International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:15, No:4, 2021

Effect of Carbon-Free Fly Ash and Ground Granulated Blast-Furnace Slag on Compressive Strength of Mortar under Different Curing Conditions

Abdul Khaliq Amiri, Shigeyuki Date

***Abstract*—**This study investigates the effect of using carbon-free fly ash (CfFA) and ground granulated blast-furnace slag (GGBFS) on the compressive strength of mortar. The CfFA used in this investigation is high-quality fly ash and the carbon content is 1.0% or less. In this study, three types of blends with a 30% water-binder ratio (w/b) were prepared: control, binary and ternary blends. The Control blend contained only Ordinary Portland Cement (OPC), in binary and ternary blends OPC was partially replaced with CfFA and GGBFS at different substitution rates. Mortar specimens were cured for 1 day, 7 days and 28 days under two curing conditions: steam curing and water curing. The steam cured specimens were exposed to two different pre-curing times (1.5 h and 2.5 h) and one steam curing duration (6 h) at 45 °C. The test results showed that water cured specimens revealed higher compressive strength than steam cured specimens at later ages. An increase in CfFA and GGBFS contents caused a decrease in the compressive strength of mortar. Ternary mixes exhibited better compressive strength than binary mixes containing CfFA with the same replacement ratio of mineral admixtures.

***Keywords*—**Carbon-free fly ash, compressive strength, ground granulated blast-furnace slag, steam curing, water curing.

I. Introduction

THE utilization of supplementary cementitious material (SCMs) in concrete and mortar as a partial replacement of cement is increasing globally with the aims of reducing CO_2 emissions produced by the cement industry, the heat of hydration, the cost of concrete, and reusing industrial wastes [1]. Furthermore, SCMs improved the workability and durability of concrete [2].

SCMs have different chemical, mineralogical, and particle properties. Therefore, the addition of different SCMs in concrete may have different effects on the properties of concrete and mortar. Fly ash (FA) and GGBFS are the two most widely used SCMs that improve both the mechanical and durability of concrete [3].

Concretes with FA generally show higher strength at later ages (after 28 days) than concretes containing only OPC [4]. Moreover, the usage of FA in concrete has environmental and economic benefits [5]. In contrast, the concrete with FA exhibits lower strength at early ages than the OPC concrete. Also, the performance of air-entraining agents (AEA) can be limited when the carbon content of FA is high (> 4%) and an extra amount of AEA may be needed for getting the desired air content [6].

Compered to OPC the early age strength gain of GGBFS is lower [7]. However, GGBFS concrete or mortar exhibits higher strength gain at later ages [8]. The particle size of GGBFS effects on strength development of concrete, the GGBFS with finer particle sizes improves the long-term strength development of concrete [9].

Researchers have studied the effect of ternary binders on concrete and mortar properties; and, ternary binders have been produced to reduce the environmental impact of cement production and improve the mechanical properties of concrete. According to [10] at the same compressive strength, the CO_2 intensity of OPC concrete is the greatest while the concrete with (OPC+FA+GGBS) has a lower value of CO_2 intensity than any of the other concrete types. Moreover, in [11], better mechanical results were observed when FA was used together with the slag. Ternary blends containing a high amount of GGBFS, FA, and superplasticizer were designed for developing a high-strength and low-heat-generating concrete, which is used for the construction of the Akashi Kaikyo Bridge that has a central span of 1991 m [12].

In this study, individual and combined effects of CfFA and GGBFS on compressive strength of mortar were investigated. For this purpose, binary and ternary blends were produced. The binary blends were contained OPC plus CfFA or GGBFS and the ternary blends were contained OPC plus CfFA and GGBFS. Mortar specimens were subjected to two types of curing: Steam curing and water curing. After 1 day, 7 days and 28 days of curing the compressive strength test was conducted on mortar samples.

II. Experimental Procedure

A. Material Used

The materials used in this study are shown in Table I. The CfFA, which is used in this study, is a high-quality FA and the carbon content is 1.0% or less.

B. Mix Proportions

Table II provides the mortar mix proportions. Three types of mortar blends with the same water binder ratio of 0.30 were prepared. The control mixture contained only OPC as a binder while in binary and ternary mixes the OPC was partially replaced with different proportions of CfFA and GGBFS.

