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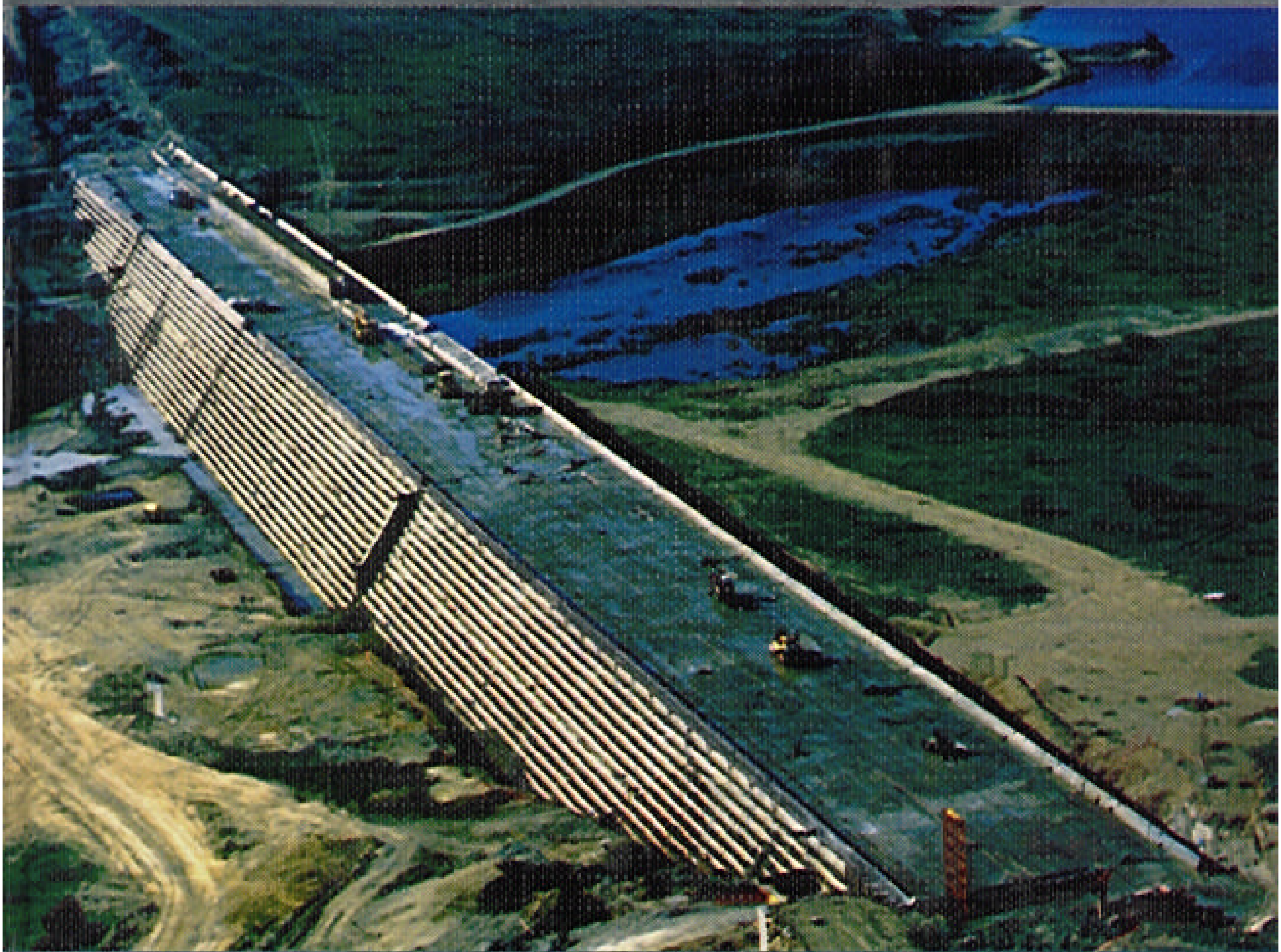

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THE USE OF BASALTIC CRUSHED POWDER (Filler) IN THE RCC

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ABSTRACT

The purpose of this report is to present test data obtained in the RCC design mixes with the inclusion of Crushed Powder filler quantities. Laboratory data on the behavior of this material makes its adoption in the RCC mixes possible.

The use of mixes with Crushed Powder filler in the test fill makes it possible to accurately evaluate the advantages of this material.

Based on these technical indications, equipment suitable for obtaining crushed sand with a large volume of filler was sought.

1-INTRODUCTION

The use of continuous grading for the RCC based on a cubic-type curve takes into consideration a substantial quantity of fines, lower than 0.075 mm, for the adequate cohesiveness of the mixing.

These fines may be of various kind: Fly Ash, Blast Furnace Slab, Natural or Calcinated Pozzolans, Silt and also the "Stone Powder", byproduct of rock crushing obtained during the aggregate production and beneficiation processes.

The use of this "Stone Powder" (fines lower than 0.075 mm) in the composition of RCC has shown considerable advantages not only improving the cohesion of the mixing while fresh, but also reducing the expansions resulting from the reactions with the cement alkali, as below described.

2- DEVELOPMENT

Natural sand resources of Brazil's Southeast & South regions (next to the Paraná River basin) are being scarce. This situation commonly forces the production of crushed sand by means of crushing rocks, which normally are of the basaltic type.

This is how dams like Itaipu (13.000.000m³ of concrete), Salto Santiago (480.000m³), Salto Osório (472.000 m³), Foz do Areia (600.000 m³), and São Simão (1.600.000 m³) among others, have used a great quantity of crushed sand in the production of concrete types.

