*- Technical Report -*

# PERCEPTION OF FLY ASH USAGE IN MONGOLIAN CONCRETE INDUSTRY

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ABSTRACT
Mongolia has not established a way to utilize fly ash, which is a by-product of burning coal. Consequently, a considerable amount of fly ash is dumped in fly ash disposal ponds in the outer suburbs of Ulaanbaatar. The purpose of this report is to investigate the current situation regarding the use of fly ash concrete in Mongolian concrete companies, and find the major obstacles for promoting fly ash concrete in Mongolia. Additionally, compressive strength tests of concrete made with different types of fly ash and cement were conducted to confirm the rationality of companies' opinions.
Keywords: fly ash concrete, compressive strength, chemical composition, Mongolia

## 1. INTRODUCTION

Mongolia relies on coal fired power generation due to its rich coal reserves. Currently, over 90% of primary energy in Ulaanbaatar city is supplied by coal fired power generation [1].

However, Mongolia has not established a way to utilize fly ash, which is a by-product of burning coal. Consequently, a considerable amount of fly ash is dumped in the fly ash disposal ponds in the outer suburbs of Ulaanbaatar as shown in Pic. 1. The dumped fly ash flies on the windy days and worsen the air condition in Ulaanbaatar. The concentrations of PM2.5 and PM10 are 68$\mu g/m^3$ and 148 $\mu g/m^3$, whereas the guideline of WHO is 10 $\mu g/m^3$ and 20 $\mu g/m^3$, respectively [2]. This current condition can cause health problems to the citizens in Ulaanbaatar city [3].

One of the countermeasures to utilize fly ash is promoting fly ash concrete. Although a little stock of fly ash is used in the construction industry, academic studies on the use of fly ash concrete in Ulaanbaatar city and properties of Mongolian fly ash are still limited. In addition, the physical and chemical properties of fly ash are generally inconsistent due to the inconsistency of original coal. This has resulted in burden to the concrete engineers, when they design mix proportions, because of the large discrepancy between assumed and practical strengths.

One of the characteristics of Mongolian fly ash is the high content of calcium. Previous researches reported that Mongolian fly ash is usually classified as Class C fly ash due to their high CaO content [4, 5]. Additionally, the authors have revealed that the compressive strength of concrete incorporated with Mongolian fly ash collected on the different dates and from different coalfields varies one ash to another [5]. Therefore, it is still a great challenge to ensure the strength performance of fly ash concrete in Mongolia.

The purpose of this report is to summarize the use of fly ash concrete in the Mongolian concrete companies. Based on the results of interviews, the major obstacles for promoting the fly ash concrete are discussed in this paper. Moreover, the additional experiments with different types of fly ash and cement were conducted to confirm the rationality of opinions.

The following benefits are expected from this report, 1) safer use of fly ash concrete, 2) enhancing the utilization of fly ash concrete, 3) reducing air pollution in Ulaanbaatar, and 4) mitigating burden of concrete engineers.

(a) Dumped fly ash (b) Flying fly ash (c) Drainage pipe (d) View of city center

Pic. 1 Fly ash in disposal pond

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Table 1. List of respondents and their experiences on fly ash concrete

| Respondents | Date of interview | Experiences on fly ash concrete |
|---|---|---|
| A | June 10th, 2015 | Currently using fly ash |
| B | June 12th, 2015 | Previously used fly ash, but no longer |
| C | June 12th, 2015 | Previously used fly ash, but no longer |
| D | June 12th, 2015 | None |

## 2. INTERVIEWS WITH CONCRETE COMPANIES IN MONGOLIA

### 2.1 Outline of Interviews

The list of respondents is given in Table 1. All respondents are working as technical managers who are familiar with fly ash concrete in each company. The number of total respondents is four. Three of them have experiences of using fly ash concrete, whereas one has never used it. All of them work in small and medium-sized enterprises.

The interview was progressed by semi-structured system. The whole interview was translated by a translator on the site, and supplemental questions were given by the authors during the interview.

