ANNA MARIA WORKSHOP XII
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Two kinds of non-traditional fly ash as concrete components

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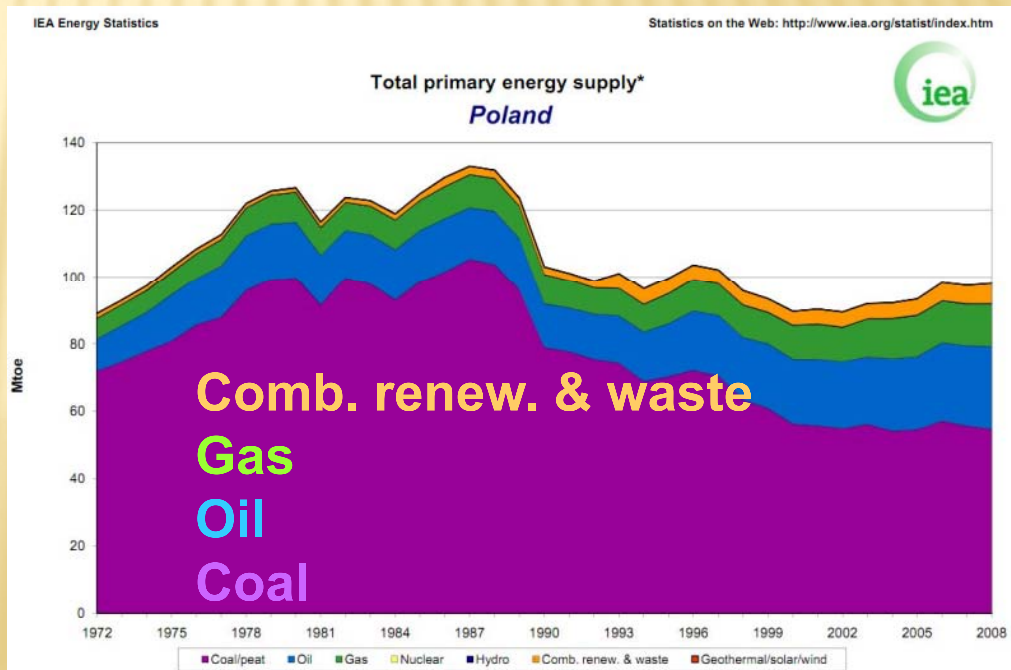
The situations in energy resources and tradition in USA and Poland are similar:

- Coal is the largest domestic energy resource — enough to last 250 years at current rates of use

- Coal was traditionally the largest single source of electricity generation, currently providing more than 50 percent of the total, and will continue to be the primary generator of electric power for years to come.



Total primary energy supply in Poland

Production of non-standard coal ash in Poland

European (EU 27) production of coal combustion products : 100 Mio t/year

Production of fly ash in Poland: about 13.4 Mio t/year

- **from hard coal – 7.11 Mio t/year**
- **from lignite – 6.3 Mio t/year**

Non-standard fly ash

- **High calcium fly ash from lignite: about 5 Mio t/year**
- **Fluidized bed combustion fly ash: about 2 Mio t/year**

Fluidized Bed Combustion Fly Ash and

High Calcium Fly Ash

do not meet the requirements defined by European Standard EN 450 to be used for cement or concrete production

FBCFA and **HCFA** do not conform to standard requirements as a concrete additive type II (pozzolanic or latent hydraulic mineral additive), European Standard EN 206

Accordingly, it has to be treated on a case-by-case basis in relation to its application

Two research projects in our group at IFTR:

- **2006-2010** Application of fly ash from Circulating Fluidized Bed Combustion in structural concretes; IFTR + 5 groups from Tech. Universities

-**2010-2013** Application of High Calcium Fly Ash as a part of binders for concretes; IFTR + 2 groups from Tech. Univ. + industrial partners

- reduction of Portland cement consumption, therefore reduction of CO_2 emission;
- reduction of useless waste materials stocked in landfills;
- extension of resources of raw materials for cement and concrete industry;
- reduction of cost of binders for concrete.

Properties of tested fly ashes

Constituent	ASTM C618		EN 450	CFBC fly ash		HC fly ash (from lignite)		
	F	C	Type II concrete additive*	from hard coal	from lignite	I	II	III
Σ SiO_2, Al_2O_3, Fe_2O_3, min. %	70	50	70	79.6	69.27	58.05	63.37	70.12
SO_3, max. %	5	5	3	3.62	3.8	4.33	4.22	3.07
Na_2O	max % 1.5	max % 1.5	max % 5 (Na_2O_{eq})	1.18	1.64	0.31	0.16	0.15
CaO free, max. %	-	-	2.5	0.3	1.4	3.43	1.24	1.46
Loss on ignition 1000°C/1h, max. %	6÷12	6	5	3.4	2.73	2.56	3.43	1.85

*inorganic addition, pozzolanic or latent hydraulic addition

Fly Ash
from
Circulating Fluidized Bed Combustion

Research project 2006 – 2010

- mixture composition and workability
- mechanical properties (strength, Young's modulus, etc.)
- stability of the pore microstructure in the fresh mix
- resistance against carbonation
- corrosion of steel reinforcement
- resistance against chloride ions penetration
- frost resistance
- bond to steel and non-metallic reinforcement

FBCFA - mixture composition

A	B	C
OC	HSC	air-entrained
w/b = 0.55	w/b = 0.45	w/b = 0.45
C=320 kg/m^3	C=360 kg/m^3	C=380 kg/m^3

Replacement of 0%, 15% and 30% of cement mass by CFBC fly ash from hard coal and from lignite

Fluidized Bed Combustion Fly Ash

Positive effects:

- Increase of long term compressive strength by 10%
- Non-steady chloride migration coefficient is decreasing with CFBCFA content
- Concrete resistivity is increasing with CFBCFA content
- Corrosion of steel reinforcement – more efficient cover
- Bond to steel and non-metallic reinforcement – no effect!

Negative effects:

- Scaling resistance is decreasing with increased CFBCFA content and unburned carbon
- Addition of CFBCFA slightly increases the depth of carbonation
- Required microstructure of air entrained voids is more difficult to be obtained but possible

High Calcium Fly Ash

Research project 2010 – 2013

- longterm monitoring of the HCFA
- mixture composition and workability
- rheological properties
- mechanical properties (strength, Young's modulus, etc.)
- stability of the pore microstructure in the fresh mix and air void system in hardened concrete
- resistance against carbonation
- resistance against chloride ions penetration
- freeze-thaw and deicing salt resistance
- air and water permeability

Properties of high calcium fly ash

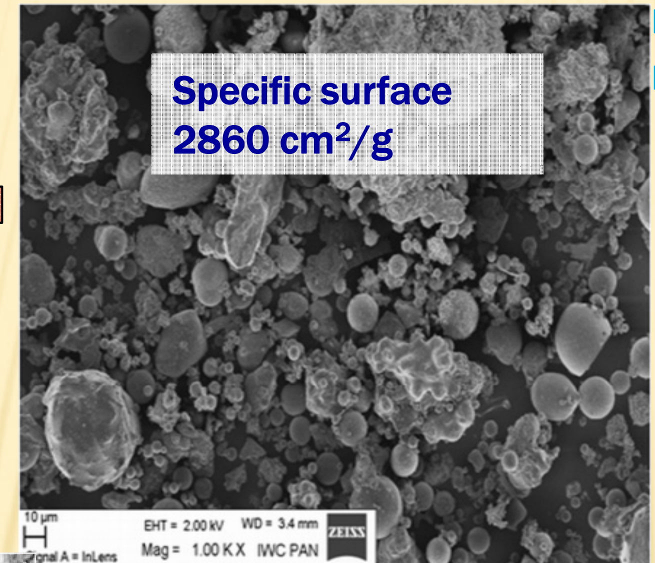
additional milling

HCFA	Fly ash designation	Density [g/cm^3]	Fineness – the residue on sieve 45μm [%]	Specific surface by Blaine [cm^2/g]
First delivery S1	S1-N : unprocessed	2.62	38.0	2860
	S1-10M: grinded 10 min	2.77	23.0	3500
	S1-28M: grinded 28 min	2.75	10.5	3870
Second delivery S2	S2-N: unprocessed	2.58	35.4	4400
Third delivery S3	S3-N: unprocessed	2.64	55.6	1900
	S3-20M: grinded 20 min	2.71	20.0	4060

