

## **INFLUENCE OF SPECIMEN GEOMETRY AND SIZE ON EXPANSION DUE TO ALKALI-SILICA REACTION**

### **EINFLUSS DER GEOMETRIE UND DER PRÜFKÖRPERGRÖßE AUF DAS DURCH DIE ALKALI-KIESELSÄURE-REAKTION VERURSACHTE AUSDEHNUNGSVERHALTEN**

Hasan Özkan

*Materials Testing Institute (MPA), University of Stuttgart, Otto-Graf-Institute*

#### **SUMMARY**

It is a well-known known problem that the damage caused by the alkali-silica reaction (ASR) depends on the surface-to-volume ratio of the concrete samples produced. However, there are very few publications which compare the expansion behaviour of damaged concretes with different specimen geometries.

Concrete specimens of different sizes and shapes were made with an alkali-sensitive aggregate and stored under humid conditions favourable to the development of alkali-silica reactivity (ASR). The expansions of specimens were measured with time.

The present paper reports on the expansion behaviour of different concrete specimens produced with a slow-late reacting aggregate.

#### **ZUSAMMENFASSUNG**

Es ist ein bekanntes Problem, dass die Schädigung infolge der Alkali-Kieselsäure-Reaktion (AKR) vom Oberflächen-Volumenverhältnis der hergestellten Betonproben abhängt. Es gibt jedoch wenige Veröffentlichungen, die das Ausdehnungsverhalten geschädigter Betone mit unterschiedlichen Prüfkörpergeometrien vergleichen.

Betonproben unterschiedlicher Größe und Form wurden mit einer alkaliempfindlichen Gesteinskörnung hergestellt und unter feuchten Bedingungen, die die Entwicklung der Alkali-Kieselsäure-Reaktion (ASR) begünstigen, gelagert. Das Ausdehnungsverhalten der hergestellten Prüfkörper wurde mit der Zeit gemessen.

Die vorliegende Arbeit berichtet über das Ausdehnungsverhalten unterschiedlicher Betonproben, hergestellt mit einer langsam und spät reagierenden Gesteinskörnung.

KEYWORDS: ASR, geometry, surface/volume-ratio, expansion, leaching

## 1. MATERIALS AND METHODS

### 1.1 AGGREGATE USED

Crushed gravel (boulders) from the Upper Rhine valley (OR) was selected for the experiments. The alkali sensitivity of the rock was assessed with the accelerated mortar test according to [1] which is derived from [2] and [3]. With the mentioned test, the aggregate was found to be ASR sensitive and these reacted most strongly in [4].

Table 1: Composition of concrete mixes

Concrete indicator	Aggregate	Storage 40°C fog chamber	Cement		Aggregate proportion <sup>1)</sup> Vol.-%
			Designation	Total alkali content M.-% Na <sub>2</sub> O <sub>equ.</sub>	
OR	crushed gravel from Upper Rhine	365 d	CEM I 32.5 R	1.30	30 + 70

<sup>1)</sup> 30 Vol.-% non-reactive sand, 70 Vol.-% reactive aggregates resp.

### 1.2 CONCRETE COMPOSITION

A portland cement CEM I 32.5 R [5] was used which was enriched with potassium sulfate (K<sub>2</sub>SO<sub>4</sub>) in the mixing water so that the Na<sub>2</sub>O equivalent was 1.30% by mass. The cement content amounted to 400 kg/m<sup>3</sup>, the water to cement ratio was 0.45. The grading curve followed almost a Fuller parabola. 30% by vol. were intensive quartz sand 0/2 mm while 40% by vol. 2/5 mm and 30% by vol. 5/8 mm were the relevant aggregate.

