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ASSESSMENT OF SELECTED FEATURES OF THREE TYPES OF ROAD CONCRETE DEPENDING ON THE APPLIED CEMENT

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ABSTRACT

The paper presents a study on the effects of different types of cement on selected properties of C30/37 road concrete. It involved three types of cement: Portland CEM I 42,5 R cement, Portland slag CEM II/B-S 32,5 R cement and CEM III/A 42,5 N LH/HSR/NA blast cement. The composition of the concrete mixtures were designed and evaluated experimentally. Test samples were prepared in laboratory conditions. The maturation period took 28 days for concrete with CEM I 42,5 R and CEM II/B-S 32,5 R, and 56 days for CEM III/A 42,5 N LH/HSR/NA cement. After maturation the samples were tested for: compressive strength, bending tensile strength and splitting tensile strength, water absorption and frost resistance. It was found that each of the concrete meets the requirements for road concrete listed in the GDDKiA technical specification [Ogólna Specyfikacja Techniczna… 2014]. In most of the tests the CEM III/A 42,5 N LH/HSR/NA cement performed best.

Keywords: road concrete, concrete strength, aeration, frost resistance, concrete pavement

INTRODUCTION

In recent years, there has been a significant increase of highways and expressways developed in concrete pavement technology. For the traditional bituminous pavements have lower durability, due to a considerable utilization load, thermal conditions and chemicals used to ensure proper exploitation in winter conditions. Concrete pavement is a rigid and highly durable pavement that maintains its form in extreme temperature conditions. A well designed, properly constructed and taken care of concrete pavement maintains the standard performance parameters for up to 50 years. It enables transferring large loads without a risk of surface deformation, especially in summer high temperature conditions, and reduces a possibility of surface heating, which has a positive effect on urban areas' microclimate and provides high surface roughness by increasing anti-slip properties, so important for road safety (Szydło 2005). In some European countries, more than 70% of road surfaces are made of concrete pavement (Szydło 2005). In Poland, because of its numerous advantages, this technology has experienced a rapid development in road construction. This applies both to the main national arteries as well as to local roads (Nowoczesne lokalne drogi… 2000).

In terms of road surface implementation, the costs of concrete pavement exceed these of traditional bituminous pavement. However, if we assess the overall costs of construction, operation and maintenance of an investment, financially it is more advantageous to use road concrete. A road paved with concrete does not require any maintenance for many years, and chloride based de-icing chemicals can be applied in winter conditions, after meeting the requirements related to the existing exposure class (Beton... 2001).

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One of the fundamental decisions taken, when developing pavements technologies, and regarding the composition of a mixture, is the selection of cement with optimal properties for a particular investment project. The choice of cement should consider detailed constrictions and criteria related to the location, the work technology, materials, climate conditions and operation of the designed facility. In the current technologies of constructing pavements, plasticizers and aeration additives are indispensable components of the concrete mixture. The selection of cement should take into account its chemical compatibility with respect to these additives. A potential specific type of exposure to aggressive factors should also be included. This applies, in particular, to facilities associated with industry, such as extraction and processing of natural resources. Another factor that should influence the decision to use specific cement may be the risk of constructing road surface with aggregates susceptible to reaction with the alkali in cement. Hence, the recommendation to apply cements with reduced content of alkali or, alternatively, aggregates with zero susceptibility to corrosion. It is also allowed to use in construction of typical pavements other cements, than CEM I, including CEM II/B-S 32,5 R and CEM III/A 42,5 N (Trybalski 2012, Katalog… 2014), reducing the significance of selecting high strength cement for compliance with the requirements of mature concrete.

The possibility of applying cements of other type than CEM I for pavement construction is beneficial also for environmental reasons. The production of clinker is one of the major sources of CO2 emission in the contemporary world – it also consumes significant amounts of energy. So, CEM II and CEM III cements are more environmentally friendly, because from 20% up to 95% of Portland clinker has been replaced by non-clinker main components. In the case of the tested cements, it is the ground-granulated blast-furnace slag, a by-product of metallurgic industry, but other additives, like fly ash, silica dust and others are used, too (PN-EN 197-1). Reduction of environmental costs of cement production has been one of the priorities of its producers for years now, but in face of urban development around the world and global climate change, the importance of this issue is constantly growing (Ondova et al. 2013).