The contents of the questionnaire were determined by referring to the previous research [6]. The main concerns of the interviews are summarized as follows: 1) procurement of fly ash, 2) information regarding properties of fly ash, 3) mix design of fly ash concrete, 4) performance of fly ash concrete, and 5) discrepancy of cement properties.

### 2.2 Results of Interviews

#### 2.2.1 Procurement of fly ash

The common answers regarding procurement of fly ash were obtained from all companies. In Mongolia, the fly ash users purchase and transport fly ash from the power plant directly. The reservation to the power plant is required when they would like to procure the fly ash.

#### 2.2.2 Information regarding properties of fly ash

When the power plant supplies the fly ash to the concrete companies, it does not provide the physical and chemical properties of fly ash. Additionally, classification is not carried out in Mongolian power plants.

Therefore, Company A conducts the experiments by itself. Additionally, Company B has avoided reporting to customers that it uses fly ash in concrete due to low reliability of the quality of fly ash concrete.

#### 2.2.3 Mix design of fly ash concrete

Concept of mix proportioning for fly ash concrete is different in each company. Company A changes the fly ash replacement rate depending on the season, thirty percent in summer and ten percent in winter. However, Company A determined these replacement rates based on the ‘intuition’, which can originate problems for the performance. Company B replaces five to ten percent of cement by fly ash. Company B preferred Russian literature to decide the fly ash replacement rate. Additionally, Company B paid attention to the water-binder ratio when the fly ash is incorporated with Chinese cement since Company B is worried about the fluctuation of quality of Chinese cement based on its previous experiences. Company C supplied the fly ash concrete only in summer due to its lower early age strength.

#### 2.2.4 Performance of fly ash concrete

A huge gap of strength performances between companies regarding fly ash concrete was confirmed in the interviews. Company A mentioned that the fly ash concrete did not satisfy the aimed value of the compressive strength on the 28th day, whereas it gave sufficient compressive strength on the 3rd and 7th day.

Company B reported that the compressive strength on the 28th day exceeded the target value, in contrast the 3rd and 7th day strength were below than the designed one. Company C stated that the compressive strengths were almost same between ordinary concrete and fly ash concrete.

#### 2.2.5 Discrepancy of cement properties

Company D mentioned that the quality of Mongolian cement is not good enough. This is the biggest reason that Company D does not promote fly ash concrete so far.

Additionally, Company B and C reported that they had experienced rapid hardening of concrete with some cement, which prevented them from casting concrete into molds at the construction sites.

### 2.3 Summary of Interview

According to the survey, the following challenges to popularize the fly ash concrete in Mongolia were confirmed.

1) The lack of information about the quality of fly ash
2) Variation regarding the quality of fly ash and cement
3) Large discrepancy of the strength of fly ash concrete
4) Inexistence of a guidebook about fly ash concrete

The above observations have proved the necessity of accumulation of data about fly ash in Mongolia, and establishment a way to predict the strength and workability with high accuracy.

## 3. EXPERIMENTAL PLAN

In this section, the authors attempt to confirm the claims by concrete companies, especially about strength performances. For this purpose we made concrete specimens using Mongolian fly ash and other materials available in the market. All experiments were carried out in a laboratory in Ulaanbaatar city.

### 3.1 Materials

#### 3.1.1 Cement

In this report, four kinds of cement were used; three from China and one from Mongolia, which are generally available in Mongolian market (hereinafter

Table 2. Chemical, mineral, and physical properties of cements

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | Specific Gravity |
|---|---|---|---|---|---|---|---|---|---|
| CEM1 | 16.5 | 7.59 | 2.31 | 54.3 | 41.7 | 15.8 | 16.2 | 7.03 | 3.00 |
| CEM2 | 17.7 | 11.3 | 2.68 | 54.5 | 7.28 | 45.2 | 25.5 | 8.16 | 3.07 |
| CEM3 | 17.5 | 7.22 | 2.22 | 59.7 | 58.3 | 6.17 | 15.4 | 6.76 | 3.01 |
| CEM4 | 16.7 | 5.72 | 3.40 | 55.6 | 56.0 | 5.64 | 9.41 | 10.3 | 2.98 |

