ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 7, Issue 2, March 2018

# Effects of Curing Conditions on Engineering Properties of Slag-based Eco-Mortar

Yu-Chen Wu, Chiao-Wei Yang, Hoang-Anh Nguyen and Ta-Peng Chang

***Abstract*—The aims of this study are to investigate the effects of four curing conditions on the engineering properties of hardened slag-based mortar which was produced by the mixture of ground granulated blast furnace slag, Type F fly ash, circulating fluidized bed combustion Fly ash, and river sand. Four curing conditions, including three different continuous initial curing periods of 3, 7 and 28 days in a chamber with the constant temperature of 30oC and constant humidity 65 % RH, respectively, then in the air until the testing at 28 days, and the fourth one being a continuous water curing of 30oC until the testing at 28 days, were studied. The results showed that, for the water-to-binder ratio of 0.35, the 28-day compressive strengths of hardened mortar of curing in 30˚C and 65 R.H condition were much higher than those of air curing after initial curing periods of 3 and 7 days and continuous water curing of 30˚C by 12.4%, 8.94% and 8.83%, respectively. It was also noticed that a slightly increase of compressive strength of hardened mortar by a narrow range from 0.34% to 2.3% with water-to-binder ratio of 0.5 being curing for 28 days in the chamber of constant 30˚C and 65 RH as compare with those of other types of curing conditions. The compressive strengths of hardened mortar with lower water-to-binder ratio obviously increase with longer initial curing period in the chamber. On the other hand, the water curing led to a lower compressive strength of hardened mortar probably due to the calcium hydroxides of hydration products being gradually dissolved in water.***

***Index Terms*—Slag-based Eco-Mortar, curing condition, compressive strength**

## I. INTRODUCTION

Currently, the Portland cement concrete is the most important material for the construction of infrastructure and building. However, the environmental issue of production of Portland cement has become a raising impact, as the cement manufacturing is responsible for about 5% of total worldwide carbon dioxide (CO2) emissions [1]. Nowadays, some researches have tried to replace partial Portland cement by the mineral admixtures such as the ground granulated blast furnace slag (GGBFS), Type F fly ash (FFA), and circulating fluidized bed combustion fly ash (CFBC fly ash), etc. to reduce the environmental impact. Rust et al. [2] found that the combinations of the pozzolans, such as GGBFS and FFA, and the other by products materials containing rich sulfur, such as CFBC fly ash, could manufacture the binding systems with major compositions of AFt crystals and C-S-H/C-A-S-H gels. Moreover, the proportions of CFBC fly ash have strong influence on the expansion which may induce micro crack [3]. As the main hydration product in slag-based binder, the formation of Aft, which is sensitive to many factors such as temperature and humidity [4, 5], has large impact on the harden properties, such as compressive strength and expansion of mortar. The study [6] reported that 3-day compressive strengths increased with curing temperature increased from 20˚C to 60˚C, however, the 28-day compressive strength starts to decrease when curing temperature increases up to 90˚C, thereby delaying AFm transforms into AFt, which causes the expansion of mortar. Thus, Zhang et al. [7] also mentioned that the higher curing temperature caused higher compressive strength for cement mortar by adding anhydrous gypsum, however, the curing temperature increased up to 90˚C caused the development of compressive strength to start to decrease. In addition, Changl. [8] showed that when curing humidity was below 100%, adding proper CFBC fly ash could reduce the shrinkage and decrease the possibilities of induced cracks. Besides, the curing humidity lower than 50% showed significant shrinkage.

On the other hand, a ternary mixtures of the ground granulated blast furnace slag (S), Type F fly ash (F) and circulating fluidized bed combustion fly ash (C) has been successfully used as the no-cement slag-based SFC eco-binder for the manufacture of better innovative construction materials such as mortar and concrete, which has a significant advantage of using lower energy consumption and ensuring better environmental preservation such as the reduction of carbon dioxide (CO2) emissions [9]. The aim of this study is to investigate the influence of four curing conditions on the engineering properties of the slag-based SFC eco-binder mortar. The experimental results show that both the initial curing period and the different curing condition affect the compressive strength. Thus, under low water-to binder-ratio the compressive strength could be influence a lot by different curing condition.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 7, Issue 2, March 2018

## II. EXPERIMENTAL METHOD

### *A. Material*

Three industrial solid by-products of Class F fly ash (FFA), ground granulated blast furnace slag (GGBFS) and CFBC fly ash (CFA) were used to produce the slag based eco-binder. The chemical and mineral compositions of three industrial by-products were given in Table 1. To produce the eco-mortars, the natural river sand with fineness modulus (FM) of 3.0 and the specific gravity (SSD) of 2.65 was used. The water absorption of the sand was 0.508 wt%.

