ASR TEST METHODS EVALUATION FOR CO NCRETES COTAINING NATURAL POZZOLANS

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Abstract

The incorporation of supplementary cementitious materials in concrete has been found to be effective in controlling the expansion due to alkali-silica reaction (ASR). The research described in this paper aims to present results covering a detailed experimental investigation in order to understand the effects of natural pozzolans on ASR mitigating. In this study concrete prism specimens were made in accordance with CSA A23.2-14A and also the mortar bars were produced in accordance with the ASTM C 1260 specification. Two types of portland cements and different natural pozzolans up to 30% replacement level were used throughout this investigation. Residual alkali and expansion of concrete mixtures were measured at various ages up to two years. Attempt was made to correlate the expansion of mortar bars, their alkali contents and CaO content of mixtures.

Test results indicate that the expansion of specimens is declined by increase of natural pozzolan replacement level, while it seems that there exists a pessimum amount in replacement level. The results of accelerated mortar bar test (AMBT) are also compared with the results of concrete prism test (CPT).

Keywords: Alkali-silica reaction, Natural pozzolan, Expansion, Alkali content, Pessimum

1. INTRODUCTION

The manufacture of portland cement is an energy consuming process (approximately 4GJ energy per ton) releasing a considerable amount of carbon dioxide as a major contributor to the greenhouse gas emission that leads to global warming [1]. Although pozzolanic materials have been used in the construction industry for many years, mineral admixtures have been used widely as substitutes for portland cement in order to improve the properties of portland cement such as decrease the rate of releasing heat, increase resistance against sulfate and other chemical substances attack, lowering permeability and also controlling the expansion due to alkali-silica reaction in concrete [2].

Cementitious materials – produced in the process of portland cement and mineral admixtures hydration – and absorption of alkali content of mixture by natural pozzolans are the main reasons of progress in durability of concrete [3]. The Ca(OH)2 content of the pure portland cement paste increases with an

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increase in the hydration age, whereas in the blended cements, it decreases with the hydration age as a result of pozzolanic reaction of the natural pozzolan present in blended system [4].

In order to understand the effect of supplementary cementing materials (SCM) on concrete permeability, resistance to chloride and sulfate attacks, the rate of alkali-aggregate reaction (AAR) and setting time and compressive strength of concrete, numerous attempts have been made [5]. Prediction of alkali-silica reaction as a serious potential threat for concrete structures can prevent a major loss of investment. The use of natural pozzolans as a reasonable method to control the expansion of concretes as a result of ASR has been studied in accordance with CSA A23.2-14A and ASTM C 1260, however the accelerated mortar bar test method (ASTM C 1260) has been recognized not to be suitable to determine the effect of cement replacement materials and also it is recommended to measure the expansion of concrete prisms at least for two years [6]. In order to establish the effect of chemical characteristics of natural pozzolans – as a low-cost replacement for cement in concrete – on the expansion of concrete and compare the result of accelerated mortar bar test with concrete prism test, a reactive aggregate, two types of portland cements and two types of natural pozzolans are chosen and 12 different mixtures are designed.

2. EXPERIMEAL DETAILS

2.1 Materials

Two different Type II portland cements and two specific natural pozzolans were obtained from two factories producing commercial blended cements. Intergrinding the clinkers and gypsum were done in the factories and the pozzolans and cements were received separately in powder form. The physical properties and chemical analysis of portland cements and natural pozzolans are shown in Table 1. The alkali content of all the cements are more than 0.6%, the limitation that is determined as the maximum allowable alkali content in mortars to prevent ASR[7]. Besides the CaO content of type N-2 natural pozzolan is 12.6%, marginally more than the recommended limitation to suppressing deleterious effects on expansion due to ASR. All the natural pozzolans meet ASTM C 618 requirements for maximum equivalent alkali content and minimum activity index at 28 days.

