ALKALI SILICA REACTION IN ULTRA-HIGH PERFORMANCE CONCRETE CONTAINING RICE HUSK ASH

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Abstract: *In the present study, the risk of alkali silica reaction of ultra-high performance concrete (UHPC) was assessed in NaOH solution and accelerated climate condition. The UHPC containing rice husk ash (RHA) with and without ground granulated blast-furnace slag (GGBS) were used. The results were compared with those of UHPCs containing silica fume (SF). The durability of the RHA-blended was high but not better than that of the SF-blended UHPCs. There should be no concern about alkali silica reaction problem in the UHPC containing RHA, especially with GGBS combination. When samples were immersed in NaOH solution, the length change result of the testing significantly depends on the permeability, the autogenous shrinkage and the size of samples.*

Keywords: *UHPC, Rice husk ash, GGBS, Silica fume, Alkali silica reaction.*

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1. Introduction

Ultra-high performance concrete (UHPC) with 28d-compressive strength over 150 MPa and advanced durability properties is a new type of concrete [1,2]. To optain the outstanding properties, UHPC commonly consists of a high amount of Portland cement, puzzolanic admixtures and fine grained aggregates, and with a high dosage of superplasticize [3-5]. The high amount of puzzolanic admixtures with high content of reactive silica makes some concerns about alkali silica reaction in UHPC [6].

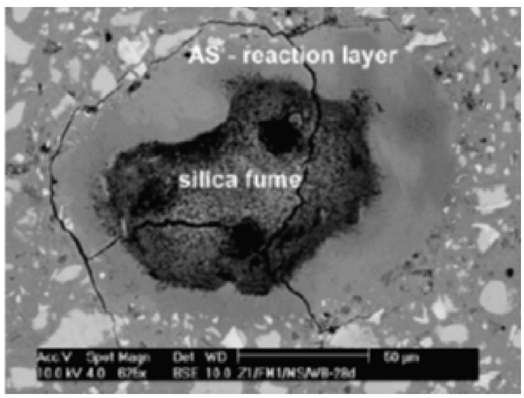

Figure 1. *Silica fume agglomeration and development of cracks caused by ASR in UHPC [6]*

The research of Graybeal [7] indicated that alkali silica reaction (ASR) would not be a problem to UHPC containing silica fume (SF). The expansion of UHPC samples was far below the threshold of the ASR test according to ASTM C1260-01 [8]. The deterioration of UHPC by ASR was also tested by cyclic climate storage (CCS) developed at the F.A. Finger for Building Materials Science (FIB), Bauhaus-University Weimar, Germany [6]. The results indicated that the expansion of all the investigated UHPC samples was very low compared with that of a normal concrete sample using a reactive aggregate. However, ASR has been locally observed in UHPC microstructure because of insufficient dispersion of SF (Fig. 1). But it had no macroscopic effect on durability.

While rice husk ash (RHA) improves the microstructure, chloride or sulfate resistance and mechanical properties of concrete, there are some concerns about the alkali silica reaction (ASR) in mixtures containing RHA due to the fairly high alkali content which inherently exists with the high amorphous silica content in RHA. Hasparyk et al. [9] tested the expansive behavior of mortar bars as specified in ASTM C1260 [8] and concluded that it is possible to reduce significantly the mortar-bar expansion for both reactive quartzite and basalt aggregates by using up to 15 wt.-% either SF or RHA replacing cement. After 14 days in NaOH 1M at 80°C, the specimens containing 12 or 15 wt.-% RHA had expansion levels lower than the prescribed limit.

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Mehta et al. [10] also had the same conclusion for the improvement of ASR resistance of RHA for mixtures using reactive aggregate. On the other hand, Ramezanianpor et al. [11] reported that an optimum amount of RHA seems to be between 7 and 10 wt.-% to control ASR of reactive aggregates. Increasing the amount of RHA can cause an increase in the expansion. Hence, the ASR risk of UHPC containing RHA is considered in this study.

2. Materials and methods

2.1 Materials

Cementitious materials used in this study were ordinary Portland cement, ground granulated blast-furnace slag (GGBS), RHA and undensified powder of SF. Quartz powder and quartz sand were utilized as filler and aggregate, respectively. Chemical compositions and physical properties of the materials are given in Table 1 và Table 2. It should be noted that the alkali content in RHA is higher than that in SF (Table 1). The RHA is a kind of mesoporous amorphous siliceous material. More characteristics of the RHA are given elsewhere [12]. Pozzolanic reactivity of the RHA is comparable with that of the undensified SF [12,13]. Superplasticizer was a polycarboxylate ether type.

