Mechanical Evaluation of MgO Improved Soil by Acoustic Emission Method

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Abstract

The technology for the recycling of residues from rice cropping must improve sustainable rice cropping in recycling society. The purpose of this study is to recycle rice crop residues and develop MgO improved soil by mixing rice husk ash and rice straw fibers into the soil. This experiment examined samples of MgO improved soil mixed with rice husk ash and rice straw fibers in four different mixture fractions and it, utilizing AE monitoring and image analysis, revealed the characteristics of material property and fracture process through splitting tests. The samples mixed with rice husk ash increased in strength, and those with rice straw fibers increased in toughness.

Keywords: AE, AE-SiGMA analysis, Image analysis, MgO improved soil, rice husk ash, rice straw fiber

1. Introduction

This study is trying to develop an eco-friendly improved soil with sufficient strength by using rice crop residues—rice hulls and rice straws. Most of them have been disposed in the process of rice cropping. Sixty percent of rice hulls and eighty percent of rice straws were wasted in Niigata, Japan in 2007. A more highly sophisticated technology of utilizing rice crop residues has been required for sustainable rice cultivation.

The purpose of this study is to recycle rice crop residues and develop MgO improved soil by mixing rice husk ash and rice straw fibers into the soil. It is expected that rice hull ash and rice straw fibers improve material properties of soil. Rice hull ash in itself contains a high amount of silica and its performance in stabilization of cement improved soil or concrete through pozolanic reaction has been shown in a different investigation [1-2]. Rice straw fiber could help soil to increase in toughness and improve the cracking deformation characteristics of the resultant composite. Fiber-reinforced concrete has overcome the tension and ductility weaknesses common to all types of concretes [3].

This experiment examined samples of MgO improved soil mixed with rice husk ash and rice straw fibers in four different mixture fractions and it, utilizing AE monitoring and image analysis, revealed the characteristics of material property and fracture process through splitting tests. Besides, crack kinematic of a location and crack-type have been identified by
AE SiGMA analysis.

2. Method

2.1 AE-SiGMA analysis

The fracture process of each sample of MgO improved soil was evaluated by AE-SiGMA analysis. AE-SiGMA analysis is available for identifying crack kinematics of a location, a crack type, and a crack orientation [4-5]. The crack type is classified from the arrival time and the amplitude of the first motion. The shear ratio ($R_s$) is determined from the eigenvalue analysis of the moment tensor. An AE source with $R_s$ over 60% is classified as a shear crack, one with $R_s$ below 40% as a tensile crack, and one with $R_s$ between 40% and 60% as a mixed-mode crack. In this study, AE event definition time (EDT) was set for 100 µs. EDT is the duration of time by which an AE event is defined.

2.2 Material

The Mix proportion is shown in Table 1. The materials were fine sand (density: 2.67 g/cm$^3$), vermiculite, rice husk ash (density: 2.32 g/cm$^3$) and rice straw fibers (length: 1.2~2.0 cm, width: 0.5 cm). Grain size accumulation curve is shown in Figure 1. The moisture content was 25%. Rice husks were passed through a 425 µm sieve. Rice husks were burned in an electric furnace at 500 degrees for 1 hour for production of rice husk ash. The ratio of grass content of rice husk ash was 97% by Rietveld analysis. In the testing program, four soil mixes were manufactured: the samples mixed with no rice hull ash and no rice straw fibers, the samples mixed with rice straw fibers, the samples mixed with rice husk ash and, the samples mixed with rice husk ash and rice straw fibers. For each of the mixes, five soil cylindrical specimen having 50 mm diameter and 100 mm height were subjected to splitting tests.

<table>
<thead>
<tr>
<th>Series</th>
<th>Fine sand (g)</th>
<th>Vermiculite (g)</th>
<th>MgO (g)</th>
<th>Rice husk ash (g)</th>
<th>Rice straw fiber (cm$^3$)</th>
<th>Water (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>280.0</td>
<td>14.0</td>
<td>58.8</td>
<td>0.0</td>
<td>0.0</td>
<td>73.5</td>
</tr>
<tr>
<td>MF</td>
<td>280.0</td>
<td>14.0</td>
<td>58.8</td>
<td>12.3</td>
<td>5.3</td>
<td>73.5</td>
</tr>
<tr>
<td>MR</td>
<td>266.0</td>
<td>13.3</td>
<td>58.8</td>
<td>12.3</td>
<td>0.0</td>
<td>73.5</td>
</tr>
<tr>
<td>MRF</td>
<td>266.0</td>
<td>13.3</td>
<td>58.8</td>
<td>12.3</td>
<td>5.3</td>
<td>73.5</td>
</tr>
</tbody>
</table>
2.3 Splitting test with AE monitoring

The characteristic of the soil was evaluated through splitting test using AE after 7 days under the standard curing. AE signals were detected by AE sensors of 150 kHz resonance (R15α, PAC) and processed (SAMOS, PAC). The frequency range was set from 5 kHz to 400 kHz. AE hits were amplified with 40 dB gain in the pre-amplifier and 20 dB gain in the main amplifier. The threshold level for detection was set for 40 dB. The experimental setup is shown in Figure 2. The sensor array is shown in Figure 3.
2.4 Image analysis

The strain distribution was estimated by digital image correction method (DICM). The basic principle of DICM is the tracking of the same points between two consecutive images. The surface of each specimen was painted thin white paint and overprinted with a speckle pattern of black. DICM configuration consisted of Xenoplan 1.4 /17 lens, light sources, and CRAS-14S5M-C CCD camera (Point Grey Research). CCD camera captured images of size 1,384 pixels by 1,036 pixels at a rate of 5 images per second.

