CONCRETO PROJETADO

Materiais constituintes e aditivos

Antonio Domingues de Figueiredo

Renan Pícolo Salvador

São Paulo, 30 de Outubro de 2019.

- ✓ UNE 83607:2014
- ✓ OBV 2013 (Áustria)
- ✓ EFNARC (Specification for Sprayed Concrete)
- ✓ ACI 506
- ✓ Congresso Sprayed Concrete (Noruega)

- ✓ Cimento
- ✓ Agregados
- ✓ Água
- ✓ Plastificante, SP, estabilizador de pega, aerador
- ✓ Aditivos aceleradores
- ✓ Adições
- ✓ Fibras

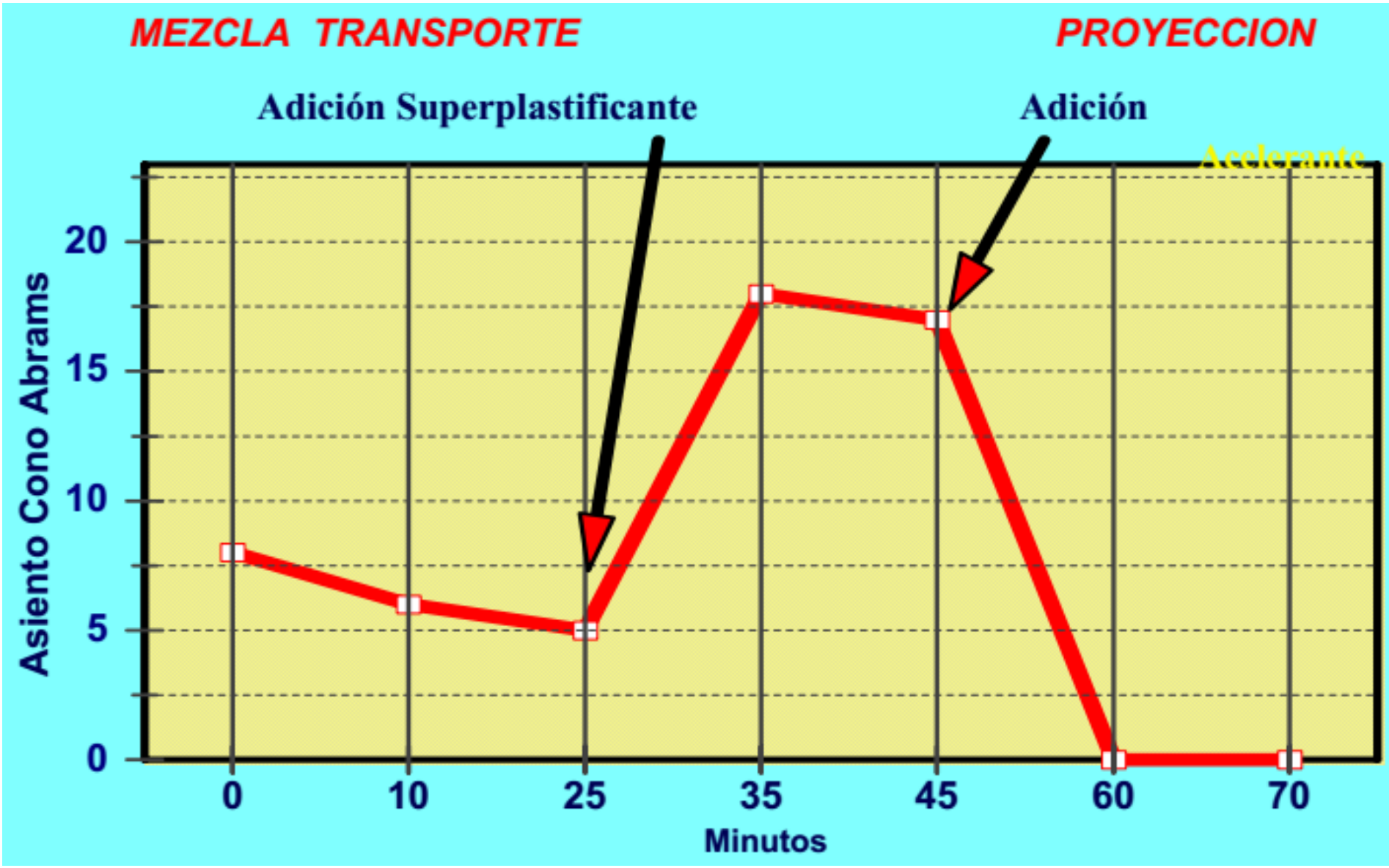
- ✓ Europa: Cimento II/A-L 42,5R (CPII F 32)

  Cimento I 52,5R (CP V)

- ✓ Brasil: CP II F

Adição	% de substituição no CP
Sílica ativa	15
Cinza volante	30
Escória de alto-forno	30

- ✓ Finura
- ✓ Composição química
- ✓ Quantidade de C_3A
- ✓ Quantidade e forma do regulador de pega
- ✓ Relação C_3A/SO_3
- ✓ Adições


MEZCLA TRANSPORTE
PROYECCION
Adición Superplastificante
Adición
Acelerante
Asiento Cono Abrams
20
15
10
5
0
0
10
25
35
45
60
70
Minutos

Superplastificantes

https://www.youtube.com/watch?v=CSZxjQwDKFo

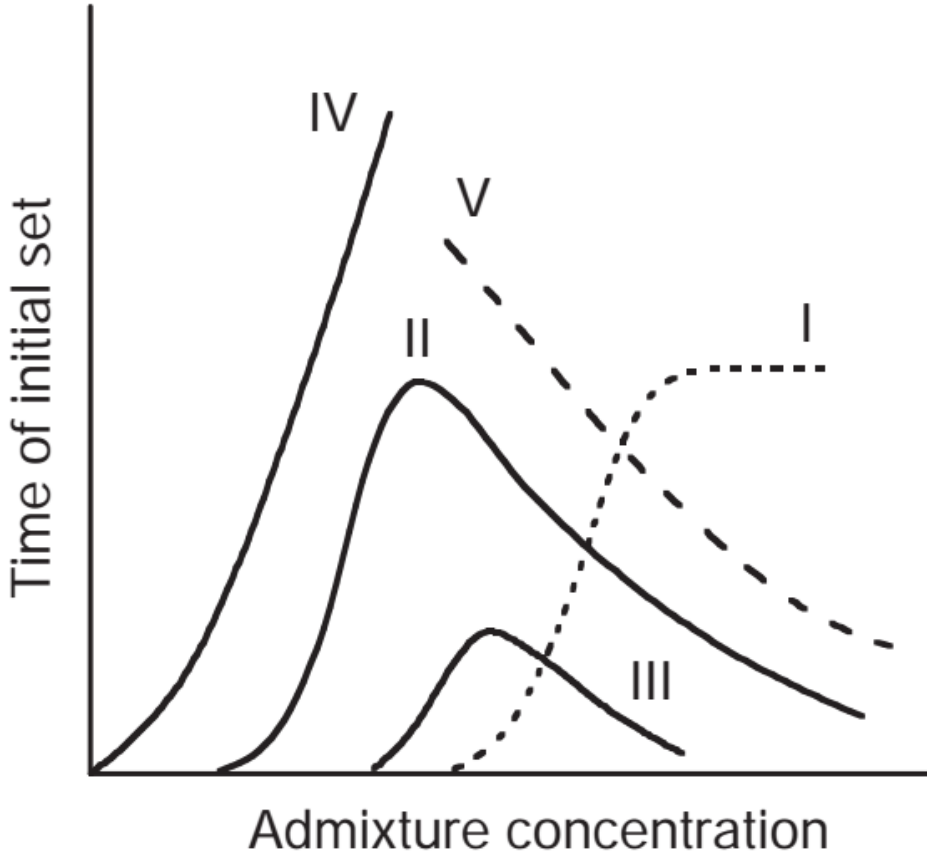
- ✓ Na maioria, compostos por sais solúveis em água, que modificam o equilíbrio iônico da água de amassamento

- ✓ Aceleradores de uso geral: sais de sódio

- ✓ Retardadores de uso geral: tensoativos e açucares (estabilizadores de pega)

- ✓ Aceleradores da hidratação de silicatos (sais de cálcio) ou de aluminatos (sais de alumínio)

- ✓ Retardadores da hidratação de silicatos (fosfatos e fluoretos) ou de aluminatos (sais de alumínio)



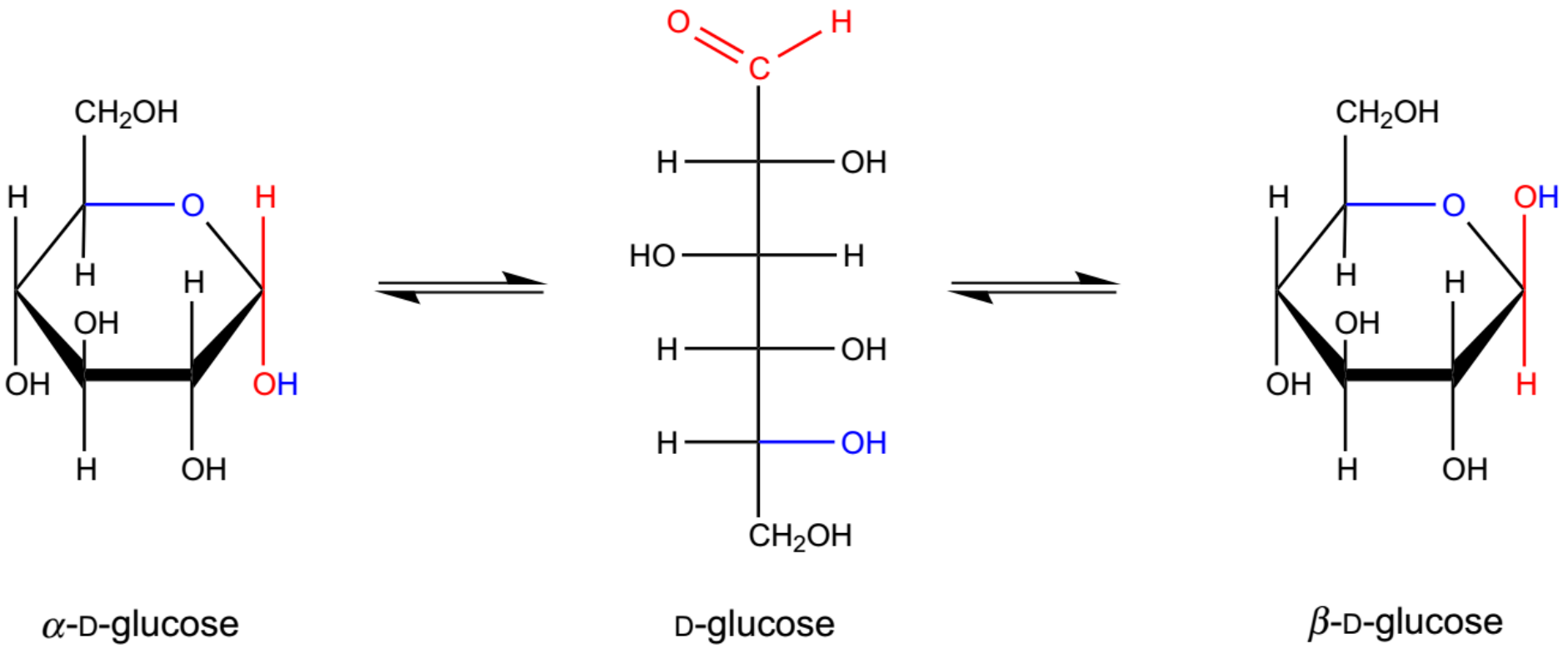
I: sulfatos de cálcio, sódio e potássio

II: Sais solúveis de cálcio (cloreto, nitrato), sulfato de alumínio e aluminato de sódio de potássio

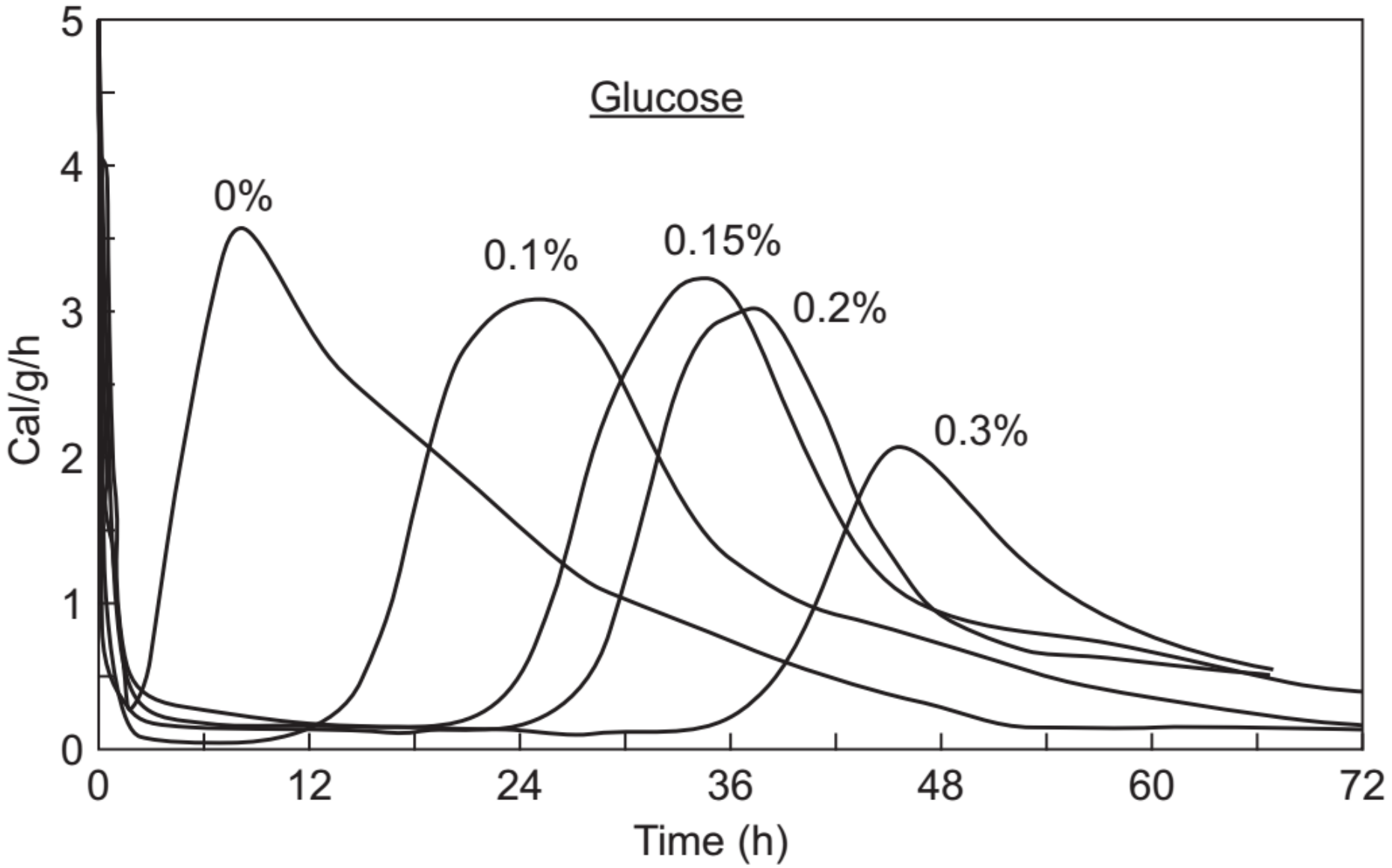
III: Carbonatos e silicatos de sódio e potássio