2.2 UHPC compositions and testing methods

Based on results of a previous study [14], sustainable UHPC compositions used in this study are given in Table 3.

Table 1. *Chemical composition of cementitious materials, (%)*

	SiO_2	Fe_2O_3	Al_2O_3	CaO	Na_2O	K_2O	MgO	SO_3	L.O.I
Cement	21.6	5.1	3.7	64.3	0.17	0.36	0.6	2.4	0.9
SF	96.0	0.0	0.1	0.6	0.20	0.69	0.2	0.4	1.2
RHA	87.4	0.3	0.4	0.9	0.04	3.39	0.6	0.4	4.6
GGBS	37.8	0.5	8.0	39.7	0.38	0.74	10.8	0.1	0.2

Table 2. *Physical properties of materials*

	Cement	SF	RHA	GGBS	Quartz powder	Quartz sand
Density, (g/cm^3)	3.2	2.3	2.19	2.91	2.64	2.64
Blaine (BET) SSA, (m^2/g)	0.462	(21.05)	(52.3)	0.670	0.438	-
Mean particle size (µm)	9.15	0.31	7.41	2.93	14.6	174.5
Comp. strength of cement (MPa)	3 days:	36.6	7 days:	49.8	28 days:	62.2

Table 3. *UHPC compositions*

<table>
<tr><th rowspan="2">Mixtures</th><th>Cement</th><th>Quartz sand</th><th>Quartz powder</th><th>RHA (SF)</th><th>GGBS</th><th>Water</th><th>SP</th><th rowspan="2">W/B</th><th rowspan="2">W/F$_v$</th></tr>
<tr><th colspan="6">(kg/m^3)</th><th>(wt.%)</th></tr>
<tr><td>U1-22.5RHA</td><td rowspan="2">780.8</td><td rowspan="4">1029.6</td><td rowspan="4">207.8</td><td>155.1</td><td rowspan="2">-</td><td rowspan="4">216.5</td><td rowspan="2">1.0</td><td>0.231</td><td rowspan="4">0.55</td></tr>
<tr><td>U1-22.5SF</td><td>(162.9)</td><td>0.229</td></tr>
<tr><td>U2-22.5RHA</td><td rowspan="2">579.3</td><td>155.1</td><td rowspan="2">183.2</td><td rowspan="2">0.8</td><td>0.236</td></tr>
<tr><td>U2-22.5SF</td><td>(162.9)</td><td>0.234</td></tr>
</table>

The paste volume is 61 vol.-% of UHPC. Quartz powder is 20 vol.-% of fine materials. W/Fv is volume of water to volume of fine materials ratio. The same volume of RHA and SF is used in mixtures. Pozzolans partially replace cement in volume. Superplasticizer dosage is in dry mass of cementitious materials. Workability and compressive strength of UHPC containing RHA are comparable with those of UHPC containing SF. Compressive strength of UHPC is over 165 MPa at the age of 28 days.

UHPC was mixed with a total mixing time of 15 minutes based on the sequence shown in Fig. 2. Samples were cast with 30-second vibration and kept in moulds at 20°C, 95% relative humidity (RH) for 48 h

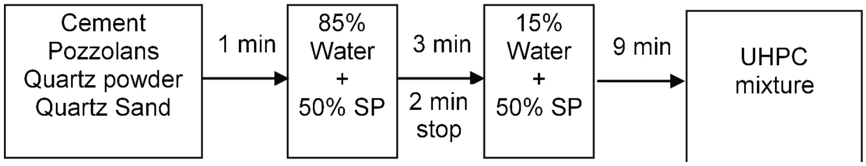

Figure 2. *Mixing procedure of UHPC*

followed by 20°C and 100% RH after demoulding until testing. To prevent the inhibition of the penetration of water and aggressive agents into specimens, Teflon was used to prepare specimen molds.

