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The Effect of Mineral Admixture on the Compressive Strength Development of Concrete

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Abstract

To evaluate the compressive strength of mineral-admixtured concrete (MAC) that incorporates fly ash (FA), ground granulated blast-furnace slag (GGBS) and silica fume (SF), uniaxial compression tests were carried out in this study. For mix proportions of concrete, a water-to-binder ratio were fixed to 0.40; compressive strength is targeted to 42 MPa at 28 days. The cylinders for compressive tests were fabricated and then placed in water at 20℃ for a total curing period of 91 days. The compressive strength at each curing age (1, 7, 28 and 91 days) was measured to evaluate the strength development characteristic of MAC. The MAC incorporating GGBS or SF exhibited sufficient compressive strengths at 91 days, whereas those at 7 and 28 days were under the specified compressive strength. These strength characteristics of MAC were also proven by comparison of test results with predictive equation of Eurocode 2.

Keywords: Mineral-admixtured concrete, Compressive strength, Ground granulated blast-furnace slag, Silica fume, Fly ash, Curing age

1 Introduction

Mineral admixtures such as ground granulated blast-furnace slag (GGBS), fly ash (FA) and silica fume (SF) are commonly used in combination with Portland cement (PC) in concrete for many applications because they improve durability and reduce porosity of concrete [1]. They also could lower cement requirement resulting in leading to a reduction for CO_2 generated by the production of cement [2]. Due to these advantage, there are many studies on the use of the mineral admixture for structural concrete [3-6]. Although it is well known that the ultimate strength is higher for the same water-to-binder ratio, the GGBS has a significant shortage in the use concrete that its strength development is considerably slower than that of PC based concrete under standard curing temperature (20℃) [7]. Even though the partial replacement of the mineral admixtures by weight increase the later strength of concrete [8], use of the mineral-admixtured concrete in construction fields has been reluctant because of lower early strength.

The aim of this paper is to predict the compressive strength development of the mineral-admixtured concrete with age using predictive equations in Eurocode 2 [9]. For this purpose, the results obtained from the equation were compared with the average results of the experiments.

2 Experimental Program

Table 1 indicates the mix proportions of concrete. In this study, water-binder ratio were set to 0.40 for the target compressive strength of 42 MPa. With each concrete mixture, 100mm x 200mm cylindrical specimens were cast for compressive strength test. The cylinders were then placed in water at 20℃ for a total curing period of 91 days. The compressive strengths of the specimens were determined at 1, 7, 28 and 91 days in accordance with ASTM C 39 [10].

Table 1. Mixture proportions of concrete

Mixture	Replacement ratio (%)	W/B	S/a	Unit weight (kg/m^3)							
				Water	Cement	FA	GGBS	SF	C	F	SP
OPC	0	0.40	0.41	165	405	0	0	0	1078	725	0.90
FA20	20	0.40	0.43	162	385	81	0	0	997	728	0.90
BS50	50	0.40	0.43	155	194	0	194	0	1054	769	0.75
BS65SF5	70	0.40	0.43	155	116	0	252	19	1048	765	0.75

3 Test Results and Discussion

The variation of compressive strength of concrete with age are presented in Figure 1. It may be concluded from the Fig. 1 that the FA content of 20% cement replacement causes an increase in compressive strength values. As reported by Roy, [7], the concrete specimens partially replaced with only GGBS show considerably slower strength development than that of OPC specimen under curing temperature of 20℃). At 28 days, BS50 and BS65SF5 specimens showed 8.9% and 11.03% lower compressive strengths than OPC specimens, respectively. However, the compressive strength at 91 days of BS65SF5 specimen was comparable with that of OPC specimen. Furthermore, BS50 specimen showed 7.43% higher compressive strength than OPC specimen. It can be referred that GGBS is effective for the later strength of concrete as concluded in Roy [7]. The compressive strength at each age for concrete specimens is listed in Table 1.

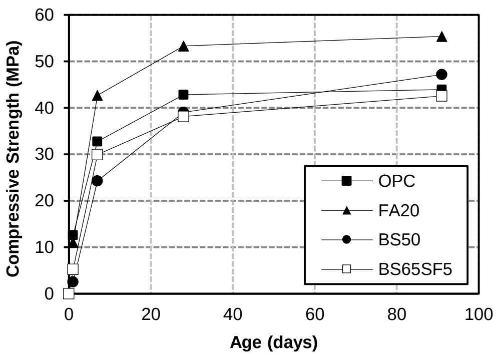


Figure 1. Compressive strength development of concrete

Table 2. Summary of compressive strength

Specimen	Compressive strength (MPa)			
	1 day	7 days	28 days	91 days
OPC	12.59	32.77	42.81	43.90
FA20	11.05	42.64	53.27	55.36
BS50	2.55	24.27	39.00	47.16
BS65SF5	5.20	29.92	38.09	42.53

