EVALUATION OF ALKALI-AGGREGATE REACTION IN AGGREGATES FROM IGNEOUS ROCKS

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Abstract

Most aggregates used for concrete in Mexico are igneous origin rocks as rhyolite, andesite and basalt. For evaluating reactivity of this materials were selected three aggregate from different sources. Reactive character of fine and course aggregates was identified combining three types of Portland cement commercially available.

Besides, the inhibition effect of alkali-silica reaction was observed using pozzolanic cement and ASTM class F fly ash by substitution of Portland cement.

Three methods were used in this study: accelerated mortar bar test ASTM C 1260, ASTM C 1567, and mortar bar test ASTM C 227. Besides, first the aggregates were analyzed by ASTM C 295 and ASTM C 289.

Thirty five combinations cement-aggregate were made identifying reactive character of each aggregate and determining the capacity of supplementary cementing materials to reduce or inhibit expansion due to the alkali-silica reaction. The results showed that accelerated mortar bar test is a method that provided information quick to evaluate effectiveness of SCM´s for reducing ASR; both natural pozzolan as FA showed good capacity to reduce expansions due to ASR.

Keywords: aggregate, alkali-silica reaction, igneous rocks, supplementary cementitious material (SCM), accelerated mortar bar test (AMBT).

1 INTRODUCTION

Mexico has a great diversity of aggregates from igneous origin for producing concrete such as rhyolites, andesites and basalts. The rocks of volcanic origin, acidic and intermediate rocks, include some rhyolites, dacites, andesites, latites, and tuffs of theses rocks type (rocks composed of compacted volcanic fragments) also may be alkali reactive. The reactivity of theses rocks can be attributed to the texture and composition of glassy or partially glassy groundmass (matrix of the rock). The basalts containing glass highly siliceous interstitial glasses are slowly alkali-silica reactive, and produce the expansion and map cracking typical of ASR in concrete [1].

Due to importance for identifying and evaluating the different aggregates from igneous origin and preventing the problems of expansion by AAR, this study presents the characterization and evaluation by petrographic examination, quick chemical method and chemical composition of these rock types. Also, accelerated mortar bar test (AMBT) –ASTM C 1260 and ASTM C 1567-, and mortar bar test ASTM C 227 were made for determining the reactivity of these aggregates and the effectiveness of supplementary cementitious materials to reduce or inhibit alkali-aggregate reaction (ARR). The accelerated methods have become critical tools in supporting engineering decisions for the selection of appropriate preventive measures against the risk of expansion and cracking due to AAR in structures that will be designed for minimum 75 to 100 years service life. [2]

This paper presents data from laboratory studies for evaluating the potentially reactivity of aggregates from igneous rock by the accelerated mortar bar test (ASTM C 1260) and for assess the suitability of SCM´s (ASTM C 1567) for reducing the expansion due to alkali-silica reaction (ASR). The results are presented for thirty five different cement-aggregate combinations tested by both accelerated methods and ASTM C 227 mortar bar.

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2 MATERIALS AND METHODS

2.1 Materials

Cements

In this study four cements and one combination cement-SCM: ordinary Portland cement with high alkali content (OPC-A), compound Portland cement (CPC-B), ordinary Portland cement with low alkalis (OPC-H), pozzolanic Portland cement (PPC-G) and ordinary Portland cement combining fly ash (OPC-A+FA) were used. Chemical and physical analysis is presented in Table 1.

Supplementary cementing materials

The materials used in this study were: ASTM Class F fly ash (FA) from Power Station Carbon II, Piedras Negras, Coahuila, combining with ordinary Portland cement (OPC-A) in substitution and a pozzolanic Portland cement type IP (PPC-G) with natural pozzolan (Puzz-G). The chemical and physical analysis are shown in Table 1.

Aggregates

Three igneous rock types volcanic extrusive were tested, both sand and gravel, from different sources: the rhyolite is from deposit Albia in Durango; the andesite as sand is from deposit San Vicente Chicoloapan in Mexico state and gravel located in Huixquilucan Mexico state; the basalt come from deposit San Isidro in Baja California Norte. These materials were homogenized and analyzed by XRF and ASTM C 114 for determining their chemical composition. The results are shown in Table 2. Aggregate type, source, location, and identification are indicated in Table 3.

2.2 Experimental methods

Petrographic examination

Besides, the components of each aggregate were identified by Petrographic Examination ASTM C 295 [3] determining the relative amounts of the constituents and lithologic components of each aggregate. Some characteristics that can be indicated in a petrographic evaluation are: type of rock, particle shape, grain size, color, mineralogical composition, scab and incrustations, deleterious particles, texture of the surface of the particle, internal structure, physical conditions, etc. For the present work, a count of 500 points was made for each sample with the purpose of determining the percentage of each component and therefore the amount of material considered potentially deleterious. The identification and classification of rocks depending on the knowledge and experience of the petrographer. In Fig. 8 are shown two rock types: rhyolite and andesite.