Shape and grain size of the HCFA

First delivery

grain size [μm]: mainly below 20
max 60
min below 2

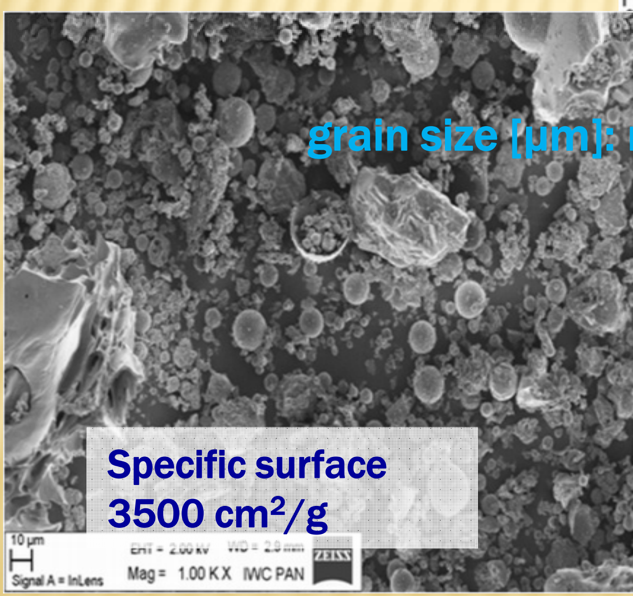


Milling during

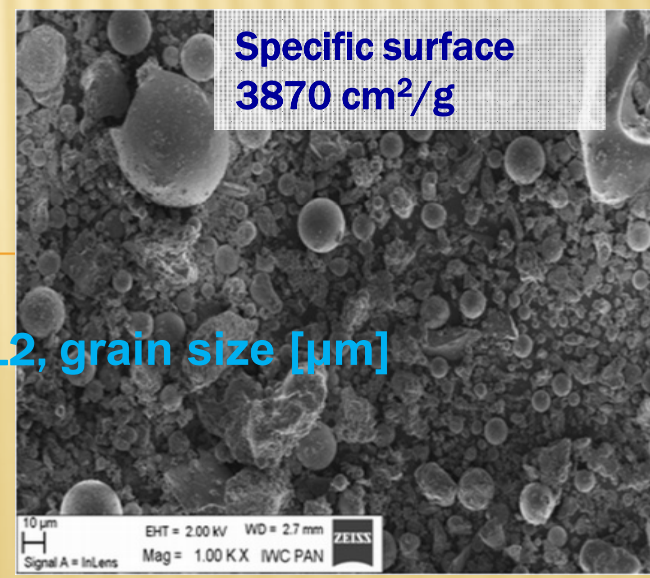
10 minutes

Milling during

28 minutes



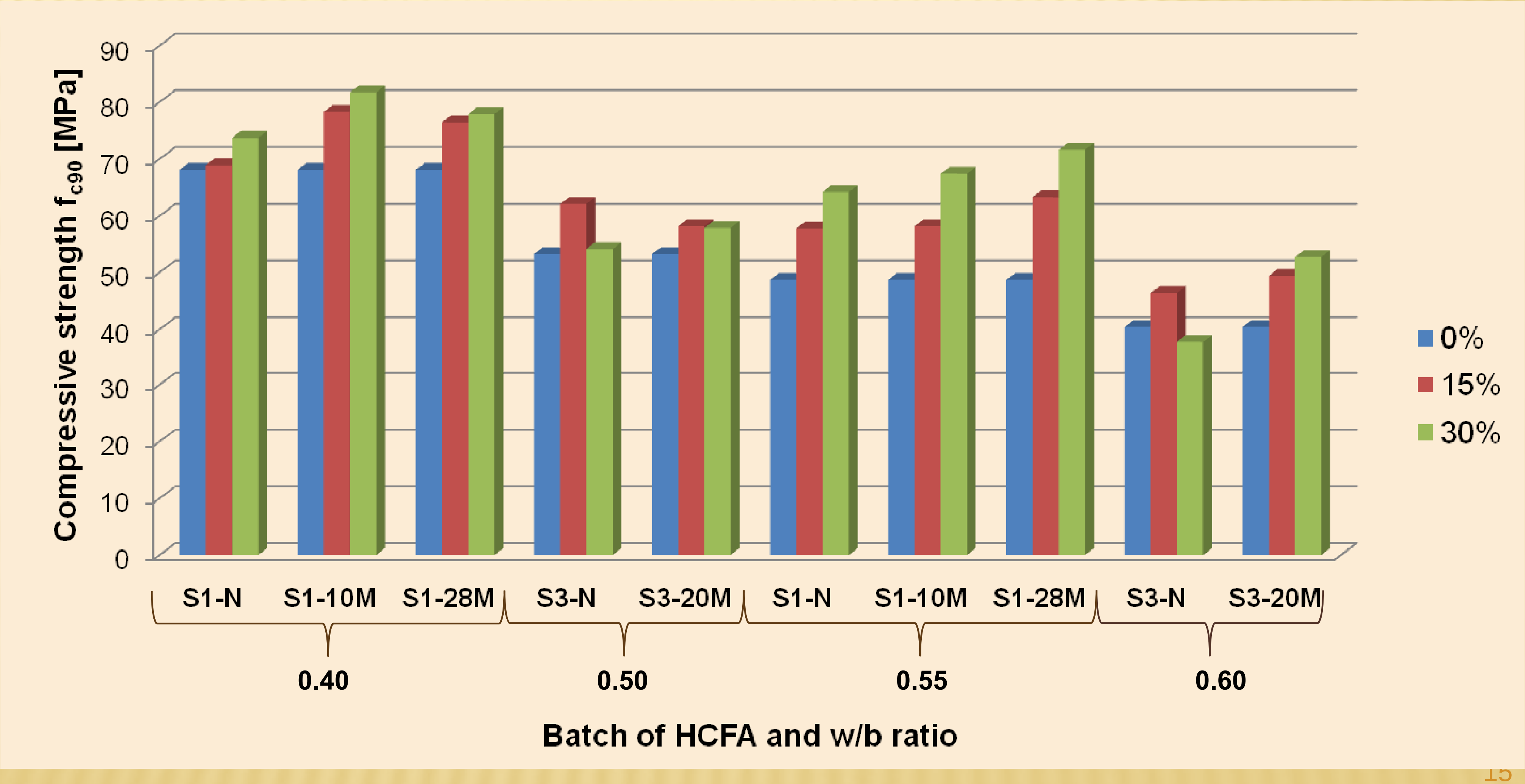
grain size [μm]: mainly below 16
max 24
min below 2



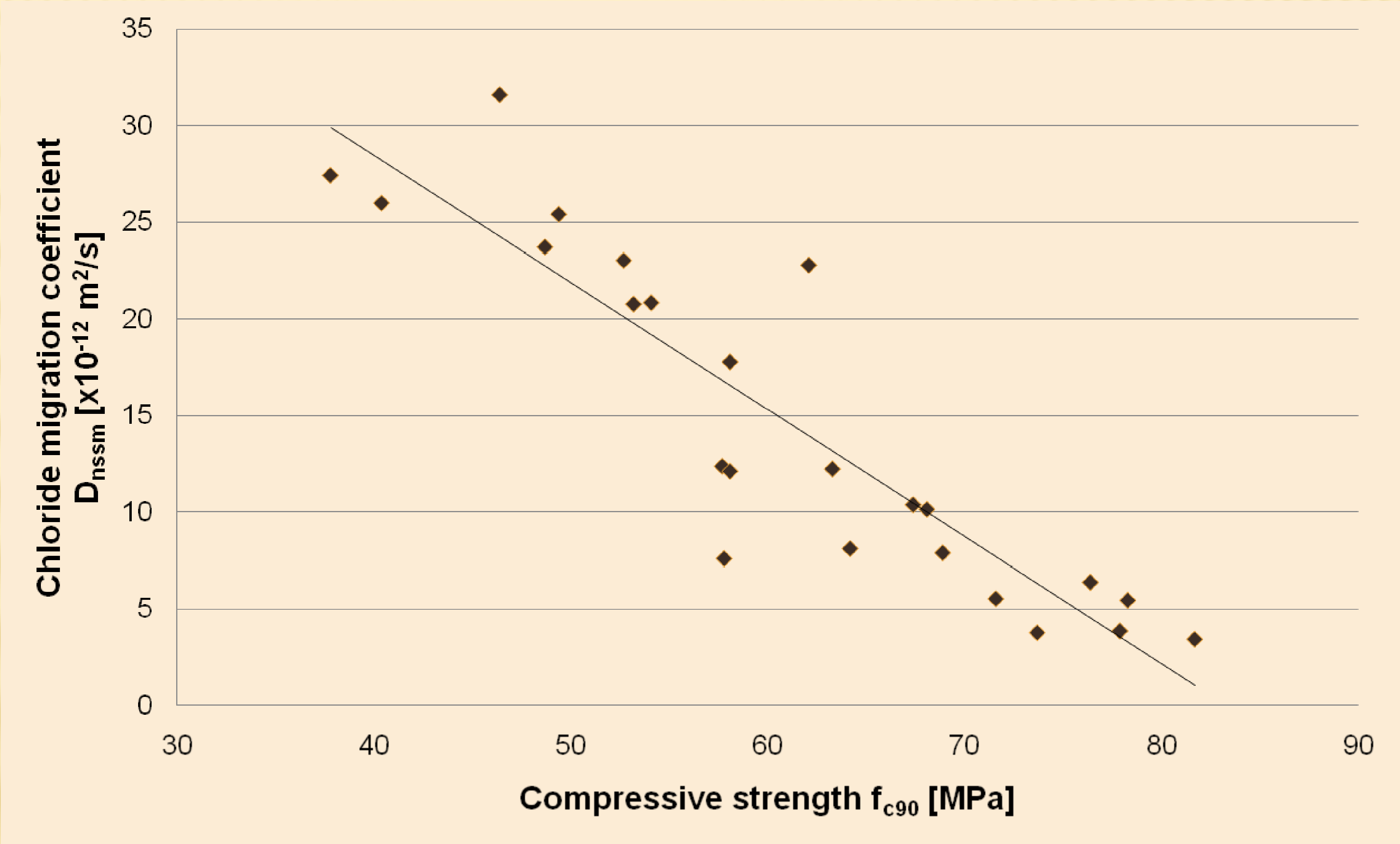
mainly below 12, grain size [μm]
max 20
min below 2

PARTIAL RESULTS – High Calcium Fly Ash

The influence of HCFA type and content on the compressive strength f_{c90} for concrete made with CEM I 42.5R for w/b =0.45, 0.50, 0.55 and 0.60



PARTIAL RESULTS – High Calcium Fly Ash

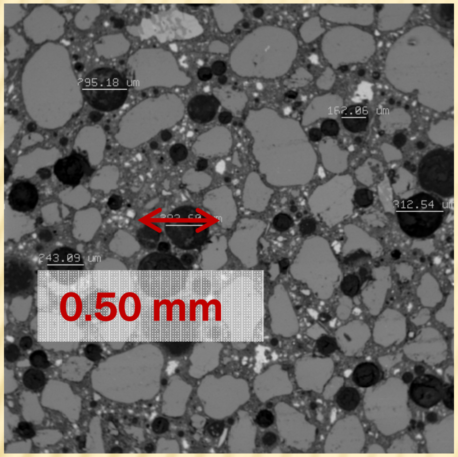


The relationship between average values of chloride migration coefficient D_{nssm} and compressive strength f_{c90} for concrete made with CEM I 42.5R

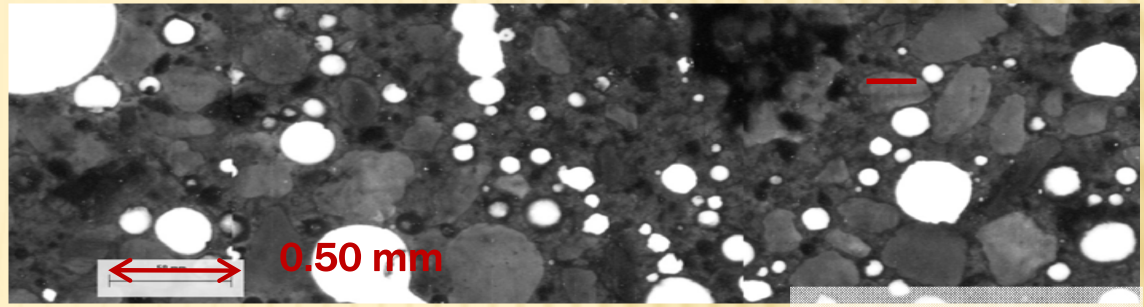
High Calcium Fly Ash - air-void microstructure

