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Research paper

Air permeability and sorptivity of concrete modified with viscosity modifying agents

Wojciech Kubissa[1], Karol Prałat[2], Szymon Kania[3]

Abstract: The paper presents the effect of a viscosity modifying admixture (VMA) on the air permeability, sorptivity and strength parameters (compressive and tensile strength) of concrete. The Atlas VM-500 admixture used in the research is a well-known additive that is commonly applied in concrete technology. Air permeability tests were carried out using the Torrent method. It was found that viscosity modifying admixtures (VMAs) have a significant impact on the permeability of concrete. The lowest values of the k_T coefficient were obtained for specimens that matured in a water environment, and which contained 0.5% of VMA. This amount of additive reduced permeability by 34% when compared to the reference series of concrete. For air-conditioned specimens with 1.2% of VMA, the maximum decrease was 28% when compared to the reference samples. In the case of samples conditioned in an environment with an increased humidity, the maximum decrease occurred with a lower VMA content of 0.5% and amounted to 27% when compared to the reference samples. In addition, it was shown that the addition of 1.2% of VMA improved the compressive strength of concrete by 2.3% during its curing in water. In turn, this amount of VMA deteriorated its strength by 10.4% when the specimens were conditioned in air, and by 8.1% when they were conditioned in high humidity.

Keywords: torrent method, air permeability, viscosity modifying agents (VMA), concretes composites

[1]PhD., Eng., Warsaw University of Technology, Faculty of Civil Engineering, Mechanics and Petrochemistry, ul. Łukasiewicza 17, 09-400 Płock, Poland, e-mail: Wojciech.Kubissa@pw.edu.pl, ORCID: 0000-0001-5626-7917
[2]DSc., PhD., Eng., Warsaw University of Technology, Faculty of Civil Engineering, Mechanics and Petrochemistry, ul. Łukasiewicza 17, 09-400 Płock, Poland, e-mail: Karol.Pralat@pw.edu.pl, ORCID: 0000-0001-5116-0379
[3]Student, Warsaw University of Technology, Faculty of Civil Engineering, Mechanics and Petrochemistry, ul. Łukasiewicza 17, 09-400 Płock, Poland, e-mail: Szymon.Kania.stud@pw.edu.pl

1. Introduction

The development of concrete technology, which is mainly due to the use of more and more advanced chemical admixtures, allows for a very precise modification of the rheological parameters of a concrete mix and hardened material. The aim is to obtain as fluid a mixture as possible. Mixtures of this type are highly exposed to the segregation of ingredients and the release of water on the upper surface of molded elements. They require additional viscosity improving admixtures (VMAs) in order to improve the cohesion of the ingredients. Such an admixture is usually used in concrete with a low w/c ratio with the simultaneous use of a superplasticizer [1, 2]. VMAs, which include cellulose derivatives and polysaccharides of microbial sources (especially welan gum), are more and more widely used, and their application will probably be expanded [3].

The application of VMAs affects the aqueous phase of a cement paste, in which chains of water-soluble polymers can absorb some of the free water in the system. This results in the increase of the viscosity of the cement paste, and as a consequence, in a lower amount of free water that can be used for bleeding. The increased viscosity of the cement paste can also improve its capacity to suspend solid particles, which in turn reduces sedimentation [4, 5].

Mineral building materials, including cement concrete, have a porous structure that can be easily penetrated by liquids and gases from the natural environment. Therefore, a measure related to the durability of concrete, the so-called permeability, is introduced. It can be determined by measuring quantities that characterize the flow of liquids or gases. Very often, for the purpose of assessing the potential durability of concrete, water absorption or sorptivity are also measured [6–8].

The presence of pores, microcracks, and networks of air voids allows for the transport of water in hardened material, which is caused by an external hydrostatic pressure, or capillary forces. Water leakage through a partition means insufficient performance of the assumed functions by the structure. The penetration of liquid into concrete may contribute to the loss of its required durability, because water is a very good environment for many chemical reactions. Additionally, it may contain aggressive substances, which cause the corrosion of concrete and its reinforcement.

Papers [9–11] focus on the problem of shrinkage cracks that occur during the hardening of concrete. Such cracks can significantly accelerate common degradation mechanisms, which include sulfate attack, chloride-induced corrosion, freezing-and-thawing attack, degradation, and/or the alkali-silica reaction. However, it is possible to reduce them by using VMAs. Bentz, in paper [11], proposed a new approach for the reduction of diffusive transport in concrete. Moreover, the author also described methods for reducing the propensity of early-age cracking, which is caused by autogenous stresses. The new approach involved the increase of the viscosity of concrete, as opposed to the densification of the binder matrix, which can lead to early-age cracking. The dependence between the diffusivity and the viscosity of the pore liquid was also noted in study [12]. The increase in the viscosity of the pore fluid allowed diffusive transport in concrete to be significantly reduced, and the durability of structures made of such material to be improved.