Quick chemical method

One quick test method to identify reactive character of aggregates with alkalis by chemical analysis, ASTM C 289 [4], was used. Each sample was prepared according to indicated in this method. Each aggregate sample was crushed and sieved to pass the 300 mμ (No. 50) sieve and to be retained on a 150 mμ (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 are plotted to identify potentially deleterious reactivity degree or innocuous character of the aggregates.

Accelerated Mortar Bar Test ASTM C 1260[5]

The course aggregates to be evaluated are crushed, washed and sieved to sand size to obtain the grading requirements according to this method. For the mortar test was used 1 part of cement to 2.25 parts of graded aggregate by mass and a water to cement ratio equal to 0.47 by mass. Three test specimens (25 x 25 x 285 mm) for each cement-aggregate combination were made. After 24 h the specimens are removed and an initial comparatory reading is made. The specimens are place in a storage container with sufficient tap water to totally immerse for a period of 24 h at 80.0 ± 2.0°C in a water bath. After this time it is taken the zero reading. After, they are immersed in 1 N sodium hydroxide solution at 80°C for 28 days. The change in length of the bars is monitored periodically for 14 to 28 days after zero reading. Expansions less than 0.10 % at 16 days are indicative innocuous behaviour. Expansions more than 0.20% are considered potentially deleterious expansion of the aggregate in concrete having high alkali content, and expansions are between 0.10 and 0.20 % at 16 days after casting include both aggregates innocuous and deleterious in field performance. This test is appropriate only for alkali-silica reactive aggregates. Although this bar test does not exactly replicate how concrete will behave, the test is a good indicator of potential reactivity and has the great advantage of being quick. (3).

Accelerated Mortar Bar Test ASTM C 1567[6]

This method permits detection within 16 days of the potential for deleterious alkali-silica reaction of combinations of cementitious materials and aggregates in mortar bars.

The aggregates are prepared according to grading requirements indicated in this method. Proportion the dry materials for the test mortar using 1 part of cementitious materials (hydraulic cement plus pozzolan, fly ash or slag) to 2.25 parts of graded aggregate by mass. A water-cementitious ratio was 0.47 by mass. Three test specimens (25 x 25 x 285 mm) for each aggregate cementitious combination were made. After 24 h in their molds at 23 °C and 100% RH, the bars were demolded and measured an initial comparator reading. After the specimens were placed in a storage container with tap water at 80 °C for 24 h, the length of the bars is measured (zero reading) and the bars are stored, immersed in 1 N sodium hydroxide solution, at 80 °C. The change in length of the bars is monitored periodically for 16 to 30 days after casting.

According to ASTM C 1567 the combinations of cement plus cementitious material and aggregate that expand less than 0.10 % at 16 days after casting are likely to produce acceptable expansions when tested in concrete (that is, Test Method C 1293) and to have a low risk of deleterious expansion when used in concrete under field conditions. When the combinations expand expand more than 0.10 % at 16 days after casting are indicative of potentially deleterious expansion.

Mortar Bar Test ASTM C 227

The course aggregate was crushed aggregate and graded to comply with the grinding requirements of ASTM C 227 [7]. This method measures the potential alkali reactivity of cement-aggregate combinations by the mortar bar and determines the susceptibility of cement-aggregate combinations to expansion reactions involving the alkalis sodium and potassium by measuring the increase or decrease in length of mortar bars containing the combination cement-aggregate during storage under prescribed conditions.

The mortar is placed in metal molds to fabricate a set of three mortar bars. After hardening, the mortar bars are demolded and measured for initial length in a comparator meeting the requirements of ASTM C 490. The specimens are placed over water in containers, and the containers are sealed to maintain 100 percent relative humidity.

The containers are stored at 38 °C to accelerate the effects of alkali-silica reaction. Periodically, the specimens are removed and length changes are determined. An average length change (for the three mortar bars) greater than 0.05 percent at three months and greater than 0.10 percent at six months test age is considered by ASTM C 33 to be excessive and indicative of potentially deleterious ASR. Specimens exhibiting expansions greater than 0.05 percent at three months but less than 0.10 percent at six months are not considered to be deleteriously expansive by ASTM C 33.

Due to the sand rhyolite has a low fineness modulus of 1.69, it used just as received, and besides it was adjusted the grading crushing part of gravel to meet grading as sand according to indicated ASTM C 227 or AMBT.

3 RESULTS AND DISCUSSION

Table 1 shows chemical and physical characteristics of cements used for evaluating character reactive of aggregates with cements high alkali content and SCM to determine their effectiveness with to inhibit alkali aggregate reaction. As it can observe in Table 1 the natural pozzolan used in the cement and fly ash have good pozzolanic activity.

Chemical composition of aggregates is shown in Table 2. The rhyolitic aggregates have acidic composition, SiO_2 content is more than 69%; andesitic aggregates present intermediate composition (SiO_2 content 63-64%) and basaltic aggregates have basic to intermediate composition, their content of SiO_2 is 56%. [1].

