Evaluation of Mechanical Hardened Properties of Mortar Using Carbon-Free Fly Ash and Normal Fly Ash

Ghawsaddin Nazari¹, Sato Takayuki and Shigeyuki Date³
¹4-1-1 Kitakananme, Hiratsuka, Kanagawa, Japan
²1-1-10 Itsutsubashi Aobaku, Sendai, Miyagi, Japan
³4-1-1 Kitakananme, Hiratsuka, Kanagawa, Japan

¹ Ghm255.b@gmail.com

Abstract. Usage of mineral admixture and chemical admixture in concrete or mortar is a usual solution to reach full compaction, particularly where reinforcement blockage and lack of skilled labour happen. In this paper effect of mineral admixtures (Carbon-free fly ash, hereafter CfFA, and nFA) on hardened properties of mortar such as compressive strength, pore size distribution and, and micro structures have been investigated. As a result, it has been confirmed that mortar containing 15% CfFA slightly increased the compressive strength under water curing condition compared to those containing 15% normal fly ash. In addition, the pore-size distribution of the mortar has been affected by variation of materials and curing condition. Mortar containing 30% CfFA had a smaller threshold diameter in comparison to that of 30% FA; however, there is no significance differences in mortar containing 15% CfFA and FA. Furthermore, CfFA-based mortar increased the amount of entrained air compared to the mortar with normal fly ash.

1. Introduction
Concrete is the most widely used construction material in the modern world. Its huge popularity is due to the result of many advantages: such as low cost, general availability, and wide applicability. However, it has a notable climate impact due to the large volumes and the energy intense production of cement clinker which has a GHG emission between 5 and 8% of the world’s total. [1, 2]. On the other hand, usage of mineral admixture as partial replacement of cement such as silica fume, fly ash (FA), bottom ash (BA), ground granulated blast furnace slag (GGBFS) and others have increased. [3-7]. These materials not only lead to reduction CO₂, development of fresh and mechanical harden properties of concrete, but also utilize the industrial by-product which needs more landfill and waste disposal.

Among them, fly ash which is a by-product of the combustion of pulverized coal in electric power generating plants is the most widely used SCM in concrete that is used in more than 50 percent of ready-mixed concrete. Appropriate use of FA prevents expansion due to alkali – silica reaction, reduces heat generation and gives better durability in concrete. [8,9]. However, the presence of carbon influences fresh properties of concrete. The carbon content affects the air entraining agents and diminishes the entrained air for a given amount of air-entraining agent. [10,11]. In addition, High volume fly ash concrete hydrates more slowly than ordinary concrete. [12,13]. This factor, which increases with increasing fly ash replacement dosage, causes problems in concrete construction where rapid stripping and demoulding are essential.


Table 1. Materials used.

| Material       | Description                  | Density (g/cm$^3$) |
|----------------|------------------------------|-------------------|
| OPC            | Ordinary Portland Cement     | 3.16              |
| nFA            | Normal fly ash (grade 2 fly ash) | 2.50            |
| CfFA           | Carbon free fly ash          | 2.20              |
| Fine aggregate | S River sand From Yamakita Kanagawa | 2.69            |
| Superplasticizer(sand) | SP Polycarboxyclic –acid based | -               |
| Air Entraining agent | AEA Polycarboxyclic –acid based | -               |
| Powder         | P OPC+ (CfFA or nFA)         | -                |
| Water          |                              | 1.0              |

Table 2. Mix proportions.

| CfFA & FA replacement (%) | W/P (%) | S/P | SP/P (%) |
|---------------------------|---------|-----|----------|
| CfFA                      | 15      | 30  | 2.0      | 0.8–1.0 |
|                           | 30      |     |          |         |
| nFA                       | 15      | 30  | 1.2–1.3  |         |
|                           | 30      |     |          |         |

Table 3. Chemical composition of CfFA and nFA.

| CFa | nFA | Chemical Composition |
|-----|-----|----------------------|
| 64.6 | 65.5 | Si (SiO2)           |
| 21.7 | 21.5 | Al (Al2O3)          |
| 8.3  | 7.9  | Fe (FeO)            |
| 3.6  | 3.4  | Ti (TiO2)           |

2. Experiment summary

2.1. Materials used and mix proportions of mortar
The materials used in this study are shown in table 1. Referring to table 2, ordinary Portland cement (OPC) was partially replaced with CfFA and normal FA, 15% and 30% respectively. Two type of chemical admixture are used, superplasticizer, PCE based, and air entraining agent. The water-cement ratio was set to 30%, and the sand-binder ratio was set to 2.0. The sand was on saturated surface dry condition from River. Using SP, the flow was adjusted to be within the range of 140±20mm and 200±mm by 15 tamping, and the air content was adjusted to 7%±0.5. The chemical composition of carbon-free fly ash and normal fly ash are also given in table 3.