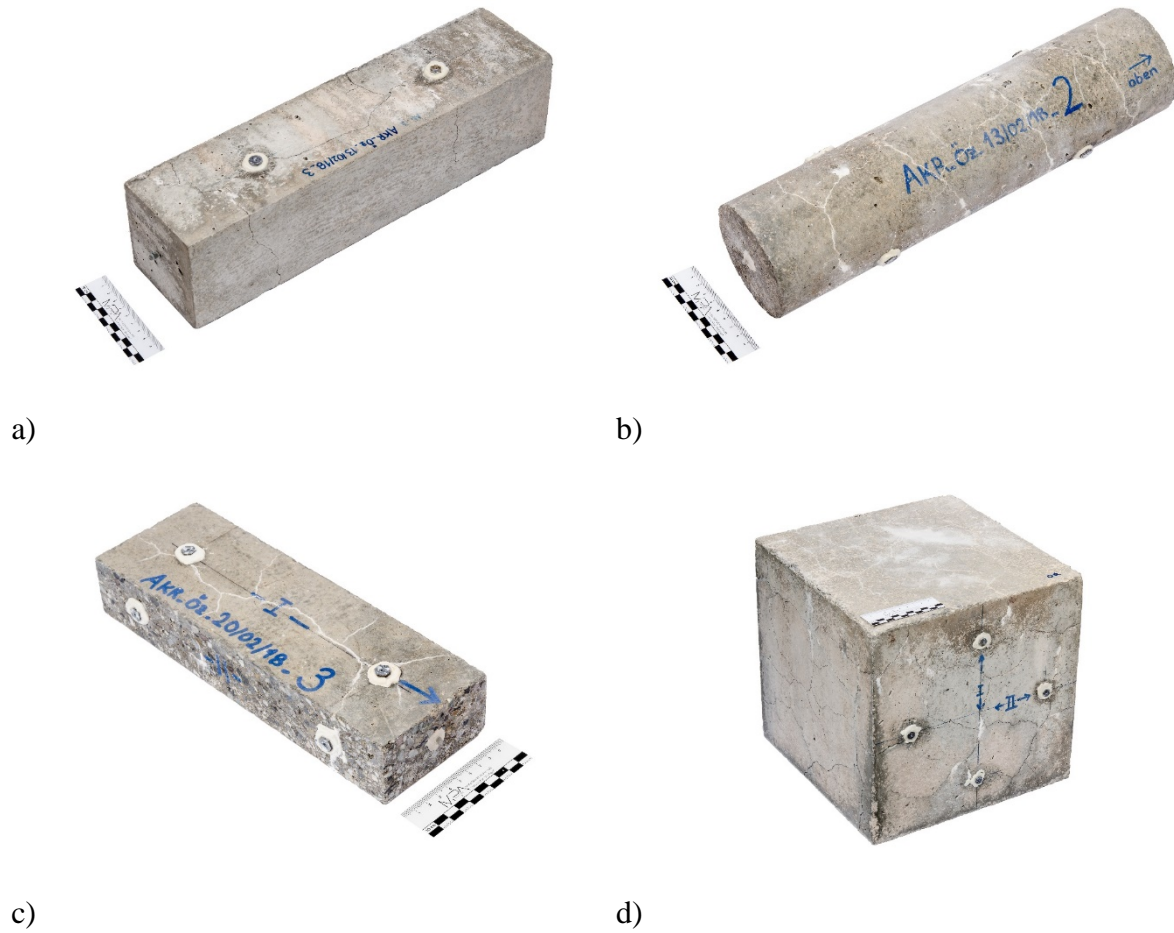
### 1.3 SPECIMENS AND STORAGE

Various test specimens (beams, cylinders, slabs and cube) with different surface/volume-ratio were produced for the expansion measurement. 30 mm cubes served for the visual inspection of edge cracks. On one formwork side of this cube the elongations in longitudinal and transverse direction were additionally determined. In addition, beams with the dimensions [7.5 x 7.5 x 28 cm<sup>3</sup>] according to ASTM C1293 [6] were produced for the investigation of the change in length. Table 2 shows the produced specimens with different surface/volume-ratio.

*Table 2: The surface/volume-ratio of specimens*

Specimen	Dimensions [cm]	Surface	Volume	Surface/Volume ratio
		A [cm <sup>2</sup> ]	V [cm <sup>3</sup> ]	A/V [-]
Beam	[5 x 5 x 20]	450	500	0.9
	[7.5 x 7.5 x 28]	953	1575	0.6
	[10 x 10 x 40]	1800	4000	0.45
	[15 x 15 x 30]	2250	6750	0.33
Cylinder	[Ø 5 x 20]	353	393	0.9
	[Ø 10 x 40]	1414	3142	0.45
	[Ø 15 x 30]	1767	5301	0.33
Slab	[5 x 10 x 30]	1000	1500	0.67
	[10 x 15 x 30]	1800	4500	0.4
Cube	[30 x 30 x 30]	5400	2700	0.2

After mixing of concrete, the specimens were stored at 20°C and 95% RH. After 28 days of storage, the concrete specimens were placed in a fog room at (40 ± 2.0)°C during 365 days. Measurements of the expansion are taken continuously up to 365 days. Fig. 1 shows examples for produced specimens (after storage in fog room) and positions of measuring points.