Petrographic examination and quick chemical method

Petrographic examination indicates the lithology and rock type. The main constituents are presented in Table 3. The igneous rocks were classified as rhyolite, andesite and basalt. The rocks of volcanic origin usually tend to be alkali-silica reactive, mainly of acidic and intermediate composition rocks. The petrographic diagnosis has some advantages, but French & Howarth. [8] mention that no rock can be regarded from its name as truly o low reactivity or as not exhibiting reaction. Rather, the presence or absence of particular features throughout the aggregate maybe use to infer potential for reaction or its absence. It can consider that petrography is an ideal starting point for alkali-aggregate reactivity assessment of aggregates and allow to identify deleterious constituents and lithology.

Quick chemical method determines potential reactivity of an aggregate with alkalis. Sand and gravel as rhyolite, andesite or basalt resulted potentially deleterious by this method (Table 3).

3.1 Results from expansion testing

Accelerated Mortar Bar Test (AMBT)

The AMBT is generally recognized as a good screening test for evaluating potential alkali-reactivity of concrete aggregates. However, it should not be used to reject aggregates [2].

As shown on Figure 1, accelerated mortar bar expansion for combinations rhyolitic aggregate (sand with adjusted grinding, sand and gravel) with OPC-A, CPC-B and OPC-H was very high, more than 0.50% at 16 days. Nevertheless, reduced expansion can be observed when it is used pozzolanic cement (PPC-G) or ordinary Portland cement with fly ash (OPC-A+FA); i. e. expansion was less than 0.10% at 16 days.

Expansion development of andesitic type rock in combinations with OPC-A, CPC-B and OPC-H, PPC-G and OPC-A+ FA, as can see in Figure 2. Significant expansions were obtained for the combinations with OPC-A, CPC-B and OPC-H; however with PPC-G and OPC-A+ FA expansions were reducing.

Expansion results of basaltic rock are shown in Figure 3. As expected expansion with OPC-A, CPC-B and OPC-H is increased with time for these combinations. Also note that at 16 days the PPC-G and OPC-A+FA were capable to reduce expansion and to maintain until 30 days.

By this method it is not possible to observe the effect of low alkalis cement (OPC-H). It can be because this method has severe conditions (NaOH storage condition and high temperature). But, for all cases where were used some SCM´s there was a significant reduction expansion of SCM (30% of natural pozzolan or 25% FA) in every combination.

ASTM C 227 Mortar Bar Test

Current practice in Mexico has often been to evaluate the potential alkali reactivity by ASTM C 227. Usually, in big job of infrastructure requires information about reactivity of aggregates and preventing possible problems due to AAR. Figures 4, 5 and 6 show the performance of three rock types in combination with different cements.

This method indicates that is not suitable for slowly reactive aggregates: Aggregates suspected of being slowly reactive should be evaluated using Test Method C 1260 or Test Method C 1293 (10).For another part, ACI 201 indicates that more elevated temperatures, longer test periods of probably 1 to 3 years, or both, will be required to develop evidence of reactivity. This prolongation of testing time makes it particularly desirable to use petrographic criteria that will allow identification of these rocks (11).

Figure 4 represents expansion development of rhyolitic type rock (sand with adjusted grinding, sand and gravel). As it can observe the adjusted sand and gravel have the same performance in expansion, because it was adjusted the grinding with crushed coarse aggregate for meet requirements indicated in this method. But, the rhyolite sand as just received not presented deleterious expansion. Also note that increased expansion of the gravel after 6 months is noteworthy with high alkalis cements (OPC-A and CPC-B). When it is used low alkalis cement expansion is reduced until 0.035% at 6 months and 0.10% at 12 months. The lowest expansion it is produced with PPC-G, at 6 moths presented 0.033% and 0.037% at 12 months. Unlike accelerated method (ASTM C 1567) the effect of cementitious materials is obtained at 16 days (Fig.1) in comparison at ASTM C 227 at 6 months.

Figures 5 and 6 illustrate the expansion of mortar bar made with of andesitic and basaltic aggregates. These rock types had expansions less than 0.05% at 6 and 12 months. In this case the use of high alkalis cements not produced excessive expansion with these materials and not represented potentially reactivity because the expansions were very low.

Figure 7 presents two comparative graphics between ASTM C 1260/1567 at 16 days and ASTM C 227 at 6 months with the different combinations. It can be observed that the combinations of aggregates /OPC-A, CPC-B and OPC-H by AMBT indicate high expansion. Although the AMBT alone is no reliable for evaluating the potential of alkali-reactivity of all the variety of aggregate sources [9]. It is feasible to use AMBT (ASTM C 1567) for evaluating SCM´s. Most of the results indicate reduction expansion when is used natural pozzolan in cement or FA.

Insofar as ASTM C 227, only rhyolitic gravel presented high expansions after 4 months with high alkalis cements. At 6 and 12 months was 0.15% and 0.25% with OPC-A. However, the low alkalis cement and PPC-G cement reduce the expansion at 6 months from 0.10% and 0.033%, respectively. Andesitic and basaltic rocks not presented some indicative of reactivity by this method.