The porous structure of ordinary concrete of higher classes, as well as high-performance concrete (which has its high values of mechanical properties due to the reduced total porosity and the shifting of the distribution of pores towards smaller diameters), is rarely available for a medium that is as dense and viscous as water [13]. Due to this, gas permeability is very often a better way to assess the accessibility of a porous structure by external media, and thus to assess the potential durability of such concrete [14–18]. In order to assess permeability, the Torrent method is more and more commonly used [19–21]. This measurement is usually limited to the air flow in the surface layer of concrete that is several centimeters thick. The greater the thickness of the layer of concrete that is subjected to the permeability measurement, the greater its permeability. Such thicknesses usually range from 10 to 100 mm. The measurement of permeability involves the application of an underpressure to the surface of the tested concrete element with the use of a highly efficient vacuum pump. The time and intensity of equaling the value of pressure to the value of atmospheric pressure depends on the permeability of the tested concrete. This measurement allows the value of the k_T permeability coefficient to be obtained [22, 23]. The air permeability of concrete is related to, among otheres, its sorptivity, susceptibility to carbonation, and its ability to transport chloride ions. Knowledge of these parameters enables the durability of the material to be predicted [22].

In article [24], the authors draw attention to the weaknesses of the methods that are currently used in most countries to ensure the proper durability of concrete and reinforced concrete structures. At the same time, they indicate the air permeability test as one of the methods that enables the quality and performance of concrete to be assessed. They postulate that requirements that are similar to those presented in papers [19, 25] should be implemented in other countries. The usefulness of gas permeability testing methods in structural diagnostics was also highlighted in paper [26]. Air permeability is an important component of the system of designing concrete structures with regards to durability. Meeting the requirements that are set out in papers [27, 28] allows the durability of a structure to be forecasted for up to 100 years.

The permeability of concrete, which can be measured using various methods, is significantly influenced by the moisture content of the concrete [29–32]. In the case of the Torrent method, this problem was solved by its authors, who experimentally determined this effect and equipped their apparatus with a probe for indirect measurements of the moisture content of concrete, the substitute measure of which is its specific resistance. Research concerning the air permeability of concrete in its specific state of water saturation is presented in [33–35]. Due to the fact that permeability strongly depends on the water content in concrete, the authors emphasized that in order to directly compare the results of different series, samples should have the same moisture content before measurements. The frequently used method of intensive drying at 105°C causes damage to samples, the formation of microcracks, and induced chemical changes, which in turn affects the results of permeation tests. In this case, drying at a maximum temperature of 65°C is recommended.

The authors of [19], whilst presenting the guidelines of the Swiss standard SIA 262/1 [25], recommend using Tramex CMEX II apparatus for measuring the moisture content of tested concrete. Measuring permeability is possible when the tested moisture content is lower than 5.5‰, and therefore it is always necessary for it to be controlled in the tested structure or specimens. The limit values of the k_T permeability coefficient were proposed for air-entrained concrete, which is used in the XF environment classes, and also the XC and XD exposure classes (Table 1).

Table 1. Limiting values of k_T specified as a function of the exposure conditions [25]

Exposure	EN 206 classes	$k_T \cdot 10^{-6}$ [m^2]
Moderate carbonation	XC1, XC2, XC3	Not required
Severe carbonation Moderate chlorides Moderate frost	XC4 XD1, XD2 XF1, XF2	2.0
Severe chlorides Severe frost	XD2 XD3 XF3, XF4	0.5

The number of publications presenting the effect of VMAs on the properties of a concrete mixture is small, and therefore the operation of VMAs is not fully understood [3, 38, 39]. This is despite the fact that it is easy to find information in literature concerning the action of many chemical admixtures, the improvement of concrete tightness after their use, the increased chemical resistance to sulphates of concretes modified with them [36], nd the increased chemical resistance to the penetration of chloride ions [37]. Even less data is available on the effect of this admixture on the properties of the resulting composite, i.e. concrete.

The aim of this study was to determine the effect of the VMA used in concrete on the air permeability, sorptivity and strength parameters (compressive and tensile strength) of the obtained composites, which were matured differently for 28 days.

2. Experimental procedures

2.1. Materials

Portland cement CEM I 42.5R from Górażdże Cement Plant according to PN-EN 197 was used. The basic physical properties reported by the manufacturer of the cement are shown in Table 2.

Table 2. Basic physical properties of the cement (according to the manufacturer's declaration)

Cement type	Setting time		Compressive strength after 28 days [MPa]	Specific surface area (Blaine) [cm^2/g]	Specific gravity [g/cm^3]	Density [g/cm^3]	Loss of ignition [%]
	start [min]	end [min]					
CEM I 42.5R	194	248	56.9	3721	3.10	1.26	3.01

All the concrete mixes contained 360 kg/m^3 of cement and had a w/c ratio of 0.45. Fractions of sand of 0–2 mm, and granite of 2–8 mm and 8–16 mm were used. The aggregates were dried in air-dry laboratory conditions. Superplasticizer Atlas Duruflow PE-220, and Atlas VM-500 VMA were used for water retention reduction and the prevention of concrete bleeding. Both of them are compliant with the PN-EN 934-2 standard. Regular tap water was used as the mixing water. The recipes of the concrete mixes and their selected properties are shown in Table 3. The consistency of the mixture was tested using the flow table test method before forming the specimens. The flow table test was carried out in accordance with PN-EN 12350-5.