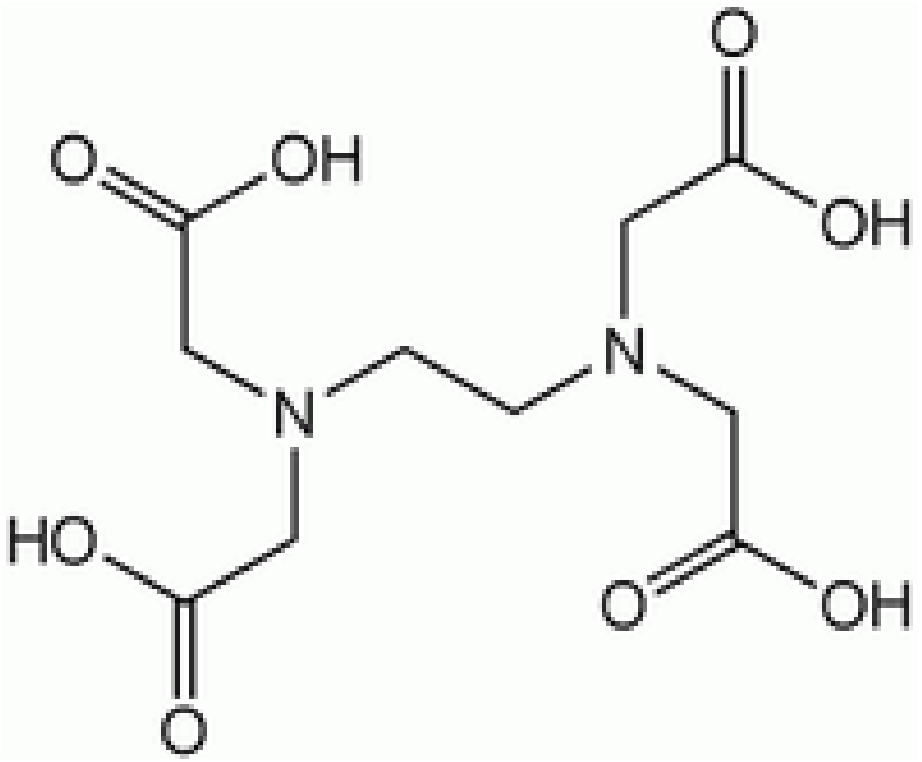
IV: Tensoativos, açucares, fosfatos, oxalatos e fluoretos de sódio, sais de chumbo e zinco.

V: Formiato de cálcio e trietanolamina

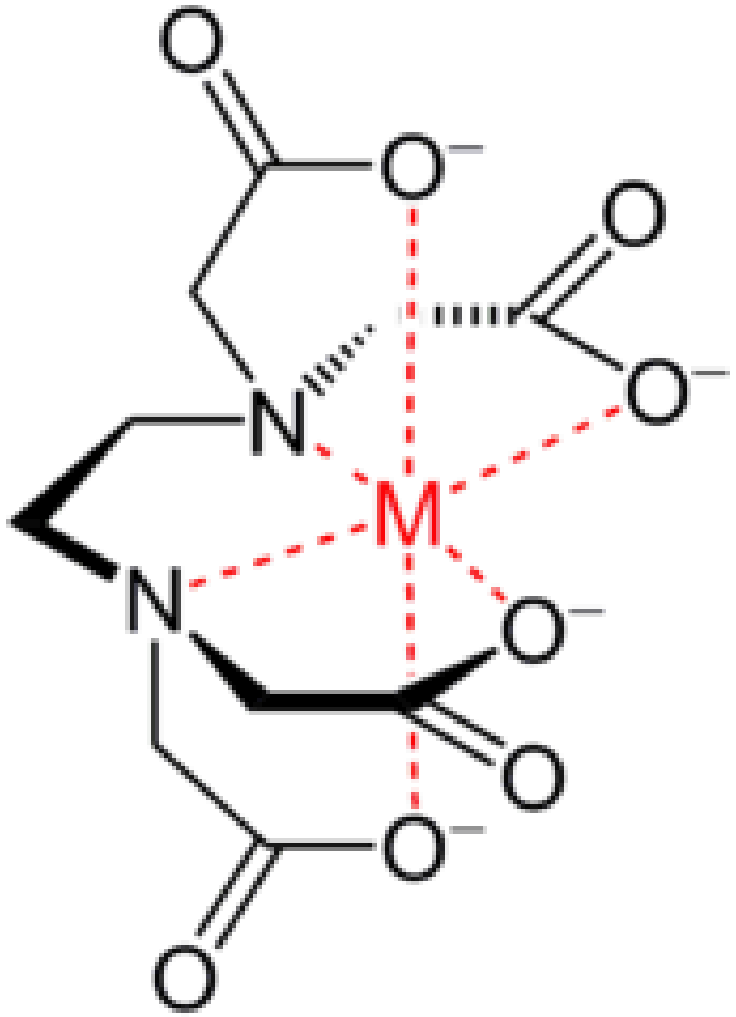


α-D-glucose D-glucose β-D-glucose

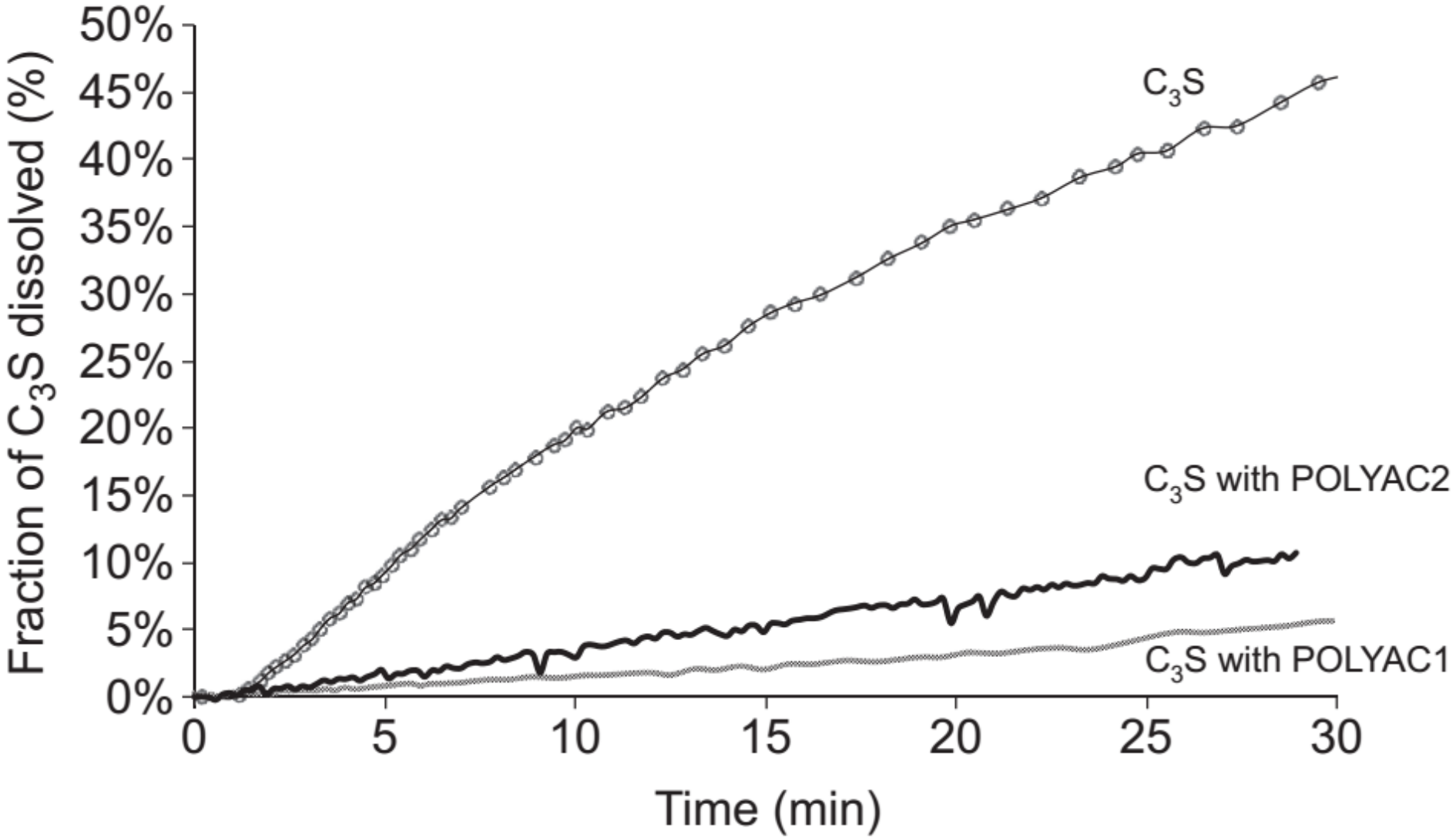

Glucose
0%
0.1%
0.15%
0.2%
0.3%
Cal/g/h
Time (h)
0
1
2
3
4
5
0
12
24
36
48
60
72



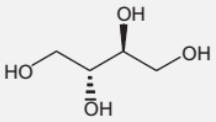
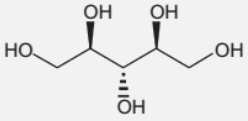
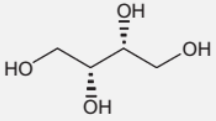
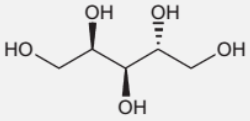
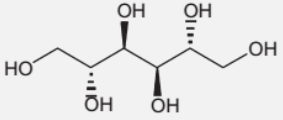
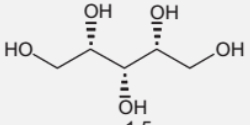
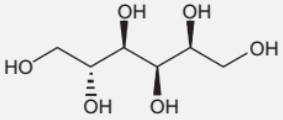
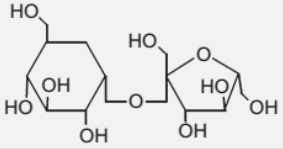
EDTA

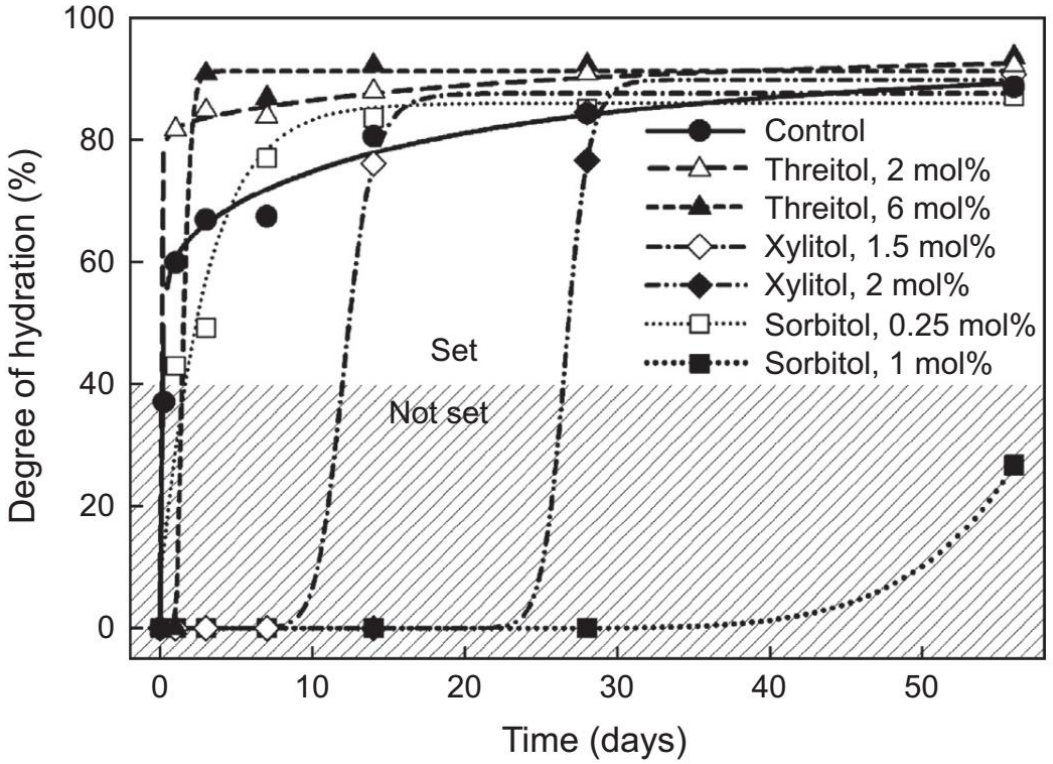


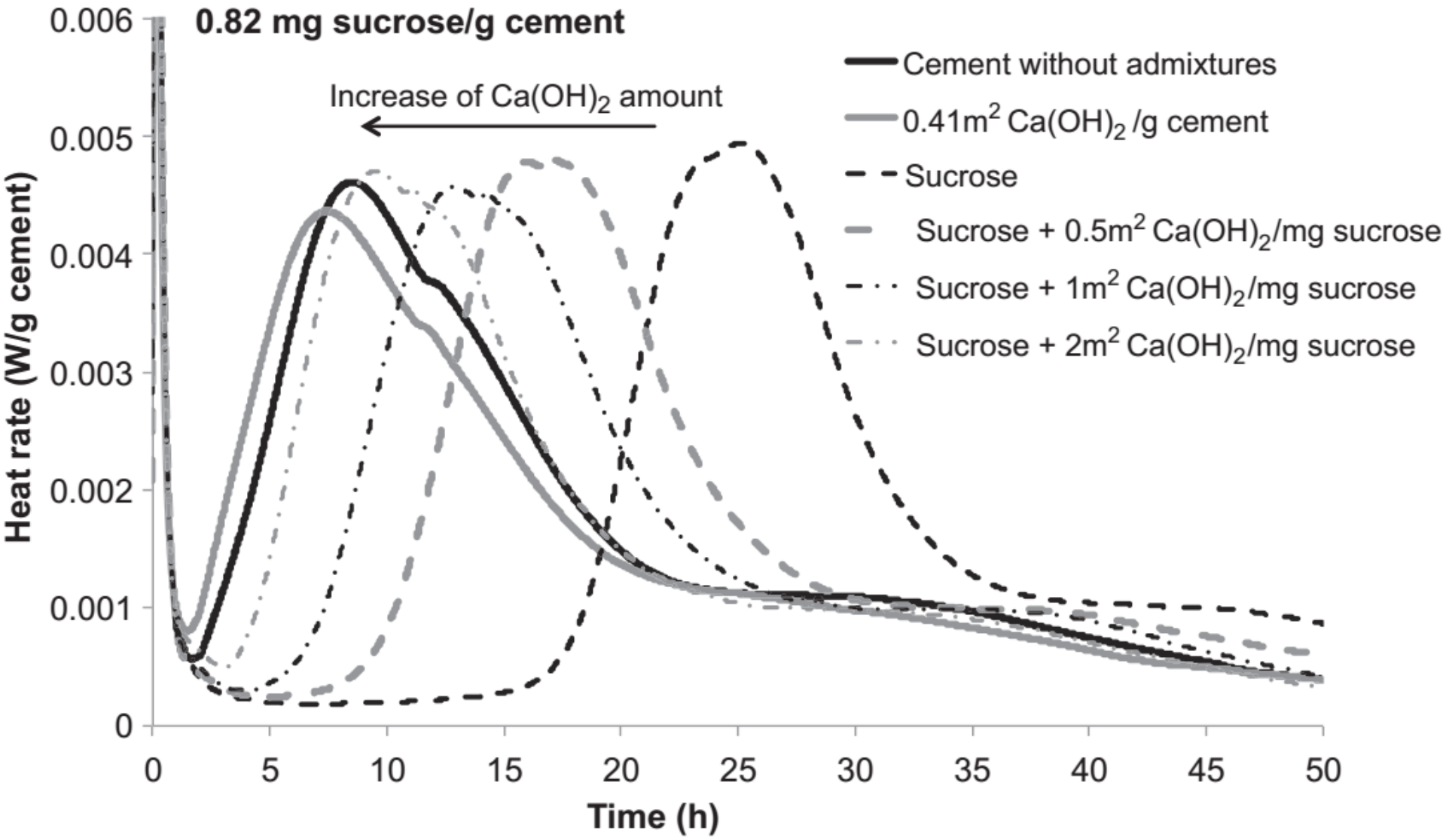
Mecanismo de retardação – inibição dissolução C_3S