RESEARCH PURPOSE AND SCOPE

The aim of the research was to point out, which of the properties of road cement made of three different types of cement are equivalent and to make a comparative assessment of selected properties of the cement, depending on the type used in the production of the mixture. Three types of concrete were used to analyse the impact of the cement type on the parameters of road concrete: CEM I 42.5 R, CEM II/B-S 32.5 R, CEM III/A 42.5 N LH/HSR/NA. The cements differed from each other by i.a.: composition, grinding degree, strength, heat of hydration and time of bonding. In a broader sense, the production of CEM II and CEM III cements has a less negative impact on the environment. This is due to the participation of combustion by-products (fly ash) and metallurgic industry by-products (blast-furnace slag) in these cements, in contrast to pure clinker of CEM I group. This is an important factor in favour of their use in road construction, which consumes huge volumes of concrete. The demonstration of the CEM II-B-S 32.5 R cement suitability for the construction of pavements, despite its normally lower strength, was also intended in the research. Moreover, it included determining the compressive strength, the bending and splitting tensile strength, water absorption and frost resistance after 28 days of maturation in the case of concrete with CEM I 42.5 R and CEM II/B-S 32.5 R cements and after 56 days in the case of concrete with CEM III/A 42.5 N LH/HSR/NA.

CHARACTERISTICS OF USED MATERIALS

Three types of cement were used in the tests. CEM I 42.5 R is a Portland cement with high early strength, without additives, which includes only the 95% clinker and binding regulator. This cement is characterised by a high heat of hydration and a rapid increase in strength. CEM II/B-S 32.5 R is a Portland slag cement with high early strength. It consists of 65–79% clinker and ground-granulated blast-furnace slag in the amount of 21–35%. CEM III/A 42.5 N LH/HSR/NA is a blast furnace slag cement. It contains from 35% to 64% of clinker and 36–65% of blast-furnace slag. It is a cement of general use with a slow increase in strength and low heat of hydration, i.e. below 270 $kJ \cdot kg^{-1}$, resistant to sulphates and low in alkali.

To determine the properties of used cements and to compare them with the standards, it was necessary to prepare mortars with standard composition and to test their compressive strength in accordance with the PN-EN 196-1 standard. The results of the strength tests of these cement-based mortars after 2 and after 28 days are summarised in Table 1. Water demand and time of bonding of the cements was also studied. Their results are shown in Table 2.

Table 1. Compressive strength of standard cement mortars

Type of cement	Compressive strength, MPa	
	after 2 days	after 28 days
CEM III/A 42,5 N LH/HSR/NA	15.03	54.53
CEM II/B-S 32,5 R	15.83	48.72
CEM I 42,5 R	27.28	52.4

All formulas adopted aggregates that meet the conditions of the General Technical Specification (Ogólna Specyfikacja Techniczna 2014): washed natural sand 0/2, granite grit 2/8 and 8/16. The used chemical additives were: Mapeplast BV34 plasticiser and Mapeair AE20 aeration additive.

Table 2. Water demand and the time of cement setting

Type of cement	Water demand	Time of setting, min.	
		beginning	end
CEM III/A 42,5 N LH/HSR/NA	0.287	225	330
CEM II/B-S 32,5 R	0.286	235	345
CEM I 42,5 R	0.272	185	300

RESEARCH METHODOLOGY

The assessment of the suitability of the cements was carried out in accordance with the PN-EN 196-1 standard. All samples were prepared pursuant to the PN-EN 12390-2 standard. The strength parameters of concrete pavements were measured on the grounds of compressive and tensile strength tests at bending. The compressive tests were performed in accordance with the following norms: PN-EN 206-1, PN-EN 12390-3 for cube of dimensions 10 × 10 × 10 cm; and tensile tests for bending as to the PN-EN 12390-5 standard, with beams of dimensions 15 x 15 x 70 cm. Mature concrete samples for testing tensility at splitting followed the PN-EN 12390-6 standard. The test of concrete absorbability was performed pursuant to PN-B-06250:1988. Frost resistance was tested according to PN-B-06250:1988 on cubic samples with 100 mm sides after 28 days of maturation for concrete with CEM I 42.5 R and CEM II/B-S 32.5 R cements and after 56 days of maturation for concrete with CEM III/A 42.5 N LH/HSR/NA cement. For each series of compressive and tensile strength tests for bending and splitting and of the absorbability test three trials were run. The number of trials in frost resistance tests equalled 12, 6 samples of which were frozen, while the other 6 were for comparative tests. These numbers were same for every of the examined concrete. Based on the results obtained for individual test samples the average values for series were calculated. All values put into tables and charts in this paper refer to average values obtained in each series.