The temperature of the concrete mixture was measured before the consistency test using a laboratory thermometer with a resolution of 0.1°C. The specimens were prepared according to PN-EN 12390-2. They were shaped in plastic moulds and compacted two times (moulds half-filled and full) on a vibrating table. The specimens after demoulding were cured for 28 days in three different ways: in water (W), in high relative humidity > 95% RH (H), and in air-dry conditions in the laboratory of RH = 50% ± 10% (A). The temperature in each case was 20°C ±2°C.

Table 3. Recipes of the concrete mixes and their selected properties [kg/m^3]

Component \ Mixture ID	C-I-R	C-I-O	C-I-M
CEM I 42.5R	360	360	360
sand 0–2 mm	656	655	652
granite 2–8 mm	614	613	610
granite 8–16 mm	614	613	610
water	162	162	162
Atlas VM-500	0.0	1.8	4.3
(as% of cement mass)	0.0	0.5	1.2
Atlas Duruflow PE-220	4.3	4.3	4.3
(as% of cement mass)	1.2	1.2	1.2
temperature [°C]	21.5	21.2	20.6
table flow [mm]	535	370	335

* designations: C-I-R – reference sample, C-I-O – sample with the optimal content of VM-500, C-I-M – sample with the maximum content of VM-500 that is allowed by the manufacturer

2.2. Compressive and tensile splitting strength tests

The compressive strength test and the tensile splitting strength test were conducted using a ToniTechnik testing-machine with a maximum force of 3000 kN according to PN-EN 12390-3 and PN-EN 12390-6, respectively. The load was increased at the rate of

0.5 MPa/s for the compressive strength test, and at the rate of 0.05 MPa/s for the splitting tensile strength test. Both tests involved six cubic specimens with a 100 mm edge length. The tests were carried out after the concrete had hardened for 28 days.

2.3. Sorptivity test

Six half-cube specimens with an edge length equal to 100 mm were subjected to tests using the mass method. The specimens were first oven-dried in a laboratory dryer at a temperature of 105°C. The basic purpose of this procedure was to obtain a constant mass. The specimens were then weighed and placed in a container with water. The water level was about 3 mm above the base of the specimens. The measurements of the weight gain due to water sorption were performed at specific time intervals over the course of 6 hours. Sorptivity S in cm/h$^{0.5}$ was calculated as the slope of the linear function that describes the ratio of the mass of the absorbed water Δm to the area F in the square root of time $t^{0.5}$ according to the following formula [40]:

$$\frac{\Delta m}{F} = S \cdot t^{0.5} \tag{2.1}$$

2.4. Torrent air permeability test

The air permeability test, which enables non-destructive measurements to be taken, was conducted with the use of the Torrent method and Proceq equipment on two cubic specimens with a 150 mm edge length. Due to the fact that the results of such tests depend on the preparation of the specimen's surface [41], four side surfaces of each specimen, which were not subjected to any previous treatment (e.g. grinding, sanding etc.), were tested. The test was performed three times: first after 56 days after concreting, the second time after 90 days after concreting, and the third time after the specimens obtained a Tramex RH 0.0% in a laboratory drier at a temperature of 65°C. The RH of these specimens was measured after their temperature dropped to room temperature. The moisture content of both specimens was also tested on each of their surfaces before the first and second air permeability test. In all cases, RH was measured four times using a Tramex CMEX II meter, which was each time rotated by 90 degrees. The mentioned measurement of specimen moisture is a non-destructive measurement. It is based on measuring the electrical impedance, which changes with the humidity of the specimen. An electric field is generated between two electrodes (transmitting and receiving). This field penetrates through the tested material. The very small alternating current flowing through the field is inversely proportional to the impedance of the material. The instrument detects this current, determines its amplitude, and thus determines the moisture value. After finishing the moisture content tests, one measurement of air permeability per surface was carried out during all three test series.

The air permeability test was conducted in laboratory conditions and started with the creation of a vacuum in a steel cell sealed with rubber gaskets. The steel cell was attached to the concrete surface, which was without any defects and cavities, in order to induce a flow of air through the concrete. In some situations, when the tested surface is inappropriate, the cell can be moved by a maximum of 1 cm from its symmetrical position on the centre of the wall. The flow of air through the concrete increases the pressure inside the cell. This change in pressure during the test is recorded using Torrent's apparatus, which automatically calculates the value of the k_T permeability coefficient and determines the depth L of the concrete layer that was penetrated by the vacuum. When the vacuum in the cell increases by 25 mbar, the measurement is finished. However, the measurements did not take more than 660 seconds, and due to the fact that the vacuum inside the cell is obtained in 60 seconds, the total testing time of each surface did not exceed 720 seconds.

3. Research results and analysis

Table 4 shows the results of tests of mechanical and physical properties. Mechanical properties are compressive strength and tensile splitting strength, which were tested after 28 days. Physical parameters, which are related to durability, include sorptivity that was measured after 28 days, and also the Torrent air permeability coefficient k_T that was measured after 56 and 90 days on specimens with natural RH and on specimens after being dried at 65°C. Each result is the average of the results obtained from six specimens, not including the result of k_T, which is the average of eight results. The standard deviation value is given in parentheses.

