"Greening" the cement

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Objective

Investigation of composite cements, in order to increase their use in local conditions

Effect on the properties of fresh concrete

- Setting time, bleeding, early age strength, sensitivity to plastic shrinkage, etc.

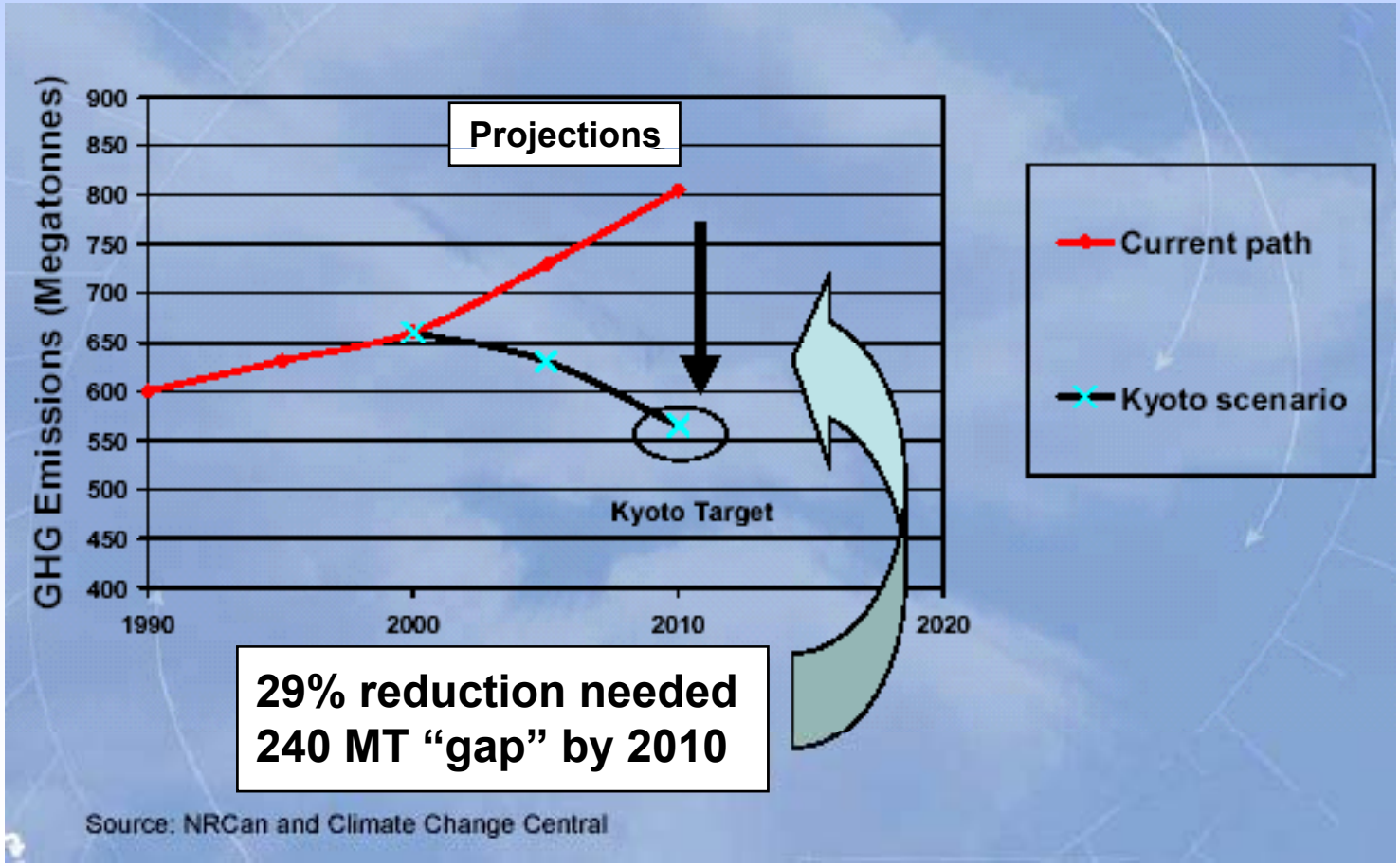
•Effect on standard properties at 28 days

