SUSTAINABLE CONCRETE WITH PORTLAND FLY ASH CEMENT AND ALKALI REACTIVE AGGREGATES

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ABSTRACT

This paper presents the findings from two research projects concerning alkali aggregate reactions (AAR) in concrete mixes containing different Norwegian cements. The main objective of the investigation has been to verify the efficacy of fly ash and Portland fly ash cement to mitigate deleterious AAR in concrete containing Norwegian alkali reactive aggregates. The concrete specimens have been tested according to the Canadian Standard CAN 3-A23.2-14A. Expansion and changes in weight have been followed for 2 years. The results indicate that concrete based on Norwegian Portland fly ash cement and alkali reactive aggregates is durable even though the total alkali content in the concrete mix exceeds 5.0 kg / m^3. The investigations also showed that the storage conditions of the concrete prisms might influence the expansion results considerably. This implies that the test methods must ensure that minerals / combination of minerals which have shown deleterious alkali aggregate reaction (AAR) in field, exceed the level of acceptable expansion, usually 0.04 % within 1 year, when tested in laboratory. The laboratory test method, CAN3-A23.2 of 1994, has proved to give satisfactory results in testing Norwegian alkali reactive aggregates. The results of the test agree well with observations in field.

Key words: Alkali reactive aggregates, cements, fly ash, storage conditions

* Grudrun Lundevall has now retired.

1 INTRODUCTION

The effectiveness of fly ash to prevent deleterious effects of alkali-aggregate reaction (AAR) has been known for a long time, and a great deal of previous works have been summarised and reviewed /1/. The effectiveness of fly ash in suppressing AAR expansion depends on both physical and chemical characteristics of the fly ash and also on the level of replacement of cement. Regarding the efficacy of the fly ash to prevent deleterious expansion due to alkali-aggregate reactions in concrete, great interest has been focused on the fineness and alkali content of the ash, as well as to the total content of alkalis in the concrete. Bouzoubaâ et al. /2/ make reference to research works which indicate that both increased fineness of the ash and intergrinding the fly ash with the clinker increase the effectiveness of a fly ash in reducing alkali-aggregate reaction and expansion significantly. Further, Shayan et al. /1/ and Chatterjee et al. /3/ report from long time storage tests which show that addition of fly ash with an alkali content as high as 1.37, or 2.5 % Na_2O eqv respectively, had no adverse effect on AAR in concrete. Shayan et al. /1/ also showed that effectiveness of fly ash to prevent deleterious AAR expansions depends on the total alkali content of the concrete. An ash / cement ratio of 0.25 eliminated AAR expansion even at 6.9 kg Na_2O eqv / m^3 concrete. In case of extremely high alkali contents, 12.5 kg Na_2O eqv / m^3, fly ash addition retards the rate of expansion and perhaps reduces the ultimate expansion /1/, /2/.

The acknowledgement of deleterious AAR in concrete is of a relatively recent date in Norway. In the last decade, however, much research work has been performed to evaluate Norwegian aggregates whether they are alkali reactive or not and to find test methods suitable for Norwegian aggregates /4/, /5/. Investigations have also been concerned about the level of alkali content in concrete and detrimental AAR in concrete containing potential alkali reactive aggregates /6/. To day Norwegian Portland fly ash cement or low-alkali Portland cement is used for concrete containing alkali reactive aggregates. The former cement is produced by intergrinding fly ash with the cement clinker. The main objective of the Norwegian research effort has been to establish recommendations for the production of durable concrete by use of alkali reactive aggregate resources. Based on national and international experiences The Norwegian Concrete Association has given recommendations for avoiding detrimental AAR in concrete. They basically put restrictions on the total alkali content of the concrete and on the type of binder /7/:

- The use of Portland Cement (CEM I). Total content of alkalis (Na_2O eqv) should be restricted to 3.0 kg / m^3 concrete.

- The use of Norwegian Portland Fly Ash Cement (CEM II/A-V), content of fly ash > 17 %) or Portland cement (CEM I) with at least 10 % silica fume. Total content of alkalis (Na_2O eqv) should be restricted to 5.0 kg / m^3 concrete.

- Concrete mixes not fulfilling these requirements can be accepted provided they are shown to be durable by field experiences or laboratory testing. Details are given in /7/.

