirmed that the Ca ingredient was removed and the crystal ratios of the quartz, which is the chief ingredient of the sand, increased greatly comparing with before processing.

Figure 20 shows $C_{Ca}$ in the Ca$^{2+}$ substitution process in Loop 2. Since Na$^+$ in the water solution and Ca$^{2+}$ in the cation exchange resin are substituted, $C_{Ca}$ increased with
time and approached a constant and the substitution is completed. It depends on the impurities, for example Ca,Mg, and others, except NaCl, which is included when salt water is generated where $C_{ca}$ is large at $t_2\equiv 0$min. The quantity of substitution is 59ppm at $t_1\equiv 30$min.

Figure 21 shows $C_{ca}$ when the CO$_2$ flow rate was $Q_c=0.1$ l/min in the CaCO$_3$ separation process. $C_{ca}$ decreased more than that for the Ca$^{2+}$ substitution process and CaCO$_3$ was generated corresponding to the decrease rate of Ca$^{2+}$. The reaction rate of Ca$^{2+}$ was 83ppm at $t_5\equiv 30$ min. Since the contact area between air and water is remarkable when the CO$_2$ micro bubble was used, the reaction velocity and efficiency can be improved considerably.[4].

Figure 22 shows recovery rate $\delta$ and fixation rate $\gamma$ of Ca derived by the conversion of the generation quantity of CaCO$_3$, $\delta$ and $\gamma$ both increased with increasing inflow time of CO$_2$ and take the maxima of $\delta_{max}\equiv 27\%$ at $t_3\equiv 20$min and $\gamma_{max}\equiv 23$ at $t_2\equiv 30$min. $\delta_{max}$ at Loop 1 is $\delta_{max}\equiv 82\%$ at $t_3\equiv 60$min, as in the results of Fig.2.

$\gamma$ decreased at $t_1\equiv 30$ min, depending on the decrease of the generation velocity of CaCO$_3$ for the inflow rate of CO$_2$. From the XRD analysis of the unknown test sample obtained after processing, we confirmed a 52.2% crystal structure of vaterite and aragonite and that then the charcoal oxidation reaction occurs.

6. Conclusions
The following results were obtained from an experimental analysis of recycling waste concrete and the fixation of CO$_2$ by micro bubble jet flow.
(1) If the test sample of waste concrete is processed by about 60min in a water solution of pH$\equiv 2.5$, almost all of the Ca ingredients are eluted and the remaining sand whose diameter is about 0.3mm can be reused as a reproduction aggregate.
(2) To improve the efficiency of the charcoal oxidation reaction, increasing the amount of cation exchange resin $I_e$ is effective.
(3) The generation quantity of CaCO$_3$ is larger for larger $C_N$ and improves the efficiency of charcoal oxidation reaction.
(4) The waste concrete processing system and the newly proposed device can make the sand of waste concrete simultaneously reproduce aggregate and the fixation of CO$_2$.

Recovery rate $\delta$ and fixation rate $\gamma$ of Ca are derived by the conversion of the generation quantity of CaCO$_3$. $\delta$ and $\gamma$ both increase with increased inflow time of CO$_2$ and take the maxima of $\delta_{max}\equiv 27\%$ at $t_3\equiv 20$min and $\gamma_{max}\equiv 23$ at $t_2\equiv 30$min. $\delta_{max}$ at Loop 1 is $\delta_{max}\equiv 82\%$ at $t_3\equiv 60$min.
(5) Since the contact area between air and water is remarkable when the CO$_2$ micro bubble is used the reaction velocity and efficiency can be improved considerably.

Acknowledgement
The authors would like to express our gratitude to Prof. K.Kamiya for his valuable suggestions.

References