The modified German Alkali Guidelines [15] or ASTM C1260-05 [8] was used to investigate the alkali silica reaction (ASR) of UHPCs. The standard test method requires demoulding the mortar bars at 24 hours, storing the bars in water bath containers and placing the containers in an oven at 80°C for a period of 24 hours. Thereafter, the samples are immersed in NaOH 1M at 80°C with the volume of solution to concrete ratio of 4. Due to the long setting time of UHPCs, samples were tested after 48 hours in form. Weight and length of three 40×40×160 mm^3 sized specimens were recorded before and after 14 days, respectively, 28 days, immersed in NaOH 1M at 80°C. To evaluate the effect of differently autogenous shrinkage of UHPCs on the length change value, the weight and length change of the samples (40×40×160 mm^3) were also recorded after 1, 15 and 29 days in water at 80°C. Therefore, the corrected length change of the samples by the NaOH solution was calculated. Additionally, five 10×40×160 mm^3 sized bars have been tested to evaluate the effect of different specimen dimensions on the results of this ASR test. The length of all samples was measured at 80°C within 20 seconds by the equipment as specified in DIN 52450.

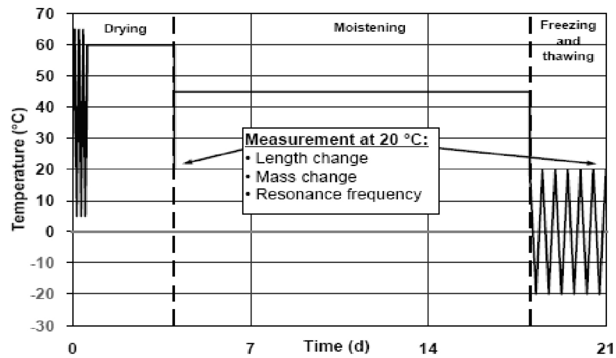

Figure 3. *Scheme of cyclic climate storage (one cycle)*

The durability of UHPCs without external aggressive agents under the accelerated conditions was also investigated. Three UHPC specimens (100×100×400 mm^3) at the age of 7 days were exposed to stimulating Mid-European climate conditions by means of cyclic climate storage (CCS). The test method was developed at the F. A. Finger Institute for Building Materials Science (FIB), Bauhaus University Weimar, Germany. One cycle of the CCS lasts 21 days, with 4 days drying at 60°C and RH < 10%, 14 days moisturizing at 45°C and 100% RH and 3 days freezing-thaw conditions between +20°C and –20°C according to the CIF test (Fig. 3). More detailed information of this method can be found elsewhere [16,17]. This test is especially suitable for considering ASR problems of concrete [6,17,18]. The expansion threshold value of sample for the CCS test without deicer solution (i.e. with water) is 0.4 mm/m after 6 cycles.

3. Results and discussion

3.1 Alkali silica reaction in NaOH solution

Results of weight and length change of three 40×40×160 mm^3 sized samples of the UHPCs after 14 and 28 days in NaOH 1M at 80°C are shown in Fig. 4. The length change values of U1-22.5SF*10 in Fig. 4b are given by multiplication of the experimental results to 10 times to make the results visible. It shows clearly that the longer the sample is in NaOH, the more the weight increases (Fig. 4a) and the larger the length changes (Fig. 4b). The RHA-modified UHPCs absorb more NaOH solution and show larger expansion than the SF-modified UHPCs. The samples containing SF are even shrunk (Fig. 4b). GGBS clearly reduces the weight and length change of the RHA-modified sample (Fig. 4).

Effect of autogenous shrinkage on length change value

It can be seen that the weight change of the samples (40×40×160 mm^3) in water (Fig. 5a) is consistent with that of the samples in NaOH 1M (Fig. 5a). NaOH accelerates the liquid absorption and the expansion of the samples (compare Figs. 4 and 5). For the length change, after one day in water at 80°C

