ALKALI SILICA REACTION IN CONCRETE WITH GRANITE -LABORATORY TESTS AND REAL SERVICE CONDITIONS

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Abstract

Damage to German concrete pavement by the alkali silica reaction has been repeatedly observed over the last two decades. Since certain slowly reacting aggregates are considered to be responsible for this damage they should be assessed in approved concrete performance tests before application in concrete pavement production. While the assessment of well-known alkali reactive aggregates in Germany provides reliable results, the assessment of granitic aggregates in concrete performance tests leads to unexpected indications of damaging ASR. In view of this, performance tests were carried out using top-layer pavement concrete compositions with granite in the coarse fractions and quartzitic sand. The results show that exposure to NaCl solutions unfavourably affects the alkali reactivity of the sand whereas the granite showed no indications of ASR. It is not known why this occurs in concrete with granite and quartzitic sand, but not with other slow reactive fine crystalline aggregates, e.g. greywacke. Investigations based on long time exposure of granite in the ASR mortar bar test reveal that the damage characteristics of ASR in granite particles differs clearly from that in fine crystalline slow reactive aggregates.

Keywords: granite, performance test, alkali ingress

1 INTRODUCTION

Within the last two decades, a damaging alkali silica reaction (ASR) in German concrete pavements has been repeatedly observed. Besides an increase in dynamic load by traffic and exposure to de-icing salts, the use of slowly reacting aggregates is considered to be to a major factor for this damage. As a consequence, performance tests for the evaluation of the ASR potential of aggregates and concrete compositions have been developed [1, 2]. According to current national regulations, the tests should be applied to avoid ASR damage in future concrete structures [3]. In this context the approved $60 \,^{\circ}C$ performance test with external alkalis provides reliable results for the common alkali reactive rock types in Germany such as greywacke or rhyolite. However, application of the $60 \,^{\circ}C$ performance test with external alkalis on concretes with granitic aggregates leads to unexpected indications of a damaging ASR. A microscopic characterization of the tested concrete showed that granite grains as well as reactive components of the natural sand used in the concrete composition contributed to ASR.

Despite this, significant ASR damage in real service concrete containing granite has not been observed up to now. As a consequence, there is only little experience in the behaviour of German granites in the performance test. However, investigations show that there are a few cases of damaging ASR where a contribution of granitic aggregates cannot, at present, be excluded. Documented cases, e.g. in Portugal and Norway, show that granitic aggregates can indeed cause an ASR [4, 5]. In view of these circumstances, a reliable assessment of concrete with granitic aggregates for application in motorway pavements cannot be guaranteed at present.

Therefore the focus of the present investigation program was on the characterization of typical damage features of ASR in concrete with granitic aggregates. Additionally, the effect of different natural quartiztic sands in concretes with granite was investigated with the performance test.

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2 MATERIALS AND METHODS

2.1 Materials and mix designs

An OPC CEM I 42.5 N with an alkali content of 0.85 wt.-% was used. A coarse granitic aggregate was used in the grading fraction 2/8 mm. In the fine grading fraction two natural sands of different mineralogical compositions were used. The mineralogical and chemical compositions of the materials are summarized in Table 1 and Table 2. The aggregates were analysed for their amount of potentially alkali reactive components with polarization microscopy. Thin sections (20x40 mm²) were prepared for each sand and the petrographic composition determined with point-counting (approx. 1000 point per sand type). The results of the microscopic investigations reveal that approximately 5 vol. % of the quartzitic components in sand 1 can be classified as potentially reactive (e.g. deformed quartz or microcrystalline quartz). Opposed to this, approximately 40 vol. % of the quartzitic components of sand 2 are potentially reactive. These are especially chert, microcrystalline quartz, deformed quartz or siliceous limestone. The quartz in the granite exhibits a subhedral to anhedral crystal shape with a slight undulatory extinction. Varieties of quartz in granite which are typically associated with ASR [4, 6] such as intensively deformed quartz or microcrystalline quartz are not present in the aggregate. Moreover, the granite exhibits no signs of deformation structures.

Two different top layer concrete compositions were produced according to [3]. Accordingly, a cement content of 430 kg/m³ and a water/cement ratio of 0.45 were used. The amount of granite 2/8 mm was 70 vol.-%. The difference between both concrete compositions is in the different sands 0/2 mm used in the fine grading fraction.

2.2 Methods for assessment and analysis

One main point of the investigation program was to provoke ASR in a granitic aggregate to characterize the microscopic damage features and to identify the reactive components. Mortar bars (40x40x160 mm³) were stored in a 1 M NaOH solution at 80 °C for one year. The mortar composition and storage conditions were based on the ASR mortar bar test of the German Alkali Guideline published by the German Committee for Reinforced Concrete (DAfStb) [7]. After 28 days, 140 days and one year of storage, thin sections of the prisms where prepared and characterized by polarization microscopy inclusive UV illumination.

