REFERENCE TESTS METHODS AND A PERFORMANCE CRITERION FOR CONCRETE STRUCTURES

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The reliability of the ASTM C 227 and CSA A 23.2.14-A test methods, has been improved by the use of containers and reactors at 38°C. Increasing the cement content from 310 to 410 kg/m^3 reduces the response time of the concrete test from 12 to 8 months. The performance test carried out at 60°C can be used to check the effectiveness of preventive measures (low alkali cement or mineral additives) when used with reactive aggregates from a given construction site. The response time of this test is then 4 to 8 weeks.

INTRODUCTION

Pathological disorders, which appeared in France in the early 1980's on a few concrete structures, have naturally led to decisions of standardization and regulation.

In 1990, two methods describing the experimental procedures to be used, in order to detect aggregates that are potentially reactive towards alkalis, were standardized.

REFERENCE TESTS METHODS

The mortar bar test method NFP 18585 (1) is close to the ASTM C 227 mortar bar expansion test, while the concrete prism test NFP 18587 (2) is derived from the Canadian ACNOR A 23.2.14 A. The main modifications concern:

- the alkali level, which is constant and fixed at 1.25% Na_2O equivalent per mass of cement. This value is achieved by the addition of NaOH to the mixing water. The Na_2O equivalent level of the cement must not be less than 0.7%;
- an increase in cement content of the concrete, which is raised from 310 kg/m^3 to 410 kg/m^3. This modification strongly accelerates the expansion kinetics, and permits a shorter response time. The experiments carried out at Lafarge Coppée Recherche in this field, show that, while maintaining the 0.04% expansion value prescribed in the ACNOR standard, the time required may be reduced from 12 to 8 months;
- the use of a special apparatus to store the mortar bars or the concrete prisms.

The authors have specified the storage conditions, following questionable results (Table 1) obtained in the following conditions:

. nature of aggregate: a siliceous limestone from the SPRATT's quarry (Ontario);
. storage condition 1: in the vapor of a reactor heated at 38°C;
. storage condition 2: in a closed metallic container, containing a few cm of water, placed in a reactor at 38°C;
. storage condition 3: each prism is enclosed in a polyethylene bag contaning a few ml of water in the bottom and then placed in the reactor.

TABLE 1 - ASTM C 227 Test (Expansion %)

Storage condition	14d	1 m	2m	4m	8m	12 m
1	0.002	0.009	0.030	0.038	0.038	0.038
2	- 0.018					

The shrinkage obtained according to condition 2, is explained by a 2°C temperature difference between the top and the bottom of the container which results in a relative humidity of only 90% in the upper part; this leads to a partial dessication of the mortar bars.

TABLE 2 - Expansion Results of the ACNOR A 23.2.14A Concrete Prism Method

Storage condition	1 m	2m	3m	4m	6m	8m	12m
1	0.007	0.016	0.017	0.021	0.020	0.024	0.024
2	0.005	0.025	0.046	0.080	0.103	0.115	0.127

The storage conditions 1 and 2 are obviously unsatisfactory and these results indeed confirm earlier findings (3, 4, 5, 6).

A drastic improvment has been obtained, when placing the metallic container used in condition 1 in the reactor used in conditions 2 or 3:

TABLE 3 - Mortar Bars and Concrete Prisms Expansion Data obtained with improved Storage Conditions

	2m	3m	6m	8m	10m	12m	24m
ASTM C 227	0.078	0.137	0.284	0.299	0.309	0.320	0.333
CSA A23.2-14	0.073	0.099	0.148	0.159	0.170	0.177	0.183

The SPRATT's aggregate which was rated as innocuous according to conditions 1 and 2, is now considered as expansively reactive towards alkalis, from 2 months on with concrete prisms and from 3 months on with the mortar bars.

The special equipment displayed in Figures 1 and 2 are now being used by Ciments Lafarge irrespective of the selected test temperature (7, 8).

Several accelerated tests (response time 3 days) are currently being standardized in France; these are validated by the reference tests quoted above. The French contractors and owners now have at their disposal a series of tests methods to determine the potential reactivity towards alkalis of both sands are coarse aggregates.

