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POROSITY PARAMETERS OF CONCRETE WITH INNOVATIVE AIR-ENTRAINING MULTICOMPONENT PORTLAND CEMENT CEM II/B-V

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ABSTRACT

This paper presents the results of a study on the pore structure of concrete according to PN-EN 480-1 with w/c ratio = 0,45; 0,50 and 0,55, made with innovative, air-entraining CEM II/B-V. Porosity parameters of concrete were obtained from the processing of computed tomography (CT) scanned images. The research results prove that the air-entraining cement CEM II/B-V, regardless of air-entraining admixture, provides the structure of air-voids in concrete which meets the requirements of European standards and guidelines for frost-resistant concrete. The type of air-entraining admixture and w/c ratio affect the porosity of concrete significantly.

Keywords
air-entraining cement, fly ash, air-entraining admixture, concrete, porosity

INTRODUCTION

In order to maintain better durability performance and extended service life in freezing and thawing environments, concrete should have an adequate air-void. For this, a suitable amount of entrained air-voids with accurate specific surface and spacing factor should be ensured. Commonly, limits on the volume of air-voids or air content are specified although the role of the spacing factor is important. This is due to the fact that the air content can be determined more effortlessly and immediately than the spacing factor (Safiuddin et al., 2006) [1]. This type of the air entrainment is desired for freeze-thaw protection. To accomplish this, air entraining agents are used to entrain or better stabilize the required air.

The type of air-entraining admixture affects the porosity of concrete significantly. Research results presented in the publication (Kqlaots et al. 2004) [2] proved that the natural admixture aeration is more powerful than the synthetic one because the natural admixture participation is much smaller than the synthetic in cement. Generally, the more water in the volume of concrete, the more air bubbles are formed (Du and Folliard 2005) [3]. It is not known which type of admixture entraining is less sensitive to changes in the quantity of water in the concrete.

Moreover, cement type is an important factor for achieving proper porosity in concrete. Most problems with appropriate air-entrainment take place in concretes with fly ash cement. The main reason is that the coke in fly ash with a developed specific surface (loss of ignition) may absorb on its surface the surface-active factor, thereby decreasing its effectiveness. Therefore, a higher amount of air-entrainment admixture may be required in order to achieve the same degree of air-entrainment. Furthermore, if the distribution of coke in concrete is irregular, areas of different air content may occur. Fly ash, even in small quantities reduces the natural air content by about 1%. Although Fagerlund (Fagerlund 1994) [4], (Fagerlund 1999) [5] proposed that for concrete with air-entrainment the effect of fly ash is negligible, provided that its content does not exceed 25% (ACI 218-95 recommends the reduction of puzzolan to a value of 25%). However, if the distribution of unburned coke in concrete is uneven, then areas of different air content may occur. Accordingly, he proposes a higher dosage of air-entrainment admixture. It is worth indicating the types of cement – apart from CEM I – recommended in a XF environment. For example, in environmental classes XF2 and XF4, the Austrian Standard qualifies cement CEM II-A-V as "recommended", while the German Standard qualifies this cement as "not recommended".

The present study is an experimental analysis of the influence of innovative air-entraining of CEM II/B-V with two different types of air-entraining admixture: natural and synthetic on the porosity structure of concrete according to PN-EN 480-1 with w/c ratios = 0.45; 0.50 and 0.55. The variation in w/c values corresponds to the indication of PN-EN 206-1, as the minimum recommended value for the XF1-XF4 class of aggressiveness of the environment.

EXPERIMENTAL PROCEDURE

The influence of the w/c ratio (0.45 and 0.55) on the porosity of concrete according PN-EN 480-1 [6] with air-entraining CEM II/B-V (Tables 1-3) with two different types of air-entraining admixture: natural and synthetic (Table 4) was investigated.

