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Study on steel furnace slags with high MgO as additive in Portland cement

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Abstract

In this study, usability of Basic Oxygen Process (BOP) slags of Kardemir Iron and Steel Plant, Karabük, Turkey as an additive into cement was investigated. Slags were ground to 4000 and 4700 cm^2/g levels, and added in ratios 15, 30 and 45 wt.%. Volume expansion, setting time, compressive strength and bending strength tests were measured according to Turkish standards. Due to impurities of the slags, the 2- and 7-day compression strengths decrease with increase in amount of Mn, but this decrease is lower in the 28-day compression strength, 30 wt.%. It is observed that the physical and mechanical properties of the resulting concrete were acceptable in the Turkish Standards Institute (TSE).

Keywords: Admixture; Physical properties; Steel slag

1. Introduction

Steel slag is the residue of steel production process and composed of silicates and oxides of unwanted elements in steel chemical composition. Steel slags show differences depending on the raw materials and process [1]. Fifty million tons per year of LD slag were produced as a residue from Basic Oxygen Process (BOP) in the world [2]. Many investigations were performed for using these slags as industrial raw materials [1–3].

In order to use these slags in cement, hydraulic properties should be known. Chemical composition is one of the important parameters determining the hydraulic properties of the slags. In general, it is assumed that the higher the alkalinity, the higher the hydraulic properties. If alkalinity is > 1.8, it should be considered as cementitious material [1].

Investigations were carried out also on the usability of steel slag as road construction material under laboratory and practical conditions. For this application, the required properties are high compression strength, wear strength and resistance to climatic conditions. The most important criterion is volume stability, in which free CaO and MgO contents of the slag play an important role. Both oxides can go into reaction with water. Hydration causes volume expansion and affects stability of volume [4].

Steel slags should be suitable for metallurgical purposes, but, at the same time, their attack to refractory lining should be as low as possible, and they should be reused as much as possible. If the basic grade of slag is lower than 2.0, merwinite and melilithe phases are formed; these phases have volume stability [4].

Free CaO of the slag can be hydrolyzed up to several months under normal atmospheric conditions with artificial weathering. Keeping the slag outdoor is a method applied for increasing the volume stability. However, hydration of MgO takes place in several years [5]. Keeping MgO slags outside is not successful. Failure can be seen after several years if slags having insufficient volume stability are used.

In this study, the addition of high MgO content slag, which comes from one of the integrated steel plants of Turkey (Kardemir), to the cement was investigated. Kardemir has 2.5 million tons steel slag in their residue areas and this is harmful for environment.

2. Materials and methods

Properties of materials, which were used in experiments, are given in Table 1. Steel slag supplied from Kardemir was added to Portland cement produced in Karçimsa Cement

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Table 1
Chemical composition of cement, steel slags and their mixtures (wt.%)

Material	CaO	SiO_2	Fe_2O_3	Al_2O_3	MgO	SO_3	Loss on ignition
Cement	64.86	21.13	4.72	5.18	2.12	0.56	1.43
Steel slag I*	37.02	18.01	14.10	2.61	14.10	0.35	1.25
Steel slag II**	37.94	18.87	11.73	2.91	14.37	0.37	1.20
C1-I	60.68	20.66	6.13	4.79	3.92	0.49	1.41
C2-I	56.51	20.19	7.53	4.42	5.71	0.50	1.38
C3-I	52.33	19.72	8.85	4.02	7.51	0.47	1.34
C1-II	60.82	20.79	5.77	4.84	3.96	0.49	1.41
C2-II	56.78	20.45	6.82	4.50	5.79	0.50	1.38
C3-II	54.74	20.11	7.88	4.16	7.64	0.47	1.34

* Slag I also contains MnO 7.52%, P_2O_5 0.78%, K_2O 0.13%, Na_2O 0.28%, TiO_2 0.5%; undissolved residual 3.75%, CaO_{free} 0.83%.

** Slag II also contains MnO 7.72%, P_2O_5 0.51%, K_2O 0.33%, Na_2O 0.81%, TiO_2 0.5%; undissolved residual 3.71%, CaO_{free} 0.83%.

Factory (Karabük, Turkey). Properties of the mixes and mixing ratios are given in Tables 2 and 3, respectively. Test of mixes was performed according to Turkish Standards Institute (TSE). Mortar bars were prepared (40×40×160 mm) such that the cement/sand/water ratio was 1:3:0.5.

The granulated slag weathered in residue areas for several years has been used in this study. The full compositions of the slags are given in Table 1.