•Effect on durability

- Carbonation, chlorides penetration, volume changes (shrinkage)

The motivation

Kyoto scenario



More motivation

Exchange and flexibility

- Annex 1 economies can meet their GHG targets by purchasing GHG emission reductions from financial exchanges or from A 2 countries under the Clean Development Mechanism
- A 1 countries can group together and have a common emission cap
- Advantages of this flexibility
  - Cost sometimes too great for developed countries, to be viable
  - Encourages non A 1 countries to develop means to reduce GHG emissions, which is made economically viable

The highest motivation

Point Carbon
EUA OTC closing price

27 November 2006
EUA DEC 2006
€9.00 ▲0.05

Methodology
Exchange prices
Carbon Market Daily

Point Carbon
EUA OTC closing price

21 February 2008
EUA DEC 2008
€21.65 **▲0.15**

Methodology
Exchange prices
Carbon Market Daily

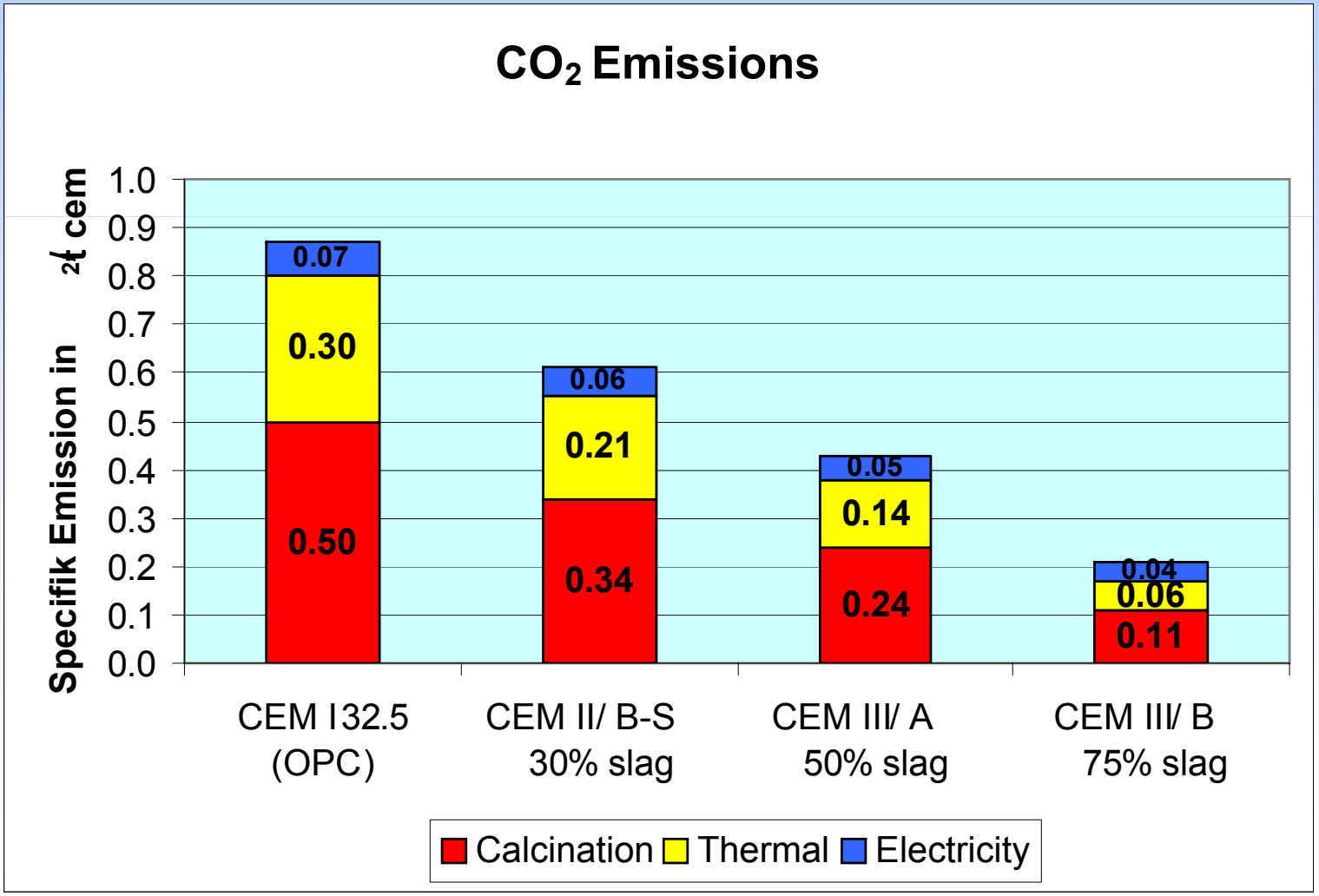
EUA price last 30 days

Historic prices

07 Nov 08
DEC 2008
€18.70 +0.55

Last 30 days

CO_2 emission from cement with various levels of slag replacement



Slag market (US Geological Survey, USGS)

Salient Statistics—United States:	2001	2002[3]	2003[3]	2004[3]	2005[e, 3]
Production, marketed[1, 4]	16.9	19.1	19.7	21.2	21.0
Imports for consumption	2.6	1.1	1.1	1.0	1.7
Exports	(5)	0.1	0.1	0.1	(5)
Consumption, apparent[6]	19.5	19.1	19.7	21.1	21.0
Price average value, dollars per ton, f.o.b. plant	8.05	[7]15.50	[7]15.00	[7]15.50	[7]15.50
Stocks, yearend	NA	NA	NA	NA	NA
Employment, number[e]	2,700	2,700	2,700	2,700	2,600