2.2. Mortar mixing method
The mixing procedure was according to "JIS R 5201" physical testing methods of cement”. The OPC was replaced with CfFA and FA. Initially, cement, sand and carbon free fly ash were mixed on a slow speed of mixer for 30 second, subsequently, water, superplasticizer and air entraining agent were
added and mixed or 60 second on slow speed as well, and finally again mixed for 30 second on fast speed. The same procedure was applied for fly ash.

2.3. Curing method
In this study, two different type of curing have been conducted: water curing and steam curing. In the water curing the specimens were kept under water for 28 days and 20°C. In steam curing, the specimens were kept in the ambient temperature for one hour at 20 °C and then steamed at 45 °C for 6 hours. After the steam curing has been done, again the specimen kept in the ambient temperature for 28 days. The detail of steam curing pattern is shown in figure 1.

2.4. Test items and test method.
2.4.1 Compressive strength. The compressive strength test was conducted in accordance with (JIS A 1108) The specimens (cylinder with 100mm height and 50mm diameter) were demolded 24 hours after casting. Consequently, the specimens with steam-cured were kept in the ambient temperature for 28 days while other specimens were kept under water for this age. After that, they were crashed.
2.4.2 Pore-size distribution using mercury intrusion porosimetry. MIP tests were performed on mortar samples after each curing for 28 days. The equipment used is an Autopore III 9420 from Micromeritics that can generate a maximum pressure of 414 MPa (60000 psi) and can evaluate a theoretical pore diameter of 0.003μm. With this machine, the MIP test is performed in two steps: the low-pressure step first evacuates gases, fills the sample holder with mercury and performs porosimetry from about 7 to 345 kPa; the high-pressure step reaches pressures between 345 kPa and 414 MPa. Low and high-pressure steps were always performed within a period of 8 h. The contact angle and surface tension assumed for all tests were respectively 130° and 485 dyn/cm.
2.4.3 X-Ray CT scanner and CT images. The μ-Focused X-Ray CT scanner is used to observe the microstructure in the specimen. An illustration of inner view and its specifications is shown in figure 2. A flat panel detector (FDP) is applied to perform a three-dimensional scan with an X-Ray Cone beam. Once the specimen was set up on the specimen table, a cone-shaped beam is emitted from the X-Ray tube and the specimen is scanned. During the scanning, only specimen table is rotated so that the X-Ray beam can penetrate from 360 degree. The scan condition in this study: voltage is 195KV, current is 160µA slice pitch 32.13μm and slice thickness is 32.13μm. Therefore, the voxel dimension is (32.13 x 32.13 x 32.13μm).

Figure 2. Schematic of the μ-focus X-Ray system.
As it is shown in figure 3, the specimen has been divided into three parts: center, inside and outside, and the volume of the selected cell was 8x8x8mm. The amount of entrained air has been calculated from center, inside and outside separately.

Figure 4 shows a two-dimensional X-Ray CT image of a specimen with diameter of 50mm. The concrete specimens consist of fine-aggregate, mortar and pore. Those are distinguished in the CT images by differences in the light and shade. The high-density aggregate shows light gray, pores with low density are black, and mortar with medium density show as dark gray.

3. Results and discussion

3.1. Comparison of compressive strength of mortar containing different amount of CfFA and FA.

Figure 5 and figure 6 represent the compressive strength of mortar in which cement has been supplemented by various amount of Carbon-free fly ash and normal fly ash. Considering 15% replacement, it was confirmed that CfFA increased the compressive strength of water-cured mortar after 28 days compared to FA; however, there is no significant change after 7 days. In contrast, under the steam-curing condition, FA 15% showed better compatibility after 28days, and had greater compressive strength than CfFA 15%.

Referring to figure 6, again CfFA 30% increased the compressive strength after 28 days under water-curing condition compared to FA 30%; however, under steam-curing condition no change can be observed. It is mentionable that Fa 30% had higher compressive strength after 7days than CfFA 30%.

Figure 5. Compressive strength of mortar containing 15% CfFA and FA.

Figure 6. Compressive strength of mortar containing 30% CfFA and FA.
3.2. Evaluation of pore-size distribution of mortar containing different amount of CfFA and FA using MIP
In this section, the pore structure of mortar with different mix proportion after 28 days of curing was discussed. Figure 7 explains the cumulative intrusion, reflecting the connected pore volume of pore size larger than specified diameter and figure 8 represents the incremental intrusion at each pore diameter and the reflected pore volume at that as well. As it is seen, the total mercury intrusion and the threshold diameter value are different in each type of mixing. The larger threshold diameter (TD) can be observed in 30% fly ash content mortar, by 0.15µm, as the total mercury intrusion reaches to 0.07 ml/g. in contrast, the TD value has been shifted to 0.09µm in 30% CfFA content mortar; however, total mercury intrusion was slightly changed. In addition, there is no significant change in the amount of total mercury intruded into 15% CfFA and 15% FA; however, the TD is different.