Table 3. Properties of fly ashes

| Name | Source of Coal | Collected Date | Power Plant |
|---|---|---|---|
| MNG1 | Shivee-ovoo | August 6th, 2014 | Ulaanbaatar, Mongolia |
| MNG2 | Baganuur | | |
| MNG3 | Shivee-ovoo | September 10th, 2014 | |
| MNG4 | Baganuur | | |
| JPN | — | — | Japan |

Table 4. Chemical composition of fly ashes

| Ash | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $SO_3$ | MgO | ig.loss | Specific Gravity | Surface Area [$cm^2/cm^3$] |
|---|---|---|---|---|---|---|---|---|---|
| MNG1 | 43.4 | 12.4 | 7.1 | 23.8 | 4.2 | 4.6 | 0.8 | 2.46 | 15409 |
| MNG2 | 47.2 | 14.2 | 12.0 | 18.6 | 1.2 | 2.2 | 1.5 | 2.49 | 26096 |
| MNG3 | 47.5 | 13.0 | 10.8 | 17.4 | 2.3 | 2.8 | 3.1 | 2.38 | 22298 |
| MNG4 | 49.4 | 13.0 | 11.0 | 16.4 | 1.6 | 1.9 | 3.6 | 2.36 | 20242 |
| JPN | 46.3 | 29.2 | 7.1 | 5.0 | 0.5 | 0.8 | 5.7 | 2.26 | 15158 |

Table 5. Properties of sand, gravel, and superplasticizer

| Materials | Source | Property |
|---|---|---|
| Sand | Bayan Sumber Bogd (Mongolia) | specific gravity 2.60 |
| | | fineness modulus 3.10 |
| Gravel | Bayan Tortsog Khairhan (Mongolia) | specific gravity 2.65 |
| | | fineness modulus 6.01 |
| Superplasticizer | Polycarboxylic Acid | — |

referred to as CEM1, CEM2, CEM3, and CEM4, respectively). The chemical composition and the mineral component of each cement calculated by Bogue equation are given in Table 2 [7].

The chemical analyses for $SiO_2$, $Al_2O_3$, and CaO were carried out in confirmatory to JIS R 5202. $Fe_2O_3$ was obtained based on JIS K 0102 method.

### 3.1.2 Fly ash

Fly ashes were collected from the power plant in Ulaanbaatar city by the authors. As shown in Table 3, the source of coal was different; two of them were from Shivee Ovoo coalfield and other two were from Baganuur coalfield.

For comparison, one Japanese fly ash was included in this test series (hereinafter referred to as MNG1, MNG2, MNG3, MNG4, and JPN, respectively).

In Table 4, the chemical composition, specific gravity, and surface area of each fly ash are tabulated. The all Mongolian fly ashes were classified as Class C fly ash due to their high CaO contents in contrast to Japanese one. The chemical compositions of fly ash were measured by the X-ray fluorescence spectrometers. The specific gravity was measured in conformity to JIS A 6201. The surface areas were calculated from the result of mean diameter gauged by the laser diffraction and scattering method analyzer.

### 3.1.3 Sand, gravel, and superplasticizer

The sand was sieved through 5mm mesh. The gravel was 20mm in maximum size. The polycarboxylate ether based high range water reducing admixture was used to achieve the appropriate workability for the concrete mixtures.

The properties of sand, gravel, and superplasticizer are tabulated in Table 5.

## 3.2 Mix Proportion

Table 6 and Table 7 show the mix proportions of MNG1 and MNG2 cases and MNG3, MNG 4 and JPN cases, respectively. In this research, not only the influences of chemical properties of fly ash but also influences of replacement rate of fly ash for compressive strength were considered. The maximum replacement rate of fly ash was 40%. The water-binder ratio for mix proportions with MNG3, MNG4, and JPN ashes were reduced to 44%, because the segregation happened when those were mixed as 46% in water-binder ratio. The superplasticizer was adjusted to obtain aimed slump (200 ± 20 mm).