*Fig. 1: Example for produced specimens (after fog room storage) and positions of measuring points:  
a) beam [10 x 10 x 40 cm<sup>3</sup>], b) cylinder [Ø 10 x 40 cm<sup>2</sup>],  
c) slab [10 x 15 x 30 cm<sup>3</sup>], d) cube [10 x 15 x 30 cm<sup>3</sup>]*

## 2. RESULTS AND SPECIFIC DISCUSSION

The expansions of all concretes specimens were measured axially (except for the cube) and on surface at regular intervals during the storage in the 40°C fog room.

Measurement of axially expansions was carried out with a digital dial gauge. The change in length could be calculated by reference to the initial measurement (zero measurement with an invar rod).

The expansion measurement on surface was carried out by using a digital position strain gauge deformation meter. The measuring marks were applied to two sides of each specimen. The distance between the two measuring marks was 200 mm (Fig. 1).

The mean expansion of tree beams is plotted in Fig. 2 as function of exposition time.

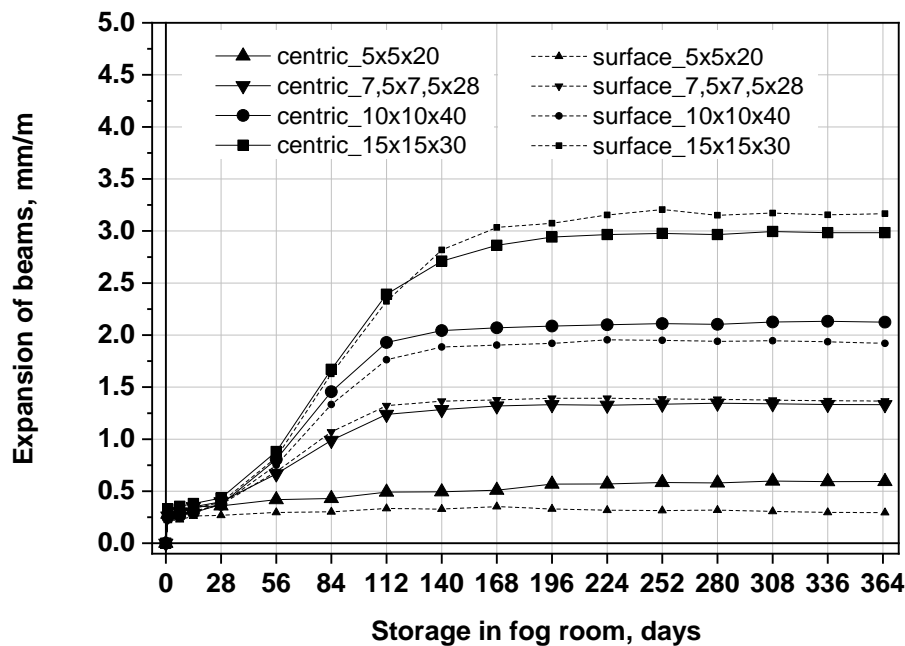


Fig. 2: Expansion of beams in fog room

The expansion of the beams exhibits the typical time-evolution of ASR-induced strains. The expansions follow an S-curve as reported by Larive [7].

The S-shape is qualitatively valid of the aggregate involved but depends quantitatively on the boundary conditions of the tests like size of specimen and temperature/humidity regime.

All lines start at low level of expansion (approx. 0.25 mm/m), increase then strongly and finally reach plateau with an asymptotic maximum. The presence of alkali hydroxides is undoubtedly one of the most important prerequisites for a damaging reaction. When the ASR can no longer progress due to the consumption of the alkalis by the reaction or decreasing quantities due to alkaline leaching, the reaction comes to a standstill and the expansions approach their asymptotic final value.

The length change in the very first time is due to the temperature change from 20 to 40°C. If one assumes a thermal coefficient of expansion of  $10 \times 10^{-6} /K$  the thermal strain would be  $0.2 \times 10^{-3}$  which can be seen in the figure approximately. The values of this expansions due to the temperature change shows table 3.