ROAD CONCRETE FORMULAS

The following criteria were assumed for designing the composition of tested concrete: strength class C30/37, S1 consistency, the technology for laying concrete mixture with a spreader, KR5÷KR7 category of movement. The following three types of cement were applied: CEM I 42.5 R, CEM II/B-S 32.5 R, CEM III/A 42.5 N LH/HSR/NA. The composition of concrete mixture meeting the assumed criteria was set by the method of known paste (Jamroży 2015) for each cement. They can be found in Table 3. Then, according to individual formulas, the batches of concrete's mixtures were prepared. A relevant amount of material was extracted out of these batches and samples of the type and amount according to the adopted methodology were provided.

For the CEM II/BS 32.5 R cement belongs to 32.5 class and the rest of the cements are class 42.5, adjustments in the formula of concrete mixture with CEM II/B-S 32.5 R cement had to be made, increasing the percentage of cement and accordingly reducing the amount of other components. The properties of individual concrete mixtures are shown in Table 3.

Table 3. Composition of concrete mixture for tested cement

Type of cement	CEM I 42.5R	CEM II/B-S 32.5R	CEM III/A 42.5N LH/ HSR/NA
Component	Mass kg · m^{-3}	Mass kg · m^{-3}	Mass kg · m^{-3}
Sand 0/2	580	570	580
Granite grit 2/8	465	460	465
Granite grit 8/16	780	780	780
Cement	380	400	380
Water	140	145	140
Plasticiser	1.52	1.6	1.52
Aeration additive	0.95	1.0	1.90

Table 4. Selected properties of the concrete mixture for tested cement

Type of cement	CEM I 42.5R	CEM II/B-S 32.5R	CEM III/A 42.5N LH/ HSR/NA
w/c ratio	0.37	0.36	0.37
Sand, %	32.9	32.6	32.9
Volume of mortar, dm^3 · m^{-3}	483	492	483
Density of the mixture, kg · m^{-3}	2347	2358	2347
Air content, %	4.7	4.6	4.7

CONCRETE PAVEMENT TESTS

In order to determine the properties of designed concrete pavements, the following tests were performed: compressive strength, bending tensile strength, splitting tensile strength, water absorption and frost resistance.

Compressive strength test

The concrete mixtures with composition as in Table 3, for the matching the type of cement, were prepared in a laboratory mixer. Then the mixture was laid in steel moulds with size and shape appropriate for a particular indication, and next compacted on a vibrating table. After 24 hours of maturation in the forms the samples were extracted and maintained in water at the temperature of 20°C until testing. The compressive strength of samples was tested after 7, 28 and 56 days. The results of these trials are presented in Figure 1.

The highest compressive strength after 28 days – 61.8 MPa – was achieved by the samples from the CEM III/A 42.5 N LH/HSR/NA cement. After 56 days of maturing the average value of compressive strength raised to 68.7 MPa. For concrete of CEM II/B-S 32.5 R cement the average after 28 days was 53.6 MPa, while for CEM I 42.5 R – 56.5 MPa. However, after the first week of maturation the strength of CEM III cement was the lowest, equalling only 29.4 MPa, compared to 46.2 MPa for CEM I 42.5 R and 39.2 MPa for CEM II/B-S 32.5 R.

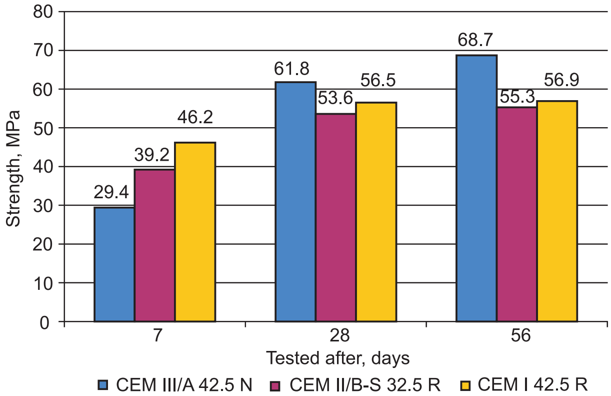

Fig. 1. Average compressive strength of the C30/37 road concrete for the tested cements