Table 1. The air-entrainment of CEM II/B-V

Cement	Established air content in the mortar, %	Air-entraining admixture type	Amount of air-entraining admixture, % mass of cement	Air content acc. PN-EN 1015-7 of mortar acc. PN-EN 480-1, %
Air-entraining CEM II/B-V	10.0	natural	0.060	10.0

Table 2. The properties of CEM II/B-V

Cement	Specific surface	Setting time		NR, %	SO_3, %	LOI, %
		start	end			
Air-entraining CEM II/B-V	4180	199	274	23.1	2.89	2.82

The air-content of fresh concrete was investigated according to PN-EN 12350-7 [7]. Ambient temperature during mortar testing was 20°C±1°C. The relative air humidity was about 50%. The porosity structure parameters of the air-entrained concrete according to PN-EN 480-11 [8] with air-entraining CEM II/B-V were estimated. Porosity parameters of concrete were obtained from the processing of computed tomography (CT) scanned images. Similar research was carried out by Ponikiewski et al., 2014 [9]. Tomographic studies of samples were performed using a CT scanner.

Table 3. The properties of components of air-entraining CEM II/B-V

Properties	CEM I 52.5 R, % mass of cement	Siliceous fly ash, % mass of cement
Loss on ignition	0.64	2.26
SiO_2	20.8	54.20
$A12O_3$	5.18	26.81
Fe_2O_3	2.94	5.62
CaO	63.9	3.03
MgO	1.38	0.82
SO_3	4.61	0.34
K_2O	0.73	2.92
Na_2O	0.12	0.61

Table 4. The amount of different components in the concrete; kg/m^3

Component	AEA type	w/c=0.45	w/c=0.50	w/c=0.55
Water		167.64	175.00	181.45
Air-entraining CEM II/B-V	synthetic AEA	-	350.00	-
Air-entraining CEM II/B-V	natural AEA	-	350.00	-
Air-entraining CEM II/B-V	synthetic AEA	372.36	-	-
Air-entraining CEM II/B-V	natural AEA	-	-	329.82
Sand 0-2 mm		522.55	522.55	522.55
Crushed gravel 2-8 mm		521.00	511.90	512.00
Crushed gravel 8-16 mm		853.09	853.10	853.00

Tomographic studies conducted on drilled core samples (with a diameter of 10 mm) which were taken from the cubic size 15x15x15 cm. On the basis of the digital image analysis of drilled concrete cores, the structure parameters of air voids were determined by the means of a computer program.

RESULTS OF THE TESTS AND DISCUSSION

Figs 1 - 9 show the porosity research results of fresh and hardened concrete with w/c= 0.45; 0.50 and 0.55 including natural or synthetic air-entraining admixture. Air entrainment of fresh concrete is more or less stable, depending on the w/c ratio and type of air-entraining admixture (Fig. 7). In the case of the synthetic admixture content of these pores is by far the largest (Figs 1, 2 and 4, 6). However, in the case of natural admixture, the proportion of micropores with diameters less than 300 microns pore is also large (Figs 8, 10), in the case of concrete with a higher w/c ratio. Figs 7 and 8 show that with the increase of the w/c ratio, air-content increases and thus the specific surface of pores, and micro pores content.

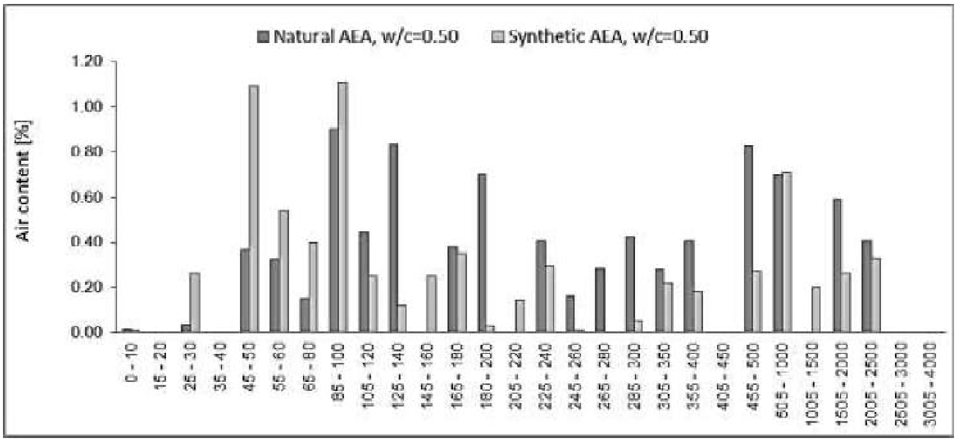

Fig. 1. Pore size distribution of concrete with CEM II/B-V, synthetic and natural AEA, w/c = 0.50

