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In Honour of Professor R.N.Swamy*

**CALORIMETRY OF PORTLAND CEMENTS WITH  
“ALUMINIC” POZZOLANIC ADMIXTURES  
(METAKAOLINS)**

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**Abstract:** The present work studies the influence of three mineral additions –plain metakaolin, metakaolin doped with  $\approx 50\%$  quartz (both are “*aluminic*” pozzolanic additions) and ground quartz with very high  $\alpha$ -SiO<sub>2</sub> content, as standard of both–, on rate heat liberation of two Portland cements with very different mineralogical composition. Main analytical techniques used for this study have been: conduction calorimetry, pozzolanicity (Frattini test) and X-ray diffraction analysis. The results obtained showed the effect of the degree of crystallinity, chemical composition and morphology of the three mineral additions on hydraulicity, as well as the relationship between cement mineralogy and the impact of the resulting interactions on the rate of heat release in the two Portland cements during hydration reactions. The findings likewise showed that the two metakaolins induced stimulation of the hydration reactions due to the generation of pozzolanic activity at a very early stage (at 48 hours). Such stimulation is described as “*indirect*”, to differentiate it from the “*direct*” variety, i.e., stimulation due primarily to the surface adsorption of water on the quartz particles (in the absence of pozzolanic activity) or on the pozzolan particles themselves. As a result of both “*direct*” and (chiefly) “*indirect*” stimulation, the heat of hydration released is comparable to the ***Synergistic Calorific Effect, SCE***. Finally, the effect of the *aluminic* PA on PC calorimetry was also observed to depend largely on the mineralogical composition of the portland cement and the *aluminic* character of the PA. In addition, due to the reactive alumina, Al<sub>2</sub>O<sub>3</sub><sup>r</sup>, content of the two metakaolins, their pozzolanic activity was found to be more ***specific*** than ***generic*** prompting more intense C<sub>3</sub>A than C<sub>3</sub>S hydration in the PCs, at least at very early on into the reaction. Conversely, their pozzolanic activity must be seen as ***unspecific***, or perhaps more precisely, ***insufficiently specific*** or ***too low-specific*** in the stimulation of C<sub>3</sub>S hydration.

**Keywords:** *Calorimetry, Portland cement, metakaolin, quartz, reactive alumina.*

## 1. INTROCUCTION

The use of mineral additions in Portland cements (PCs) is a long-standing practice. Nowadays, different types of mineral additions are added to the clinker Portland during grinding or directly to the cement itself. These include: hydraulically active mineral admixtures (pozzolanic and autopoizzolanic), hydraulically inactive ones (lacking pozzolanic activity). The reactivity of pozzolanic additions is strongly associated with the amorphous and/or vitreous condition of their structure [1,2]. Nevertheless, these can also be differentiated in relation to their “*silicic*” [3-11] or “*aluminic*” [3,4][6][8-18] character, irrespective of whether they are “*siliceous*” or “*siliceous and aluminous*” pozzolans [19].

According to the findings previous research conducted by Talero, Mejía, Martín-L. and Rahhal [4-8], “*aluminic*” pozzolans reduce (sometimes very quickly) the sulphatic resistance of the Portland cement with which they are blended, even when the PC used is SRPC [3,4][12] [14-18]. However, in the absence of sulphates they raise mechanical strengths, particularly at earlier ages [12]. By contrast, they prevent or at least hinder chloride attack on steel reinforcements; first, chemically, and then, physically [6][10,11][13]. They are able to afford physical protection because the volume of the Friedel’s salt generated is similar to the molecular volume of the calcium aluminate hydrates in the ordinary PC. In other words, since the salt is not expansive it fills in the pores and micropores in the concrete or mortar. While characterization by conventional methods takes at least 28 days [4][6][12][14-18], the same results can be obtained in 48 hours with conduction calorimetry [8].

