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BLAST-FURNACE SLAG CEMENTS FOR CONCRETE DURABILITY IN MARINE ENVIRONMENT

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Abstract

For many years, granulated blast furnace slag cements have proved to give a very high resistance against chloride penetration compared to that of pure portland cements. In recent years, however, more optimized, high-performance portland cements and combinations of portland cements with pozzolanic materials such as and fly ash and silica fume have been introduced for concrete structures in severe environment.

In the present paper, the results of an experimental investigation are reported, with the objective to compare the resistance against chloride penetration of different types of cement currently being used for concrete structures in chloride containing environment. These cements included two different types of granulated blastfurnace slag cement, two different types of high performance portland cement and one type of fly ash cement, all compared to an ordinary type of portland cement. Combinations of these cements with silica fume were also included in the test program. All the cements were tested both in a standardized concrete mixture for laboratory testing and a mixture typically being used for marine concrete work in Norway. The water/binder ratio of the two mixtures was 0.45 and 0.38, respectively. The testing which was based on an accelerated non-steady state migration method in combination with electrical resistivity measurements, clearly demonstrated that the blastfurnace slag cements gave the highest resistance against chloride penetration, while the pure portland cements gave the lowest resistance. In particular the slag cements gave a very high early age resistance against chloride penetration, which may be especially important for concrete construction work in severe marine environment.

1. Introduction

Extensive experience has shown that blastfurnace slag cements generally give better durability and long-term performance of concrete structures in severe environment compared to that of pure portland cements [1]. The slag affects both the chemical and physical characteristics of the concrete in such a way that the resistance both against chloride penetration, alkali-aggregate reaction and chemical deterioration may be substantially increased. In The Netherlands, which is one of the countries where blastfurnace slag cements have been extensively used for a long time, approximately 2 million tons of slag cement are annually being produced, which make up approximately 60% of the domestic cement market [1]. The extensive Dutch experience with blastfurnace slag cements confirms the good durability properties, and in particular, the experience demonstrates that slag cements may substantially improve the durability of concrete structures in marine environment [1]. In countries where pure portland cements have typically been used for concrete structures in chloride containing environments, both extensive and very severe durability problems due to chloride-induced corrosion exist [2].

In recent years, more optimized, high-performance portland cements and portland cements blended with pozzolanic materials such as fly ash and silica fume have been introduced for concrete structures in severe environment. In order to investigate the different resistance against chloride penetration of different types of cements currently being used for concrete structures in chloride-containing environment, an experimental investigation was undertaken, some preliminary results of which are reported in the following.

2. Experimental program

2.1 Materials

In the current test program, six different types of cement were used (Table 1), including two blastfurnace slag cements (CEM III/B 42.5 LH HS and CEM III/A 52.5) with 70 % and 53 % slag, respectively, one portland cement blended with 20 % fly ash (CEM IV/A), one high performance portland cement (CEM I 52.5R LA) and one high performance portland cement blended with silica fume (ArmitBinder 10A). The ArmitBinder type of cement has been specially developed for very aggressive environments, but it is a non-standardized cement [3]. As a reference, an ordinary portland cement of type CEM I 42.5R was also used.

All the cements were tested in two different types of concrete mixtures, of which one was a standardized concrete mixture for laboratory testing (Mix 1) [4], and one was a mixture typically being used in Norway for new concrete structures in marine environment (Mix 2). Mix 2 also included 10% silica fume by weight of cement. The two concrete mixtures had a water/binder ratio of 0.45 and 0.38, respectively. For both concrete mixtures, a naphthalene-based superplasticizer with a solid content of 42% was used, while the aggregate was mostly of siliceous origin with a maximum particle size of 16 mm..

Table 1. Cement types.

Symbol	Cement type
GGBS1	CEM III/B 42.5 LH HS
GGBS2	CEM III/A 52.5
PFA	CEM IV/A
HPC1	CEM III/A 52.5
HPC2	ArmitBinder 10A
OPC	CEM I 42.5R

For each concrete mixture, a number of ∅100 x 200 mm concrete cylinders and 100 mm concrete cubes were produced. After casting, all specimens were kept under plastic sheets until demoulding the following day. Thereafter, the specimens were stored in water at 21 ± 2 °C until time of testing.

