VERIFICATION OF THE APPLICABILITY OF MIXED CEMENT TYPES FOR THE PRODUCTION OF CONCRETE PAVEMENTS

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Abstract

Concrete is the most widely used building material today. Due to the increase in the utility value of buildings, more and more emphasis is placed on the durability of buildings, which especially applies to concrete products exposed to frost and chemical deicing agents. Cement concrete pavements have the ability to transmit the effects of traffic and withstand adverse weather conditions. Concrete pavements can withstand high traffic loads without permanent deformations and have a long service life. However, it must be said that in the case of damage to the CB pavements, repairs require longer closures due to more demanding production and laying technology. The expected lifespan of a concrete road type is at least 30 years with basic and minimal maintenance, while the life cycle of tarmac roads is much shorter.

Currently, great importance is placed on reducing emissions arising from industrial production, especially cement production, where it is stated that the production of 1 ton of cement produces approximately 0.6 tons of CO_2. Reducing emissions is possible thanks to secondary raw materials that are produced in large volumes in the Czech Republic, for which a suitable use is being sought.

Keywords

Concrete pavement, cement, admixtures, durability, carbon footprint

1 INTRODUCTION

Concrete pavements (CP) 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, and anti-slip properties and must be resistant to the action of chemical deicingagents, which are used in the maintenance of such surfaces in winter [1], [2], [3], [4], [5].

The steady increase in heavy freight traffic puts a strain both on highways and 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 at the centre of attention. Therefore, decisions are being made more and more often about the construction of cement-concrete pavements of traffic areas [5], [6], [7], [8].

The traffic areas discussed must meet the following requirements:

- resistance to heavy traffic loads,
- resistance to high line load,
- adequate anti-slip properties,
- reserves for heavy traffic loads,
- low maintenance/abrasion resistance [4].

In summary, these requirements are related to durability and sustainability. Cement-based materials have become the most commonly used construction materials in the construction industry due to their properties (high compressive strength, high heat resistance, and excellent availability). Global cement production is projected to reach approximately 5.5 Gt in 2050 with ever-increasing infrastructure development and demand for the most widely used construction material (concrete). However, the production of each ton of regular Portland cement leads to massive energy consumption and the creation of greenhouse gas emissions, especially CO_2. Climate change and global warming have been cited as the main consequences among the huge environmental impacts

DOI 10.13164/juniorstav.2024.24039

caused by greenhouse gas emissions. The most promising strategy is the use of secondary waste materials as a partial replacement for cement. 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 [1], [2], [3], [4], [5], [6], [7].

Over the past few decades, many studies were conducted to investigate the mechanical properties and durability of cement-based composites containing different types of secondary waste materials. Most often, siliceous fly ash, ground granulated blast furnace slag or high-temperature fly ash was used. Studies have shown that the use of blended cements can increase the long-term mechanical properties. In terms of durability, replacing cement with secondary waste material can reduce the negative impact of aggressive media [2], [5], [7].

2 AIMS

The aim of the research was the experimental verification of new types of cement and concrete mixtures for concrete pavements with a significantly reduced carbon footprint and increased durability. The article is aimed at their use in the field of transport constructions with a focus on the use of suitably mixed types of cement, reducing the creation of greenhouse gases to increase the service life of CP, 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 was to assess the applicability of various types of mixed cement for the production of cement-concrete pavements in order to reduce environmental impacts on the environment while achieving the required durability.

3 METHODOLOGY

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

4 RAW MATERIALS USED

6 types of cement were used for the production of the bottom layer of concrete. Road cement CEM I 42.5 R (sc) was used from the Mokrá cement plant, which is commonly used for the production of cement pavement. Furthermore, Portland mixed cement CEM II/A-S 42.5 R was used from the Mokrá cement plant. A pair of types of cement from Hranice was also used: CEM III/A 42.5 N and CEM II/C-M(S-LL) 42.5 N. The last two Types of cement were used from the Radotín cement plant, namely CEM II/A-LL 42.5 R and CEM II/B-M (S-LL) 42.5 N. Washed mined aggregate was used in fraction 0/4 mm. Crushed coarse aggregate was used in fractions 4/8 mm, 8/16 mm and 16/32 mm. A super plasticizing additive was used to adjust the consistency of the concrete. Furthermore, an effective aerating additive was used to introduce effective air into the concrete. The composition of individual types of concrete is shown in Tab. 1.