During the construction of Itaipu Dam, it was observed that within each one of the crushing lines (1.800 t/h each) there were rejects of about 10-15t/h, next to the crushed sand washing (produced by VFC & Hydrofine-type Recrushers). At first, the visual observation of these rejects didn't indicate the presence of cohesive materials that could be considered prejudicial because the rejects resulted from the action in the classifying tanks and dehydrator screws. In the circuit previous to that of the crushed sand production, there was no clay, or other material. On the other hand, Technical Specifications were being complied with as regards to the maximum limit of materials lower than 0.075 mm for the conventional type of concrete.

This situation gave rise to the evaluation of that reject with views of incorporating it to the CVC and RCC conventional types of concrete, as described by the reference [1]. Contemporaneously, during the construction of the Urugua-i Dam (Argentina), in RCC, the use of a grading curve near to that of the cubic type, for the aggregates' composition (basaltic), it was necessary to incorporate a certain amount of fines. As a part of the mixing studies for the Urugua-i Job, carried out at the Itaipu Laboratory, it was suggested the incorporation of the basalt "Stone Powder" to the mixing, and this was adopted [2].

At that opportunity, the physical improvement of the properties were noticed but the physical-chemical action of the "Stone Powder" fines were not identified.

During the studies made for the Capanda Dam construction, Norberto Odebrecht Company and its consultant, together with Itaipu Laboratory and Eng. Albert Ossipov (from the Moscow Scientific Research Center Hydroproject Institute) performed extended studies [3 & 4] aiming at the characterization of the "Stone Powder" Activity as regards the Calcium Hydroxide that is released during the cement hydration. This action is similar to that of an Activity with Cement and with Lime, normally observed in the characterization of Pozzolanic Materials.

The introduction of the method for Fixing Lime within Sands in some Brazilian Laboratories [3, 5 to 7] came after such studies and also the use of "Stone Powder" in the RCC for the Capanda construction [3 and 4].

The construction of the Jordan River Derivation Dam, in RCC, using basaltic aggregates and based on a cubic-type grading curve (Dmax=50mm), reducing the cement content to a minimum, and also foreseeing the execution of the Salto de Caxias Dam gave ground for the development by COPEL of an wide study about the "Stone Powder" utilization, as below depicted.

3-EQUIPMENT

The production of crushed sand may be done by means of crushing rocks using special crushers for fines, "Impactor", "Hydrofine" or "VFC-Very Fine Crusher" type.

Figures 1 and 2 show VFC and Barmac Crushers which were chosen by the Contractor for the construction of the Jordan River Derivation Dam.

Figure 1 - 48VFC Recrusher

Figure 2 - Barmac Recrusher

Figure 3 compares crushed sand from basalt produced by the two types of Recrushers.

4-APPRAISAL AND CHARACTERISTICS

4.1-Materials characteristics

- Cement The characteristics of the types of cement studied are shown in Figure 4.

Figure 3 - Aspect of the crushed sand produced by the 48VFC (left) and Barmac (right) Crushers

- Fly Ash The characteristics of the fly-ash studied are shown in Figure 4.
- "Stone Powder" The characteristics of the "Stone Powder" are shown in Figure 4.

4.2-Grading

The advantages of the use of fines (material lower than 0.075 mm) in the RCC mixing (and also in the CVC) as regards the grading aspect, using the cubic-type curve was already mentioned [1 to 7], and it has been recommended, *e.g.*:

..."The fine material in a crushed stone sand differs from that in natural sand in that it consists largely of stone dust and not clay. A higher content of it can therefore be tolerated and may be advantageous by improving the plasticity of concrete mixes containing angular crushed rock aggregate"...[8]

The filler (lower than 0.075 mm) contained in the sands obtained by the Barmac and 48VFC Crushers had their grading determined by the Laser Diffraction Granulometer. Figure 5 shows grading and normal distribution curves obtained.