From the study of the metakaolin-lime-water systems at 20 and 60°C, the influence of temperature on the pozzolanic reaction has been determined. At 60°C, the samples present an acceleration of the reaction in the younger ages, while, initially, samples at 20°C present a greater proportion of uncombined lime and at 180 days all of it has combined [20]. Its pozzolanic activity, when blended with cement Portland has been found to be between that of silica-fume and a fly ash [21]. However, studies on resistance to compression, porosity, reaction degree and calcium hydroxide content have found that the pozzolanic reaction rate of a metakaolin is greater than that of a silica fume and a fly ash [22].

Totally crystalline mineral additions (hydraulically inactive) only participate as fillers to dilute the cemen portland. However, in the study in which non hydraulic filler (rutyl) was incorporated individually to the main cement components this was found to increase the hydration rate of each of them [23]. The same tendency was also observed in the mechanical strength of mortars with the incorporation of non hydraulic fillers of different origin (limestone, granitic and siliceous), and the increased resistance was attributed to the action of particles of each filler as nucleation sites for the calcium hydroxide crystals [7][24].

To date, however, experimental research has not determined how Portland cements differing in their mineral composition behave when blended with mineral additions containing varying proportions [3] of reactive alumina,  $\text{Al}_2\text{O}_3^{\text{I-}}$  (tetra- or penta-coordinated alumina [25][24]). The aim of the present study was to obtain such data by exploring the effect of the  $\text{Al}_2\text{O}_3^{\text{I-}}$  content of pozzolanic mineral additions on the hydration of Portland cements with widely varying mineralogical compositions.

## 2. MATERIAL AND METHODS

The following cementitious materials were selected for the experiment: two Portland cements, one –PC1– with a high  $C_3A$ (%) content, and the other –PC2–, with a minimum  $C_3A$  content ( $\approx 0\%$ ); three mineral additions –two pozzolanic–, a high purity metakaolin M ( $\geq 95.0\%$ ) with 29% reactive alumina [3] content and 48% reactive silica [26] content, and a metakaolin doped with quartz ( $\approx 50\%$ ), MQ, with 15% reactive alumina [3] content and 38% reactive silica [26] content, and finally, a non-pozzolanic or crystalline mineral addition: ground quartz, Q, with very high  $\alpha$ - $SiO_2$  content (ground sand from Ottawa-Illinois-USA origin). Distilled water was used as mixing water in all cases.

The chemical composition, density and Blaine specific surface (BSS) of Portland cements and mineral additions are presented In Table 1. The potential composition of the Portland cements studied, found by substituting the chemical composition in the Bogue formulae, was as follows: 51%  $C_3S$ , 16%  $C_2S$ , 14%  $C_3A$  and 5%  $C_4AF$ , for PC1, and 79%  $C_3S$ , 2%  $C_2S$ , 0%  $C_3A$  and 10%  $C_4AF$ , for PC2. The differences in the chemical and mineralogical compositions of the two Portland cements were also partially reflected in their varying density, while their fineness was comparable (Blaine Specific Surface, BSS).

