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# RECYCLABILITY OF FLY ASH CONCRETE PAVEMENT MADE WITH LIMESTONE AGGREGATE

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The present study aims to develop a recyclable concrete pavement incorporating fly ash. All aggregates used in the concrete were crushed limestone sand and gravel, so the concrete pavement can be recycled into raw materials for cement production. To use fly ash as much as possible and to obtain adequate strength development, the present study focuses on pavement concrete made with cement-replacement ratio of 40% by mass. The foci of the study were to confirm the recyclability for cement production and to evaluate the applicability of the recyclable pavement concrete. Portland cement was made with the fly ash concrete to examine fundamental properties of the cement. Physical and chemical properties of the recycled cement were tested and compared to the properties of ordinary Portland cement defined in Japanese standards. The fundamental tests confirmed that the physical and chemical properties of the recycled cement meet the requirements of Portland cement. It is concluded that the recyclable fly ash concrete pavement having high early strength is a preferred material in terms of sustainability.

*Keywords*: Recycled cement, Recyclable concrete, Byproduct, Cementitious materials.

## 1 INTRODUCTION

In Japan, the electric power supply from the thermal plants has significantly increased after the Fukushima earthquake disaster. Fly ash, the most common byproduct in coal-thermal plants, has increased along with the increase of power supply. This byproduct should be reused to mitigate environmental impacts. Of interest is that the fly ash is an alternative cementitious material for cement concrete. It should be noted that the replacement by fly ash must decrease alkali content in cement concrete. Pavement material is a typical application for concrete incorporating fly ash because few pavements use reinforcing bars. In addition, recycling of the concrete must be relatively easy after the service life of the pavement material. Yoshitake *et al.* (2013, 2014) prepared a high-volume fly ash (HVFA) concrete with limestone aggregate, and reported that the hardened concrete had a recyclable chemical composition.

Based on the previous investigations, the authors have developed a fly ash concrete pavement recyclable for cement production. The recyclable concrete incorporates fly ash of 40% by mass of cementitious materials. This study confirmed the recyclability for cement production and evaluated the applicability of recyclable pavement concrete. Portland cement was made with the fly ash concrete to examine fundamental properties of the cement. Physical and chemical properties of the recycled cement were tested and compared to the properties of ordinary Portland cement made to Japanese standards. The paper reports the properties of recycled cement and discusses the applicability for raw material of Portland cement.

## 2 RECYCLABLE CONCRETE PAVEMENT

### 2.1 Fly Ash

Type II fly ash (as defined in JIS A 6201, 2008) was used and is the most common byproduct of coal-burning power plants. Type II fly ash has similar properties to class F fly ash, as used in ASTM standard C618.

### 2.2 Portland Cement

The largest concern of the pavement concrete incorporating fly ash is low strength development at early age. Concrete pavement of high early strength is preferable to create passable roads as soon as possible. To improve early strength development, ordinary Portland cement (as defined in JIS R 5210, 2009) was used in this study whereas blast furnace slag cement (JIS R 5211, 2009) is often used in most concrete pavements in Japan.

### 2.3 Limestone Aggregate and Filler

Limestone sand (< 5 mm, 2.62 g/cm$^3$) and crushed limestone aggregate (5–20 mm, 2.68 g/cm3) were used to ensure cement production recyclability. Limestone aggregate was obtained from a mine in Mine-city (Yamaguchi, Japan). In addition, limestone powder was additionally incorporated into the concrete to improve strength development at an early age.

### 2.4 Mixture Proportion

Table 1 gives a mixture proportion of the recyclable concrete pavement. The concrete mixture proportion was designed to achieve a specified flexural strength (4.5MPa) at the age of 7 days. The concrete was made with a water-cementitious material ratio (***w/cm***) of 0.33, and indicated extremely low consistency such as the slump value of 20 mm in average. Referring to a previous report (Kumar *et al*., 2007), the ratio of cement replacement by fly ash (***FA/cm***) was designed as 0.40 to achieve strength development at an early age.

### 2.5 Flexural Strength

Figure 1 (a) and (b) shows the flexural strength development at early ages and high later age, respectively. Concrete pavement is passable for traffic when the flexural strength is equal to or higher than 3.5 MPa (JCA 2010). Figure 1(a) shows that the fly ash concrete achieved the required strength after 2 days. For comparison, the graph shows a previous test result of a pavement concrete made with a cement-replacement of 0.4

