EFFECT OF FLYASH ADDITION ON ALKALI-SILICA EXPANSION

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ABSTRACT

The influence of flyash on the alkali-silica reaction was investigated by preparing cement paste, mortar and concrete specimens with 25-30 weight percent replacement of cement with flyash.
Standardized (ASTM C411) and modified accelerated test methods have been used.
Results obtained so far indicate that the presence of flyash reduces the expansion in cement paste, mortar and concrete. This is valid also, where the specimens contain reactive aggregate and cement with high alkali content.
Also, long term tests have been carried out, with and without flyash, with normal and high alkali Portland cement, and with varying contents of reactive aggregate.
Long term tests with concretes show no harmful alkali-silica reaction after a 5 years period, neither in concrete with flyash nor in concrete without flyash.

Key-words: alkali-silica reaction, expansion, flyash, cement paste, cement mortar, concrete, methods.

1. INTRODUCTION

In the recent years alkali-silica reaction is getting a wide spread attention throughout the world. In this context Denmark is in a particularly difficult position. Many of the Danish aggregate sources, both sand and gravel, contain significant quantities of reactive silica. Consequently, alkali-silica reaction is a constant threat to concrete structures. The situation is further aggravated by the use of sodium chloride (NaCl) as de-icing salt during the winter months, because NaCl acts as an accelerator of alkali-silica reaction /1/.

Any reliable and commercially viable admixture which can either eliminate alkali-silica reaction or decrease the rate of reaction will be highly desirable in Denmark. A number of research workers have reported that the use of flyash reduces expansion due to alkali-silica reaction /2/, /3/, /4/. The object of the present work was to evaluate Danish flyashes in this respect.

The effect of flyash on the expansion due to alkali-silica reaction of mortar or concrete samples can be evaluated either by the use of closed systems where the total alkali-content of the systems do not change with time, which is the case when testing is carried out according to e.g. ASTM C441 or modified ASTM method /5/, or open systems where samples are in contact with an alkali-salt solution as is the case with the so-called NaCl bath method /1/. The evaluation can also be carried out by an accelerated test method or by a long time storage method /6/. In the present investigation both open and closed systems as well as accelerated and long time storage methods have been used.

2. MATERIALS AND EXPERIMENTAL TECHNIQUES

An ordinary Portland cement, a high alkali Portland cement, and a Portland flyash cement (Standard-Cement from Aalborg Portland) containing about 25% flyash were used in this investigation. Three types of sand were used, namely RILEM standard sand, CBL standard reactive sand and very reactive sand from Nymølle. Nymølle sand was used in conjunction with the Portland flyash cement. Non-reactive graded gravel was used to make concrete samples. Graded crushed pyrex glass was used in the ASTM type tests.

A large number of concrete cylinders were cast in 200 x 100 ø mm moulds. In the first 24 hours these cylinders were stored in a room maintained at 100% RH and 20 ^{0}C. Thereafter they were demoulded and stored in a fog room until tested.

At intervals of 28 days, 1, 2 and 5 years two cylinders of each of the mixes were tested for their compressive strengths.

Three cylinders from each of the mixes were used to measure their volume changes during storage in the fog room. Just before each volume measurement the cylinders were water saturated. The volume of each of the cylinders was determined using the Archimedian principle. Volume measurements were carried out at intervals of 1, 3, 6 months, and 1 and 2 years.

Mortar prisms for testing according to ASTM C-441 as well as a modified version of this method due to Mehta /5/ were made. They were cured and their lengths measured following the prescriptions of the methods.

Prisms for testing according to the NaCl bath method were made from a mortar consisting of one part of Portland-flyash cement and 3 parts of Nymølle sand and having a water/cement ratio of 0.5 /1/. The prisms were humid cured for the first 24 hours, demoulded and then water cured for 27 days. Thereafter the prisms were transferred to a saturated NaCl solution bath, maintained at 50 ^{0}C. The lengths of the prisms were measured at weekly intervals.

3. RESULTS AND DISCUSSIONS

Results of this investigation are shown in the tables 1, 3 and 4, and in the figures 1, 2, 3, 4 and 5. These results will be discussed in the following order:

3.1 Alkali contents of cements and flyash

From table 1 it can be seen that the alkali contents of Portland cements No. 1 and No. 2 are 0.74% and 1.18%, respectively, and that of the flyash is 2.34% Na_2O equivalent. The acid soluble alkali content of the Portland flyash cement is 0.6% Na_2O equivalent.