2.2 Testing procedures

In order to test the resistance against chloride penetration, an accelerated non-steady state migration test method was applied [5]. As part of this testing, the electrical resistivity of the concrete was also recorded. For both types of concrete, all testing was carried out at 7, 28, 90 and 180 days, but for Mix 1, an additional 3-day testing was also carried out. The compressive strength was recorded as a reference for concrete quality.

3. Results and discussion

3.1 Compressive strength

Both from Table 2 and Fig. 1 it can be seen that the ArmitBinder type of cement (HPC2) gave a considerably higher compressive strength compared to that of the other types of cement. For Concrete Mix 1, this cement gave a 28 day strength of 78,7 MPa, while the other cements gave strengths varying from 53,9 to 64,0 MPa. For Mix 2, the 28 day strength for the ArmitBinder was 87,2 MPa, while the other cements gave strengths varying from 66,1 to 78,5 MPa. At 180 days, the ArmitBinder had reached 108,2 MPa, while the other cements varied from 69,2 to 87,1 MPa.

Table 2. Compressive strength for Concrete Mix 1 (MPa).

Age (days)	GGBS1	GGBS2	PFA	OPC	HPC1	HPC2
28 (μ/σ)	57.1/0.40	64.0/4.75	53.9/4.25	55.6/0.79	55.1/1.15	78.7/0.42
180 (μ/σ)	62.9/.46	81.2/0.42	61.0/3.84	72.3/1.30	78.6/0.95	---

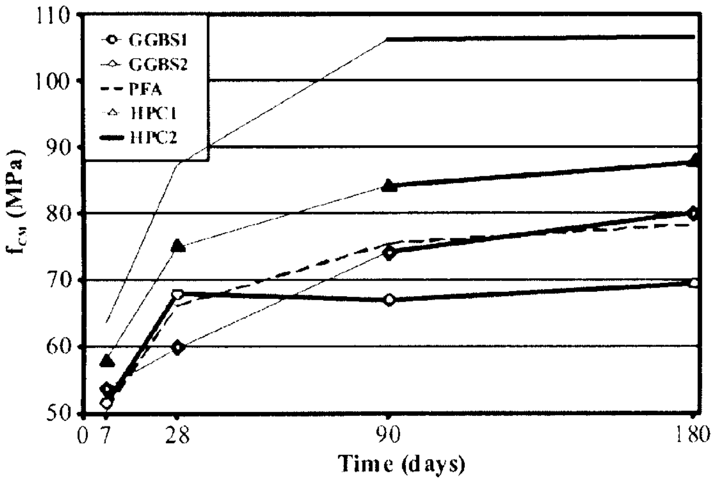

Fig. 1. Development of compressive strength for Concrete Mix 2.

3.2 Chloride diffusivity

From Figs. 2 and 3 which demonstrate the development of chloride diffusivity for both concrete mixtures, it can be seen that the two slag cements (GGBS1 and GGBS2) gave a distinctly lower chloride diffusivity at an early age compared to all the other types of cement, thus demonstrating a very high early age resistance against chloride penetration. For Concrete Mix 1, the ArmitBinder (HPC2) had reached a resistance close to that of the slag cements after 28 days, while the other cements still showed a relatively low resistance against chloride penetration. At 90 days, however, the fly ash cement (PFA) had almost reached the same resistance as that of the slag cement with the lowest slag content (GGBS2), while the ArmitBinder had reached about the same resistance as the slag cement with the highest slag content (GGBS1). At 180 days, both the high performance portland cements (HPC1) and the ordinary portland cement (OPC) still showed a relatively low resistance against chloride penetration.

Also in combination with 10% silica fume (Mix 2), it can be seen from Fig. 3 that the two slag cements (GGBS1 and GGBS2) produced a much higher early age resistance against chloride penetration compared to that of all the other types of cement. At 28 days, the two slag cements still showed the highest resistance against chloride penetration, but the difference to the other cements was not so distinct any longer. At 90 and 180 days, the ArmitBinder (HPC2) had reached the same level of resistance as that of the slag cements, where also the high-performance portland cement (HPC1) and the fly ash cement (PFA) had reached a high resistance against chloride penetration.