Table 8 shows the mix proportions to confirm the influence of cement properties on the compressive strength. JPN ash was used as a standard fly ash. The maximum replacement rate was 20%. A description to the mix nomenclature is given below the Table 8.

Table 6. Mix proportion of concrete incorporated with MNG1 and MNG2

| W/B [%] | FA/(OPC+FA) [%] | Air Content [%] | Unit Weight [kg/m$^3$] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | W | OPC | S | G | FA | Ad |
| 46 | 0 | 5.0 | 165.1 | 358.2 | 1006.9 | 884.9 | 0 | 5.0 |
| | 10 | | 163.9 | 320.1 | 999.6 | 878.5 | 35.6 | 5.0 |
| | 20 | | 162.7 | 282.5 | 992.4 | 872.2 | 70.6 | 4.9 |
| | 30 | | 161.5 | 245.4 | 985.4 | 866.0 | 105.2 | 4.9 |
| | 40 | | 160.4 | 208.8 | 978.4 | 859.9 | 139.2 | 4.9 |

Table 7. Mix Proportion of Concrete Incorporated with MNG3, MNG4 and JPN

| W/B [%] | FA/(OPC+FA) [%] | Air Content [%] | Unit Weight [kg/m$^3$] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | W | OPC | S | G | FA | Ad |
| 44 | 0 | 5.0 | 157.7 | 361.4 | 1015.9 | 892.8 | 0 | 6.5 |
| | 10 | | 157.6 | 322.5 | 1007.1 | 885.1 | 35.8 | 5.0 |
| | 20 | | 156.5 | 284.6 | 999.8 | 878.7 | 71.1 | 5.0 |
| | 30 | | 155.4 | 247.2 | 992.6 | 872.4 | 105.9 | 4.9 |
| | 40 | | 154.3 | 210.4 | 985.5 | 866.1 | 140.2 | 4.9 |

Table 8. Mix proportion of concrete for different kinds of cement

| W/B [%] | FA/(OPC+FA) [%] | Air Content [%] | Unit Weight [kg/m$^3$] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | W | OPC | S | G | FA | Ad |
| 44 | 0 | 5.0 | 157.7 | 361.4 | 1015.9 | 892.8 | 0 | 6.5 |
| | 10 | | 157.6 | 322.5 | 1007.1 | 885.1 | 35.8 | 5.0 |
| | 20 | | 156.5 | 284.6 | 999.8 | 878.7 | 71.1 | 5.0 |

CEM1 - MNG1 - 10

Fly ash replacement rate

Kind of fly ash

Kind of cement

### 3.3 Specimen, Curing Condition, and Strength Test

One axis horizontal mixer was used to mix concrete. The size of the molds was $\phi$10×20cm. After mixing concrete, the slump test and air content test were carried out in conformity to JIS A 1101 and JIS A 1128. The specimens were demolded after two days from the casting and cured in water at 20±2°C. All specimens were cured in water until the day of compressive strength tests. The compressive strength tests were carried out on the 3rd, 7th, 28th and 91st days.

## 4. EXPERIMENTAL RESULTS

### 4.1 Effect of Difference of Fly Ash on Compressive Strength

Fig. 1 illustrates the difference of compressive strength by the fly ash replacement rate. Fig. 1 shows that the fly ash concrete with MNG1 and JPN has high compressive strength from early age. In the case of 10% and 20% replacement rates, the compressive strength exceeds that of concrete without fly ash even at the early ages of the 3rd day. Finally, all mix proportions incorporated with fly ash surpassed the concrete without fly ash from the 28th day.