Bending tensile strength tests

Due to the nature of how concrete pavement works, an important parameter for assessing the properties of concrete is the bending tensile strength. The results of bending tensile strength tests are shown in Figure 2. The highest strength was achieved for the CEM II/B-S 32.5 R cement, after 28 days it equalled 7.76 MPa. The lowest result was obtained for CEM III/A 42.5 N LH/HSR/NA cement, after 56 days of maturation it was 5.71 MPa. Concrete with CEM I 42.5 R has shown strength of 6.19 MPa after 28 days.

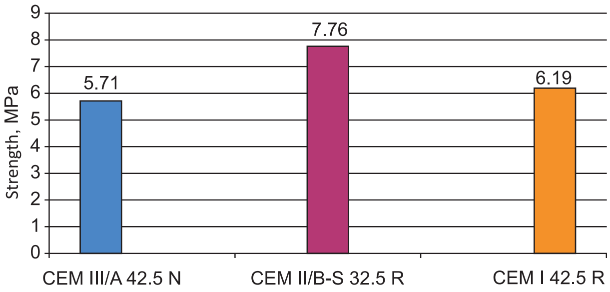

Fig. 2. Average bending tensile strength of the C30/37 road concrete, after 28 days for the CEM I 42.5 R cement and CEM II/B-S 32.5 R cement, after 56 days for the CEM III/A 42.5 N LH/HSR/NA cement

Splitting tensile strength tests

Splitting tensile strength tests are an alternative way to determine this concrete feature. The test was performed according to the PN-EN 12390-6 standard on cylindrical samples of dimensions $d \times h = 150 \times 300$ mm after 7 and 28 days for CEM I 42.5 R and CEM II/B-S 32.5 R cements and after 28 and 56 days for CEM III/A 42.5 N LH/HSR-NA cement. The highest strength was obtained for concrete that used the CEM III/A 42.5 N LH/HSR/NA cement, after 28 days it amounted to 4.87 MPa, and after 56 days – 5.18 MPa. Splitting tensile strength for other cements was tested after 28 days. It totalled to 4.54 MPa for CEM I 42.5 R and 4.34 for CEM II/BS 32.5 R cement. Their performance was shown in Figure 3.

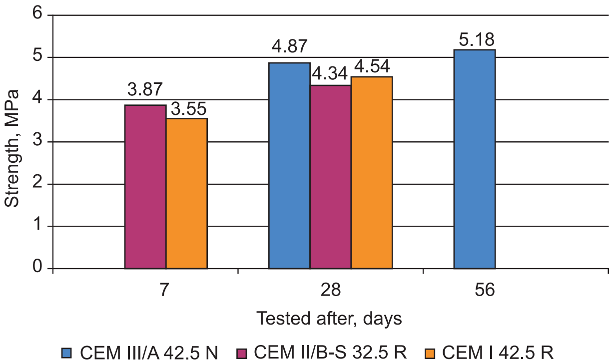

Fig. 3. Average splitting tensile strength of the C30/37 road concrete

Absorbability tests

The test of concrete absorbability was made according to PN-B-06250:1988 standard. The absorbability was tested after 28 days of maturation. Concrete made with the CEM III/A 42.5 N LH/HSR/NA cement has demonstrated the lowest absorbability. It was 2.37%. For concrete with CEM II/BS 32.5 R cement the absorbability amounted to 2.87%, and for concrete with CEM I 42.5 R cement – 2.88%.

Frost resistance test

Depending on the application, concrete pavement must have either frost resistance degree of F150 or F200. In the described research, 200 cycles of freezing and thawing were conducted for tests of concrete that was supposed to reach the F200 degree of frost resistance. The research, performed in an automated chamber for testing frost resistance, was conducted in accordance with PN-B-06250:1988 standard on cubic samples with 100 mm side after 28 days of maturation for concrete with CEM I 42.5 R and CEM II/BS 32.5 R cement after 56 days of maturation for concrete with CEM III/A 42.5 N LH/HSR/NA. The results are presented in Figure 4.