SEM

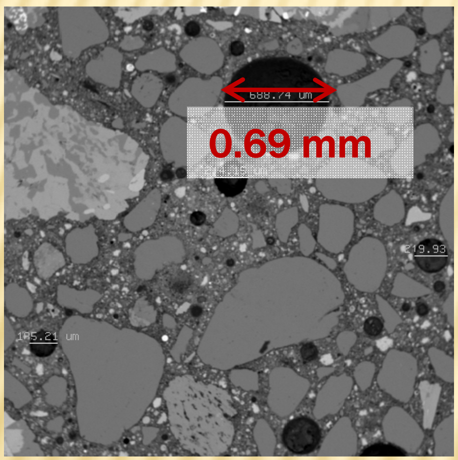
Plane sections



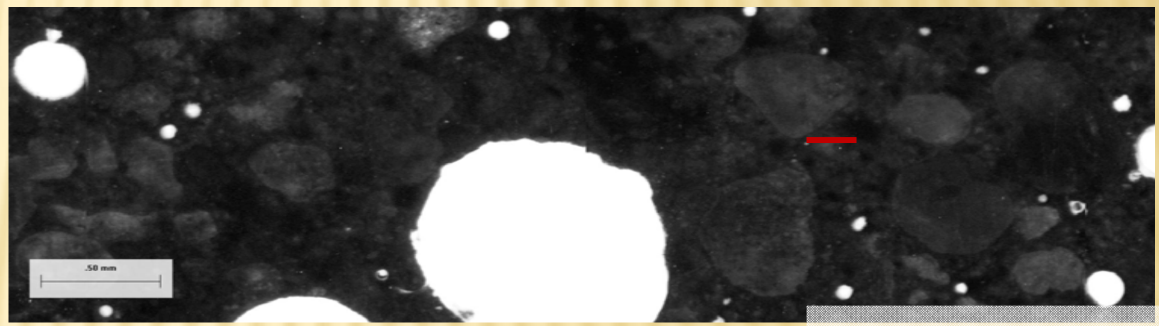
without HCFA



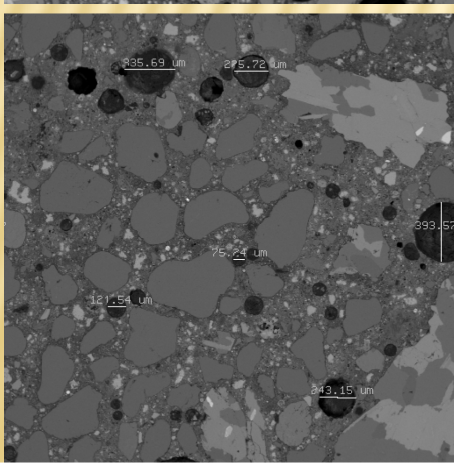
L=0.16 mm



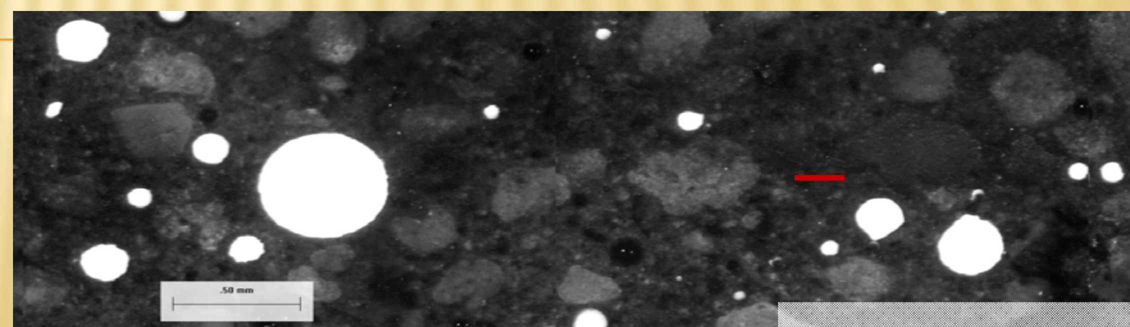
15% HCFA
milled during
28 min



L=0.30 mm



30% HCFA
milled during
28 min



L=0.28 mm

PARTIAL RESULTS – High Calcium Fly Ash

- Milling of HCFA did not reduce significantly the content of spherical, glassy particles but it did influence on the specific surface of the ash particles.

- The content of the unburned carbon particles increased with the increase of the amount of the high calcium fly ash.

Air-void microstructure

- The air-void content and spacing factor in hardened concrete due to the use of HCFA as type II addition was decreasing.

- The increasing of the degree of milling of the HCFA causes the decreasing of the air-void content in the range of the larger diameters.

PARTIAL RESULTS – High Calcium Fly Ash

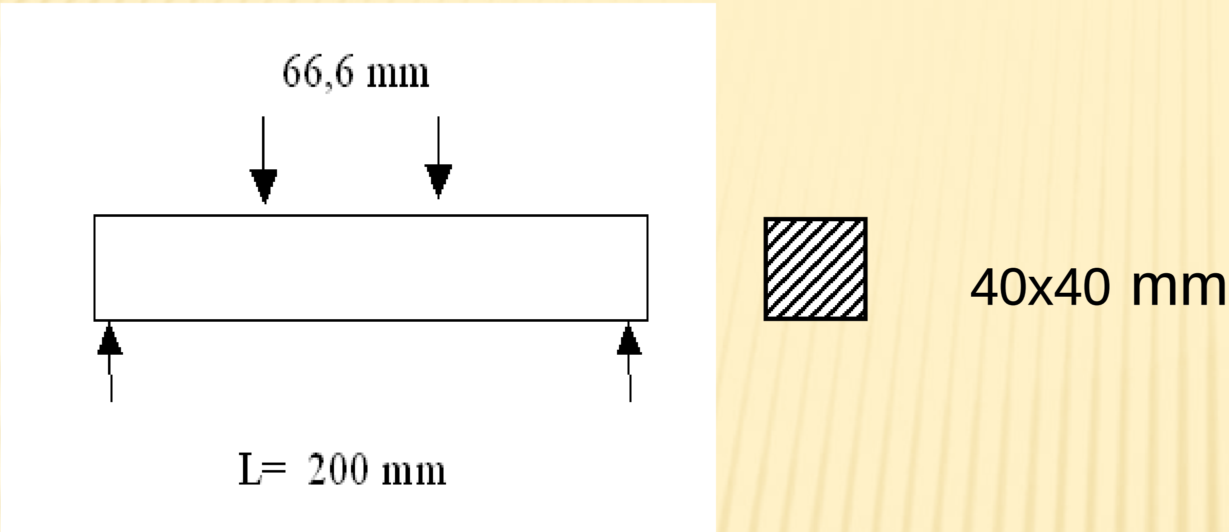
Migration of chloride ions

- Increasing content of high calcium fly ash significantly decreased the chloride migration coefficient of concrete containing Portland cement.

- Grinding of HCFA was found to provide only slight improvement of its performance in respect to chloride penetration.

- The relationship between the chloride migration coefficient and the compressive strength of concrete at 90 days was found to be close to linear relationship.

HEALING OF CRACKS IN FIBRE REINFORCED MORTAR BEAMS



Series R3 was composed of:

- **specimens made with Type I cement; 0%**
- **specimens made with 30% replacement of cement;**
- **specimens made with 60% replacement of cement, with HCFA**

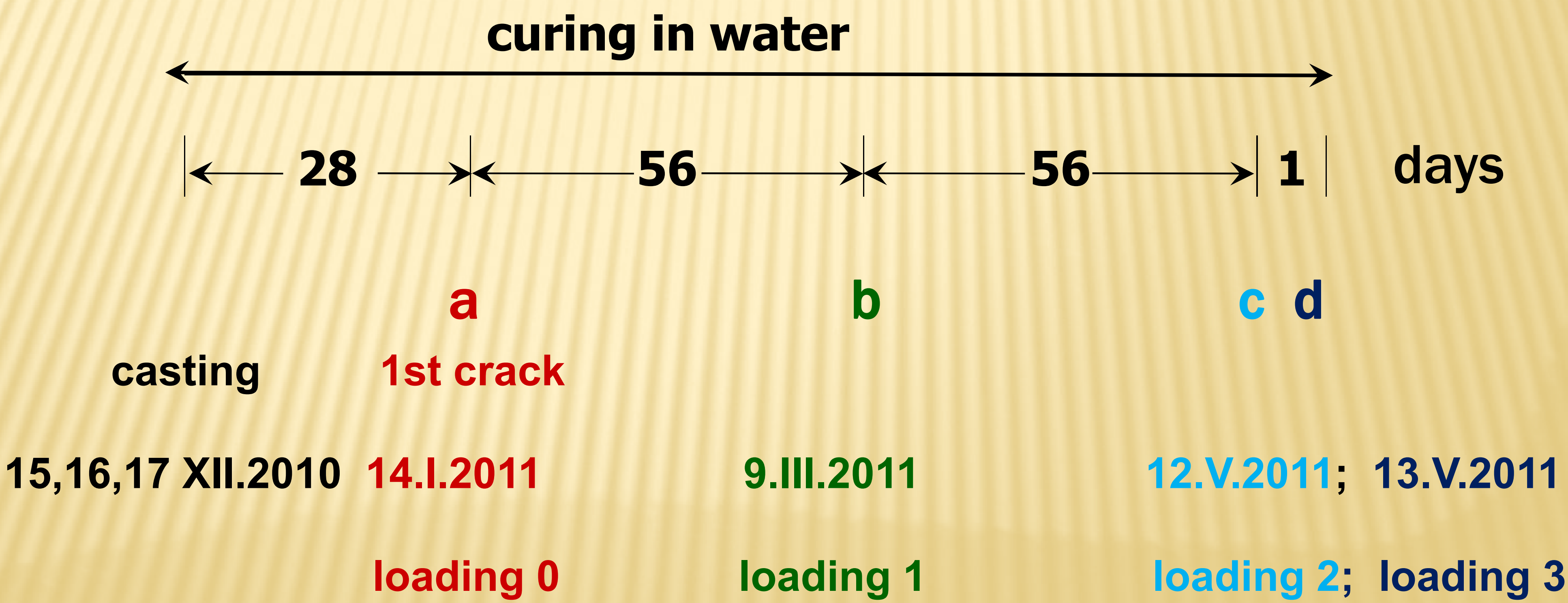
HEALING OF CRACKS IN FIBRE REINFORCED MORTAR BEAMS