The aggregate from Ostoor deposit was used as reactive aggregate. The aggregate was divided into fine aggregate and coarse aggregate. The Ostoor aggregate was received in five grading fractions: 0 to 4 mm (fine aggregate), 4 to 10 mm (13.7%), 10 to 30 mm (31.5%), 30 to 60 mm (27.4%), 60 to 120 mm (27.4%). in order to determine the effect of different active aggregates, coarse aggregate and fine aggregate were used separately in different mixtures. In this study fine aggregate and coarse aggregate were tested in accordance with ASTM C 289 (chemical test), and ASTM C 295 (petrographic test). The results of these tests show that the proportion of rhyolite, chert and chalcedony in coarse aggregate and fine aggregate are 25.5% and more than 30% respectively and they are potentially reactive aggregates. The results of petrographic test for both coarse aggregate and fine aggregate are shown in Table 2.

Physical properties and chemical analysis of portland cements

The physical properties and chemical analysis of portland cements are determined and reported in Table 1. According to the results, the equivalent alkalis (as Na_2O) for all the portland cements are significantly more than 0.6%, while the equivalent alkali content of PC-1 is 1.43% and the equivalent alkali content of PC-2 is just 1.06%. Besides the fineness of PC-1 and PC-2 are marginally less than 2800 cm^2/g. In addition compressive strength of PC-1 and PC-2 at 28 days is 39.8 and 34.3 MPa respectively, which represents the rate of chemical reactions until this age.

Physical properties and chemical analysis of natural pozzolans

Table 1 shows the physical properties and chemical analysis of natural pozzolans. Considering the test results, the level of CaO contents are 6.44% and 3.10% for NP-1 and NP-2 respectively. The equivalent alkali (as Na2O) of NP-1 is 0.68% and it is more than that of NP-2 by approximately 50%. However, it is less than 1.50% as specified by ASTM C 618. The activity index for NP-1 and NP-2 at 28 days is 99.0% and 78.2% respectively, however the activity indexes of them at 7 days are in reverse order (73.8% and 69.3% respectively).

2.2 Manufacturing and testing methods

ASTM C 289: Chemical Method

In order to identify reactive characteristic of aggregates with alkalis the chemical test method was performed. Each sample was prepared in accordance with ASTM C 289 [8]. Each aggregate sample was crushed and sieved to pass the no. 50 sieve and to be retained on a no. 100 sieve. Reaction between sodium hydroxide solution (1 N) and siliceous component in the aggregate for 24 h at 80 °C was determined to obtain the reduction in the alkalinity and the amount of dissolved silica. The test results indicate that all the aggregates are potentially reactive.

ASTM C 1260: AMBT

The accelerated mortar bar test (AMBT) is the most widely used accelerated method for determining the alkali-silica reactivity of concrete mixtures. 12 different mixtures (see Table 3) were designed in order to determine the effects of aggregate, cementitious composition and chemical properties of each material on expansion of mortar bars due to alkali silica reaction. The mixing and moulding procedures followed the requirements of standard. After demoulding the bars and placing them into a water bath at room temperature for one day, the samples were stored in containers containing 1N NaOH at 80±2 °C and readings were taken at 1, 3, 7, 10, 14, 21, 28 and 35 days as described in ASTM C 1260 [9]. The test results for fine aggregate and coarse aggregate are plotted in Table 4.

CSA A23.2-14A: CPT

For each concrete mixture in this study (the composition of cementitious materials are shown in Table 3), three 75 by 75 by 275 mm concrete prisms were cast for ASR expansion testing in accordance with CSA A23.2-14A [10]. Reagent grade sodium hydroxide (NaOH) was added to the mixing water to increase the total equivalent alkali level (as Na2O) to 1.25%. Tehran aggregate was used as an innocuous aggregate in this study.

After 24 hours, concrete prisms were demoulded and placed into a water bath at room temperature for one day. The concrete prisms lengths were measured (L_0) and then the samples were stored in a container at 38 °C and R.H.>98%. Expansion measurements were performed at regular intervals up to two years. The test results for different concrete mixture designs are shown in Figures 1 and 2.

