Influence of steel slag on the properties of steam-cured concrete

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Abstract. In this paper, the influence of steel slag on the compressive strength, permeability to chloride ion and carbonation resistance of steam-cured concrete was investigated. The results show that for steam-cured concrete with water to binder ratio (W/B) of 0.45, replacing 30% of cement by steel slag tends to decrease its compressive strength, increase its chloride permeability and weaken its carbonation resistance. But the properties of steam-cured concrete with steel slag can be improved by decreasing the W/B. When the W/B of concrete containing 30% steel slag is 0.38, its strength, chloride permeability and carbonation resistance are all very close to that of pure cement concrete with W/B of 0.45 under steam curing condition.

1. Introduction

Steel slag is an industrial by-product from the steel production. The chemical components of steel slag mainly include CaO, SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, and MnO[1]. And its common mineral constituents are olivine, merwinite, C_3S, C_2S, C_4AF, C_2F, RO phase and some free-CaO [2]. The existence of C_3S, C_2S, C_4AF and C_2F endows steel slag certain cementitious properties, making it a potential mineral admixture for concrete. However, due to the low cooling rate of steel slag, the activity of its cementitious minerals is much lower than that in Portland cement [3].

It has been reported [4,5] that adding steel slag would slow down the hydration of the blended cements and have negative effect on the strength and durability of concrete. However, it was found [6] that high curing temperature can excite activity of steel slag. The research of Wang et al [7] show that the early strength of concrete containing 50% steel slag can be obviously promoted under high temperature curing condition for a short period (only 1 day). Shi et al [8] also indicated that elevating the curing temperature can effectively promote the early strength development of high-volume steel slag concrete, but it can hardly improve the chloride permeability. Steam curing method is a kind of curing method using high curing temperature, which is simple and provides easy operation. It is often used in the production of precast concrete elements [9]. However, Wang et al [10] found that elevated temperature curing at early ages has some negative effects on the late-age properties of concrete. In order to decrease the negative effect, the temperature of steam curing is normally lower than 70℃.

In this study, three water to binder ratios (0.45, 0.41 and 0.38) were adopted and the concrete specimens were cured using steam curing method. The aim is to investigate the influence of steel slag on the properties of steam-cured concrete and compare the properties of steam-cured concrete with different water to binder ratios.

2. Raw materials and test methods

The cement used in this study was Portland cement complying with the Chinese National Standard GB 8076-2008, whose specific surface area was 359 kg/m^3. Table 1 shows the chemical compositions of the cement. The steel slag used was a kind of basic oxygen furnace steel slag with the specific surface area of 422 kg/m^3. Its chemical compositions are listed in Table 2. Natural river sand with

particle size smaller than 5 mm was used as fine aggregate for concrete preparation. And the coarse aggregate used was crushed limestone with particle size between 5 and 20 mm.

Table 1 Chemical compositions of the cement / %

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
26.21	6.02	4.36	53.45	2.53	2.75

Table 2 Chemical compositions of the steel slag / %

CaO	SiO_2	Al_2O_3	Fe_2O_3	MnO	SO_3	MgO	P_2O_5
39.12	16.21	4.45	24.24	1.54	0.31	7.52	1.35

Table 3 shows the mix proportions of the concretes. The pure cement concrete was adopted as the reference sample and the steel slag replacement ratio was 30% (mass ratio). Besides, three water to binder ratios were adopted: 0.45 (Samples C0 and S1), 0.41 (Sample S2) and 0.38 (Sample S3).

Table 3 Mix proportions of the concretes / (kg/m^3)

Samples	Cement	Steel slag	Water	Fine aggregates	Coarse aggregates
C0	340	0	154	839	1067
S1	238	102	154	839	1067
S2	238	102	139.4	849	1078
S3	238	102	129.2	850	1081

Concretes of 100×100×100 mm were prepared for the property tests. After molding, the specimens were first cured at at 20±1℃ for 8 hours and then steam-cured at 60±1℃ for 10 hours. After cooling down, the specimens were demoulded and then cured under the condition of 20±1℃ until test ages. The relative humidity during the curing process was higher than 95%.