3.1. Consistency

The C-I-R reference series reached the F4 consistency with a result of 535 mm. The addition of VMA significantly lowered the flowability of the mixture, which in the C-I-O series had a flow of 370 mm (F2 class). When the maximum dose of the admixture was added, the C-I-M series had a spread of 335 mm (F1 class). Despite significant differences in the consistency of the mixtures, no problems with the appropriate compaction of the samples were found. However, changes in consistency caused by the addition of VMA are significant and should be taken into account when designing concrete mixture recipes. This is especially important in cases in which a certain consistency is required, e.g. due to the requirements related to pumping. In the reference mixture, the separation of milk and water was observed on the upper surface of the samples during compaction. This phenomenon did not occur in the series with the addition of VMA.

3.2. Compressive and tensile splitting strength

The effect of the treatment method of the concrete and the addition of VMA on the compressive strength is regular and similar in each of the tested series: C-I-R, C-I-O and C-I-M. The highest compressive strength was obtained in the case of the samples cured in the water (W), and was on average equal to 66.68 MPa in the case of the samples without the addition of VMA. The samples of the reference series (without VMA conditioned in H and A conditions) had average strength values of 61.51 MPa and 57.74 MPa, respectively. With

Table 4. Test results of the concrete composites modified with VMA

Obtained results	Tested composite and the method of its treatment								
	C-I-R (VMA = 0%)			C-I-O (VMA = 0.5%)			C-I-M (VMA = 1.2%)		
	A	W	H	A	W	H	A	W	H
Compressive strength after 28 days [MPa] (σ [MPa])	57.74 (1.38)	66.68 (1.35)	61.51 (2.11)	55.41 (1.42)	67.74 (1.38)	59.54 (2.51)	51.75 (2.16)	69.22 (1.50)	56.51 (2.26)
Tensile splitting strength after 28 days [MPa] (σ [MPa])	3.41 (0.25)	3.58 (0.34)	3.91 (0.33)	3.67 (0.57)	3.97 (0.17)	4.26 (0.29)	3.55 (0.35)	3.81 (0.34)	3.95 (0.39)
Sorptivity after 28 days [cm/h$^{0.5}$] (σ [cm/h$^{0.5}$])	0.160 (0.011)	0.109 (0.010)	0.117 (0.016)	0.141 (0.007)	0.098 (0.007)	0.109 (0.007)	0.146 (0.012)	0.102 (0.006)	0.107 (0.007)
Permeability after 56 days of conditioning $k_T \cdot 10^{-16}$ [m^2] (the Torrent method) (σ [m^2])	1.089 (0.601)	0.005 (0.002)	0.393 (0.258)	0.919 (0.295)	0.002 (0.001)	0.265 (0.145)	0.393 (0.217)	0.021 (0.026)	0.329 (0.185)
Permeability after 90 days of conditioning, $k_T \cdot 10^{-16}$ [m^2] (the Torrent method) (σ [m^2])	1.814 (1.035)	0.017 (0.004)	0.672 (0. 358)	1.381 (0.576)	0.006 (0.003)	0.456 (0.154)	1.249 (0.327)	0.009 (0.004)	0.545 (0.293)
Permeability after drying at 65°C, $k_T \cdot 10^{-16}$ [m^2] (the Torrent method) (σ [m^2])	10.713 (4.862)	1.541 (0.273)	7.346 (2.670)	8.957 (1.905)	1.028 (0.163)	5.382 (1.037)	7.801 (1.073)	1.328 (0.124)	6.043 (2.625)

the increasing amount of VMA in the concrete, the samples cured in the water increased their compressive strength by 1.6% and 3.8% in the case of the optimal and maximum addition of VMA, respectively. A reverse relationship was observed in the case of the series of concrete conditioned in A and H conditions, as well as in O and M conditions. In these cases, with an increasing amount of VMA, a decrease in the compressive strength of the samples was observed – in the first case by 4.0% and 10.4%, and in the second by 3.2% and 8.1%, respectively (Fig. 1a).

a) b)

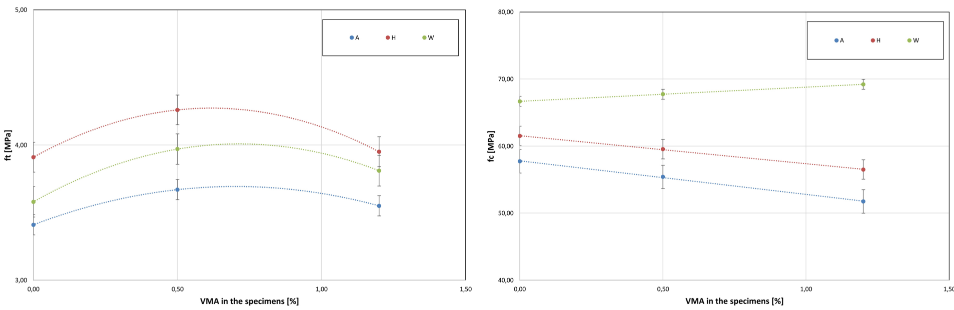

Fig. 1. Graph of the dependence between the amount of VMA and: a) the compressive strength, b) the tensile splitting strength

Regardless of the conditioning method, the highest strength values were obtained in the samples with a content of VMA equal to 0.5%. The highest values of tensile splitting strength were obtained for the samples cured in H conditions. When the optimal amount of admixture was added, the obtained strength was by 16.1% higher than that of the samples stored in air, and by 7.3% higher than that of the samples cured in the water (Fig. 1b). It should also be noted that there was only an increase in the compressive strength with an increase in the addition of VMA in the case of the samples cured in the water.

