



ASSESSMENT OF AGGREGATE MIXTURE REACTIVITY IN CONCRETE AT 60°C

OCENA REAKTYWNOŚCI MIESZANINY KRUSZYW W BETONIE W TEMPERATURZE 60°C

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Abstract

Research on the durability of structural concrete requires careful selection of aggregates, particularly considering their reactivity to alkali-silica reaction (ASR). The Miniature Concrete Prism Test (MCPT) allows for shortened testing time and eliminates the need for aggregate crushing, making it a practical alternative to other methods. The aim of the research is to evaluate the reactivity of aggregate mixtures with varying mineral compositions. Research results confirm the significant impact of fine aggregates on concrete expansion in the MCPT method in NaOH solution at 60°C. The observed expansion correlates with a reduction in concrete's elastic modulus.

Keywords: alkali-silica reaction (ASR), concrete expansion, MCPT method, fine aggregate, durability

Streszczenie

Badania nad trwałością betonu konstrukcyjnego wymagają starannej selekcji kruszyw, szczególnie uwzględniającej ich reaktywność na reakcję alkalia-krzemionka (ASR). Metoda Miniature Concrete Prism Test (MCPT) pozwala na skrócenie czasu badania i eliminację konieczności rozdrabniania kruszywa, co czyni ją praktyczną alternatywą dla innych metod. Celem badań jest ocena reaktywności mieszaniny kruszyw o zróżnicowanym składzie mineralnym. Wyniki badań potwierdzają znaczący wpływ kruszywa drobnego na ekspansję betonu w metodzie MCPT w roztworze NaOH w temp. 60°C. Obserwowana ekspansja koreluje z redukcją modułu sprężystości betonu.

Słowa kluczowe: reakcja alkalia-krzemionka (ASR), ekspansja betonu, metoda MCPT, kruszywo drobne, trwałość

1. INTRODUCTION

Designing concrete mixtures for durability in the operational conditions of engineering structures requires the selection of components considering the stability of their properties in aggressive environments. Mineral aggregates in cement concrete are generally components with unchanged mechanical properties. Exceptions include aggregates containing reactive silica minerals susceptible to reacting with sodium and

potassium hydroxides in the pore solution of cement concrete, known as the alkali-silica reaction (ASR). Their use in structural concrete can cause premature damage in the form of cracking, delamination, and swelling of elements, thereby reducing the operational suitability of the structure [1-2].

The selection of non-reactive aggregates is mainly conducted through petrographic analysis of the aggregate and analysis of potential concrete

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expansion under conditions that accelerate the harmful effects of ASR. The classification of aggregate reactivity is generally performed separately for each aggregate fraction, especially distinguishing between coarse and fine aggregates. According to standard recommendations, identified reactivity in one of the aggregate fractions requires treating the entire aggregate mix the same way and applying appropriate measures to prevent ASR-induced damage. Alternatively, the reactive aggregate fraction should be replaced with a non-reactive one. This approach does not align with current trends in the sustainable use of mineral resources.

The role of fine aggregate reactivity sometimes raises controversy. Literature reports indicate that expansion due to ASR increases with decreasing aggregate grain size due to the increased surface area of reactive aggregate components. However, it has been found that this relationship is not monotonic for some mineral aggregates, and the greatest expansion occurs for intermediate fractions [3-4]. Due to the dependence of reactivity on grain size, aggregates should be classified based on tests of the same fractions that will be used in concrete without crushing them.