TABLE 1: CHARACTERISTICS OF THE MATERIALS

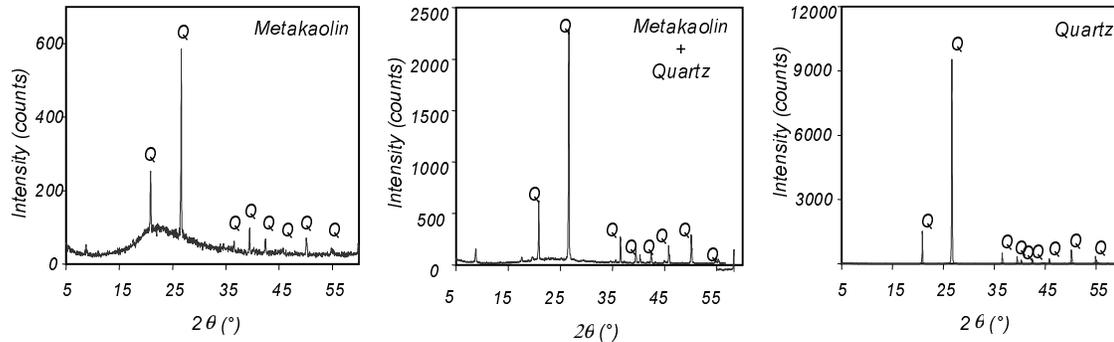
Parameters \ Materials	Portland Cements		Mineral additions		
	PC1	PC2	M	MQ	Q
PF, %	1.6	1.1	0.4	0.6	-
IR, %	0.7	0.2	-	0.2	-
SiO <sub>2</sub> , %	19.2	21.7	57.5	73.6	99.9
Al <sub>2</sub> O <sub>3</sub> , %	6.4	1.5	41.6	23.1	-
Fe <sub>2</sub> O <sub>3</sub> , %	1.7	4.1	0.5	1.2	-
CaO, %	63.9	68.0	0.0	0.6	-
MgO, %	1.5	0.4	0.0	0.0	-
Na <sub>2</sub> O, %	0.9	0.4	-	0.1	-
K <sub>2</sub> O, %	0.5	0.2	-	0.7	-
SO <sub>3</sub> , %	3.5	2.3	0.0	0.0	-
Density	3.08	3.21	2.52	2.55	2.70
Blaine Specif. Surf, (m <sup>2</sup> /kg)	319	301	333	398	395

Figures 1 and 2 show a more or less diffuse band [2] reflecting the primordially amorphous condition of the M (density, 2.52) and MQ (density, 2.55). No such diffuse band appears on the diffractogram in Figure 3, whose well-defined peaks reflect the highly crystalline nature of Q. Moreover, these additions have much lower densities than either of the PCs.

First of all, 6 blended cements with 80%/20% (PC-n°/Mineral Addition M, MQ or Q ratios) were prepared with 2 portland cements –PC1 and PC2– and 3 mineral additions –M, MQ and Q–.

Secondly, the Frattini test [27] was conducted on all these blended cements at the age of two days to confirm whether or not they exhibited pozzolanic properties (Table 2). Frattini test compares the amount of calcium hydroxide which, after a specific time period, in this case 2

days, the aqueous solution in contact with the hydrated sample contained at 40°C, with the solubility isotherm of calcium hydroxide in an alkaline solution at the same temperature. In this experiment, there is pozzolanic activity when the calcium hydroxide concentration in the sample solution studied is below the solubility isotherm, or simply, positive result (= result +).



**FIGS. 1, 2, 3.- XRD PATTERNS OF THE THREE MINERAL ADDITIONS SHOWING PRESENCE OF QUARTZ (Q).**

**TABLE 2: RESULTS OF POZZOLANIC ACTIVITY (FRATTINI).**

Cements	2 days (mM/l) [OH <sup>-</sup> ] [CaO]	
	PC1	72.5
PC1/M	<b>51.5</b>	<b>4.2</b>
PC1/MQ	<b>55.0</b>	<b>6.4</b>
PC1/Q	65.0	9.5
PC2	42.5	21.5
PC2/M	<b>32.0</b>	<b>13.3</b>
PC2/MQ	<b>41.0</b>	<b>26.6</b>
PC2/Q	44.5	21.9

Values given in **bold** represent points in the subsaturation zone (= result +)

