# Long-term durability of coal ash mixed material under various environments

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**ABSTRACT**

In Japan, emissions of coal fly ash have been increased due to actual operation of thermal power station after the Great East Japan Earthquake, occurred in 2011. Currently, coal ash mixed material was invented by Power Company, University and Construction Company to promote a recycling of these coal fly ash. There are some kinds of the coal ash mixed material such as plastic material, slurry, solidified crushed material, and solidified granulated material. Although the construction results reported on each material and used effectively at port section, further applications development has been required with increasing emissions of the coal fly ash. Moreover, in order to promote effective utilization of these coal ash mixed materials, it is important to guarantee the quality, safety to the surrounding environment, and long-term durability of the material. Because of such a background, this study examined the mechanical characteristics and leaching properties of coal ash mixed material for long-term under exposure conditions simulating the various environments.

**Keywords:** coal fly ash; coal ash mixed material; durability; unconfined compression strength; leaching properties; needle penetration strength

## 1 INTRODUCTION

Coal ash generated from thermal power plants in Japan is approximately 12 million tons. Much of coal ash is generated from electric power companies, and their thermal power plants are built around the port area. The effective use of coal ash accounts for the majority of the cement field, and its effective use in the civil engineering field has not progressed much. Therefore, Japan Coal Energy Center (JCOAL) published "Effective Use Guidelines for Coal Ash Mixture (edited by Port Construction)" in order to expand the use of coal ash generated from the coal ash thermal power plant in the civil engineering field (JCOAL, 2011). Also they published "Guidelines for Effective Utilization of Coal Ash Mixing Materials (Earthquake Recovery Materials Edition)" which can be used for restoration and reconstruction work which was seriously damaged by the Great East Japan Earthquake (JCOAL, 2014). In addition, "Guidelines for Effective Use of Coal Ash Mixing Material (High Standard Road Embroidery)" aimed at promoting the application to high-standard road embankment was published (JCOAL, 2015).

Although publication of these guidelines increased the use of coal ash mixed materials, further applications development has been required with increasing emissions of coal fly ash. Moreover, in order to promote effective utilization of these coal ash mixed materials, it is important to guarantee the quality, safety to the surrounding environment, and long-term durability of the material (Fujikawa et al. 2015). However the evaluation of long-term mechanical properties, durability and environmental safety of coal ash mixed materials has little accumulation of data. In the future, accumulation of these data is an important issue in effective use of coal ash mixed materials.

Therefore this study examined the mechanical characteristics and leaching properties of long-term coal ash mixed material under exposure conditions simulating the various environments to establish a long-term durability evaluation method of coal ash mixed material and to accumulate data on long term durability.

## 2 TESTING PROSEDURE

### 2.1 Material and testing condition

This study focused on slurry type of coal ash mixed material (slurry material). The slurry material was prepared by mixing coal ash, cement and water and poured into a PVC mold having a diameter of 5 cm and a height of 10 cm. Table 1 shows the physical properties and chemical components of coal ash using in this study. Also Table 2 shows design mix proportion of the slurry material. The amount of cement per 1m$^3$ of the slurry material was fixed at 50, 75, 100 kg/m$^3$ so that the target unconfined compressive strength of 28 days curing was approximately 300 to 1000 kN/m$^2$. The design mix proportions were determined after conducting preliminary tests considering the conditions which satisfied the flow value of 220 ± 20mm. The flow value of the slurry material was estimated according to the JHS A 313 flow test standard (Japan Highway Public Corporation 1992 **"**Test method for Air mortar and air milk").

After that, the slurry material was poured into a mold made of PVC. After casting, the specimen was shaped on the next day, demolished on the following day, wrapped in a wrap, and curing was carried out in a constant temperature room at 20 °C. The mechanical properties of the slurry material were evaluated using the unconfined compression test (JIS A 1216) and a needle penetration test, respectively.

