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PRODUCTION OF CONCRETE PAVEMENTS USING MIXED CEMENTS

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Abstract. Currently, great importance is attached to the reduction of emissions in industrial production, especially in the production of cement, when it is indicated that during production 1 ton of cement produces approximately 0.6 ton of CO_2. Reducing emissions is possible thanks to secondary raw materials, which are produced in large quantities in the Czech Republic volumes for which a suitable use is sought. Some secondary raw materials are suitable for use in concrete mixes, which are used to improve the rheology of the fresh concrete mixture as well as the properties hardened concrete. Currently, there is an effort to eliminate the production of cement, to which its partial replacement by admixtures could also contribute. Therefore it is necessary determine the optimal admixture that could be used to replace part of the cement in concrete mix. A large consumer of concrete mixes are transport structures, where it is possible for some of the cement used to be replaced by an admixture.

Keywords: Cement, concrete pavemets, admixtures, durability, carbon footprint.

1. Introduction

Concrete is mainly used in buildings and infrastructure around the world, where it is mainly produced using ordinary portland cement (OPC) as a binder. In recent years, annual world cement production has increased from 1.0 billion tons to approximately 1.7 billion tons, which is enough to produce 1 m^3 of concrete per person. As a result, the cement industry is generally considered to be a high growth industry. However, since the end of the 19th century, industry has been struggling with the need to reduce the burden on the environment, including carbon dioxide (CO_2) emissions. Some estimates suggest that the amount of CO_2 emissions from global OPC production may be as high as 7 % of total global CO_2 emissions. In addition, the production of OPC is associated with serious environmental side effects, such as environmental pollution caused by dust and the enormous energy consumption required by the plasticity temperature above 1 300° C. For these reasons, the cement industry has been challenged in the last 10 years to effectively reduce and control CO_2 emissions [1–3].

Four alternative technologies to reduce CO_2 emissions in the cement industry were commonly discussed; 1) changing the fuel to a fuel with a lower carbon content, for example from coal to natural gas during the calcination of limestone; 2) adding a chemical absorption process to capture CO_2 3) changing the clinker production process with efficient grinding and converting from a wet to dry process and 4) adding large volumes of supplementary cementitious materials (SCM) such as ground granulated blast furnace slag (GGBS), fly ash (FA) and/or silica fume (SF). Of these four technologies, the use of cement mixed with admixtures is the most practical and economical method that can be directly applied in the field of ready-mixed concrete. In addition, the use of GGBS or FA can provide additional environmental benefits, including conservation of natural resources and recycling of industrial by-products. Research has shown that the addition of additives is capable of reducing CO_2 emissions by 22 %. They also pointed out that the greenhouse gas impact calculated from blended cement is reduced by up to approximately 22 % compared to traditional OPC [2, 4].

Concrete pavements are intended for very high traffic loads and as such are preferably used for the construction of airport runways, expressways or highways. Concrete for the production of these structures must meet the requirements for workability, mechanical resistance, resistance to climatic influences, anti-slip properties and must be resistant to the action of chemical de-icing agents, which are used in the maintenance of such surfaces in winter [5].

The steady increase in heavy freight traffic not only puts a strain on highways, but also on other public transport areas. Choosing the right technology at the right place is a difficult task for every road construction administration. At the same time, the requirements for durability and sustainability are in the center of attention. Therefore, decisions are being made more and more often about the construction of cement-concrete covers on traffic areas. In addition to this, mixing cement with these raw materials can improve the long-term mechanical properties and durability of concrete and thereby extend the life of concrete structures [2–5].