Table 3: The strains due the temperature change from 20 to 40°C

Specimens	Dimensions [cm]	Centric-Expansion [mm/m]	Surface-Expansion [mm/m]
Beam	[5 x 5 x 20]	0.280	0.233
	[7.5 x 7.5 x 28]	0.262	0.229
	[10 x 10 x 40]	0.265	0.238
	[15 x 15 x 30]	0.330	0.288
Cylinder	[Ø 5 x 20]	0.273	0.238
	[Ø 10 x 40]	0.268	0.246
	[Ø 15 x 30]	0.324	0.277
Slab	[5 x 10 x 30]	0.271	0.229
	[10 x 15 x 30]	0.274	0.257
Cube	[30 x 30 x 30]	—	0.333

There are big differences between the expansions of beams. The differences between axial expansions (centric) and surface expansion are very small. The test specimens reacted almost simultaneously in the beginning of fog-room-storage. They start after approx. 30 days to react. The beams [15 x 15 x 30 cm<sup>3</sup>] expanded most. The surface/volume ratio of the beams [15 x 15 x 30 cm<sup>3</sup>] is significantly lower (0.33) than that of other beams, so that alkali leaching is significantly lower.

These specimens reached a maximum elongation of approx. 3.0 mm/m after 224 days in fog room. The beams [10 x 10 x 40 cm<sup>3</sup>] are second and reach their asymptotic maximum at 2.1 mm/m after 160 days. The beams [7.5 x 7.5 x 28 cm<sup>3</sup>] show after 140 days a maximum of 1.4 mm/m. As expected, the beams [5 x 5 x 20 cm<sup>3</sup>] does not react.

The cylinder specimens showed a similar course. Only the specimens with 15 cm diameter showed different expansions on their surface and axial. When looking at the expansion curves, it is noticeable that the cylinder specimens with the same surface/volume ratio were subjected to greater expansions due to ASR than the beams. It should not be forgotten here that the concrete samples were produced with the same aggregate and with the same concrete formulation. These cylinders with 15 cm diameter reach the final value of 4.1 mm/m after 196 days in fog room. The cylinders with 10 cm diameter reach their asymptotic maximum at 3.0 mm/m after 168 days. Like the small beams [5 x 5 x 20 cm<sup>3</sup>], the small cylinders with 5 cm diameter did not react.

Fig. 3 shows the cylinder expansions in the fog room.

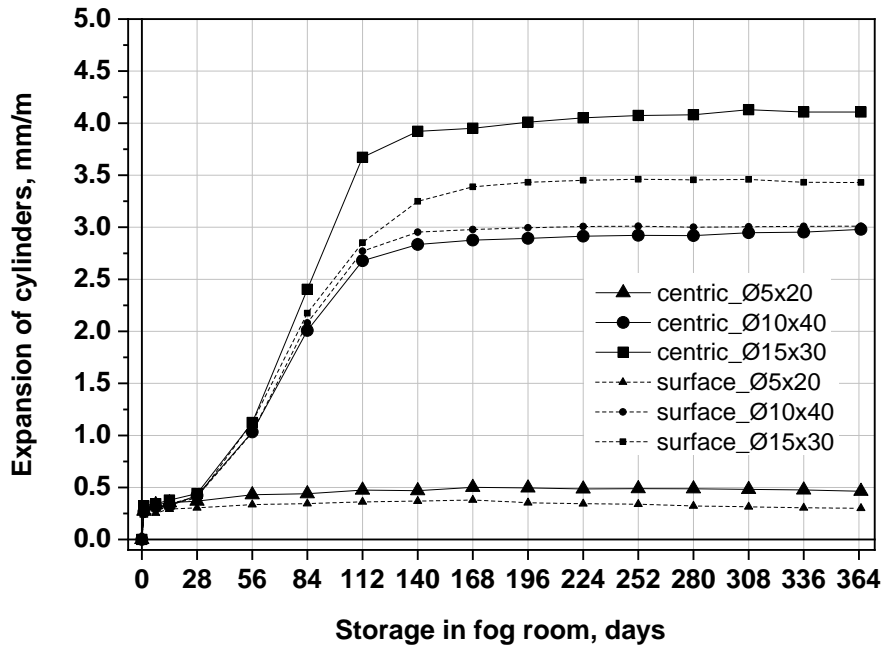


Fig. 3: Expansion of cylinders in fog room

Depending on the specimen geometry, their expansion and the extent of the expansion (ASR damage) vary. The problem of alkali leaching on expansion measurements from specimens under humid conditions is a well-known problem [8]. According to [9], under extremely humid conditions, like in the German fog chamber with temperature of 40°C, intensive alkali leaching occurs. An effective measure to reduce the amount of alkali leaching during storage in fog room is to increase the cross section of the samples. The extent and amount of alkali leaching will decrease as the surface/volume ratio decreases as the alkalis have a longer distance to diffusion. The advantage of increasing the sample size is reported by Bakker [10] and Thomas [11].