Worldwide and in Poland, the susceptibility of aggregates to the alkali-silica reaction is primarily classified using the accelerated 14-day method at 80°C (PB/1/18 [5]) and the 1-year method at 38°C (PB/2/18 [6]). However, both methods have their drawbacks. The accelerated method requires crushing the aggregate to 2 mm, making it difficult to accurately assess the reactivity of mixed aggregate fractions. The 1-year method is problematic due to intensive alkali leaching and the impractically long testing time. The problem

of alkali leaching from concrete specimens in sealed containers occurs due to water condensation on the specimens' surfaces, leading to outward alkali diffusion from the concrete's interior and causing reduced prism expansion [7]. The Miniature Concrete Prism Test (MCPT) [8], standardized in 2019, aims to eliminate the drawbacks of the above methods with a relatively short testing time (8 weeks) without the need to crush coarse aggregate. In laboratory studies [9, 10], the MCPT method showed good agreement with the 1-year method and, more importantly, better agreement with the measurements of ASR effects on concrete blocks exposed to natural climatic conditions [11].

The aim of the research is to assess the reactivity of aggregate mixtures for concrete, composed of fine and coarse aggregate fractions with diverse mineral compositions. The research scope includes coarse crushed aggregate from solid rock and naturally occurring fine aggregates (sands). Alongside the PB/1/18 [5] methodology, the MCPT methodology was applied, i.e., the procedure for testing the expansion of concrete samples exposed to a 1 M NaOH solution at 60°C.

2. MATERIALS AND RESEARCH METHODS

For the tests, coarse crushed aggregate from greywacke (S) and amphibolite (A) with fractions of 2/8 and 8/16 were used. Natural quartz sands (B, W, T) and a mixture of natural sands (X) with a grain size of up to 2 mm were used as fine aggregates. The selection of sand was justified by the variation in potential alkali reactivity (Table 1). Portland cement CEM I 52.5 R with an alkali content of $Na_2O_{eq} = 0.88$ was used to make the concrete. Table 2 presents the chemical composition of the cement.

Table 1. Mineral aggregate characteristics

Symbol	Aggregate type	Density [g/cm ³]	Expansion acc. to PB/1/18 [5] [%]	
			14-day	28-day
S	Greywacke gravel	2.71	0.31	0.52
A	Amphibolite gravel	2.89	0.16	0.26
B	Natural pit sand	2.65	0.09	0.23
W	Natural riverbed sand	2.66	0.30	0.46
T	Natural pit sand	2.65	0.36	0.57
X	Sand mixture (50% mass of B+50% mass of W)	2.66	0.16	0.32

Table 2. Cement composition in accordance with PN-EN 196-2

Cement type	Constituent [%]								
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	LOI
CEM I 52.5 R	19.42	5.45	2.94	64.10	1.75	3.50	0.24	0.97	1.03

Concrete mixtures were designed according to the MCPT procedure [8], with a limitation on the coarse aggregate grain size to 12.5 mm. The aggregate mix was composed of appropriate fractions of gravel and sand. The fine aggregate was used without altering the grain size, and the missing 2/4 mm fraction was filled with 2/4 mm coarse aggregate. The amount of cement was constant, 420 kg/m³, the water-cement ratio (w/c) equaled 0.45; sodium hydroxide was added to the mixing water to increase the alkali content to Na₂O_{eq} = 1.25%. A modification of the procedure was the use of a mixture of aggregates with different reactivities.

Samples with gauge studs were formed from each mixture, each measuring 50 × 50 × 285 mm. The samples were compacted on a vibrating table and stored in molds at high humidity (RH > 95%) for 24 hours. The samples were then placed in water at 60°C for 24 hours, after which they were immersed in a 1 molar sodium hydroxide solution and stored for 84 days. Reference samples were stored in water at 20-22°C during the same period.

Periodically, measurements of the expansion of the samples and the resonant modulus of elasticity of the concrete were carried out using a GrindoSonic MK5 device with a piezoelectric detector, similar to [12]. At the end of the tests, compressive strength was measured on 50 mm cubic samples cut from the concrete beams.

3. RESULTS AND DISCUSSION

Table 3 presents a summary of the expansion test results and the compressive strength measurements of concrete after the expansion tests, as well as the reference samples stored in water at 20°C. The values are averages from three samples, with a variation not exceeding ±11%.