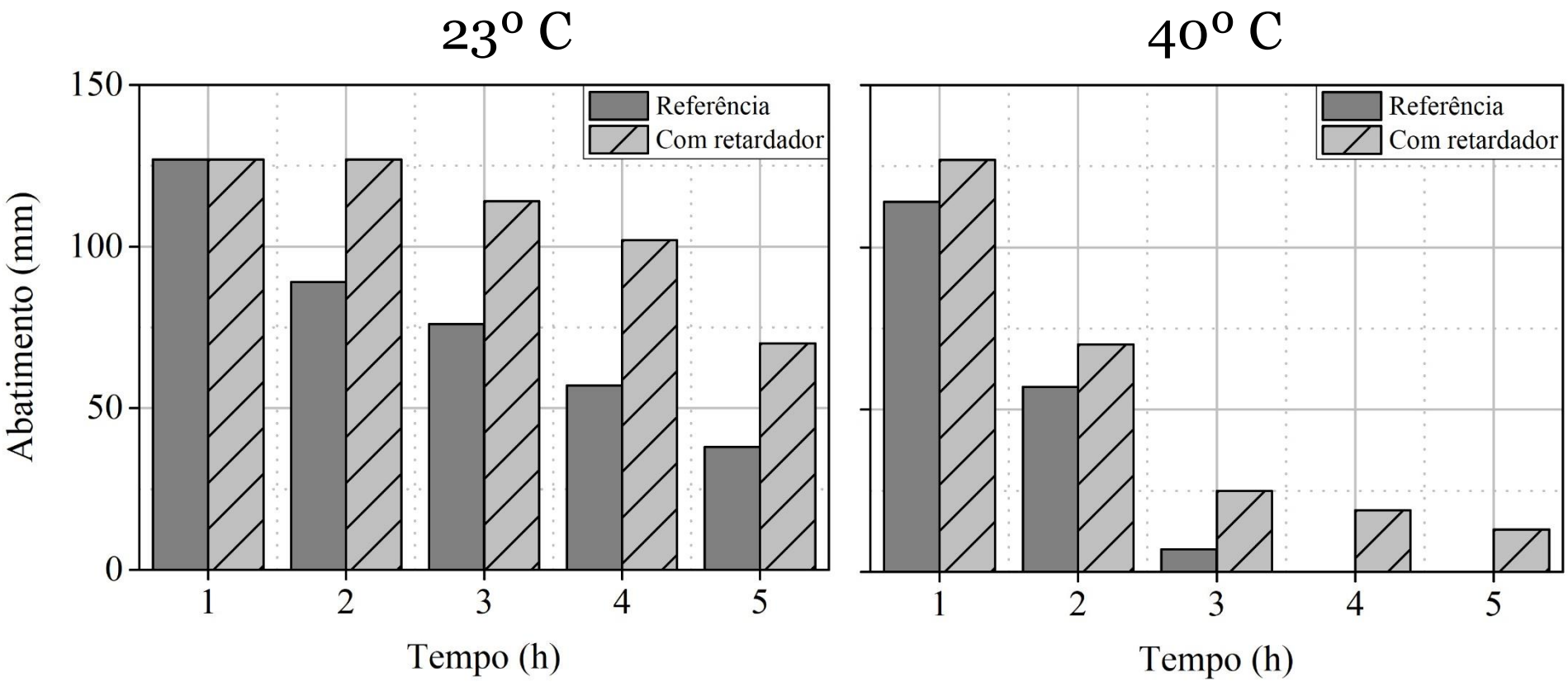


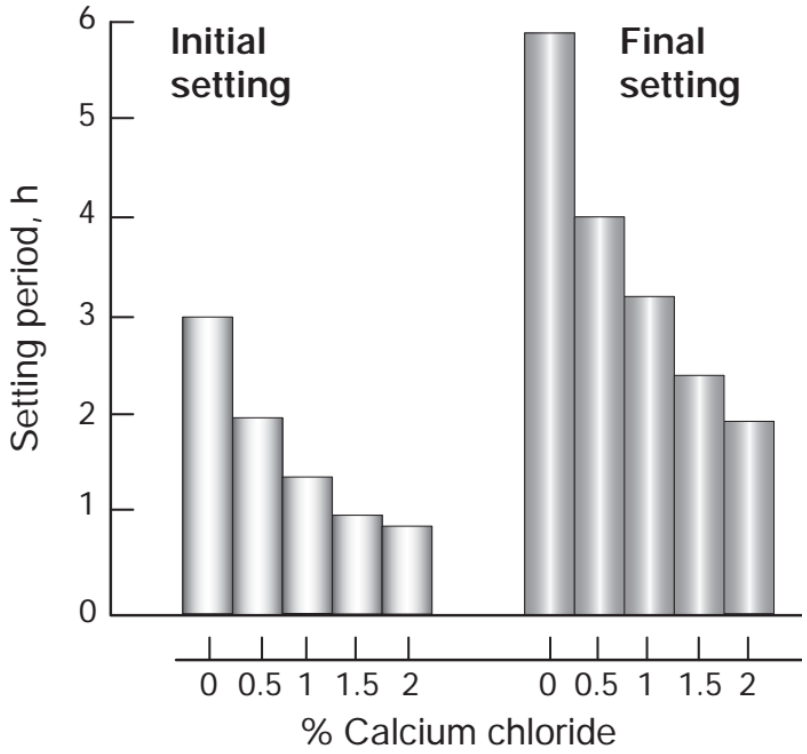
Açucares

	Additive	Concentration mol%	Concentration wt%	Days to reach 40% hydration
Erythritol (0)[a]		–	–	0.3
		1.9	1.0	0.3[b]
Adonitol (0)		1.5	1.0	0.3[b]
Threitol (1)		2.0	1.1	<0.3[c]
		4.0	2.1	<0.3[c]
		6.0	3.2	1.5[c]
Arabitol (1)		2.0	1.3	1.5[c]
		4.0	2.7	Ca. 20
		6.0	4.0	>56
Mannitol (1)		1.3	1.0	2[c]
Xylitol (2)		0.50	0.33	<0.3
		1.0	0.67	2
		1.0	Ca. 10	
	1.5	2.0	1.3	Ca. 20
Sorbitol (2)		0.25	0.20	0.5[d]
		0.50	0.40	2[d]
		1.0	0.80	>56
Sucrose		0.025	0.037	2[d]
		0.10	0.15	>56



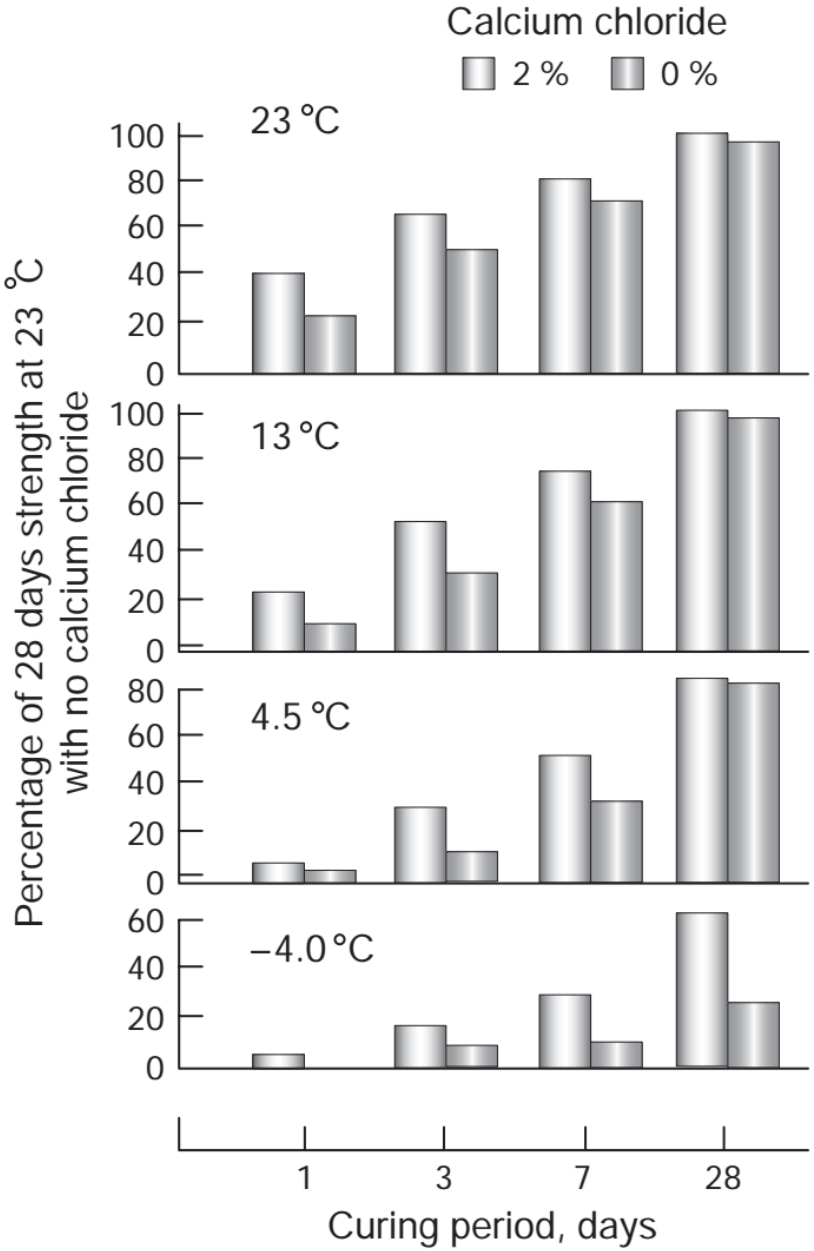

0.82 mg sucrose/g cement
Increase of Ca(OH)2 amount
Cement without admixtures
0.41m2 Ca(OH)2 /g cement
Sucrose
Sucrose + 0.5m2 Ca(OH)2/mg sucrose
Sucrose + 1m2 Ca(OH)2/mg sucrose
Sucrose + 2m2 Ca(OH)2/mg sucrose
Heat rate (W/g cement)
0.006
0.005
0.004
0.003
0.002
0.001
0
0
5
10
15
20
25
30
35
40
45
50
Time (h)


23º C
40º C
Abatimento (mm)
150
100
50
0
Referência
Com retardador
1
2
3
4
5
Tempo (h)



Acelerador de pega

Acelerador de endurecimento

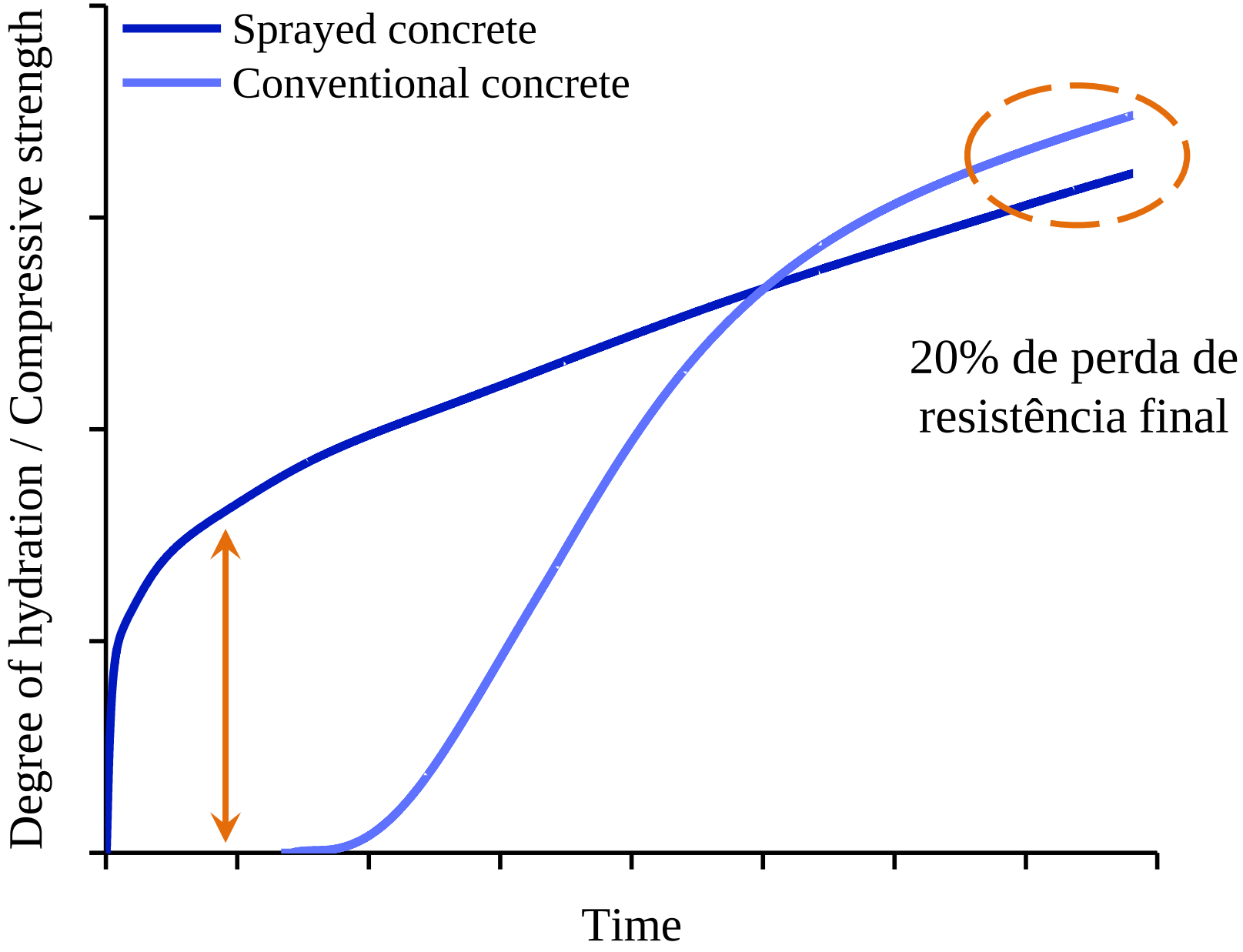


- ✓ Diminuir o tempo de pega e o tempo necessário para dar acabamento no elemento