3. Results and discussion

Results of the applied tests were given in Tables 4 and 5. All the setting time of the cement mixes is in accordance with TS 24 [6] as seen in Table 4. But differences exist depending on the additive content. The setting time for the cements with additive is longer than that of all the cements without addition. As observed on a similar research, low Al_2O_3 content may be a reason for longer setting time [1]. As the addition amount is increased, MgO increases (Table 1). This is observed in other studies, in which the MgO content and setting time (initial and final) increase [7,8]. In this study, it is observed that only the final setting time increases as the MgO increases in samples with 15 and 30 wt.% slag additions. In Zheng et al.'s work, MgO addition was used and it was found that MgO retarded the initial hydration of cement and increased the setting time of cement. The setting times of finer mixtures with additive (C1-II, C2-II and C3-II) are shorter as seen in Table 4, because the reactions of mixtures having larger surface area are faster. The steel slag II being finer, the setting time is shorter than for slag I.

Volume expansions of the cements with and without addition were given in Table 4. All the values are suitable for TS 24. Volume expansion of the cement with addition is lower than that of the cements without addition.

The 7- and 28-day bending strengths of Portland cements with and without addition (seen in Table 5) are suitable for TS 24. Since there is no value on the 2-day results in Turkish standards, comparison was not made. Results of the 2- and 7-day tests are inversely proportional to the amount of additive. In addition, the 7-day bending strength value of the concrete obtained from C3-I type cement is close to the limit of standard value. The 28-day strength values of the concrete obtained from CO and C1-I type cements are equal. It is seen that bending strength decreases as the additive increases in finer ground cements with slag addition.

The 2-, 7- and 28-day compression strengths of the cements with and without addition are suitable for TS 24 (Table 5). Due to the difference in surface area of the cements and different amounts of additive, compression strengths are different. Compression strength changes inversely with additive amount; as the amount of additive increases, compression strength decreases. Compression strength increases when the impurity levels decrease in cement mixture [3]. The strengths of C3-I are near the limit value of the standard TS 24 .The experimental result of compression strength is very close to the standard value of TS 24.

The 2-day compression strength of the C3-I cement, which is Portland cement with 45% slag addition, is lower than the TS 24 values. The 7- and 28-day results are higher

Table 2
Physical characteristics of mixes

Material	Fineness (wt.%) +0.09 mm	+0.045 mm	Specific surface (cm^2/g)	Specific gravity (g/cm^3)
Steel slag I	28	7	4000	3.54
Steel slag II	22	5.8	4700	3.57
Cement	1.5	0.1	4100	3.28

Table 3
Composition of cement mixes

Cement mixture	Portland cement (wt.%)	Steel slag I/II (wt.%)
CO	100	0
C1-I/II	85	15
C2-I/II	70	30
C3-I/II	55	45

Table 4
Volume expansion and setting time of cement mixes

Cement mixture	Vicat setting time (h:min)		Volume expansion (mm)		
	Initial	Final	Cold	Hot	Total
CO	3:15	4:15	2	1	3
C1-I	4:24	5:30	1	0	1
C2-I	4:18	6:06	1	0	1
C3-I	3:50	5:10	1	0	1
C1-II	3:54	5:12	1	1	2
C2-II	3:54	5:42	1	0	1
C3-II	3:24	4:54	1	0	1
TS 24	min 1 h	max 10 h	–	–	max 10 h

Table 5
Compressive and bending strength of cement mixes

	Compressive strength (MPa)			Bending strength (MPa)		
Mixture	2 days	7 days	28 days	2 days	7 days	28 days
CO	23.9	42.9	58.0	4.8	6.9	8.5
C1-I	18.1	34.7	48.2	4.1	6.3	8.5
C2-I	15.0	30.8	38.5	3.7	5.6	7.4
C3-I	10.2	23.4	35.7	2.7	4.0	6.4
C1-II	20.3	38.9	52.6	4.8	6.5	8.4
C2-II	15.2	32.4	45.8	3.5	6.0	7.2
C3-II	11.1	28.3	43.7	3.2	4.9	7.1
TS 24	min 10	min 21	min 32.5	–	min 4.0	min 5.5

than the value of the standards. Compression strength of the C1-II, C2-II and C3-II type cements are higher than those of C1-I, C2-I and C3-I type cements. The reason for these differences is the specific surface area of the slag (Table 2). Since fine mixture has higher surface area, it goes into reaction faster. Compression strength is generally decreased with the increased amount of the impurities in mix cements. It can be seen from Table 5 that the strength decreases with increasing additive amount. Due to impurities of the slags, the 2- and 7-day compression strengths decrease with the increase in amount of Mn, but this decrease is lower in the 28-day compression strength (Table 5). Pera et al. [10] have found that manganese has a negative influence on the reactivity and strength of the slag at early stage, but it does not hinder long-term activation.

4. Conclusion

It is found that physical and mechanical properties of the concretes are suitable for TS standards [6,9] when using steel slag from Karabük, Turkey having 4700 and 4000 cm^2/g specific surface area with 30% addition to the Portland cement. In order to satisfy this requirement, 30% slag addition should be chosen. With this addition, adequate physical and mechanical properties are obtained.

In order to optimize the usage of steel slag, steel producers, refractory producers and slag users should continue to collaborate.

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