Study on the Influence of Blast Furnace Slag on Chloride Ion Penetration Property

P Subpa-asa¹, K Ken², F Satoshi³, D Shigeyuki⁴

¹ Graduate student, Department of Civil Engineering, Graduate School of Science and Technology, Tokai University, Hiratsuka-pref., Japan, 259-1292.
² Chief manager, DC CO., LTD., Technical Center, 1-17, Asano-cho, Kawasaki-ku, Kawasaki-shi, Kanagawa, 210-0854, Japan
³ Assistant manager, DC CO., LTD., Technical Center, 1-17, Asano-cho, Kawasaki-ku, Kawasaki-shi, Kanagawa, 210-0854, Japan
⁴ Professor, Civil Engineering Department, Faculty of Engineering, Tokai University, Kanagawa-pref., Japan, 259-1292.

Email: prangsub@gmail.com

Abstract. Sustainability is becoming more and more important, which is why the concrete and cement industry are attempting to reduce negative impacts to the environment. One of the methods regarding this is to use industry by-products from the manufacturing of steel products like blast furnace slag (BFS) to replace the raw materials required in cement. The chloride ion penetration has to also be taken into consideration since it reinforces the concrete structure. Thus, the influence of BFS on blocking resistance and chloride ion penetration by using BFS with different Blaine value is studied by using “Standard on Test Methods for Chloride Ion Diffusion Coefficients in Concrete” by electrophoresis (Draft) (JSCE-G571-2003)” and the total chloride ion amount was measured in accordance to JIS R 5202. The result is that using BFS in cement has influences on the penetration properties.

1. Introduction

Reinforced concrete structures (RC structure) where steel is embedded and the two materials act together as resisting forces. Chloride ions are also infiltrated and corrosion of the reinforcing bars can occur, causing cracks. These cracks from corrosion expansion are the chloride damage which then affects the performance of the structures. Concrete which is a constituent material of the structure is required to have high durability to prolong its use.

Steel slag is the unavoidable by-product of the manufacturing of steel products which includes useful materials like blast furnace slag (BFS). Japan has accumulated approximately 40 million tons of iron and BFS products. The largest use of BFS is in cement, as raw materials. In addition, the total annual sales for domestic consumption and exports reach a combination of 17.8 million tons. BFS is also used as a fine aggregate for concrete, or as sand. Fine aggregate is the second-largest use of BFS, with sales of 1.8 million tons per year in Japan. [1] It has been found that concrete with BFS has excellent resistance to sulfuric acid, freezing and thawing resistance and resistance to damage by salt attacks. [2-4] Furthermore, BFS is more effective in preventing corrosion of the reinforcing bars in concrete due to its denser cured body, as compared with ordinary Portland cement, and its high ability to immobilize chloride ions. Although, the mechanism of immobility of chloride ions in concrete containing BFS has not been clarified.
Cement replacement levels were generally conserved at 30-70% by the fine BFS powder. The workability of cement was improved by the adjusting water-cement ratio. [5] To compare, when the fine BFS powder was added, the properties changed as air void, the long-term strength, the chemical resistance and density were improved. Therefore, this study is aimed to confirm the influence of BFS on blocking resistance and the performance of chloride ions by using three different Blaine values.

| Abbreviations | Properties                                      | Density (g/cm$^3$) |
|---------------|------------------------------------------------|-------------------|
| N             | Ordinary Portland cement                        | 3.16              |
| BFS           | Ground granulated Blast Furnace slag (Blaine value of 3,000 4,000 6,000) | 2.90              |
| S             | Sand                                            | 2.64              |
| AG            | Anhydrous Gypsum plaster                        | 2.91              |
| W             | Water                                           | 1.00              |

2. Methodology

2.1 Materials and formulations used
Table 1 and Table 2 show materials properties and mixed proportions. The BFS and anhydrous gypsum plaster (AG), adjusted with the amount of SO3 were 2.41% (the amount of SO3 in level 1) the larger the amount SO3, the early strength increases and shrinkage decreases. The percentages of the BFS replacement used in this experiment were 45% and 22.5% and the latter will confirm the change in the performance of the chloride ions’ immobility.

2.2 Mixing-curing method
The proportions of the mortar were mixed in accordance with JIS R5201,” Physical testing methods of cement”. [6] The curing condition was at two levels which are water curing and steam curing, the pre-time was 2 hours and the temperature was raised at 20C/1hour in advance. Then, it was held at 60C for 24 hours. After that, it fell at 10C/hour. Steam curing was carried out for 28 days.