- ✓ Aumentar a taxa de ganho de resistência mecânica, para remoção das formas em menor tempo

- ✓ Reforços estruturais (questões de segurança)

- ✓ Aplicação de concreto em superfícies verticais


Sprayed concrete
Conventional concrete
Degree of hydration / Compressive strength
Time
20% de perda de resistência final

- ✓ Aceleradores de pega
- ✓ Aceleradores de endurecimento

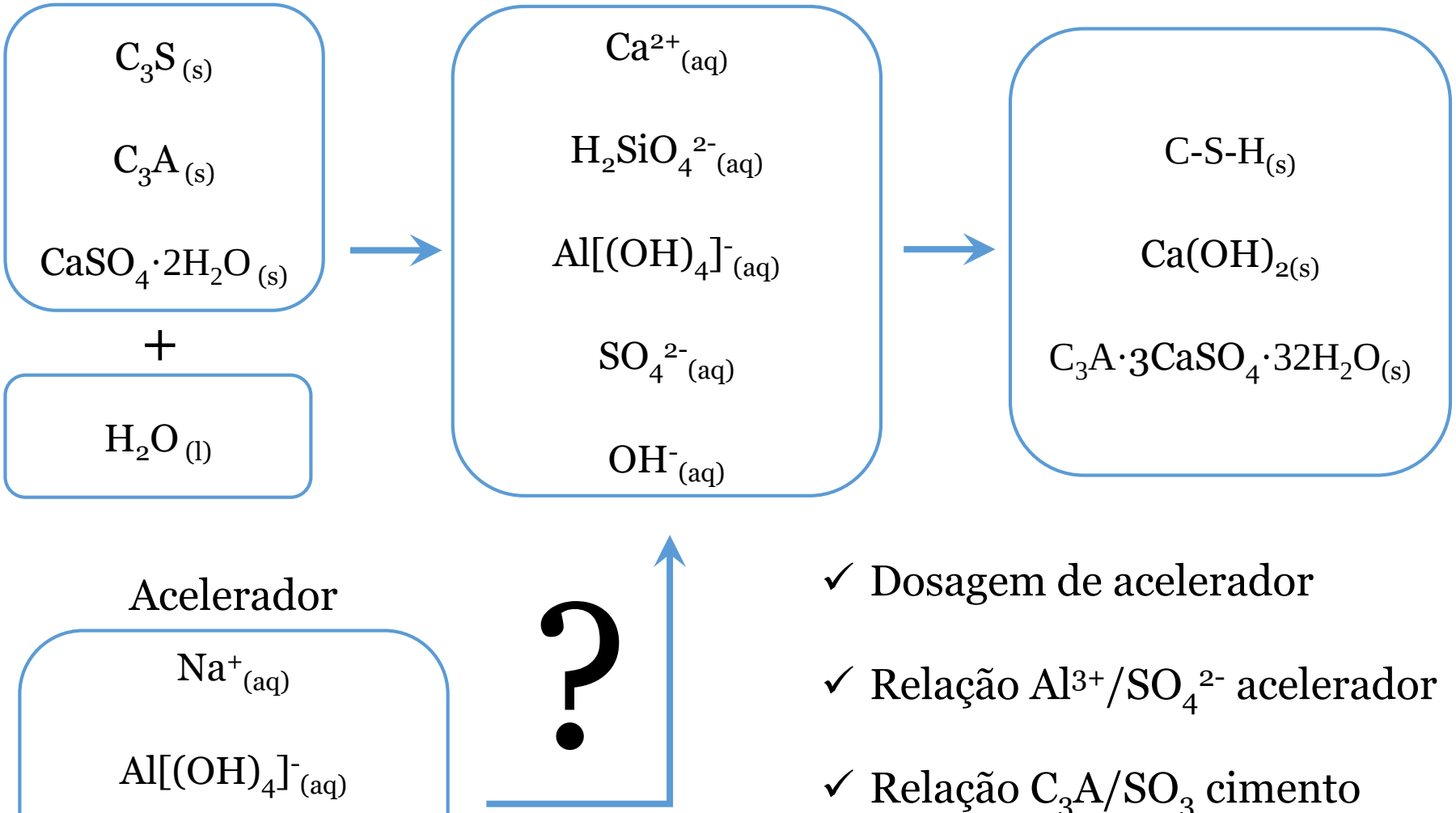
Composição	Modo de ação	Dosagem (% smc)	Desvantagem
Carbonatos de metais alcalinos	Aceleram a hidratação da alita	2,5 - 6,0	Perda de resistência última (30 - 40%)
Silicatos de metais alcalinos	Precipitação de C-S-H	> 10,0	Não promove alto ganho de resistência inicial
Aluminatos de metais alcalinos	Formação de etringita e AFm	2,0 - 5,0	Perda de resistência última (20 - 25%), alto teor de álcalis
Sulfato de alumínio (livre de álcalis)	Formação de etringita	3,0 - 10,0	Não promove resistência inicial como os aluminatos

Item	Sulfato de alumínio	Aluminato de sódio
Fonte de alumínio	Sulfato de alumínio, hidróxido de alumínio	Hidróxido de alumínio
Solubilizante	Ácido (fórmico, fosfórico, acético)	Hidróxido de sódio
Relação Al^{3+}/SO_4^{2-}	0,40 - 0,65	-
pH	2 - 3	12
% de sólidos	45 - 50	38 - 40

Como definir qual cimento e acelerador utilizar?

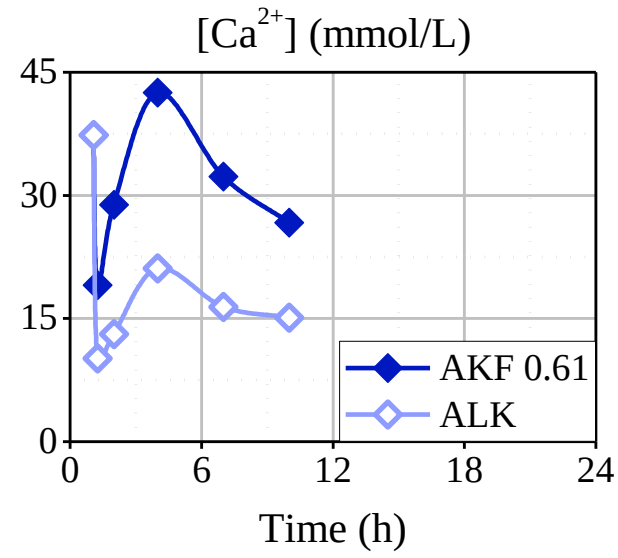
A compatibilidade entre cimento e acelerador é o princípio químico fundamental para o desenvolvimento de resistência mecânica!

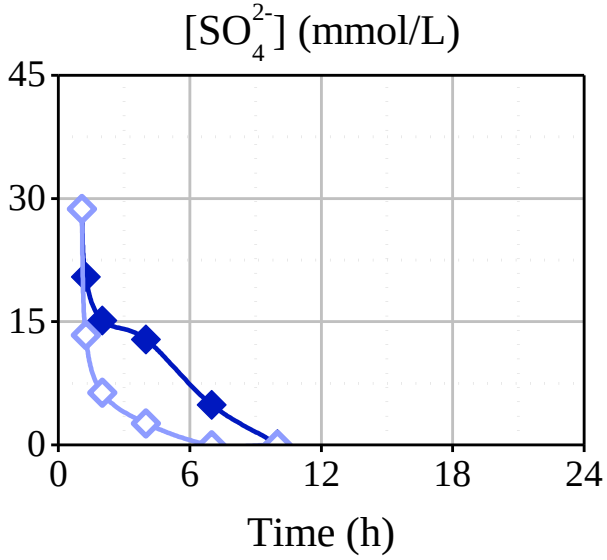
Teste de campo obrigatório!

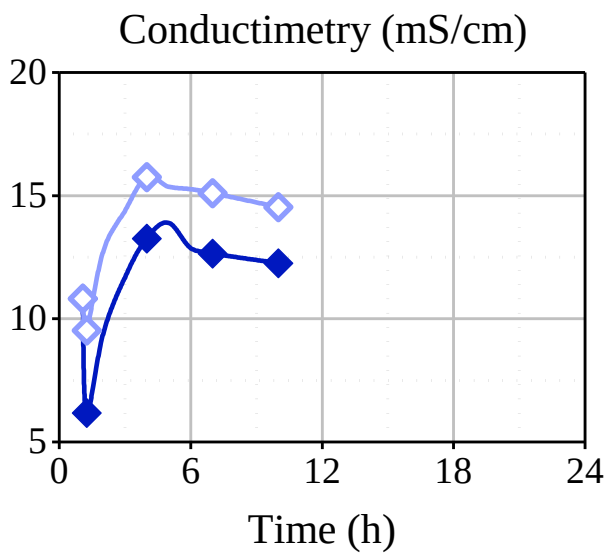


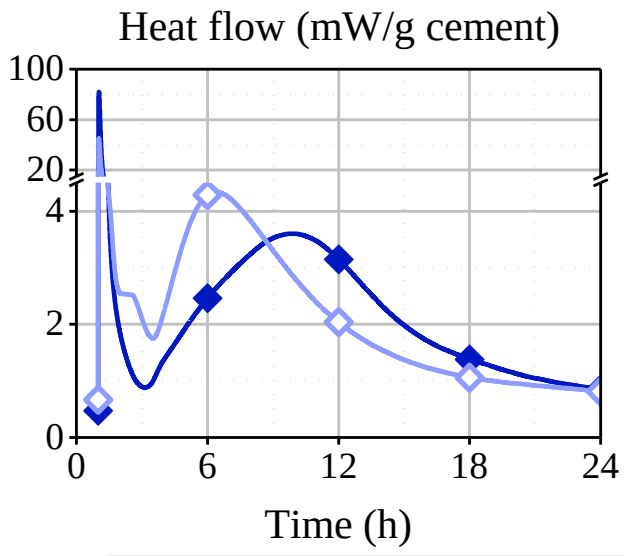
- ✓ Dosagem de acelerador
- ✓ Relação Al^{3+}/SO_4^{2-} acelerador
- ✓ Relação C_3A/SO_3 cimento
- ✓ Relação Al^{3+} acelerado / SO_4^{2-} dissolvido no meio

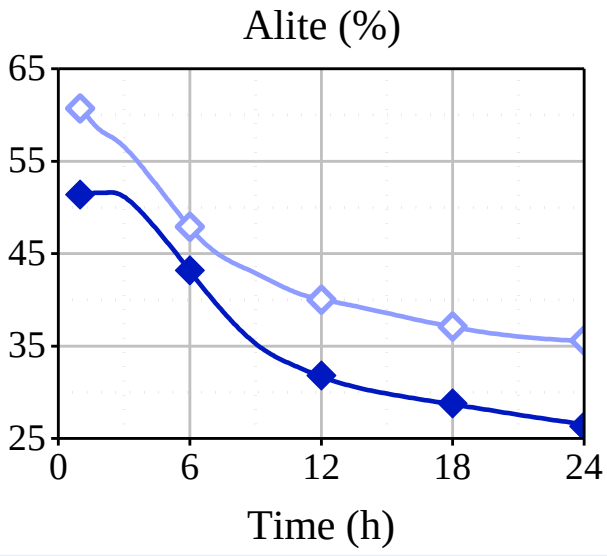
Análise da fase líquida, DRX e calorimetria - aluminato de sódio

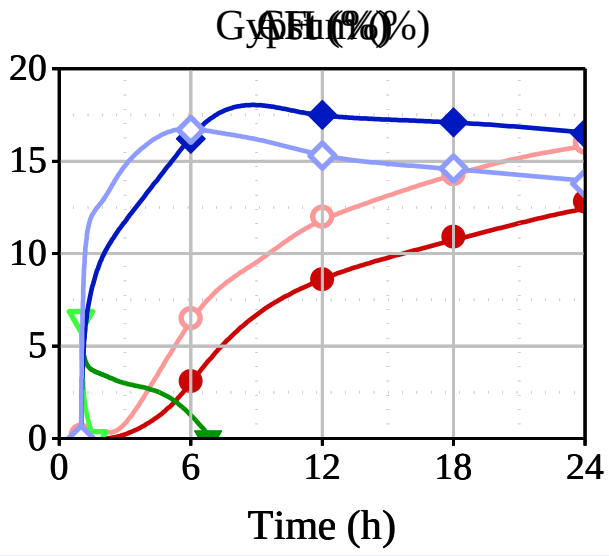












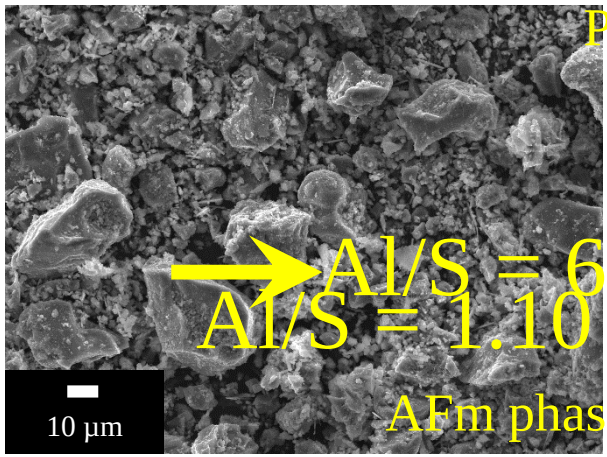
Reference (no accelerator)