For a mean temperature of 20°C and curing in accordance with EN 12390 [11] the compressive strength of concrete at various ages f_{cm} (t) may be estimated from following Eqs. (1) and (2);

$$f_{cm}(t) = \beta_{cc}(t) f_{cm} \tag{1}$$

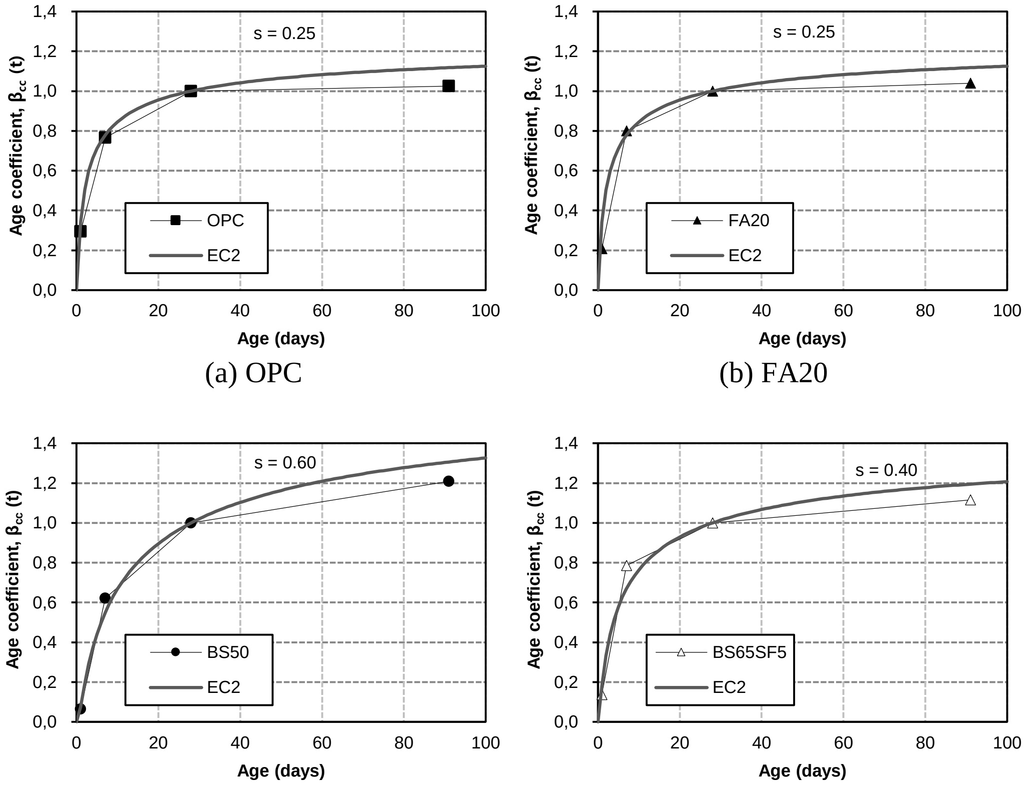
with

$$\beta_{cc}(t) = \exp\left\{ s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\} \tag{2}$$

where;

$f_{cm}(t)$ is the mean concrete compressive strength at an age of t days
f_{cm} is the mean compressive strength at 28 days according to Table 3.1[10]
$\beta_{cc}(t)$ is a coefficient which depends on the age of the concrete (t)
t is the age of the concrete in days
s is a coefficient which depends on the type of cement
= 0.20 for rapid hardening high strength cements (R) (CEM 42.5R, CEM 52.5)
= 0.25 for normal and rapid hardening cements (N) (CEM 32.5R, CEM 42.5)
= 0.38 for slow hardening cements (S) (CEM 32.5)

In this study, to evaluate the strength development of concrete with age, the age coefficient, $\beta_{cc}(t)$ was compared with the test results. The compressive strength at each age of concrete was normalized by the relevant 28-day-compressive strength. Figure 2 presents the comparison of compressive strength development by testing with that by Eq. (2). Among the variables in Eq. (2), the binder type coefficient, s was controlled to fit the predictive curve to the compressive test result. As shown in Figures 2(a) and 2(b), the test results were well-predicted when 0.25 was used as s for OPC and FA20 specimens. However, as shown in Figures 2(c) and 2(d), 0.60 and 0.40 were respectively used as s for OPC and FA20 specimen; this means that the GGBS and SF are slow hardening binders resulting in lower early-strength of concrete. It should be noticed that the predictive results for OPC and FA20 specimens are well-fitted with the test results at all ages while the 7-day compressive strengths of BS50 and BS65SF5 are underestimated by the predictive equation. It may be proven that the target strength of mineral-admixtured concrete incorporating GGBS or SF should be a compressive strength at 91 days rather than that at 28-day.



(a) OPC (b) FA20

(c) BS50 (d) BS65SF5

Figure 2. Comparison of test results and predictive equation

4 Conclusion

In this study, the compressive strength development of MAC was evaluated by testing and comparison with the predictive equation in Eurocode 2. The test results showed that the MAC exhibited a slower strength development than PC based concrete, but the later strength of MAC was improved. These strength development characteristics of MAC were predicted by controlling the binder type coefficient, and the analytical results shows that current equation for compressive strength development of PC based concrete is not proper for predicting strength of MAC because the current equation uses 28-day compressive strength as a standard target strength. Therefore, it is referred that the standard target strength should be a compressive strength at 91 days when mineral admixtures are used as binder for concrete mixture.

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