Net import reliance[8] as a percentage of apparent consumption	8	5	5	4	8

[7]The higher price in 2002-05 represents more complete data on sales of ground granulated blast furnace slag, which sold for almost **$60 per ton**, as opposed to air-cooled blast furnace and steel slags, which sold, on average, in the range of about $4 to $7 per ton.

U.S. Geological Survey – Slag 2008

Research program

Four series of mixes were prepared:

- Concrete containing cement only
- Concrete containing cement + water reducing admixture
- Concrete containing cement + fly-ash
- Concrete containing cement + water reducing admixture + fly-ash

In each series, AV mix was prepared first, and the other mixes were prepare using the same mix composition with different cements.

- Total 4 mixes X 3¼ types of cement X 3 curing regimes
- 50 cubes, 16 beams and 6 cylinders for each mix

Type of cements

- The following cements were investigated:
  - CEM II/B-M(L-V) containing ~15% limestone, ~15% fly-ash (and minor slag, ~5%) → 65% clinker
  - CEM II/B-M(S-L-V) containing ~11% slag, ~11% limestone and ~11% fly-ash → ~65% clinker
- The cements were compared with cement containing ~12% fly ash (AV)
- Some properties in one mix only were compared with CEM I (~95% clinker)

Properties of cements

Type of cement	Setting time (min)		Specific surface area ($cm^2/gr.$)	Density	Strength (MPa)	
	initial	final			2 days	28 days
AV	280	360	3710	3.02	25.7	61.0
MB(L-V)	110	190	4510	2.91	26.8	57.0
BM(S-L-V)	120	200	4351	2.95	25.7	58.2