2 AIMS

The objectives of the projects have been to investigate:

* The capability of Norwegian Portland fly ash cement to prevent deleterious AAR in concrete of high alkali contents. (Series 1)
* The effect of different types of Portland cements with respect to deleterious AAR in concrete containing 5 kg Na_2O / m^3 and cast with potential alkali reactive aggregates. (Series 2)
* The minimum content of fly ash needed to prevent deleterious AAR in concrete containing 5 kg Na_2O / m^3 and cast with potential alkali reactive aggregates. (Series 3)
* The influence of storage conditions on the expansions of test prisms. (Series 4)

3 MATERIALS AND EXPERIMENTALS PROCEDURES

3.1 Materials

Different Norwegian construction cements were applied in the experiments. The types and names of the cements are given in Table 1. The chemical and physical characteristics of the cements are provided in Table 2 together with the composition of the fly ash (FA).

Table 1. Types and names of the NORCEM cements

General notation	Cement types	Trading names	Trading names, abbreviated
Portland fly ash cement	CEM II / A - V- 42, R	Standard FA	STD FA
Ordinary Portland cement	CEM I - 42,5 R	Standard	STD
Low alkali Portland cement	CEM I - 52,5 LA	Anlegg	ANL
Rapid hardening Portland cement	CEM I - 42,5 RR	Industri	IND
Sulphate resisting Portland cement	CEM I - 42,5 R - SR - LA	Sulfatresistent	SR

Table 2. Characteristics of the cements and the fly ash (The different cements are denoted by the abbreviated trading names)

Oxides	STD FA	STD	ANL	IND	SR	FA
SiO_2 (%)	-	20.3	21.2	19.6	21.5	55.4
Al_2O_3 (%)	-	4.6	4.1	4.6	3.7	27.4
Fe_2O_3 (%)	-	3.4	3.3	3.3	4.8	3.9
CaO (%)	-	62.8	64.4	62.4	63.9	3.6
MgO (%)	-	2.3	1.7	2.6	1.9	1.0
SO_3 (%)	2.7	2.6	2.9	3.3	2.5	-
K_2O (%)	1.22	0.93	0.43	1.18	0.53	1.06
Na_2O (%)	0.41	0.30	0.22	0.43	0.19	0.28
Na_2O eqv (%)	1.22	0.91	0.50	1.21	0.54	0.98
Free lime (%)		0.9	0.5	1.9	1.0	-
Loss on ignition (%)	1.4	2.1	2.5	2.6	0.4	-
Blaine fineness (m^2 / kg)	420	358	373	556	304	620
Free carbon (%)	-	-	-	-	-	3.0

The low-calcium fly ash (ASTM type F / EN 450) is used in the Standard Portland fly ash cement. The fly ash that was added to the concrete mixes (Series 3) was ground separately ahead of concrete mixing.

The sand (0 - 5 mm) was a non-reactive granitic natural sand. The coarse aggregates were two alkali reactive rocks: Cataclasite was used in the Series 1, 2, and 3. Rhyolite was used in Series 4. The aggregates were crushed and fractions of 5 - 10, 10 - 14, and 14 - 20 mm were provided.

3.2 Concrete mixes

In this investigation 14 concrete mixes have been studied. The mix proportions of the test concretes and the properties of the fresh mixes are described in Tables 3 - 6.

In order to obtain the desired alkali contents, sodium hydroxide (NaOH) was dissolved in the mix water and added to the concrete during mixing.

Table 3. Mix proportions and properties of fresh mixes - Series 1

Mix		STD FA - 3.5	STD FA - 5	STD FA - 7
Total Na_2O eqv (from cement + added NaOH) (kg / m^3)		3.5	5	7
Cement	STD FA (kg / m^3)	410	410	410
Sand 0 - 5 mm (kg / m^3)		770	770	770
Aggregates	5 - 10 mm (kg / m^3)	333	333	333
	10 - 14 mm (kg /m^3)	"	"	"
Cataclasite	14 - 20 mm (kg /m^3)	"	"	"
NaOH addition (kg / m^3)		0	2.0	4.5
Total water (kg / m^3)		197	197	197
w / c - ratio		0.48	0.48	0.48
Slump (mm)		70	65	75
Air content (%)		1.5	1.8	2.0
Density (kg / m^3)		2411	2410	2401
Compressive strength (MPa) 28 days		51.3	47.6	38.9

Table 4. Mix proportions and properties of fresh mixes - Series 2

Mix		STD FA 5	ANL - 5	STD - 5	IND - 5	SR - 5
Total Na_2O eqv (from cement + added NaOH) (kg / m^3)		5	5	5	5	5
	STD FA (kg / m^3)	410				
	ANL (kg / m^3)		410			
Cement	STD (kg / m^3)			410		
	IND (kg / m^3)				410	
	SR (kg / m^3)					410
Sand 0 - 5 mm (kg / m^3)		770	787	787	787	787
Aggregates	5 - 10 mm (kg / m^3)	333	337	337	337	337
Cataclasite	10 -14 mm (kg / m^3)	"	"	"	"	"
	14 - 20 mm (kg / m^3)	"	"	"	"	"
NaOH addition (kg / m^3)		2.0	3.8	1.6	-	3.6
Total water (kg / m^3)		197	197	197	197	197
w / c - ratio		0.48	0.48	0.48	0.48	0.48
Slump (mm)		70	80	75	70	90
Air content (%)		1.8	2.0	1.8	1.6	2.1
Density (kg / m^3)		2410	2412	2120	2439	2422
Compressive strength (MPa), 28 days		47.6	52.4	45.7	59.4	47.0