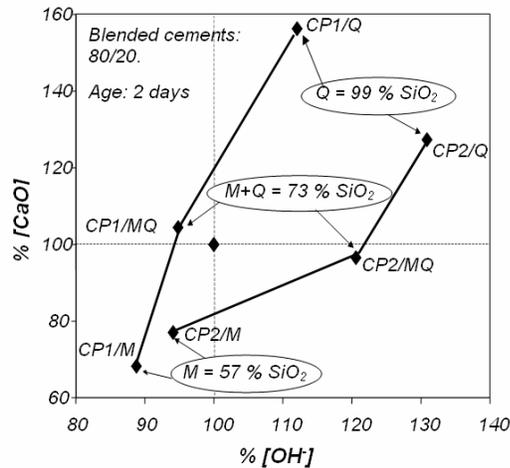
Thirdly, evolution of the rate of heat liberation was measured by conduction calorimetry for cement pastes. The baseline temperature for the measurements was 25°C and the water/binder (=w/b) ratio used for all the cases was 0.5 (in weight). Data records were completed for the first 48 hours of hydration, and the total heat produced at this age was obtained from the integral under the heat liberation curve versus time.

Lastly, X-ray diffraction analysis of the cement pastes was then conducted to measure the change in production and/or consumption of calcium hydroxide (semiquantitative or comparative analysis only), at the ages derived from the calorimetric curves. For blended cements with PC1: first trough, second trough (between the second and the third peak) and the third trough (at the end of the calorimetry test); and for blended cements with PC2: first trough and second trough (at the end of the calorimetry test).

### 3. RESULTS AND DISCUSSION

Table 2 gives two-day  $[\text{OH}^-]$  and  $[\text{CaO}]$  as well as the two-day results of the pozzolanicity test or Frattini test for the four pozzolan-cement blends. Quartz, naturally, exhibited no pozzolanic activity with either of the two portland cements, although the rate of hydration was observed to rise. Initially, this higher rate of reaction in the PC fraction is due, among other possible reasons, to water (from the mixing water) adsorption on the surface of the particles of the mineral additions, a process that may be termed “*direct*” induction or stimulation [28-30], which differs from “*indirect*” stimulation [30], a mechanism discussed below. Such “*direct*” stimulation or stimulation by “*direct*” way or “*through*” way, was verified in the PC/Q blended cements, in which at these early ages (up to 2 days age),  $[\text{OH}^-]$  and  $[\text{CaO}]$  were higher than mathematically predicted when Q was assumed to be inert (physic and chemically) –relative comparison–, and they also were higher than the  $[\text{OH}^-]$  and  $[\text{CaO}]$  for their respective plain Portland cement –absolute comparison–.

Figure 4 shows the percentages of each of the plain PC, of the  $[\text{OH}^-]$  and  $[\text{CaO}]$ , per gram of Portland cement. The pairs of blended cements with plain metakaolin have been grouped together below and to the left of 100%  $[\text{CaO}]$  and  $[\text{OH}^-]$ , respectively. Blended cements with metakaolin and  $\approx 50\%$  quartz content are either below the 100%  $[\text{CaO}]$  or to the left of the 100%  $[\text{OH}^-]$ . Blended cements with quartz are found above 100%  $[\text{CaO}]$  and  $[\text{OH}^-]$ . A tendency for calcium hydroxide to remain in solution can be found with increased quartz content in the samples, as logical.



**FIG. 4:** %  $[\text{OH}^-]$  AND %  $[\text{CaO}]$  OF THE SAMPLES PER GRAM OF PORTLAND CEMENT RELATIVE TO THE RESPECTIVE STANDARD

These results may be interpreted to mean that the rate of release of calcium hydroxide, CH, (portlandite) grows in the presence of mineral additions, with the compound remaining in solution when the addition is crystalline or non-pozzolanic and combining when it is pozzolanic. The rate of calcium hydroxide generation and evolution was very low in M- and MQ-containing cement pastes during the first 48 hours, which is consistent with the high two-day pozzolanic activity exhibited by these two additions (Table 2). The amount of CH generated was observed to increase in both Portland cements when blended with Q, providing further evidence that this mineral *stimulates* hydration reactions *directly*.

Figures 5 and 6 show the calorimetric curves drawn up during the first 48 hours for OPCs PC1 and PC2 alone and with M, MQ and Q.