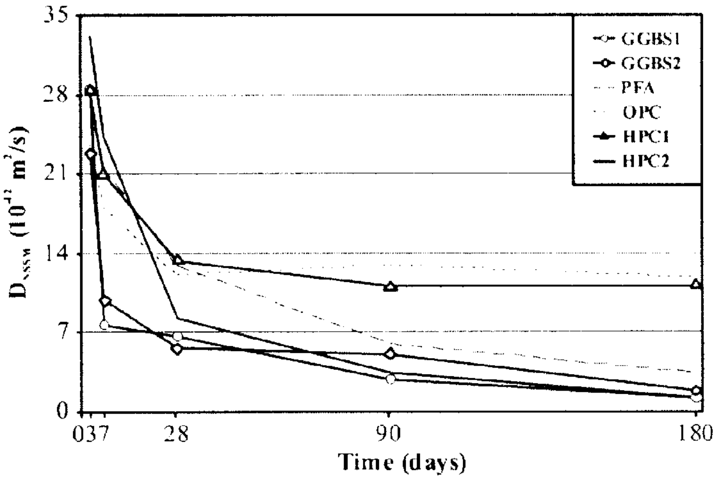

Fig. 2. Development of chloride diffusivity for Concrete Mix 1.

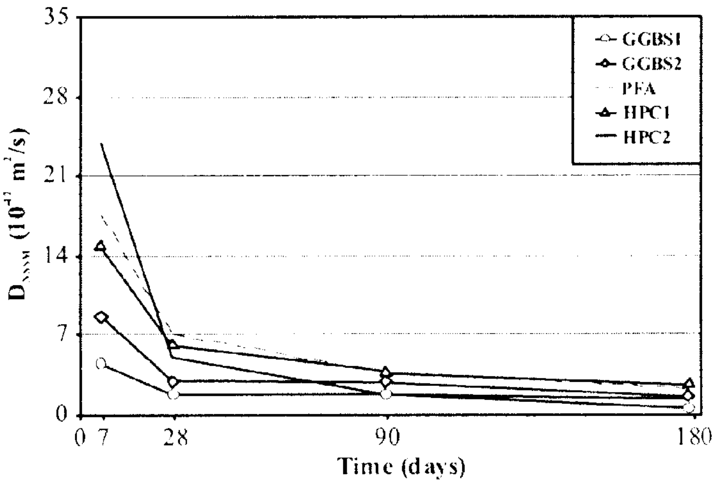

Fig. 3. Development of chloride diffusivity for concrete Mix2.

3.3 Electrical resistivity

As can be seen from Figs. 4 and 5, a similar development of electrical resistivity for the different types of cement as that of chloride diffusivity was observed.

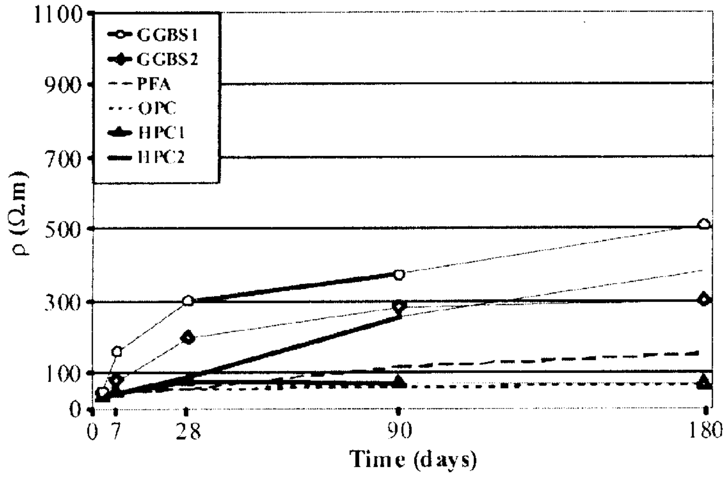

Fig. 4. Development of electrical resistivity for Concrete Mix 1.