Table 5. Mix proportions and properties of fresh mixes - Series 3

Mix		STD - 0 % FA	STD - 5 % FA	STD - 10 % FA	STD - 20 % FA	STD - 35 % FA
Total Na_2O eqv (from cement + added NaOH), (kg / m^3)		5	5	5	5	5
Cement	3 parts STD 1 part ANL (kg / m^3)	408	390	369	329	265
Fly ash addition (kg / m^3)		-	20.4	41.2	82.3	143
Sand 0 - 5 mm (kg / m^3)		788	793	793	796	788
Aggregates Cataclasite	5 - 10 mm (kg / m^3)	337.7	339.7	339.7	341	337.3
	10-14 mm (kg / m^3)	"	"	"	"	"
	14-20 mm (kg /m^3)	"	"	"	"	"
NaOH addition (kg / m^3)		2.17	2.40	2.61	3.05	3.65
Total water (kg / m^3)		193	195	190	191	189
w / (c + FA) - ratio		0.47	0.47	0.46	0.46	0.46
Slump (mm)		80	70	80	80	80
Air content (%)		2.2	1.5	1.5	1.5	1.7
Density (kg / m^3)		2405	2420	2415	2425	2400
Compressive strength (MPa), 28 days		44.0	42.7	44.9	41.1	36.6

Table 6. Mix proportions and properties of fresh mixes - Series 4

Mix		STD	IND
Total Na_2O eqv (kg / m^3)		4.7	4.2
Cement	STD (kg / m^3)	500	
	IND (kg / m^3)		360
Sand 0 - 5 mm (kg / m^3)		743.2	828.2
Aggregates Rhyolite	5 - 10 mm (kg / m^3)	247.7	343.7
	10 - 14 mm (kg / m^3)	247.7	343.7
	14 - 20 mm (kg / m^3)	247.7	343.7
w / c - ratio		0.40	0.48
Slump (mm)		110	150
Air content (%)		1.8	2.3
Density (kg / m^3)		2370	2389
Compressive strength (MPa), 28 days		62.6	58.5

3.3 Test method

The Canadian Standard CAN 3-A 23.2-14A /8/ has been used in testing concrete prisms (100 x 100 x 450 mm) with respect to alkali aggregate reaction. The prisms of the series 1, 2 and 3 have been stored above water in closed 50 litres polyethylene boxes lined with wet cloths, 3 prisms in each box. The prisms of series 4 have been stored above water in closed larger containers. In addition prisms from the two concrete mixes, series 4, were wrapped in wet cotton cloth and 2 thick polyethylene bags before being stored above water in closed large containers. Initially the cloths were wetted with 100 grams water. At each measurement water was added to the cloths to adjust the water content to 100 grams. Changes in length and weight of the prisms have been followed for 2 years.

4 RESULTS AND DISCUSSION

The results as changes in length with respect to exposure time are provided in Figures 1 - 4. Changes in length and weight of the prisms during the test period are further given in Appendix, Tables A1 - A4.

4.1 The Influence of Portland Fly Ash Cement and Fly Ash on Deleterious AAR

4.1.1 Alkali content

The results from Series 1 (Figure 1, and Appendix, Table A1) show that the expansion of the prisms have not exceeded 0.03 % after 1 year of exposure, which comply with the recommendations from the Norwegian Concrete Association /7/. Even with a total alkali content of 7.0 kg / m^3 concrete this limit has not been exceeded. According to the recommendations /7/ the total alkali content should be ≤ 5.0 kg / m^3 concrete to prevent detrimental AAR in concrete cast with potential alkali reactive aggregates and CEM II/A-V (Norwegian produced Portland fly ash cement, content of fly ash > 17 %). The results from the present investigations, however, indicate that it may be possible to prevent detrimental AAR in concrete cast with potential alkali reactive aggregates and Norwegian Portland fly ash cement (STD FA) even with a total alkali content of 7.0 kg / m^3 concrete. The results show that the recommendations given by the Norwegian Concrete Association are on the safe side.