Table 1. Chemical analysis of cements and flyash

		Portland cement No.1	Portland cement No.2	Flyash
SiO_2	%	21.03	20.45	49.50
Al_2O_3	%	4.78	4.77	22.39
Fe_2O_3	%	3.06	2.98	10.08
CaO	%	64.58	63.14	6.31
MgO	%	1.23	-	3.59
SO_3	%	2.59	3.48	0.68
L.O.I.	%	1.07	0.98	3.20
K_2O	%	0.62	1.18	0.79
Na_2O	%	0.33	0.40	2.64
Na_2O eqv.	%	0.74	1.18	2.34
Free CaO	%	0.65	1.77	0.59
Total	%	98.34	95.80	99.77

From the above figures it can be calculated that the total alkali contents of Portland cement-flyash mixes used to make concrete cylinders (table 2) were 1.45% Na_2O equivalent for the mixes No. 3 and 8, and 1.84% Na_2O equivalent for the mixes No. 4 and 9, respectively. For the ASTM type accelerated tests flyash/Portland cement ratios were 30/70, which implies that their alkali contents were 1.22% and 1.53% Na_2O equivalent. These high alkali contents have to be compared with that of the Portland flyash cements whose content of acid soluble alkalies seldom goes over 0.6% Na_2O equivalent.

3.2 Effect of flyash addition in closed systems

Long time storage test. Table 2 shows the mix proportions of this series. Compressive strengths and volume changes of cylinders made from these mixes are shown in the tables 3 and 4, and in the figures 1 and 2. Note that half of these mixes were made with RILEM standard sand while the other half contained reactive sand.

An examination of table 3 shows that all the mixes gained strength between 28 days and 1 year and that the addition of flyash resulted in a considerably higher strength level than in concrete without flyash. Thereafter they either gained strength or maintained it. This has happened irrespective of the variation in the alkali content, the presence of reactive sand or flyash.

Table 2. Mix composition of concrete samples used in long time storage test

Mix No.	1	2	3	4	5	6	7	8	9	10
Portland cement No. 1	270		270		405	270		270		405
Portland cement No. 2		270		270			270		270	
RILEM sand	744	744	624	624	450					
Gravel	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170
Reactive sand						744	744	624	624	450
Flyash			100	100	150			100	100	150
Water	160	160	160	160	180	160	160	160	160	180

Table 3. Compressive strengths of concrete cylinders (MN/m^2)

Time \ Mix No.		1	2	3	4	5	6	7	8	9	10
28 days	$\bar{x}$	26.6	28.4	37.2	32.8	50.0	34.7	31.3	34.3	32.2	49.2
	s	1.9	3.6	0.7	1.9	1.5	3.0	0.7	1.9	0.8	0.4
1 year	$\bar{x}$	37.2	33.9	56.8	46.8	71.5	42.7	39.9	41.8	44.3	59.0
	s	4.6	3.8	3.7	5.5	5.9	1.5	3.0	2.8	2.2	5.2
2 years	$\bar{x}$	40.1	37.8	60.3	50.9	72.0	43.2	41.1	44.4	44.1	62.7
	s	5.3	2.6	2.9	2.5	4.7	2.8	2.5	2.8	2.3	4.1
5 years	$\bar{x}$	41.0	40.3	59.8	45.0	75.9	49.3	45.7	42.7	44.5	63.9
	s	4.2	1.1	2.5	4.5	5.1	2.1	0.3	3.4	8.5	4.9

Table 4. Volume change of concrete cylinders (‰)