REQUIREMENT	UNITY	CP IS-32 ITAMBÉ	CP-V-32 ITAMBÉ	CP IS-32 VOTORAN	CP-V-32 VOTORAN	CP-V-32 ELDORADO	FLY ASH GENERAL	CRUSHED SAND AND FILLER FILLER 1	FILLER 2	FILLER 3	CEMENT GENERAL	DIATOMITO GENERAL	POZZOLAN CALC.CLAY
% RETAINED ON # 200	%	2.36	0.87	2.5	0.1	0.7					2,3 a 8,8		
% RETAINED ON # 325	%	10.6	4.8	16.9	1.3	3.1	27 a 41	16.6			10,4 a 29,6	11.6	20 a 60
SPECIFIC SURFACE BLAINE	cm2/g	3670	4600	3670	4800	5220	2900 a 3200	2520	3650	4320	2900 a 4000	13700	3000 a 8000
MEAN DIAMETER	microns						9 a 15				9 a 20	2 a 5	3 a 10
APPARENT SPECIFIC GRAVITY	g/cm3										1,3 a 1,5		0,75 a 0,81
ABSOLUT SPECIFIC GRAVITY	g/cm3	3.1	3.26	3.1	3.15	3.22	2 a 2,3	2.96	2.79	2.76	3,0 a 3,15	2.3	2,63 a 2,65
TIME OF SETTING - INITIAL	h : min	3:36	2:22	3:16	2:40	2:30					1:30		
- FINAL	h : min	6:10	5:00	5:30	5:15	4:47							
LE CHATELIER - EXPANSION	mm	0.03	0.02	0.01	0.02	0.01							
AUTOCLAVE - EXPANSION	%												
IAP-WATER	%						110 a 115					105	103 a 111
IAP-LIME	Kgf/cm2						39 a 78					64	24 a 82
IAP-CEMENT	%						74 a 78					89	73 a 95
MORTAR EXPANSION							0.02						0,002 a 0,009
REDUCTION OF EXPANSION	%						57 a 75					101	71 a 84
COMPRESSIVE 3 DAYS	Kgf/cm2	250	266	232	361	240					143 a 233		
STRENGTH 7 DAYS	Kgf/cm2	331	315	274	403	361					215 a 315		
(AGE) 28 DAYS	Kgf/cm2	365	380	378							315 a 476		
HEAT OF 7 DAYS	cal / g										57 a 84		
HYDRATION (AGE) 28 DAYS	cal / g										67 a 95		
LOSS ON IGNITION	%	3.7	4	2.66	2.5	3.21	5	2.28	2.13	2.68	1,0 a 3,67		0,6 a 1,6
INSOLUBLE RESIDUE	%	0.56	0.73	0.72	0.66	0.54		91.26	89.61	89.41	0,05 a 17,89		
SiO2	%	19.65	19.28	18.89	18.64	19.49	52	49.31	49.54	50.17	15 a 23		74 a 75
Fe2O3	%	3.23	3.62	3.03	3.23	3.33	7.1	17.71	16.93	16.05	2,5 a 3,8		4,8 A 5,8
Al2O3	%	4.56	4.69	4.37	4.69	4.75	30	11.56	13.12	10.93	5 A 10		15,1 a 16,5
CaO	%	62.2	60.82	61.85	61.17	62.37		9.45	10.31	9.45	50 a 65		0,6 a 1,0
MgO	%	2.59	3.09	5.56	4.94	1.98	0.9	5.8	4.94	5.19	1,0 a 6,0		2,01 a 2,41
SO3	%	2.89	3.12	2.75	3.27	3.23	0.4	0.04	0.1	0.03	1,15 a 2,82		/ - - /
Na2O	%	0.03	0.05	0.05	0.05	0.03		0.93	1.1	0.9	0,04 a 0,91		/ - - /
K20	%	0.76	0.76	0.71	0.71	0.82		1.03	1.11	1.13	0,03 a 0,86		/ - - /
AVAILABLE ALKALIES	%	0.053	0.55	0.52	0.52	0.57		1.61	1.83	1.64			
FREE LIME	%	1.45	1.53	2	1.58	1.03		0.07	0.17	0.11			
C3S	%	60.46	55.42	66.63	61.84	59.83					35 a 59		
C2S	%	10.81	13.55	3.98	6.87	10.82					14 a 35		
C3A	%	6.63	6.31	6.46	6.97	6.96					6 a 12		
C4AF	%	9.82	11	9.21	9.82	10.12					7 a 12		
SiO2+ Al2O3+ Fe203	%						90	78.58	79.59	77.15		95	94 a 97

Figure 4 - Data of the materials used for study

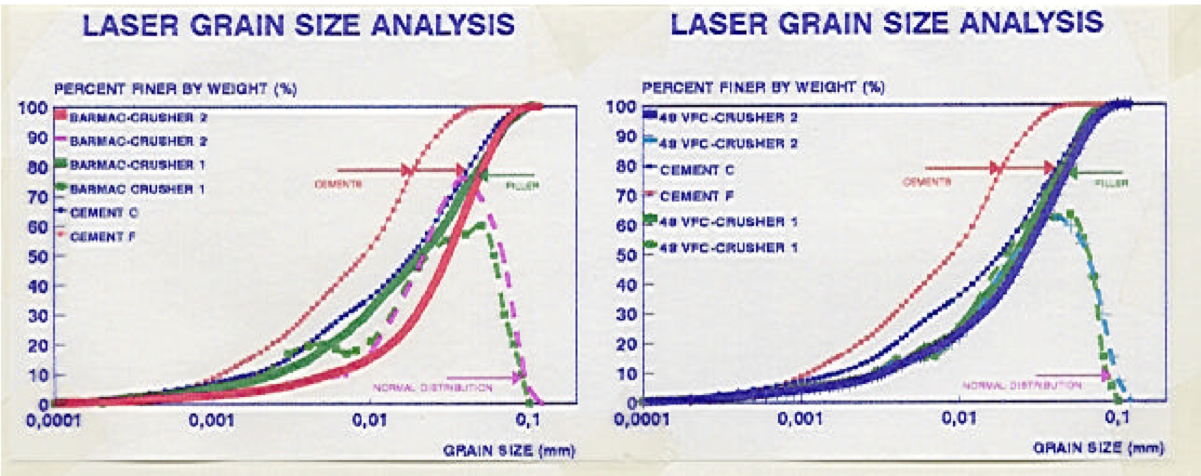

Figure 5- Filler Grading (Material lower than 0.075 mm)

4.3-Fineness

The Filler samples tested were:

Crusher	Blaine Specific Surface (cm2/g)
Barmac	1909
48 VFC	2351

Figure 6 - Blaine Fineness of the Filler samples (material lower than 0.075 mm)

4.4-Mean Diameter

The averaged diameter of the "Stone Powder" particles when compared to other materials is shown in Figure 4.