When an aggregate is characterized as deleterious, it must either be rejected and another found or preventive measures have to be taken. The second solution is preferable, since it is cheaper.

In order that the preventive measures are accepted by the organizations in charge of taking decisions, it is necessary to have a means of checking the effectiveness of the solution for the proposed concrete mix and for the construction under consideration.

This is why Lafarge Coppée Recherche and Ciments Lafarge have carried out the study which has led to the following results.

PERFORMANCE TEST

Principle of the Test

In order to be functional, the test used to verify the efficiency of the preventive measure must meet several constraints:

- the response time should not be longer than 1 - 2 months. In effect, the test should be included in the range of tests made when the concrete mix design is being carried out;
- realization using the exact composition of the concrete which complies to the specifications of the job requirements.

The composition being unchangeable, the only variable remaining to accelerate the test, is the temperature. It must be judiciously chosen so that the test does not take too long and that the hydrates of the cement paste are not affected; the deterioration of the ettringite would provoke a shrinkage which would partially compensate the expansion due to ASR. A few experiments have been made which confirm that 60°C is a satisfactory temperature.

The concrete prisms are allowed to harden 24 hours in metallic moulds at 20°C and 100% relative humidity, after which their initial length is measured. The prisms are then arranged in a container, which is itself placed in a regulated reactor generating water vapor at 60°C.

Reproductibility of the Test

The reproductibility of the test has been checked, according to the following conditions:

- three aggregates:
  . siliceous limestone from SPRATT, which develops a fast expansion rate;
  . a polyphasic rock (SUDBURY), with slow expansion kinetics;
  . a polyphasic rock (CHAMBON), whose expansion develops at a moderate rate;
- two operators, each performing the test at several weeks interval.

The results are assembled on the following table.

TABLE 4 - Reproductibility of the Test

Aggregates	Operator	Expansion (%)		
		4w	8w	12 w
SPRATT	1	0.051	0.066	0.071
	2	0.050	0.064	0.072
SUDBURY	1	0.023	0.055	0.077
	2	0.021	0.051	0.073
CHAMBON	1	0.045	0.092	0.106
	2	0.047	0.095	0.112

The good reproductibility obtained depends on the prevention of dessication during cooling period. To achieve this, when the container is removed from the reactor, it is necessary that it is allowed to cool, with the lid removed, in a room or cabinet at 20°C in which the atmosphere is saturated (RH = 100%).

Determination of the Expansion Limits

A series of 27 concretes have been made using a high alkali cement or a local low alkali cement and 21 aggregates. These were either natural or artificial (calcined flint), deleteriously reactive or unreactive, Canadian or European. For each concrete, 3 prisms were stored at 38°C and 100% R.H. (standard NF P 18 587) and 3 at 60°C and 100% H.R.

The results obtained according to these conditions are assembled on Table 5.

TABLE 5 - Comparison of the Expansion Values from the Concrete Prisms Tests, at 38°C and 60°C

No.	Aggregates	Cement Content	Na_2O kg/m^3	W/C	38°C	60°C	
					8m	4w	8w
1	SPRATT	410	5.125	0.48	0.126	0.051	0.064
2	SUDBURY	410	5.125	0.49	0.073	0.023	0.055
3	PITTSBURG	410	5.125	0.52	0.273	0.08	0.102
4	CHAMBON	410	5.125	0.53	0.17	0.045	0.092
5	BEAUHARNOIS	410	5.?125	0.52	0.083	0.065	0.114
6	LES CEDRES	410	5.125	0.51	0.038	0.023	0.034
7	VAL RHONE	410	5.125	0.46	0.092	0.029	0.044
8	WALLERS	410	5.125	0.5	0.023	0.012	0.018
9	CIVAUX	410	5.125	0.5	0.039	0.012	0.018
10	RHYOLITHE MC	410	5.125	0.59	0.074	0.016	0.021
11	RHYOLITHE F	410	5.125	0.63	0.006	0.000	0.003
12	G	410	5.125	0.45	0.049	0.029	0.064
13	GR	410	3.854	0.44	0.044	0.019	0.039
14	GR	410	1.968	0.44	0.007	0.000	0.001
15	CALCAIRE OMYA	410	5.125	0.49	0.011	0.01	0.01
16	V.L.G.	410	5.125	0.5	0.011	0.004	0.007
17	KER	410	5.125	0.52	0.028	0.014	0.029
18	F	410	5.125	0.62	0.012	0.01	0.01
19	S.B.	410	5.125	0.51	0.011	0.016	0.016
20	CALCINED FLINT	410	5.125		0.292	0.119	0.125
21	CH	410	3.854	0.43	0.11	0.031	0.05
22	CH	410	1.189	0.43	0.000	0.002	0.003
23	V	410	0.984	0.52	0.001	0.003	0.003
24	B.F.	410	3.854	0.5	0.009	0.005	0.006
25	B.F.	410	0.984	0.52	0.001	0.002	0.003
26	B.Sd	410	3.854	0.49	0.01	0.006	0.007
27	B.Sd	410	0.984	0.51	0.000	0.000	0.003