Tab. 1 Composition of concrete recipes.

Mixture Raw Material [kg/m^3]	**CEM I (sc)**	**CEM II/A-S**	**CEM III/A**	**CEM II/C-M (S-LL)**	**CEM II/A-LL**	**CEM II/B-M (S-LL)**
CEM	*360*	*360*	*360*	*360*	*360*	*360*
DTK 0/4 mm	*537*	*537*	*537*	*537*	*537*	*537*
HDK 4/8 mm	*181*	*181*	*181*	*181*	*181*	*181*
HDK 8/16 mm	*544*	*544*	*544*	*544*	*544*	*544*
HDK 16/32 mm	*544*	*544*	*544*	*544*	*544*	*544*

DOI 10.13164/juniorstav.2024.24039

Water	*165*	*165*	*185*	*175*	*170*	*182*
Super plasticizer	*1.8*	*1.8*	*1.8*	*1.8*	*1.8*	*1.8*
Aerator	*0.13*	*0.08*	*0.07*	*0.07*	*0.09*	*0.08*

5 EXPERIMENT

When designing and mixing individual type of concrete, 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 cement 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 4-6%. Subsequently, the bulk density of the fresh concrete was determined according to CSN EN 12350 – 6, which ranged from 2,260 to 2,300 kg/m^3. From each concrete, test specimens were produced (cube with an edge of 150 mm, prism of 100 × 100 × 400 mm) on which the physical and mechanical properties were determined. At the age of 2, 7, 28 and 60 days, the volumetric weight of the hardened concrete was tested according to CSN EN 12 390 – 7 and the compressive strength according to CSN EN 12 390 – 3. At the age of 28 days, the tensile strength by bending according to CSN EN 12 390 – 5, transverse tensile strength according to CSN EN 12 390 – 6 and according to CSN EN 12 390 – 13 modulus of elasticity in compression [9], [10], [11], [12], [13], [14] was also tested.

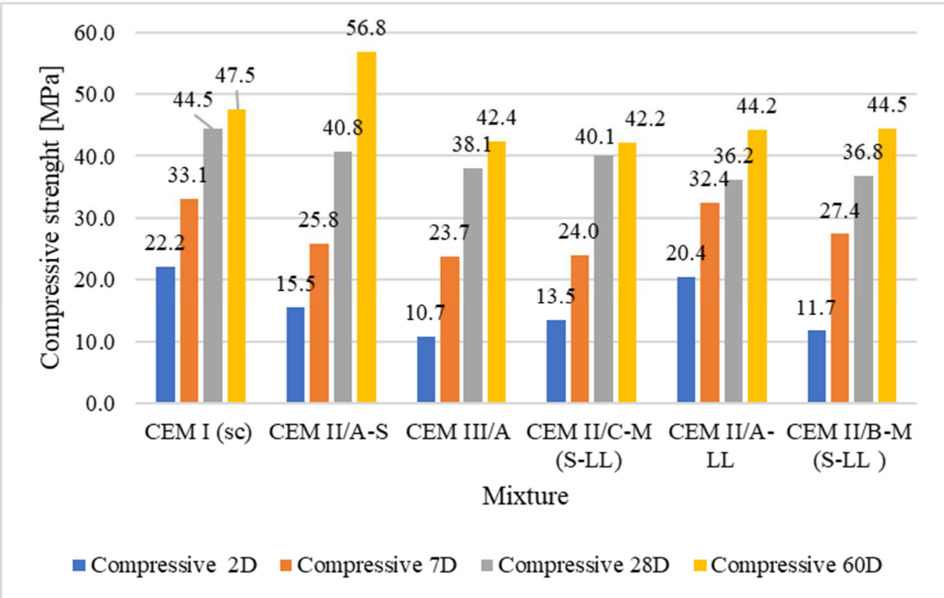

Fig. 1 Strength development over time.