Abdul Khaliq Amiri is a graduate student and Shigeyuki Date is Associate Professor of Civil Engineering Department, Faculty of Engineering, Tokai University, Hiratsuka, Japan (e-mail: ab.khaliq9161@gmail.com, sdat@tokai-u.jp).

TABLE I
MATERIALS USED

Materials		Quantity	Density (g/cm^3)
Cement	OPC	Ordinary Portland Cement	3.16
	CfFA	Carbon-free Fly Ash	2.2
	GGBFS	Blast Furnace Slag fine powder (4000 Blaine)	2.89
Sand	S	River Sand Yamakita Kanagawa	2.69
Superplasticizer	SP	Master Gelinue 8000S S	-
Air entraining agent	AEA	Master Air 303 A	-

C. Mixing and Casting

The fine aggregate was prepared to SSD condition. A Hobart type mixer with a maximum capacity of 20 liters was used in this study. Initially, cement, mineral admixtures, and sand were mixed in a dry state for 30 seconds at low speed (110 rpm). Next, water, SP, and AEA were poured and mixed for one minute at low speed (110 rpm). Finally, mortar was mixed for 30 sec at high speed (230 rpm). This procedure applied for all the mixes. After the completion of the mixing process, mortar cylinder specimens were cast with the dimension of 50 mm in diameter and 100 mm in height.

D. Curing Conditions

After casting of mortar specimens, the molded specimens were covered with a plastic sheet to prevent moisture loss during the curing period. Mortar specimens were exposed to two types of curing: Water curing and steam curing. Water cured specimens after casting were kept at 20 ± 2 °C and 60% humidity for 24 h. Steam cured specimens were subjected to steam curing after 90 min and 150 min of pre-curing time, the steam curing duration was for 6 hours at 45 °C and 100% humidity, as the steam curing pattern is shown in Fig. 1. All the specimens were demolded after 24 h, the demolded specimens were subjected to water curing at a temperature of 20 ± 2 °C and the specimens were kept in a water tank until testing days.

E. Test Items

Mortar cylinders with the dimensions of 50 mm in diameter and 100 mm in height were tested for determination of Compressive strength. The samples were exposed to compressive strength test after 1 day, 7 days and 28 days of curing.

TABLE II
MIX PROPORTIONS

Mix Code	OPC (%)	CfFA (%)	GGBFS (%)	W/P (%)	S/P (%)
Control	100	0	0	30	2
F15	85	15	0		
F30	70	30	0		
S15	85	0	15		
S30	70	0	30		
F7.5S7.5	85	7.5	7.5		
F15S15	70	15	15		
F30S30	40	30	30		

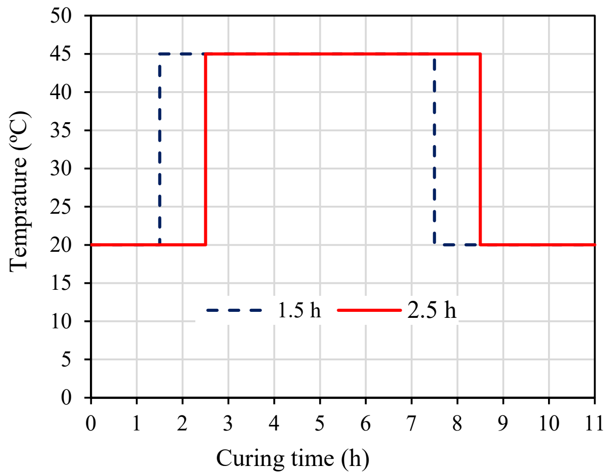


Fig. 1 Steam curing pattern

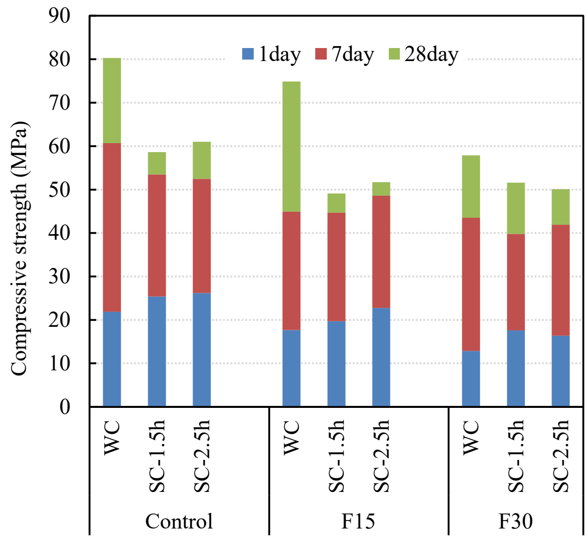


Fig. 2 Effect of CfFA on compressive strength of mortar

III. RESULTS AND DISCUSSIONS

Compressive strength is one of the most important properties of concrete since other mechanical properties of concrete can be indicated with compressive strength. The tests for determining the compressive strength of mortar were conducted on mortar specimens after 1 day, 7 days and 28 days of curing.