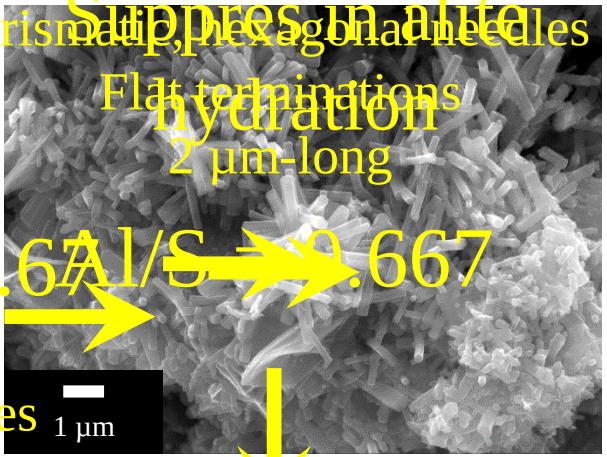
Alkali-free accelerator

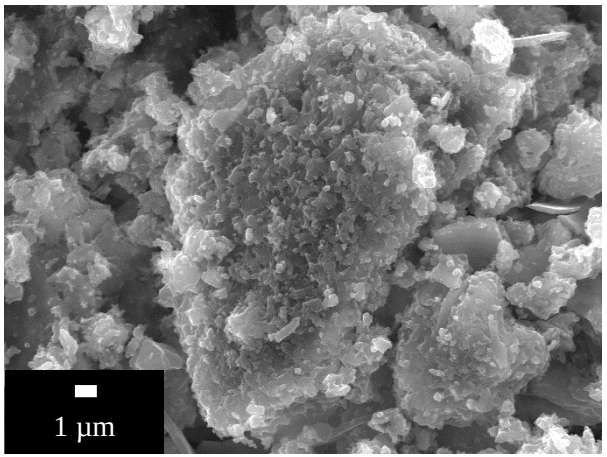
Alkaline accelerator

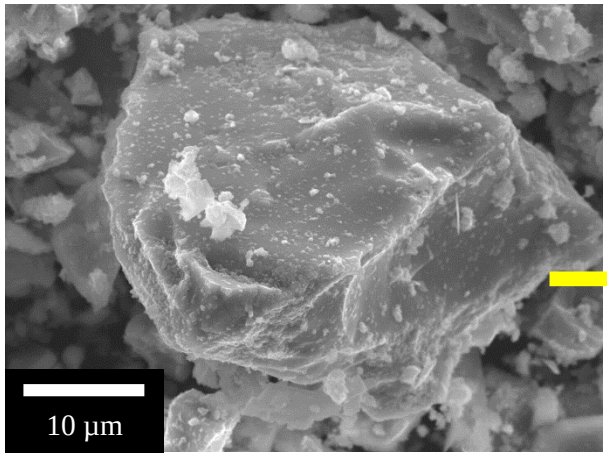
15 min

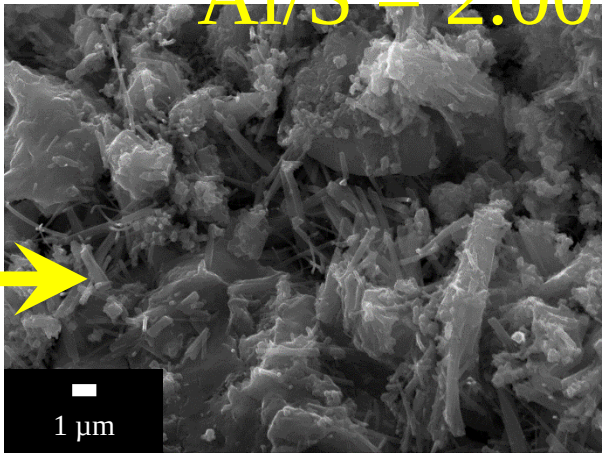
3 h

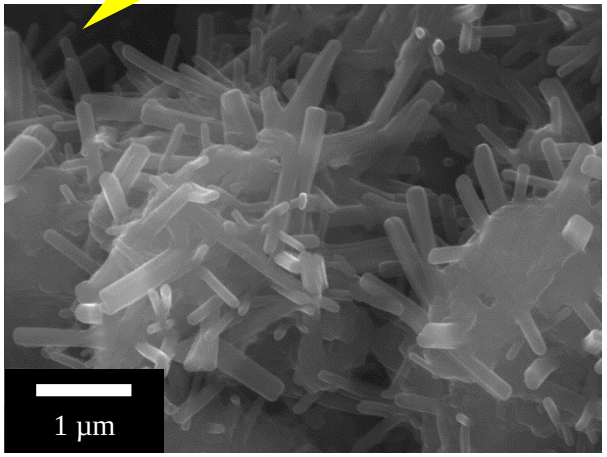












Al/S = 6.67

Al/S = 1.10

AFm phases

(C-A-H)

Suppres in alite hydration

Prismatic, hexagonal needles

Flat terminations

2 µm-long

Al/S = 0.667

Al/S = 2.00

Como o processo de mistura influencia a cinética de hidratação?