**Table 1: Physical and chemical compositions of three industrial solid by-products**

| | GGBFS | CFBC | FFA |
|---|---|---|---|
| Specific gravity | 2.90 | 2.70 | 2.26 |
| Fineness, $cm^2/g$ | 6000 | 3000 | - |
| $SiO_2$,wt.% | 34.86 | 5.22 | 61.1 |
| $Al_2O_3$,wt.% | 13.52 | 2.21 | 18.0 |
| $Fe_2O_3$,wt.% | 0.52 | 0.581 | 6.93 |
| CaO,wt.% | 41.77 | 56.8 | 3.82 |
| MgO,wt.% | 7.18 | 2.06 | 1.33 |
| $SO_3$,wt.% | 1.74 | 32.4 | 0.40 |
| $K_2O$,wt.% | - | - | 1.14 |
| $Na_2O$,wt.% | - | - | 1.14 |
| $TiO_2$,wt.% | - | - | 0.71 |
| L.O.I,wt.% | 4.27 | - | 2.76 |

GGBFS: ground granulated blast furnace slag; FFA: Class F fly ash; CFA: circulating fluidized bed combustion (CFBC) fly ash.

### *B. Mix proportioning and specimens*

Based on the previous study [9] ,the adequate engineering properties of cementitious paste using the ternary mixture of an optimum amount of CFBC fly ash of 15% wt.% to combine with the binary mixture of GGBFS and FFA were verified. Thus, an amount of 15% wt% CFBC fly ash together with a weight ratio of FFA to GGBFS of 20/80 were fixed in this study to make the eco-mortar. In addition, two water to binder ratios of 0.35 and 0.5 were designated. The weight ratio of sand to ternary mixture of GGBFS, FFA and CFBC fly ash was fixed at 2.75. The mix proportions of eco-mortar are described in Table 2. In the table, the characters C, F and S referred to CFBC fly ash, Type F fly ash, and GGBFS, respectively. The numbers following the characters represent the weight percentage of materials used in the slag-based eco-binder. The amount of SP was determined based on the weight percentage of total binder. For example, the mixture designation of 0.35C15S8F2 meant that the W/B ratio of the mix was 0.35 (Water/ (CFBC+FA+GGBFS) = 0.35 wt.%), CFBC fly ash was 15 wt.% (CFBC/(FA+GGBFS) = 15%), and S8F2 was (FA/(GGBFS+FA) = 20%, GGBFS/(GGBFS+FA) = 80%). The cubic specimens with dimensions of 50×50×50 mm were casted for the compressive strength test.

**Table 2: Mix proportions for slag-based eco-mortar (Units: $kg/m^3$)**

| | CFBC | GGBFS | FFA | Water | Sand | SP (wt,%)[a] |
|---|---|---|---|---|---|---|
| 0.35-C15-S8F2 | 74.41 | 396.86 | 99.22 | 207.64 | 1568.8 | 0.11 |
| 0.50-C15-S8F2 | 68.55 | 365.58 | 91.39 | 270.10 | 1445.2 | 0.1 |

[a] Weight percent of powder of GGBFS+FFA+CFBC.