ASTM C 856: Petrographic Examination of Hardened Concrete

Two samples of concrete prism test (F-1-30 and F-2-30) after one year being placed in a container at 38 °C and R.H.>98%, were broken in three parts. Broken samples were examined, with reference to ASTM C 856 [11], by using optical and stereoscopic microscopes in order to identify the presence of typical products originated by ASR. The test results are illustrated in Figure 3.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. ASTM C 289: Chemical Method

The test results for coarse aggregate and fine aggregate are determined separately. (SC [mM/L], RC [mM/L]) for fine aggregate and coarse aggregate are (800,225) and (700,200), respectively. The test results show that all the aggregates are potentially reactive, however fine aggregate seems to be more reactive compared with coarse aggregate.

3.2. ASTM C 1260: AMBT

To understand the effect of natural pozzolans on AMBT expansions the results are measured up to35 days, instead of 14 days. Table 4 shows the 35-day AMBT expansion results for all samples in the study. Considering ASTM C 1260, expansion up to 0.20% means reactive behavior of the aggregate, while the expansion below 0.10% by the same age determines innocuous aggregate. In case of replacing a part of portland cement by natural pozzolans, it is recommended to continue plotting the expansions of mortar bars up to 35 days [6].

Using this expansion criterion, it is observed reactive potentially behavior for all the samples, by the age of 35 days. In case of 30% replacement of natural pozzolans (F-1-30, F-2-30, C-1-30, C-2-30), however, the 14-day expansions are below the standard limit. It can be seen from the test results that the expansion of samples and the rate of expansion growth are significantly reduced by increase of natural pozzolan replacement level. It should be mentioned that in the same natural pozzolan replacement levels for all the cementitious compositions, the AMBT expansion results are similar: The range of expansion values for 0%, 20% and 30% natural pozzolan replacement are 0.488%-0.620%, 0.229%-0.326% and 0.100%-0.130% respectively. Considering the less expansion results of coarse aggregate compared with the samples with the same cementitious composition, it can be found that fine aggregate is more reactive than coarse aggregate in this study.

3.3. CSA A23.2-14A: CPT

The 104-week CPT expansion results are shown in Figures 1 and 2. According to CSA A23.2-14A, the mixtures with expansion results exceeding 0.04% at 52 weeks are known as reactive samples. It is suggested that the expansion measurements should be performed up to 2 years when cementitious composition includes natural pozzolans [6]. It can be observed that approximately all expansions do not cease at 52 weeks, while the measured expansions for most of the samples are not changed considerably at 104 weeks. Therefore, the 104-week results are more trustable compared with 52-week results to assess the impact of natural pozzolan replacement on the expansion of concrete prisms.

As shown in Figures 1 and 2, the replacement of portland cement by natural pozzolan is effective in reducing the expansion of control concrete prisms at 104 weeks in all except one of the concrete prisms (F-1-30). At this age, the expansions are decreased between 2% and 32% compared with relevant control concrete prisms, while in the case of F-1-30 there is an increase of about 11% in the expansion at the same age. In this point of view, the 52-week results are similar to 104-week results.

As expected, 30% replacement of portland cement by natural pozzolan is more effective than 20% replacement, in mitigating the expansion of concrete prisms due to alkali silica reaction. This is not the case for NP-1. The 104-week expansion of F-1-20, F-1-30, C-1-20 and C-1-30 are 0.037%, 0.059%, 0.036% and 0.059% respectively.

The maximum reduction of 104-week concrete prisms expansions for F-1, F-2, C-1 and C-2 compared with relevant control samples are 30%, 22%, 32% and 17% respectively. There is a significant correspondence between the different results of samples with the same cementitious composition and the reactivity of aggregates. In other words, the results indicate that the fine aggregate is more reactive than coarse aggregate in this study and consequently, for instance the reduction in concrete prisms expansions of F-1 is less than that of C-1.

On the other hand, the differences between the samples with the same aggregate and different cementitious composition relate to the chemical and physical properties of cementitious compositions (see Table 1 and 3). As expected, the pozzolanic activity index is observed to enhance the reduction of concrete prisms expansions. Although CaO is introduced by a number of scientists to have a deleterious effect on expansion of concrete prisms due to ASR, it cannot be confirmed by this study. NP-1 contains the largest amounts of CaO in this study (6.44%). It has, nevertheless, the greatest effect on controlling the expansion of concrete prisms compared with NP-2.