4.5-Form

The evaluation of the sand filler form was carried out petrographically, through optical microscopy, with emphasis to the morphology. Figures 7 and 8 show fragments of the fines produced by the two types of crushers: 48VFC and Barmac. From the photo-micrographics, magnified 200 times, it is observed that the Barmac Crushers produce fragments both homogeneous and with an equidimensional form while the 48 VFC Crusher produces more elongated fragments with a serialized grading.

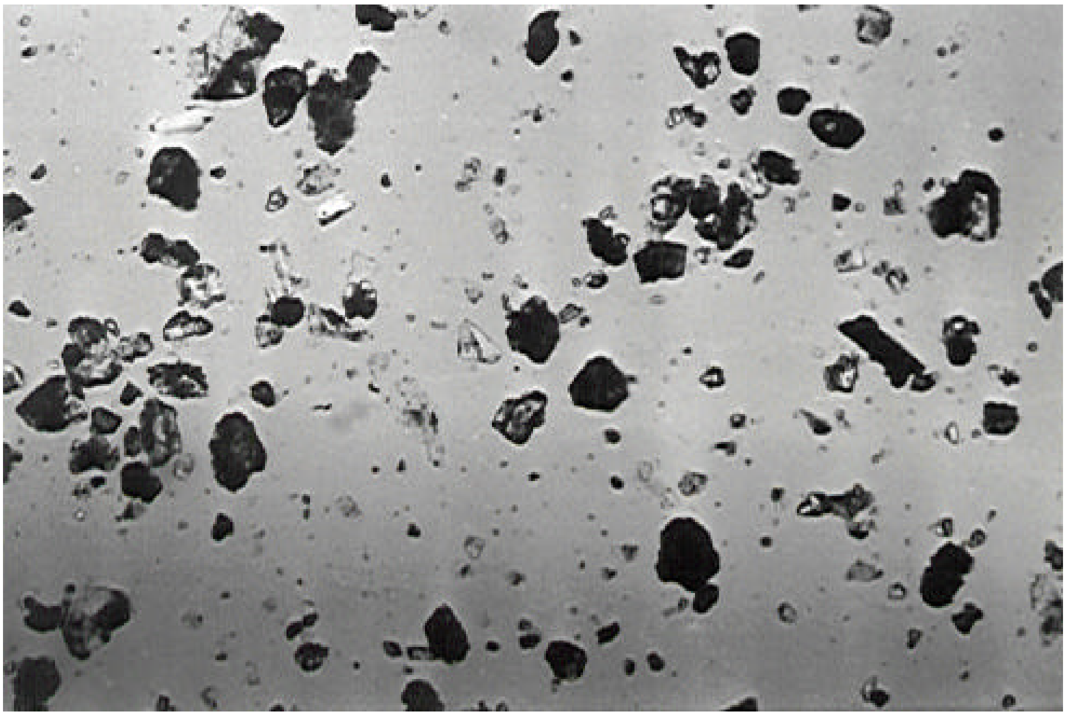

Figure 7- Photo-micrographics of the Filler produced by the Barmac - magnification 200x.

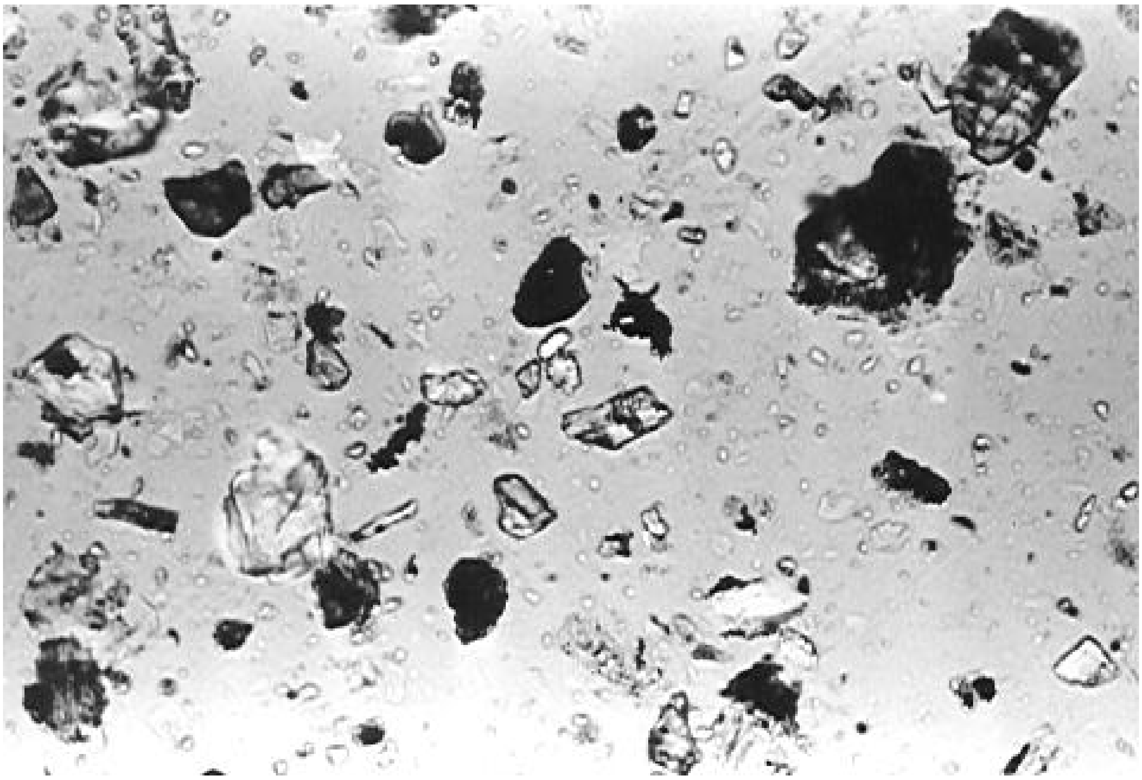

Figure 8- Photo-micrographics of the Filler produced by the 48VFC - magnification 200x.