A. Effect of CfFA on Compressive Strength

Fig. 2 shows the compressive strength of mortar containing 15% and 30% of CfFA as OPC replacement. As the CfFA content in mortar increased the compressive strength of mortar decreased. CfFA mortars showed lower strength gain than the OPC mortars at early ages. In the literature reviews, similar results were observed that the inclusion of FA in concrete resulted in a lower compressive strength at later ages [13].

F15 that was exposed to water curing revealed higher compressive strength than the steam cured control mixture and F30. However, after 28 days of steam curing, the specimens incorporating 15% and 30% CfFA showed similar compressive strength. At later ages, a great distinction observed between strength development of water cured and steam cured mortar specimens containing 15% CfFA while there is a slight difference between strength gain of mortars with 30% of CfFA, as indicated in Fig. 2.

B. Effect of GGBFS on Compressive Strength

Fig. 3 presents the strength development of mortar containing 15% and 30% of GGBFS. The increase in GGBFS content caused a decrease in the compressive strength of mortar. At 28 days, under steam curing conditions, S15 showed higher compressive strength than S30 and control mixture. Moreover, S15 exhibited greater strength than S30 under both water and steam curing conditions. Under water curing conditions, at later ages, the compressive strength of the control mix was higher than both S15 and S30. Mortar specimens incorporating GGBFS exhibited lower early age strength gain than the control mixture at early ages. However, at later ages, mixtures containing GGBFS showed greater strength development than OPC mortar. Similar observations were reported by [14].

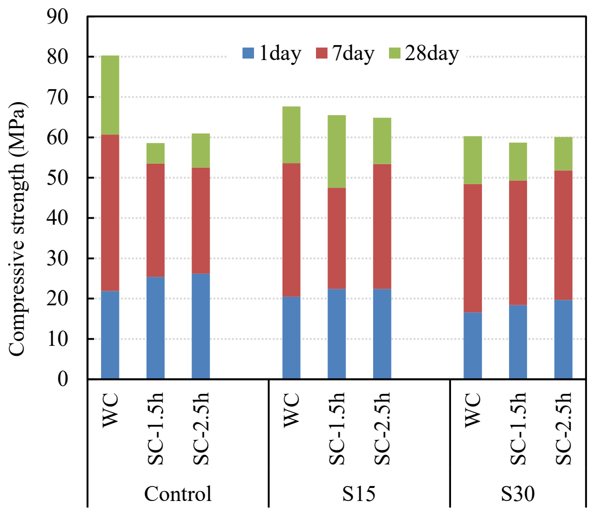
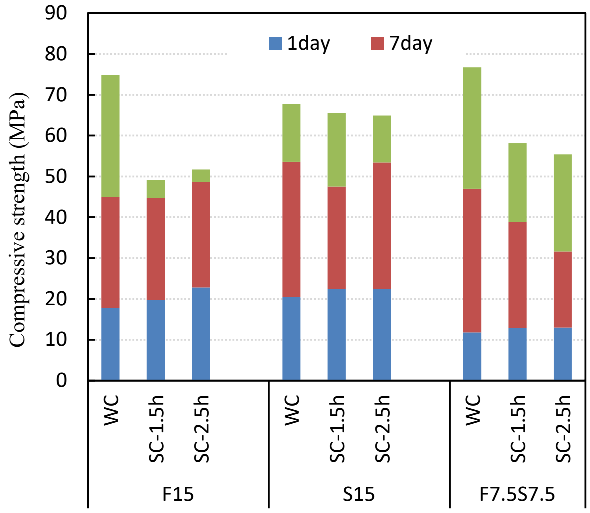