Recipe Raw Material [$kg\,m^{-3}$]	CEM I 42.5 R (sc) Mokrá	CEM II/A-S 42.5 R Mokrá	CEM III/A 42.5 N Hranice	CEM II/C-M (S-LL) 42.5 N Hranice	CEM II/A-LL 42.5 R Radotín	CEM II/B-M (S-LL) 42.5 N Radotín
CEM	360	360	360	360	360	360
DTK 0/4 Tovačov	537	537	537	537	537	537
HDK 4/8 Rosice	181	181	181	181	181	181
HDK 8/16 Rosice	544	544	544	544	544	544
HDK 16/32 Rosice	544	544	544	544	544	544
Voda	165	165	185	175	170	182
Muraplast FK 19	1.8	1.8	1.8	1.8	1.8	1.8
Centrament Air 202	0.13	0.08	0.07	0.07	0.09	0.08

Table 1. Composition of concrete recipes.

2. Aims

The aim of the article is the experimental verification of new types of cements and concrete mixes for cement-concrete road pavements with a significantly reduced carbon footprint and increased durability. The article is aimed at use in the field of transport constructions with a focus on the use of suitable mixed cements, reducing the formation of greenhouse gases to increase the service life of concrete pavements, extend the time for repairs and reduce the total costs for the construction and operation of the highway network in the Czech Republic.

The main goal will be to assess the applicability of mixed cements for the production of cement-concrete covers due to the reduction of environmental impacts on our environment while achieving the required durability, especially the XF4 environment.

3. Methodology

This work deals with the lower layer of cement-concrete cover. The work was divided into 2 main stages. For the first stage, concretes with mixed cements were designed and produced. In the last stage, the achieved results were processed and compared based on the results of physical and mechanical properties with individual types of cement.

4. Used raw materials

In the experimental part, 6 concrete mixtures were produced, differing from each other only in the cement used. Two cements were used from the Mokrá cement plant, Portland cement CEM I 42.5 R (sc) and Portland mixed CEM II/A-S 42.5 R. Cements CEM II/A-LL 42.5 R and CEM II/B-M (S-LL) 42.5 N were used from the Radotín plant. And cements CEM III/A 42.5 N and CEM II/C-M(S-LL) 42.5 N from the Hranice cement plant. Four types of aggregates from two areas were used for production. The washed mined aggregate in fraction 0/4 was from the Tovačov locality and the coarse crushed aggregate in fractions 4/8, 8/16 and 16/32 from the Rosice locality. Both the plasticizing additive Muraplast FK 19 and the aerating additive Centrament AIR 202 conc. were used from MC Bauchemie. The composition of the individual mixes produced is shown in Table 1.

5. Experiment

When designing and mixing individual recipes, the goal was to achieve a consistency of fresh concrete mixture with a cone settlement in the range of 40–60 mm. During the mixing of the concrete mixture, the amount of water and plasticizer was adjusted due to the different compositions of the cements in order to achieve the desired consistency of the concrete. Furthermore, the air content was measured on the fresh concrete. A different amount of aeration admixture was added to each mix to achieve an optimum fresh concrete air content of 6.5 %. Subsequently, the bulk density of the fresh concrete was determined according to ČSN EN 12350-6, which ranged from 2 260 to 2 300 $kg\,m^{-3}$. From each recipe, test bodies were produced (cube with an edge of 150 mm, beam 100 × 100 × 400) on which the physical and mechanical properties were determined. At the age of 2, 7, 28 and 90 days, the volumetric weight of the hardened concrete was tested according to ČSN EN 12 390-7 and the compressive strength according to ČSN EN 12 390-3 [6–8].

It follows from the measured results, see Figure 1 that the replacement of cement with admixtures significantly negatively affects the short-term compressive strengths of concrete. As expected, the highest compressive strength after 2 days of maturation is achieved by road Portland cement, which contains the highest percentage of clinker. The higher the replacement of cement with admixtures, the lower the strengths. The lowest compressive strength value after 2 days was evaluated for CEM III/A from Hranice. The most significant increase in strength between 28 and 90 days is for the test samples that contain the active ingredient. This difference may be caused by the pozzolanic activity, which becomes apparent after a longer period than 28 days. The highest compressive strength of all concretes was achieved after 60 days of curing. Concrete with the used cement CEM II/A-S 42.5 R Mokrá achieves the highest compressive strength. As the age of the samples increased, the difference in strength values disappeared.