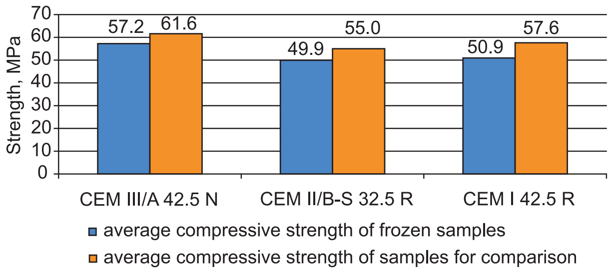

Fig. 4. Compressive strength of the C30-37 road concrete samples after frost resistance tests

Concrete with CEM III/A 42.5 N LH/HSR/NA cement performed best in the cyclic freezing and thawing test. The average mass loss of the sample after the test was 0.3%. The average strength dropped after the study by 7.1%. For concrete with CEM II/B-S 32.5 R the mass loss totalled 0.2% and strength drop of 9.4%. The highest drop in strength was indicated for concrete with CEM I 42.5 R, totalling 11.6%, and the mass loss of the samples was 0.3%.

FINAL CONCLUSIONS

The properties of concrete of different types of cement were very similar.

The CEM III/A 42.5 N cement stands out, reaching the highest compressive strength, equal to 68.7 MPa after 56 days of maturation, the lowest water absorption – 2.37% – and the lowest strength drop after 200 cycles of freezing, amounting to only 7.1%.

The tested concrete is far from exceeding the norms for concrete resistance to frost as to the frost resistance degree F200. This guarantees a long-term durability of the pavement.

Both the strength drop and mass loss of the studied concrete were significantly lower than the maximum rates required by the Catalogue of typical rigid pavement construction [2014], amounting to respectively 20% and 5%.

Each one of the examined concrete displayed water absorption significantly below the value of 5% required by the Catalogue... [Katalog… 2014].

SUMMARY

The results from the tests confirm that road concrete developed on the basis of each of the formulas, and so for each of the three applied types of cement, meets all the requirements set by relevant normative acts and technical specifications. Therefore, by meeting the technological requirements and with the proper maintenance of the pavement made of each of three types of cement will be durable.

For practical applications a variety of factors should be considered when selecting cement, such as the type of road construction, expected traffic load, time commissioning and the presence of non-standard chemical threats. Despite the very good quality of concrete with CEM III cement, the long period of reaching the designed strength can be a limitation. The advantage of cements is their low heat of hydration, which reduces a risk of shrinkage these cracks, especially in periods of temperature rise.

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OCENA WYBRANYCH WŁAŚCIWOŚCI TRZECH RODZAJÓW BETONU DROGOWEGO W ZALEŻNOŚCI OD UŻYTEGO CEMENTU

ABSTRAKT

W artykule opisano badania wpływu rodzaju cementu na wybrane właściwości betonu drogowego klasy C30/37. Wyniki badań poddano analizie. Użyto trzech różnych cementów: cementu portlandzkiego CEM I 42,5 R, cementu portlandzkiego żużlowego CEM II/B-S 32,5 R oraz cementu hutniczego CEM III/A 42,5 N LH/HSR/NA. Skład mieszanek betonowych ustalono doświadczalnie. Próbki betonów do badań przygotowano w warunkach laboratoryjnych. Okres dojrzewania wynosił 28 dni dla betonów z cementem CEM I 42,5 R i CEM II/B-S 32,5 R oraz 56 dni dla betonu z cementem CEM III/A 42,5 N LH/HSR/NA. Próbki poddano badaniom: wytrzymałości na ściskanie, wytrzymałości na rozciąganie przy zginaniu, wytrzymałości na rozciąganie przy rozłupywaniu, nasiąkliwości oraz mrozoodporności. Na podstawie wykonanych badaniach stwierdzono, że każdy z badanych cementów nadaje się do użycia w betonie drogowym. Wszystkie badane betony spełniły wymagania stawiane w Ogólnej Specyfikacji Technicznej GDDKiA [2014]. W większości badań najwyższe wartości badanych cech osiągnięto dla betonu na cemencie hutniczym CEM III/A 42,5 N LH/HSR/NA.

Słowa kluczowe: beton drogowy, wytrzymałość, napowietrzanie, mrozoodporność, drogi betonowe