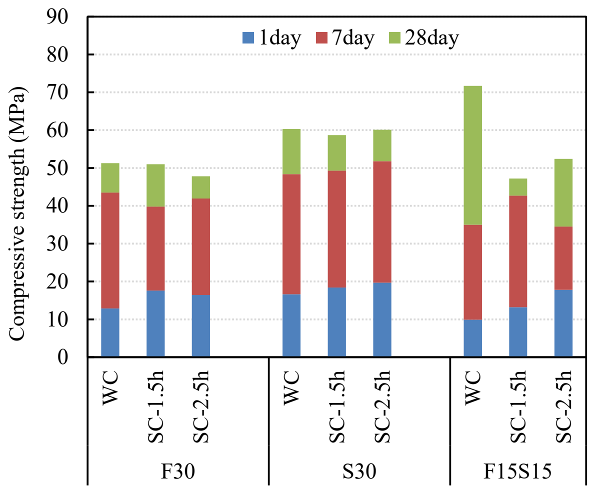
Fig. 3 Effect of GGBFS on compressive strength of mortar

C. CfFA vs. GGBFS

According to Figs. 4 (a) and (b), the specimens with lower substitutions of both CfFA and GGBFS showed more effective strength development than the higher substitutions. Similar compressive strength was exhibited by CfFA and GGBFS mixes after one day of curing while GGBFS mixes showed higher compressive strength than CfFA mixes after 28 days of curing. At later ages, there is a huge difference in strength value of water-cured and steam-cured specimens containing 15% CfFA while there is no considerable difference in strength value of mortar specimens with 15% GGBFS that were subject to water and steam curing. However, as the replacement ratio of CfFA increased, the difference between the strength values of steam-cured and water-cured mortars decreased. The mortar specimens incorporating each CfFA and GGBFS revealed lower early-age strength than the control mix, as indicated in Figs. 2 and 3.



(a)



(b)

Fig. 4 Compressive strength of mortar with (a) 15% SCMs, and (b) 30% SCMs

D. Combined Effect of CfFA and GGBFS on Compressive Strength

From Fig. 5, it can be noted that the higher amount of SCMs in ternary blends of mortar resulted in lower strength development at early ages and higher strength development at later ages. Also, as the content of SCMs in ternary mixes increased the compressive strength decreased. According to Fig. 5, after 28 days of steam curing, ternary mixes containing 30% and 60% SCMs revealed similar compressive strength. However, water cured ternary mix with 30% SCMs had greater strength value than that of the ternary mix with 60% SCMs at all ages.

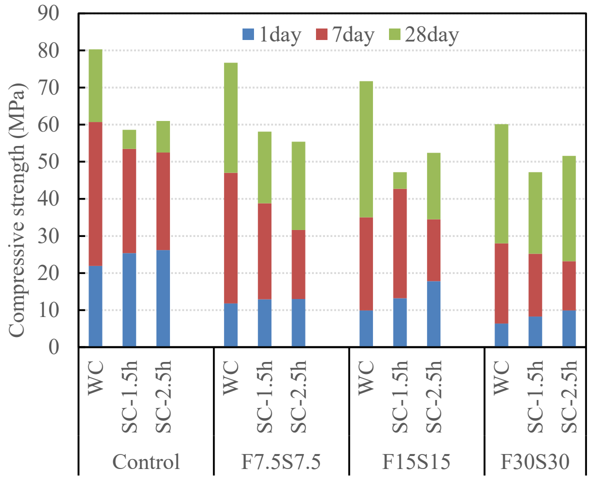


Fig. 5 Compressive strength of ternary mixes

According to Figs. 4 (a) and (b), under water curing condition, the ternary mixes exhibited greater compressive strength than the binary mixes with the same replacement ratios of SCMs (15% and 30%) at later ages. However, after 28 days of steam curing, binary mixes containing GGBFS revealed a higher strength value than those of the binary mixes containing CfFA and the ternary mixes with the same content of SCMs.

After 28 days of water curing, among the binary and ternary mixes, the highest value belongs to F7.5S7.5 while the strength value of F7.5S7.5 is slightly lower than the strength of water-cured control specimens and higher than the strength of control specimens that were exposed to steam curing, as shown in Fig. 6. This can be evident that the ternary mixes with lower substitution of SCMs will reach similar or even higher compressive strength than OPC mortar at later ages (90 days). Results of [15] confirmed that the ternary mixes containing low calcium FA and blast furnace slag at ratios of (25% FA +10% slag) and (10% FA +25% slag) have shown higher compressive than OPC mortars at the age of 90 days under normal curing condition.