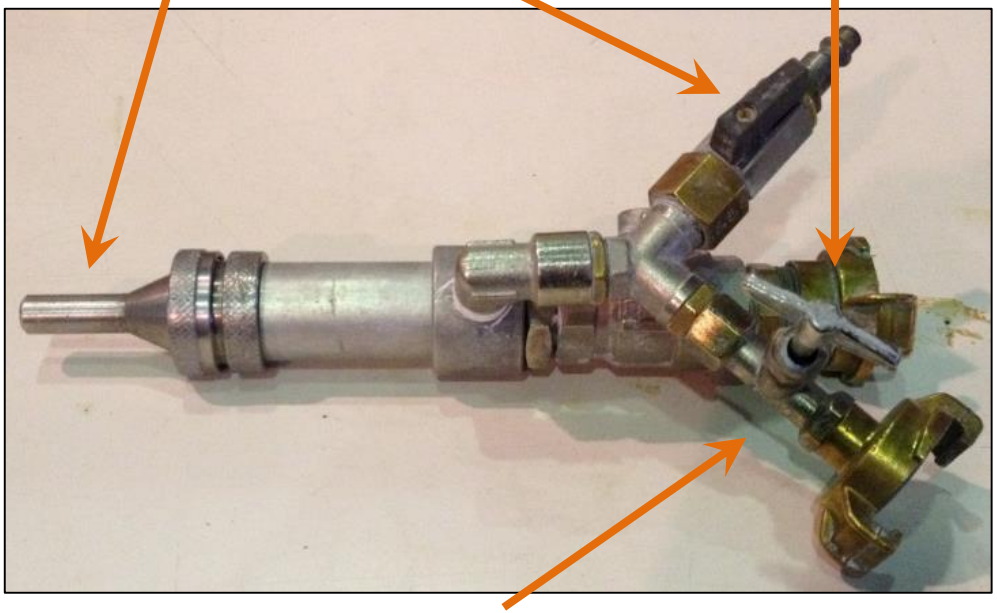

etalco


12
10
11

Outlet of sprayed paste

Inlet of compressed air

Inlet of cement paste



Inlet of accelerator

Inner diameter: 6.0 mm

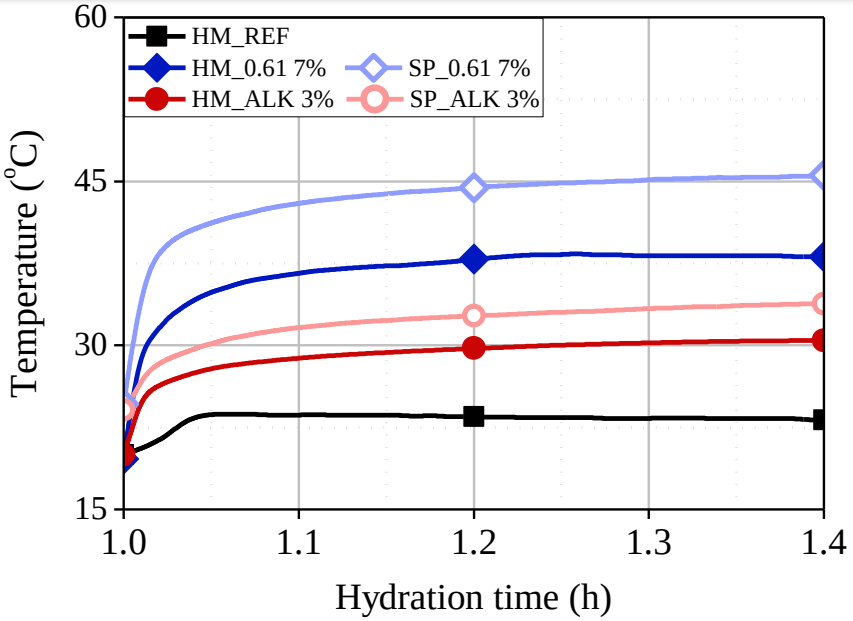


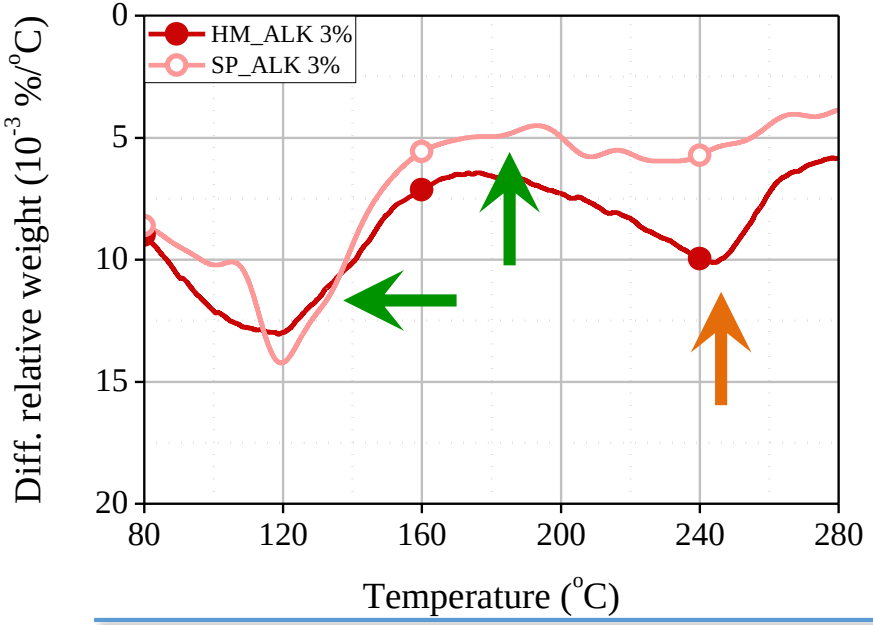
Ext. cylinder. Height: 30.0 mm

Base diameter: 14.0 mm



Inlet of accelerator and compressed air





T > 30 ºC

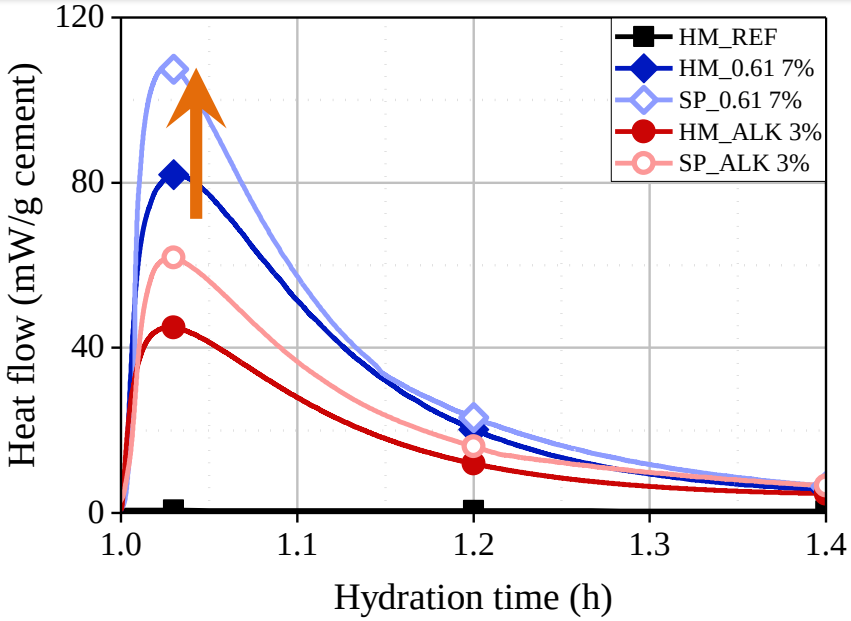
↑ solubility C_3A

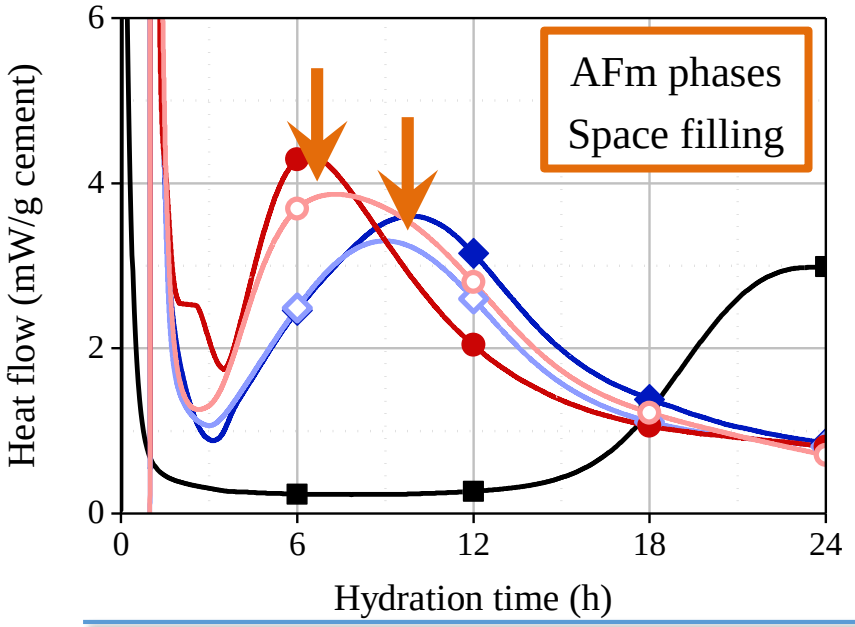
↓ solubility gypsum

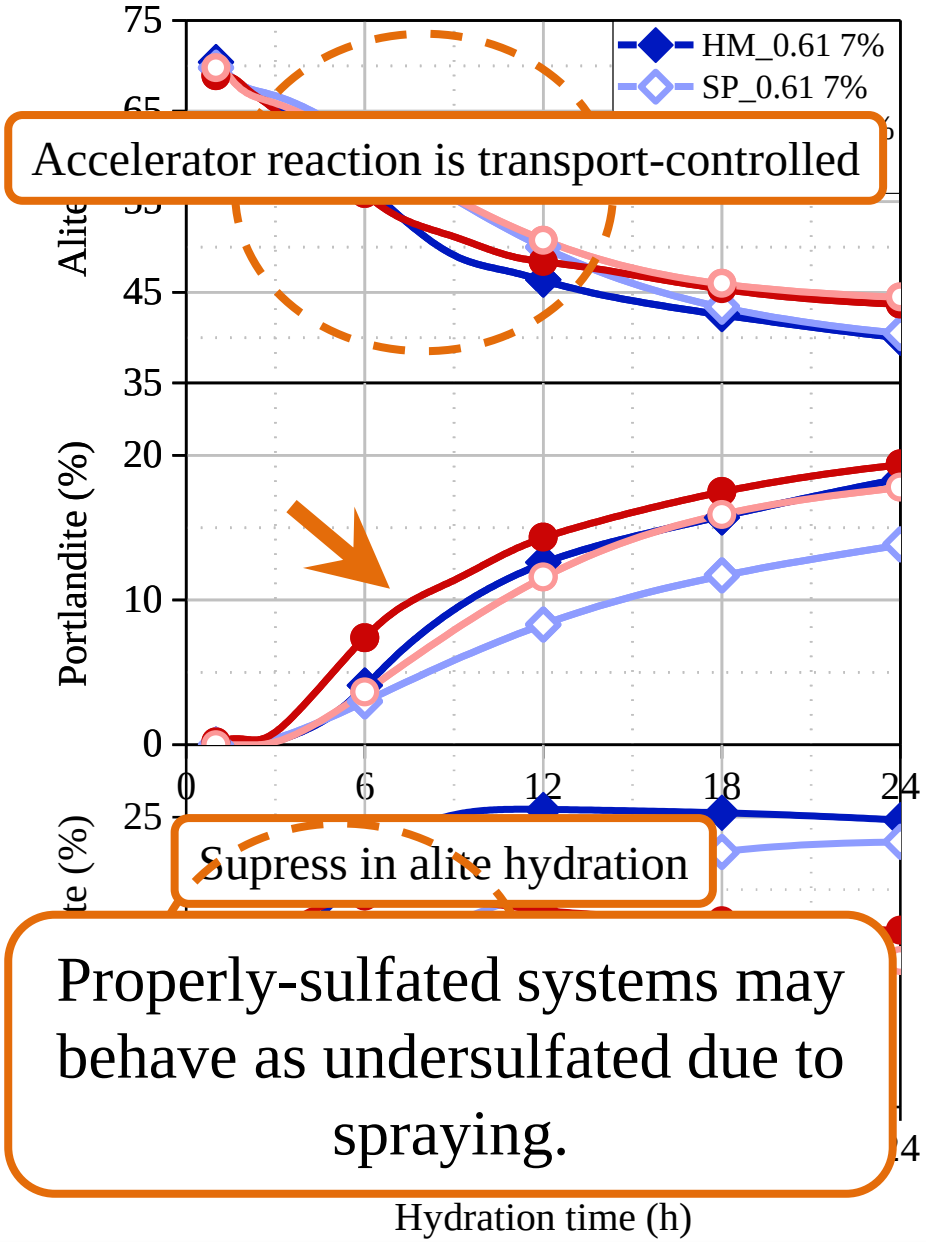
AFm phases

Monosulfoaluminate

Aluminum hydroxide
(column in ettringite)


HM_REF
HM_0.61 7%
SP_0.61 7%
HM_ALK 3%
SP_ALK 3%
Heat flow (mW/g cement)
Hydration time (h)

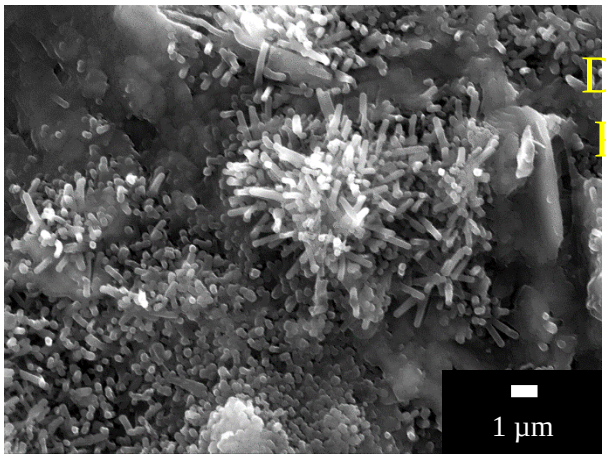

AFm phases
Space filling
Heat flow (mW/g cement)
Hydration time (h)


HM_0.61 7%
SP_0.61 7%
Accelerator reaction is transport-controlled
Portlandite (%)
Supress in alite hydration
Properly-sulfated systems may behave as undersulfated due to spraying.
Hydration time (h)

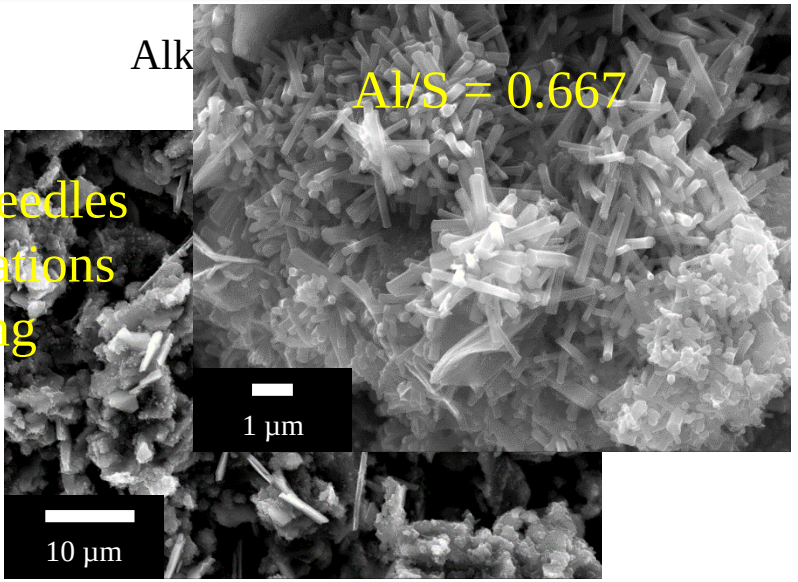
Alkali-free accelerator

Alk

15 min



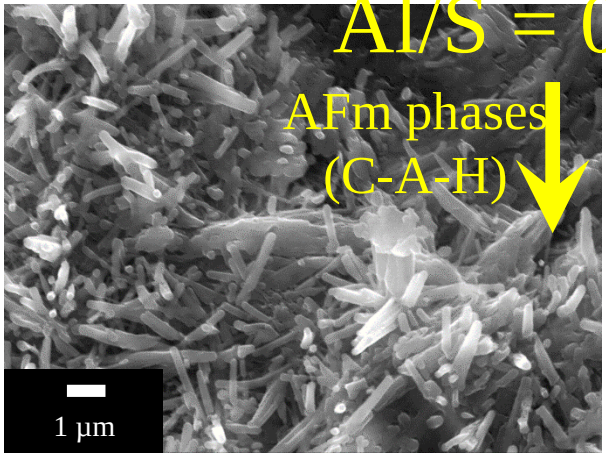
Disarranged needles
Round terminations
1.5 µm-long

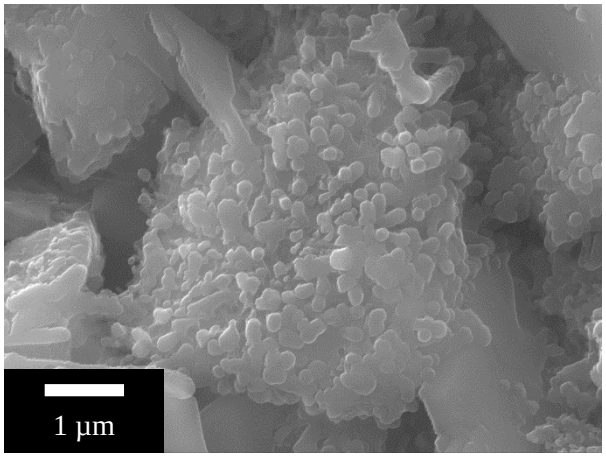


Al/S = 7.05

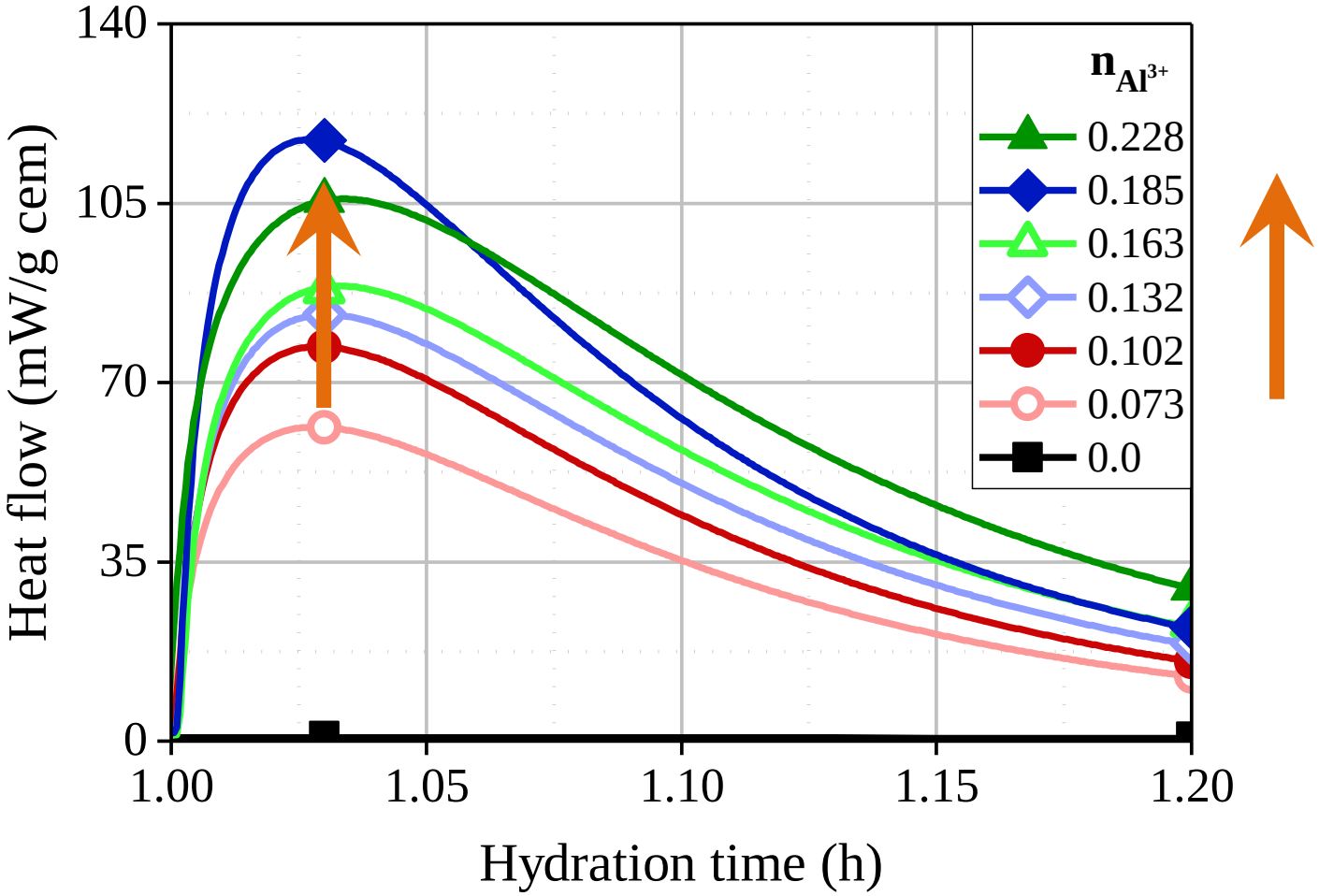
Al/S = 0.933

3 h



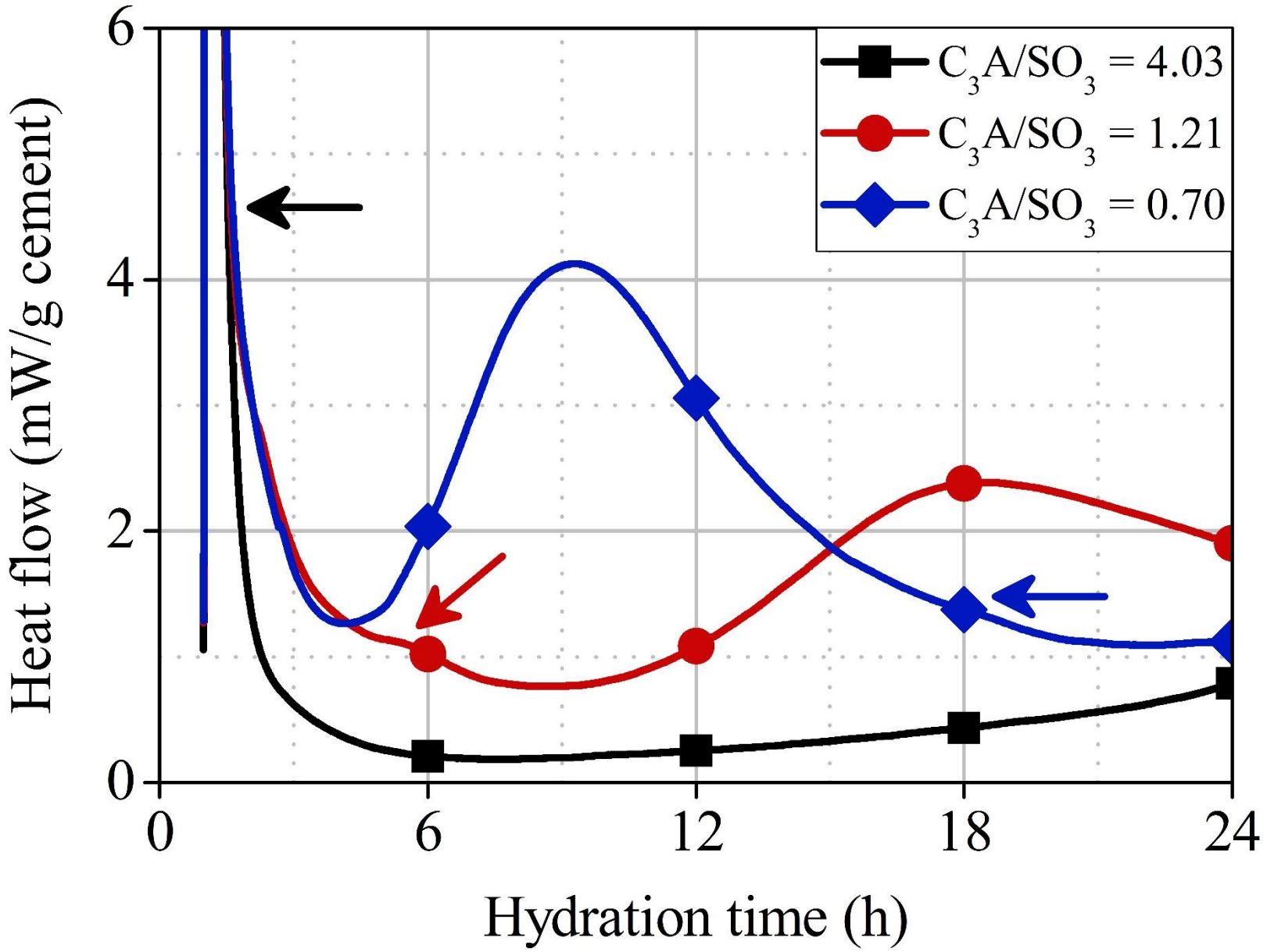


Como a composição química do cimento e do acelerador afeta a evolução da hidratação e da resistência mecânica?