4.1.2 Cement type

The results from Series 2 (Figure 2 and Appendix, Table A2) show that the concrete mixes containing Ordinary Portland cement (STD), Low alkali Portland cement (ANL), Rapid hardening Portland cement (IND) or Sulphate resisting Portland cement (SR), respectively, and 5 kg Na_2O / m^3 concrete, have passed the limit of expansion, which is 0.04 % within 1 year, already after 12 weeks. As can be seen from Figure 2, the corresponding prisms cast with concrete containing Norwegian Portland fly ash cement (STD FA), have just expanded 0.020 % after 2 years of exposure. This shows a very striking difference between the Portland cements and the Portland fly ash cement. The advantage of using Portland fly ash cement to avoid detrimental AAR is apparent.

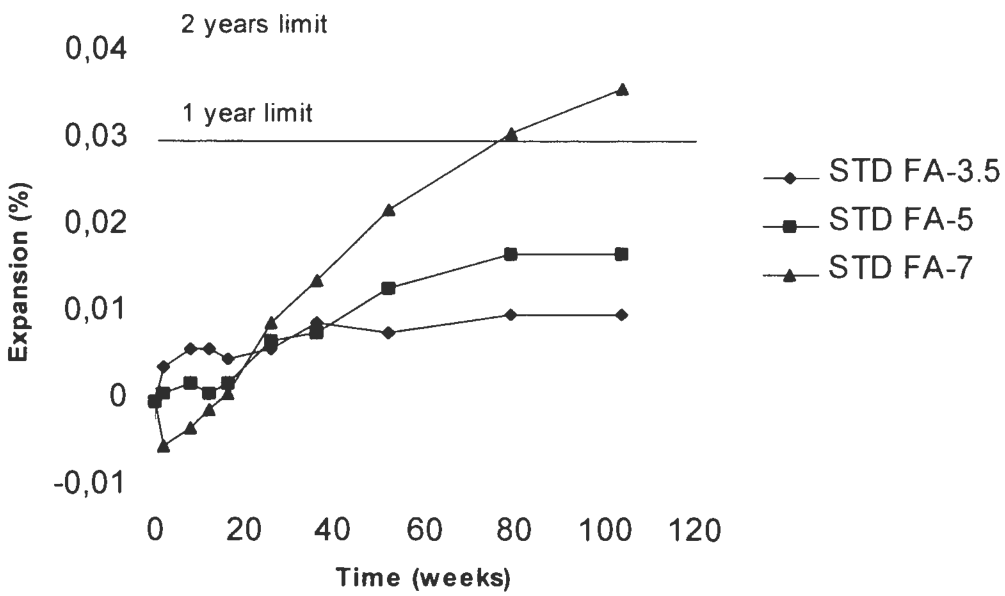

Figure 1 Expansion in concrete prisms of Series 1. The concrete mixes contain Portland fly ash cement (STD FA) and different content of alkalis (3.5, 5 or 7 kg Na_2O eqv / m^3).

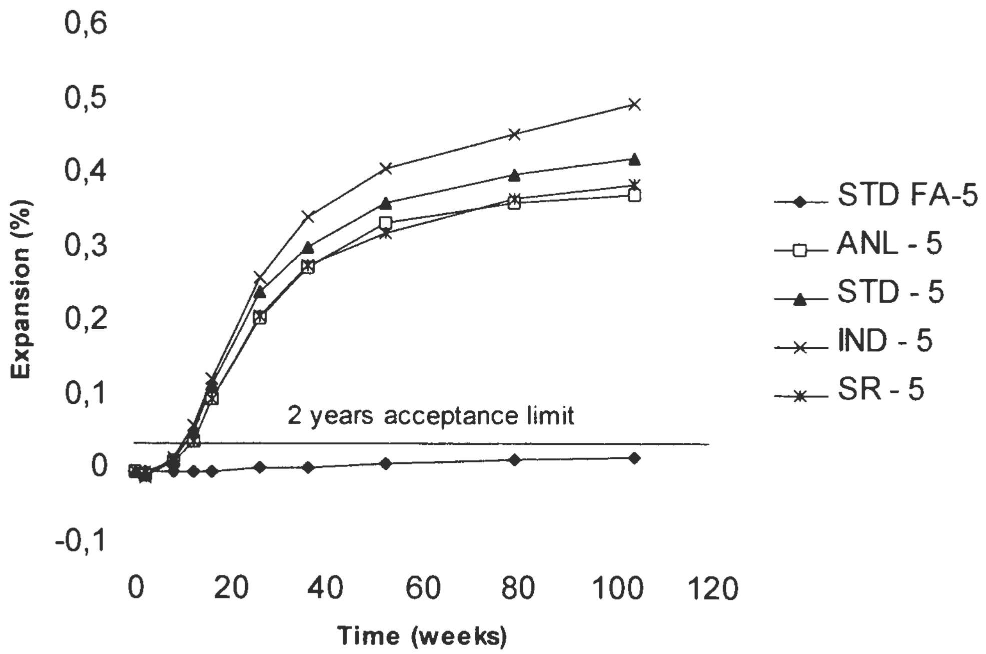

Figure 2 Expansion in concrete prisms of Series 2. The concrete mixes contain different types of cement (STD FA, ANL, STD, IND, or SR) and 5 kg Na_2O eqv / m^3.