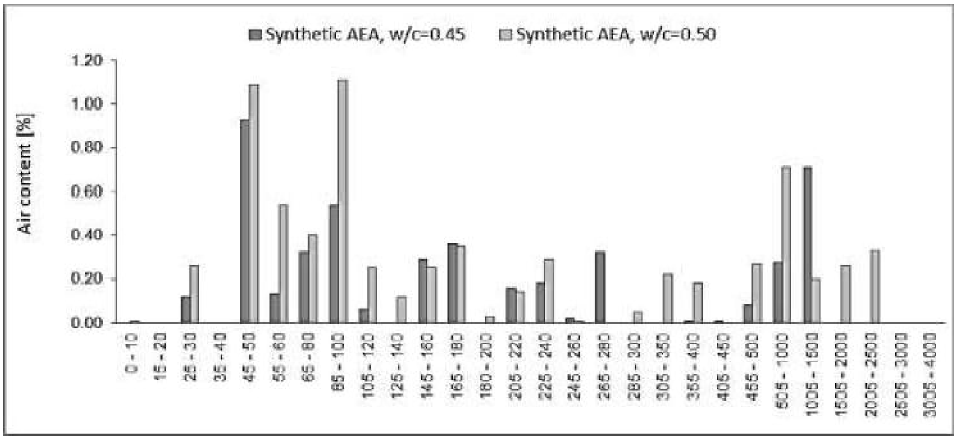

Fig. 2. Pore size distribution of concrete with CEM II/B-V, synthetic AEA, w/c = 0.50 and 0.45

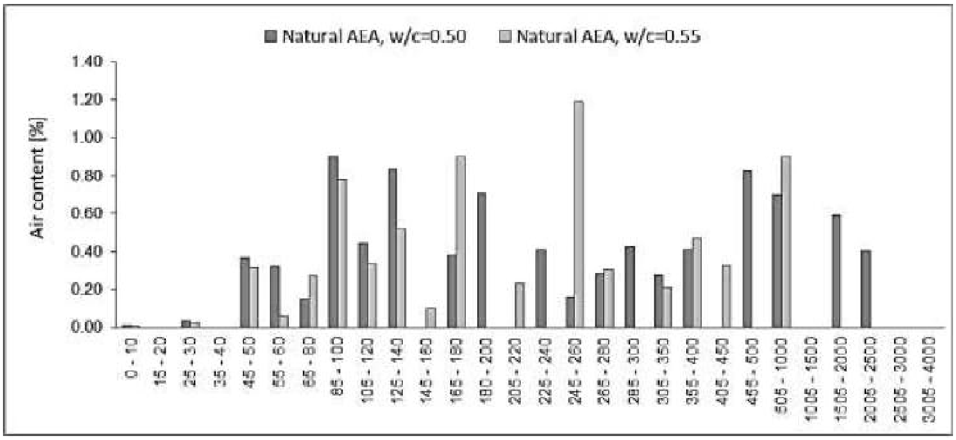

Fig. 3. Pore size distribution of concrete with CEM II/B-V, natural AEA, w/c = 0.50 and 0.55