3. Results and discussion

3.1 Material property

The results of material property are summarized in Table 2. The samples with rice hull ash were over two times higher than the samples with no rice hull ash in splitting tensile strength. There was, on the other hand, almost no significant difference among the samples with rice straw fibers. The samples with rice hull ash decreased and the samples with rice straw fibers increased in the maximum of displacement. The samples with rice hull ash increased and the samples with rice straw fibers did not change in the velocity of P wave. These results suggest that the mixing of rice hull ash could be effective for stabilizing soil. On the other hand, the effects of the mixing of rice straw fibers could not be shown by these indicators; splitting tensile strength, the maximum of displacement and the velocity of P wave.
3.2 Chemical reaction

These increases in splitting tensile strength and in the velocity of P wave must be attributed to progress in consolidation through the pozzolanic reaction between Mg(OH)$_2$ and silicic acid. XRD Rietveld analysis, a chemical one, was conducted to verify effects of the mixing rice hull ash on the chemical reaction. The results of Rietveld analysis of the anhydrous phase are given in Table 3. Though the amount of bluecite (Mg(OH)$_2$) in the samples with rice hull ash was lower than in the samples with no rice hull ash and no rice straw fibers, the amount of the amorphous in the samples with rice hull ash was higher than in the samples with no rice hull ash and no rice straw fibers. These results suggest that the structure of the samples with rice hull ash are complicated and stabilized through the pozzolanic reaction.

<table>
<thead>
<tr>
<th>Series</th>
<th>Splitting tensile strength (N/mm$^2$)</th>
<th>Maximum of displacement (mm)</th>
<th>P wave velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>MF</td>
<td>MR</td>
</tr>
<tr>
<td>Average</td>
<td>0.08</td>
<td>0.11</td>
<td>0.25</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.01</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>Max</td>
<td>0.08</td>
<td>0.12</td>
<td>0.31</td>
</tr>
<tr>
<td>Min</td>
<td>0.07</td>
<td>0.09</td>
<td>0.21</td>
</tr>
</tbody>
</table>

3.3 Evaluation of fracture process using AE parameters

The relations between load-displacement curve and the total AE hits are shown in Figure 4. In the case of the samples mixed with no rice hull ash and no rice straw fibers, the relationship is a linear one, which clearly shows the existence of brittle fracture. In the case of the samples mixed with rice hull ash, the relationship consists of two phases: one in which the relationship is linear before the maximum load and one in which it is non-linear after the maximum load. This result suggests that the mixing of rice hull ash caused an increase in
fracture toughness.
The verification of the effects of the mixing of rice straw fibers must be helped by using AE hits for and indicator. The number of AE hits is an indicator for AE generation behavior, which shows micro-crack formation, per unit of time. The mixing of rice straw fibers decreased the total AE hits and it seemed to make AE generation behavior a gradual one (Figure 4). The rate of change in the total AE hits from 60 to 100 % at y-axis displacement in each sample is shown in Figure 5. The rates of change in total AE hits made clear differences in fracture process in the samples. The Tukey method showed at 1 % of significant difference that the rate of change in the samples mixed with rice hull ash and rice straw fibers was lower than that in the samples mixed with rice hull ash. This suggest that the mixing of rice straw fibers caused fracture process to change from brittle fracture to ductile fracture and made an increase in toughness. The samples mixed with no rice hull ash and no rice straw fibers and the samples mixed rice straw fibers showed no significant difference in the rate of change.
The reason seems to be that grate difference in elastic coefficient between matrix and fiber hinders tensile effect.

Figure 4. Relations between load-displacement curve and the total AE hits
The result of AE-SiGMA analysis of series MR and of MRF is shown in Figure 6. AE events of series M were not detected. In recent similar researches, characteristics of generation behavior of concrete-cracks in splitting tests have been reported that the cracks grow from the boundary surface between specimens and loading plates in cyclic loading test [6]. The crack grow near 0.3 ~ 0.4 d (d: diameter of the specimen) from the center of specimen [7-8]. In this study, the analytical results showed similar trend to the previous investigations. AE events were detected near 0.2 ~ 0.4 d before the maximum of the load, and were distributed near the center after the maximum of the load (Figure 6).

4. Conclusion

This experiment examined samples of MgO improved soil mixed with rice husk ash and rice straw fibers in four different mixture fractions and it, utilizing AE monitoring and image
analysis, revealed the characteristics of material property and fracture process through splitting tests. The results are summarized as follows:

1) The tensile strength and the velocity P wave of the improved soil mixed with rice hull ash were over two times higher than that of the soil mixed with no rice hull ash.

2) XRD Riteveld analysis revealed that the structure of the samples with rice hull ash are complicated and stabilized through the pozzolanic reaction.

3) The samples mixed with rice hull ash and rice straw fibers was lower than that in the samples mixed with rice hull ash in the rates of change in total AE hits. The verification of the effects of the mixing of rice straw fibers must be helped by using AE hits for and indicator.

4) Both image analysis and AE-SiGMA analysis indicated that a concentration of horizontal stain and the excellence of the tensile crack in the specimen.

References