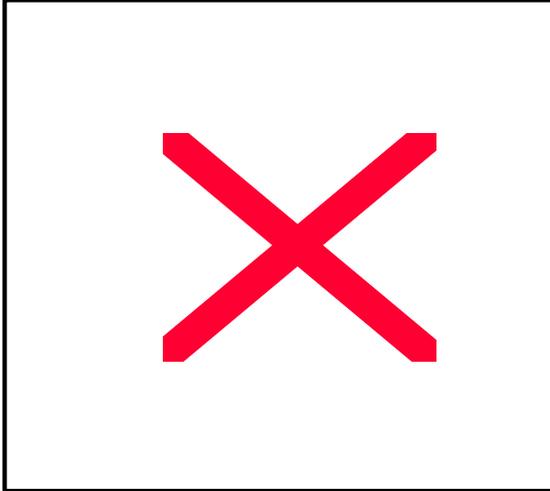


FIG. 5: CALORIMETRIC CURVES WITH PC1

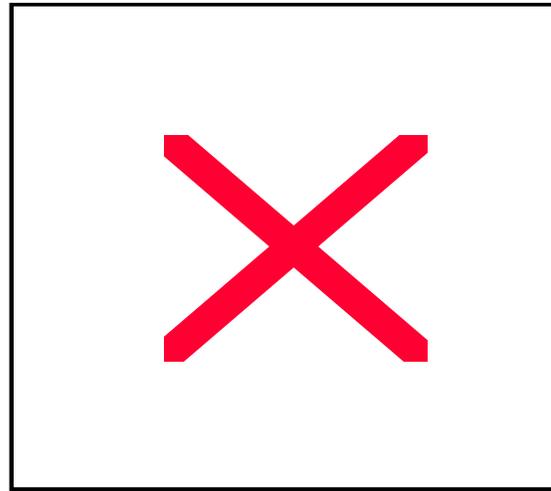


FIG 6: CALORIMETRIC CURVES WITH PC2

The calorimetric curve of PC1 (Fig.5) presents three peaks corresponding to initial hydrolysis, to hydration of  $C_3S$  and to transformation of AFt phase to AFm phase, respectively. Blended cements with PC1 also present three peaks in their respective calorimetric curves. The first trough can be observed to have advanced and attenuated for all the blended cements; an advance of the second and third peaks is observed for all the blended cements and a significant augmentation for blended cements with metakaolins.

The calorimetric curve for PC2 (Fig.6) shows only two peaks, corresponding to initial hydrolysis and  $C_3S$  hydration, respectively. The third peak did not appear because of the absence of  $C_3A$  for this Portland cement PC2. The PC2 blended cements also had two peaks on their calorimetric curves, on which both the first valley and second peak were found to be retarded and attenuated.

Figure 7 shows the total heat liberated at 48 hours per gram of Portland cement, in per cent. The nature and character of the mineral additions and the mineralogical composition of the Portland cements can be observed to affect the calorimetric behaviour of the respective blends both separately and jointly. Moreover, there is evidence in all cases that PC hydration was *directly* and/or *indirectly* stimulated, for the total heat values were similar to or greater than the values for the respective plain Portland cement. Logically, they were also greater than the values for the respective blended cements, assuming their mineral addition to be inert.

Such stimulation was more intense in the PC1 than the PC2 blends. When the mineral addition contained metakaolin, the effect grew with the reactive alumina,  $Al_2O_3^r$ , content (the concurrence with the respective total alumina – $Al_2O_3\%$ – content, as shown in Table 1, is circumstantial only). Such behaviour is observed for both metakaolins, and proves once again that at least at very early ages, their pozzolanic activity, due primarily to their respective  $Al_2O_3^r$  content, is more *specific* than *generic*, prompting more intense  $C_3A$  than  $C_3S$  hydration (Figs. 5 and 6, respectively). In the present paper this type of stimulation of hydration reactions has been termed “*indirect*” to differentiate it from “*direct*” stimulation, as explained above. This effect was less directly proportional (Fig.7) than might have been expected, however, because the w/b ratio was held constant at 0.5 for all the cements studied. Nevertheless, as far as the mineralogical composition of Portland cements is concerned, generally speaking, cements with a high  $C_3A$  and low  $C_3S$  content exhibited earlier and