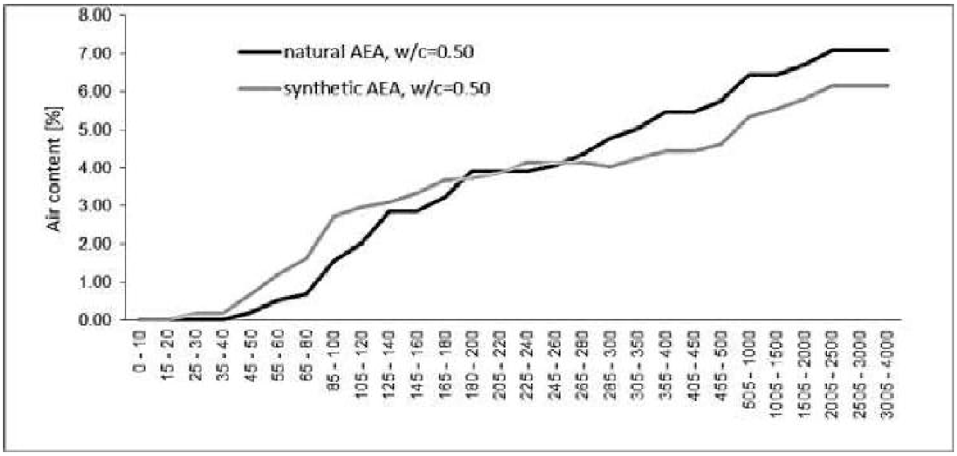

Fig. 4. Cumulative air content of concrete with CEM II/B-V, synthetic and natural AEA, w/c = 0.50

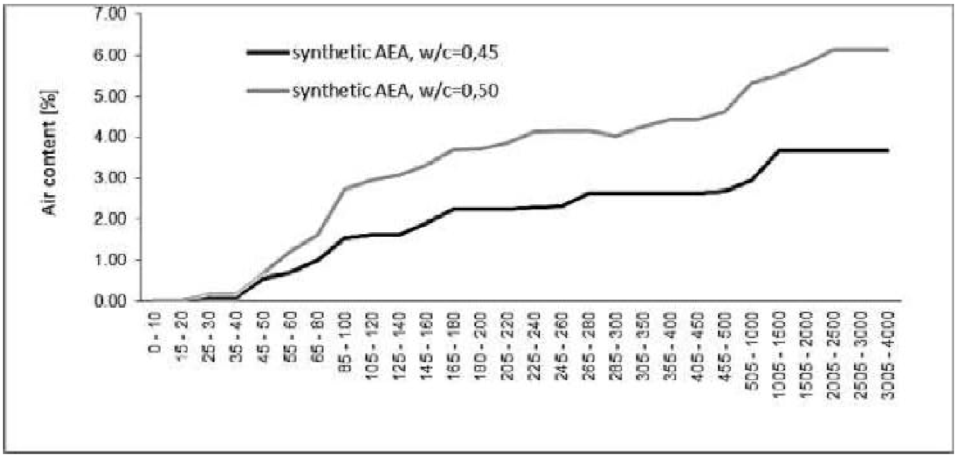

Fig. 5. Cumulative air content of concrete with CEM II/B-V, synthetic AEA, w/c = 0.50 and 0.45

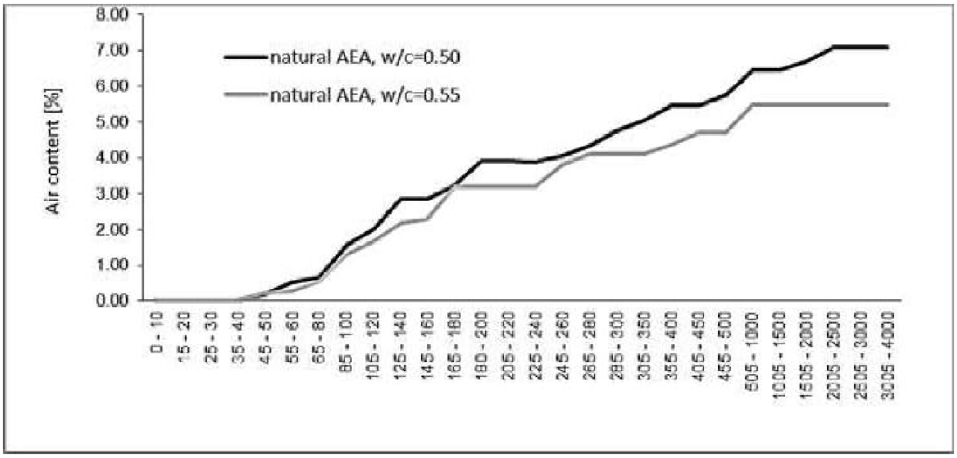

Fig. 6. Cumulative air content of concrete with CEM II/B-V, natural AEA, w/c = 0.50 and 0.55.