For performance tests on concrete made with granite the German standardized 60 °C concrete performance test with external supply of alkalis was applied. Accordingly, nine concrete specimens (75x75x280 mm³) were made for each concrete composition and exposed to the conditions shown in Table 3. Three different storage solutions were used - two NaCl solutions with 3 wt. % und 10 wt. % of sodium chloride and a reference solution of de-ionized water. The results of the performance test are assessed with a maximum expansion value of 0.3 mm/m for the 3 % NaCl solution and 0.5 mm/m for the 10 % NaCl solution [1]. The different reaction behaviour of the granite and the sands for the NaCl solutions was investigated. As well as changes in ultrasonic pulse velocity for the determination of the dynamic Young's modulus, changes in mass and length were recorded at intervals of 14 days. After the ten testing cycles (140 d), thin sections of the specimens were prepared for microscopic characterization of the concrete microstructure.

3 **RESULTS and DISCUSSION**

The exposure of the mortar prisms with granite to 1 M NaOH solution at 80 °C resulted in an expansion of 7.26 mm/m after 330 days. The development of the mortar microstructure regarding ASR in the granite grains is described below. As expected, no signs of damage were found in the thin sections of the mortar prisms before solution storage (Figure 1). After 28 days storage in the 1 M NaOH solution, the specimens exhibited an average expansion of 1.36 mm/m. Pronounced changes were observed in the aggregate grains. As shown in Figure 2 there is a significant amount of microcracks within the granite grains which are systematically located along grain boundaries between single quartz crystals. It is well-known that grain boundaries are preferred pathways for the permeation of the pore solution into the grain [8, 6]. The examination with UV illumination illustrates that up to this period of exposure the microcracks are limited to the aggregate components and do not continue into the surrounding hardened cement paste matrix. Moreover, no alkali-silica gel was found in microcracks. A few air voids were filled with alkali-silica gel. After 330 days of exposure an intensive damage pattern caused by ASR was found in the specimens. Dissolution of quartz along the grain boundaries was observed. Figure 3 shows that dissolution structures and associated cracks are concentrated in the quartz. However, a small amount of cracking was also observed within feldspar (Figure 4). Furthermore, the mortar is characterized by a large amount of alkali-silica gel and cracks running through the aggregate and the cement paste matrix (Figure 4). Alkali-silica gel is typical

located in air voids and in cracks at the transition zone between grains and cement paste. A systematic formation of alkali-silica gel in the inner parts of granite grains, as for example observed by Velasco-Torres et al. [6] in real service concrete damaged by ASR, was not found.

The results of the 60 °C concrete performance test with external supply of alkalis for the granite concretes with different sands are summarized in Figure 5 below. It is obvious that the storage in deionized water caused no significant expansion and changes to the dynamic Young's modulus. The exposure to a 3 % NaCl solution led in both concretes to similar expansion values after 140 days, 0.28 and 0.33 mm/m for the concrete with sand 2 and the concrete with sand 1, respectively. Accordingly, the concrete expansions are in the range of the 0.30 mm/m threshold after 10 cycles of exposure. A distinctive discrepancy of the expansion behaviour was observed for the 10 % NaCl solution. While the concrete with sand 1 showed a final expansion of 0.49 mm/m after 140 days, the expansion of the concrete with sand 2 reached a value of 2.46 m/mm. The specimens with sand 2 exhibited a high expansion increase after only 42 days. The simultaneous decrease of the dynamic Young's modulus indicates the beginning of a damaging ASR at this storage time. The different development of expansion and the dynamic Young's modulus for the two concretes agrees with the results of polarization microscopy. This is mainly due to the different sands. Numerous reactive components especially siliceous limestone, chert and microcrystalline quartz - of the concrete with sand 2 are characterized by ASR (Figure 6). Originating in the sand grains, the cracks systematically run into the surrounded cement paste matrix sometimes reaching the concrete surface. In contrast, the specimens with sand 1 show slight indications of ASR caused by components of the sand. In both concretes, granitic grains show an occasional and not systematic crack orientation. The formation of alkali-silica gel was not observed in these cracks. Accordingly, the association with ASR caused by granitic components was not detectable after 10 cycles of exposure. Further exposure of the concretes to the 60 °C concrete performance test with external supply of alkalis should provide more precise conclusions on the crack development in granitic aggregate related to ASR.

The specimens exposed to de-ionized water and a 3 % NaCl showed no microscopic indications of ASR. An effect of the NaCl concentration of the storage solution with regard to damage development is apparent in the concrete with sand 2. Obviously the increase from 3 wt. % to 10 wt. % NaCl in the storage solution leads to a significant increase in ASR in many of the reactive components of sand 2. Such a distinct effect in the 60 °C concrete performance test with external supply of alkalis shows that an ASR in the sand fraction can contribute to the expansion and thus also to the assessment of the concrete composition with regard to its ASR potential. The behaviour of the sand was unexpected especially because the performance test was developed with focus on the coarse aggregate because they cause ASR damage in real service. Even previous publications about the investigation of the 60 °C concrete performance test with external supply of alkalis on concrete with greywacke and rhyolite (most common slow reactive aggregates in Germany) did not mentioned such contribution of sand on the test results [1, 9]. Moreover, in Germany, ASR damage in real service concrete caused by sand is unknown.