The demoulding strength of concrete was measured. And at the ages of 3, 28 and 90 days, the compressive strength of concrete was tested.At the ages of 28 and 90 days, the permeability of concrete to chloride ion was tested according to ASTM C1202 “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”.

A carbonation chamber with 20±1℃ and 65±5% relative humidity inside was used for the accelerated carbonation test. After initial curing for 3 days, the specimens were put into the carbonation chamber. The carbonation depth of concrete was measured after carbonating for 28 days and 90 days. One percent phenolphthalein in alcohol solution was used to show the visible interface between the carbonated and un-carbonated zone.

3. Results and discussion

3.1 Strength

Fig. 1 presents the demoulding compressive strength of the concretes. It is clear that replacing 30% of cement by steel slag may decrease the demoulding strength of concrete under steam curing condition. Taking the demoulding compressive strength of Sample C0 as the reference, the decrease ratio of demoulding strength is 45.2%, 30.6% and 9.5% for Samples S1, S2 and S3, respectively. Therefore, the demoulding strength of steam-cured concrete containing steel slag can be improved by decreasing the water to binder ratio (W/B). The steel slag concrete with W/B of 0.38 may have relatively close demoulding strength compared with the pure cement concrete prepared at W/B of 0.45 under steam curing condition.

The compressive strength of the concretes at the ages of 3, 28 and 90 days are shown in Fig. 2. In general, the result is very similar to that in Fig. 1. The compressive strength of Samples S1, S2 and S3 are all lower than that of Sample C0 at any age. And decreasing the W/B of steam-cured concrete can increase its compressive strength when the steel slag replacement ratio is 30%. When the W/B of steam-cured concrete containing 30% steel slag reaches 0.38, its compressive strength is quite close to that of pure cement concrete with W/B of 0.45 at the ages of 3, 28 and 90 days.

3.2 Permeability to chloride ion

Figs. 3(a) and 3(b) show the charge passed and chloride permeability grade of the concretes at the ages of 28 and 90 days, respectively. It can be seen from Fig. 3(a) that the four samples all exhibit high permeability to chloride ion at the age of 28 days. At 90 days, Samples C0 and S3 exhibit moderate permeability to chloride ion, while Samples S1 and S2 still exhibit high permeability. It is noted that the charge passed of Samples S1 is obviously higher than that of Sample C0 both at 28 and 90 days. And the charge passed of concrete gradually decreases as the W/B gets lower.

Thus, it can be concluded that adding 30% steel slag in steam-cured concrete may influence its resistance to chloride ion penetration at W/B of 0.45. But with the decrease of W/B, the chloride permeability of steam-cured concrete containing steel slag can be improved. When the W/B of steel slag concrete is 0.38, it can have the same permeability grade to chloride ion to the pure cement concrete with W/B of 0.45 under steam curing condition.