Mix composition

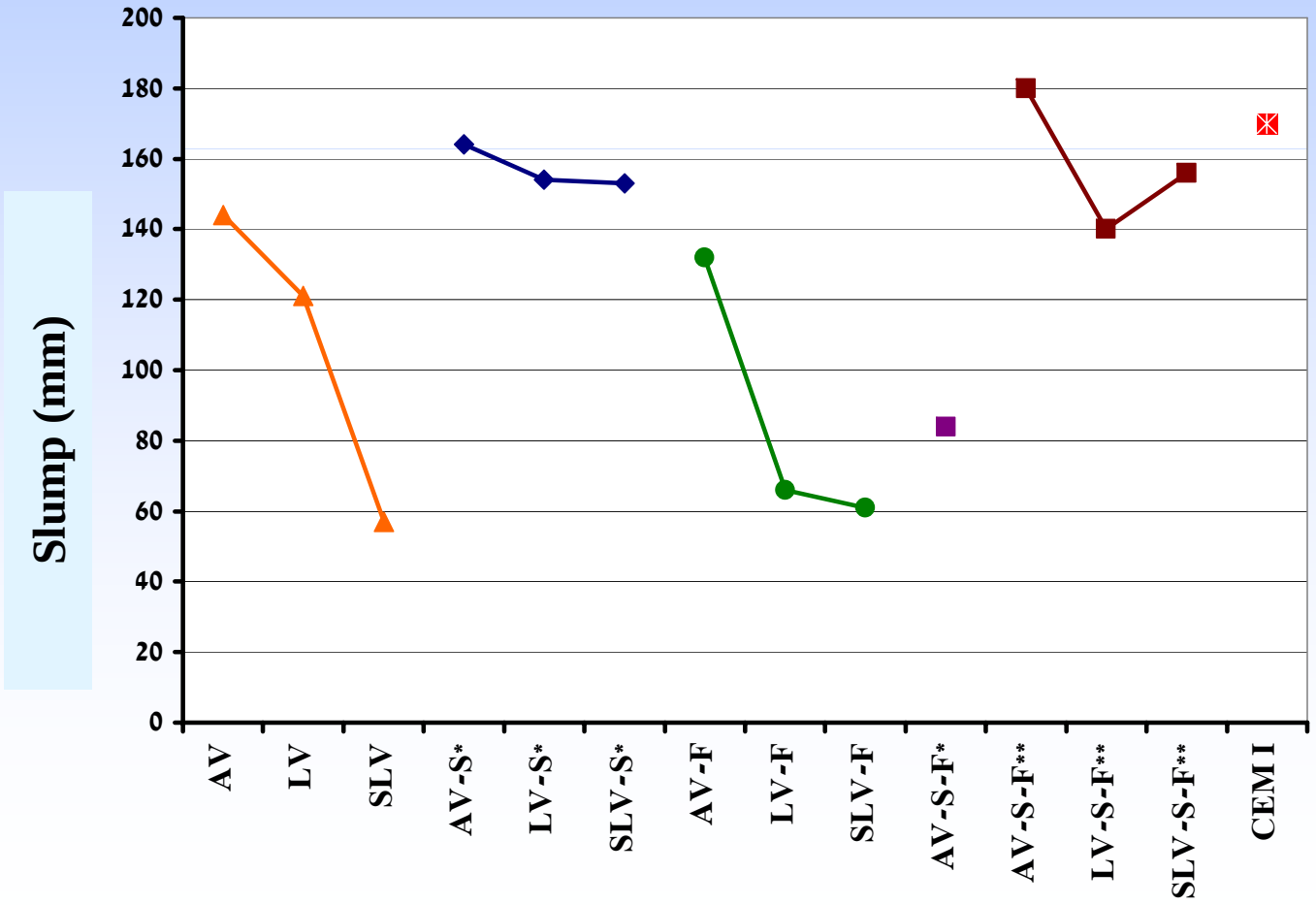
Mix No.	Mix design-ation	Composition (kg/m³)								W/C
		coarse	Crushed sand	Filler	Nat. sand	Fly-ash	Cement	Water	WR admixture	
1	AV	835	692	81	228	–	304	204	–	0.67
2	LV	833	691	81	228	–	303	203	–	0.67
3	SLV	838	695	82	229	–	305	205	–	0.67
4	AV-S*	832	690	81	304	–	273	183	1.94	0.67
5	LV-S*	832	690	81	304	–	273	183	1.91	0.67
6	SLV-S*	832	690	81	303	–	273	183	1.91	0.67
7	AV-F	844	700	82	150	82	287	206	–	0.72[1]
8	LV-F	834	692	81	149	81	283	204	–	0.72[1]
9	SLV-F	834	692	81	149	81	283	204	–	0.72[1]
10	AV-S-F*	836	694	82	225	82	254	184	1.78	0.72[1]
11	AV-S-F**	835	692	81	219	81	253	183	4.55	0.72[1]
12	LV-S-F**	829	688	81	218	81	252	182	4.53	0.72[1]
13	SLV-S-F**	833	684	81	219	81	253	183	4.55	0.72[1]
14	CEM I	827	686	81	226	–	301	202	–	0.67