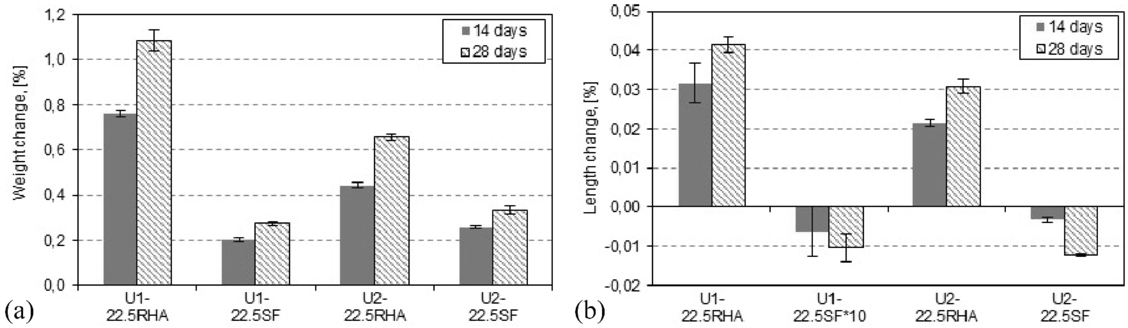

***Figure 4.** a) Weight and b) length change of 40×40×160 mm³ samples in the NaOH solution*

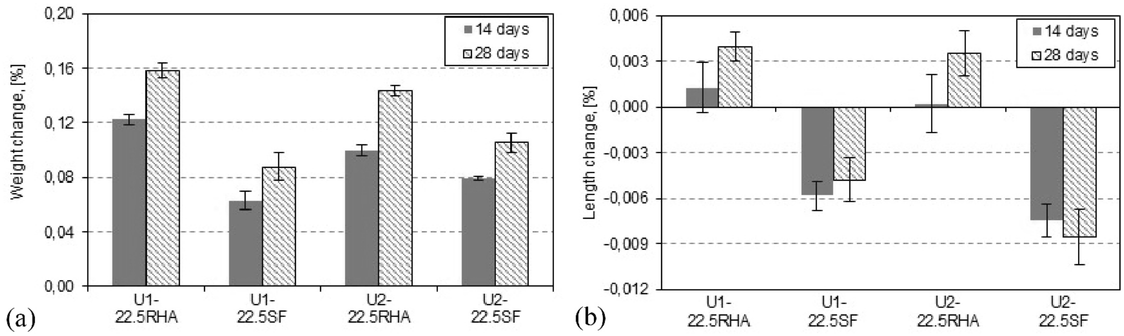

***Figure 5.** a) Weight and b) length change of 40×40×160 mm³ samples in water (replacing NaOH)*

the samples containing RHA slightly expanse during the next 28 days. Meanwhile, shrinkage is observed in the samples containing SF (Fig. 5b). The length change values measured in water is subtracted from the length change values measured in the NaOH solution. Hence, the corrected length change values in Fig. 6 present the absolute length change due to ASR in the NaOH solution. Obviously, the corrected length change of the RHA-blended UHPC samples is decreased. Except for U2-22.5SF after 28 days in the solution, the corrected length change of SF-modified UHPCs is now in the expansion range (Fig. 6). From this finding, it can be concluded that the difference in autogenous shrinkage of different UHPCs should be taken into account in the final expansion results, as the indicator of deterioration degree of UHPCs.

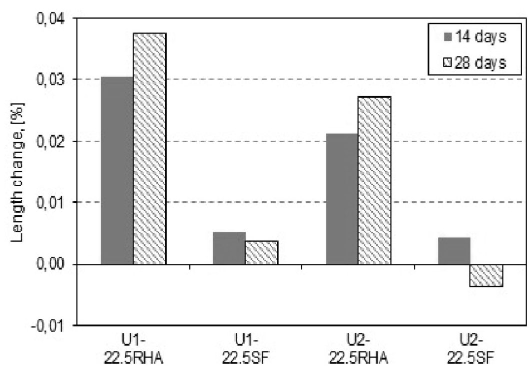

***Figure 6.** Corrected length change of 40×40×160 mm³ sized samples in the aOH solution*

Effect of sample dimension on weight and length change

Results of the weight and length change of 40×40×160 mm³, respectively, 10×40×160 mm³ sized samples during 28 days in the NaOH solution are shown in Fig. 7. The length change values of U2-22.5RHA are magnified 10 times in Fig. 7b (U2-22.5RHA*10). And the length change values of U1-22.5SF*100 and U2-22.5SF*100 in Fig. 7b are the multiplication of the experimental results to 100 times.

As expected, the reduction of the cross sectional area of the samples increases the weight change (i.e. NaOH solution absorption, Fig. 7a and hence accelerates the expansion of all the samples (Fig. 7b). Expansion of the small sized SF-modified samples is observed. In contrast, the larger sized SF-modified bars (40×40×160 mm³) are shrunk (Fig. 7b). The effects of hydration period in the NaOH solution and pozzolan addition on the deterioration of the UHPCs are more significant for specimens with smaller cross sectional area.