The equivalent alkali content of cementitious composition is observed to have a considerable direct influence on the expansion results. The 52-week and 104-week expansion results of control samples containing PC-1 are more than those of control samples containing PC-2 (equivalent alkali content of PC-2 is less than PC-1).

Using polynomial equations in order to find the pessimum amount of natural pozzolan replacement, it can be comprehended that in 50% of mixtures in this study a pessimum percentage of natural pozzolan replacement can be found (F-1 and C-1). The pessimum percentage of natural pozzolan replacement for F-1 and C-1, obtained by using 104-week expansion results, are 14% and 15.2% respectively. It is important to mention that the pessimum percentage for NP-1 is approximately the same in F-1 and C-1 and it seems that the change in type of aggregate can be neglected. In the other cases an increase in natural pozzolan amount leads to reduction in expansion of concrete prisms (F-2 and C-2).

3.4. Comparative analysis of AMBT and CPT

A comparison between the CPT at one year and two years and the AMBT at 14 days and 35 days is presented in Table 5.

The comparison with CPT at one year and AMBT at 14 days in aggressive solution shows that 58% of samples (7 out of 12) are classified differently by two methods. 50% of samples are classified as potentially reactive or reactive in the AMBT and passed in the CPT, and 8% of samples are passed in the AMBT and failed in the CPT.

According to the results, 75% of samples (9 out of 12) are classified differently by AMBT at 35 days, compared with CPT at one year. All of these samples are classified as potentially reactive or reactive in the AMBT. However, they are passed in the CPT.

The comparison with CPT at two years and AMBT at 14 days in aggressive solution indicates that approximately 66% (8 out of 12) of samples are classified the same by two methods. However, 17% of samples are classified as potentially reactive in the AMBT and passed in the CPT, and 17% of them are passed in the AMBT and failed in the CPT.

One third of samples are classified as potentially reactive or reactive in AMBT at 35 days in aggressive solution, while they are passed in CPT at two years.

Considering these statistics, the best correlation between CPT and AMBT belongs to CPT at two years and AMBT at 14 days.

3.5. ASTM C 856: Petrographic examination of hardened concrete

The results of petrographic examination of hardened concrete for some of fine aggregate samples at one year are indicated in Figure 3. The results show that a fine aggregate with maximum dimension of 9.5 mm containing rhyolite, chert, chalcedony, quartz, quartzite, granite, basalt, mica, and mafic is used in concrete prisms. Up to 10% of portland cement is not hydrated, and also the Ca(OH)2 contents in hardened cement pastes for F-1-30 and F-2-30 are approximately 8% and 10% respectively. According to the other researches, the $Ca(OH)^2$ content of the pure portland cement pastes increases with an increase in the hydration age, whereas in the blended cements, it decreases with the hydration age as a result of pozzolanic reaction of natural pozzolan contents in the blended systems [7]. Besides, the difference between the $Ca(OH)^2$ contents of two samples is correlated with the activity index of NP-1 and NP-2. The ASR gel as shown in Figure 3, confirms the alkali silica reaction in both samples. The average dimension of ASR gel is approximately 50 to 75 micron.

4. CONCLUSIONS

Based on experimental results of this investigation the following conclusions can be drawn:

1. The results of accelerated mortar bar test method are approximately the same for a constant natural pozzolan replacement with an individual aggregate. It means that this test method is not an appropriate method to assess the influence of natural pozzolans replacement on expansion due to ASR. Nevertheless, the AMBT method is a suitable accelerated method to distinguish reactive aggregates.
2. The results of concrete prism test indicates that the expansion of specimens do not cease at 52 weeks. The growth of expansions, however, is declined significantly at the age of 104 weeks. Therefore it is recommended to measure the expansion of concrete prisms (CSA A23.2-14A) which contain natural pozzolans as a part of their cementitious composition up to two years.
3. In general, the effect of natural pozzolans to suppress alkali silica reaction depends on the reactivity of aggregate, the level of natural pozzolan replacement, the equivalent alkali content of cementitious composition and the activity index of natural pozzolan.
4. The maximum reduction of concrete prism expansion compared with control sample increases with an increase in activity index of natural pozzolan.
5. The expansion of specimens is declined by increase of natural pozzolan replacement level, while in some cases a pessimum amount in natural pozzolan replacement level exists.