### *C. Four curing conditions and test method*

In this study, four curing conditions for making the eco-mortar as shown in Table 3 were studied, where the testing ages of 3, 7, 14, and 28 days were performed after the 50 mm cubic specimens was cast. The specimens were demolded 24 h after casting and cured at four curing conditions which including three different continuous initial curing periods of 3, 7 and 28 days in a chamber with the constant temperature of 30°C and constant humidity 65 % RH, respectively, then in the air until the testing at 28 days, and the fourth one being a continuous water curing of 30°C until the testing at 28 days, were studied. The compressive strength test was conducted at ages of 3, 7, 14 and 28 days, respectively, in accordance to ASTM C109.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 7, Issue 2, March 2018

**Table 3: Four curing conditions for eco-mortar**

| Designation | Initial curing condition[a] | Later curing condition continuously until test day (after initial curing regime) |
|---|---|---|
| | Curing period (day) | |
| CD#1 | 1 | Same as the initial curing regime |
| CD#2 | 3 | Subsequent curing in ambient temperature |
| CD#3 | 7 | Subsequent curing in ambient temperature |
| CD#4 | 1 | Subsequent curing in 30°C water |

[a] Curing in the chamber with constant values of 65% RH and 30 °C.

## III. RESULTS AND DISCUSSIONS

### *A. Compressive strength*

#### *1) Effects of curing conditions*

The effects of curing conditions on compressive strengths of slag based eco-binder is shown in Fig 1. When W/B = 0.35, the mortars with curing condition CD#1 developed better compressive strength than other three types of curing conditions regardless of testing ages. The 28-day compressive strength of specimens with curing condition CD#1 is higher than that with curing conditions CD#2, CD#3 and CD#4 by 12.4%, 8.94% and 8.83%. In addition, the steeper slope of later compressive strength development of mortar with curing condition CD#1 was found to reach the highest 28-day compressive strength. Due to insufficient moist environment, the specimen with condition CD#2 resulted in lower compressive strength. Furthermore, the compressive strengths of mortar increased with conditions CD#1 and CD#3, i.e., with longer age curing at 30˚C and 65 RH curing condition. On the other hand, the water curing of conditions CD#4 led to a lower compressive strength of hardened mortar, probably due to the calcium hydroxides of hydration products being gradually dissolved in water. On the other hand, the influence of curing conditions on the compressive strengths of eco-mortar with high value of W/B of 0.5 at all four ages of 3, 7, 14, 28 days seems insignificant as shown in Fig. 2.

#### *2) Effect of water-to-binder ratio (W/B)*

The effect of water-to-binder ratio (W/B) of mortar on compressive strengths of slag-based eco-binder is shown in Fig 3, where the curing condition has more impact on lower water-to-binder ratio than that with higher water-to-binder ratio. Such results implies that a very stringent selection of curing condition is highly essential for manufacturing the SFC mortar with sufficient compressive strength at all curing ages.