3.3. Evaluation of pore-size distribution of mortar containing different amount of CfFA and FA using X-Ray Ct test
Figure 9 and figure 10 represent both the amount of entrapped air and entrained air in the mortar partially replaced by 15% and 30% CfFA and normal fly ash. Considering the 15% replacement, it has been confirmed that the CfFA not only increased the amount entrained air in the mortar, but also it has the tendency to increase toward the center. In contrast, normal fly ash had a lower value of entrained air and also the value tend to decline toward the center.

Figure 7: Mercury penetration rate vs pore diameter.  
Figure 8: accumulated pore volume vs pore diameter.

Figure 9. Percentage of entrapped and entrained air in mortar containing 15% CfFA and 15% FA.
Figure 10. Percentage of entrapped and entrained air in mortar containing 30% CfFA and 30% FA.

This comparison could be observed in 30% replacement. Referring to the center, the amount of entrained air in CfFA is almost twice as much as in normal fly ash. This difference has slightly been changed in the location of inside of the mortar. In CfFA, entrained air tended to decline toward the edges; however, by the percentage of 3.3%, still CfFA had a greater value of entrained air than normal fly ash. In contrast, in the location of outside, the amount of entrained air is higher in normal fly ash than CfFA.

4. Conclusions

The following conclusions has been derived from the experimental study of effect of carbon-free fly ash and normal fly ash on the harden properties of mortar:

1- CfFA slightly increased the compressive strength of mortar after 28 days of water curing compared to FA; however, there is no significance change after 7 days.
2- CfFA-15% had smaller threshold diameter (TD) compared to FA-15%.
3- The accumulated pore volume in CfFA-30% was lower than FA-30%.
4- The percentage of entrained air is higher in CfFA than FA, both 15% and 30%.

5. References

[1] International Energy Agency, Cement technology roadmap 2009 - Carbon emissions reductions up to 2050, http://www.iea.org/publications/freepublications/publication/Cement.pdf.
[2] Olivier, J.G.J., Janssens-Maenhout, G., Muntean, M., and Peters, J.A.H.W., Trends in global CO2 emissions; 2016 Report, The Hague: PBL Netherlands Environmental Assessment Agency; Ispra: European Commission, Joint Research Centre, 2016.
[3] H.A. Toutanji, Z. Bayasi, Effect of curing procedures on properties of silica fume concrete, Cem. Concr. Res. 29 (1999) 497 – 501.
[4] N. Bouzoubaa, M. Lachemi, Self-compacting concrete incorporating high volumes of class F fly ash preliminary results, Cem. Concr. Res. 31 (2001) 413 – 420
[5] Y.M. Zhang, W. Sun, H.D. Yan, Hydration of high-volume fly ash cement pastes, Cem. Concr. Compos. 22 (2000) 445 – 452.
[6] M. Cheriaf, J.C. Rocha, J. Pera, Pozzolanic properties of pulverized combustion bottom ash, Cem. Concr. Res. 29 (1999) 1387 – 1391.
[7] I. Kula, A. Olgun, Y. Erdogan, V. Sevinc, Effects of colemanite waste, coal bottom ash and fly ash on the properties of cement, Cem. Concr. Res. 31 (2001) 491 – 494.
[8] C.S. Poon, L. Lam, Y.L. Wong, A study on high strength concrete prepared with large volumes of low calcium fly ash, Cem. Concr. Res. 30 (2000) 447 – 455
[9] M.H. Shehata, M.D.A. Thomas, The effect of fly ash composition on the expansion of concrete due to alkali – silica reaction, Cem. Concr. Res. 30 (2000) 1063 – 1072
[10] U.S.dept of Transportation Federal Highway Administration: www.fhwa.dot.gov
[11] ACI material Bulletin E3-01: Cementitious Materials for Concrete.
[12] P. Seabrook, K. Campbell, Levelton Engineering Ltd: Sustainability in Construction: Using Fly Ash as a Cement Replacement. Journal of the Association of Professional engineers and Geoscientist of BC, September 2000

[13] A. Bilodeau, V. M. Malhotra, and P. T. Seabrook, Materials Technology Laboratory: Use of High-Volume Fly Ash Concrete at the Liu Centre. 2001. (Class F fly ash)

Acknowledgement
This research was supported by the Nippon paper corporation and civil and architectural department of the Tokai University.