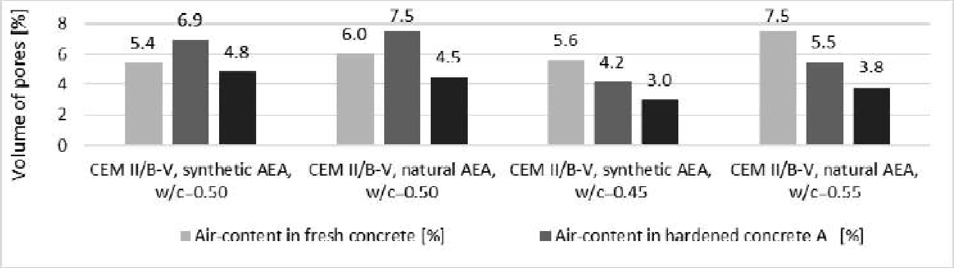

Fig. 7. Influence of w/c and type of CEM II/B-V on the air content of fresh concrete (A_c) and hardened concrete (A) and content of air-voids with a diameter smaller than 0.300 mm (A_{300}).

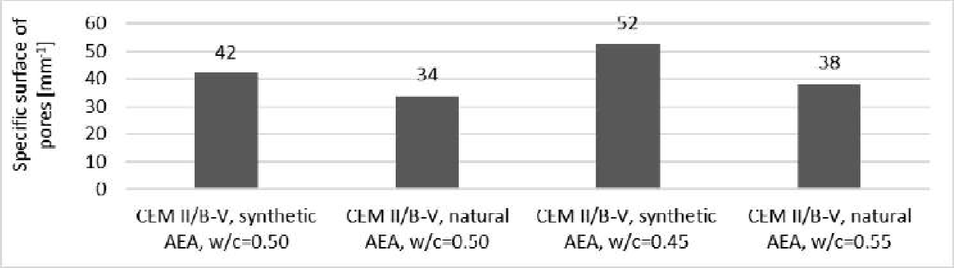

Fig. 8. Influence of w/c and type of CEM II/B-V on specific surface of the air voids of concrete.

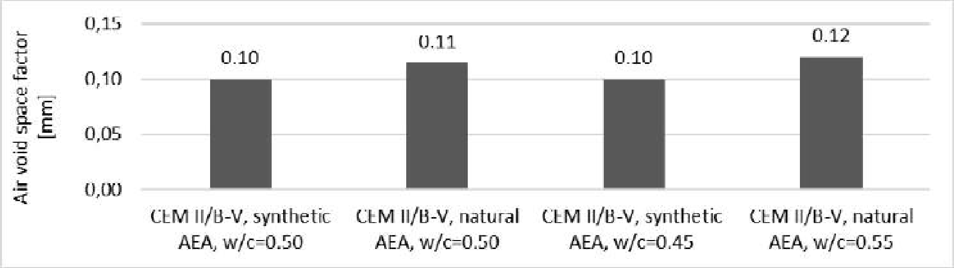

Fig. 9. Influence of w/c and type of CEM/II B-V on the air-voids space factor of concrete (L)

As shown in Figs 5 and 6, the influence of the w/c on the resultant cumulative air content depends on which type of air-entraining admixture was used in the concrete composition. It is interesting and needs further elaboration. The foaming property of surfactants can be affected by the impurities present in the host solution (Du and Folliard 2005) [3]. However the research results presented in Figs 2 and 3 and in Figs 5 and 6 indicate that changing the amount of water in the concrete relative to the cement clearly differentiates content and pore size in the case of synthetic air-entraining admixture, than in the case of natural air-entraining admixture.

Research results presented in a publication (Kqlaots et al. 2004) [2] proved that the natural admixture aeration is more powerful than the synthetic one because the natural admixture participation is much smaller than the synthetic in cement. Commercially available air-entraining agents are generally manufactured from chemically complex raw materials, and the final products may consist of blends of these raw materials plus other raw materials or chemicals, hence it is challenging to define the air-entraining agents chemically except by a rather broad classification.

Synthetic detergents allow the quick production of the air bubbles in concrete; these bubbles tend to be coarser than those produced using wood-derived materials (Zhang et al. 2002) [11]. While their primary application has been for foaming agents, some are also used as the air-entraining agents. Generally speaking, the synthetic ones produce air quicker than the organic ones; yet, the organic ones have better compatibility with other admixtures than the synthetic ones (Whiting et al. 1998) [10].