For Concrete Mix 1, the two slag cements showed a distinctly higher electrical resistivity compared to that of all the other types of cement up to an age of 28 days. At 90 days, the ArmitBinder (HPC2) had approached the resistivity of the slag cement with the lowest slag content (GGBS2), while the two pure portland cements (HPC1 and OPC) had not improved very much, and the fly ash cement only showed a small improvement.

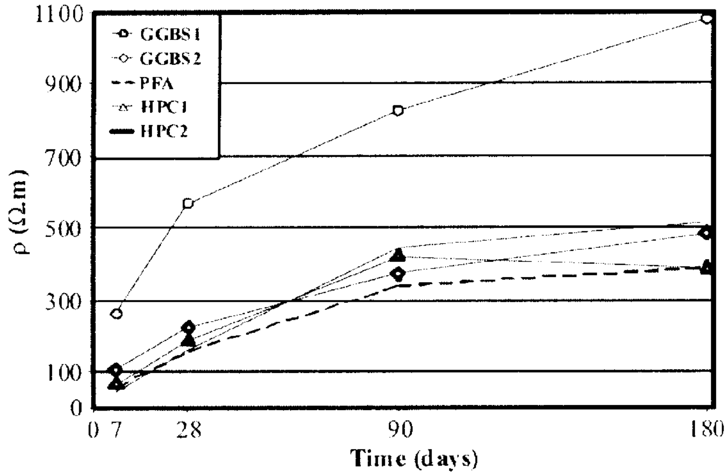

Fig. 5. Development of electrical resistivity for Concrete Mix 2.

In combination with 10% silica fume (Mix 2), the slag cement with the highest slag content (GGBS1) showed a distinctly higher electrical resistivity than all the other types of cement all the way up to 180 days. At 180 days, the electrical resistivity of the GGBS1 was still twice that of both the slag cement with the lowest slag content (GGBS2) and the ArmitBinder (HPC2). After 90 days, neither of the two pure portland cements nor the fly ash cement had given any further increase in electrical resistivity.

3.4 Effect of cement type

For a given concrete with a given moisture condition, there is a close relationship between chloride diffusivity and electrical resistivity [6]. Therefore, both of these parameters should reflect the resistance of the concrete against chloride penetration. By applying such accelerated testing as that in the present work, however, it may be argued that the obtained test results do not properly reflect the complete resistance of the concrete against chloride penetration. In a natural diffusion process there will always be an additional, beneficial effect of chloride binding [7, 8], which is not properly reflected in a non-steady state of migration testing. However, the obtained results should be on the safe side. Also, the obtained results should reflect the big difference of the various cements to resist chloride penetration into concrete.

Of all the various types of cement tested, the obtained results clearly demonstrate the good ability of the slag cements to give a high resistance of the concrete against chloride penetration, which is in general agreement with existing experience [1]. In particular, it was observed that the early age resistance against chloride penetration was very high compared to that of all the other types of cement, which may be specially important for concrete construction work in severe marine environment [2]. The results also demonstrate that the slag cement containing 70% slag (GGBS1) gave a distinctly higher resistance than the slag cement with 53% slag (GGBS2), while both the high-performance pure portland cement (CEM I 52.5R LA) and the ordinary portland cement (CEM I 42.5R) gave a relatively low resistance against chloride penetration. The test results further demonstrate that the different resistance against chloride penetration of the various types of cement was reduced in the more dense concrete with 10% silica fume. However, the slag cements still showed the best performance all the way up to a curing period of 90 days.

4. Conclusions

The present experimental investigation was only based on a limited number of variables and the testing was only based on accelerated test methods, which may not reflect the complete resistance of concrete against chloride penetration. However, based on the test results obtained, the following conclusions appear to be warranted:

1. Of all the different types of cement tested, the granulated blastfurnace slag cements gave the highest resistance of concrete against chloride penetration.

2. Both slag cements gave a very high early age resistance against chloride penetration, which may be specially important for concrete construction work in severe marine environment.

3. The slag cement with the highest slag content (70%) gave the highest

resistance against chloride penetration, while the pure portland cements gave the lowest resistance.

4. In combination with 10% silica fume, the different resistance against chloride penetration of the various types of cement was distinctly reduced. Still, the slag cements showed the highest resistance against chloride penetration; in particular at an early age.

5. Aknowledgement

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