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CHANGES IN THE THERMAL EXPANSION COEFFICIENT OF CONCRETE DUE TO EXPOSURE TO AGGRESSIVE CHEMICAL ENVIRONMENT

WPŁYW ODDZIAŁYWANIA CHEMICZNEGO NA ROZSZERZALNOŚĆ TERMICZNĄ BETONÓW CEMENTOWYCH Z KRUSZYWA WĘGLANOWEGO

Abstract

An analysis of the impact of long-term sulphate examination conditions on the thermal expansion of ordinary cement concrete made with the use of various limestone aggregates is presented in the paper. The article contains the results of selected chemical and temperature laboratory testing. This issue is of significant value for the description of cement concrete durability under aggressive conditions in a wide range of temperatures. The experimental results can usefully be applied to predicting the sustainability of ordinary cement concrete as well as its joints working under defined aggressive conditions.

Keywords: durability, ordinary cement concrete, limestone aggregate, sulphates, CTE, coefficient of thermal expansion

Streszczenie

Przedmiotem artykułu jest analiza wpływu długoterminowego oddziaływania siarczanów na rozszerzalność termiczną betonu cementowego z kruszywem wapiennym. Opisano laboratoryjne badania chemiczne oraz termiczne. Zagadnienie to ma istotne znaczenie dla opisu pracy betonu w środowisku agresywnym w szerokim zakresie temperatury. Wyniki badań mogą być wykorzystane w zagadnieniach związanych z opisem trwałości zarówno elementów betonowych, jak i ich połączeń.

Słowa kluczowe: trwałość, beton cementowy, kruszywo wapienne, siarczany, rozszerzalność temperatura

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Symbols

A – surface area
l – length
T – temperature
ρ – density
α – thermal expansion coefficient
σ – normal stress
E – Young's modulus

1. Introduction

Concrete structures at service temperatures are often exposed to the harmful effects of mechanical and chemical factors, e.g. load level, changes in temperature and moisture and also the impact of various chemical agents (Fig. 1). The intensity of their negative action affects changes in the mechanical properties of structures.

The impact of temperature is connected with two different attacks. One of them describes changes caused by a cyclic freeze-thaw action in association with freezing and removal of frozen water. It is well known that these cyclic changes have a significant effect on the rate and extent of degradation [1]. The second is related to insolation and the effects of daily variable thermal changes. Thermal stresses in boundary area increase the degree of degradation due to the coefficients of thermal expansion (CTE). There are also changes observed in the value of the Young modulus [2].

Fig. 1. Example of concrete structures exposed to environmental conditions

The coefficient of thermal expansion (CTE) significantly depends on material type, moisture degree, environmental temperature, and degree of degradation due to the material's corrosion. The susceptibility of concrete to corrosion is strictly related to the aggregate (Fig. 2) and cement type, and the way it is exposed to the aggressive action [3–8].

Knowledge of all the environmental factors influencing the mechanical behaviour of the concrete allows efficient numerical analysis [9] and design to be carried out.