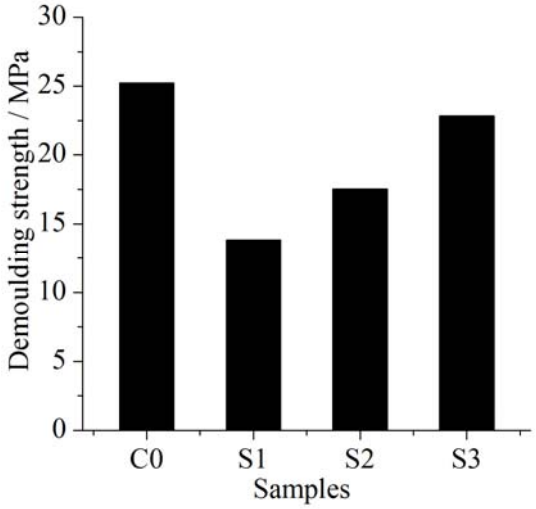

Fig. 1 Demoulding strength of the concretes

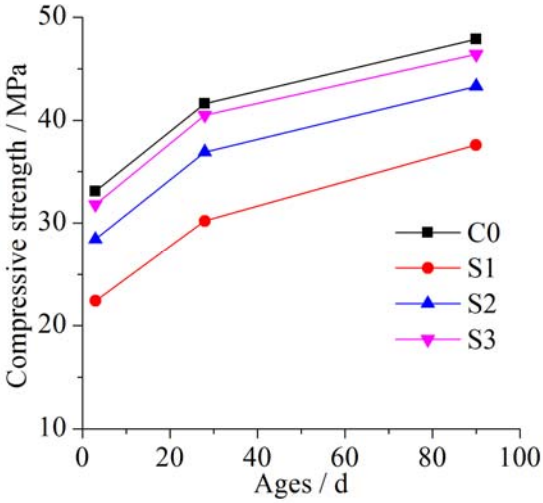

Fig. 2 Compressive strength of the concretes

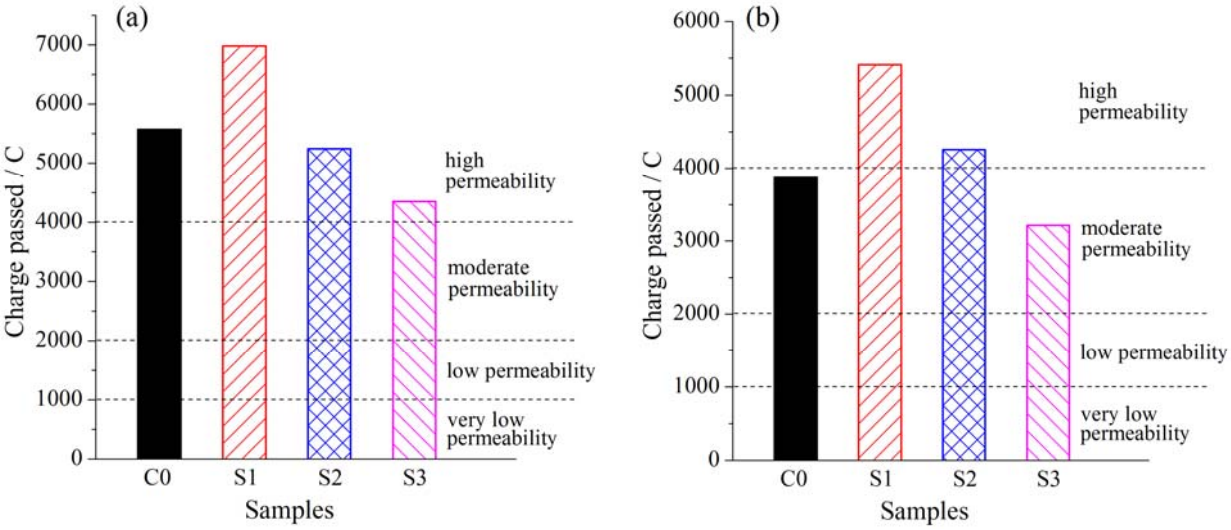

Fig. 3 Chloride ion permeability of the concretes at 28 d (a) and at 90 d (b)