Further, some investigators believe six months is not long enough to adequately evaluate some aggregate types (Stark, 1980). When slowly expanding aggregate is being evaluated, the trend of the expansion versus time graph at the end of the test should be considered when making the evaluation. If it is obvious that in time the mortar bars will exceed the 0.10 percent expansion limit, care is needed in the use of such potentially reactive aggregates.

4 CONCLUSIONS

A total of 35 combinations were tested with aggregates from extrusive igneous rocks come from different sources by AMBT and ASTM C 227 mortar bar. The following conclusions can be drawn from data reported in this paper:

1) AMBT (ASTM C 1260) alone is not reliable for evaluating the potential of alkali-reactivity for extrusive igneous rocks because in all cases the aggregates resulted with potential alkali reactivity with both high alkali cement and low alkali cement.
2) AMBT (ASTM C 1567) is an indicative good tool to evaluate the effectiveness of SCM´s obtaining good results at 16 days; this permit to detect the suitable dosage to reduce expansion due to ASR by this method more rapid.
3) The rhyolite gravel and sand with adjusted grinding resulted most reactive by ASTM C 227. The others, andesite and basalt produced expansion less than 0.05% at 6 and 12 months.
4) Despite igneous rocks of extrusive type can be represent a risk of potential reactivity AAR due to from volcanic rocks with acid character, the results a long time allow to determine if it can present deleterious expansion. Besides, it is recommended verify the performance in structures where it has used this aggregate type. It is important longer test periods to develop evidence of reactivity.

5 REFERENCES

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Tabla 1. Chemical and physical analysis of cements and supplementary cementing materials

Method	Chemical Analysis		Unit	OPC-A	CPC-B	OPC-H	PPC-G	OPC-A+FA	Puzz-G	FA
FRX	SiO_2	Silicon dioxide	%	19.23	20.23	21.38	73.22	31.31	73.36	56.96
FRX	Al_2O_3	Aluminium oxide	%	5.04	5.28	4.27	6.37	10.80	13.52	21.82
FRX	Fe_2O_3	Ferric oxide	%	2.79	3.00	3.82	3.58	4.31	2.81	3.79
FRX	CaO	Calcium oxide	%	60.92	61.69	62.18	41.03	42.55	0.04	0.74
FRX	MgO	Magnesium oxide	%	1.27	1.19	1.06	0.18	1.00	0.14	1.07
FRX	SO_3	Sulfur trioxide	%	3.82	3.02	2.36	2.35	2.57	2.52	0.79
FRX	Na_2O	Sodium oxide	%	0.40	0.30	0.20	0.50	0.10	4.26	0.85
FRX	K_2O	Potassium oxide	%	0.60	0.50	0.50	0.70	0.40	6.80	1.69
FRX	TiO_2	Titanium oxide	%	0.30	0.29	--	0.17	--	--	--
FRX	P_2O_5	Phosphorus pentoxide	%	0.07	0.04	0.17	--	--	--	--
FRX	Mn_2O_3	Manganic oxide	%	--	--	--	--	--	--	--
ASTM C 114		Free calcium oxide	%	0.57	0.73	0.68	0.94	0.57	--	--
ASTM C 114		Total Alkali content, (Na_2O equivalent)	%	0.79	0.63	0.53	0.96	0.36	8.73	1.96
ASTM C 114		Insoluble residue	%	0.36	4.44	0.30	22.68	23.15	74.78	76.80
ASTM C 114		Loss on ignition (950 °C)	%	3.70	3.90	2.30	5.00	4.10	5.50	4.70
		Physical Analysis								
ASTM C 188		Density	Mg/ML	3.09	3.05	3.14	2.83	2.57	2.27	1.98
ASTM C 430		Fineness, passing No. 325 (45 μm) sieve	%	92.9	97.7	99.1	94.1	88.7	93.9	51.2
ASTM C 109		Compressive Strength								
		3 days	MPa	27.00	24.16	25.63	18.59	18.12		
		7 days	MPa	32.36	32.69	33.93	24.43	24.79		
		28 days	MPa	40.08	40.01	40.73	39.55	41.65		
ASTM C 311		Pozzolanic activity index with portland cement at 28 days	control percentage	--	--	--	--	--	90.9	100.8