Generalized relationships were proposed for all the methods of conditioning the samples (3.1) and (3.2) $f_c = f(VMA)$ and $f_t = f(VMA)$:

$$f_c = A \cdot VMA + B \tag{3.1}$$

$$f_t = C \cdot VMA^2 + D \cdot VMA + E \tag{3.2}$$

for which equation constants A, B, C, D and E are included in Table 5.

Based on the determination coefficients R^2, a very good match of the results was found.

Table 5. The values of constants A, B, C, D, and E for equations 3.1. and 3.2

Conditioning method	A	B	C	D	E
A	–5.01	57.80	–0.5762	0.8081	3.41
H	–4.18	61.55	–0.9524	1.1762	3.91
W	2.12	66.68	–0.8405	1.2002	3.58

3.3. Sorptivity

Figure 2 shows a graph of the dependence between sorptivity and the compressive strength of the samples cured in different conditions. Regardless of the conditioning method of the samples, there was a decrease in sorptivity with an increase in the amount of VMA, which can be seen to be a desired effect. In the case of the samples conditioned in the water, the lowest result (10.1% lower than the result of the reference series) was obtained by the series with 0.5% of VMA. An increase in the content of VMA to the maximum possible value of 1.2% resulted in a smaller decrease in sorptivity by 6.4% when compared to the result of the reference series.

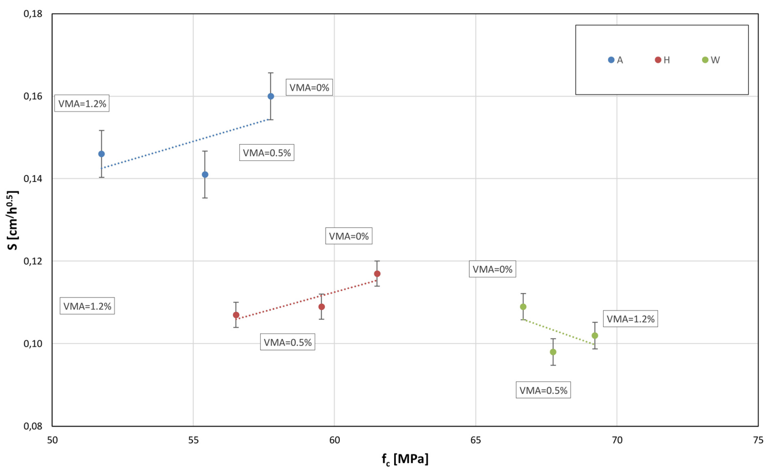

Fig. 2. Graphs of $f_c = f(S)$ of the samples conditioned in different environments

A similar effect of adding VMA was observed in the case of the air-conditioned samples. There was a decrease in sorptivity by 11.9% (when the dose was optimal and equal to 0.5%), and by 8.8% (when the dose was maximal and equal to 1.2%) when compared to the results of the reference series. The differences in the values of sorptivity in the case of the samples conditioned in high humidity conditions, when compared to the results obtained in the case of the reference series, decreased by 6.8% for the series with 0.5% of VMA and by 8.5% for the series with 1.2% of VMA.

The samples of the reference series conditioned in the A environment had 43.9% higher sorptivity than the samples conditioned in the water. In turn, the samples conditioned in the H environment had 11.2% higher sorptivity than the results of the samples conditioned in the water. This is confirmed by the results presented in literature [42–44].

When assessing the class of concrete durability on the basis of the criteria presented in [8], it can be concluded that the samples conditioned in the water and in high humidity meet the requirements for a high durability class. In turn, the sorptivity of the samples conditioned in air exceeds the limit value of 0.120 cm/h^{0,5} by 17–33%, which classifies them to the medium durability class.

3.4. Relative humidity

The conditioned samples were dried in air-dry laboratory conditions and their humidity was tested after 28, 56 and 90 days. The results are shown in Figure 3. There were 32 measurements conducted using the Tramex meter (four measurements on each of the eight faces of the tested specimens).