4.1.3 Amount of fly ash

The results from Series 3 (Figure 3 and Appendix, Table A3), which aim was to investigate the minimum amount of fly ash needed to avoid deleterious AAR in concrete containing potential alkali reactive aggregates and 5 kg Na_2O eqv / m^3 concrete, show that the concrete without fly ash addition passed the limit of 0.04 % after 16 weeks of exposure. The mix with 5 % fly ash exceeded the 2 years limit of expansion (0.04 %) after 26 weeks, and the mix with 10 % fly ash exceeded this limit of expansion after 52 weeks. As can be seen from Figure 3, the mixes with 20 % or 35 % fly ash addition are far below the limits of 0.03 % expansion after 1 year or 0.04 % after 2 years of storage. Thus, the results indicate that a fly ash addition of about 20 % is sufficiently to avoid deleterious AAR in concrete containing potentially alkali reactive aggregates with a total alkali content of 5 kg Na_2O eqv / m^3 concrete.

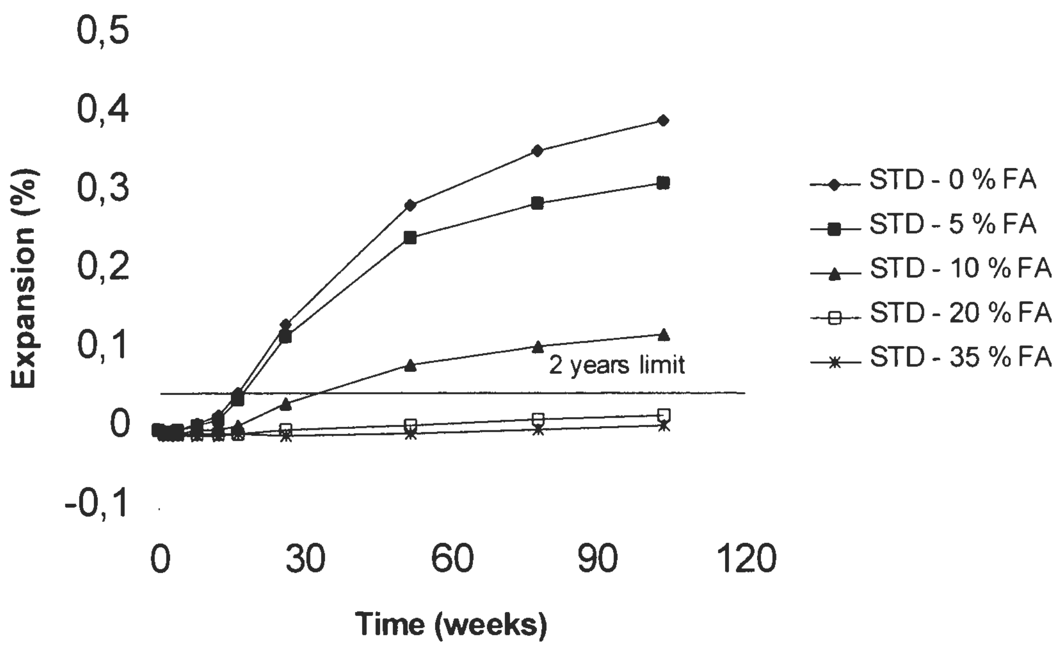

Figure 3 Expansions in concrete prisms of Series 3. The concrete mixes contain STD and ANL in the proportion 3 : 1 and different content of fly ash (0, 5, 10, 20 or 35 %). Total alkali content 5 kg Na_2O eqv / m^3.

4.2 Possible Explanations to the Beneficial Effect of Fly Ash

The obvious positive effect of fly ash addition to avoid detrimental AAR in concrete containing alkali reactive aggregates, may according to literature /9/, /10/ be due to the lower concentration of $Ca(OH)_2$ in the cement paste. The $Ca(OH)_2$ concentration is reduced because of the pozzolanic reaction between cement and fly ash. When studying the microstructure of exposed alkali reactive concrete with and without fly ash addition, Thaulow and Thordal Andersen /9/ and Bleszynski and

Thomas /10/ observed a marked difference in the chemical composition of the gel that had been formed in the transition zone between aggregate particles and cement paste phase. In the concrete without fly ash they found a calcium-rich alkali-silica gel which had caused a great deal of cracking in the concrete. In the concrete containing fly ash they found an alkali-silica gel with a very low content of calcium, which had caused neglectable cracking around the reaction sites.