4.6-Permeability

The reduction of the RCC permeability dosed with the addition of "Stone Powder" obtained from crushing was already mentioned in references [1, 9 to 11].

4.7-Compression Strength

The compression strength of the RCC and CVC concretes is improved with the inclusion of the "Stone Powder" [1, 5, 7]. The improvement in strength results from the Pozzolanic action demonstrated by the "Stone Powder" to fix the Calcium Hydroxide released during the cement hydration and it must be cited that:

"... The reaction of active forms of silica with lime improves strength,..." [8]

4.7.1-$Ca(OH)_2$ Fixation

It is known that:

"... Diffusion of ions or molecules through a gel containing a solution may take place in two ways: (1) through the liquid phase in the ordinary way, and (2) by surface diffusion if the soluble material is subject to adsorption by the solid phase. Surface diffusion is what the term implies: a migration of adsorbed ions from one part of the internal surface to another part. The movement takes place in response to a gradient in surface concentration (a gradient in the degree of saturation of surface) just as ordinary diffusion depends on the gradient in solution concentration. Therefore, the relative amounts of adsorbed lime and adsorbed alkali that reach the reaction site should depend on the relative amounts adsorbed in the outer part of the gel layer..." [12].

The test for evaluation of the calcium hydroxide is carried out according to the ex-soviet TOCT-25094 method, adapted according to Dr. Albert D. Ossipov orientation. The test comprises the $Ca(OH)_2$ measurement, established to be 20 g of crushed material, lower than 0.075 mm, from a saturated $Ca(OH)_2$ solution, under a temperature of 40 °C for a period of 28 days. The quantity of $Ca(OH)_2$ fixed by the aggregate fines is obtained after titration. It is recommended to have a $Ca(OH)_2$ minimum fixation of 30 mg per 100 g of fine material. Figure 9 show data obtained.

4.7.2-Pozzolanic Activity Index with Cement

The Pozzolanic activity Index of the Filler, with Cement, is determined by the test performed, based on the ASTM-C-311 method, to verify the pozzolanic action of the material, as depicted in Figure 10.

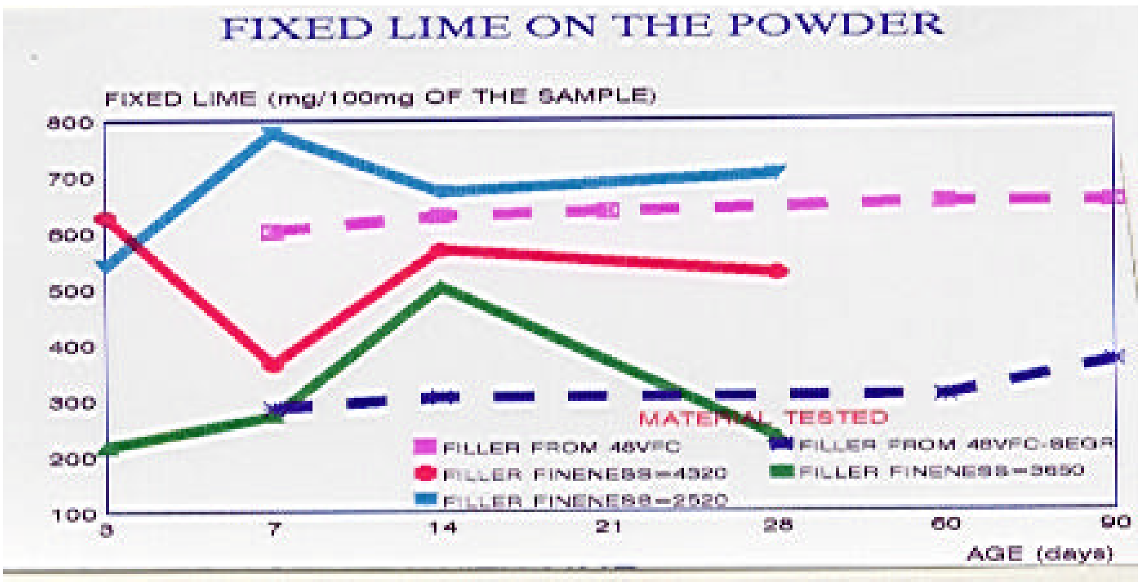

Figure 9- Calcium Hydroxide Fixation in Fines (Method TOCT-25094, adapted).