Figure 3 shows the expansion after 4 weeks at 60°C as a function of that after 8 months at 38°C.

It can be seen that all the concretes that are rejected by the reference test at 38°C are also rejected by the test at 60°C if the expansion limit is fixed at 0.015%. Note that concrete 19 which is classed as non deleterious at 38°C would be eliminated by the 60°C test.

Figure 4 shows the relationships between the expansions developed at the age of 8 weeks at 60°C and those obtained after 8 months at 38°C. All the concrete prisms which are considered deleteriously expansive at 38°C are similarly classified by the test at 60°C, if the limit of expansion chosen is 0.02% at 8 weeks. Note that concrete 19 is no longer rejected and the reactivity of aggregate 10 is confirmed.

Although each age of evaluation leads to a reliable diagnosis, our proposition is to make the measurements at 4 and at 8 weeks.

Validation of the Test and the Expansion Limits

The credibility of the test at 60°C has been verified by using it with preventive measures such as:

- low alkali cement (0.48% Na_2O eqv.);
- high alkali cement (1.19% Na_2O eqv.);
- 93% high alkali cement + 7% fume silica;

- 75% high alkali cement + 25% fly ash;
- 75% high alkali cement + 25% artificial pozzolana;
- 75% high alkali cement + 25% metakaolin;
- 65% high alkali cement + 35% blast furnace slag;
- 40% high alkali cement + 60% blast furnace slag;
- 5% high alkali cement + 25% ground aggregate from CHAMBON;
- 75% high alkali cement + 25% European reactive limestone;
- 100% blast furnace and fly ash cement.

Each of the eleven cements defined above, has been employed to manufacture concretes, using two aggregates:

. polyphasic rock from CHAMBON;
. European siliceous limestone, similar to the Canadian SPRATT's aggregate.

The expansion results obtained at 38°C and 60°C are presented in Table 6 (CHAMBON's aggregate) and in Table 7 (limestone).

TABLE 6 - Mineral additions (CHAMBON)

Aggregates	Cement Content	Na_2O kg/m^3	W/C	Mineral Additions	38°C 8m	60°C 4w	60°C 8w
CHAMBON	410	4.88	0.54	0	0.303	0.085	0.199
	410	4.80	0.59	7% SF	0.042	0.017	0.025
	410	4.80	0.54	25% Fly ash	0.02	0.011	0.018
	410	4.22	0.66	25% KAL	0.073	0.028	0.042
	410	3.98	0.63	25% MET	0.021	0.003	0.000
	410	4.59	0.52	35% SLAG	0.073	0.017	0.032
	410	4.35	0.51	60% SLAG	0.008	0.000	0.000
	410	3.66	0.55	25% CHAM	0.149	0.033	0.053
	410	3.66	0.56	25% Cal Filler	0.105	0.03	0.039
	410		0.51	C. L. C.	0.012	0.006	0.009
	410	1.97	0.51	0	0.015	0.003	0.01

TABLE 7 - Mineral additions (Limestone)