greater hydration reactions due to *direct* but particularly to *indirect* stimulation (Figs. 5 and 7). Cements with a low  $C_3A$  and high  $C_3S$  content, by contrast, exhibited retarded and attenuated reactions (Figs. 6 and 7). As a result, the differences in the amount of heat of hydration per gram of Portland cement were more significant in PC1 than in PC2 blends (Fig.7).

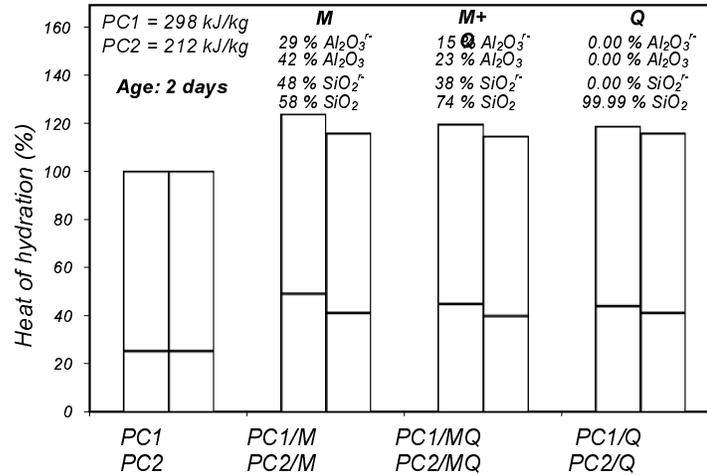


FIG.7: % TOTAL HEAT OF SAMPLES PER GRAM OF PORTLAND CEMENT

By contrast, “*indirect*” stimulation of hydration at very early ages must be seen to be *unspecific*, or perhaps more precisely, *insufficiently specific* or *too low-specific* for  $C_3S$  hydration, inasmuch as the specific “*indirect*” stimulation of its hydration is enough lesser than for its plain PC2 and for its PC2/Q blended cement as well (Fig.6).

In short, while *indirect* stimulation of hydration in PC1 by the two pozzolanic additions, M and MQ, increases with their respective  $Al_2O_3^-$  content, being the heat liberation rate of their 2nd peaks greater than its plain PC1 and its PC1/Q blended cement, in PC2 it is lesser. All this can be attributed to the *Synergistic Calorific Effect, SCE*, between the  $C_3A$  in PC1 and the  $Al_2O_3^-$  in pozzolans M and MQ. As far as the mineralogical composition of Portland cements is concerned, generally speaking, cements with a high  $C_3A$  and low  $C_3S$  content exhibited earlier and greater hydration reactions due to *direct* but particularly to *indirect* stimulation (Fig. 5 and 7). Cements with a low  $C_3A$  and high  $C_3S$  content, by contrast, exhibited retarded and attenuated reactions (Figs. 6 and 7). As a result, the differences in the amount of heat of hydration per gram of Portland cement were more significant in PC1 than PC2 blends.

In order to confirm evolution of the hydration reactions during the first 48 hours, the compounds present were identified and the progress of each one with age was studied using X-ray diffraction. Table 3 shows the phases of the Portland cement, its main reaction products and its evolution.

Regarding the formation and evolution of calcium hydroxide, CH, in the blended cement pastes with plain metakaolin and metakaolin with  $\approx 50\%$  quartz content, was very low during the first 48 hours coinciding with the strong pozzolanic activity of both pozzolanic additions at 2 days old, as logical (Table 2). For blended cements with quartz, increases in the amount of CH generated were observed with both Portland cements, and for this reason, reflecting *direct* stimulation (Fig.4).