Figure 1 shows the change in length of the concrete samples over time during exposure to a 1 molar sodium hydroxide solution at 60°C. According to the MCPT procedure, the criteria for aggregate reactivity are as follows: expansion of concrete samples after 8 weeks of exposure up to 0.03% corresponds to non-reactive aggregate, 0.03-0.12% to moderately reactive, and 0.12-0.24% to highly reactive. Based on MCPT criteria, the coarse aggregates tested, even when compared with non-reactive sand B, fall into the category of moderately reactive aggregates. It was observed that replacing non-reactive quartz sand (B) with another natural sand of higher potential reactivity (Table 1) resulted in a significant increase in concrete expansion, reaching up to 110%.

Greywacke aggregate is recognized in the literature as potentially reactive [13], except for deposits in New Zealand. The primary reason for their reactivity is the presence of reactive minerals such as microcrystalline and cryptocrystalline quartz [14]. Especially when exposed to de-icing agents, greywacke aggregates significantly contribute to concrete degradation, manifesting as considerable cracking and a substantial reduction in the modulus of elasticity [15].

Amphibolite aggregates found in Poland are considered non-reactive, as confirmed by observations of currently used concrete structures. However, literature data [13] indicate that among the main minerals in amphibolite, there may be hornblende, plagioclase, quartz, epidote, calcite, and titanite, with quartz, chlorite, and calcite present in the veins. The reactive phase of amphibolite is primarily microcrystalline quartz, and also cryptocrystalline quartz found in veins and shear zones. Both the type and amount of reactive minerals ultimately influence the aggregate's susceptibility to reaction with sodium and potassium hydroxides in concrete.

Table 3. Summary of concrete samples expansion and compressive strength measurements

Mix	Expansion in 1 M NaOH at 60°C [%]		Compressive strength [MPa] after exposure to	
	56-day	84-day	NaOH 60°C	H ₂ O 20°C
SB	0.065	0.092	57.2	59.0
SW	0.093	0.119	64.3	73.1
ST	0.120	0.158	64.2	73.9
AB	0.048	0.075	56.6	67.6
AX	0.069	0.115	55.5	63.8
AW	0.095	0.159	51.9	66.5

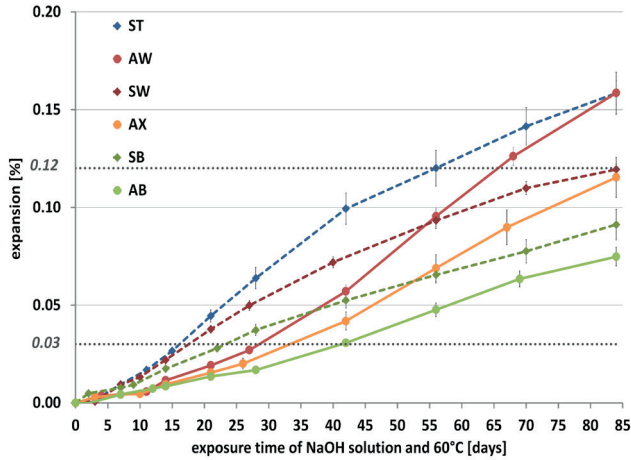


Fig. 1. Expansion of concrete specimens during exposure to NaOH solution and 60°C

For all aggregate mixtures, the effect of the fine aggregate used on the final expansion of concrete samples was observed – greater potential reactivity of the sand leads to greater final expansion of the aggregate mixture in the MCPT. Replacing non-reactive quartz sand (B) with potentially reactive sand (W) resulted in a moderate increase in expansion, about 20 – 30%, of concrete samples with greywacke (S), while with amphibolite (A) it was as much as 110%. A similar correlation, i.e., a significant influence of sand reactivity on the final expansion of concrete samples, was found in studies involving external alkali exposure [15]. In [16], river sand was identified as a cause of ASR damage in analyzed structures, and laboratory studies showed that depending on the type of non-reactive coarse aggregate used (limestone and granite), the classification of sand reactivity could change.