5. REFERENCES

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TABLE 1: Physical properties and chemical analysis of portland cements and natural pozzolans

Portland cements			***Natural pozzolans***		
Chemical analysis, %	PC-1	PC-2	*Chemical analysis, %*	NP-1	NP-2
SiO_2	21.34	26.90	$SiO_2 + Al_2O_3 + Fe_2O_3$	85.32	86.07
Al_2O_3	3.40	5.05			
Fe_2O_3	4.80	3.40	SO_3	0.03	0.00
MgO	2.60	0.80			
CaO	62.72	54.88	Moisture	0.23	0.87
SO_3	2.28	1.58			
C_3S	56.95	52.20	Loss on ignition	3.84	3.00
C_2S	18.22	19.70			
C_3A	0.89	7.80	CaO	6.44	3.10
C_4AF	14.60	10.30	MgO	2.20	0.60
Free lime	1.62	2.60	Cl^-	0.017	0.010
Equivalent alkalis (as Na_2O)	1.43	1.06	Equivalent alkalis (as Na_2O)	0.68	0.44
Loss on ignition	0.91	2.01			
Physical tests			*Physical tests*		
Fineness: Blaine, cm^2/g	2760	2787	Fineness: Passing 45 mm, %	82.0	94.0
Expansion in autoclave test	0.76	0.14			
Initial setting time, min	165	89			
Final setting time, min	215	279			
Compressive strength, MPa			*Pozzolanic activity with portland cement*		
3 days	21.5	20.0	Activity index at 7 days, %	73.8	69.3
7days	31.2	27.8	Activity index at 28 days, %	99.0	78.2
28 days	39.8	34.3	Specific gravity, g/m^3	2.50	2.56

TABLE 2: Results of aggregate petrographic test under optical microscope							
Fine aggregate, %	**#8**	**#16**	**#30**	**#50**	**#100**	**#200**	**Total**
Carbonates	7.3	3.9	4.8	6.8	19.9	11.6	6.6
Granite, Quartz	14.7	22.7	28.0	37.5	40.4	28.9	22.7
Rhyolite, Chert, Chalcedony	44.5	29.6	31.1	16.0	19.2	11.2	34.0
Volcanics	27.5	34.5	29.4	20.4	11.2	40.4	29.1
Derived	6.0	9.3	6.7	9.3	9.3	7.9	7.6
Clastics	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coarse aggregate, %	**>3/2"**	**1"**	**3/4"**	**1/2"**	**3/8"**	**3/16"**	**Total**
Carbonates	4.2	7.9	9.4	8.8	7.9	9.5	8.6
Granite, Quartz	12.5	11.2	13.7	23.2	17.4	21.6	16.3
Rhyolite, Chert, Chalcedony	26.7	28.4	25.1	21.6	26.7	20.9	25.2
Volcanics	28.5	30.5	19.6	21.6	27.5	22.3	25.5
Derived	7.1	6.3	11.0	11.2	8.7	5.4	8.1
Clastics	21.0	15.7	21.2	13.6	11.8	20.3	16.3

TABLE 3: Composition of cementitious materials and the the type of aggregate in samples					
Code	***Natural pozzolan***		***Portlan cement***		***Reactive aggregate***
	Type	***Proportion, %***	***Type***	***Proportion, %***	
F-1-0	NP-1	0	PC-1	100	Fine aggregate
F-1-20	NP-1	20	PC-1	80	Fine aggregate
F-1-30	NP-1	30	PC-1	70	Fine aggregate
F-2-0	NP-2	0	PC-2	100	Fine aggregate
F-2-20	NP-2	20	PC-2	80	Fine aggregate
F-2-30	NP-2	30	PC-2	70	Fine aggregate
C-1-0	NP-1	0	PC-1	100	Coarse aggregate
C-1-20	NP-1	20	PC-1	80	Coarse aggregate
C-1-30	NP-1	30	PC-1	70	Coarse aggregate
C-2-0	NP-2	0	PC-2	100	Coarse aggregate