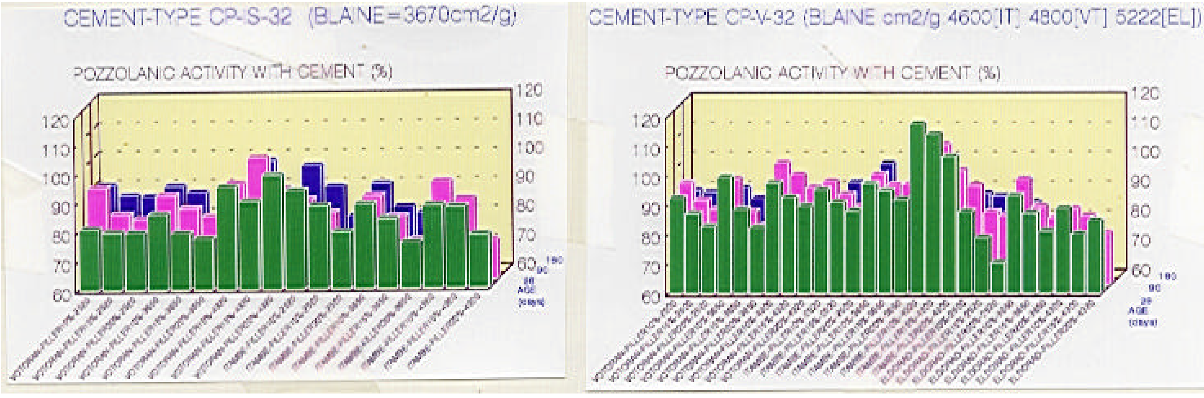

Figure 10 - Pozzolanic Activity of the Materials, with Cement (ASTM-C-311)

4.7.3-Pozzolanic Activity Index with Lime

The Pozzolanic activity Index of the Filler, with Lime, is also determined by the test performed, based on the ASTM-C-311 method, bearing the same concept as above. Figure 11 shows the values obtained.

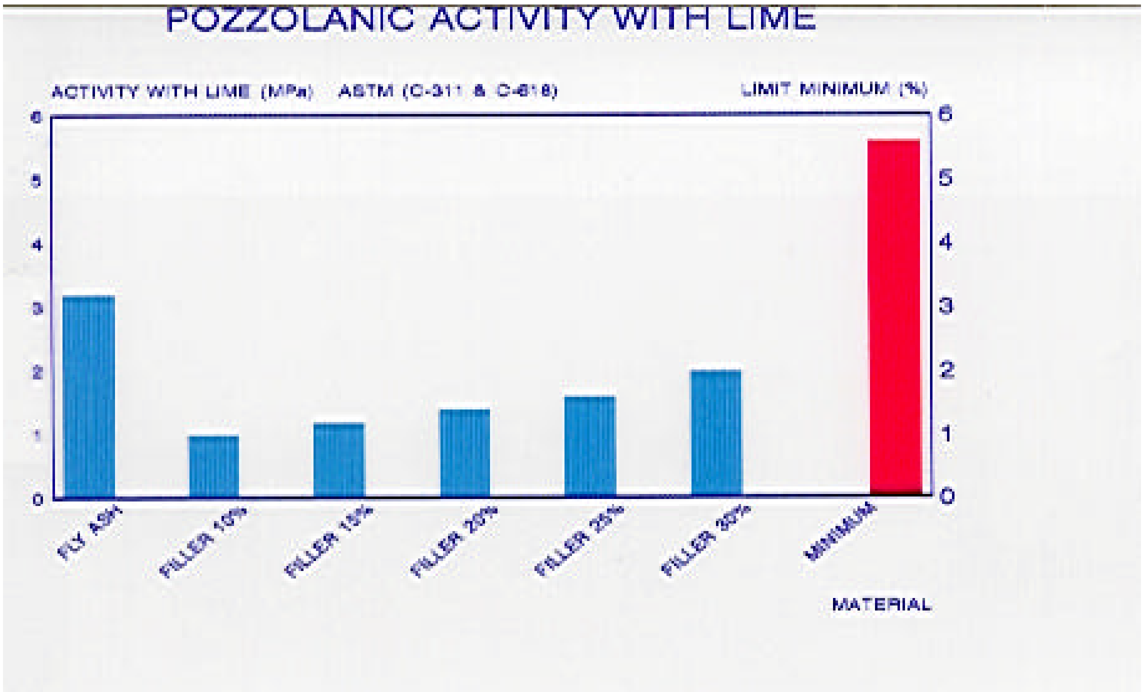

Figure 11- Values of the Activity with Lime (ASTM-C- 311)

4.7.4- Uncombined Calcium Hydroxide

The determination of the Uncombined Calcium Hydroxide is carried out according to the ASTM-C-500, item 7, *"Uncombined Calcium Hydroxide Test"*. This series of tests with values up to the age of 180 days, had the purpose to research, by means of an alternative method, the cement $Ca(OH)_2$ fixation, both available and uncombined. Figure 12 shows the values obtained.

4.7.5-Pozzolanicity Index

The pozzolanicity is determined after the ABNT-NBR-5733 method (Brazil), based on the Fratini Test. Figure 13 shows the values there obtained.

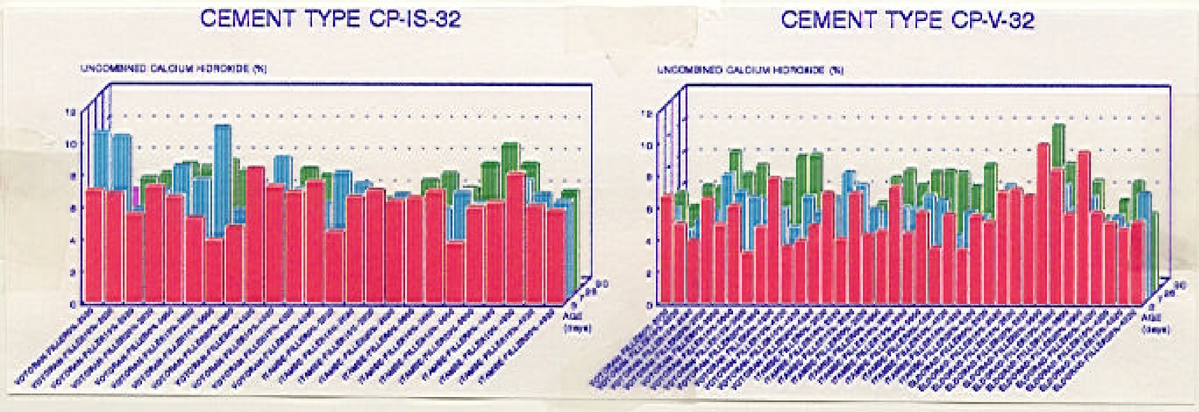

Figure 12- Uncombined Calcium Hydroxide Fixation Values (ASTM-C-500, item 7)