The measured results showed (see Fig. 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 was achieved by road Portland cement, which contains the highest percentage of clinker. The higher the replacement of cement with admixtures, the lower the strength. The lowest compressive strength value after 2 days was determined for CEM III/A from Hranice.

The most significant increase in strength between 28 and 60 days is for test samples that contain the active ingredient. This difference can be caused by the pozzolanic activity, which becomes apparent after a period longer than 28 days. The highest compressive strength of all types of concrete 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. The difference in strength values disappeared as the age of the samples increased.

The comparison of the remaining mechanical parameters can be seen in Tab. 2. The highest results in the flexural tensile strength test were achieved with concrete with CEM I road cement, and similar to the compressive strength, the lowest flexural tensile strength was achieved by concrete with micro-ground limestone. However, the differences were not so striking. Transverse tensile strength values ranged from 3.1 to 4.2 MPa for all types of

DOI 10.13164/juniorstav.2024.24039

concrete. The highest value was observed for concrete with road cement similarly to the previous strength parameters. The differences between the individual types of concrete and cement used were not significant.

Tab. 2 Results of mechanical properties.

Recipe	Bulk density of fresh concrete [kg/m³]	Bulk density of hardened concrete [kg/m³]	Tensile splitting strength [MPa]	Flexural tensile strength [MPa]	Modul of elasticity in compression [GPa]
CEM I (sc)	*2,290*	*2,310*	*4.2*	*5.9*	*31.9*
CEM II/A-S	*2,300*	*2,310*	*3.7*	*5.4*	*29.5*
CEM III/A	*2,270*	*2,290*	*3.5*	*4.9*	*29.2*
CEM II/C-M (S-LL)	*2,250*	*2,280*	*3.1*	*5.1*	*28.9*
CEM II/A-LL	*2,270*	*2,300*	*3.1*	*4.8*	*30.5*
CEM II/B-M (S-LL)	*2,290*	*2,270*	*3.4*	*5.3*	*28.3*

From the range of achieved results of the static modulus of elasticity, it is not possible to clearly determine a more favourable type of cement for the production of concrete in order to obtain a higher modulus of elasticity. However, the highest static modulus of elasticity was achieved when road Portland cement was used. The difference between the individual types of cement was insignificant. The static modulus of elasticity depends more on the quality and fraction of the aggregate and other components of the concrete than on the cement used.

Determination of Cement Concrete Surface Resistance exposure to water and chemical deicing agents – method A

Determination of the resistance of the cement surface concrete against the action of water and chemical deicersof substances was carried out according to the CSN 73 1326/Z1 standard. The test was based on cyclic cooling and heating of the test specimen. The purpose of the test was to assess the resistance of concrete surfaces in winter, when these types of concrete are exposed to frost and the action of chemical deicing substances. Cube-shaped test specimens with an edge length of 150 mm at the age of 90 days were used for the test. The result of the cement concrete surface resistance test against the action of water and chemical deicing agents is given as a number divided by a dash. The first part is the waste value in g/m², The number of cycles during which this value was reached can be found after the dash [15].

Tab. 3 Determination of concrete surface resistance exposure to water and chemical deicing agents.