Time \ Mix No.		1	2	3	4	5	6	7	8	9	10
28 days	$\bar{x}$	0	0	0	0	0	0	0	0	0	0
	s	0	0	0	0	0	0	0	0	0	0
3 months	$\bar{x}$	-0.64	-0.53	0.80	-1.80	0.69	-0.42	-0.69	-0.90	-0.37	0.53
	s	0.98	2.08	2.78	2.34	1.00	1.10	0.80	1.13	1.28	5.45
6 months	$\bar{x}$	-2.13	-0.89	-0.47	-1.59	1.43	0.11	-1.37	-1.65	-3.12	0.44
	s	1.03	4.40	4.25	2.01	2.23	1.86	2.74	5.83	1.39	3.45
1 year	$\bar{x}$	-7.49	-3.57	-2.38	-5.56	-2.71	-2.81	-3.17	-2.86	-1.20	-1.43
	s	1.17	2.40	2.49	2.84	1.01	0.89	2.57	1.08	0.60	1.51
2 years	$\bar{x}$	-6.70	-1.27	-5.41	-1.11	-4.31	-0.80	-2.06	-1.12	-2.85	-0.31
	s	1.22	1.16	1.32	0.61	1.51	0.95	1.30	0.61	0.81	1.99

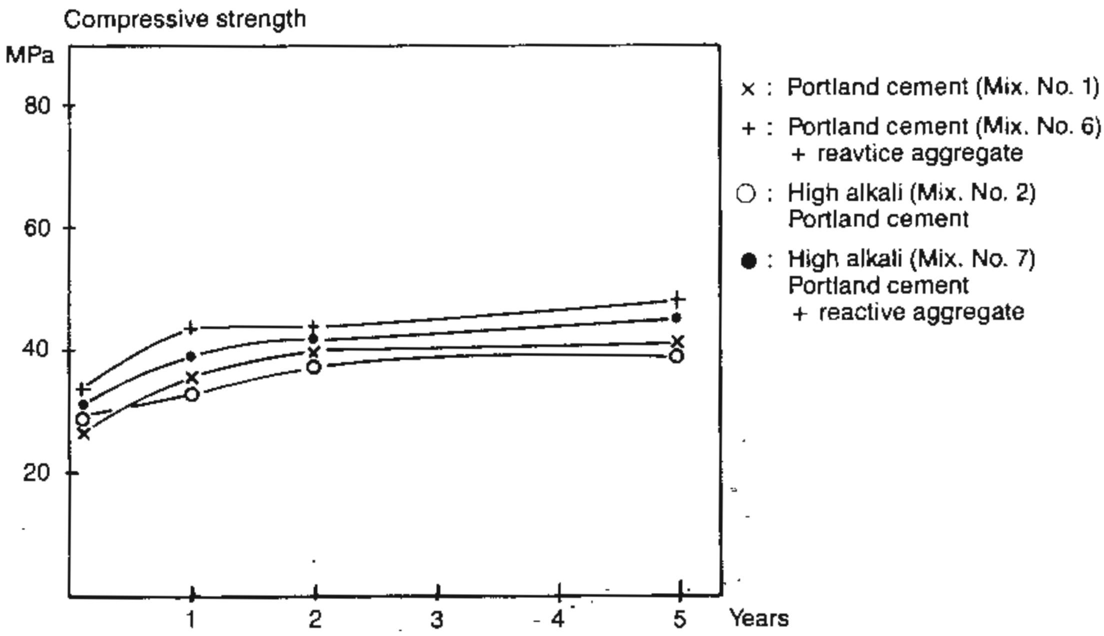

Figure 1. Examples of compressive strength development of concrete with and without addition of reactive aggregate. Mixes without flyash