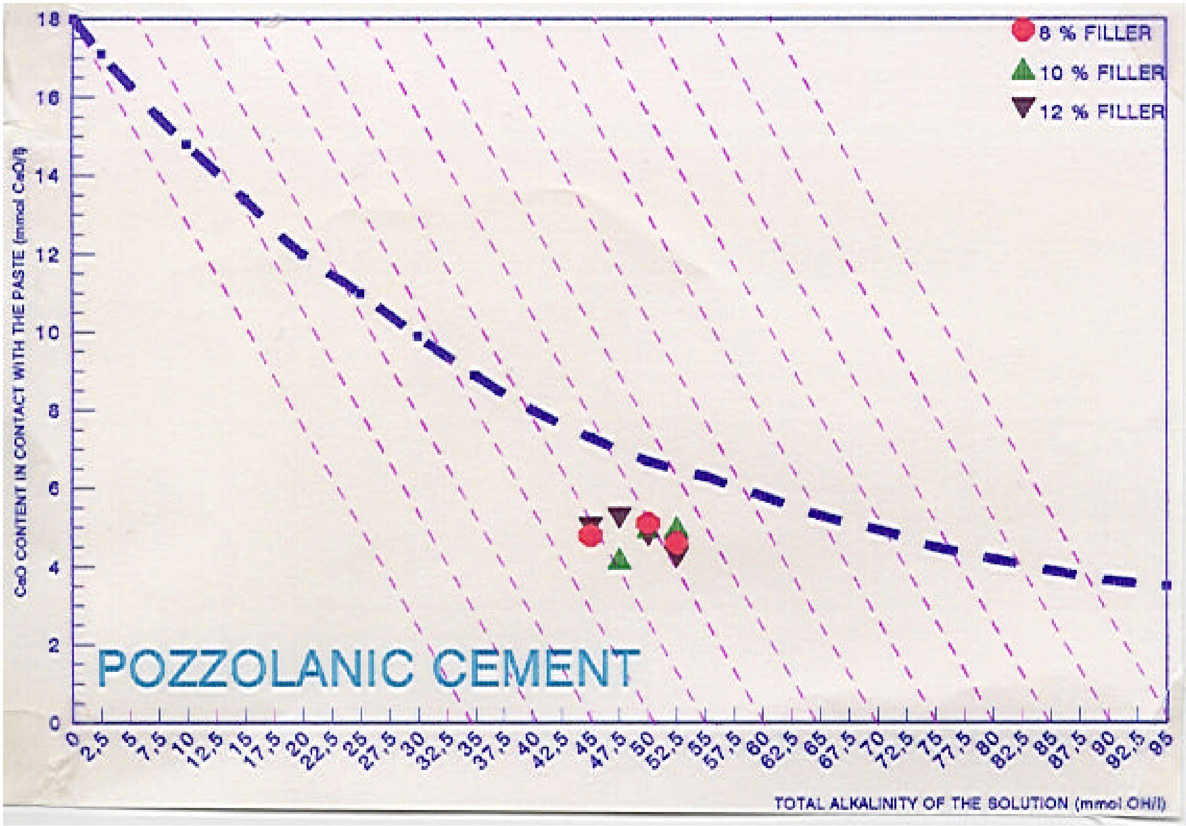

Figure 13- Values of the Pozzolanicity Index Tests (ABNT-NBR-5733, Brazil)

4.8-Reaction with the Cement Alkalies

4.8.1-Expansion Reduction

It must be remembered that:

"... There is in fact a complex relation between the quantity and fineness of the reactive material, the alkali content of cement, and the degree of expansion. Thus, ..., pozzolans which are reactive silicate materials are often a corrective for alkali-aggregate expansion... "[8]

"... When the reactive mineral is powdered, it can be used in a wide range of proportions without causing expansion. This was demonstrated by Vivian [13] when opal was ground to pass N° 300 sieve and used in several proportions, expansion was practically zero for all proportions, the particle size of the reactive mineral is clearly an important factor ..."

"...When an aggregate contains reactive mineral and is used with an amount of alkali greater than it can tolerate, expansion can be prevented by adding an appropriate amount of pulverized reactive mineral, as has been shown by Hanna [14], Stanton [15] and others... "[12]

The reduction of the expansion using the aggregate fines is determined by the joint application of the ASTM-C-441 and NBRI (below mentioned) methods. Is has also the role of a pozzolanic material, as shown in Figure 14.