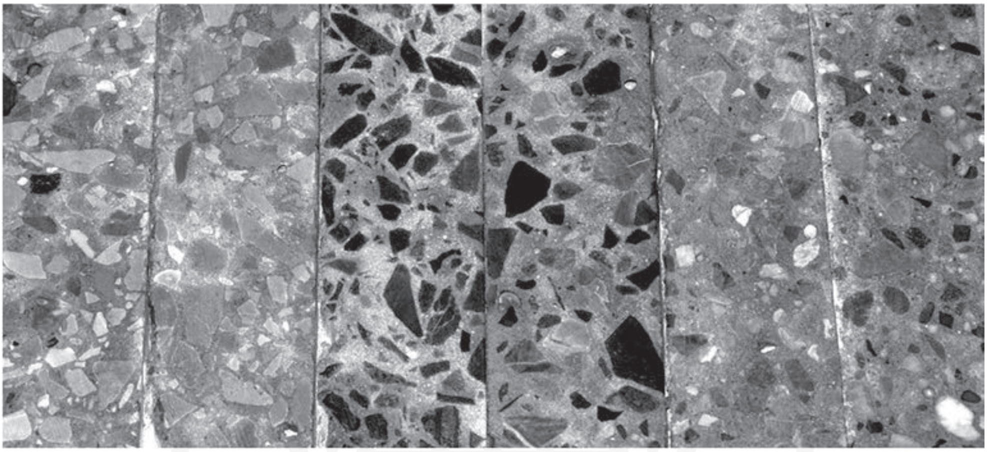

Fig. 2. Example cross-section of concrete prisms to environmental treatment

2. Experimental details

The materials used in this investigation were locally sourced and satisfied the requirements of respective Polish Standards [10–11].

2.1. Characteristics of aggregates examined

Two limestones aggregates out of six various types of carbonate as well as gravel aggregates (Fig. 2), were selected for this examination.

Two commercial granularities of limestone aggregate were investigated separately, as 2–8 and 8–16 mm, to cover the desired 2–16 mm range. The key features of the selected limestone aggregates (type A, type B) are shown in Tables 1 and 2.

Table 1

Examined concrete matrix composition

Property	Aggregate type A – examined aggregate	Aggregate type B – examined aggregate
structure	sparite and micrite	sparite and micrite
texture	compact, structured	compact, unstructured
grain size	Ø 60-200 μm (sparite) and 1 μm (micrite)	Ø 50–100 μm (sparite) and 2 μm (micrite)

Table 2

Mineral composition of the examined limestone aggregates

Main minerals	Calcite	Dolomite	Quartz	Clay
Limestone aggregate – type A	98.9%	0.7%	0.1%	0.4%
Limestone aggregate – type B	95.2%	2.8%	0.4%	1.6%

2.2. Concrete proportions and specimen preparation

The impact of the defined exposure conditions on the durability of cement concrete was investigated for concrete matrix composition, as shown in Table 3.

Table 3

Examined concrete matrix composition

	Aggregate type A	Aggregate type B
cement – CEM I 42.5R NA	360 kg/m^3	360 kg/m^3
water	180 kg/m^3	180 kg/m^3
fine aggregate – Bukowno sand	620 kg/m^3	620 kg/m^3
coarse aggregate	1245 kg/m^3	1245 kg/m^3

The concrete matrix was used to form beams with a size 10 × 10 × 50 cm. After 28 days of storage in a wet environment at temperature $t = 20 \pm 2$ºC, the beams were cut into prisms with size approximately 4 × 4 × 16 cm (Fig. 3) and conditioned for two years in laboratory conditions prior to testing [6–8].

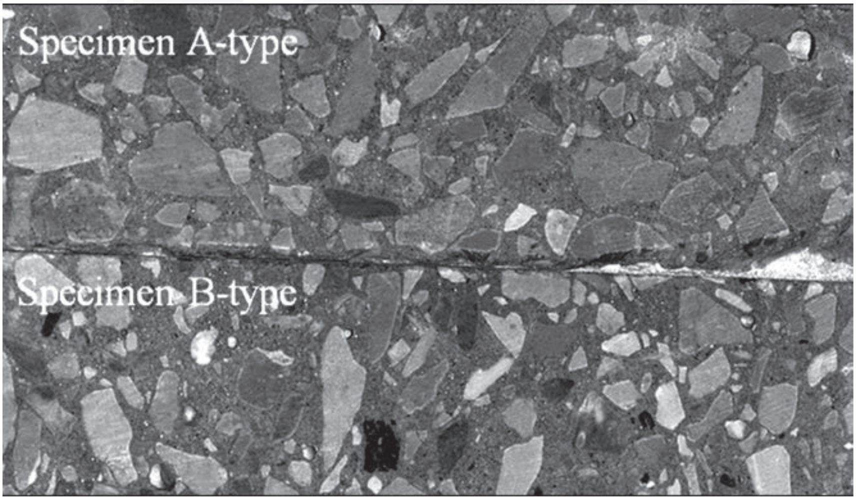

Fig. 3. Outer layer – the cut side – of the ordinary cement concrete prisms made with the use of limestone aggregate type A and B

2.3. Corrosive exposure

The environmental exposure applied to both types of concrete included storing in laboratory conditions – references sample and immersion to 5% Na_2SO_4 solution at a constant temperature of 20 ± 2ºC. The corrosive solution was changed every 28 days.