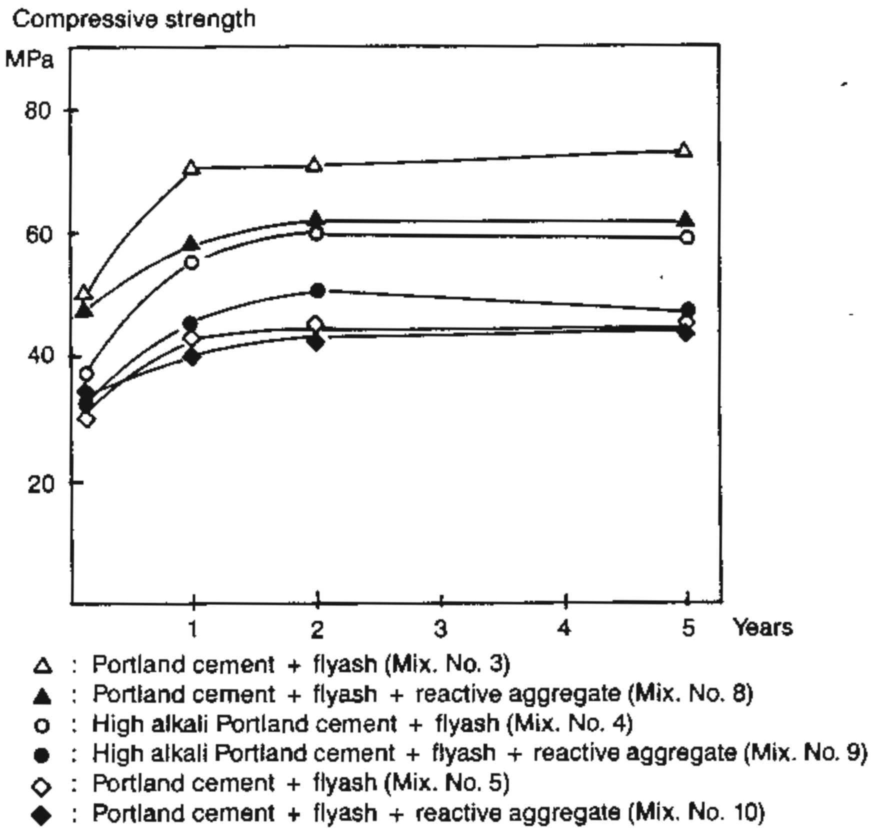

Figure 2. Examples of compressive strength development of concrete with flyash and reactive aggregate

An examination of table 4 shows that none of the concrete mixes suffered any permanent volume expansion. At 2 years all the mixes showed a volume shrinkage. The volume shrinkage could be due to a slight drying out during the long storage period under conditions which may not have been completely fog saturated at any time. The volume shrinkage has happened irrespective of the variation in the alkali content, the presence of reactive sand or flyash.

Results of the tables 3 and 4 together will indicate either that 5 years is too short a time for the development of alkali-silica reaction in concrete or that the reactivity of the reactive sand is not high enough to develop alkali-silica reaction within 5 years. The reason may also be that the amount of the reactive aggregates in mixes is above the pessimum limit. At least one point is clear, viz. that an alkali content of 1.84% Na_2O equivalent did not show any adverse effect.

Accelerated tests. Table 5 shows the mix proportions of the mortars used for the accelerated testing of mortar bars. Note that in ASTM C-441 only crushed pyrex glass was used as aggregate; whereas in the Mehta method a mixture of RILEM sand and crushed pyrex glass was used. Moreover the cement/aggregate ratio varies in these two methods.

Table 5. Mix compositions used in accelerated testing

Mix No.	1	2	3	4	5	6	7	8
Portland cement No. 1	300		210		500		350	
Portland cement No. 2		300		210		500		350
RILEM sand					100	100	100	100
Graded crushed pyrex glass	900	900	900	900	400	400	400	400
Flyash			90	90			150	150
Water	150	150	150	150	200	200	200	200
Test Method	ASTM C-441				MEHTA			

The figures 3 and 4 show the results of the expansion measurements of the two series.

The figures 3 and 4 show that in each case the flyash containing prisms expanded less than corresponding prisms without flyash. This reduction of the expansion occured in spite of alkali contents of 1.22% and 1.53% of the flyash Portland cement mixtures. Note also that the prisms of the Mehta method expanded more than those of the ASTM C-441 method. This and other differences between the results of these two methods may be due to the differences in their mix compositions.