Recipe	Weight change [%]	Flexural tensile strength ref [MPa]	Flexural tensile strength frozen [MPa]	Degree of frost resistence [%]
CEM I 42.5 R (sc) Mokrá	-0.17	5.9	6.3	106
CEM II/A-S 42.5 R Mokrá	-0.28	5.4	5.8	108
CEM III/A 42.5 N Hranice	-0.45	4.9	3.9	80
CEM II/C-M (S-LL) 42.5 N Hranice	-0.36	5.1	4	78
CEM II/A-LL 42.5 R Radotín	-0.88	4.8	4.3	89
CEM II/B-M (S-LL) 42.5 N Radotín	-0.66	5.3	5.2	96

Table 2. Evaluation of the frost resistance test.

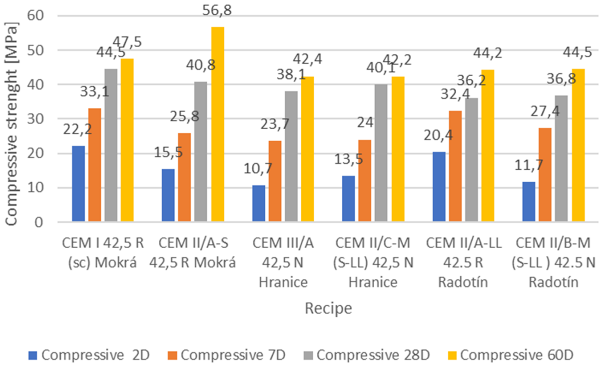

Figure 1. Strength development over time.

Recipe	A [% vol.]	A_{300} [% vol.]	L [mm]
CEM I 42.5 R (sc) Mokrá	6.6	3.5	0.19
CEM II/A-S 42.5 R Mokrá	6.2	4.1	0.21
CEM III/A 42.5 N Hranice	7.4	3.7	0.23
CEM II/C-M (S-LL) 42.5 N Hranice	7.5	3.1	0.19
CEM II/A-LL 42.5 R Radotín	6.9	3.5	0.22
CEM II/B-M (S-LL) 42.5 N Radotín	7.3	4.2	0.18

Table 3. Characteristics of air in hardened concrete (A – pore volume, A_{300} – volume of effective pores, L – distribution of air pores).

5.1. Determination of frost resistance of concrete

Determination of frost resistance was carried out according to ČSN 73 1322. For the frost resistance test, the test specimens are water-saturated beams that are subjected to alternating freezing and thawing. 2 sets of test specimens were prepared for the test. One set is frozen and the other unfrozen serves as a comparison. Freezing takes place in freezing cycles, with one cycle consisting of 4 hours of freezing and 2 hours of thawing. Once the required number of freezing cycles has been reached, the test is finished. The result is weight loss of frozen bodies expressed in percent, tensile strength after bending and coefficient of frost resistance. The ratio of the arithmetic mean of the strength of frozen bodies and the arithmetic mean of unfrozen beams is called the coefficient of frost resistance. If the frost resistance factor is at least 75 %, we can call the concrete frost-resistant [9].

All concrete formulas passed in terms of frost resistance coefficient, i.e. all formulas have a higher coefficient greater than 75 % (see Table 3). Some concretes even have a frost resistance coefficient higher than 100 %. This phenomenon can probably be explained by rehydration of unhydrated cement grains. The weight loss for all manufactured recipes was a maximum of 0.88 % of the original weight of the frozen beam.

5.2. Air content in hardened concrete

The essence of the test to determine the characteristics of the air pores in hardened concrete, their mapping is possible based on an approximation to get an approximate idea of the amount of pores in the aerated test samples.The air pore structure is determined by scanning along a series of measuring straight lines, parallel to the original top surface of the sample. Number of air of pores intersected by measuring lines are recorded, as are the individual lengths bowstring. Mathematical analysis of the recorded data then enables a description of the system air pores in terms of the required parameters. The measurement is carried out on a cut-out from the test body, which can be seen in Figure 2.