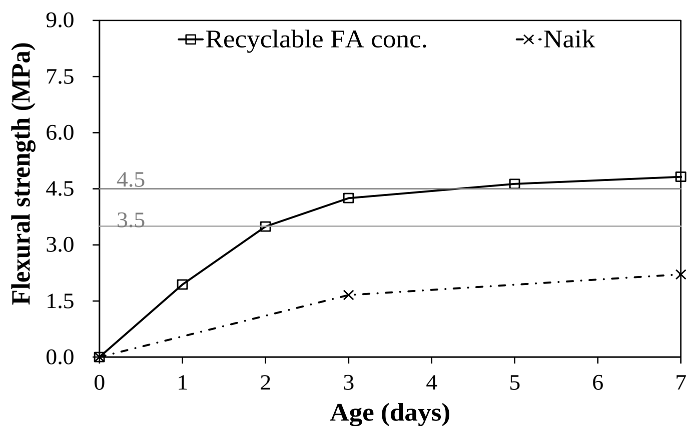
(Naik *et al*. 1995). The test result verified the effect of limestone powder (i.e., the micro-filler effect) and the acceleration of the reaction at an early age.

Table 1. Mixture proportion of the recyclable concrete (unit: $kg/m^3$).

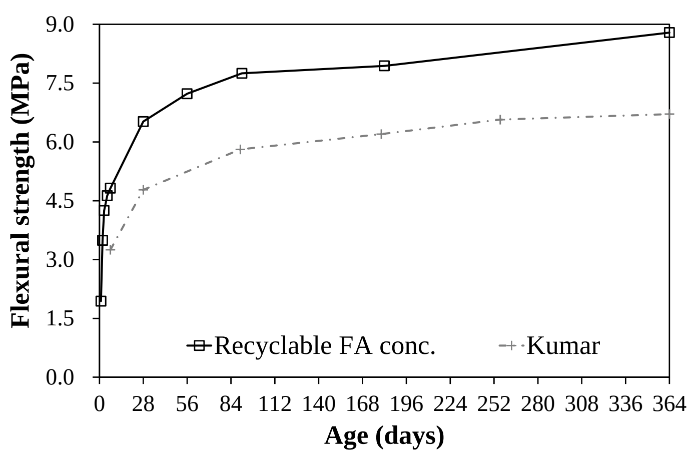
| Water | Cement | Fly ash | LP[a] | Sand | Gravel | HRWRA[b] | AEA[c] |
|---|---|---|---|---|---|---|---|
| 110 | 200 | 134 | 50 | 820 | 1033 | 4.01 | 1.20 |

a: Limestone powder; b:high range water-reducing agent; c: air-entraining agent.

A previous test result (Kumar *et al*. 2007) is shown on Fig.1(b) for comparison. The referred strength data were recorded in a test on pavement concretes incorporating class-F fly ash (***FA/cm*** = 0.4, ***w/cm*** = 0.34). The concrete tested in this investigation had higher strength than the referred strength data. The difference in strength development was probably due to the different aggregate and water content of the concrete mixtures.




(a) Early age.




(b) High later age.

Figure 1. Flexural strength development.

## 3 RECYCLED CEMENT

### 3.1 Chemical Components of the Recyclable Concrete Pavement

This study examined properties of the recycled cement to confirm the recyclability of the pavement concrete. For this purpose, a Portland cement (recycled) was made from test specimens of the fly ash concrete. The tested concrete was a raw material for manufacturing cement as an alternative material of limestone. The study examined chemical and physical properties of the recycled cement.

The hardened concrete was dried in an oven (105°C) for 24 hours and crushed using a ball mill. Chemical compositions of the concrete were examined employing a Japanese standard test (JIS R 5202, 2010) and X-ray fluorescence analysis. The chemical compositions are summarized in Table 2.

Table 2. Chemical compositions of the recyclable fly ash concrete (%).

| ig.loss | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | others |
|---|---|---|---|---|---|---|---|
| 39.43 | 3.25 | 1.05 | 0.55 | 50.28 | 0.47 | 0.20 | 4.77 |

### 3.2 Recycled Cement Clinker

The cement clinker was made with an electric furnace. The temperature of the furnace increased from 1000°C to 1200°C over 20 minutes and from 1200°C to 1450°C over 10 minutes. The temperature was maintained at 1450°C for 30 minutes and then reduced to 1350°C. Afterward, the clinker was removed from the furnace and quenched to a room temperature of 20°C. The chemical properties of the cement clinker were examined using the test method in JIS R5202 (2010). The mineralogical compositions were estimated using the Bogue formulae (1929), as summarized in Table 3.

Table 3. Mineralogical compositions of the recycled clinker and cement (%).

| | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ |
|---|---|---|---|---|
| Clinker | 55.1 | 23.1 | 9.4 | 9.0 |
| Cement | 52.9 | 21.6 | 8.7 | 8.9 |

### 3.3 Properties of the Recycled Cement

The cement clinker and gypsum were mixed and ground in a ball mill to produce the recycled cement. The chemical compositions of the recycled cement were examined employing a Japanese standard test (JIS R5202, 2010) and X-ray fluorescence analysis. Based on the chemical tests, the mineralogical compositions of the recycled cement were calculated using the Bogue formulae. The mineralogical and chemical compositions of the recycled-cement clinker are summarized in Tables 3 and 4, respectively. It was confirmed that the chemical compositions satisfied the requirements of Portland cement defined in JIS R5210 (2010).