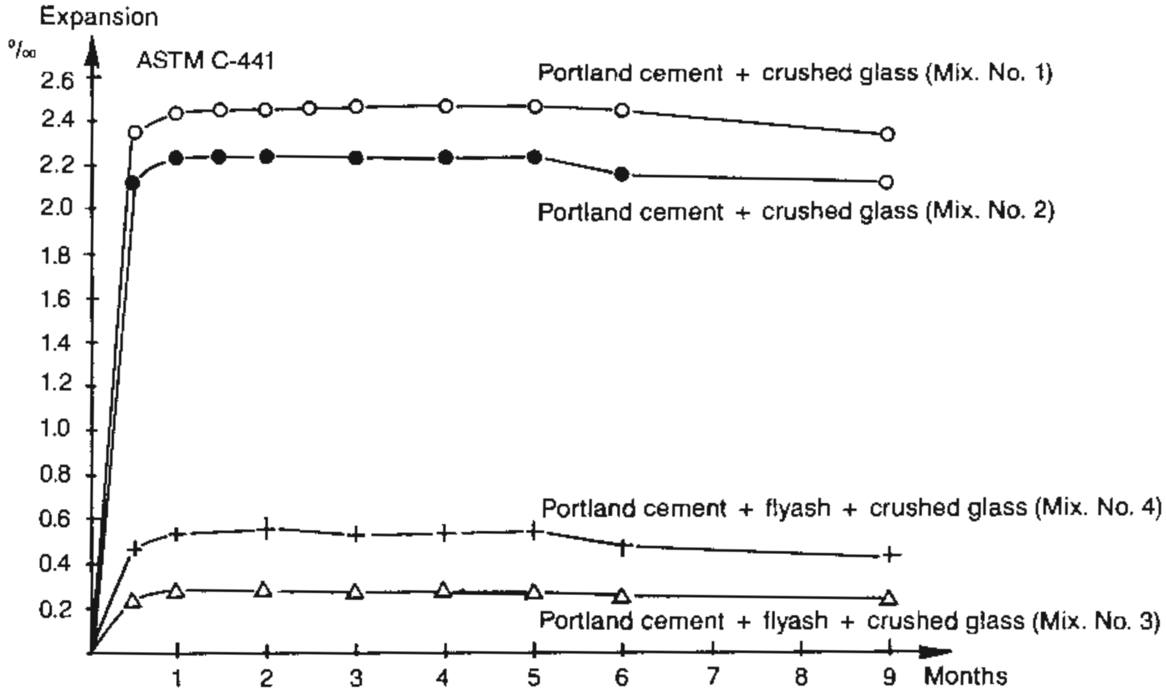

Figure 3. Time-expansion curves of mortar bars

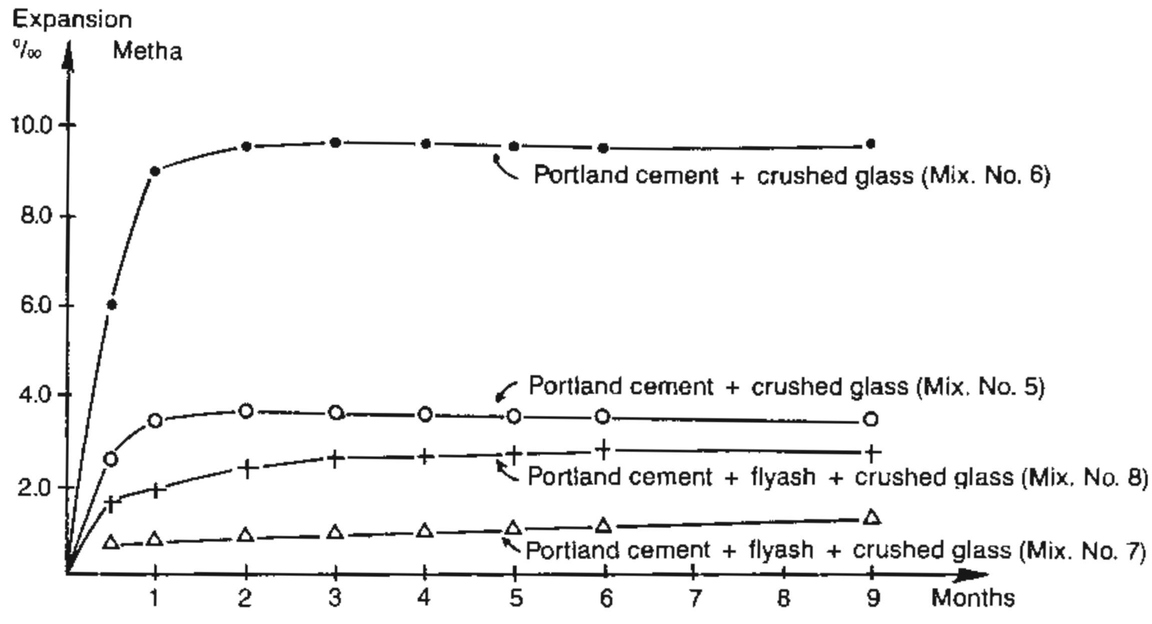

Figure 4. Time-expansion curves of mortar bars

3.3 Accelerated testing in an open system

Figure 5 shows the expansion curve of prisms made with Standard-Cement and Nymølle sand. These were stored in a saturated NaCl bath at 50^0 C. For comparison purposes, the expansion curve of prisms made with the same Nymølle sand and a low alkali sulphate resistant cement has also been included in figure 5. From the figure it is obvious that, compared to low-alkali cement mortar, Portland flyash cement mortar has a lower rate of expansion.