Concrete samples made with the use of various aggregates are tested in parallel.

2.4. Diagnostic features

2.4.1. Linear dimension changes cause by the corrosive exposure

The diagnostic feature adopted for the test was the change to the linear dimension (elongation) of the samples in the function of the presence of the Na^+ and SO_4^{2-} ions. During the length measurements, the samples were also weighed and observed for the presence of cracks and scratches. Any visible changes were snapped. The linear dimension changes were to be measured every 28 days. The study of the behaviour of both concrete types in the aggressive medium was carried out in parallel.

The obtained results are presented in 3.1. and 3.2.

2.4.2. Linear thermal expansion

The linear coefficient of thermal expansion (CTE) was determined on rectangular specimens with dimensions of approx. 48 × 48 mm and a total length of about $L = 165$ mm. The concrete samples were tested in a thermal chamber in a range of temperature conditions from chamber temperature (ca. 23°C) up to 60°C. The heating process was conducted for about 3 hours due to reaching the stabilised elongation value ΔL (Fig. 4). The displacement was measured with a WA-20 HBM Inductive Standard Displacement Transducer connected to a digital bridge QUANTUM MX840. An output voltage temperature sensor was also connected to the bridge. The WA-20 transducer generated the additional load $F = 1{,}2$ [N] on the examined concrete sample.

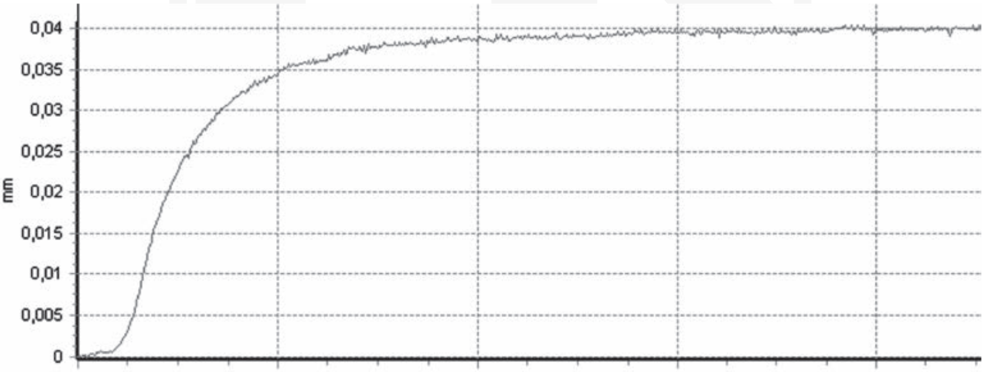

Fig. 4. An example diagram illustrating the elongation of the sample during the thermal examination as a function of exposure time

The linear coefficient of thermal expansion (CTE) was estimated by equation 1.

$$\alpha = \frac{\Delta l}{l_0 \Delta T} \tag{1}$$

where:

α – thermal expansion coefficient, 1/°C,
Δl – sample elongation, mm,
l_o – initial length, mm,
ΔT – change of temperature, °C.

The obtained results are presented in 3.3.

3. Results

3.1. Linear dimension changes cause by the corrosive exposure

The concrete prisms made of limestone aggregate type A and B were exposed in the conditions described in 2.4.1.

The dependence of the dimension changes of the samples as a function of exposure time and type of aggregate are shown on Fig. 5.