Table 2. Chemical analysis of aggregates from igneous rocks

Method		Chemical Analysis	Unit	SR	GR	SA	GA	SB	GB
FRX	SiO_2	Silicon dioxide	%	69.10	71.55	62.95	64.22	56.50	56.71
FRX	Al_2O_3	Aluminium oxide	%	12.60	11.64	17.92	16.66	17.72	17.57
FRX	Fe_2O_3	Ferric oxide	%	3.45	3.06	4.67	5.01	6.15	6.46
FRX	CaO	Calcium oxide	%	3.49	2.02	5.68	4.99	8.47	7.78
FRX	MgO	Magnesium oxide	%	0.46	0.27	1.22	1.09	2.36	2.80
FRX	SO_3	Sulfur trioxide	%	--	--	--	--	--	--
FRX	Na_2O	Sodium oxide	%	1.94	1.81	3.21	3.13	2.86	2.77
FRX	K_2O	Potassium oxide	%	5.58	7.40	2.88	3.07	1.25	1.14
FRX	TiO_2	Titanium oxide	%	0.63	0.29	0.89	0.83	1.35	1.30
FRX	P_2O_5	Phosphorus pentoxide	%	0.06	0.07		0.20	0.37	0.32
FRX	Mn_2O_3	Manganic oxide	%	--	--	--	--	0.16	--
FRX	SrO		%	0.02	--	0.05	0.04	0.12	0.11
FRX	ZrO	Zirconium oxide	%	0.42	0.03	0.03	0.03	0.05	0.05
FRX		Total Alkali content, (Na_2O equivalent)	%	5.61	6.68	5.10	5.15	3.68	3.52
ASTM C 114		Loss on ignition (950 °C)	%	2.3	1.8	0.4	0.7	2.6	3.0

Tabla 3. Mineralogical composition (ASTM C 295) and results of quick chemical method (ASTM C 289) of igneous rocks

ID	Aggregate	Aggregate Type	Source	Deposit Location	Constituents	Deleterious Material, %	Dissolved silica, mmoles/L	Reduction in alkalinity, mmoles/L	Final Result
					ASTM C 295		ASTM C 289		
SR	Sand	Rhyolite	Río Nazas (Albia)	Durango	Quartz, feldspar, rhyolite, tuff, carbonate, mafic minerals	35	538.46	163.33	Potentially deleterious
SA	Sand	Andesite	San Vicente	Edo. de México	Andesite	100	656.12	133.33	Potentially deleterious
SB	Sand	Basalt	San Isidro	Baja California Norte	Basalt	--	617.27	253.33	Potentially deleterious
GR	Gravel	Rhyolite	Río Nazas (Albia)	Durango	Basalt, rhyolite, granite, limestone, tuffs, amorphous quartz	45	657.79	233.33	Potentially deleterious
GA	Gravel	Andesite	Huixquilucan	Edo. de México	Andesite	100	499.99	346.67	Potentially deleterious
GB	Gravel	Basalt	San Isidro	Baja California Norte	Basalt	--	441.44	386.67	Potentially deleterious