The variation in the damage of U1-22.5RHA with the different sized samples is displayed at the Fig, 8a and Fig. 8b. The addition of GGBS clearly improves the durability of UHPC containing RHA in the NaOH solution (compare Fig. 8b and Fig. 8c). By means of SEM, it is observed that the alkali silica gel appears in pores below the surface of U1-22.5RHA (Fig. 9). There are also some small cracks around the pore after 14 days in NaOH 1M at 80°C (Fig. 9b).

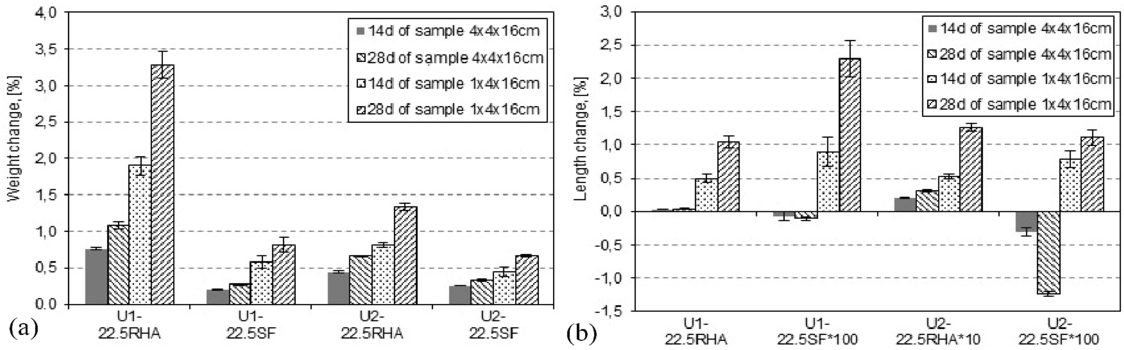

Figure 7. *a) Weight and b) length change of different sized samples in the NaOH solution*

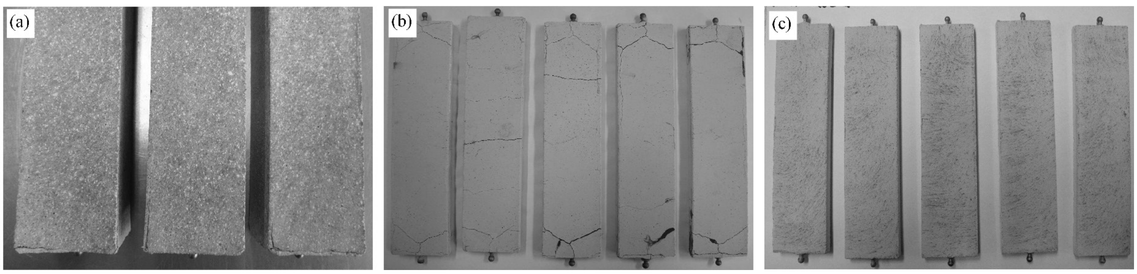

Figure 8. *Different deterioration degree of UHPCs containing RHA after 28 days in the NaOH solution by different sized samples and pozzolans: a) 40×40×160 mm^3 and b) 10×40×160 mm^3 samples of U1-22.5RHA; c) 10×40×160 mm^3 sample of U2-22.5RHA*

Generally, the results of durability of the UHPCs in NaOH solutions show that the samples containing SF possess higher durability than the samples containing RHA. The combination of GGBS and RHA or SF improves the durability of the UHPCs containing RHA or SF. The more the aggressive solution absorbed, the higher the expansion of the samples. These results are in a good agreement with the results of the effects of the pozzolans on the water absorption coefficient of the UHPCs [19].

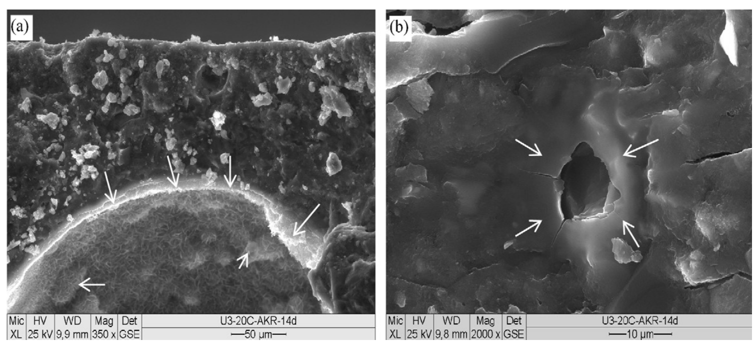

Figure 9. *ASR in U1-22.5RHA after 14 days in the NaOH solution: a) alkali silica gel in pore below surface of sample (arrows); b) alkali silica reaction layer with cracks around a pore (arrows)*