Table 1. Physical properties and chemical components of coal ash using in this study.

| Physical properties | | | Chemical compornent | | |
|---|---|---|---|---|---|
| $\rho_s$ | (g/cm$^3$) | 2.347 | $SiO_2$ | (%) | 58.2 |
| w | (%) | 0.0 | CaO | (%) | 7.9 |
| $w_L$ | (%) | N.P. | $Al_2O_3$ | (%) | 20.0 |
| $w_P$ | (%) | N.P. | FeO | (%) | 5.0 |
| $F_c$ | (%) | 99.7 | MgO | (%) | 1.7 |
| | | | $Na_2O$ | (%) | 0.5 |
| | | | $K_2O$ | (%) | 1.9 |

Table 2. Design mix proportion of the slurry material.

| Cement contents (kg/m$^3$) | Coal ash (kg/m$^3$) | Water (kg/m$^3$) | Wet density (g/cm$^3$) | Flow value (mm) |
|---|---|---|---|---|
| 50 | 985 | 564 | 1.599 | 222 |
| 75 | 975 | 560 | 1.610 | 219 |
| 100 | 960 | 558 | 1.618 | 212 |

## 2.2 Exposure test method

After curing the slurry material for 7 days, water immersion and seawater immersion exposure test was conducted in a thermostatic room at 20 ± 3 °C. Distilled water was used as a solvent for water immersion exposure considering groundwater and rainfall. And also seawater which was pressurized filtration to remove floating matter was used for seawater exposure simulating the port area. The slurry material used for these exposure tests was taken off the wrap and directly contacted with the solvent. The solvent exchange was done once a month.

## 2.3 Evaluation method of deterioration of the slurry material

In order to observe the condition of deterioration, water and seawater immersion exposure curing was performed in a state in which only the upper surface was opened using a specimen that was cured for 7 days. The solvents are the same as those used in 2-2. The needle penetration test was performed at a pitch of 10 mm from the upper end face of the specimen using the specimen which was divided in half in order to reveal the strength change from the upper end face of the specimen in the depth direction (as shown in Figure. 1).

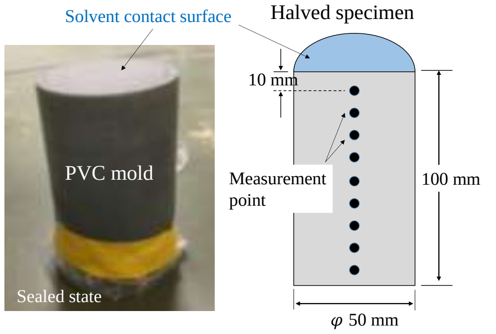



Fig. 1. Measurement position of needle penetration test.

# 3 RESULTS AND DISCUSSION

## 3.1 Long term mechanical characteristics of coal ash mixed material under various exposure conditions

The results of the unconfined compression test of the slurry material on 28 days curing are shown in Figure 2. The unconfined compressive strength and stiffness of the slurry material increased with increasing the cement contents. Also the target strength of the slurry material was set to approximately $q_{u28}$ = 300 to 1,000 kN/m$^2$, and it was revealed that the target strength was satisfied under all conditions.

Figure 3 shows the unconfined compression test results of each exposure conditions (Airborne exposure, water immersion exposure and seawater exposure) on 7 days curing of the slurry material, respectively.

The unconfined compressive strength of the slurry material increases with increasing the cement contents and the number of exposure days for all the case. In the exposure test conducted this time, strength development was particularly noticeable especially in seawater exposure. Since blast furnace cement is used as solidifying material, it is considered that the hardening and pozzolanic reaction occurred due to latent hydraulicity of slag due to alkali stimulation with soaking in seawater (pH=8.53). As a result, it is considered that the strength has increased compared to the other two kinds of exposure tests. In water immersion exposure and seawater exposure conditions, it was found that the unconfined compressive strength