TABLE 4: Expansion of mortar bars in accordance with ASTM C 1260 (%)							
Code	**Age, days**						
	0	**3**	**7**	**14**	**21**	**28**	**35**
F-1-0	0.000	0.182	0.283	0.401	0.448	0.518	0.588
F-1-20	0.000	0.061	0.108	0.154	0.176	0.226	0.269
F-1-30	0.000	0.000	0.020	0.030	0.040	0.080	0.110
F-2-0	0.000	0.140	0.270	0.400	0.460	0.540	0.620
F-2-20	0.000	0.057	0.116	0.180	0.237	0.286	0.326
F-2-30	0.000	0.010	0.010	0.030	0.060	0.100	0.130
C-1-0	0.000	0.121	0.233	0.332	0.425	0.457	0.488
C-1-20	0.000	0.040	0.084	0.131	0.175	0.199	0.229
C-1-30	0.000	0.000	0.010	0.030	0.050	0.070	0.100
C-2-0	0.000	0.130	0.270	0.410	0.480	0.540	0.570
C-2-20	0.000	0.047	0.107	0.196	0.249	0.297	0.319
C-2-30	0.000	0.000	0.000	0.040	0.070	0.110	0.130

TABLE 5: Comparative analysis of AMBT and CPT				
Code	***AMBT, 14 days***	***AMBT, 35 days***	***CPT, 1 year***	***CPT, 2 years***
F-1-0	R	R	R	R
F-1-20	PR	R	NR	NR
F-1-30	NR	PR	R	R
F-2-0	R	R	NR	R
F-2-20	PR	R	NR	R
F-2-30	NR	PR	NR	NR
C-1-0	R	R	MR	R
C-1-20	PR	R	NR	NR
C-1-30	NR	PR	NR	R
C-2-0	R	R	NR	R
C-2-20	PR	R	NR	R
C-2-30	NR	PR	NR	NR
R: Reactive, PR: Potentially Reactive, NR: Non-Reactive				