Aggregates	Cement Content	Na_2O kg/m^3	W/C	Mineral Additions	38°C 8m	60°C 4w	60°C 8w
European	410	4.88	0.51	0	0.159	0.059	0.091
Limestone	410	4.80	0.56	7% SF	0.02	0.008	0.012
	410	4.80	0.50	25% Fly ash	0.015	0.009	0.012
	410	4.22	0.63	25% KAL	0.127	0.029	0.045
	410	3.98	0.58	25% MET	0.021	0.000	0.000
	410	4.59	0.49	35% SLAG	0.021	0.007	0.01
	410	4.35	0.48	60% SLAG	0.014	0.006	0.01
	410	3.66	0.51	25% CHAM	0.11	0.025	0.041
	410	3.66	0.52	25% Cal Filler	0.105	0.022	0.033
	410		0.46	C. L. C.	0.007	0.006	0.006
	410	1.97	0.48	0	0.014	0.006	0.01

Figure 5 shows the expansion values after 4 weeks of curing at 60°C as a function of those obtained at 38°C after a period of 8 months. All the preventive measures which are considered ineffectual by the reference test method are also rejected by the test at 60°C. If the expansion values are measured at 8 weeks (Figure 6), the same conclusions are drawn as those obtained at 4 weeks.

NOTA: A 7% fume silica addition which is an efficient preventive measure with the siliceous limestone aggregate, appears not to be operative with the CHAMBON's aggregate, which releases alkalis. A 10% addition, which is now under test for a few months seems to be the correct level for this aggregate.

The proposed test, which measures the performance level of a preventive measure, can be used as an acceptation test, and could advantageously substitute for the alkalis balance as prescribed in some countries. As shown in Figures 7 and 8, there is no correlation between the expansion values obtained after an 8 month curing period at 38°C and the alkalis provided by the hydraulic phase (9).

CONCLUSIONS

Potentially reactive aggregate should not be automatically eliminated for concrete making; since among other reasons, the economic consequences must be considered.

They may be employed by using preventive measures such as a low alkali cement, when locally available or a mineral additive with a high alkali cement.

It is however absolutely necessary that the contractor and the owner can be assured of the efficiency of the preventive measure considered with the concrete formulation specified for the worksite.

The work of Lafarge Coppée Recherche and Ciments Lafarge shows that a concrete prism test at 60°C can ensure the validity of the proposed solution after a 4 and/or 8 weeks period.

This acceptation test, which measures the performance, appears preferable to the alkalis balance.

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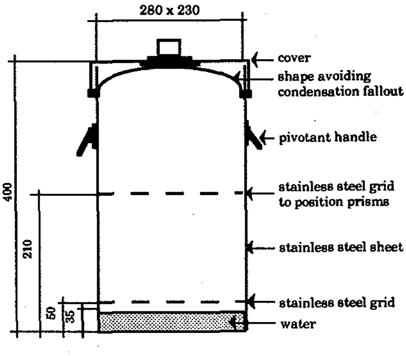
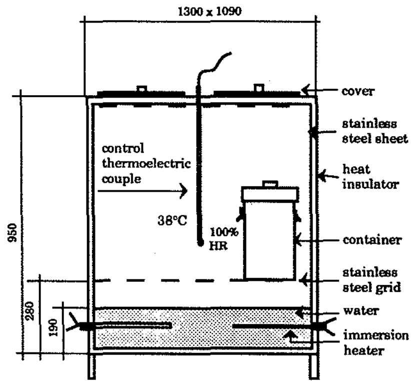


Figure 1 The container is able to receive 30 mortar bars or 6 concrete prisms



The double regulation system ensures the homogeneous repartition and maintenance of the 100 % RH and 38°C.