All concrete samples analyzed showed a decrease in the resonant modulus of elasticity and compressive strength of the concrete due to storage of the samples in a NaOH solution at 60°C (Fig. 2). The reduction in modulus of elasticity was greater with higher reactivity of the sand used in the aggregate mix. Samples with reactive sand (W), after being stored under ASR-promoting conditions, exhibited a significantly lower modulus of elasticity compared to samples with non-reactive sand – unlike the reference samples stored in water. In terms of compressive strength, no similar dependence was noted, although storage of samples under ASR-promoting conditions caused a significant decrease in strength – ranging from 2% to 15%.

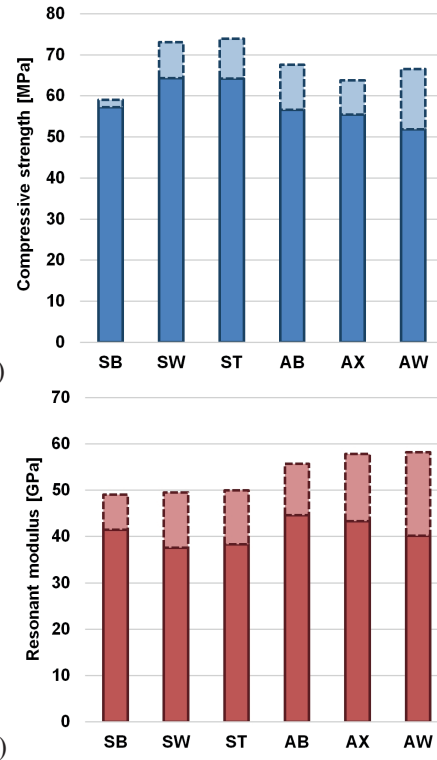


Fig. 2. Compressive strength (a) and resonant modulus of elasticity (b) of concrete after storing samples for 84 days under ASR-promoting conditions (solid line) and reference samples stored in water (dashed line)

The degree of deterioration in mechanical properties is a significant factor in assessing the risk associated with the occurrence of reactions [12]. Generally, all mechanical properties of concrete are expected to worsen due to the destructive effects of the alkali-aggregate reaction, and the degree of deterioration depends on the reactivity of the aggregate, the grain size, and the expansive properties of ASR products. Exposure of concrete samples to 60°C and high humidity in [17] showed a clear decrease in the modulus of elasticity by 21–36% and a moderate decrease in compressive strength by 7–14%. The current study results confirm this range of changes in mechanical properties and validate the varied susceptibility of these properties to ASR-induced damage – the modulus of elasticity of concrete is most closely correlated with the extent of damage due to the alkali-aggregate reaction in concrete.

4. CONCLUSIONS

Based on the conducted research, the main conclusions are as follows:

1. The use of the “Miniature Concrete Prism Test” (MCPT) to assess the reactivity of a mixture of

different fractions of mineral aggregates with varying reactivities allows for the identification of the impact of fine fractions on concrete expansion due to ASR. The variability in the potential reactivity of natural quartz sands leads to a significant increase in concrete sample expansion, reaching up to 110% after 84 days of exposure to a NaOH solution at 60°C.

2. Concrete sample expansion in an ASR-promoting environment is correlated with a reduction in the

resonant modulus of elasticity. With increased potential reactivity of the natural sand used in the aggregate mix, there is a greater reduction in the modulus of elasticity of the concrete.

3. The method for determining aggregate reactivity in concrete using a 1 molar NaOH solution at 60°C allows for the categorization of reactivity in a manner similar to methods previously used in the country.

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Funding

This paper was funded by the National Science Centre as part of the Preludium project titled “Prediction of thermo-elastic properties of composite materials in the system of reactive silica with alkali metal hydroxides in the field of temperature and gamma irradiation” (2023/49/N/ST8/02157).