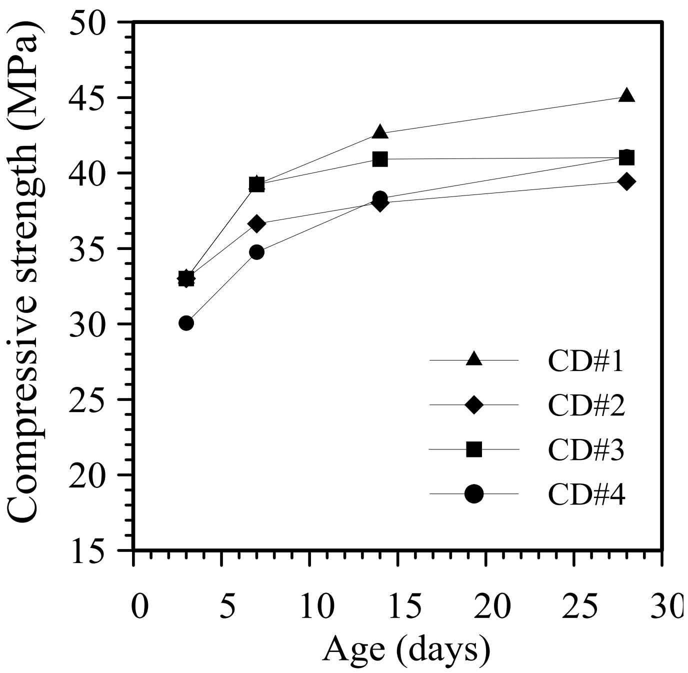


**Fig 1. Effect of curing conditions on compressive strength of slag-based eco-mortar (Mix ID: 0.35C15S8F2)**

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 7, Issue 2, March 2018

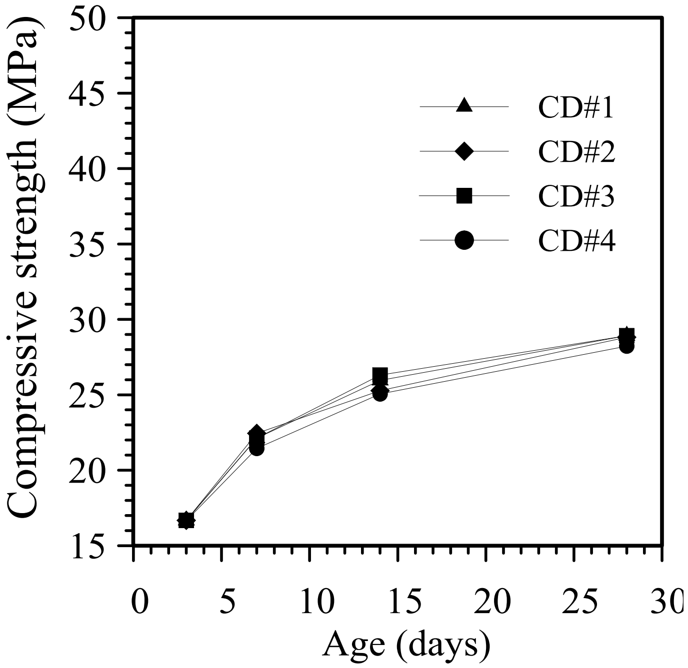


**Fig 2. Effect of curing conditions on compressive strength of slag-based eco-mortar (Mix ID: 0.5C15S8F2)**

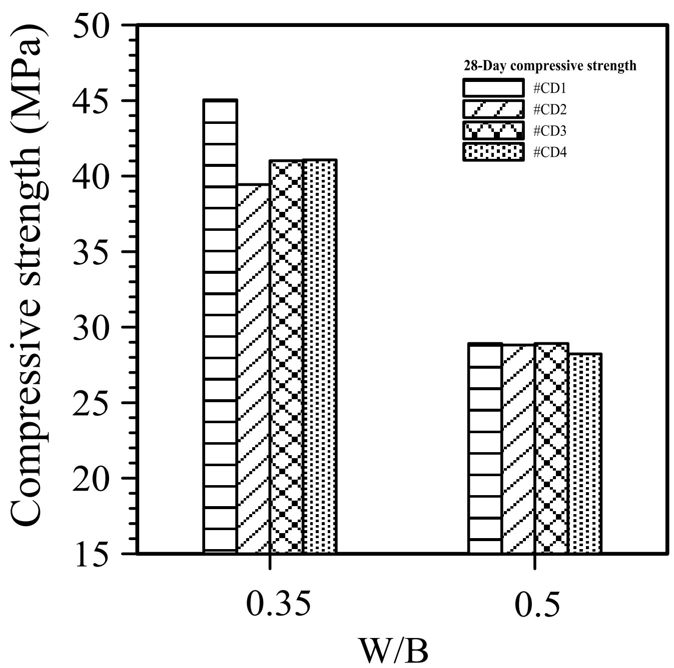


**Fig 3. Effect of water-to-binder ratio on compressive strength of slag-based eco-mortar**

## IV. CONCLUSION

The slag-based eco-binder proposed in this study has been shown being able to act as an alternative cement with the low energy consumption to make the eco-mortar. Based on the experimental results, the following conclusions can be drawn:

1. The compressive strengths of slag-based eco-mortar could reach 25.05 MPa at 28 days. Therefore, the optimal curing condition of being cured in the chamber of constant 30˚C and 65 RH could obtain the better results than

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 7, Issue 2, March 2018

other types of curing conditions.

2. Under the low water-to-binder ratio of 0.35, the initial curing period has more apparent impact on the 28-day compressive strength, in which the compressive strengths of mortar with curing conditions CD#1 and CD#2 are 39.44 MPa and 45.05 MPa, respectively. On the other hand, under high water-to-binder ratio of 0.5, the compressive strengths of mortar at four curing ages of 3, 7, 14 and 28 days are not apparently affected by the four curing conditions.

## ACKNOWLEDGMENT

The authors would like highly acknowledge the financial supports from the Ministry of Science and Technology, Taiwan, through the grants of 103-2221-E-011 -075 -MY3 and 103-2221-E-011 -078 -MY3 to the National Taiwan University of Science and Technology to conduct this study.