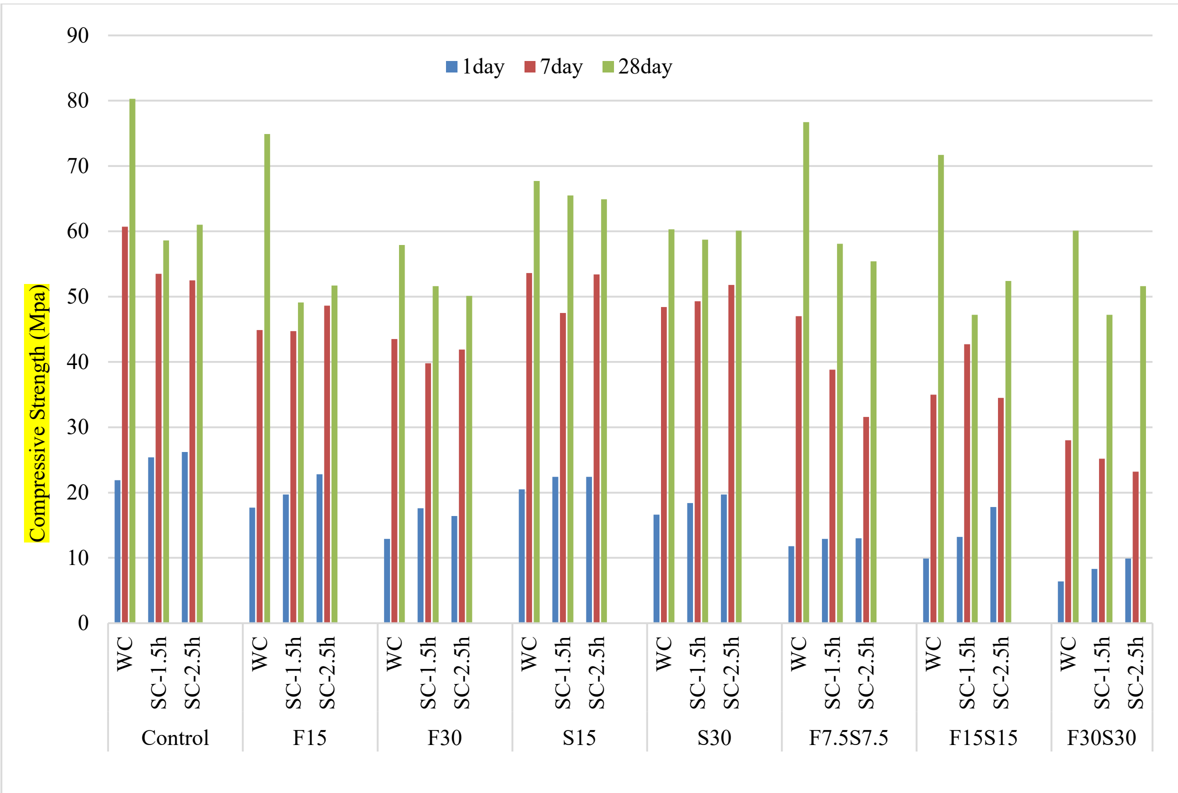


Fig. 6 Effect of curing on compressive strength of mortar at 1 day, 7 days and 28 days

E. Effect of Curing Regimes on Compressive Strength

A total of nine cylindrical specimens from each group were cast for determining the compressive strength of mortar after 1 day, 7 days and 28 days of curing. The specimens were exposed to two types of curing: water curing and steam curing.

As can be seen from Fig. 6, irrespective of curing methods, an increase in compressive strength throughout the whole period of curing was observed in all the mortar specimens. Steam curing improved the early-age compressive strength but decreased the long-age compressive strength of mortars. On the contrary, water curing improved the compressive strength at later ages but decreased at early ages. After 28 days of curing, there is a significant difference in the strength value of water cured and steam-cured binary mixes containing CfFA and ternary mixes. In contrast, there a slight difference in long-age strength of water-cured and steam-cured binary mixes incorporating GGBFS. However, the difference in strength values decreased as the content of CfFA in binary and ternary mixes increased. The specimens that were cured under steam curing conditions, except specimens containing 30% CfFA all other specimens with the longer pre-curing time (2.5 h), exhibited higher early-age strength than the shorter pre-curing time (1.5 h).