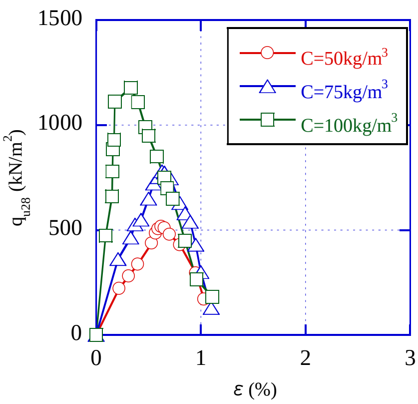
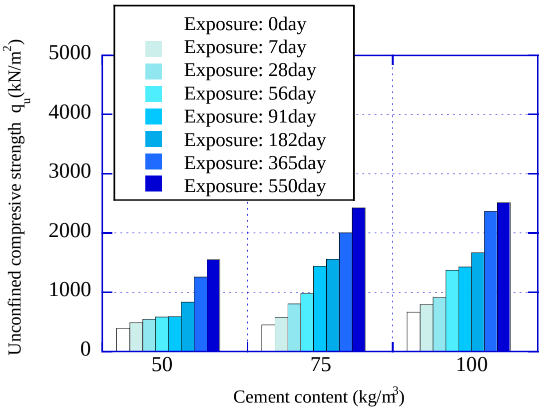
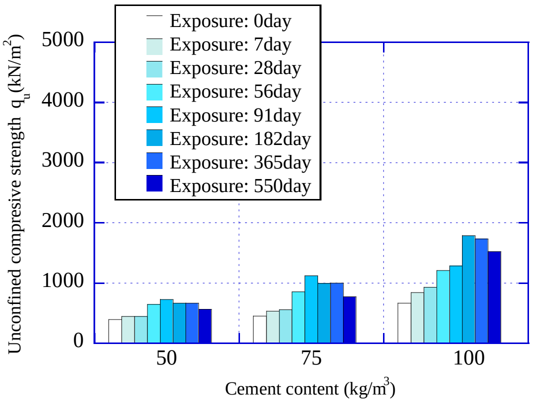


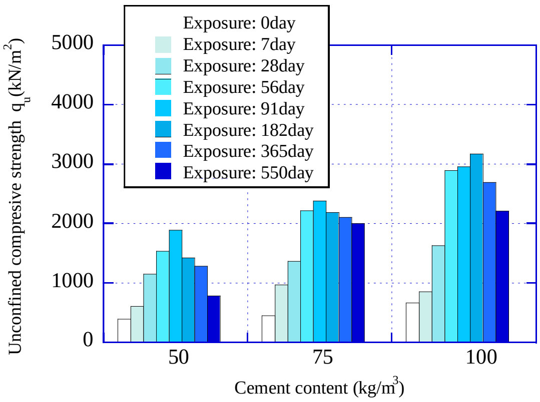

Fig. 2. Results of the unconfined compression test of the slurry material on 28 days curing.




(a) Airborne exposure




(b) Water immersion exposure




(c) Seawater immersion exposure

Fig. 3. The unconfined compression test results of each exposure conditions.

peaked at 91 days of curing, and after that the unconfined compressive strength decreased. Generally, elution of calcium hydroxide promotes deterioration of the specimen because it makes the sample porous. Therefore, elution of calcium in the specimen is considered as a main cause of deterioration and decreasing strength. Figure 4 shows the relationships between exposure days and cumulative calcium elution amounts of each mix proportion. Calcium elution

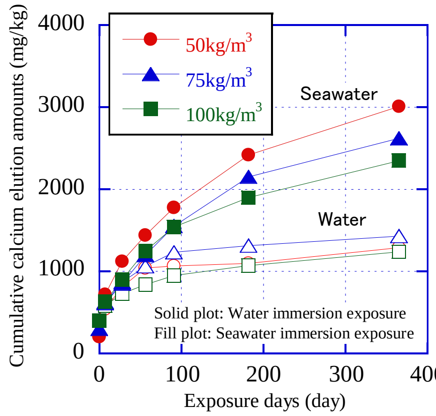



Fig. 4. Relationships between exposure days and cumulative calcium elution amounts.

volume was more seawater immersion exposure condition than water immersion condition. As one of the reasons that calcium elution amount was large under seawater immersion exposure condition compared to water condition, it is reported that the following reaction occurs when cement treated soil contacts with seawater (Hara et al. 2013).

$$MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCl_2 \quad (1)$$

$$MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4 \cdot 2H_2O \quad (2)$$

This reaction formula shows that brucite is formed and calcium hydroxide is eluted in the form of calcium chloride or calcium sulfate. Since the seawater used in the experiment contains a lot of magnesium ions, it is considered that the above reaction occurred by exposing the specimen to the seawater. As a result, insoluble magnesium hydroxide called brucite was formed and calcium chloride and calcium sulfate were eluted. This elution phenomenon under seawater exposure conditions is a factor that eluted more calcium than water immersion exposure. As a result, it is considered that the interior of the specimen became porous and caused a decrease in strength.