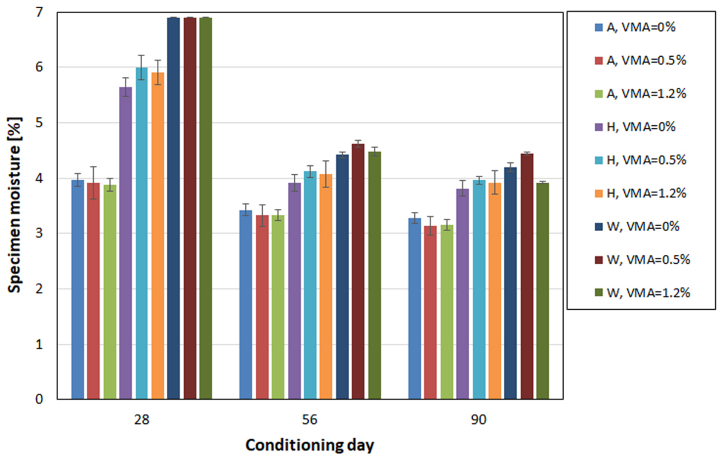

Fig. 3. Moisture content of the samples with different amounts of VMA conditioned in different environments

The samples that were conditioned in air had the lowest moisture content, while the samples conditioned in the water had the highest moisture content. During the testing of the moisture content of the samples, it was noticed that the influence of the applied admixture was slightly irregular. After 90 days, the samples were additionally dried at 65°C until they were completely dry, and it was noticed in the case of the air-conditioned samples that the moisture content of the samples decreased with an increased amount of VMA. The changes are also noticeable in the case of the samples conditioned in the water and in the highly humid environment. In both cases, the samples with a VMA content equal to 0.5% had the highest moisture content.

3.5. Air permeability

Concrete permeability tests were carried out after 56 and 90 days of conditioning the samples, as well as after drying them at 65°C in order to obtain a moisture content of 0% (measured using Tramex apparatus). On different days of the conditioning process, the samples with different amounts of VMA had different moisture contents (Fig. 3), and it was therefore necessary to make them completely dry in order to directly compare the results. Only in such a way can measured permeability (in completely dried concrete) be compared in the case of testing samples that are modified with a different amount of VMA and which are conditioned in different environments. Figure 4 shows a graph of the dependence between the k_T permeability coefficient and the relative humidity of the samples that have different contents of VMA and which are conditioned in different environments.

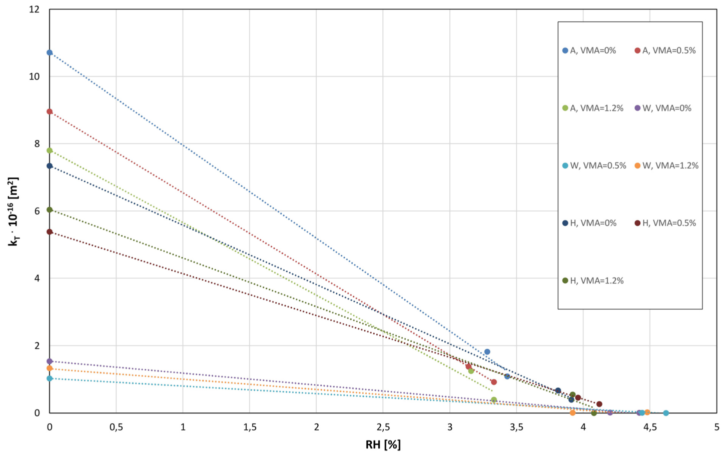

Fig. 4. Graph of the k_T permeability coefficient as a function of the relative humidity (*RH*) of the samples that have a different content of VMA, and which are conditioned in different environments

After the samples were dried at 65°C, the highest kT values were found in the concrete without VMA, regardless of their conditioning method. For all the series of samples, the generalized relationship (3.3) was determined. The constants K and *L* of the equation are presented in Table 6. On the basis of the determination coefficients R^2, a very good adjustment of the results was found (3.3).

$$k_T = K \cdot RH + L \tag{3.3}$$

Table 6. The values of the constants *K* and *L* of equation (3.3)

Conditioning method and VMA dosage	*K*	*L*
A + 0% VMA	–2.76	10.72
A + 0.5% VMA	–2.41	8.96
A + 1.2% VMA	–2.16	7.81
W + 0% VMA	–0.35	1.54
W + 0.5% VMA	–0.23	1.03
W + 1.2% VMA	–0.31	1.32
H + 0% VMA	–1.77	7.35
H + 0.5% VMA	–1.24	5.38
H + 1.2% VMA	–1.44	6.05

The addition of VMA has a significant impact on the permeability of concrete. The lowest values of the k_T coefficient, equal to $1.028 \cdot 10^{-16}$ m^2, were obtained for the samples that contained 0.5% VMA and which were conditioned in water. This amount of admixture resulted in the reduction of permeability by 34% when compared to the result of the reference series. In the case of the samples conditioned in the A and H environments, the effect of the admixture on the reduction of the concrete's permeability was also noticed. In the case of the air-conditioned samples, the maximum decrease was equal to 28% for the samples with 1.2% VMA when compared to the reference samples. In the case of the samples conditioned in the H environment, the maximum decrease occurred for the lower VMA content of 0.5%, and amounted to 27% when compared to the reference samples. The obtained results of the series of concretes conditioned in the high RH are comparable with the results presented in article [45]. The authors of this study seasoned their samples for 21 days in the standard conditions of high humidity, and then stored them until the measurements were performed in air-dry conditions in the laboratory. Most of the k_T results presented in the article are lower than the value of $0.1 \cdot 10^{-16}$ m^2, which is a value several times lower than the results of the reference series and the series with the addition of VMA. Torrent [46] presented the results of extensive research concerning the dependence between k_T and the moisture content of concrete, which was measured in various ways. Samples were made with the use of various types of cement, and their w/c ratio was 0.40 and 0.65. The samples were cured in high humidity conditions for approximately 100 days, and then gradually dried. Air permeability was tested at different RH values. Comparing the results with the corresponding RH value measured using Tramex apparatus, it can be stated that the permeability of the samples cured in the W environment is similar to the results of the series with a w/c = 0.40. In turn, the samples conditioned in the A environment had permeability corresponding to the series with a w/c = 0.65.