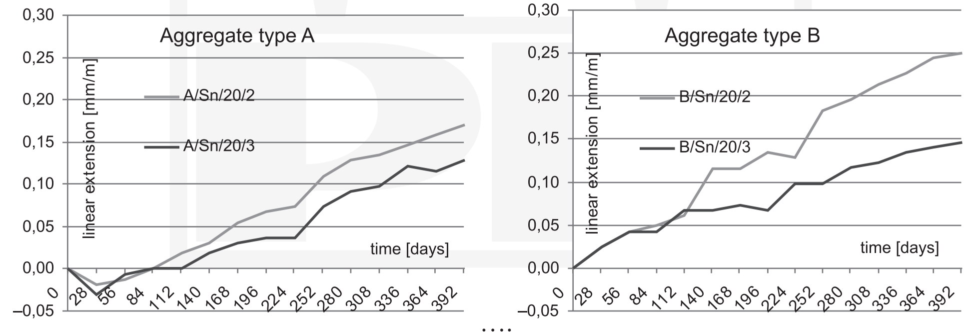

Fig. 5. The changes of concrete samples dimension as a function of aggregate type and exposure time

As expected, the linear extensions were strictly dependent on the type of aggregate examined at defined corrosion conditions. At the end point of this investigation, after 1 year of continuous exposure to a wet environment at t = 20ºC, the environment containing Na^+ and SO_4^{2-} ions was found to cause changes on a linear dimension. The most significant linear dimension changes were observed during the first six months – a large primary increase was continued by a sudden slope. In the case of concrete made with aggregate B, a slightly higher slope range was observed.

3.2. Cement concrete examination – visual inspections

Corrosion exposition to a medium containing sodium and sulphate(VI) ions can cause damage in concrete structure. The very first visible result of the sulphate(VI) ion attack is the presence of micro cracks and small scratches on the surface layer of the examined concrete sample. During the time of corrosive exposition, the micro cracks can enlarge and connect up to form a long continuous line.

Typical surface appearances of the prisms of both examined concretes after 1-year exposition to corrosive conditions are shown in Fig. 6 and 7. Visible cracks and micro cracks between particles and at their borders, marked with small yellow arrows on Fig. 6 and 7, are also shown on the surface layer of each sample.

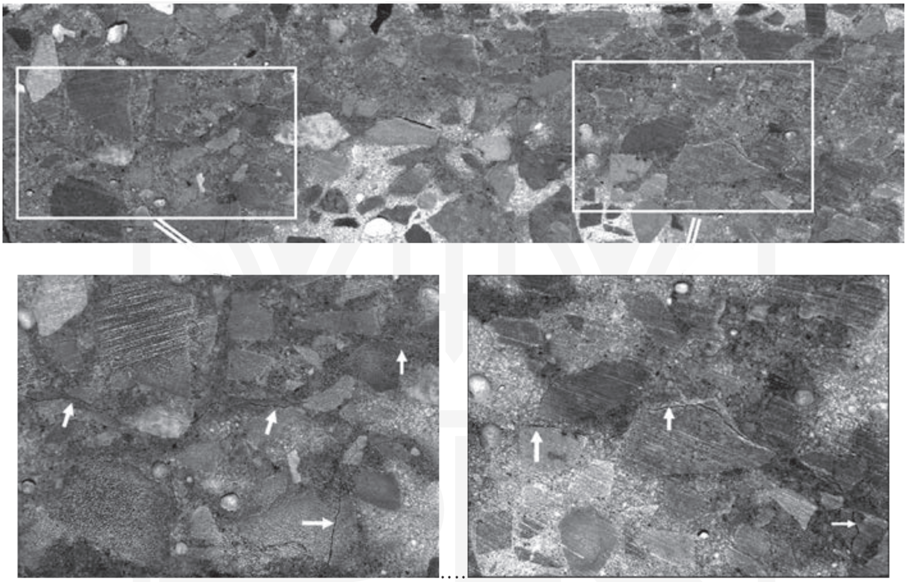

Fig. 6. The external surface of concrete type A prisms after 1-year exposition to sodium sulphate(VI) solution; magn. 1,5×

The macroscopic observation of the concrete sample surfaces exposed to the defined sodium sulphate(VI) solution revealed an increased presence of pores, cracks and scratches in the surface layer of each sample made of both types of limestone aggregates. In comparison, these observations were not made in reference samples.