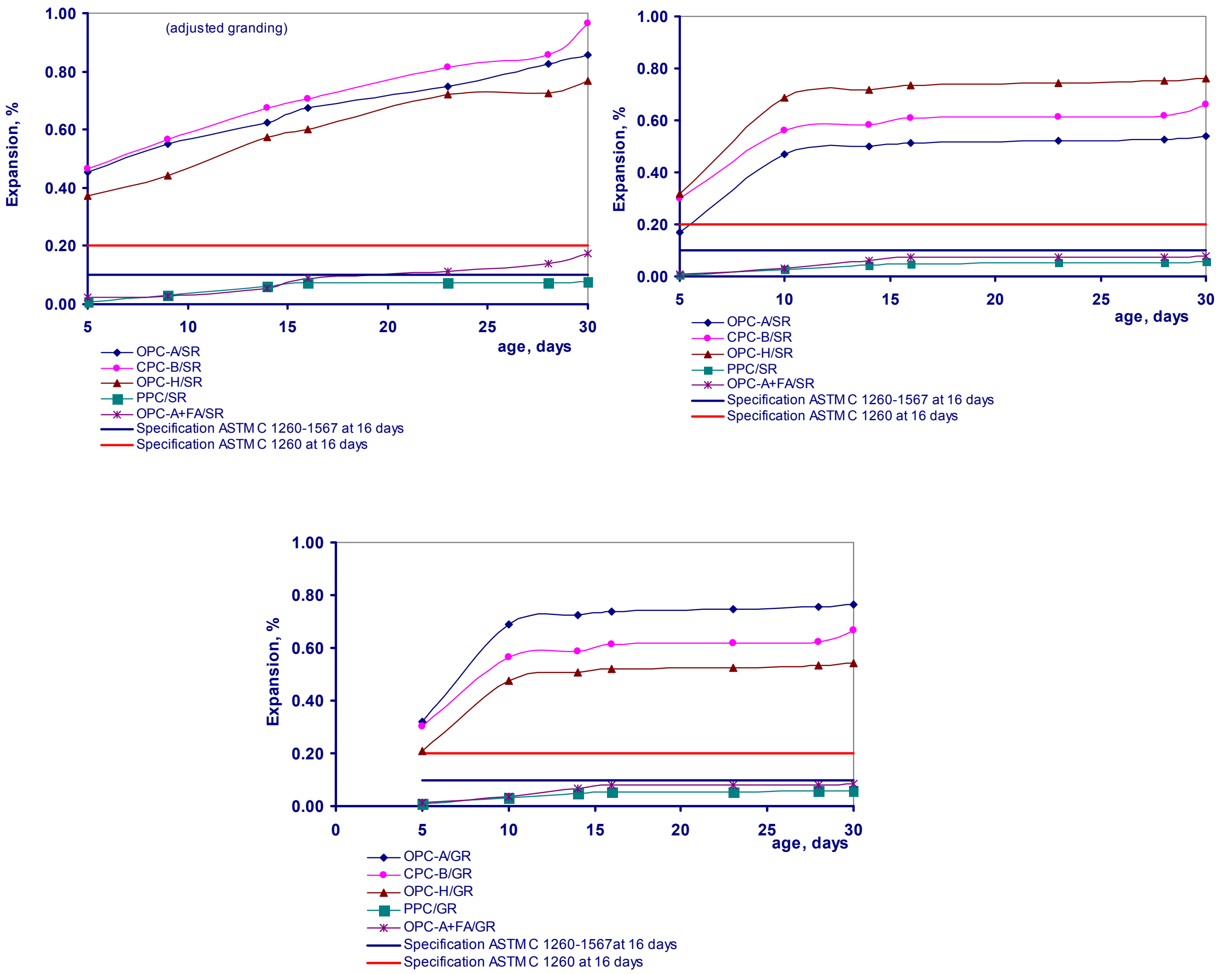


Figure 1. ASTM C 1260/1567 mortar bar expansion development of rhyolitic rock as sand (SR) and gravel (GR) in combination with different cement types and SCM´s

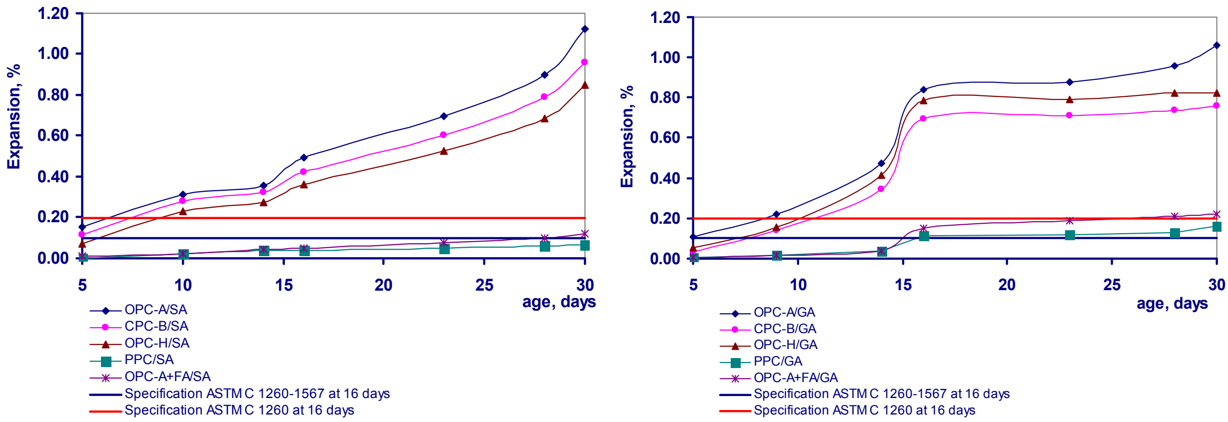


Figure 2. ASTM C 1260/1567 mortar bar expansion development of andesitic rock as sand (SA) and gravel (GA) in combination with different cement types and SCM´s

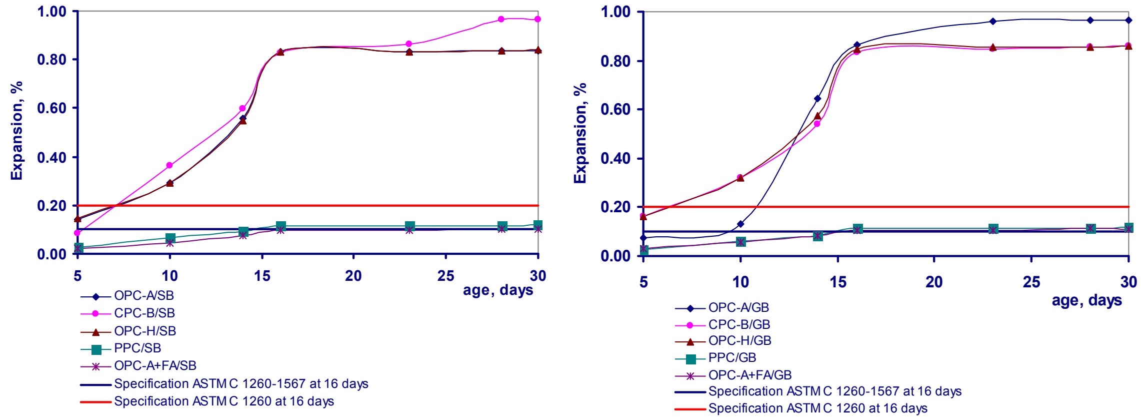


Figure 3. ASTM C 1260/1567 mortar bar expansion development of basaltic rock as sand (SB) and gravel (GB) in combination with different cement types and SCM