Number of cycles	Average measured waste values [g/m²]			Designation according to the standard CSN 73 1326
	50	100	150	
CEM I (sc)	*20.12*	*56.23*	*110.54*	*110.5 – 150*
CEM II/A-S	*52.35*	*111.76*	*232.55*	*232.55 – 150*
CEM III/A	*71.37*	*139.61*	*271.76*	*271.76 – 150*
CEM II/C-M (S-LL)	*60.20*	*157.45*	*410.78*	*410.78 – 150*
CEM II/A-LL	*88.24*	*253.33*	*425.10*	*425.10 – 150*
CEM II/B-M (S-LL)	*66.84*	*196.51*	*478.54*	*478.54 – 150*

The resistance of the cement concrete surface against the action of water and chemical deicing agents was determined on the test specimens. No test sample was classified as class 1, i.e., intact according to the test standard. All tested samples were included in the second class (slightly disturbed), where the determined waste is up to 500 g/m². Concrete with road cement showed the smallest waste, when after 150 freezing cycles the waste was 110.54 g/m². For the types of concrete where cement with additives were used, a higher resistance to chemical deicersof substances was expected, due to the so-called pore-blocking effect, which affects the pore structure of the concrete. This effect occurs both in mixtures with pozzolans and with latently hydraulic substances and is manifested mainly in the area of capillary pores by the fact that certain portions of the pores become impermeable.

DOI 10.13164/juniorstav.2024.24039

Fig. 2 Test sample of concrete with road cement after the durability test of the cement concrete surfaceagainst the action of water and chemical deicing agents.

4 DISCUSSION

From the results of the short-term (2 and 7-day) strengths of the individual recipes, as expected, the recipe with road cement from Mokrá cement plant achieved the highest compressive strength value. The lowest values were achieved by the types of cement with the lowest clinker content in them. The most significant increase in strength between 28 and 90 days applied for the test samples that contained the active admixture. This difference may be due to the pozzolanic activity, which becomes apparent after a period longer than 28 days. The highest compressive strength of all types of concrete was achieved after 90 days of curing. The difference in strength values disappeared as the age of the samples increased. Aeration of the concrete mixture also had a significant effect on the magnitude of the determined compressive strength. If the air content was higher in the mixture, the compressive strength of the concrete decreased by up to 5% for every 1% of air in the concrete mixture [1], [6], [7].

The evaluation of the other strength characteristics was similar to the compressive strength of concrete. The highest strengths were achieved with concrete, where road cement from Mokrá cement plant was used. The differences between the strengths could be due to the age of the samples. When tested with a longer ageing time, types of mixed cement could show pozzolanic activity, similar to compressive strength. It was not possible to unequivocally determine a more favourable type of cement for the production of concrete in order to obtain a higher modulus of elasticity from the range of static modulus of elasticity results achieved. The static modulus of elasticity depended more on the quality and fraction of aggregates and other concrete components than on the cement used. No test specimen was classified as intact when tested for resistance to water and chemical deicing agents. All tested samples were classified as slightly disturbed. For the types of concrete where cement with additives was used, a higher resistance to chemical deicersof substances was expected, thanks to the so-called pore-blocking effect, which affects the pore structure of the concrete. This effect occurs both in mixtures with pozzolans and with latently hydraulic substances and manifests itself mainly in the area of capillary pores by the fact that certain parts of the pores become impermeable [3], [4], [6].

5 CONCLUSIONS

The article deals with the issue of verifying the use of types of mixed cement for the production of cement-concrete pavements with a focus on reducing the carbon footprint, increasing durability and reducing the total costs of construction of transport structures.

It can be said, from the obtained theoretical and practical information, that even types of cement with a lower clinker content and replacement of admixtures could be used for the production of cement concrete pavements. In addition to mechanical properties, other aspects such as ecology and financial complexity are currently being monitored. Without negatively affecting the properties of the concrete structure, options are being sought to reduce the amount of cement needed, as the requirement to eliminate CO_2 production, which is generated during cement production and is currently being increased. It is advisable to use waste materials such as blast furnace slag in order to eliminate emissions. It is possible to replace cement with micro-ground limestone even though it is not a waste material [1], [2], [3], [4], [5], [6], [7], [8].

Acknowledgement

The paper was written in the framework of the BUT specific research project FAST-J-23-8400: Verification of the applicability of mixed cements for the production of concrete pavements.

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