In contrast to that, the compressive strengths of concrete incorporated with MNG2, MNG3, and MNG4 are relatively low. It can be assumed that this is due to the discrepancy in chemical composition of fly ash. However, MNG2 and JPN cases show the typical strength enhancements due to the pozzolanic reaction of fly ash in late ages. However, the high replacement rates such as 40% can give only about 70% of compressive strength of concrete without fly ash even on the 91st day in Fig. 1(b), (c), and (d).

The above observations show that the compressive strength development differs from one ash to another.

### 4.2 Effect of Difference of Cement on Compressive Strength

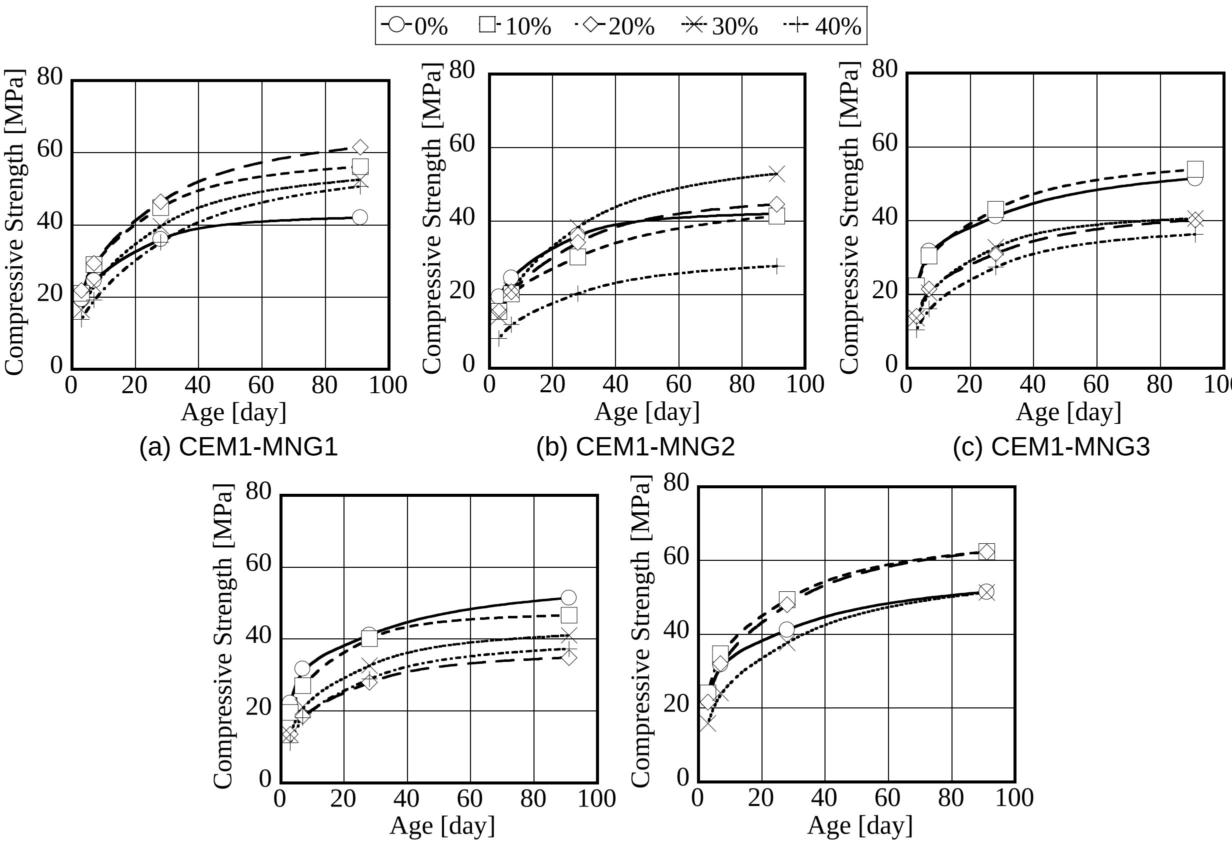
Fig. 2 illustrates the results of a compressive strength test. Although all specimens were mixed in the same mix proportion and incorporated with the same kind of fly ash, large differences can be confirmed in Fig. 2.