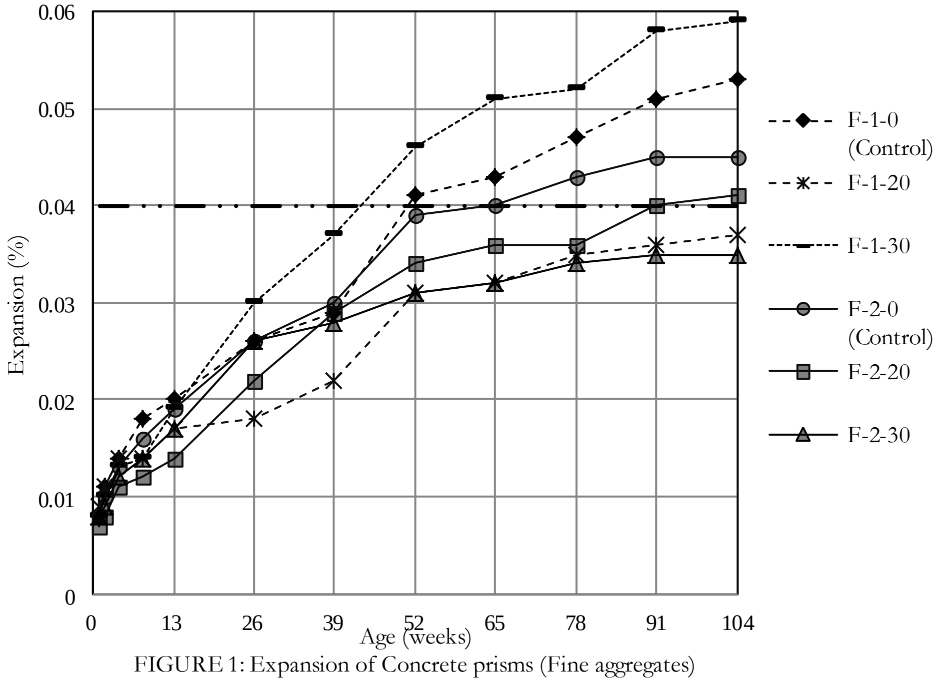
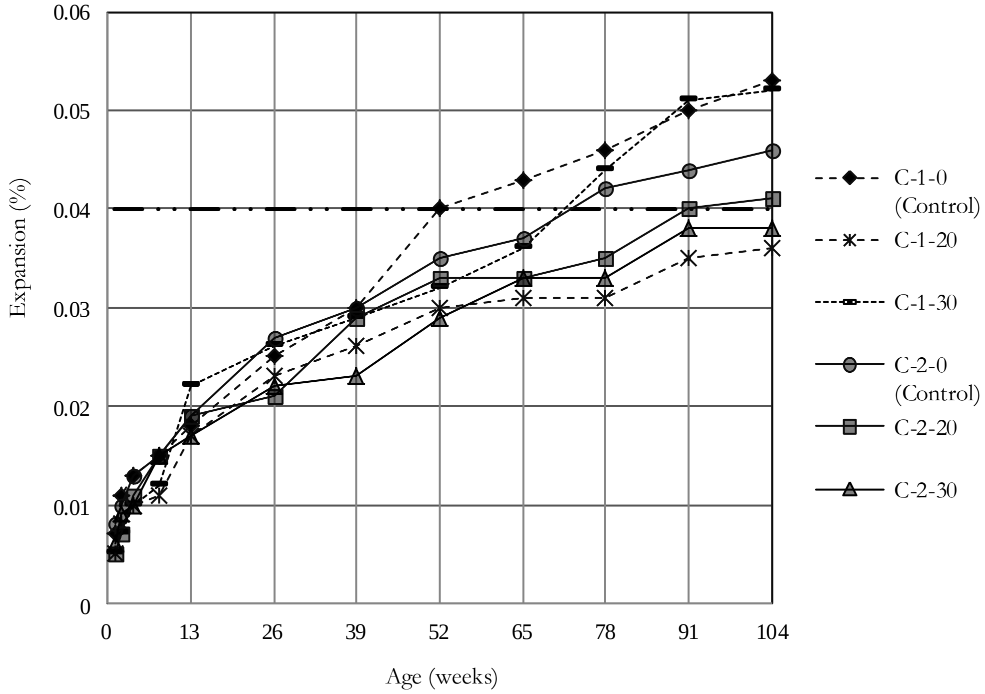


FIGURE 1: Expansion of Concrete prisms (Fine aggregates)



FIFURE 2: Expansion of Concrete prisms (Coarse aggregate)

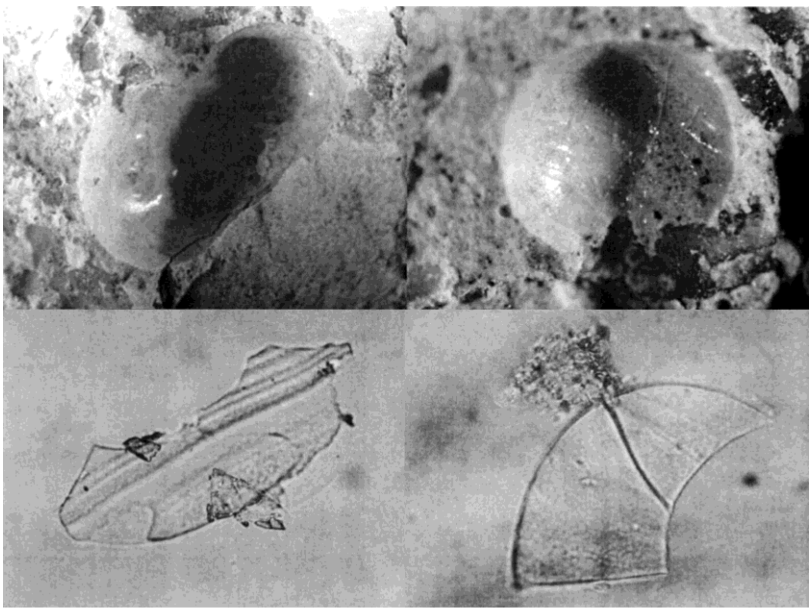


FIGURE 3: Results of petrographic examination of hardened concrete at one year (left: F-1-30, right: F-2-30)