**TABLE 3: X-RAY DIFFRACTION DATA**

Cements	Phases present and their evolution							
	C <sub>3</sub> S	C <sub>2</sub> S	C <sub>3</sub> A	C <sub>4</sub> AF	G	CH	Aft	AFm
PC1, 1 <sup>st</sup> trough	P	P	P	A	P	P	P	P
PC1, 2 <sup>nd</sup> trough	<	<	<	A	<	>>	=	>
PC1, 3 <sup>rd</sup> trough	<	<	<	A	<	>>	=	>
PC1/M, 1 <sup>st</sup> trough	P	P	P	A	A	P	P	P
PC1/M, 2 <sup>nd</sup> trough	<	<	<	A	A	>	>	>
PC1/M, 3 <sup>rd</sup> trough	<	<	<	A	A	>	>	>
PC1/MQ, 1 <sup>st</sup> trough	P	P	P	A	A	P	P	P
PC1/MQ, 2 <sup>nd</sup> trough	<	<	<	A	A	>	>	>
PC1/MQ, 3 <sup>rd</sup> trough	<	<	<	A	A	>	>	>
PC1/Q, 1 <sup>st</sup> trough	P	P	P	A	P	P	P	P
PC1/Q, 2 <sup>nd</sup> trough	<	<	<	A	<	>>	=	>
PC1/Q, 3 <sup>rd</sup> trough	<	<	<	A	<	>>	=	>
PC2, 1 <sup>st</sup> trough	P	P	A	P	A	P	A	A
PC2, 2 <sup>nd</sup> trough	<	<	A	=	A	>>	A	A
PC2/M, 1 <sup>st</sup> trough	P	P	A	P	A	P	A	A
PC2/M, 2 <sup>nd</sup> trough	<	<	A	<	A	>	A	A
PC2/MQ, 1 <sup>st</sup> trough	P	P	A	P	A	P	A	A
PC2/MQ, 2 <sup>nd</sup> trough	<	<	A	<	A	>	A	A
PC2/Q, 1 <sup>st</sup> trough	P	P	A	P	A	P	A	A
PC2/Q, 2 <sup>nd</sup> trough	<	<	A	=	A	>>	A	A

G = Gypsum; P: presence, A: absence, > increase, <: decrease, = unchanging.

Moreover, formation of the tri-substituted aluminous ferrite phase (Aft or ettringite), and its partial transformation to the mono-substituted aluminous ferrite phase (AFm) for blended cements with PC1, corresponding with the third peak of the calorimetric curves, was observed (Fig.5). For blended cements with PC2, absence of the Aft and AFm phases was verified corresponding with absence of the third peak in the calorimetric curves (Fig.6) and of C<sub>3</sub>A in PC2.

Observations about the morphology of the three mineral additions:

- Plain metakaolin, M, presented pozzolanic activity at 2 days although it can be assumed that this activity started long before since calcium hydroxide was only detected in low intensities in the diffractograms. However, this induced stimulation of the hydration reactions since more hydration heat was generated per gram of Portland cement at 48 hours. This greater heat generation could also have been due to the pozzolanic reaction. For this reason, this induced stimulation of the hydration reactions must be considered by “*indirect way*” for differing it to the induced stimulation by “*direct way*” or “*through way*”, due to the initially superficial adsorbed water of the quartz particles mainly, which never shows pozzolanic activity, as logical.
- Metakaolin with ≈ 50% of quartz content, MQ, also presented pozzolanic activity at 2 days, since calcium hydroxide was recorded in low intensities in the diffractogram. Also, its particles seemed to act as foci of stimulation of hydration reactions by “*indirect way*”

as well, since the total heat at 48 hours of the blended cements was more than 100% of the heat of each Portland cement.