In the case of both observed ordinary cement concretes with various types of limestone aggregate, the cracks and scratches could be observed as cohesive separately for concrete and aggregate as well as adhesive ones. The cohesive nature of aggregates destruction reveals information about their susceptibility to a corrosion environment containing Na^+ and SO_4^{2-} ions. The adhesive failure of concrete occurring at the border of cement mortar and all types of aggregates is typical for this sort of chemical load. All the changes of ITZ which were observed in the cases of concrete prisms of both limestone aggregates demand further observation. Accurate identification is possible after further testing of the samples under a scanning microscope. The results of this will be presented in future.

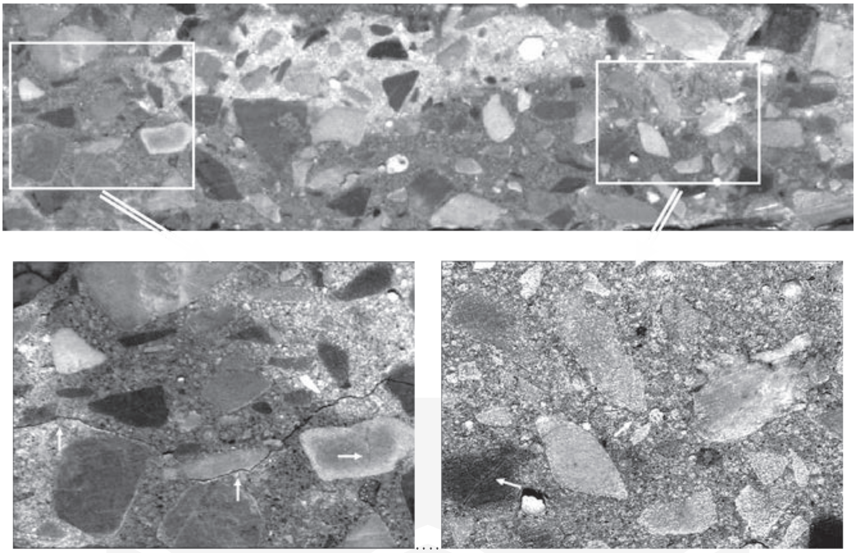

Fig. 7. The external surface of concrete type B prisms after 1-year exposition to sodium sulphate(VI) solution; magn. 1,5×

3.3. Linear thermal expansion

The concrete prisms made of limestone aggregate type A and B were examined in manner way described in 2.4.2.

The coefficients of thermal expansion obtained for the samples during the test and their characteristics are presented in Table 4.

Table 4

Values of coefficient of temperature expansion and specific gravity obtained for the examined concrete prisms

Specimen	CTE	Special gravity ρ [g/ccm]	Remarks
A/18.01.10	8.04 E-06	2.37	stored in laboratory conditions
A/Sn/20/2	6.85 E-06	2.40	exposed to chemical conditions
A/Sn/20/3	6.74 E-06	2.39	exposed to chemical conditions
B/19.01.10	8.25 E-06	2.41	stored in laboratory conditions
B/Sn/20/2	7.51 E-06	2.39	exposed to chemical conditions
B/Sn/20/3	7.15 E-06	2.38	exposed to chemical conditions

CTE results showed significant changes in their values for the chemically treated prisms exposed to the defined aggressive environment in comparison with the reference prisms. In the case of the A samples, the noticed loss of CTE value was approximately 15%. However, the loss of CTE values marked to the B samples showed differences from 9 to 14%.

Further observations are required to determine the model of behaviour and sustainability of concrete made with various types of aggregates exposed to the aggressive environment defined and variable temperature fields.

4. Conclusions

- Corrosive exposure to the sulphate medium caused changes in the surface layer of concrete prisms. Cracks and scratches on the surface of the tested samples were observed. The explanation of these phenomenon was presented in [1, 3, 4–8],
- Observed changes were strictly dependent on the aggregate's chemical composition,
- Studies have found changes in the values of CTE after the chemical examination,
- Further research is required to determine the nature of behaviour of concrete exposed to aggressive attack and various service temperature conditions.

Acknowledgements

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