4 CONCLUSIONS

The microstructural development of ASR in granite was investigated based on long time exposure according to the ASR mortar bar test (German Alkali Guideline). The microstructure at early damage conditions showed a systematic formation of microcracks along grain boundaries within the granite grains, but no significant formation of alkali-silica gel and no visible cracks in the cement paste matrix. This differs clearly from equally damaged mortar made with fine crystalline slow reactive aggregates which exhibit the well-known ASR characteristics, i.e. of crack migration from the grain into the surrounded cement paste matrix and formation of ASR products within these cracks. After one year of exposure ASR damage features were observed such as dissolution along grain boundaries of quartz in the granite and the formation of alkali-silica gel within cracks and air voids.

Investigations on top-layer pavement concrete compositions with granite showed that the concentration of NaCl solution (3 wt. % or 10 wt. %) used in the 60 °C concrete performance test with external supply of alkalis can affect the alkali reactivity of the sand fraction. However, why this occurs especially in concrete with granite and sand in particular, but not with other slow reactive fine crystalline aggregates it not yet known. Regarding a reliable assessment of concrete compositions and aggregates, an unequivocal transfer of the results from the 60 °C concrete performance test with external supply of alkalis for application in real service motorway pavement concrete cannot be guaranteed.

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Ovides	Sand 1	Sand 2	Granite	CEM I 42.5 N
Oxides		[wt.%]		
LOI	0.16	11.59	1.10	2.07
Na ₂ O	0.03	0.03	2.66	0.35
K ₂ O	0.85	0.46	4.83	0.75
Na ₂ O-Eq.	0.59	0.34	5.84	0.85
CaO	0.15	12.96	0.49	65.33
MgO	0.05	2.03	0.46	0.98
Fe ₂ O ₃	0.67	1.03	2.15	1.79
Al ₂ O ₃	1.90	1.98	13.52	4.83
SiO ₂	95.7	69.45	74.51	21.19
SO3	< 0.01	< 0.01	< 0.01	2.74

TABLE 1: Chemical composition of the materials.

DI	Sand 1	Sand 2	Granite		
Phase	[wt.%]				
Mica	n.d.	n.d.	9.95		
Calcite	n.d.	14.57	0.70		
Chlorite	n.d.	n.d.	2.49		
Amphibole	n.d.	n.d.	n.d.		
Dolomite	n.d.	8.32	n.d.		
Potassium feldspar	3.76	2.82	25.23		
Plagioclase	1.49	2.72	28.44		
Pyroxene	n.d.	n.d.	1.79		
Quartz	94.75	64.66	31.39		
Amorphous content	n.d.	6.91	n.d.		

n.d. – not detectable

TABLE 2: Mineralogical composition of the aggregates.

	1 d	in mould, 20 °C and 100 %RH	
Initial storage: total 28 d	7 d	20 °C and ≈ 100 %RH	
	14 d	20 °C and 65 % RH	
	6 d	60 °C and ≈ 100 %RH	
	1 d	20 °C and ~ 100 % RH, measurement	
	5 d	60 °C (dry)	
Cyclic storage:	5 d 2 d	60 °C (dry) 20 °C in storage solution ¹)	
Cyclic storage: 10 cycles of 14 d	5 d 2 d 6 d	60 °C (dry) 20 °C in storage solution ¹⁾ 60 °C and ≈ 100 % RH	
Cyclic storage: 10 cycles of 14 d total 140 d	5 d 2 d 6 d 1 d	60 °C (dry) 20 °C in storage solution ¹) 60 °C and ≈ 100 % RH 20 °C and ≈ 100 %RH measurement	

TABLE 3: Storage in the 60 °C concrete performance test with external supply of alkalis. 100 %RH = moist storage over water, 65 %RH = in climatic chamber.





200 µm

FIGURE 1: Expansion of the of the mortar prisms with granite after a storage of one year in 1 M NaOH solution at 80 °C (left); Photomicrograph of the microstructure of the granite in mortar before exposure to the NaOH solution; PPL (right).



FIGURE 2: Photomicrograph of the microstructure of granite after 28 days in NaOH solution at 80 °C with a crack formation along crystal boundaries; PPL (left); UV light illumination (right).



FIGURE 3: Photomicrograph of the microstructure of granite after one year in NaOH solution at 80 °C with a crack formation and dissolution along crystal boundaries and within single quartz crystals; PPL (left); XPL (right).



FIGURE 4: Photomicrograph of the microstructure of granite after one year in NaOH solution at 80 °C with dominated signs of damage in quartz crystals (left) and the formation alkali-silica gel (AS gel) in cracks right; PPL.



FIGURE 5: Development of the dynamic Young's modulus und expansion of concrete with sand 1 and sand 2 in the 60 °C concrete performance test with external supply of alkalis.



FIGURE 6: Cracked chert grain with the formation of alkali-silica gel at the transition zone between grain and the surrounded hardened cement paste in the concrete with granite and sand after 10 cycles of exposure in the concrete performance test with a 10 % NaCl solution; PPL (left); UV light illumination (right).