IV. Conclusions

In this study, an experimental investigation was conducted on mortar specimens incorporating various SCMs to study the effect of CfFA and GGBFS on the compressive strength of mortars. The mortar specimens were subjected to water curing and steam curing. The present investigation came to the following conclusions:

- The specimens with lower substitution ratios of both CfFA and GGBFS showed greater compressive strength than the higher ratios.
- F7.5S7.5 had the highest compressive strength value among the binary and ternary mixes at the age of 28 days.
- S15 specimens showed the highest compressive strength among all the steam cured specimens at later ages.
- Steam curing improved the strength of mortar at early ages but decreased at later ages.
- Compared to reference mortar both CfFA and GGBFS showed higher later age strength gain and lower early age strength gain.
- At age of 28 days, steam cured binary mixes of GGBFS showed greater compressive strength than steam cured OPC, ternary mixes and binary mixes that contain CfFA.

References

[1] R. J. Detwiler, J.I. Bhatty, S. Bhattacharja “Supplementary Cementing Materials for Use in Blended Cements, Research and Development Bulletin Rd112T, Portland cement Association, Skokie, Illinois, U.S.A, 1996 , pp. 15–64.

[2] T. Ayub, S.U. Khan, F.A. Memon, 2014. Mechanical characteristics of hardened concrete with different mineral admixtures: a review. Sci. World J.2014. https://doi.org/10.1155/2014/875082

[3] J.M. Ortega, M.D. Esteban, I. Sánchez, M.Á. Climent, Performance of Sustainable Fly Ash and Slag Cement Mortars Exposed to Simulated and Real In Situ Mediterranean Conditions along 90 Warm Season Days. *Materials* 2017, 10, 1254.

[4] M.M. Johari, J.J. Brooks, S. Kabir, P. Rivard. Influence of supplementary cementitious materials on engineering properties of high strength concrete. Construction and Building Materials 25 (2011) 2639–2648

[5] C. Meyer, The greening of the concrete industry. Cement Concr. Compos.2009,31(8),601-605.https://doi.org/10.1016/j.cemconcomp.2008.12.010.

[6] S.K. Bremseth, Fly ash in concrete A literature study of the advantages and disadvantages COIN Project report 18-2010 (Sintef Building and Infrastructure, Blindern, 2009)

[7] J. Liu, D. Wang, Application of Ground Granulate Blast Furnace Slag-Steel Slag Composite Binder in a Massive Concrete Structure under Severe Sulphate Attack, Advances in Materials Science and Engineering, 2017, https://doi.org/10.1155/2017/9493043

[8] D.M. Roy, G.M. Idorn, Hydration, structure and properties of blast-furnace slag cements, mortars and concrete, ACI J. Proc. 79 (6) (1982) 445–457.

[9] R.A. Rivera, M.Á. Sanjuán, D.A. Martín, Granulated Blast-Furnace Slag and Coal Fly Ash Ternary Portland Cements Optimization. Sustainability 2020, 12, 5783.

[10] K.H. Yang, Y.B. Jung, M.S. Cho, S.H. Tae, Effect of supplementary cementitious materials on reduction of CO2 emissions from concrete, J. Clean. Prod. 103 (2015) 774-783

[11] D. S. Shen, Z. E. Mao, High Quality Fly Ash Concrete, Shanghai Science & Technology Press, China 1992, pp. 54–57

[12] S. Kashima, N. Furuya, R. Yamaoka, High-Strength Concrete for Wall Foundation Using Ternary Blended Cement with Intermixture of Blast-Furnace Slag and Fly Ash. Fly Ash, Silica Fume, Slag, & Natural Pozzolans in Concrete, Proceedings 4th CANMET/ACI International Conference; Istanbul, Turkey, Vol. 2, 1992, 1451-1469

[13] P. Nath, P. Sarker, Effect of fly ash on the durability properties of high strength concrete, Procedia Eng., 14 (2011), pp. 1149-1156

[14] H. Zhao, W. Sun, X. Wu, B. Gao, 2015. The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures. J. Clean. Prod. 95, 66e74. https://doi.org/10.1016/j.jclepro.2015.02.050.

[15] M.C. Alonso, J.L. García Calvo, M. Sánchez, A. Fernandez, Ternary mixes with high mineral additions contents and corrosion related properties, Mater. Corros., 63 (12) (2012), pp. 1078-1086