An alternative explanation come from Hong and Glasser /11/. On examining why fly ash and other pozzolans seem to reduce AAR in concrete containing alkali reactive aggregates they studied absorption of alkalis in C-S-H gels. Their results indicated that decreasing C/S-ratio of the C-S-H gel lead to increasing alkali absorption and / or adsorption. The presence of fly ash will lower the C/S-ratio of the gel. A greater absorption of alkali ions in the C-S-H gel may be expected in the fly ash cement paste. Consequently these alkali ions will be removed from the pore solution and will not be available for the AAR.

Xu and Hooton /12/ explain that the efficiency of fly ash and other pozzolans to reduce AAR in concrete in terms of the microstructure of the paste. They experimentally measured migration and concentration of alkalis by moisture gradients and electrical potential differences, and concluded that matrices with low transport properties can be considered to have a positive effect on AAR resistance by reducing the potential for ionic ingress, migration, and concentration within the concrete mass.

4.3 Storage Conditions

The results of Series 4 (Figure 4 and Appendix, Table A4) quite clearly show that storage conditions may influence the results. The prisms, which have been stored wrapped in wet cloth as recommended by RILEM TC 106-AAR /13/, show an accelerated and greater expansion compared to the prisms having been stored unwrapped. The prisms stored in wet cloth exceed the expansion limit of 0.04 % already after 12 weeks storage. The unwrapped prisms "STD-U" pass the limit after 26 weeks of storage, whilst the unwrapped prisms "IND-U" do not pass the limit of 0.04 % within 1 year storage. This means that rhyolite, the aggregate in this mix and one of the most reactive rocks in Norway, in this case would have been characterised as "innocuous". No effort has been done to investigate why different storing conditions result in different expansion results. However, it has to be pointed out that the unwrapped prisms, Series 4, show no increase in weight from week 8 and onwards, see Appendix, Table 4A. A possible explanation for the lower expansions obtained when a large number of prisms are stored in large containers, may therefore be a lack of humidity which more or less brings the alkali aggregate reaction to stop.

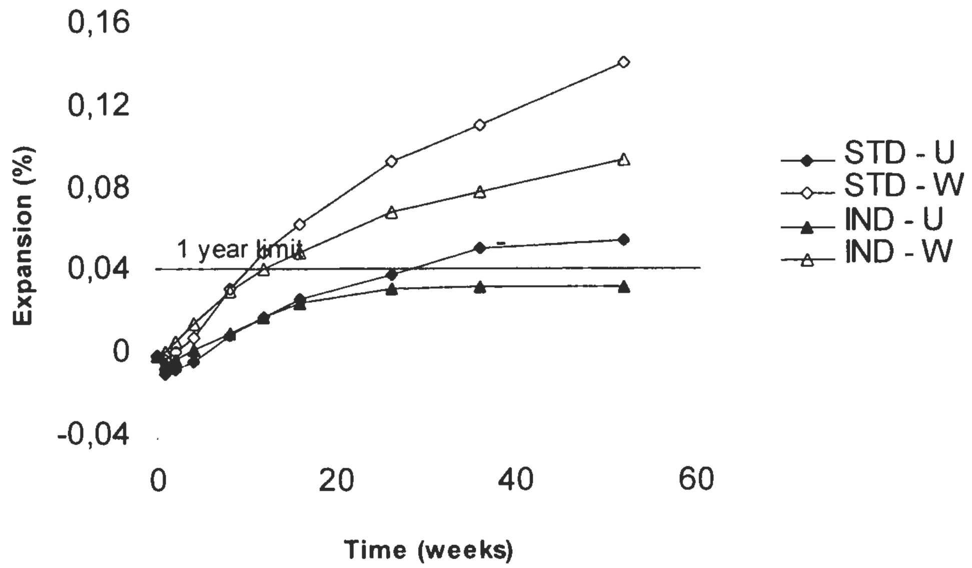

Figure 4 Expansions in concrete prisms containing STD or IND cement. The prisms have been stored in large containers above water, wrapped in wet cloth (W) or unwrapped (U).

These results show the importance of establishing laboratory test methods which ensure that concretes having shown deleterious AAR in performance, exceed the level of acceptable expansion when tested in laboratory according to test methods in use.