a – first crack at age of 28 days

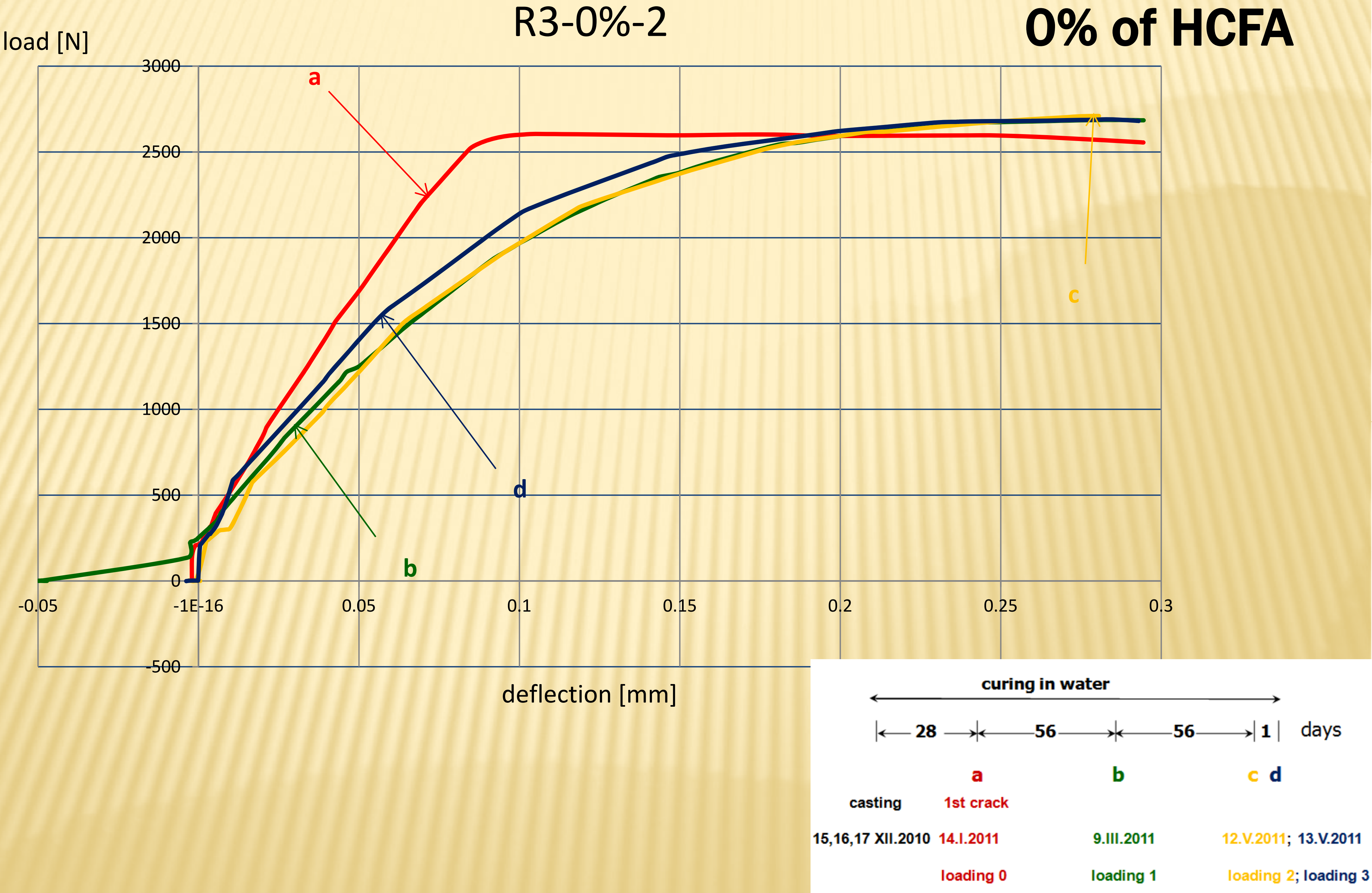
b – loading after next 56 days

c – loading after next 56 days (all together after 112 days)