Fig. 3 shows the comparison of the compressive strength on the 28th day. Fig. 3(a) gives the compressive strength of concrete without fly ash. The compressive strength varies depending on the type of cement. CEM3 gives the highest strength, and CEM1 shows the lowest strength among four cements.

Fig. 3(b) shows the compressive strength in 10% of fly ash replacement rate case. In contrast to Fig. 3(a), CEM1 gives the highest strength of the all. The compressive strength in CEM4 case is reduced greatly by being incorporated with JPN ash.

Fig. 3(c), illustrates the compressive strength in 20% of fly ash replacement rate. Although CEM3 gives the highest compressive strength, a large gap cannot be found in Fig. 3(c).

The following reasons can be stated as the influential factors.




(a) CEM1-MNG1 (b) CEM1-MNG2 (c) CEM1-MNG3

(d) CEM1-MNG4 (e) CEM1-JPN

Fig. 1 Compressive strength development

1) Difference in chemical composition of cement
2) Affinity between cement and fly ash

## 5. CONCLUSION

This report investigated the practical use of fly ash in concrete companies in Mongolia. In addition, the compressive strength tests on the concrete incorporated with different types of fly ash were conducted. The obtained findings are summarized as follows.

1) There are no specific guidelines for the mix design of fly ash concrete in Mongolia, which can lead the concrete engineers to determine the mix proportion based on the empirical experiences.
2) A large discrepancy regarding the quality of fly ash and cement was reported by the concrete companies in Mongolia. This unpredictable variance makes the engineers stop to promote fly ash concrete.
3) The chemical compositions of collected fly ash from the coal power plant in Ulaanbaatar city vary significantly from one to another even within the same coalfield.
4) It can also be assumed that the difference in chemical composition of cement provides the gap in the compressive strength of the fly ash concrete.

Our experiments proved that rationality of dissatisfaction of concrete companies in using fly ash in concrete. However, further experiments and investigations are required to establish more informative database regarding the properties of fly ash and cement, which enables concrete engineers to grasp the limits of strength variation of fly ash concrete. Additionally, a practical prediction model should be proposed based on the accumulated database to promote fly ash concrete in the Mongolian concrete industry.

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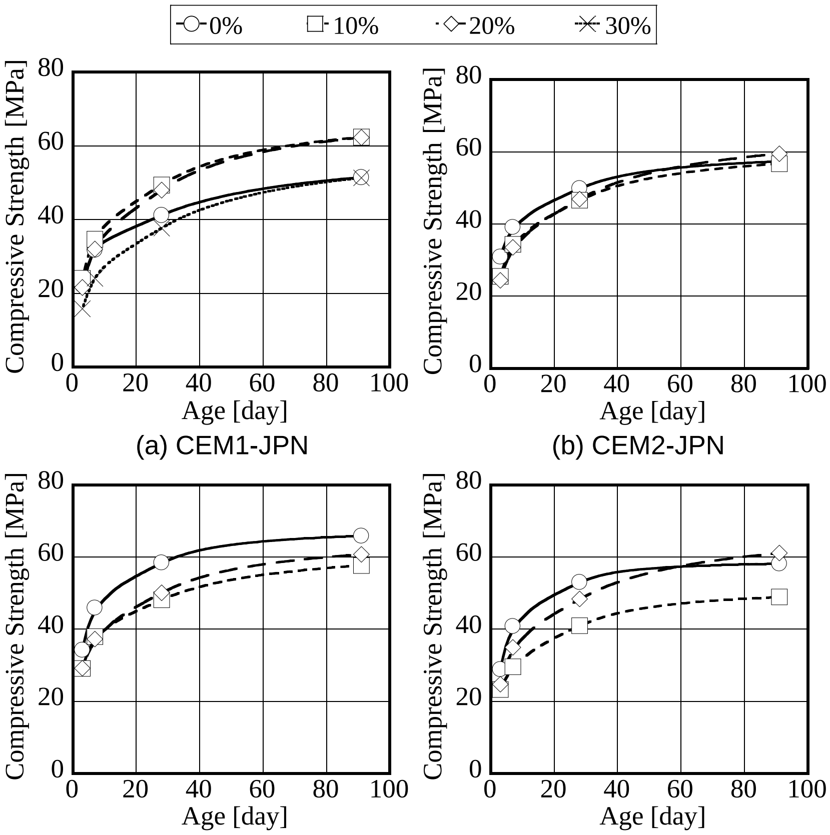
## REFERENCES