According to the standard ASR test methods, the alkali content of cement has been found to have a minor effect on expansion of the standard mortar at w/b of 0.47 because the high ingress of NaOH 1M into the standard mortar [8]. For UHPC, the water absorption of these UHPCs is very low and different. It was found that water and Na+ ions from environment diffuse into the same sized samples differently (Fig. 4a and Fig. 5b). Furthermore, it is known that the size of sample in the American standard [8] is 25×25×285 mm^3 which is different from 40×40×160 mm^3 sized sample in the German standard [15]. The weight change of different sized samples in Fig. 7a unveils that reducing the cross sectional area (i.e. the concrete volume per unit length) results in an increased ingress level of aggressive agent (Na+ ions) into the matrix. Hence, the length change value which indicates the deterioration of UHPC in the ASR test is strongly affected by the level of Na+ ions diffusing into the matrix. It relates to both the water absorption coefficient and the sample size in this accelerated test method with the external aggressive agent (Fig. 7b).

3.2 Alkali silica reaction in cyclic climate storage (CCS)

Cyclic climate storage (CCS) test was conducted on 100×100×400 mm^3 sized samples at the age of 7 days. The length change results during the examination are shown in Fig. 10. Obviously, the expansion after the first cycle (21 days) is typical for concrete due to the water absorption [17]. The regular contractions of all the samples after the first cycle are observed during the test. SF and GGBS increase the contraction of the sample (Fig. 10). The length change values of all the samples are far below the limit value of 0.4 mm/m after 16 cycles (336 days). For comparison, a normal concrete [18] with cement, greywacke aggregates (reactive aggregate), quartz sand at water to cement ratio of 0.45 has been integrated into Fig. 10. This indicates that the durability of the UHPCs is very high. There should be no concern about the ASR in the UHPCs containing RHA.

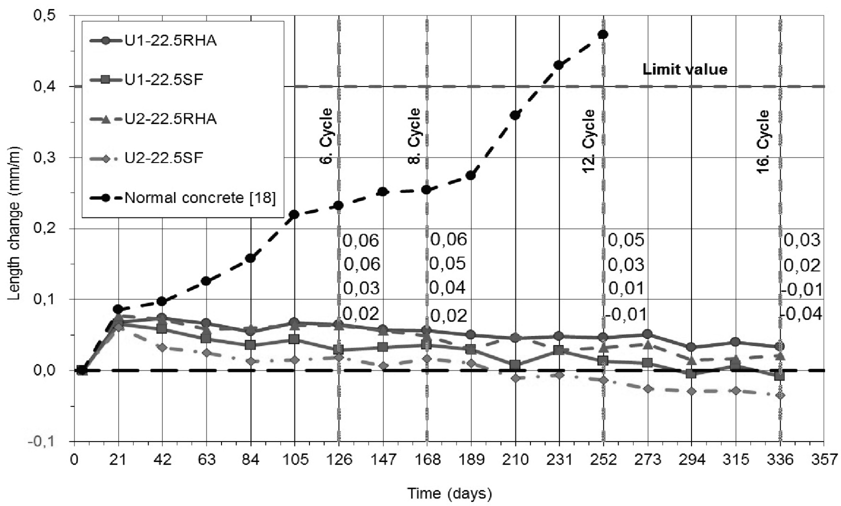

Figure 10. *The length change of the normally treated UHPCs and a normal concrete [18] (with reactive aggregate) in CCS*

4. Conclusions

The following conclusions can be drawn from the results of this study:

- There should be no concern about alkali silica reaction problem in the UHPC containing RHA, especially with GGBS combination. In terms of durability, RHA can be a good pozzolan to completely substitute SF in UHPC production.

- The durability of UHPCs containing RHA is high but not better than that of the SF-blended UHPCs. The permeability (i.e. Ca(OH)2 solution absorption) of UHPC should be considered as the important parameter which strongly affects the durability of UHPC in the aggressive environment.

- The difference in autogenous shrinkage and the size of sample (i.e. the concrete volume per unit length) will strongly affect the length change result of the testing.

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