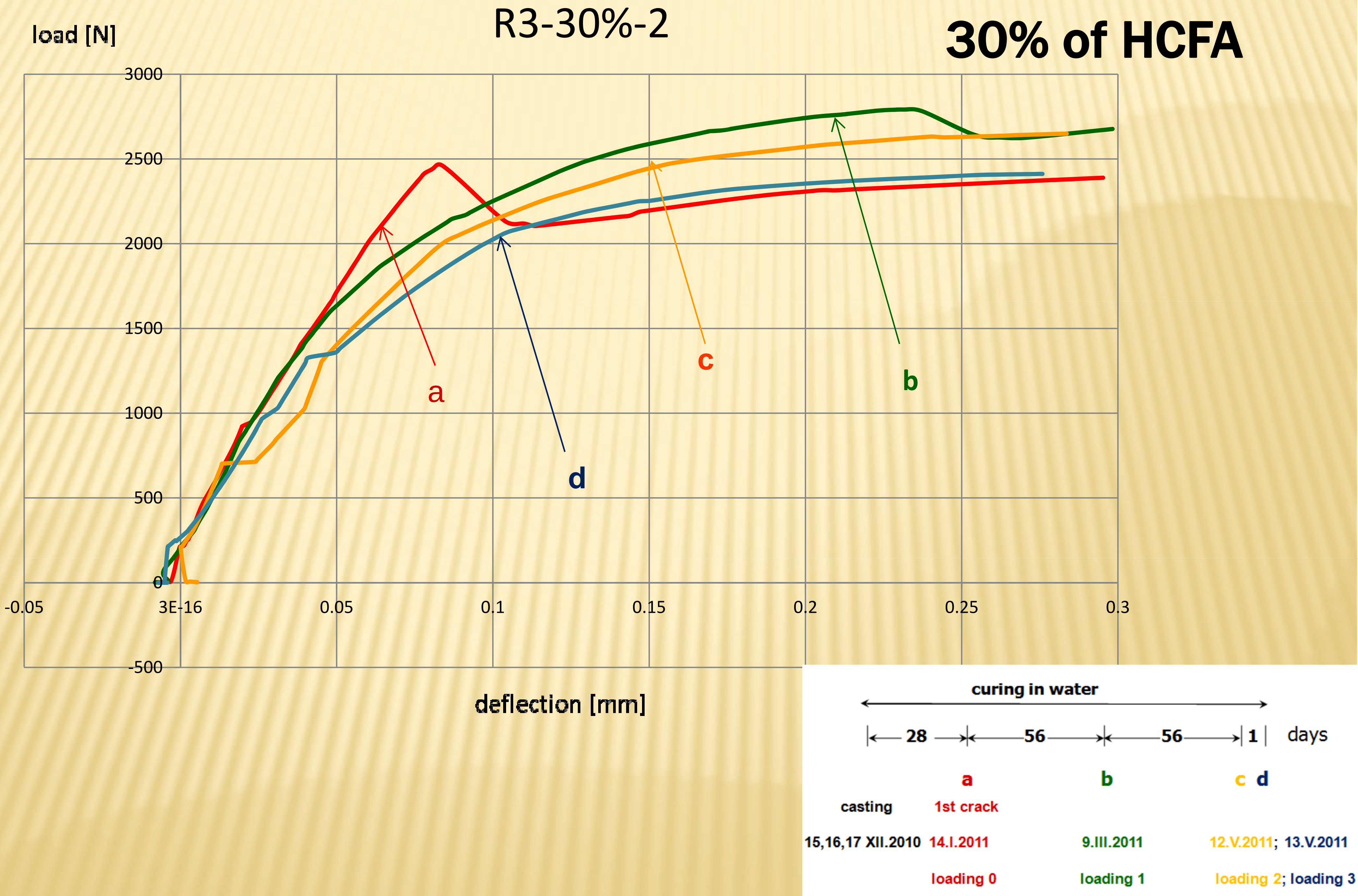
d – loading after next day



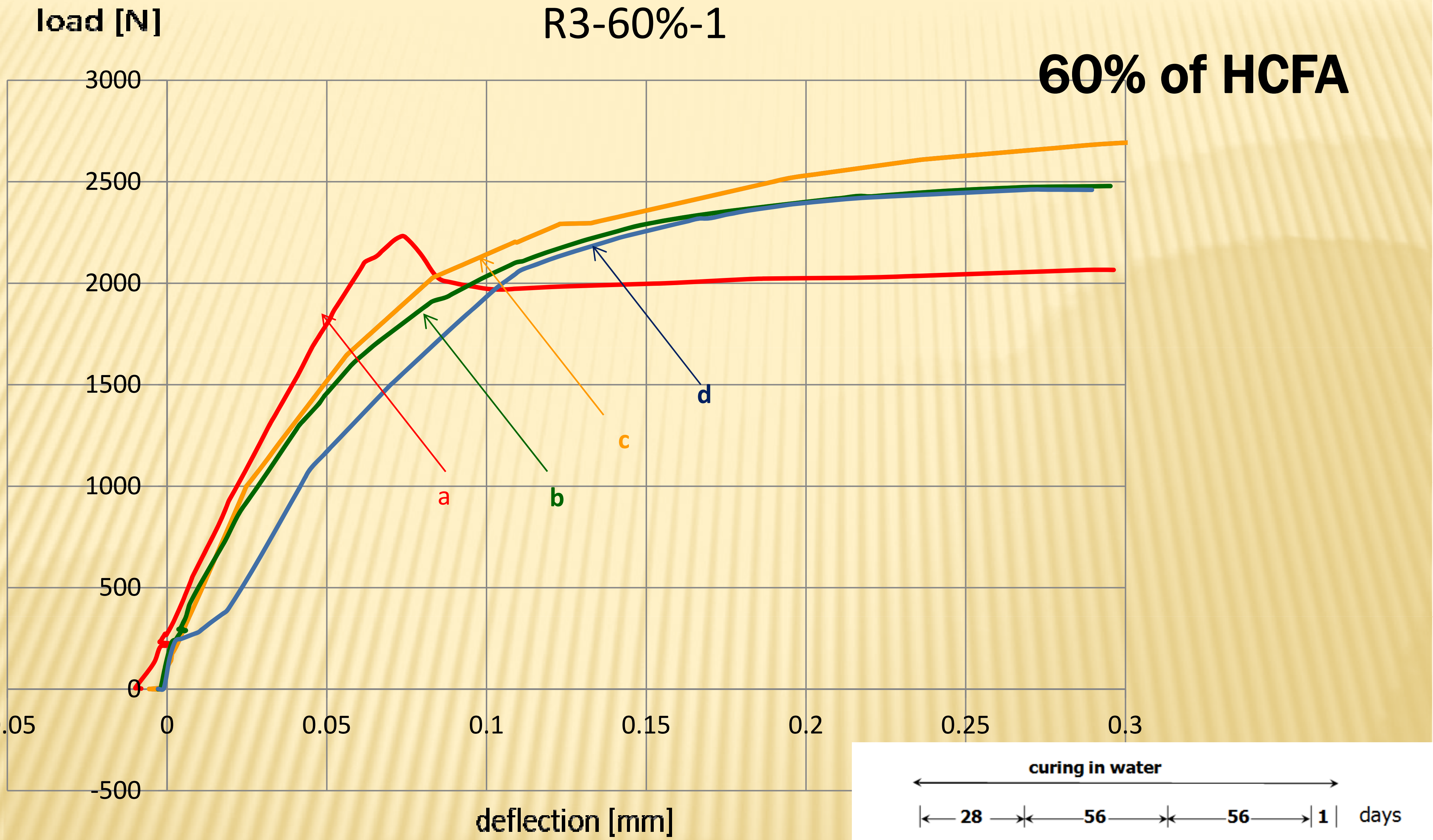
Load – deflection curves

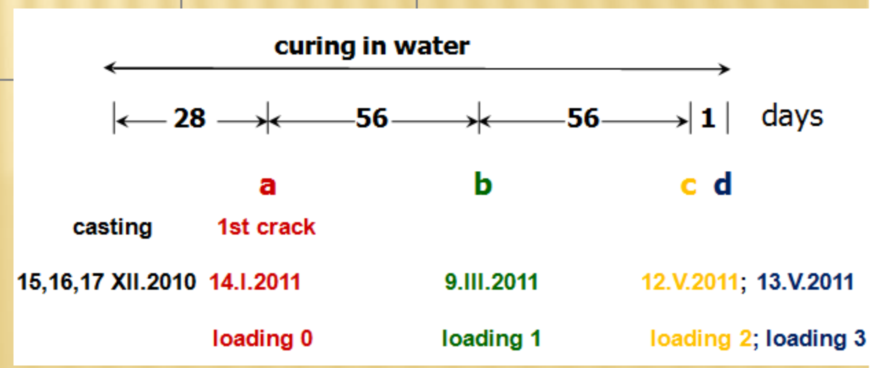


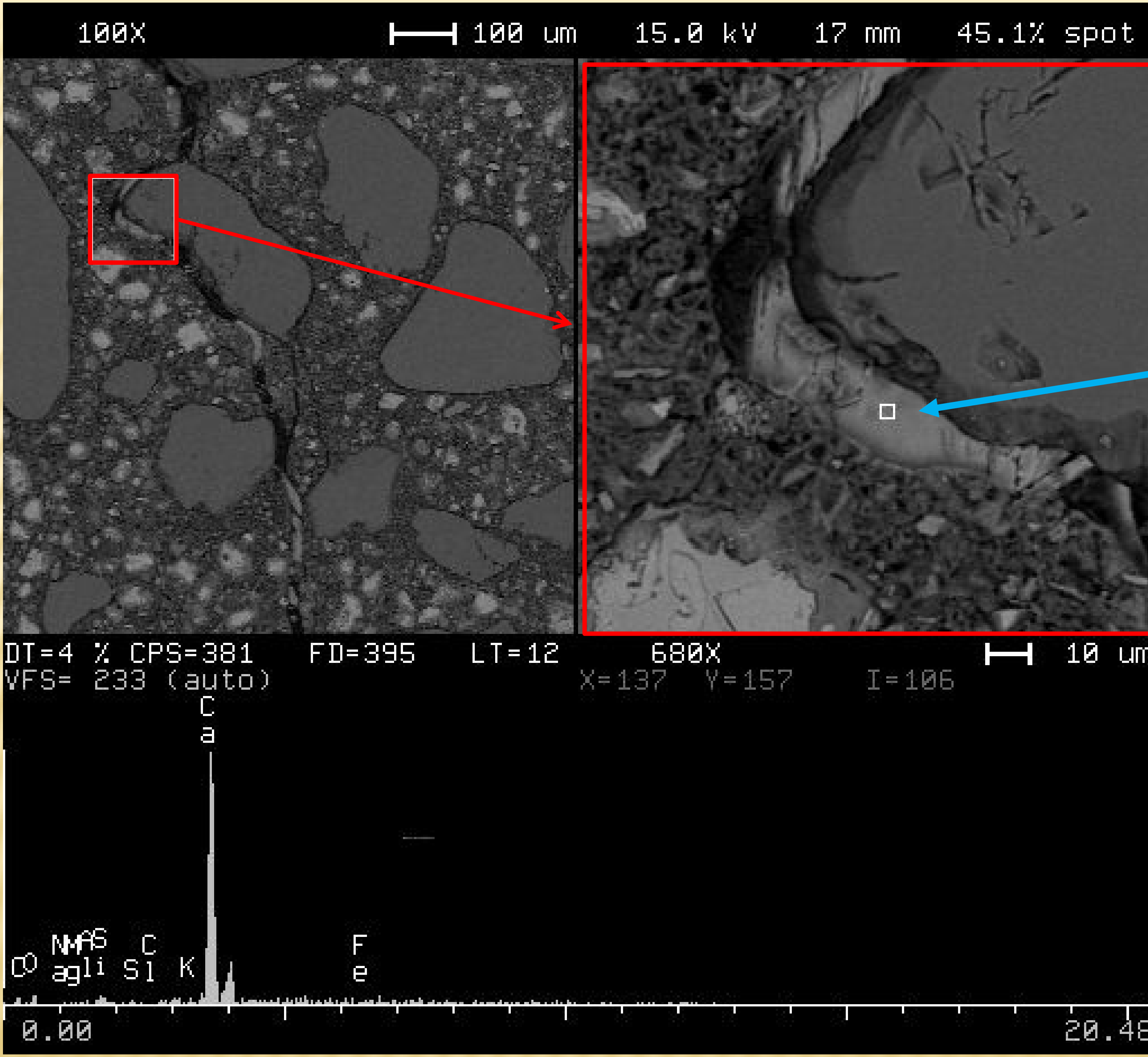
Load – deflection curves



Load – deflection curves





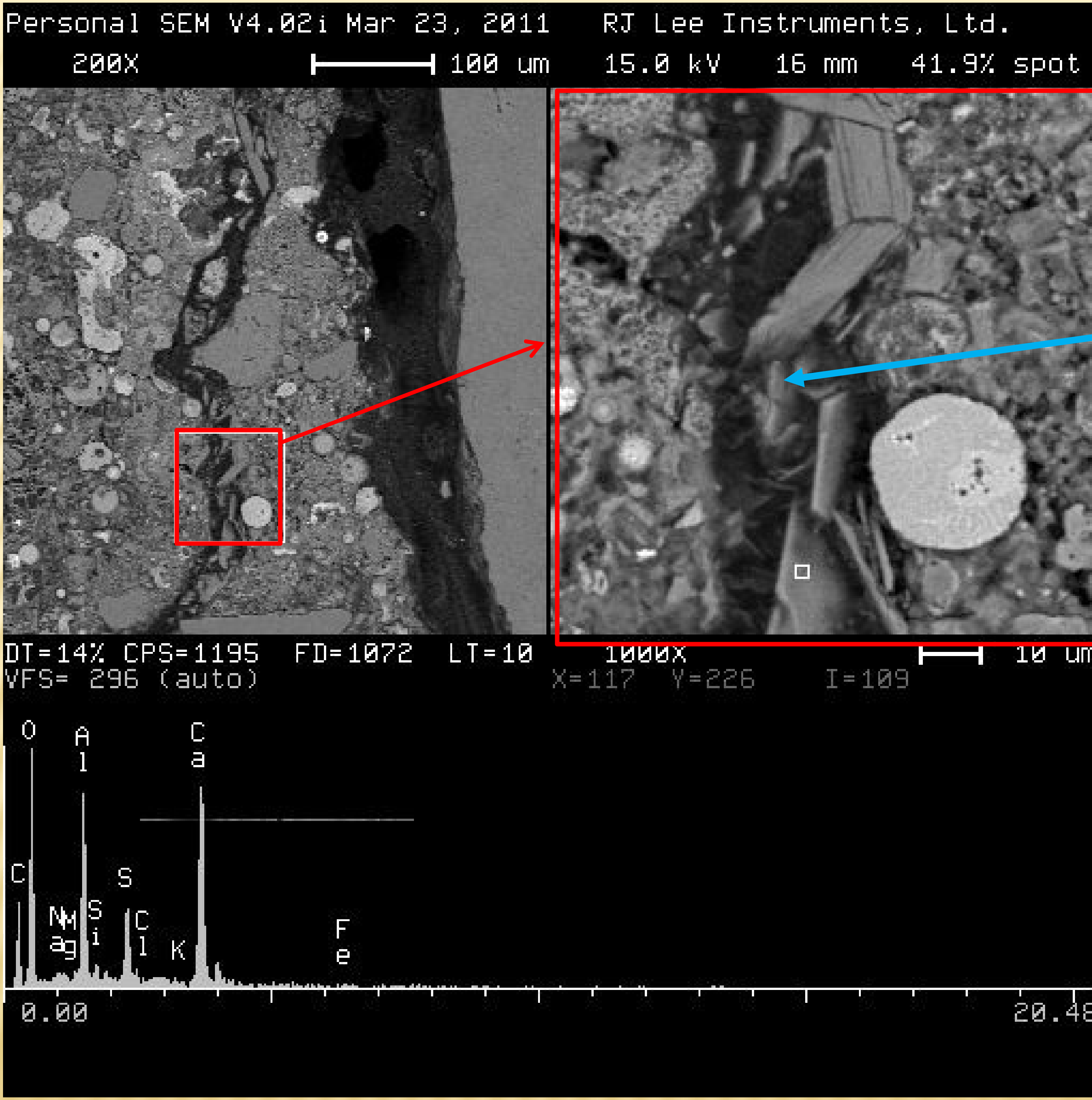


0% of HCFA

R3-0%-10c

portlandite
in the crack
around a sand
grain