In Norway, long term testing of aggregates with respect to AAR are performed according to the Canadian Standard CAN3-A23.2-14A /8/. The method prescribes testing of unwrapped specimens stored above water in small closed containers. Similar differences as those found between the wrapped and unwrapped specimens of Series 4, have also been observed for unwrapped prisms stored in small versus large containers /14, 15/. This indicates that the storage conditions provided in the Canadian Standard /8/ resemble the storage conditions of wrapped specimens quite well. The laboratory test results obtained when using the Canadian Standard CAN3-A23.2-14A /8/ agree well with Norwegian field experiences. Aggregates observed to give harmful reactions in the field have also been characterised as reactive when tested in laboratory.

5 CONCLUSIONS

- Use of Norwegian Portland fly ash cement (CEM II / A-V) was found to prevent deleterious alkali aggregate reactions (AAR) in concrete containing alkali reactive aggregates.

- Cement containing about 20 % fly ash, such as Norwegian Portland fly ash cement, appears to prevent detrimental AAR in concrete containing alkali reactive aggregates even with a total alkali content as high as 7 kg Na_2O eqv / m^3 concrete.

- When testing concrete prisms with respect to deleterious AAR, the measured expansions seem to be very sensitive to the storage conditions. The Relative Humidity (RH) in the storage containers should be closely watched.

- The results clearly point out the importance of establishing laboratory test methods which ensure that concretes having shown deleterious AAR in performance, exceed the level of acceptable expansion when tested in laboratory according to test methods in use.

- The laboratory test method Canadian Standard CAN3-A23.2-14A of 1994 which prescribes storing of a restricted number of prisms above water in closed small containers, has proved to give satisfactory results in testing Norwegian alkali reactive aggregates. Aggregates observed to give harmful reactions in the field, have also been classified as harmful according to Canadian Standard Canadian Standard CAN3-A23.2-14A /8/.

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7 REFERENCES

/1/ A. Shayan, R. Diggins, I. Ivanusec: "Long-term effectiveness of fly ash in preventing deleterious expansion due to alkali-aggregate reaction in concrete". Proceedings of the 10th International conference on alkali-aggregate reaction in concrete. Melbourne, 1996, pp 538 - 545.

/2/ N. Bouzoubaâ, M. H. Zhang, V. M. Malhotra, D. M. Golden: "Blended fly ash cements - A review". Sixth CANMET /ACI International conference on fly ash, silica fume, slag and natural pozzolans in concrete. Supplementary papers. Bangkok, 1998, pp 717 - 749.

/3/ S. Chatterjee, Z. Fördös, N Thaulow: "Alkali-Silica reaction- Danish experience". The alkali silica reaction in concrete. Edited by R. N. Swamy. Blackie and Son Ltd., London 1992, pp 188 - 207.

/4/ V. Jensen: "Alkali aggregate reaction in southern Norway". Doctor technicae thesis. The Norwegian Institute of Technology, Trondheim, 1993. 262 p.

/5/ "NORMIN 2000: "Alkali aggregate reactions in concrete", main project report, Norwegian Aggregates Producers Association, Oslo, March 1999. 166 p. (In Norwegian).

/6/ V. Jensen: CEMEXPO "Durability - Alkali reactions". SINTEF Report no. STF22 F96802, SINTEF Civil and Environmental Engineering, Trondheim, 1996. 21 p. (In Norwegian).

/7/ "Durable concrete with alkali reactive aggregates". Publication no.21. Norwegian Concrete Association, Oslo. April 1996. 27p. (In Norwegian).

/8/ "Concrete prisms test". Canadian Standard Association CSA CAN3-A23.2-14A. 1994.

/9/ N. Thaulow, K. Thordal Andersen: "New knowledge about alkali reactions", Dansk Beton, no.1, 1988, pp 14 -19. (In Danish).

/10/ R. F. Bleszynski, M. D. A. Thomas: "Microstrutural studies of alkali-silica reaction in fly ash concrete immersed in alkaline solutions". Advanced Cement Based Matrials, Vol 7, No. 2, 1998, pp 66 - 78.

/11/ S.-Y. Hong, F. P. Glasser: "Sorption of sodium and potassium on C - S - H gels". Communications of the 18th Conference on Cement and Concrete Science. Institute of Materials, London, 1998.

/12/ Z. Hu, R. D. Hooton: "Migration of alkali ions in mortar due to several mechanisms." Cement and Concrete Research, Vol. 23, 1993, pp 951 - 961.

/13/ RILEM TC 106-AAR: "Aggregates for alkali-aggregate reaction. International assessment of aggregates for alkali-aggregate reactivity". Materials and Structures, Vol. 33, March 2000, pp 88 - 93.