When comparing the obtained k_T results after 90 days of the sample's maturation with the requirements presented in Table 1, it can be concluded that all the samples met the requirement of $k_T < 2.0 \cdot 10^{-16}$ m^2. The stricter requirement of $k_T < 0.5 \cdot 10^{-16}$ m^2 was met in the case of the samples cured in the water and in the case of the CIO series cured in the H conditions. In this case, the addition of VMA allowed the requirements presented in Table 1 to be fulfilled, and the k_T result of the reference series exceeded the limit value by 34%.

4. Conclusions

1. The addition of VMA dosed in the optimal amount fulfilled its role and prevented bleeding. In the reference mixture, the separation of milk and water was observed on the upper surface of the samples during compaction. This phenomenon did not occur in the series with the addition of VMA.
2. At the maximum dosage, a change of consistency by three classes was observed, with a change by two classes being observed for the optimal dosage. The change in the consistency did not adversely affect the possibility of compacting the mixture, or the correct preparation of the samples.

3. The compressive strength of the series with the addition of VMA, when compared to the results of the reference series, increased for the samples conditioned in the water, and decreased for the samples conditioned in the H and A environments. The splitting tensile strength was the highest, regardless of the conditioning method, for the samples with 0.5% of VMA.
4. Regardless of the sample's treatment method, a decrease in sorptivity was noticed with an increase in the amount of VMA. The decrease in sorptivity was up to 11.9% when compared to the result of the reference series.
5. After the samples were dried at the temperature of 65°C, the highest k_T values were found in the concrete without the addition of VMA, regardless of the sample's conditioning method. The admixture caused a decrease in air permeability up to 34% when compared to the results of the reference series.

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Przepuszczalność i sorpcyjność betonu wykonanego z użyciem dodatku modyfikującego lepkość

Słowa kluczowe: dodatki modyfikujące lepkość, kompozyty betonowe, metoda Torrenta, przepuszczalność powietrza

Streszczenie:

Wprowadzenie

Mineralne materiały budowlane, w tym także betony cementowe posiadają porowatą strukturę, którą bardzo łatwo mogą penetrować ciecze i gazy znajdujące się w środowisku naturalnym. Dlatego też wprowadza się miarę, powiązaną z trwałością betonu tzw. przepuszczalność, którą określić można na drodze pomiaru wielkości charakteryzujących przepływ cieczy lub gazów. Bardzo często na potrzeby oceny potencjalnej trwałości betonu prowadzony jest pomiar nasiąkliwości lub sorpcyjności [6–8, 33].

W celu oceny przepuszczalności coraz częściej uznanie znajduje metoda Torrenta [19–21]. Pomiar ten ogranicza się do przepływu powietrza w kilkucentymetrowej, powierzchniowej warstwie betonu. Na przepuszczalność betonu mierzoną różnymi metodami, bardzo istotny wpływ ma jego stan wilgotnościowy [29–32]. W przypadku metody Torrenta problem ten zostałprzez jej twórców rozwiązany na drodze doświadczalnego ustalenia tego wpływu i wyposażeniu aparatu w sondę do pośredniego pomiaru wilgotności betonu, której zastępczą miarą jest jego oporność właściwa. Celem niniejszej pracy było określenie wpływu zastosowanych w betonach dodatków VMA na przepuszczalność powietrza oraz sorpcyjność, jak i parametry wytrzymałościowe (ściskanie i rozłupywanie) otrzymanych kompozytów, pielęgnowanych przez 28 dni w zróżnicowany sposób.

Materiały i metody

Wszystkie mieszanki betonowe zawierały 360 kg/m^3 cementu o współczynniku w/c 0,4. Użyto piasku frakcji 0–2 mm oraz granitu frakcji 2–8 mm i 8–16 mm. Kruszywa były w stanie powietrzno-suchym. W mieszankach zastosowano superplastyfikator Atlas Duruflow PE-220 oraz domieszkę zmniejszającą retencję wody Atlas VM-500. Oba dodatki są zgodne z normą PN-EN 934-2. Jako wodę do mieszania używano wody wodociągowej. Receptury mieszanek betonowych i ich wybrane właściwości przedstawiono w tabeli 3. Konsystencję mieszanki badano zgodnie z normą PN-EN 12350-5. Temperaturę mieszanki betonowej przed badaniem konsystencji mierzono termometrem laboratoryjnym z rozdzielczością 0,1°C. Próbki przygotowano zgodnie z normą PN-EN 12390-2, formując je w plastikowych formach, dwukrotnie zagęszczając na stole wibracyjnym. Próbki po wyjęciu z formy pielęgnowano przez 28 dni trzema różnymi sposobami: w wodzie (W), przy wysokiej wilgotności względnej > 95% RH (H) oraz w warunkach suchych w powietrzu w laboratorium RH = 50% ± 10% (A). Temperatura w każdym przypadku wynosiła 20°C ± 2°C. Podczas eksperymentu prowadzono badania przepuszczalności powietrza, sorpcyjności wilgotności oraz wytrzymałości na ściskanie i rozciąganie przez rozłupywanie, próbek kondycjonowanych w różnych warunkach.