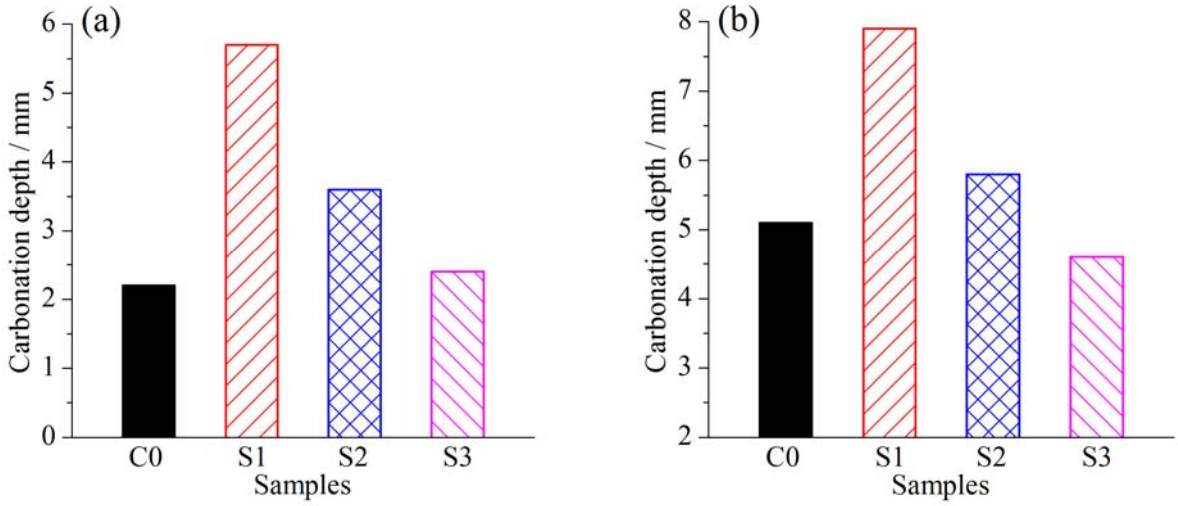

Fig. 4 Carbonation depth of the concretes at 28 d (a) and at 90 d (b)

3.3 Carbonation depth

Figs. 3(a) and 3(b) present the carbonation depth of the concretes after carbonating for 28 days and 90 days, respectively. It is obvious that the carbonation depth of Sample S1 is much larger compared with that of Sample C0 both at the ages of 28 and 90 days. For Sample S2, its carbonation depth is much smaller than that of Sample S1 but still larger than that of Sample C0. However, the carbonation depth of Sample S3 is very close to that of Sample C0. At 90 days, the carbonation depth of Sample S3 is even a little smaller compared with that of Sample C0.

Therefore, adding 30% steel slag in steam-cured concrete tends to weaken its carbonation resistance at W/B of 0.45. But the carbonation resistance of steel slag concrete can be improved with the decrease of W/B. The steel slag concrete with W/B of 0.38 can have almost the same carbonation resistance to the pure cement concrete with W/B of 0.45 under steam curing condition.

4. Conclusion

For steam-cured concrete with W/B of 0.45, replacing 30% of cement by steel slag tends to decrease its compressive strength, increase its chloride permeability and weaken its carbonation resistance. But the properties of steam-cured concrete with steel slag can be improved by decreasing the W/B. When the W/B of concrete containing 30% steel slag is 0.38, its strength, chloride permeability and carbonation resistance are all very close to that of pure cement concrete with W/B of 0.45 under steam curing condition.

References

[1]. Shi C. Steel slag—its production, processing, characteristics, and cementitious properties. Journal of Materials in Civil Engineering. Vol. 16 (2004) No. 3, p. 230-236.

[2]. Hu SG, Wang HX, Zhang GZ, et al. Bonding and abrasion resistance of geopolymeric repair material made with steel slag. Cement and Concrete Composites. Vol. 30 (2008) No. 3, p.239–244.

[3]. Zhang TS, Yu QJ, Wei JX, et al. Investigation on mechanical properties, durability and micro-structural development of steel slag blended cements. Journal of Thermal Analysis and Calorimetry. Vol. 110(2011) No. 2, p.633-639.

[4]. Kourounis S, Tsivilis S, Tsakiridis P E, et al. Properties and hydration of blended cements with steelmaking slag. Cement and Concrete Research. Vol. 37(2007) No. 6, p.815-822.

[5]. Wang Q, Yan PY, Yang JW, et al. Influence of steel slag on mechanical properties and durability of concrete. Construction and Building Materials. Vol. 47(2013), p.1414-1420.

[6]. Wang Q, Shi MX, Zhang ZQ. Hydration properties of steel slag under autoclaved condition. Journal of Thermal Analysis and Calorimetry. Vol. 120(2015) No. 2, p.1241-1248.

[7]. Wang Q, Li MY, Jiang GH. The difference among the effects of high-temperature curing on the early hydration properties of different cementitious systems. Journal of Thermal Analysis and Calorimetry. Vol. 118(2014) No. 1, p.51-58.

[8]. Shi MX, Wang Q, Zhou ZK. Comparison of the properties between high-volume fly ash concrete and high-volume steel slag concrete under temperature matching curing condition. Construction and Building Materials. Vol. 98(2015), p.649-655.

[9]. Ho D W S, Chua C W, Tam C T. Steam-cured concrete incorporating mineral admixtures. Cement and concrete research. Vol. 33(2003) No. 4, p.595-601.

[10]. Wang Q, Li MY, Zhang B. Influence of pre-curing time on the hydration of binder and the properties of concrete under steam curing condition. Journal of Thermal Analysis and Calorimetry. Vol. 118(2014) No. 3, p.1505-1512.