The synthetic agents are more active in lowering the surface tension of cement filtrate than their vinsol resin counterparts (Zhang et al. 2002) [11]. The results of the research presented in Fig. 6-14 show that a greater the amount of micro pores in concrete is the result of a synthetic air-entraining admixture. In concrete with synthetic entraining admixtures the air pores have smaller diameters than in concrete with natural air-entraining admixture, which are being transferred into their specific surface. As shown in Fig. 9, the synthetic admixture is more favorable than the natural one because of the value of the air-voids spacing factor of concrete. The obtained results are consistent with the published results in (Łaźniewska-Piekarczyk 2013) [12].

The air-voids structure of concrete is considered to protect against the damaging effects of cyclic freezing-thawing, if the total air content of concrete is between 4% and 7%, the air-voids space factor $\bar{L}$ is smaller than 0.20 mm or 0.22 mm. Specific surface area of air-voids α is in the range16-24 mm^{-1}, and volume of micropores smaller than 0.300 mm (A_{300}) is at least 1.5% (Brandt and Kasperkiewicz 2003) [13], (Brandt 2010) [14], (Glinicki 2005) [15], (Glinicki 2011) [16].

In Glinicki's publications (Glinicki 2011) [15] (Glinicki 2005) [16], (Glinicki 2014) [17] standard specifications for air entrainment of concrete designed for the exposure in XF2 to XF4 classes are presented as given in the EN-206 [18], general technical specification of the GDDKIA for concrete road pavements [19], Austrian ONORMB 4710-1 standard [20], Danish DS 2426 standard [21], German DIN 1045-2 standard [22].

The new edition of the EN 206 standard from (2014) [19] makes reference to the criterion of the air void spacing factor specified in PN-EN 934-2, determined as for PN-EN 480-11. In the PN-EN 934-2 standard related to the admixtures for concrete the threshold value of $\bar{L} \leq 0.20$ mm is specified in the air entrained concrete

In the general technical specification of the GDDKIA for concrete road pavements (19) dated 2003 the limit for the spacing factor $\bar{L} \leq 0.20$ is provided. The air content in air-entrained concrete should be not less than 3.5% of the compacted concrete mixture, as a result of the AE agent use.

In the Austrian ONORMB 4710-1 standard, Danish DS 2426 standard the detailed specifications for the air void microstructure in hardened concrete are provided. According these standards, depending on the class of frost exposure, the minimum air content in the mixture or concrete should be from 2.5% to 4.5%; the minimum content of micro-voids A_{300} should be from 1.0% to 1.8%; and the maximum void spacing factor $\bar{L}$ should be from 0.18 mm to 0.20 mm.

The German DIN 1045-2 standard does not introduce a detailed specification for air voids microstructure in air-entrained concrete. The specified air content in the concrete mix is within the limits from 3.5% to 5.5%, depending on the aggregate size.

The porosity parameters of concrete with CEM II/B-V presented in Figs 7-9 meet all mentioned above requirements and those of the European standards for frost-resistant concrete also.

In view of the research results presented above (Figs 1-9) it can be concluded that innovative, air-entraining cement CEM II/B-V, regardless of the used air-entraining admixture, provides an proper porosity of concrete (acc. PN-EN 480-1) with w/c = 0.45-0.55.

CONCLUSIONS

Based on the research results conducted by the reference concrete according to PN-EN-480-1 with w/c = 0.45, 0.50 and 0.55 (as recommended by PN-EN 206-1 for XF1-XF4 classes) it is concluded that:

- the air-entraining cement CEM II/B-V, regardless of the air-entraining admixture used, provides the air-voids structure that meets the requirements of European standards and guidelines for frost-resistant concrete.
- the influence of the w/c to the resultant pore size depends on type of air-entraining admixture which was used in the concrete composition. Changing the amount of water in the concrete in relation to the cement clearly differentiates content and pore size in the case of synthetic air-entraining admixture, than in the case of natural air-entraining admixture.
- a greater amount of micro pores in concrete is the effect of a synthetic air-entraining admixture. In concrete with synthetic entraining admixtures the air pores have smaller diameters than in concrete with natural air-entraining admixture, which are being transferred into their specific surface. The synthetic admixture is more favorable than the natural one also because of the value of the air-void spacing factor of concrete.

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