### 3.2 Understanding the depth of degradation due to differences in exposure conditions

Since the unconfined compressive strength decreased with the increase in exposure curing in the water immersion/seawater immersion exposure test, the strength deterioration mechanism was evaluated using the needle penetration test. Figure 5 shows the relationship between penetration resistance and unconfined compressive strength. Since the correlation was found between the penetration resistance and the unconfined compressive strength, the compressive strength converted from the result of the needle penetration test is used for the subsequent of the results. Figure 6 shows the relationship between the distance from the contact surface and the converted unconfined compressive strength. When comparing the converted unconfined compressive strength at each depth obtained from the needle penetration test with the various

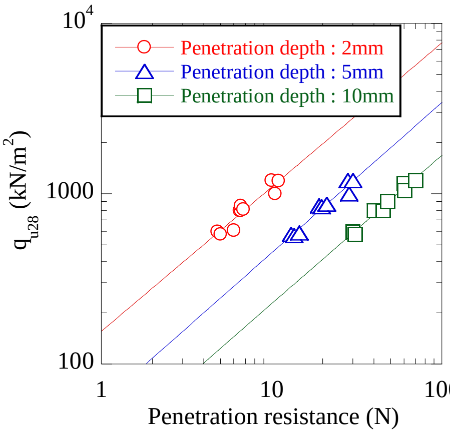
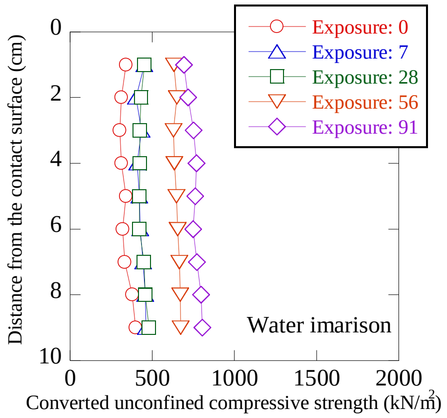
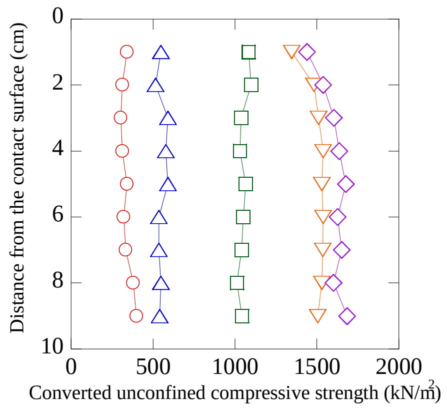



Fig. 5. Relationships between penetration resistance and unconfined compressive strength.




(a) Water immersion exposure




(b) Seawater immersion exposure

Fig. 6. Relationship between the distance from the contact surface and the converted unconfined compressive strength.

exposure results shown in Figure 4, it can be seen that the compressive strength at the same number of days has the same strength. Under the water immersion exposure condition, the converted unconfined compressive strength was low up to 2 cm deep from the solvent contact surface at 91 days of exposure. Also under the seawater exposure of 56 days, the converted unconfined compressive strength decreased from the solvent contacting surface to 2 cm deep. Similarly, at exposure days of 91 days, the converted unconfined compressive strength decreased to 4 cm deep from the solvent contact surface.

From these results, it was revealed that the deterioration proceeds from the contact surface with the solvent and spreads deeper into the specimen as the number of exposure days increases. As described above, calcium eluted from the surface of the specimen, it is considered that the sample became porous and caused the strength to decrease.

Based on the above results, the reason why the strength reduction occurred after 91 days in the exposure test shown in Figure 4 is considered to be that the surface deterioration advanced to the deep portion and the strength decreased as confirmed by the needle penetration test.

## 4 CONCLUSION

As a result of experimental investigation on long-term durability of coal ash mixed material under various environments, the following conclusion was obtained.

1) The strength of coal ash mixed material increases with increasing cement addition rate and curing days. However, under water immersion and seawater immersion exposure conditions, there is a possibility that the strength decreases after half a year due to leaching out of calcium from coal ash mixed material.

2) Progress of deterioration of the coal ash mixed material proceeds from the surface of the specimen toward the deep part. In addition, the progress of the deterioration is faster better of seawater exposure.

When utilizing a slurry-type coal ash mixed material, construction of the case, such as direct contact with water or seawater, it is necessary to pay attention in terms of long-term durability.

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