Unfortunately, however, no comment could be made about the long term expansion capacity of the mortar prisms made with these two types of cements. More work will be needed for this purpose. However, the beneficial effect of flyash addition is clear, even in the open system.

This type of test has not previously been reported in the literature.

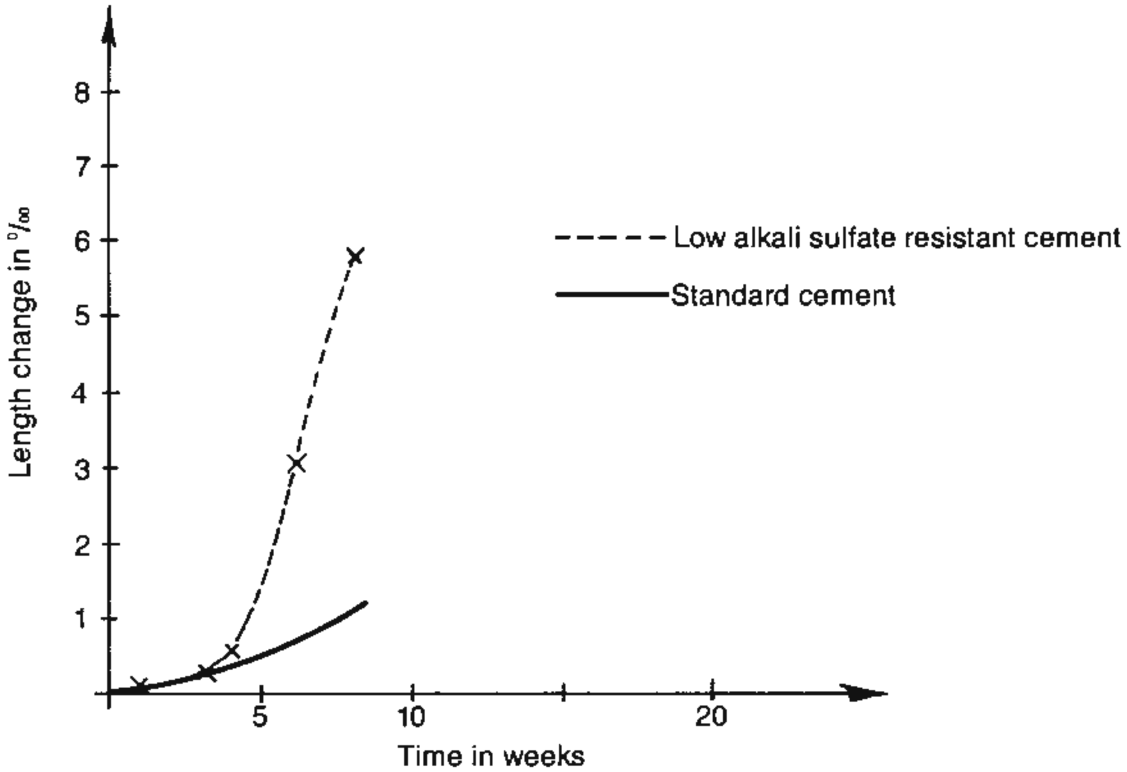

Figure 5. Time-expansion curves of mortar bars stored in NaCl bath (low alkali sulphate resistant cement compared with Standard-Cement)

4. CONCLUSIONS

1. Long time storage tests show that addition of flyash to concrete mixes has no adverse effect even if its alkali content is as high as 2.34% Na_2O equivalent.

2. Accelerated tests according to ASTM show that the addition of flyash, even of high alkali content, to Portland cements reduces expansions due to alkali-silica reaction.

3. Accelerated tests with unlimited supplies of alkali salt show that the addition of flyash to Portland cement reduces, at least, the rate of expansion, may be also the ultimate expansion.

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