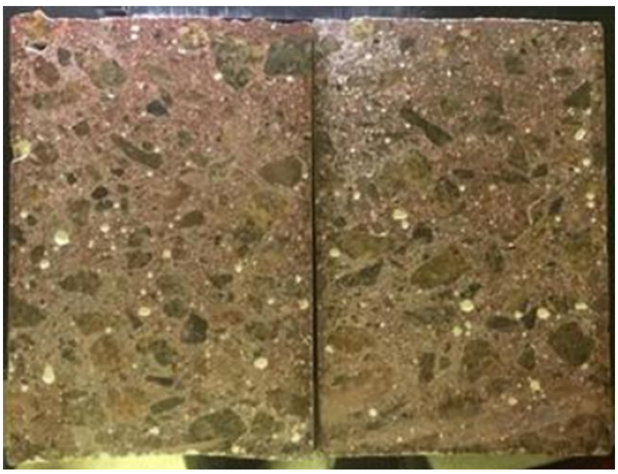

Figure 2. Prepared body for determining the air content in hardened concrete.

The characteristics of air pores in hardened concrete were determined on the test specimens, see Table 3, namely the total air content, the content of microscopic pores up to 300 μm and the spatial distribution of air pores. The total air content in the hardened concrete was in the range of 6.2–7.5 %. The effective microscopic air content of A_{300} ranged from 3.1 to 4.2 %. The spatial distribution of air pores was in the range of 0.19 to 0.23 mm. All these indicators assume that the designed concretes with different cements will resist weather effects, especially frost.

6. Discussions

From the results of the short-term (2 and 7 day) strengths of the individual formulas, as expected, the formula with road cement from Mokré achieved the highest value of compressive strength. The lowest values were achieved by cements with the lowest clinker content in the cement. The most significant increase in strength between 28 and 90 days is for the test samples that contain the active admixture. This difference may be due to the pozzolanic activity, which becomes apparent after a longer period than 28 days. The highest compressive strength of all concretes was achieved after 90 days of curing. As the age of the samples increased, the difference in strength values disappeared. Aeration of the concrete mixture also has a significant effect on the magnitude of the determined compressive strength. If the air content is higher in the mixture, the compressive strength of the concrete decreases by up to 5 % for every 1 % of air in the concrete mixture [1, 3, 5].

In terms of concrete's frost resistance, all formulas achieved frost resistance coefficients above 78 %. For recipes with cements from the wet plant, the coefficient of frost resistance even reached over 100 %. A spacing factor was determined on the hardened concrete in order to compare the results with the values measured in the fresh state. Regarding the total air content A, in the fresh concrete the value was in all cases slightly lower than the value obtained from the microscopic determination of the air content in the hardened concrete. The effective microscopic air content of A_{300} ranged from 3.1 to 4.2 %. The spatial distribution of air pores was in the range of 0.19 to 0.23 mm. All these indicators assume that the designed concretes with different cements will resist weather effects, especially frost [3, 4].

7. Conclusion

The study deals with the issue of verifying the use of mixed cements for the production of cement-concrete covers with a focus on reducing the carbon footprint and increasing durability and reducing the overall costs for the construction of transport structures.

From the information obtained, it follows that for the production of cement-concrete covers they could also use cements with a lower clinker content and replacement of admixtures. Blast furnace slag is among the most suitable admixtures for road concrete that can replace cement. In addition to mechanical properties, other aspects such as ecology and financial complexity are currently being monitored. As the requirement to eliminate the volume of CO_2, the largest producers of emissions of which are industries, is currently being increased, cement production in particular is energetically demanding, for this reason possibilities are being sought to reduce the amount of cement required without negatively affecting the properties of the proposed concrete structure. In order to eliminate emissions, the use of waste raw materials such as blast furnace slag is suitable. It is possible to replace cement with micro-ground limestone even though it is not a waste material.

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