Wyniki

W tabeli 6 przedstawiono wyniki badań właściwości mechanicznych i fizycznych. Sprawdzanymi właściwościami mechanicznymi były wytrzymałość na ściskanie i rozłupywanie, testowane po 28 dniach. Parametry fizyczne związane z trwałością reprezentuje sorpcyjność mierzona po 28 dniach oraz współczynnik przepuszczalności powietrza Torrenta k_T mierzony po 56 i 90 dniach na próbkach o naturalnej wartości RH oraz po wysuszeniu w temperaturze 65°C. Uzyskano również wartości wilgotności względnej zmierzone miernikiem Tramex po 28, 56 i 90 dniach. Każdy wynik był średnią uzyskaną z badań sześciu próbek, z wyjątkiem wyniku k_T, który był średnią z 8 pomiarów i RH z Tramex, który był średnią z 32 pomiarów.

W przypadku pielęgnacji próbek w wodzie zauważono tendencję do spadku sorpcyjności przy dodaniu domieszki VMA. Najniższy wynik, niższy o 10.1% od wyniku serii referencyjnej uzyskała seria z 0.5% dodatkiem VMA. Wzrost zawartości dodatku VMA do maksymalnej możliwej do zastosowania wartości 1.2% spowodował natomiast mniejszy spadek sorpcyjności S, o 6.4% w porównaniu z wynikiem serii referencyjnej. Podobny efekt dodatku VMA zaobserwowano przy pielęgnacji próbek kondycjonowanych w powietrzu. Spadek sorpcyjności przy optymalnej dawce 0.5% wyniósł 11.9% w porównaniu z wynikiem serii referencyjnej, a przy maksymalnej dawce 1.2% wyniósł 8.8% w porównaniu z wynikiem serii referencyjnej. W przypadku pielęgnacji próbek przy wysokiej wartości wilgotności, wzrost ilości domieszki powodował spadek sorpcyjności. Różnice w porównaniu do wyniku uzyskanego w serii referencyjnej wyniosły 6.8% w serii z dozowaniem 0.5% oraz 8.5% w serii z dozowaniem 1.2%.

Dodatki VMA mają znaczący wpływ na przepuszczalność betonu. Najniższe wartości współczynnika $k_T = 1.028 \cdot 10^{-16}$ m^2, uzyskano w przypadku próbek zawierających 0.5% VMA i dojrzewających w środowisku wodnym. Taka ilość dodatku, spowodował a obniżenie przepuszczalności o 34% w porównaniu z wynikiem serii referencyjnej.

W przypadku próbek kondycjonowanych w powietrzu oraz w środowisku bardzo wilgotnym również zauważono wpływ dodatku na obniżenie przepuszczalności betonu. W przypadku próbek kondycjonowanych w powietrzu maksymalny spadek wynosił 28% przy VMA = 1.2% w porównaniu z próbkami odniesienia. W przypadku próbek kondycjonowanych w środowisku o podwyższonej wilgotności maksymalny spadek wystąpił przy mniejszej zawartości VMA = 0.5% i wynosił 27% w porównaniu z próbkami odniesienia.

Wnioski

1. Domieszka VMA dozowana w ilości optymalnej spełniła swoja role i zapobiegła zjawisku bleedingu. W mieszance referencyjnej podczas zagęszczania zaobserwowano wydzielanie się mleczka i wody na górnej powierzchni próbek. Zjawisko to nie występowało w seriach z dodatkiem VMA.
2. Przy dozowaniu maksymalnym zaobserwowano zmianę konsystencji o trzy klasy, przy dozowaniu optymalnym o dwie klasy. Nie wpływało to ujemnie na możliwość zagęszczania mieszanki i prawidłowe wykonanie próbek.
3. Wytrzymałość na ściskanie serii z dodatkiem VMA w porównaniu do wyników serii referencyjnych rośnie w przypadku próbek kondycjonowanych w wodzie, maleje w przypadku próbek kondycjonowanych w warunkach H i A. Wytrzymałość na rozłupywanie jest największa niezależnie od sposobu kondycjonowania przy ilości VMA = 0.5%.
4. Niezależnie od sposobu pielęgnowania próbek wraz ze wzrostem ilości domieszki VMA zauważono spadek sorpcyjności. Spadek sorpcyjności wyniósł do 11.9% w porównaniu z wynikiem serii referencyjnej.
5. Po wysuszeniu próbek w temperaturze 65°C, niezależnie od sposobu dojrzewania próbek zawsze przy RH = 0 najwyższe wartości k_T występują w betonie bez zawartości domieszki VMA. Domieszka powodowała spadek przepuszczalności powietrza do 34% w porównaniu z wynikiem serii referencyjnej.

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