## REFERENCES

[1] Xi, F., S. J. Davis, P. Ciais, D. Crawford-Brown, D. Guan, C. Pade, T. Shi, M. Syddall, J. Lv, L. Ji, L. Bing, J. Wamg , W. Wei, K. Yang, B. Lagerblad, I. Galan, C. Andrade, Y. Zhang and Z. Liu (2016). Substantial global carbon uptake by cement carbonation, Nature Geoscience 9, 880-883.

[2] Rust, D., R. Rathbone, K. C. Mahboub, and T. Robl (2012). Formulating low-energy cement products. J Mater Civ Eng, 24(9):1125–31.

[3] Sheng G, Q. Li, J. Zhai (2012). Investigation on the hydration of CFBC fly ash, Fuel, 98:61–6.

[4] Grounds, T., D.V. Nowell, F.W. Wilburn (1995), The influence of temperature and different storage conditions on the stability of super sulfated cement, J. Therm.Anal. Calorim. 45 (3) . 385–394.

[5] Barıs, K. E., and L. Tanaçan (2017). Earth of Datça: Development of pozzolanic activity with steam curing, Construction and Building Materials, 139, 212–220.

[6] Xia, Y., Y. Yan, and Z. Hu (2012). Research on Affecting Factor to Performance of Non-autoclaved Aerated Concrete with Circulating Fluidized Bed Fly Ash, Journal of Wuhan University of Technology, 34(3), 25-30 (in Chinese).[7] Zhang, Z., J. Qian (2017). Effect of protogenetic anhydrite on the hydration of cement under different curing temperature, Construction and Building Materials, 142, 417-422.

[7] Chang, C. H. (2013). The research on the conformity to standards of CFBC fly ash as alkali activator and Its concrete properties, Master Thesis, National Chiao-Tung University, Taiwan (in Chinese).

[8] Chen, C.T., H.-A., T. P. Chang, T. R. Yang, T. D. Nguyen (2015). Performance and microstructural examination on composition of hardened paste with no-cement SFC binder, Construction and Building Materials, pp.264-272.

## AUTHOR BIOGRAPHY

**Yun-Chen Yu** is a master in National Taiwan University of Science and Technology (NTUST) (Taiwan Tech), Department of civil and construction engineering, Taipei, Taiwan (R.O.C). He completed his B.S. from the National Chung Yuan Christian University (NCYCU), Department of civil engineering, Taoyuan, Taiwan (R.O.C), M.S. from the National Taiwan University of Science and Technology (NTUST) (Taiwan Tech), Taipei, Taiwan (R.O.C) in 2017.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 7, Issue 2, March 2018

| | |
|---|---|
|  | **Chiao-Wei Yang** is a master student in National Taiwan University of Science and Technology (NTUST) (Taiwan Tech), Department of civil and construction engineering, Taipei, Taiwan (R.O.C). He completed his B.S. from the National Chung Hsing University (NCHU), Department of civil engineering, Taichung, Taiwan (R.O.C). |
|  | **Hoang-Anh Nguyen** is working as a lecturer of Department of Rural Technology, College of Rural Development, Can Tho University of Can Tho University, Vietnam. He completed his B.E. in Department of Civil Engineering, Can Tho University, Vietnam in 2010. Completed MSc and Ph. D. in Department of Civil and Construction Engineering, National Taiwan University of Science and Technology (NTUST) (Taiwan Tech), Taiwan (R.O.C) in 2014 and 2016, respectively. Total publications are about 16 on construction materials. |
|  | **Ta-Peng Chang** is working as a distinguished professor in National Taiwan University of Science and Technology (NTUST) (Taiwan Tech), Department of civil and construction engineering, Taipei, Taiwan (R.O.C). He completed his B.S. from the National Taiwan University of Science and Technology (NTUST) (Taiwan Tech), Taipei, Taiwan (R.O.C), M.S. from the University of Washington, Seattle, USA and Ph.D. from the Northwestern University, Illinois, USA. His professional interests include concrete materials, behavior of granular materials, lightweight concrete, Finite Element Method, failure analysis of materials, effects of temperature on material behavior and non-destructive testing. |