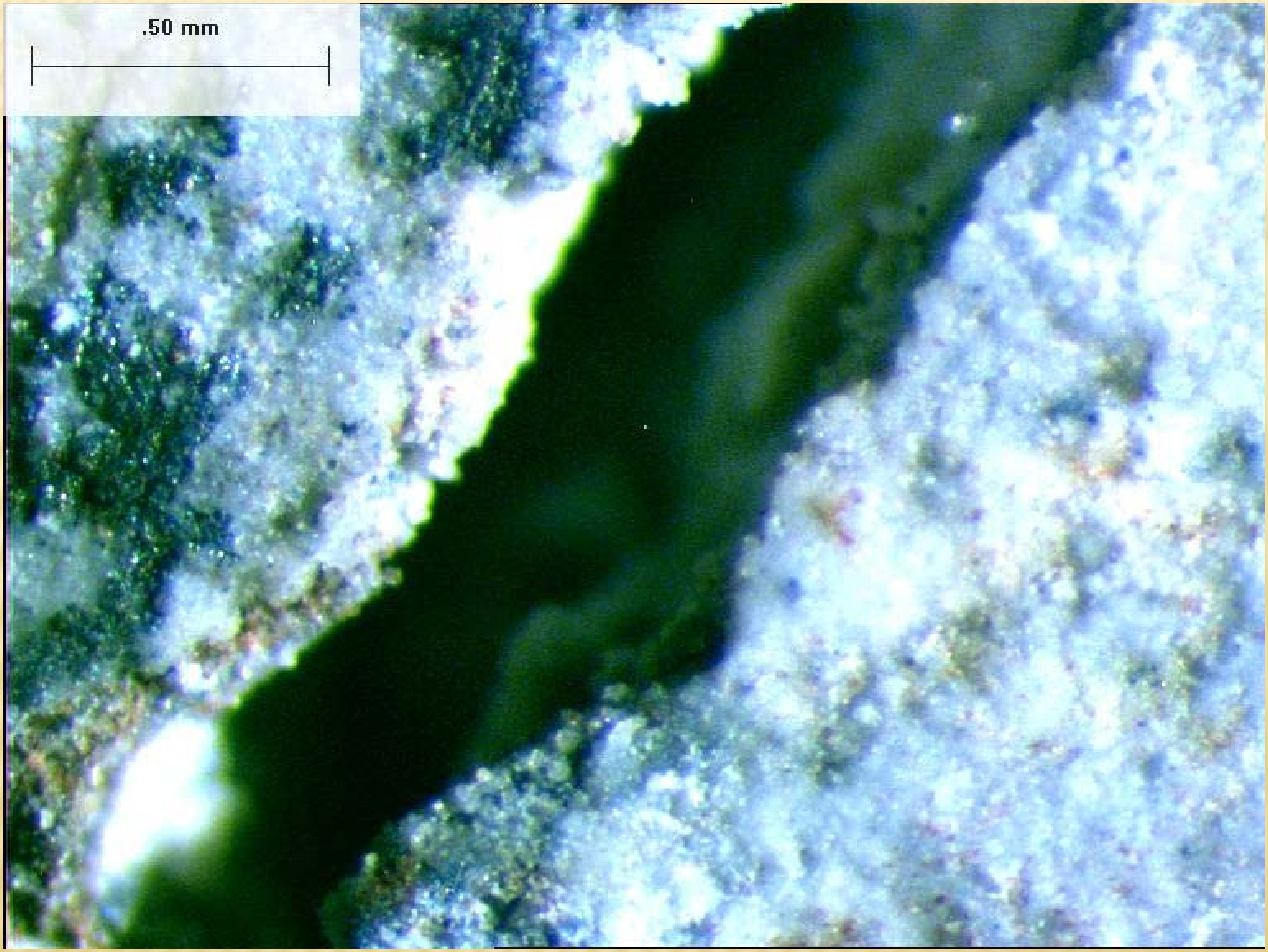
60% of HCFA



R3-60%-12c

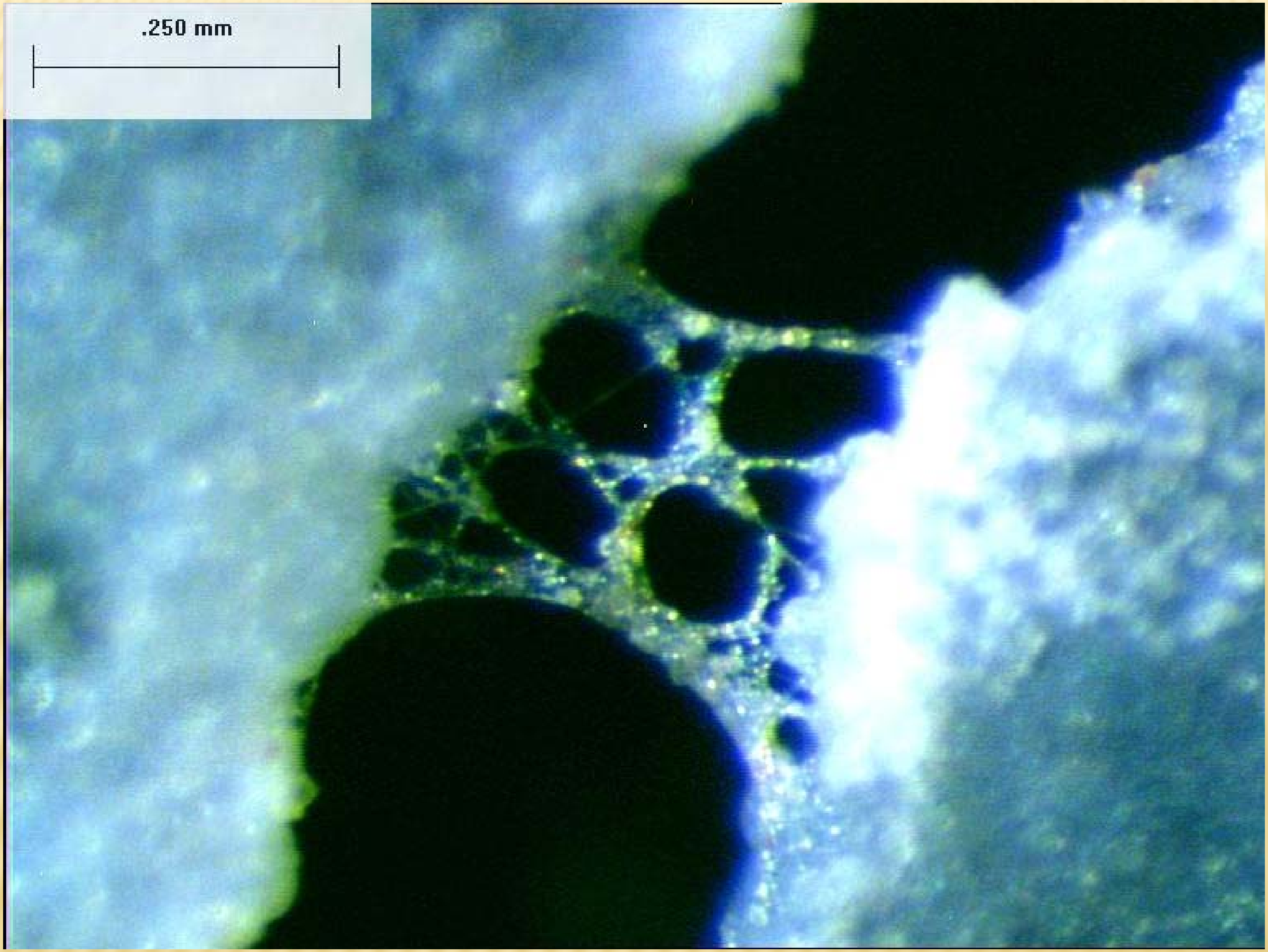
monosulfate in the fine crack

0% of HCFA



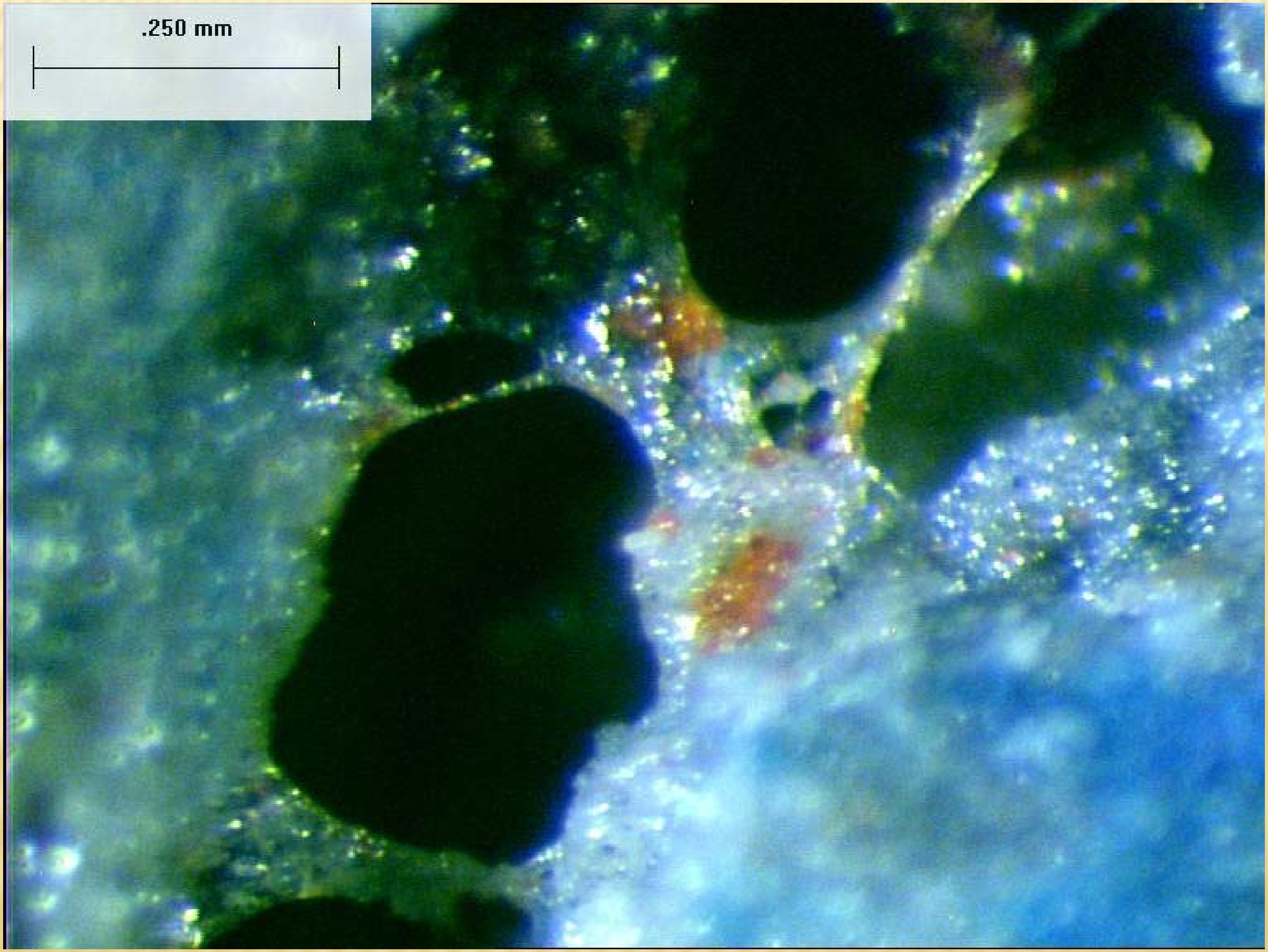
R3-0%-7

60% of HCFA



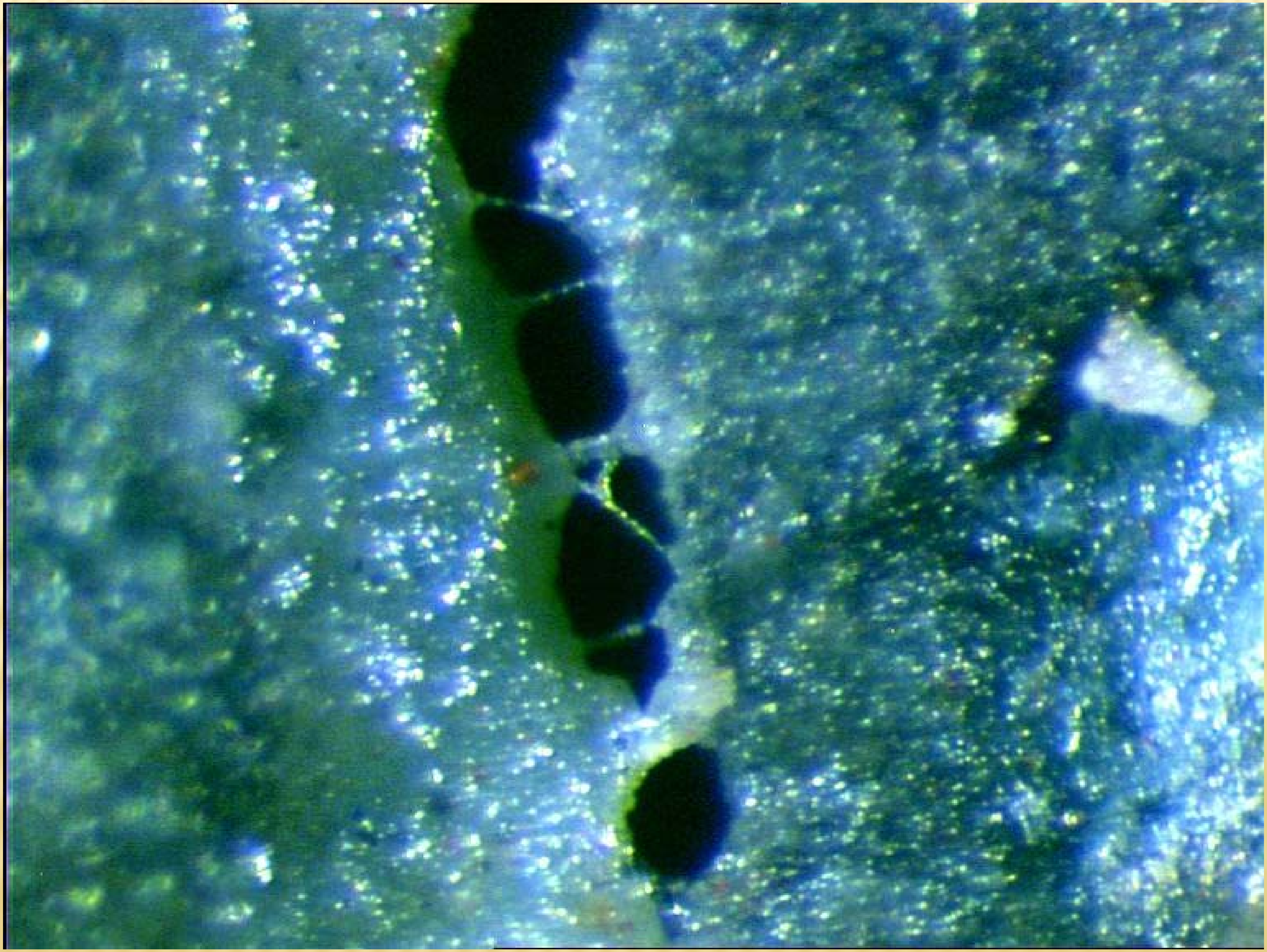
R3-60%-3

60% of HCFA



R3-60%-3

60% of HCFA



R3-60%-3

PARTIAL RESULTS – High Calcium Fly Ash

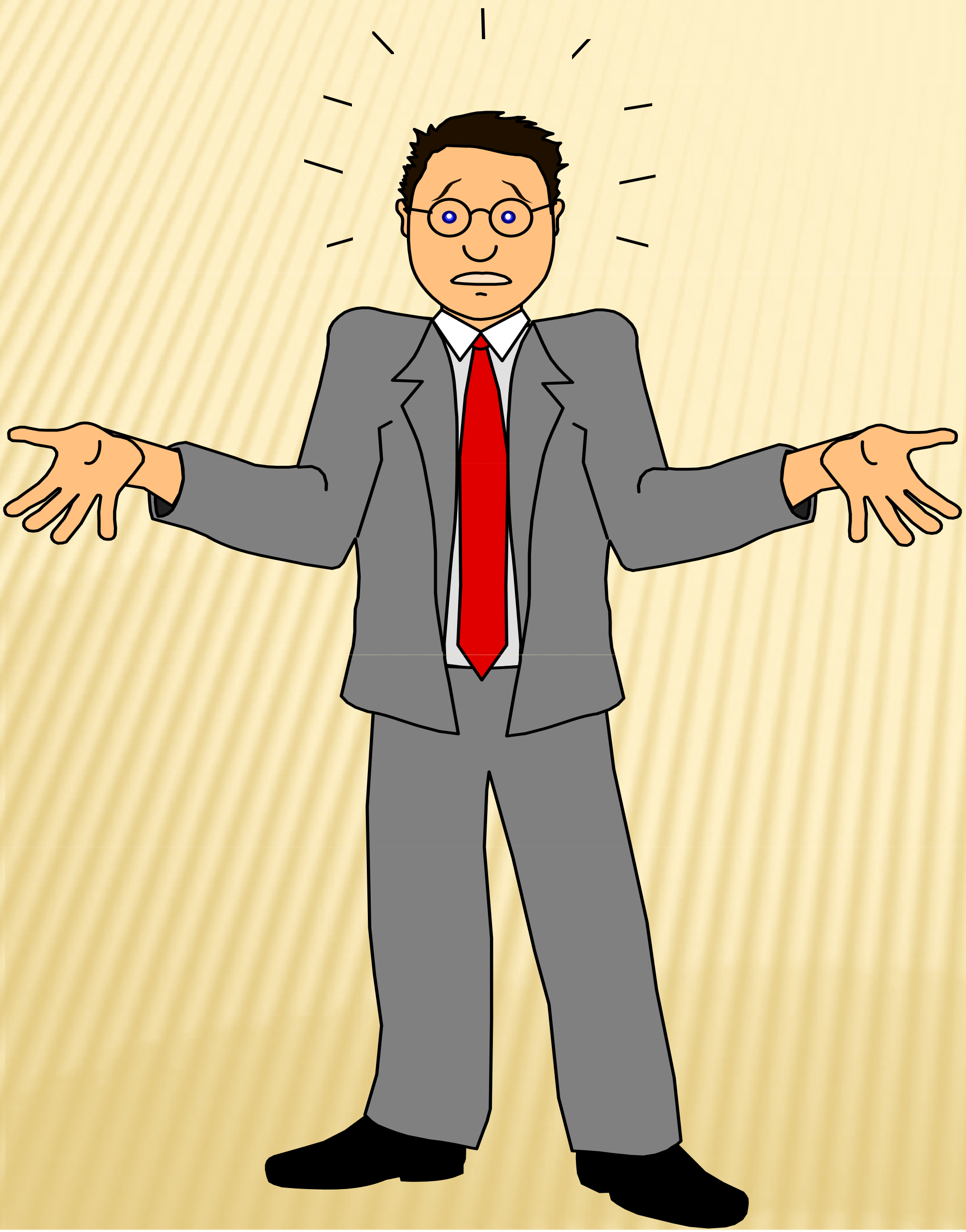