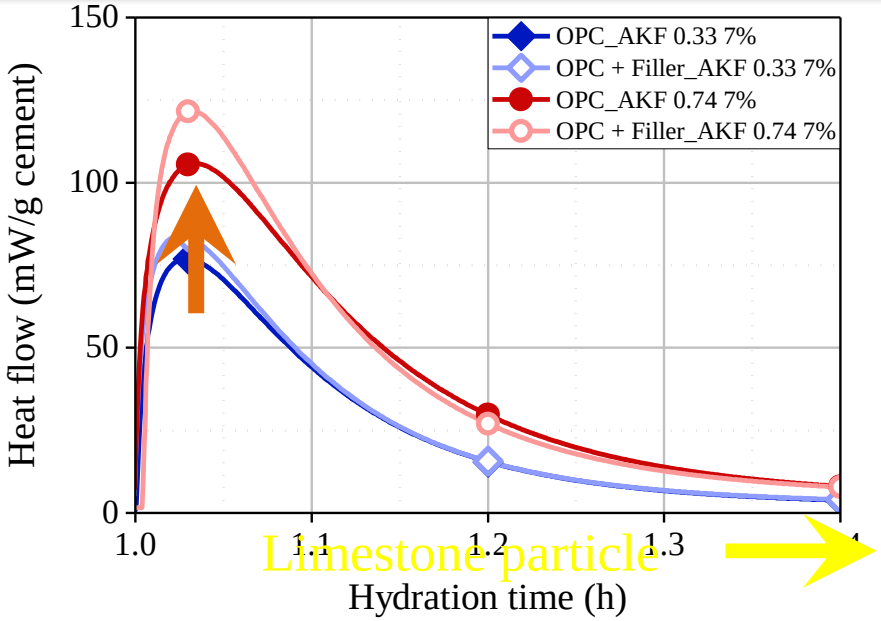


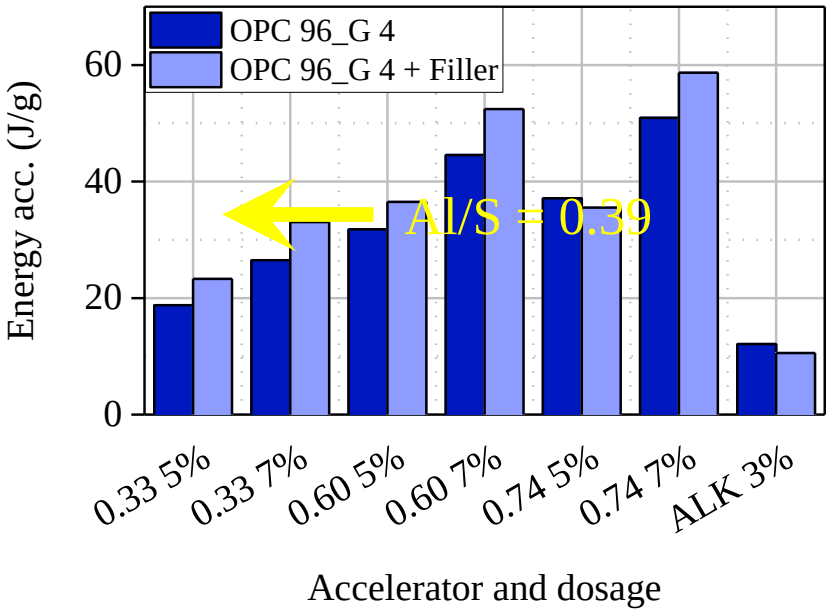
Accelerator reactivity, setting rate ∝ $[Al^{3+}]$

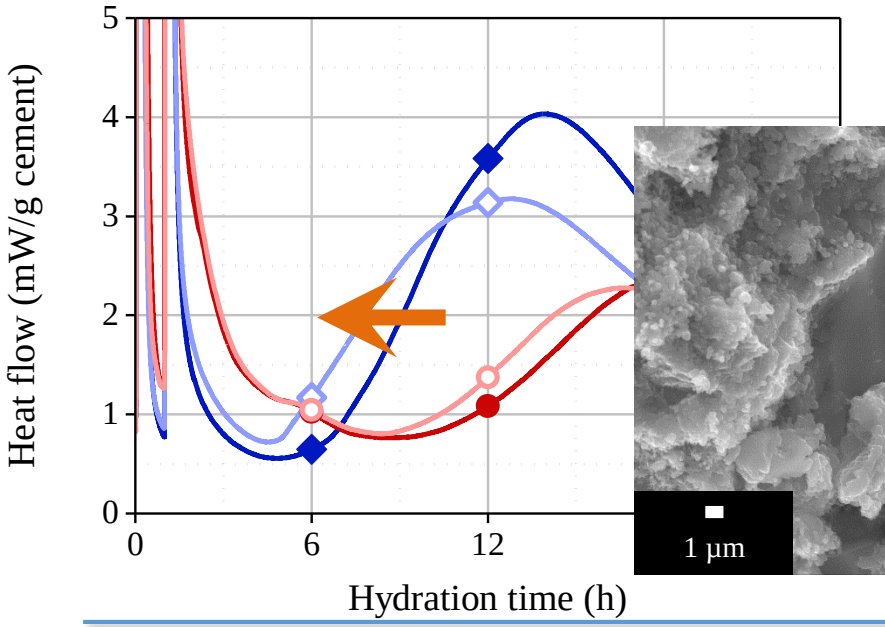
$0.12 < Al^{3+} < 0.18$ mmol/g cement

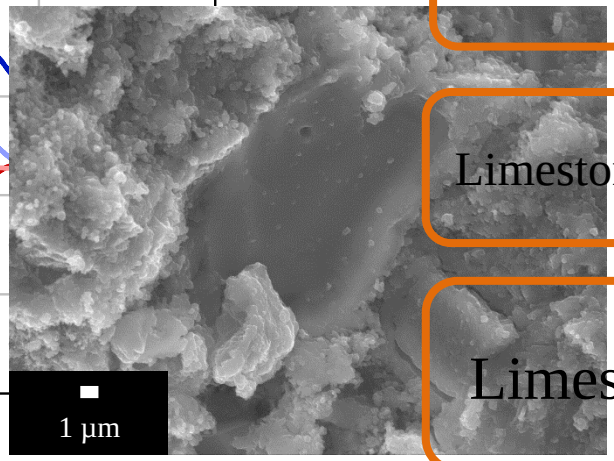

Heat flow (mW/g cement)
Hydration time (h)
0
2
4
6
0
6
12
18
24
C3A/SO3 = 4.03
C3A/SO3 = 1.21
C3A/SO3 = 0.70