The slabs also showed a similar behaviour. The larger specimens had larger expansions at the end.

The slabs with [10 x 10 x 30 cm<sup>3</sup>] have a similar value of surface/volume ratio (0.4) as beams [10 x 10 x 40 cm<sup>3</sup>] (0.45). The end values are also similar (2 mm/m). It is remarkable that the surface expansions were significantly greater than the axial strains. Fig. 4 shows the slab expansions in the fog room.

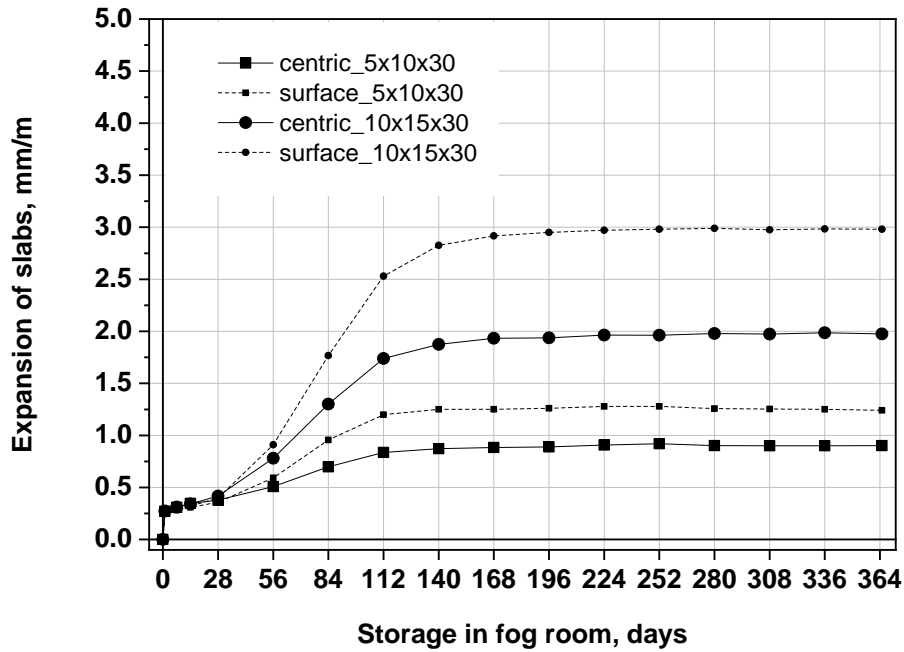


Fig. 4: Expansion of slabs in fog room

The expansions of cube were the largest (approx. 3.6 mm/m). As with the other test specimens, the reaction started after approx. 56 days. However, the final expansion was reached at a later time, namely 252 days.

Fig. 5 shows the expansions of cube during the storage in fog room.