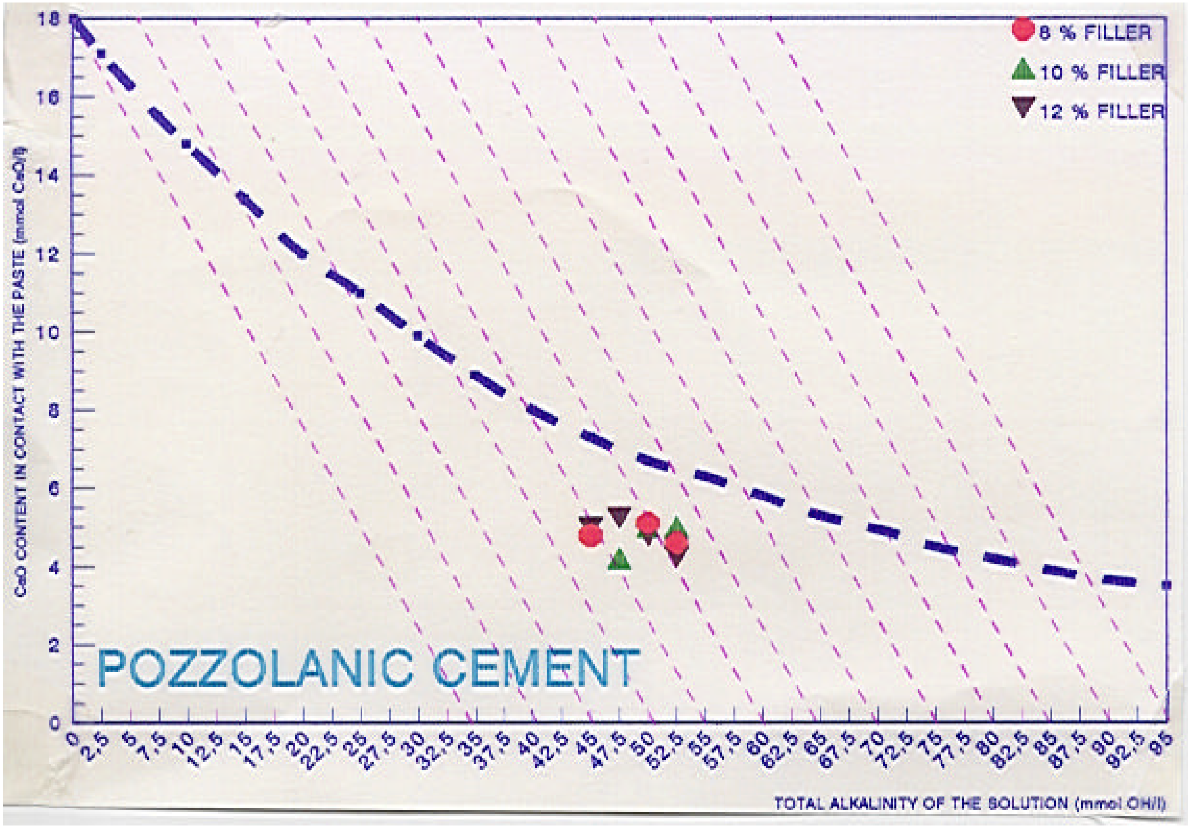

Figure 14- Expansion Reduction

4.8.2-Potential Reactivity - Accelerated Method

Determination of potential reactivity between the cement Alkalies and the fines were carried out by means of accelerated tests, following the South African National

Building Research Institute (NBRI) method, using the Pirex glass(ASTM-C-441) for comparison. Figure 14 shows the results obtained.

4.8.3- Petrograph Analysis

Petrograph analysis of the "Stone Powder" obtained by means of the Basalt crushing and carried out following the ASTM-C-295 confirmed:

- Coloration: from light to heavy gray;
- Mineral Composition: predominant feldspar (plagioclase); quartz, pyroxene, chlorite subordinates.

5-COMMENTS

The "Stone Powder" produced from basaltic rocks and also from other rocks having a given content of silica, have properties of interest for its incorporation to the concretes. Filler used in this report which were originally obtained by means of basalt crushing have shown:

- Fineness similar to that of a generic cement and somewhat inferior than those of the traditional pozzolanic materials, even when produced in the conventional crushing systems and therefore there is no need for different equipment;

- Grading curves obtained with the Filler produced by distinct machines has shown differences of a certain magnitude, identified by the major concentration (70% to 80%) of grains with dimensions of about 0.040 mm, in the material produced by Barmac, in relation to a concentration of 65% for the material produced by the 48VFC Recrusher;

- Averaged diameters of the Fillers under study are of a slightly higher magnitude (around 0.025 mm) than that of the cements normally produced (0.010-0,015 mm);

- The form of grains when analyzed under the microscope has shown differences sensitive to the electronic microscope showing that the grains of the material produced by the Barmac are more equidimensional;

- Fillers presented Calcium Hydroxide fixation (following Ossipov method) as it can be seen by the Calcium fixation tests (and also ASTM-C-500) thus identifying a pozzolan activity;

- Pozzolanic Activity Indexes with Lime and with various Cements (ASTM-C-311 & 618) confirm the pozzolanic activity of the Fillers studied that is also demonstrated by the Fratini method;

- Pozzolanic Activity Indexes with various cements have proved to grow according to the age and Fineness (Blaine) of the incorporated Fillers;

- Fillers tested have demonstrated a substantial efficiency to reduce the expansions resulting from the Alkali-Silica Reaction thus demonstrating another important pozzolanic action.

The set of data submitted in this report makes evident a substantial Pozzolanic characteristic of the Fillers studied which states the validity of its use in RCC and also in conventional types of concrete [1; 5; 7] which corroborates the theoretical expectation mentioned in the text.

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