or maybe in place of conclusions ☺

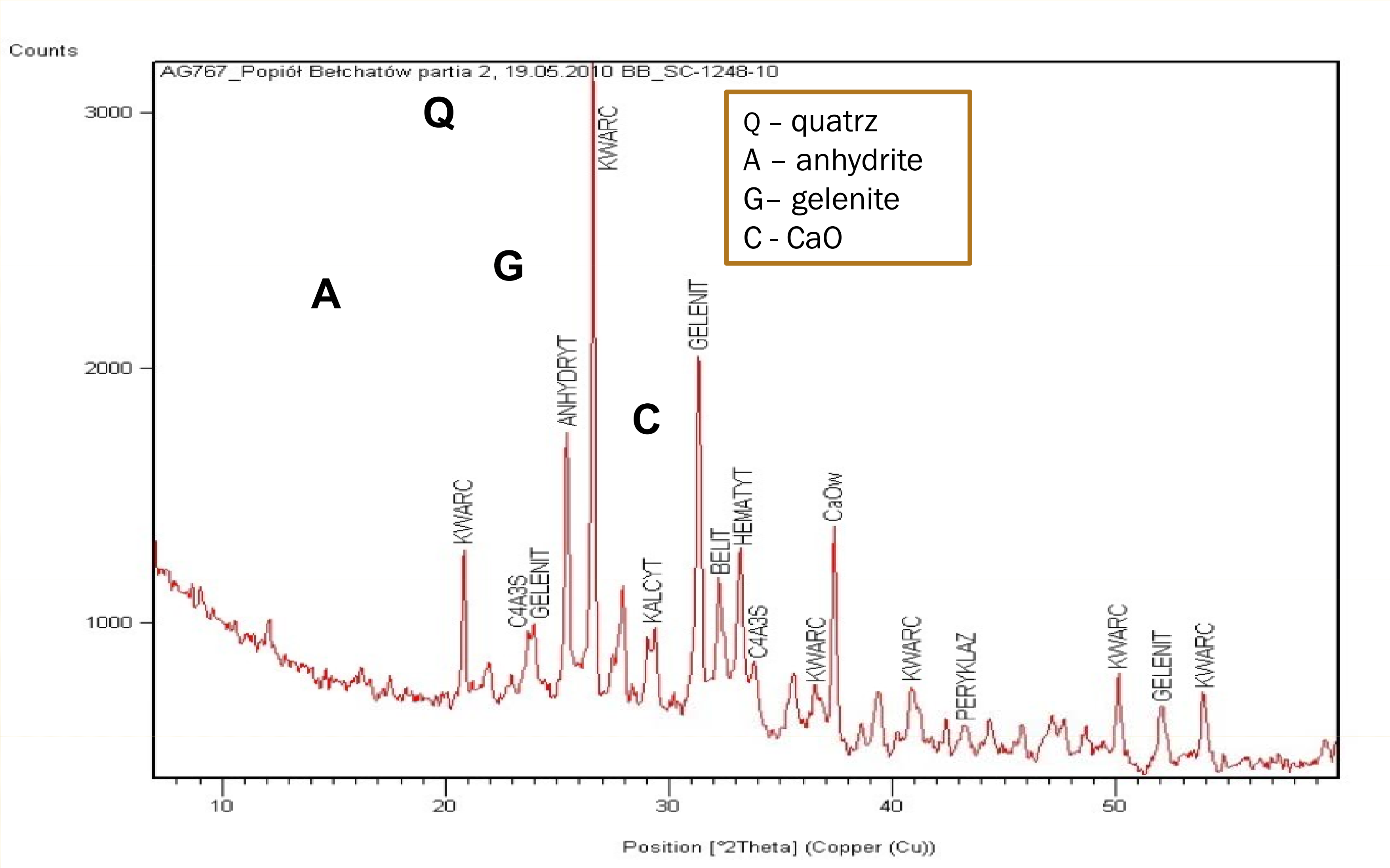
- increase of stiffness of specimens due to crack healing is shown on load-deflection curves;
- products of healing are observed inside microcracks after 16 weeks of curing in water;
- HCFA apparently stimulated crack healing;
- complete crack healing was not obtained, only initiation of the process.