[1] Japan Coal Energy Center. "*Mongolian Coal Usage*". 31 December 2016 (in Japanese) <http://www.jcoal.or.jp/coaldb/country/10/post_49.html>

[2] World Health Organization. "Ambient (Outdoor) air pollution database, by country and city". *Outdoor Air Pollution in the World Cities*. 31 December 2016 <http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/>

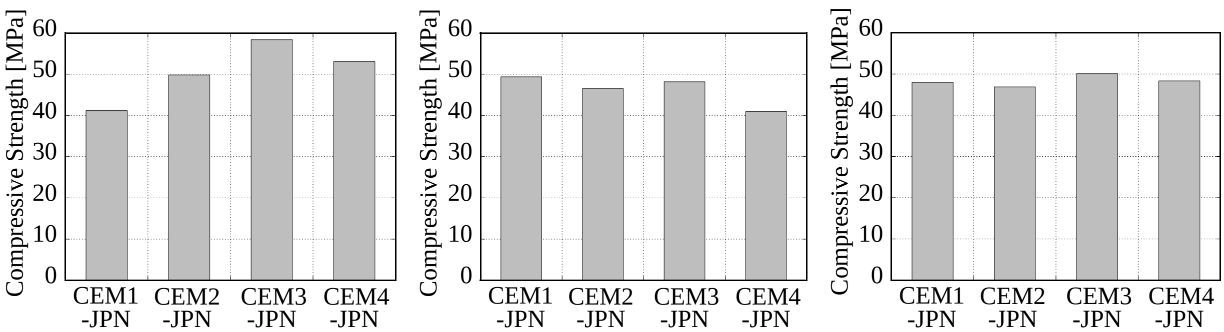
[3] Gerelmaa Gunchin, Lodoysamba Sereeter, Shagjjamba Dagva, and Amartavan Tsenddavaa. "Air Particle Matter Pollution in Ulaanbaatar City, Mongolia" *International Journal of PIXE*. 22. 165-171. 2012.9




(a) CEM1-JPN (b) CEM2-JPN

(c) CEM3-JPN (d) CEM4-JPN

Fig. 2 Compressive strength development




(a) FA/(OPC+FA)=0% (b) FA/(OPC+FA)=10% (c) FA/(OPC+FA)=20%

Fig. 3 Comparison of compressive strength on the 28th day among four different cements


[4] Batmunkh, N. and Ishida, T. and Nikraz, H. "Performance Evaluation of Coal Ash Concrete as Building Materials in Mongolia", *2009 World of Coal Ash (WOCA) Conference*, 1-17, 2009

[5] Hiroo Kashima, Atsushi Suzuki, and Dinil Pushpalal. "Study on Strength Properties of Concrete Using High Calcium Mongolia Fly Ash". *Proceedings of the Japan Concrete Institute*. 121-126. 2015 (in Japanese)

[6] Takeshi Narita, Kenji Funamoto, Kiyoshi Ogawa, Yasuhiro Honda, Shinji Takada, and Hideo Kasami. "Investigation of Uses of Ready Mixed Concrete Using Fly Ash", *AIJ Journal of Technology and Design*, Vol. 23, 1-4, 2006.6 (in Japanese)

[7] A. M. Neville, *Properties of Concrete 5th Edition*, Trans-Atlantic Publications. 8, 2011