2.3 Rapid chloride penetration test (RCPT)
The methodology of the chloride ion penetration test is shown in Fig. 1 and the specimen geometry has a diameter of 100 mm and a thickness of 50 mm in a cylinder shape. The influence of the BFS on blocking resistance and chloride ion penetration by using BFS with different Blaine values is studied by using the “Standard on Test Methods for Chloride Ion Diffusion Coefficients in Concrete” by electrophoresis (Draft) (JSCE-G571-2003) [7] and the total number of chloride ions was also measured.
Table 2. Mixed proportion.

| Mix proportion | *W/B | Unit weight (kg/m$^3$) |
|----------------|------|-----------------------|
|                |      | *W | N | BFS (Blaine value) | AG | S |
| Sample-1       |      | 636 | | | | |
| Sample-2       |      | 493 | 143 | 3,000 | 6.2 | |
| Sample-3       |      | 350 | 268 | 4,000 | 12.4 | |
| Sample-4       | 50%  | 318 | 493 | 4,000 | 143 | 6.2 | 1,272 |
| Sample-5       |      | 350 | 268 | 6,000 | 12.4 | |
| Sample-6       |      | 493 | 143 | 4,000 | 6.2 | |
| Sample-7       |      | 350 | 268 | 4,000 | 12.4 | |

*W/B is the ratio of water to the binder.

3. Results and discussion

3.1 Chloride ions diffusion coefficient

Figures 2 and 3 show the results of the chloride ions diffusion coefficient of the specimen through steam curing and water curing. The chloride ions diffusion coefficient of concrete with no BFS has the same tendency with adding BFS by 22.5% of cement replacement, which is higher than adding BFS by 45% of cement replacement. The exception is that the penetration of chloride ions is suppressed even with the same amount of addition and there was a difference depending on the Blaine value. More resolution of the Blaine value affects the chloride ions diffusion coefficient in a way that it decreases. This could be because of the densification of the mortar as the degree of fineness increases. Products that went through steam curing had more texture than products that was cured by water, so the chloride ion property lowered.
Figure 2. The result of the diffusion coefficient of the steam curing.

3.2 Chloride ion content
After confirming that the penetration rate of chloride ion is constant, the energization was stopped and the specimen was taken out. The amount of chloride ion penetration from the concrete was measured with a parameter analyzer. Figures 4 and 5 show the analysis results of water curing and steam curing, respectively. As a result, the addition rate and fineness of the ground granulated blast furnace slag increased, which causes the amount of chloride ions remaining in the specimen to increase.

Figure 3. The result of the diffusion coefficient of the water curing.
Figure 4. The analysis results of water curing.

The lead time of the BFS concrete was getting longer. The degradation prediction of the amount of chloride ions retained due to the chloride damage is currently based on the diffusion coefficient. On the other hand, the immobility of chloride ions leads to an increase in useful life from the viewpoint of corrosion of the reinforcement, so in the future, it would be beneficial to explore this effect further.

Figure 5. The analysis results of steam curing
4. Conclusion
The study investigated the possibility of making BFS concrete. The following findings were obtained within the scope of this research on the influence of BFS on the Chloride shielding property of the mortar.

1. Chloride curing deteriorated slightly through steam curing.
2. The higher the fineness and addition rate of the BFS, the more effects to the chloride penetration rate in concrete.

5. References
[1] Nippon Slag Association 2015 *Iron and Steel Slag Statistics* 1-7
[2] Takeshi Takeshi Iyoda 2014 *Jpn Ces* 66 51
[3] Jariyathitipong P, Hosotani K, Fujii T. and Ayano T 2013 *J. Jpn. Soc. Civil Eng. (Materials and Concrete Structures)* 69 337
[4] Fujii T and Ayano T 2014 *J. Jpn. Soc. Civil Eng. (Materials and Concrete Structures)* 70 417
[5] Jariyathitipong P, Fujii T. and Ayano T 2014 *Cement Science and Concrete Technology* 67 427
[6] JIS R 5201 *Physical testing methods of cement*. Translated and published by Japanese Stands Association
[7] JSCE-G571-2003 *Test method for effective diffusion coefficient of chloride ion in concrete by migration*. Japan Society of Civil Engineers
[8] JIS R 5202: 2010 *Methods for chemical analysis of cement*. Translated and published by Japanese Stands Association