/14/ V. Jensen, B. Fournier: "Influence of different procedures on accelerated mortar bar and concrete prism test: Assesment of seven Norwegian alkali reactive aggregates". To be published. 10 p.

/15/ I. Meland: "Sustainable concrete - Durability: Alkali reactions". SINTEF Report no. STF22 F99725, SINTEF Civil and Environmental Engineering, Trondheim 1999. 10 p. (In Norwegian).

Table A 1.Changes in length and weights of the test prisms - Series 1

Time (weeks)	STD FA - 3.5		STD FA - 5		STD FA - 7	
	changes in length (%)	changes in weights (%)	changes in length (%)	changes in weights (%)	changes in length (%)	changes in weights (%)
2	0.004	0.09	0.001	0.15	- 0.005	0.11
8	0.006	0.26	0.002	0.27	- 0.003	0.23
12	0.006	0.31	0.001	0.28	- 0.001	0.25
16	0.005	0.33	0.002	0.31	0.001	0.27
26	0.006	0.36	0.007	0.32	0.009	0.29
36	0.009	0.40	0.008	0.36	0.014	0.36
52	0.008	0.43	0.013	0.43	0.022	0.46
78	0.01	0.48	0.017	0.46	0.031	0.52
104	0.01	0.50	0.020	0.46	0.036	0,56

Table A 2. Changes in length and weights of the test prisms - Series 2

Time weeks	STD FA - 5		ANL - 5		STD - 5		IND - 5		SR - 5	
	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)
2	0.001	0.15	-0.004	0.08	-0.002	0.09	-0.007	0.18	0	0.07
8	0.002	0.27	0.014	0.28	0.018	0.33	0.019	0.46	0.014	0.23
12	0.001	0.28	0.042	0.39	0.055	0.44	0.064	0.64	0.041	0.26
16	0.002	0.31	0.100	0.58	0.118	0.62	0.127	0.80	0.099	0.47
26	0.007	0.32	0.209	0.74	0.245	0.83	0.265	0.98	0.213	0.71
36	0.008	0.36	0.278	0.88	0.306	0.91	0.347	1.11	0.279	0.82
52	0.013	0.43	0.338	1.05	0.365	1.06	0.410	1.27	0.325	0.93
78	0.017	0.46	0.364	1.05	0.402	1.02	0.459	1.33	0.369	0.99
104	0.020	0.46	0.376	1.06	0.425	1.06	0.498	1.43	0.390	1.30

Table A 3. Changes in length and weights of the test prisms - Series 3

Time weeks	STD 0 % FA		STD 5 % FA		STD 10 % FA		STD 20 % FA		STD 35 % FA	
	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)
2	-0.003	0.101	-0.003	0.108	-0.005	0.091	-0.005	0.155	-0.008	0.018
4	0.001	0.156	-0.001	0.144	-0.004	0.127	-0.006	0.200	-0.008	0.054
8	0.008	0.257	0.004	0.216	-0.001	0.182	-0.006	0.237	-0.008	0.091
12	0.018	0.313	0.013	0.270	0	0.209	-0.005	0.255	-0.007	0.127
16	0.046	0.395	0.039	0.279	0.005	0.237	-0.004	0.282	-0.006	0.136
26	0.133	0.588	0.119	0.577	0.033	0.337	0	0.310	-0.007	0.154
52	0.248	0.855	0.244	0.811	0.083	0.525	0.005	0.358	-0.005	0.200
78	0.354	0.990	0.287	0.920	0.106	0.616	0.012	0.395	0	0.227
104	0.392	1.08	0.312	1.00	0.121	0.682	0.018	0.446	0.004	0.266

Table A 4. Changes in length and weights of the test prisms - Series 4

Time weeks	STD - U		STD - W		IND - U		IND - W	
	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)	chs. in length (%)	chs. in weight (%)
1	-0,009	0,04	-0,002	0,31	-0,004	0,01	0,002	0,23
2	-0,007	0,15	0,002	0,39	-0,002	0,10	0,007	0,28
4	-0,003	0,22	0,009	0,46	0,003	0,14	0,016	0,35
8	0,010	0,33	0,033	0,60	0,011	0,19	0,032	0,44
12	0,019	0,42	0,050	0,70	0,019	0,31	0,042	0,56
16	0,028	0,50	0,064	0,80	0,026	0,36	0,050	0,62
26	0,039	0,54	0,094	0,92	0,033	0,36	0,070	0,74
36	0,052	0,57	0,112	0,97	0,034	0,36	0,080	0,78
52	0,056	0,59	0,142	1,00	0,034	0,36	0,095	0,80