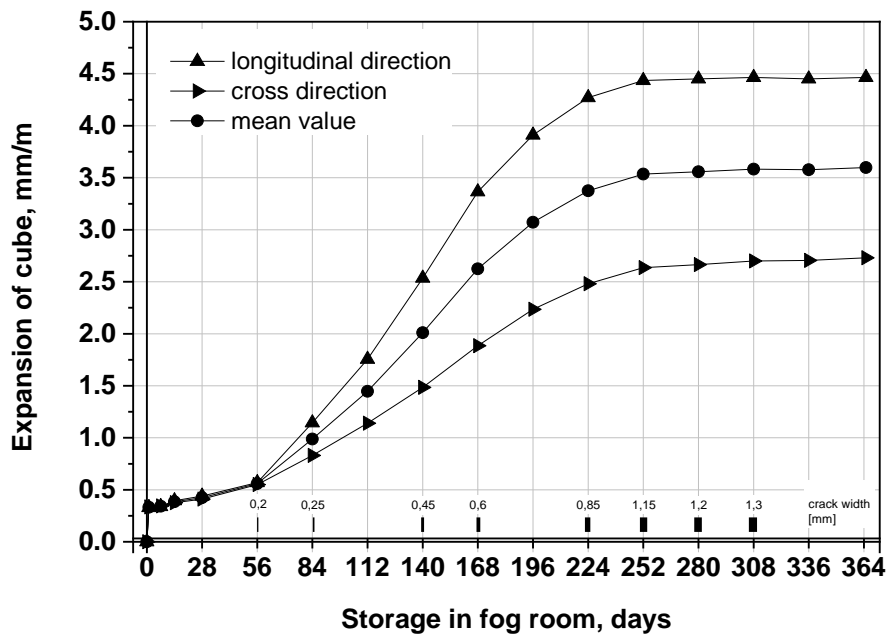


Fig. 5: Expansion of cube in fog chamber



At present, the mechanical properties such as compressive strength and the modulus of elasticity of the concrete specimens produced are being investigated in order to find out what influence the specimen geometry has on these properties.

### 3. CONCLUSIONS

The investigations have been performed on concrete specimens with different surface/volume ratio. The following conclusions can be drawn:

- The expansions of all specimens due to ASR measured during storage in the 40°C fog chamber followed an S-curve. The typical shape of the curve is very important and can be used later for the prediction of expansion in real structures [4].
- The measured expansions on the surface generally showed greater strains than the axial strains.
- The time of maximum reaction is strongly dependent on the size and type of specimens
- The more solid a test specimen is, the more alkalis are available for the reaction and the reaction takes longer until all of the concrete's own alkalis are consumed.
- Leaching is a major factor influencing the reaction. The risk of leaching is of secondary importance with greater specimens (lower surface/volume ratio).

### REFERENCES

- [1] FRANKE, L., WITT, S.: *Accelerated test for alkali reaction: application of an internationally recognized quick test to German conditions*, Concrete Plant + Precast Technology 70, No. 5, 2004, pp. 14-21
- [2] OBERHOLSTER, R.E., DAVIES, G.: *An accelerated method for testing the potential alkali reactivity of siliceous aggregates*. Cement and Concrete Res. 16, No. 2, 1986, pp. 181-189. Key Engin. Materials Vol. 711 671
- [3] RILEM RECOMMENDED TEST METHOD AAR-2, *Detection of Potential Alkali-Reactivity of Aggregates. The Ultra accelerated Mortar-bar Test*, Materials and Structures 33, No. 229, 2000, pp. 283-289
- [4] ÖZKAN, H.: *Kriechen von Beton unter Einfluss einer Alkali-Kieselsäure-Reaktion*, Dissertation, Universität Stuttgart (2018)

- [5] DIN EN 197 TEIL 1: *Zusammensetzung, Anforderungen und Konformitäts-Kriterien von Normalzement*, Berlin (Beuth) 2011
- [6] ASTM C1293-18a: *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction*, American Society for Testing and Materials (ASTM) International, West Conshohocken, PA, 2018
- [7] LARIVE, C.: *Apports combinés de l'expérimentation et de la modélisation à la compréhension de l'alcali-réaction et de ses effets mécaniques*, Thèse de doctorat, L'École Nationale de Ponts et Chaussées (1997)
- [8] BOKERN; J.: *Concrete tests for ASR assessment: effects of testing environment on preconditions for an ASR and transferability of test results*, in: M.A.T.M. Broekams, B.J. Wigum (Eds.), 13th International Conference on AAR in Concrete, Trondheim, Norway: 511-520 (2008)
- [9] LINDGARD, J., THOMAS, M.D.A., SELLEVOLD, E.J., PEDERSEN, B., ANDIC-CAKIR, Ö., JUSTNES, H., RONNING, T.F.: *Alkali-silica reaction (ASR)-performance testing: Influence of specimen pre-treatment, exposure conditions and beam size on alkali leaching and beam expansion*. Cem. Concr. Res. 53: 68-90 (2013)
- [10] BAKKER, R.F.M.: *The influence of test specimen dimensions on the expansion of alkali reactive aggregate in concrete*. In: G.M. Idorn, S. Rostam (Eds.), 6th International Conference on Alkali- Aggregate Reaction in Concrete, Denmark, S. 369-375 (1983)
- [11] THOMAS, M., FOURNIER, B., FOLLIARD, K., IDEKER, J., SHEHATA, M.: *Test methods for evaluating, preventive measures for controlling expansion due to alkali-silica reaction in concrete*. Cem. Conc. Res. 36: 1842-1856 (2006)