- The quartz, Q, did not present pozzolanic activity, logically, but there was also evidence of stimulation of the hydration reactions; although in contrast, by “*direct way*” or “*through way*” only, reflected by an increased calcium hydroxide concentration during the first 48 hours and also because it had developed a greater heat of hydration per gram of Portland cement at the same age.

Observations about the mineralogical composition of the Portland cements:

- The use of Portland cements with high  $C_3A$  content and low  $C_3S$  content, in general, produced advances and increases in the hydration reactions (Fig. 5).
- The use of Portland cements with low  $C_3A$  content and high  $C_3S$  contents caused delays and attenuations (Fig. 6).

#### 4. CONCLUSIONS

The conclusions to be drawn from the above experiments are as follows:

1. The initial release and subsequent pattern of heat of hydration as reflected in the hydration curves for the blended cements, are substantially affected by the mineralogical characteristics of the respective Portland cements.
2. Adding ground crystalline quartz, Q, a non-pozzolan, stimulates the hydration reactions in the PC fraction of PC/Q blended cements due, among other possible reasons, to the adsorption of water on the surface of the quartz particles. This effect, here termed “*direct*” stimulation, occurs in conjunction with an increase in CH and higher heat of hydration per gram of PC. As a result, mineral addition Q cannot be regarded to be completely inert, physically speaking, at least up to the age of two days. A fuller discussion and justification of these observations can be found in references [8] and [29].
3. The pozzolanic and hydraulic activities of both “*aluminic*” pozzolans, M and MQ, depend extensively on the non-crystallinity of their structure, and more specifically, on their  $Al_2O_3^f$  content. Indeed, after 48 hours, both M and MQ exhibit pozzolanic activity that stimulates hydration, primarily “*indirectly*”. This effect must be regarded to be “*indirect*” in light of the highly significant pozzolanic activity in both pozzolans at very early ages, generated primarily by  $Al_2O_3^f$ . It goes hand-in-hand with a decrease in CH and an increase in heat of hydration per gram of PC.
4. Such pozzolanic activity is observed in both M and MQ, due primarily to their respective  $Al_2O_3^f$  content, and at least at very early ages, is more *specific* than *generic*, prompting more intense  $C_3A$  than  $C_3S$  hydration. Conversely, this prior pozzolanic activity must be seen as *unspecific* or *insufficiently specific*, or perhaps still more precisely, *too low-specific* in the stimulation of  $C_3S$  hydration, inasmuch as the specific “*indirect*” stimulation of its hydration is enough lesser than for its plain PC2 and for its blend with Q as well. See section 7. Final Question.
5. When metakaolin is added to OPC to make high performance bulk concrete, account must be taken of its *direct* and *indirect* effect on the generation of heat of hydration to minimize undesirable consequences, for the amount of heat of hydration released may be comparable to the amount generated by the *Synergistic Calorific Effect, SCE*. Even so, *expansive hydraulic cements* [31] can be manufactured with *aluminic* pozzolans for the significant expansion [4][14-18] attained when an optimum proportion of excess gypsum is added [32].

## 5. FINAL QUESTION

Pursuant to Conclusion 4, the following Final Question can be raised: Why is pozzolanic activity observed to be high two-days cements containing not *aluminic* but *silicic* pozzolans, such as silica fume, for instance? Is such pozzolanic activity also more *specific* than *generic* for the same result? (the same result is stimulation by *indirect way* prompting more intense C<sub>3</sub>A than C<sub>3</sub>S hydration as well), or perhaps is it more *unspecific* or *insufficiently specific* or *too low-specific*?, or perhaps still more precisely, might it actually *specifically hinder* C<sub>3</sub>A hydration, such as in the case of sulphate attack? The answer is to be found in references [4,5][30][33], as well as in subsequent paper on sulphate attack [35], to be released in the very near future.

## 6. ACKNOWLEDGMENTS

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