Intern. Symp. on Brittle Matrix Composites 10

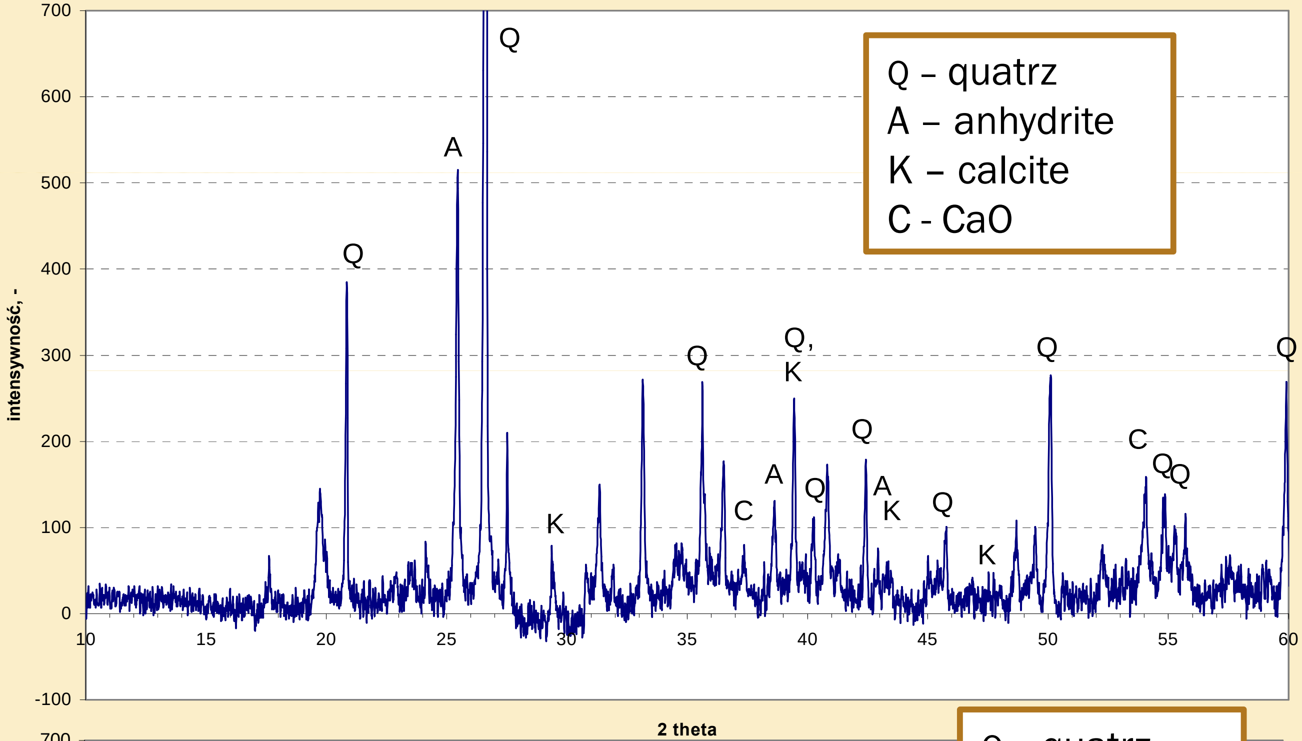
Warsaw, October 15 - 17, 2012

Thank you!

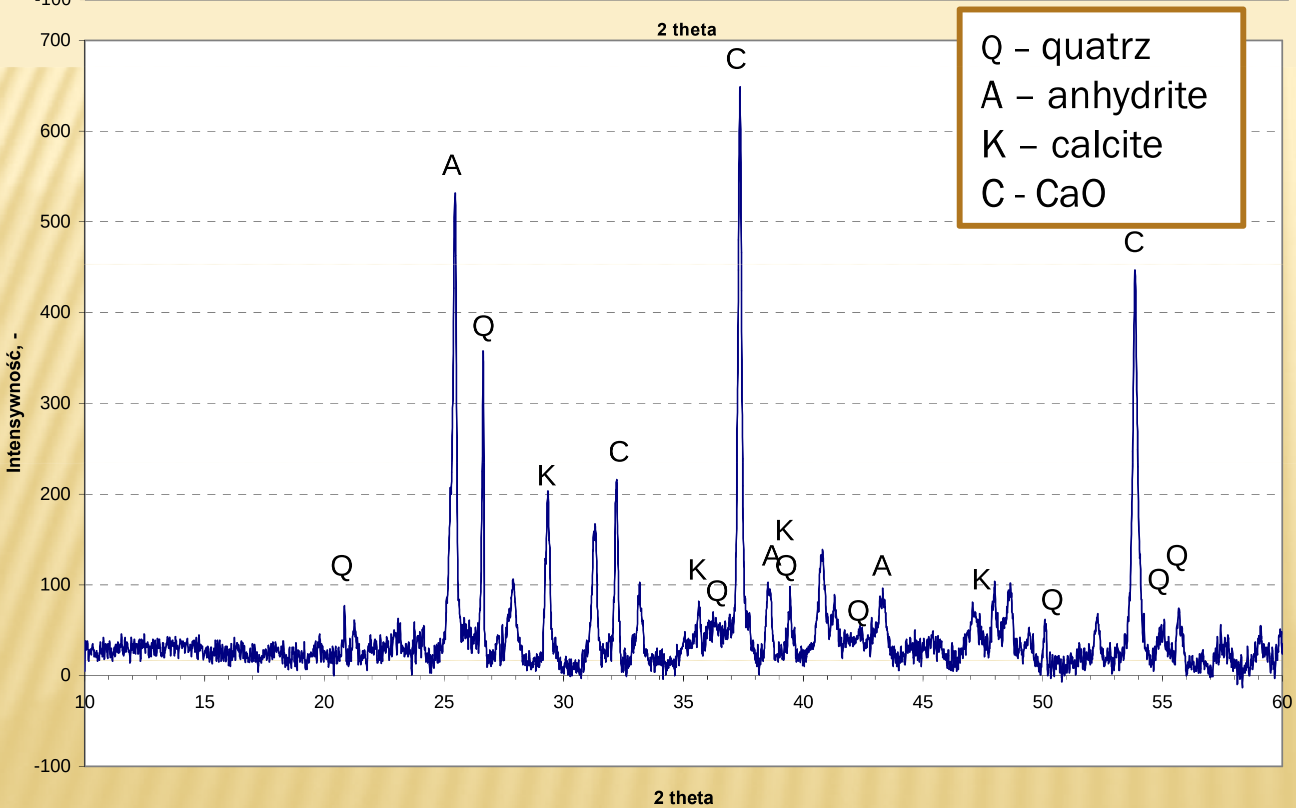




XRD of HC Fly Ash (from lignite)

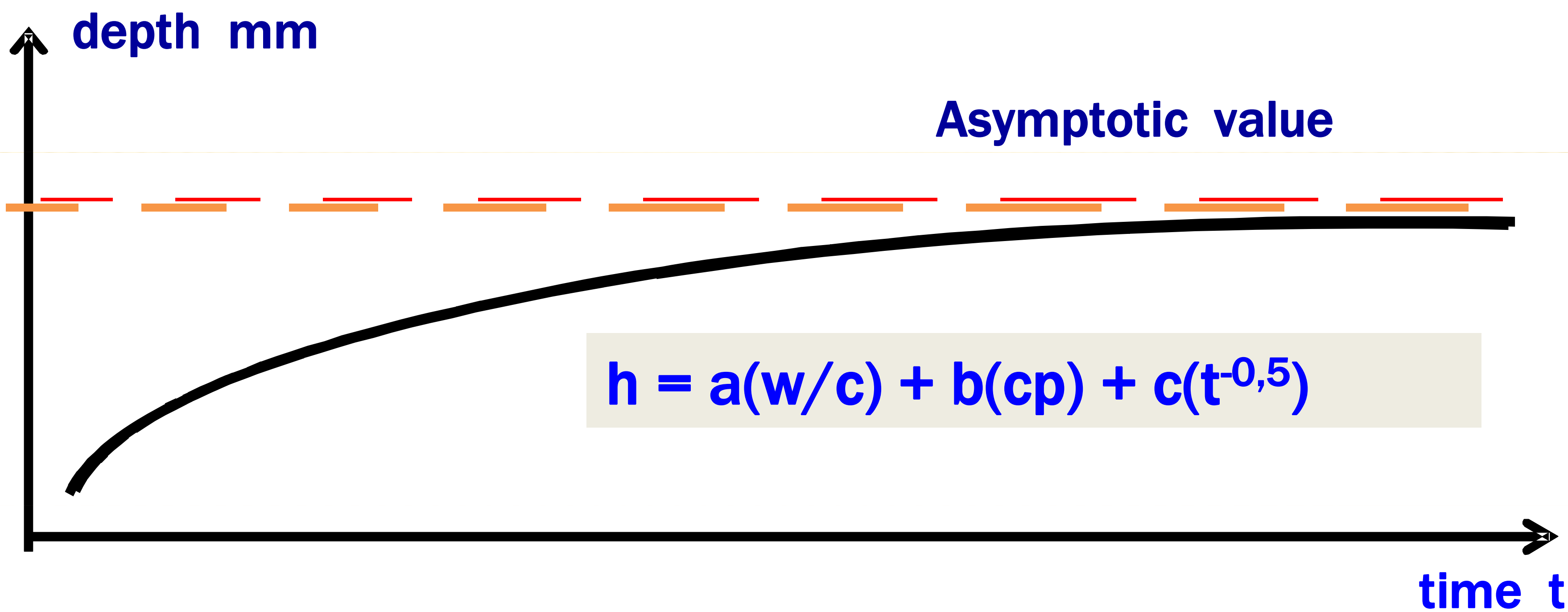


XRD of FBC fly ash (from anthracite)

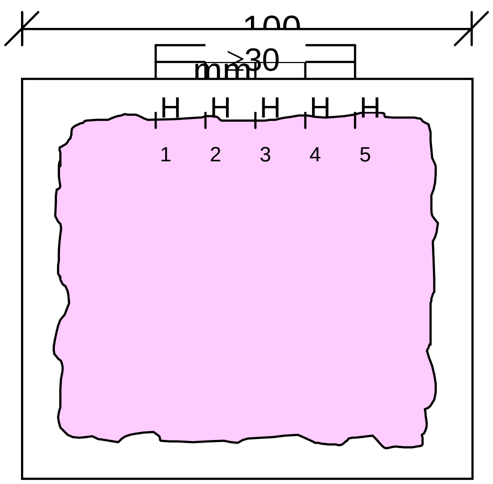


XRD of FBC fly ash (from lignite)

Carbonation in time



Test according to EN 3295:2004



specimens 100x100 mm,

1% CO_2 ; >56 days