Table 4. Chemical compositions of the recycled cement.

| | Recycled cement | JIS R 5210 | | Recycled cement | JIS R 5210 |
|---|---|---|---|---|---|
| ig.loss | 1.21 % | < 5.0 % | $Na_2O$ | 0.31 % | N/A |
| $SiO_2$ | 21.45 % | N/A | $K_2O$ | 0.52 % | N/A |
| $Al_2O_3$ | 5.16 % | N/A | $R_2O$ | 0.65 % | < 0.75 % |
| $Fe_2O_3$ | 2.93 % | N/A | $TiO_2$ | 0.27 % | N/A |
| CaO | 64.41 % | N/A | MnO | 0.05 % | N/A |
| MgO | 0.79 % | < 5.0 % | $P_2O_5$ | 0.15 % | N/A |
| $SO_3$ | 2.57 % | < 3.5 % | Cl | 0.00 % | < 0.0035 % |

Table 5. Physical properties of the recycled cement.

| | Recycled cement | JIS R 5210 |
|---|---|---|
| Density | 3.12 g/cm$^3$ | N/A |
| Blaine fineness | 3320 cm$^2$/g | > 2500 cm$^2$/g |
| Setting time start-end | 1h. 53m. – 2h. 53m. | 60m. – 10h. |
| Soundness | Good | Good |
| Comp. strength at 3 days | 32.5 MPa | > 12.5 MPa |
| at 7 days | 47.5 MPa | > 22.5 MPa |
| at 28 days | 61.5 MPa | > 42.5 MPa |

Physical properties given in JIS R5201 (1997) were also examined. Table 5 presents the test results of the recycled cement. The strengths of the cement were higher than the minimum strength given in JIS R5210 (2010). It was also confirmed that the physical properties of the recycled cement meet the requirements of Portland cement defined in JIS R5210 (2010).

## 4 CONCLUSIONS

This study confirmed the recyclability for cement production and evaluated the applicability of the recyclable pavement concrete made with limestone aggregate and high volume fly ash. The conclusions of this investigation:

(1) The recyclable fly ash concrete achieved the minimum strength (3.5 MPa) for passable pavement at an age of 2 days, and the specified strength (4.5 MPa) of most concrete pavement at an age of 7 days. Furthermore, the matured fly ash concrete achieved a very high flexural strength (8.8 MPa).

(2) Recycled Portland cement was made from test specimens of the fly ash concrete. The fundamental tests confirmed that the physical and chemical properties of the recycled cement meet the requirements of Portland cement defined in Japanese Industrial Standard (JIS R5210).

(3) It is concluded that the recyclable fly ash concrete pavement having high early strength is a preferred material in terms of sustainability.

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## References

Bogue, R.H., Calculation of the compounds in Portland cement, *Industrial and Engineering Chemistry*, ACS publications, 1, 192-197, 1929.

Japan Cement Association (JCA), Research on concrete pavement that allows early opening to traffic, *Report of the Committee on Pavement*, R-27, 2, 2010. (in Japanese).

Japan Industrial Standard (JIS), Physical testing methods for cement, JIS R5201, 1997. (in Japanese).

Japan Industrial Standard (JIS), Fly ash for concrete, JIS A6201, 2008. (in Japanese).

Japan Industrial Standard (JIS), Portland cement, JIS R5210, 2009. (in Japanese).

Japan Industrial Standard (JIS), Portland blast-furnace slag cement, JIS R5211, 2009. (in Japanese).

Japan Industrial Standard (JIS), Methods for chemical analysis of cements, JIS R5202, 2010. (in Japanese).

Kumar, B., Tike, G. K., and Nanda, P. K., Evaluation of properties of high-volume fly-ash concrete for pavements, *Journal of Materials in Civil Engineering*, ASCE, 19(10), 906-911, Oct. 2007.

Naik, T. R., Ramme, B. W., and Tews, J. H., Pavement construction with high-volume class C and class F fly ash concrete, *ACI Materials Journal*, ACI, 92(2), 200-210, Mar.-Apr. 1995.

Yoshitake, I., Komure, H., Nassif, A. Y., and Fukumoto, S., Tensile properties of high volume fly-ash (HVFA) concrete with limestone aggregate, *Construction and Building Materials*, Elsevier, 49, 101-109, Dec. 2013.

Yoshitake, I., Wong, H., Ishida, T., and Nassif, A. Y., Thermal stress of high volume fly-ash (HVFA) concrete made with limestone aggregate, *Construction and Building Materials*, Elsevier, 71, 216-225, Nov. 2014.