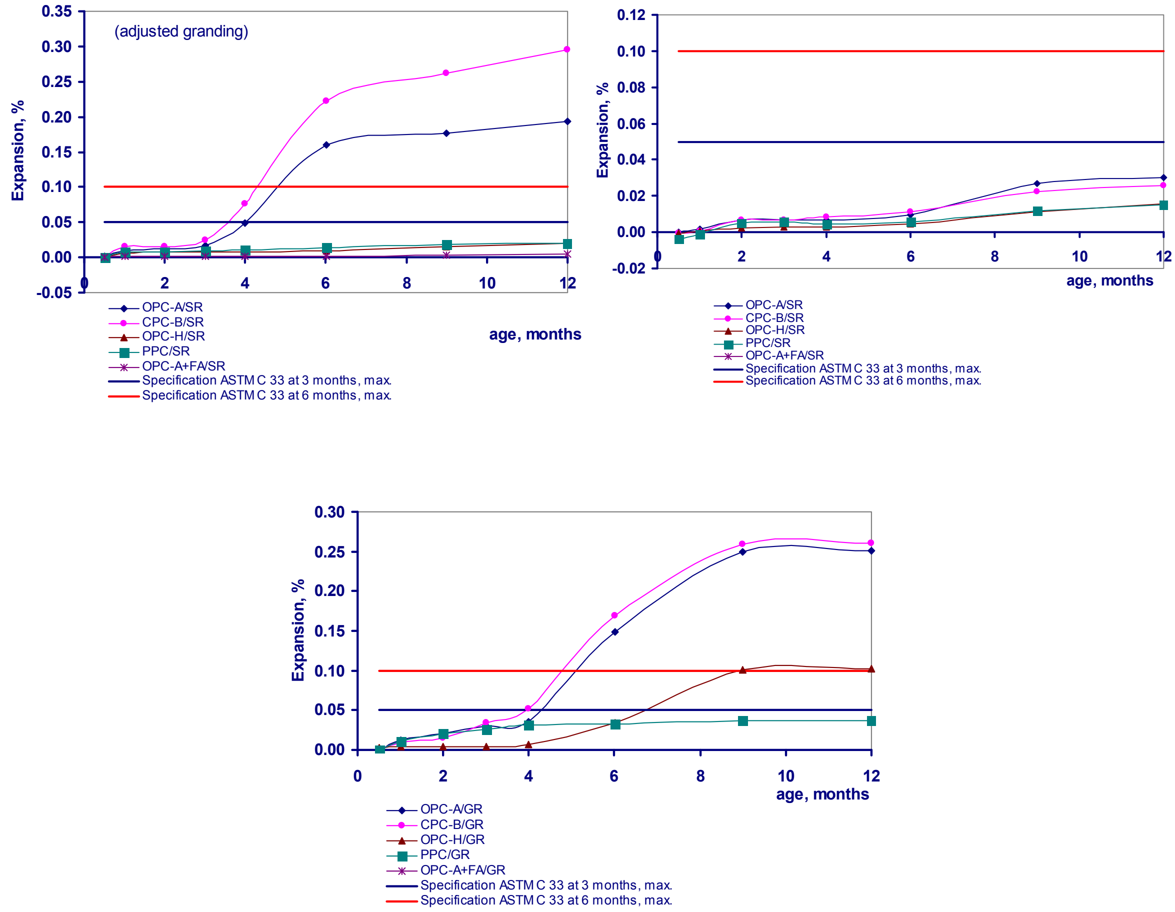


Figure 4. ASTM C 227 mortar bar expansion development of rhyolitic rock as sand (SR) and gravel (GR) in combination with different cement types and SCM

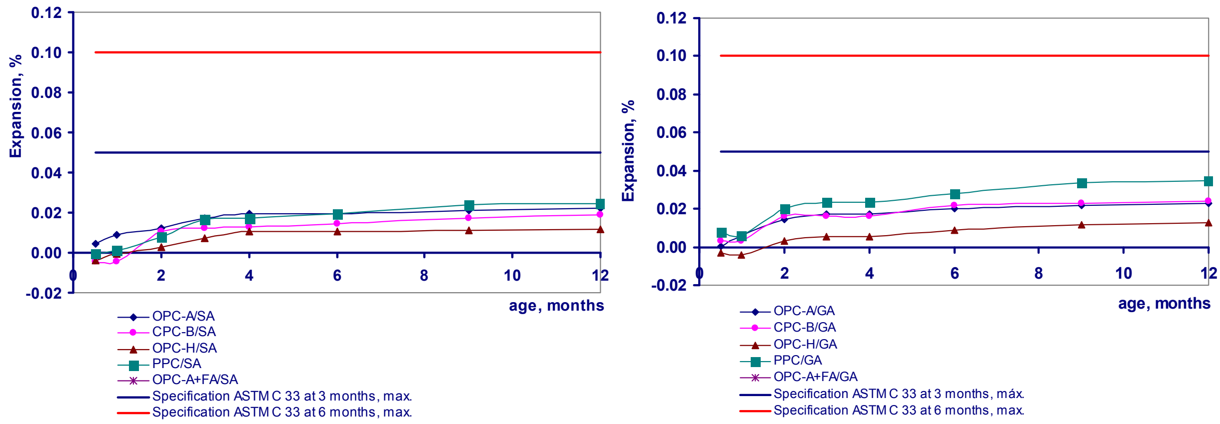


Figure 5. ASTM C 227 mortar bar expansion development of andesitic rock as sand (SA) and gravel (GA) in combination with different cement types and SCM