Figure 2 The metallic reactor may contain 9 containers

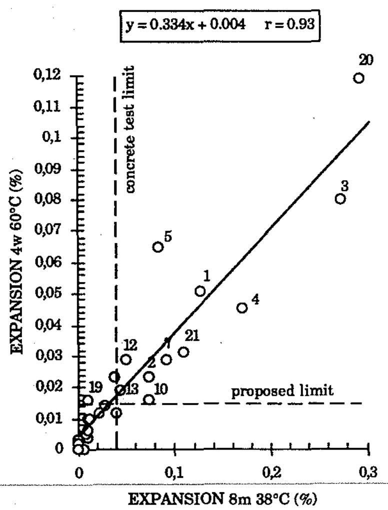


Figure 3 Expansion values after 4 weeks at 60°C, versus expansion values after 8 months at 38°C

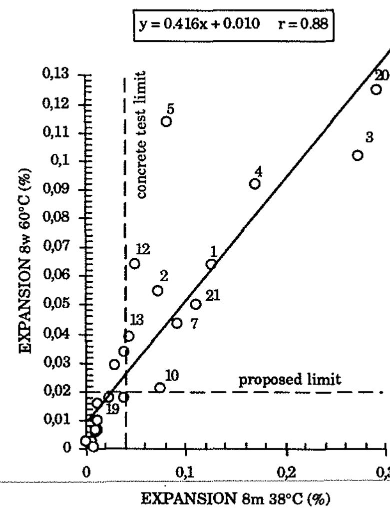


Figure 4 Expansion values after 8 weeks at 60°C, versus expansion values after 8 months at 38°C

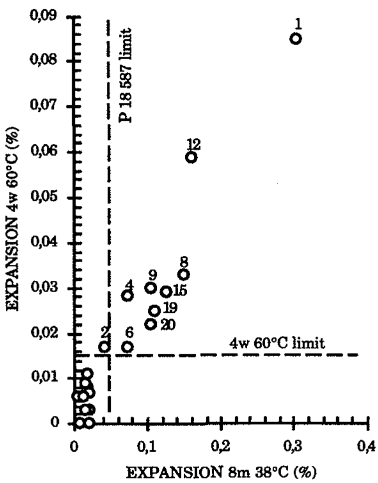


Figure 5 Expansion values at 4 weeks and 60°C, as a function of the expansion at 38°C and 8 months

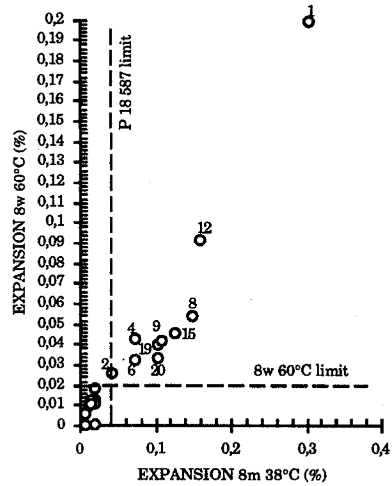


Figure 6 Expansion values at 8 weeks and 60°C, as a function of the expansion at 38°C and 8 months

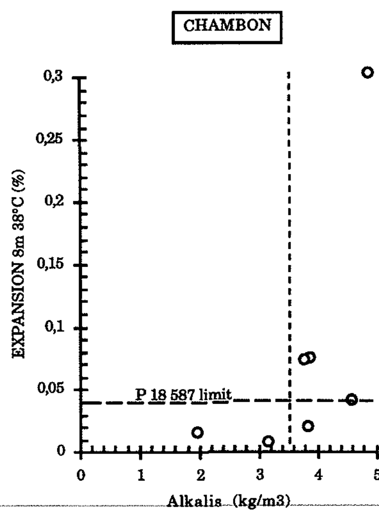


Figure 7 Relationship: concrete prism expansion (CHAMBON's aggregate)/alkali level of the cement

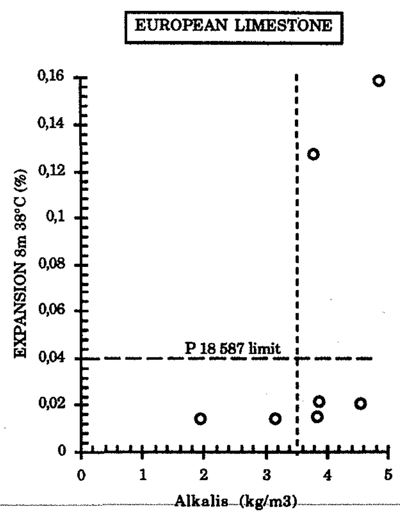


Figure 8 Relationship: concrete prism expansion (European limestone)/alkali level of the cement