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Effect of Ground Granulated Blast Furnace Slag and Polymer Microspheres on Impermeability and Freeze-Thaw Resistance of Concrete

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Abstract

The primary objective of this study was to assess freeze-thaw resistance of concrete whose structure was modified by varying the water/binder ratio and ground granulated blast furnace slag content, and by air entrainment. The innovative method of the polymer microspheres-based air entrainment was used to provide a stable pore structure.

Test results show that the method is very effective both in providing adequate air entrainment and in improving freeze-thaw resistance of concrete. All air-entrained concrete specimens with polymer microspheres (the spacing factor of $\bar{L} \leq 0.25$ mm) had a good resistance to the action of frost, regardless of the W/S ratio and the slag cement content.

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Keywords: concrete; freeze-thaw resistance; air entrainment; polymer microspheres; permeability; absorption;

1. Introduction

Applications of cements containing the addition of ground granulated blast furnace slag bring considerable technical and economic benefits. Reduced pore size and improved impermeability of the paste are the main effects of the modification. Lower permeability is a major factor in marked improvement of concrete corrosion resistance. The reduction in the clinker content decreases hydration heat, which is important in massive structures, and limits alkali

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content thus preventing alkali-silica reaction in concrete. Whether concretes made with blast furnace slag are resistant to moisture, temperatures below zero and de-icing salt is an outstanding issue. According to ACI Committee 226, the addition of the slag cement should not exceed 50% due to the freeze-thaw resistance. The Polish supplements to the PN-EN 206-1 standard (PN-B-06265:2004) specify the slag amount in the exposure class XF4 as a function of CEM III class: up to 50% for 32.5R, above 50% for 42.5R and more than 80% for marine structures.

Experience shows that concretes with a slag-rich cement are extremely susceptible to damage under conditions of the combined action of frost and de-icing salts [1]. Additionaly, the study presented by Rusin et al. [4] demonstrates that concretes with GGBS cement have a markedly lower level of freeze-thaw resistance relative to the concretes made with CEM I, irrespective of W/B. Giergiczny et al. [3] reports that the use of cement containing larger amounts of slag may result in reduced total air and micropore contents in the hardened concrete and increased value of the air pore spacing factor $\bar{L}$. Deja [2] observes the worsening of the air entrainment effect in such concretes. The authors of this study [7] ascertain that an increase in the slag amount reduces the resistance to surface scaling. Test results indicate that proper air entrainment is essential to ensure good freeze-thaw resistance of concrete made with slag.

An outstanding problem in building practice is obtaining the air void structure that will be repeatable and stable in terms of both the total volume and the size of air voids [5]. Many air void instability-related problems can be avoided through the use of particles with tailored diameters, the so-called microspheres. The microspheres are used in the cement paste to introduce air voids with suitable dimensions that will not change in time. This solution is innovative in that it eliminates fundamental problems associated with coalescence and size variation of air voids. Good effectiveness of the method has been proved by the authors' own research on air entrainment of concrete mixtures with the use of polymer microspheres [6].

Ten series of concretes were tested, including non-air-entrained concretes and those air-entrained with microspheres. The analysis focused on how the three factors, namely slag cement amount added, W/B ratio and air entrainment affect the impermeability of concrete and its freeze-thaw resistance.

2. Materials and Methods

The objective of this study was to assess the physical properties and freeze-thaw resistance of concrete modified with various W/B ratios, varied content of ground granulated blast furnace slag in the binder and air entrainment. The concretes tested had the W/S ratios of 0.40-0.50.

The testing programme involved making two series of concrete (non-air-entrained and air-entrained concretes), for which the compositions were adopted according to the 5 points design, with the following factors investigated: X_1 – water/binder ratio (W/B) and X_2 – slag/cement ratio (GGBS/C). Coded variables were: X_1= (W/B – 0.45)/0.05; X_2= (GGBS/C –0.25)/0.25

The five points design is shown in Fig. 1 and the coded and real values of the factors under investigation are summarized in Table 1.

Table 1. Coded and real values of investigated factors.

Point	X_1	X_2	W/S	GGBS/C
1 (6)	-1	-1	0.40	0
2 (7)	-1	1	0.40	0.50
3 (8)	1	-1	0.50	0
4 (9)	1	1	0.50	0.50
5 (10)	0	0	0.45	0.25

The relationship is described by the regression function in the form of a non-full second degree polynomial $y = a_0 + a_1*X_1 + a_2*X_2 + a_{12}*X_1*X_2$. The correlation coefficient, R, is the measure of how well the function fits the measurement results. The experiment allows determining the relationships between factors X_1, X_2 and the given characteristic of the concrete.