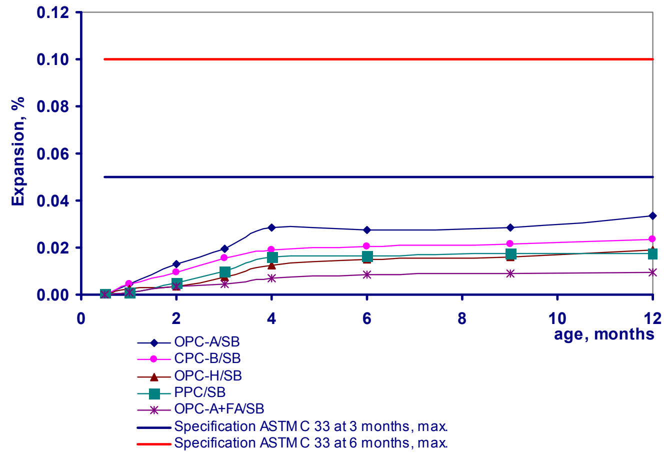


Figure 6. ASTM C 227 mortar bar expansion development of basaltic rock as sand (SB) in combination with different cement types and SCM

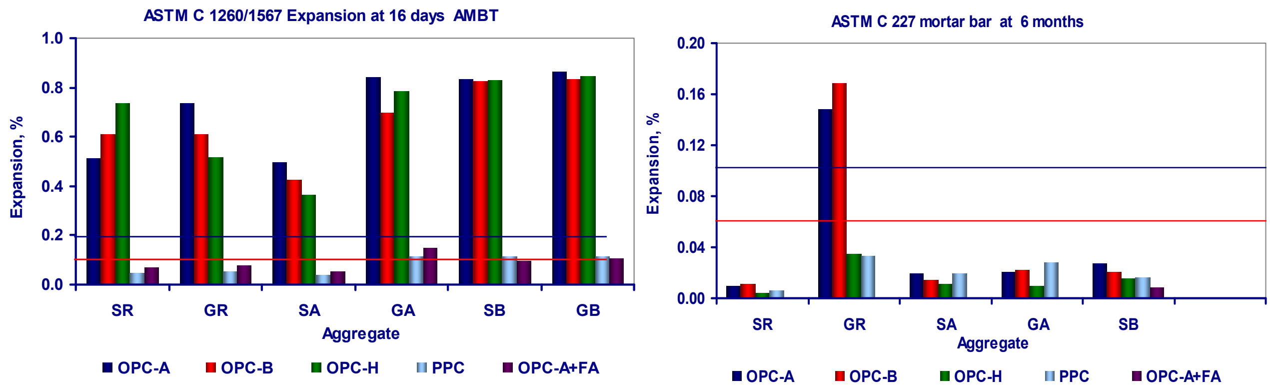
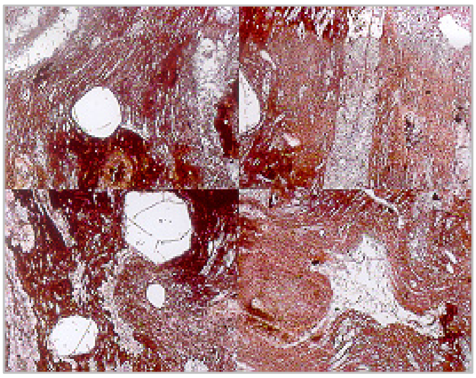


Figure 7. Comparison between expansion of AMBT and ASTM C 227 for aggregates of igneous origin and different combinations of cements and SCM´s



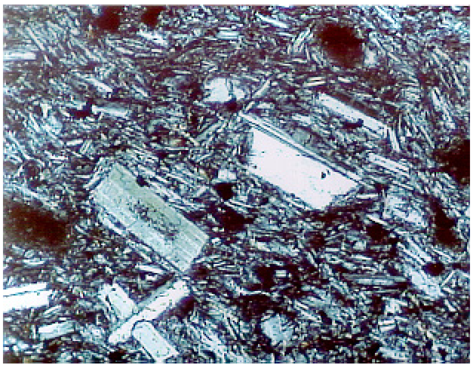


Figure 8. Micrographs of igneous rock types from Mexico. Left: rhyolite with characteristic hexagonal quartz, and right: andesite). (40×).