Uso de filer calcário





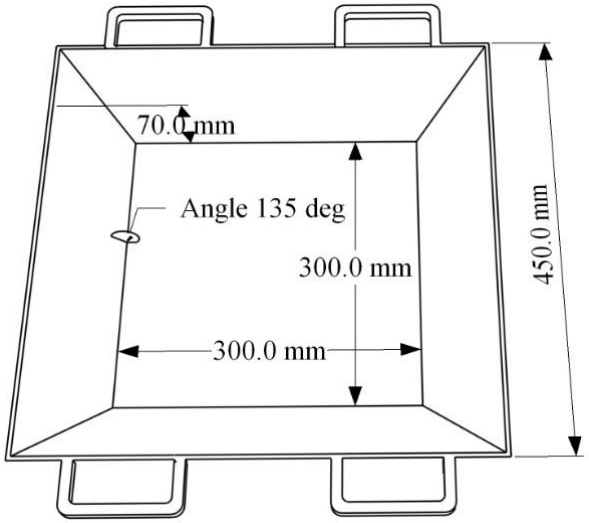


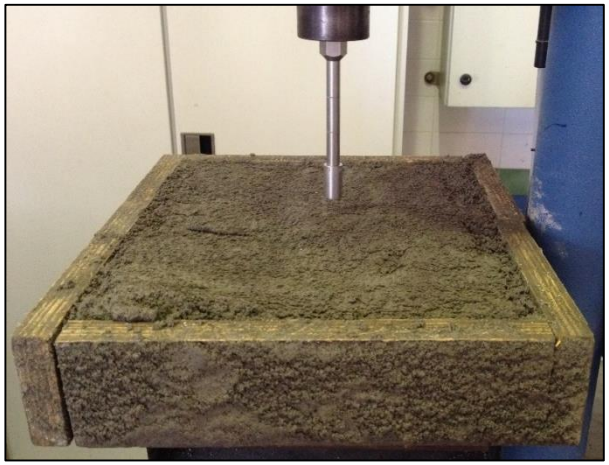


Limestone filler accelerates setting

Limestone filler accelerates hardening

Limestone filler is beneficial

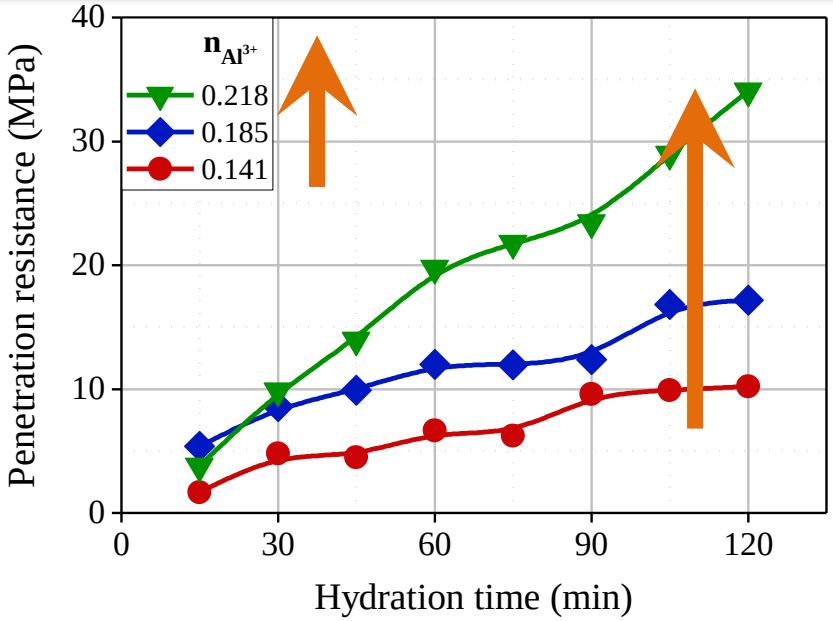

70.0 mm
Angle 135 deg
300.0 mm
300.0 mm
450.0 mm

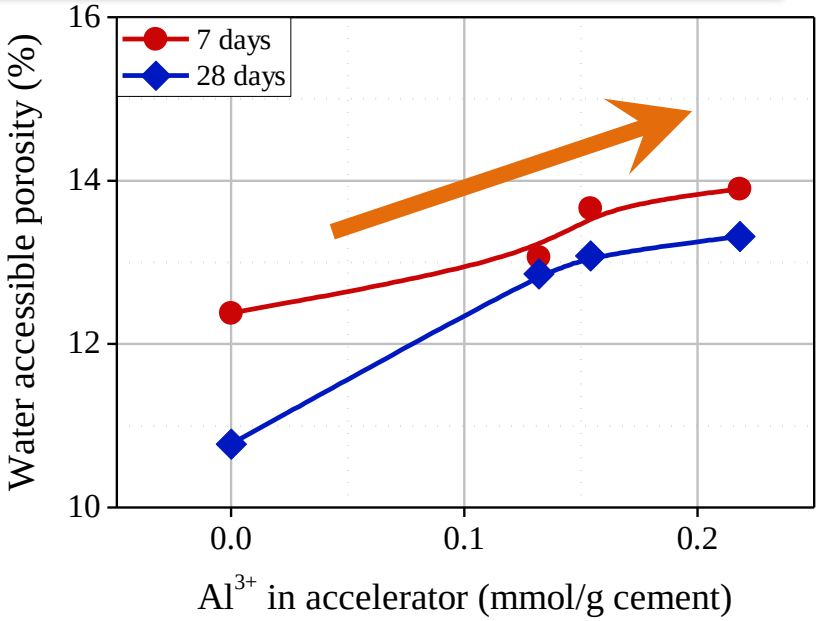


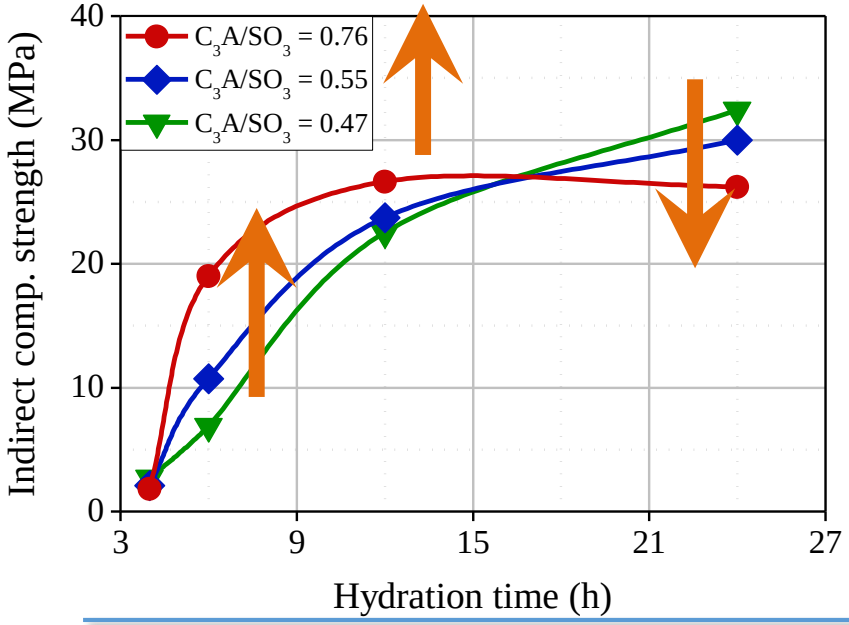


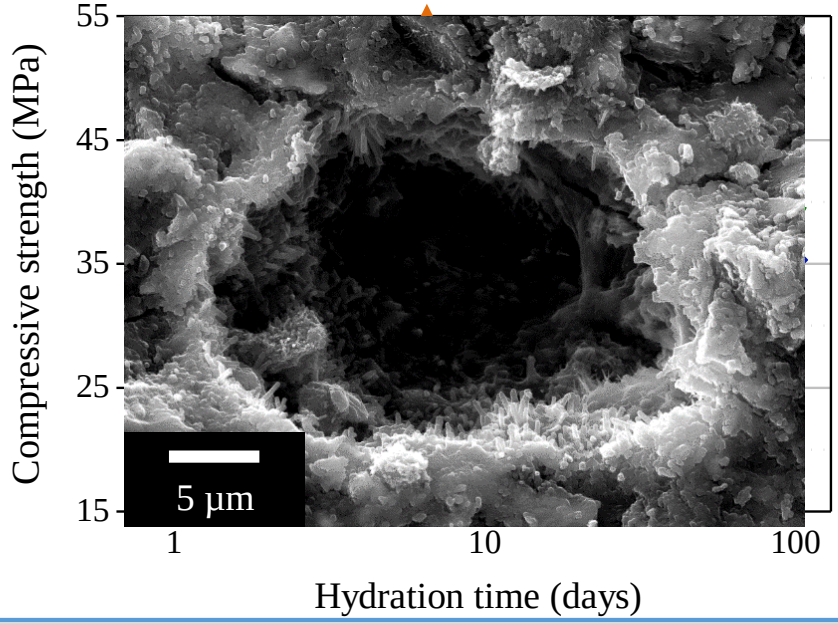


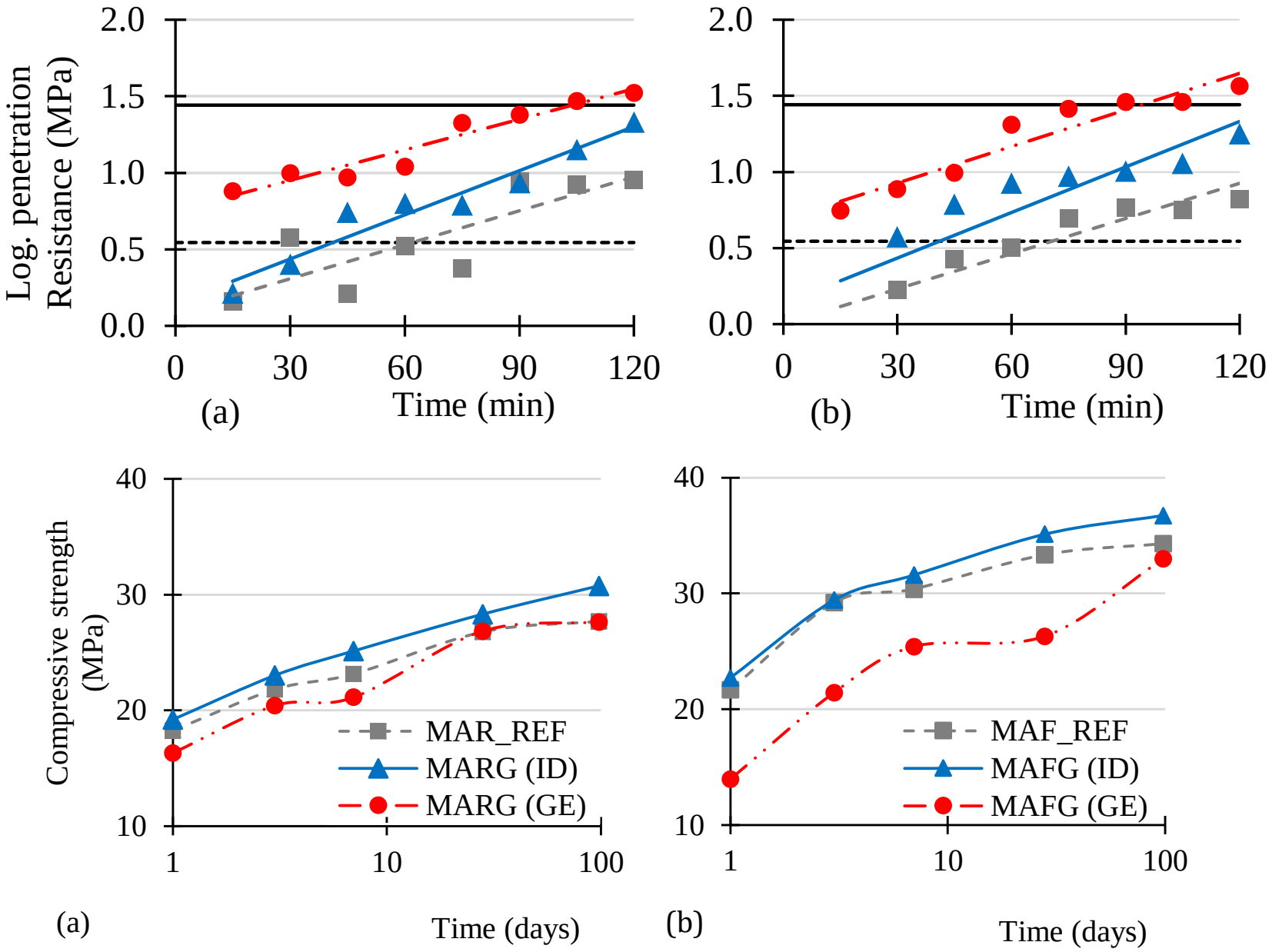



Penetration resistance (MPa)
Hydration time (min)
$n_{Al^{3+}}$
0.218
0.185
0.141
0
10
20
30
40
0
30
60
90
120

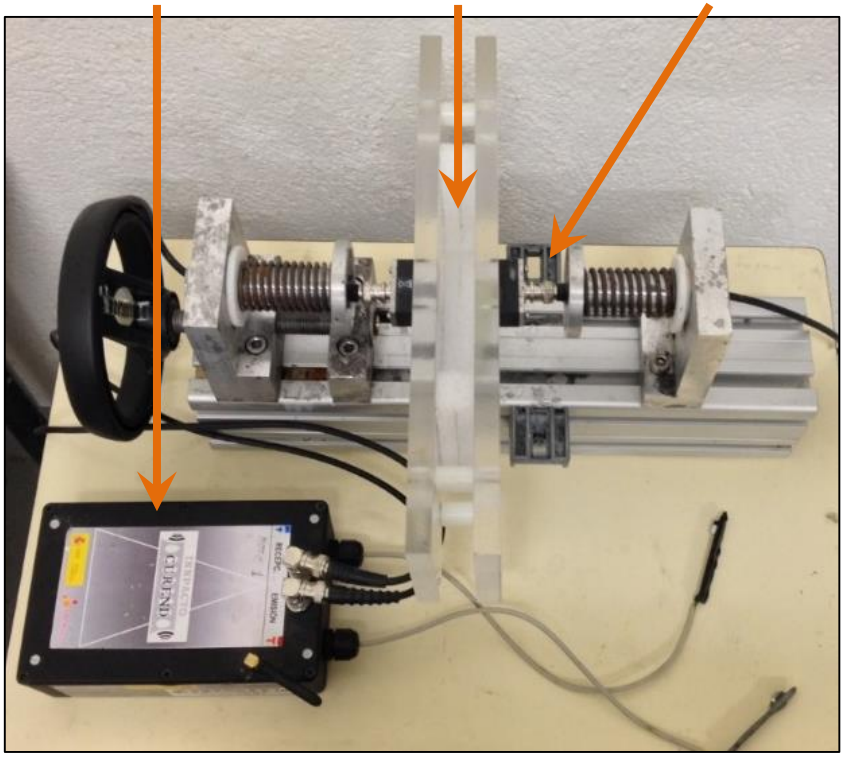

Water accessible porosity (%)
Al^{3+} in accelerator (mmol/g cement)
7 days
28 days
10
12
14
16
0.0
0.1
0.2


Indirect comp. strength (MPa)
Hydration time (h)
C_3A/SO_3 = 0.76
C_3A/SO_3 = 0.55
C_3A/SO_3 = 0.47
0
10
20
30
40
3
9
15
21
27

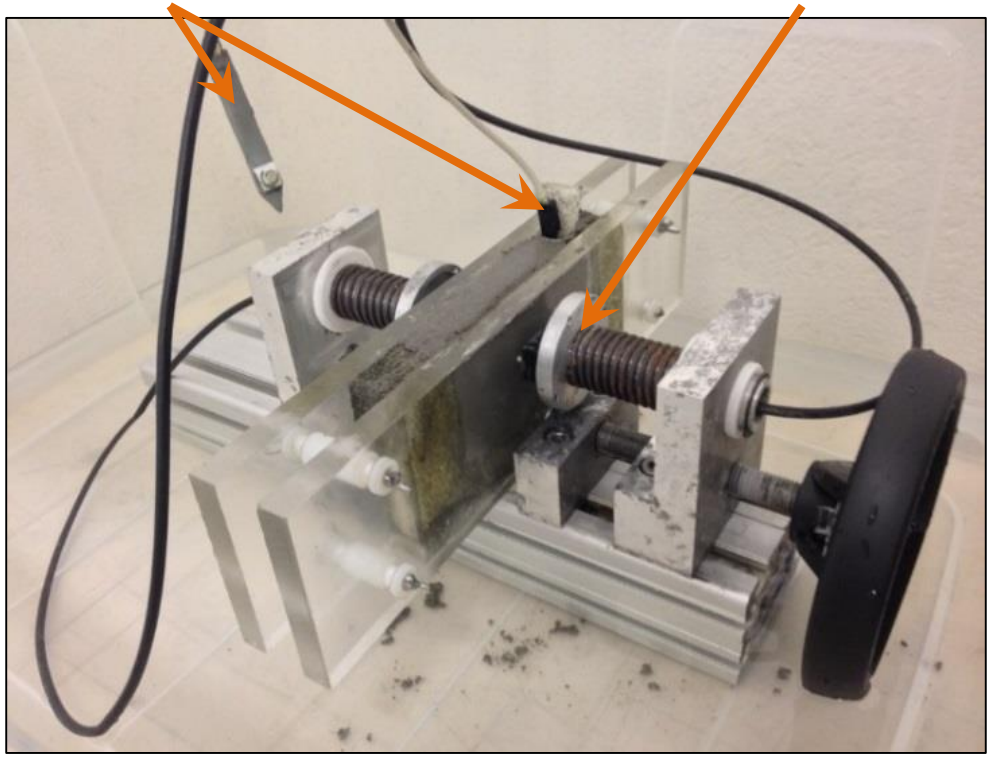

Compressive strength (MPa)
Hydration time (days)
5 µm
15
25
35
45
55
1
10
100

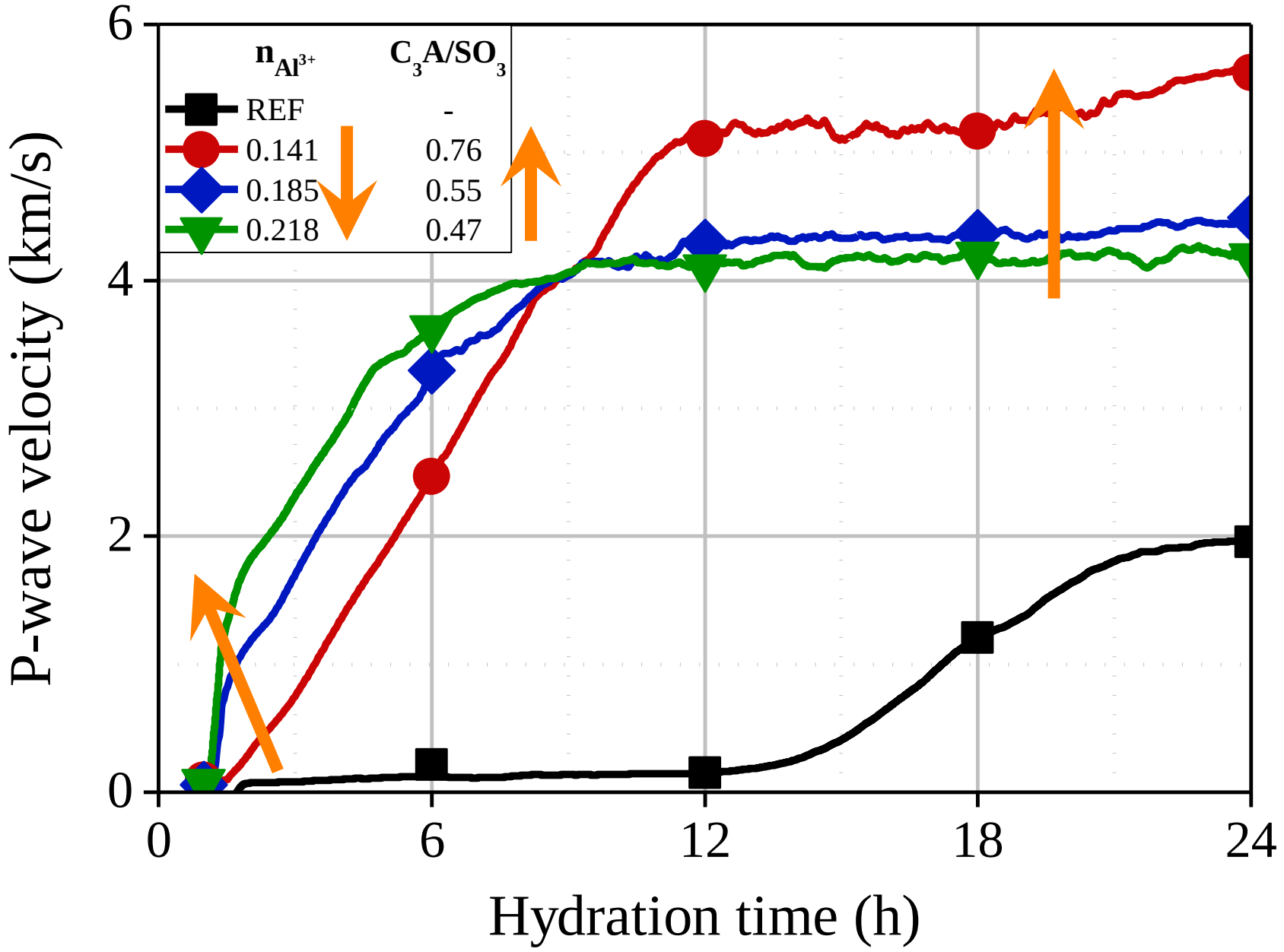

Log. penetration Resistance (MPa)
2.0
1.5
1.0
0.5
0.0
0
30
60
90
120
Time (min)
(a)
(b)
Compressive strength (MPa)
40
30
20
10
1
10
100
Time (days)
MAR_REF
MARG (ID)
MARG (GE)
MAF_REF
MAFG (ID)
MAFG (GE)

WilTempUS Mold Transducer



T/RH sensors Coupling device




$n_{Al^{3+}}$
C_3A/SO_3
REF -
0.141 0.76
0.185 0.55
0.218 0.47
P-wave velocity (km/s)
Hydration time (h)
0
2
4
6
0
6
12
18
24

1) Avaliação primária de reatividade e compatibilidade pode ser realizada em pastas, por calorimetria.

2) Determinação de resistência mecânica deve ser feita em teste de campo, obrigatoriamente.