[1] Water to cement only, not considering the fly-ash. Fly-ash efficiency is 0.25 as determined in early experiments

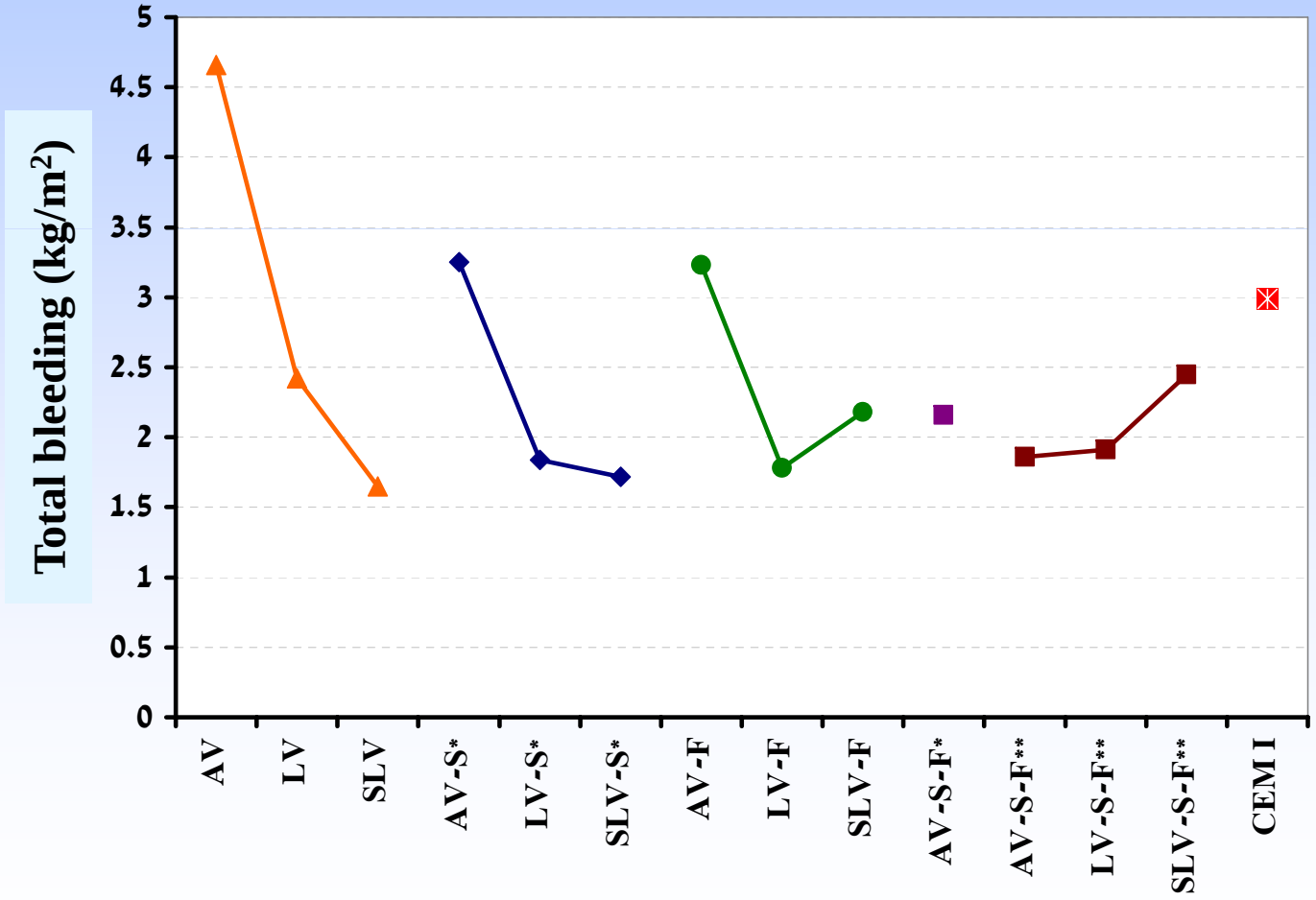
Results:

Fresh concrete

Slump

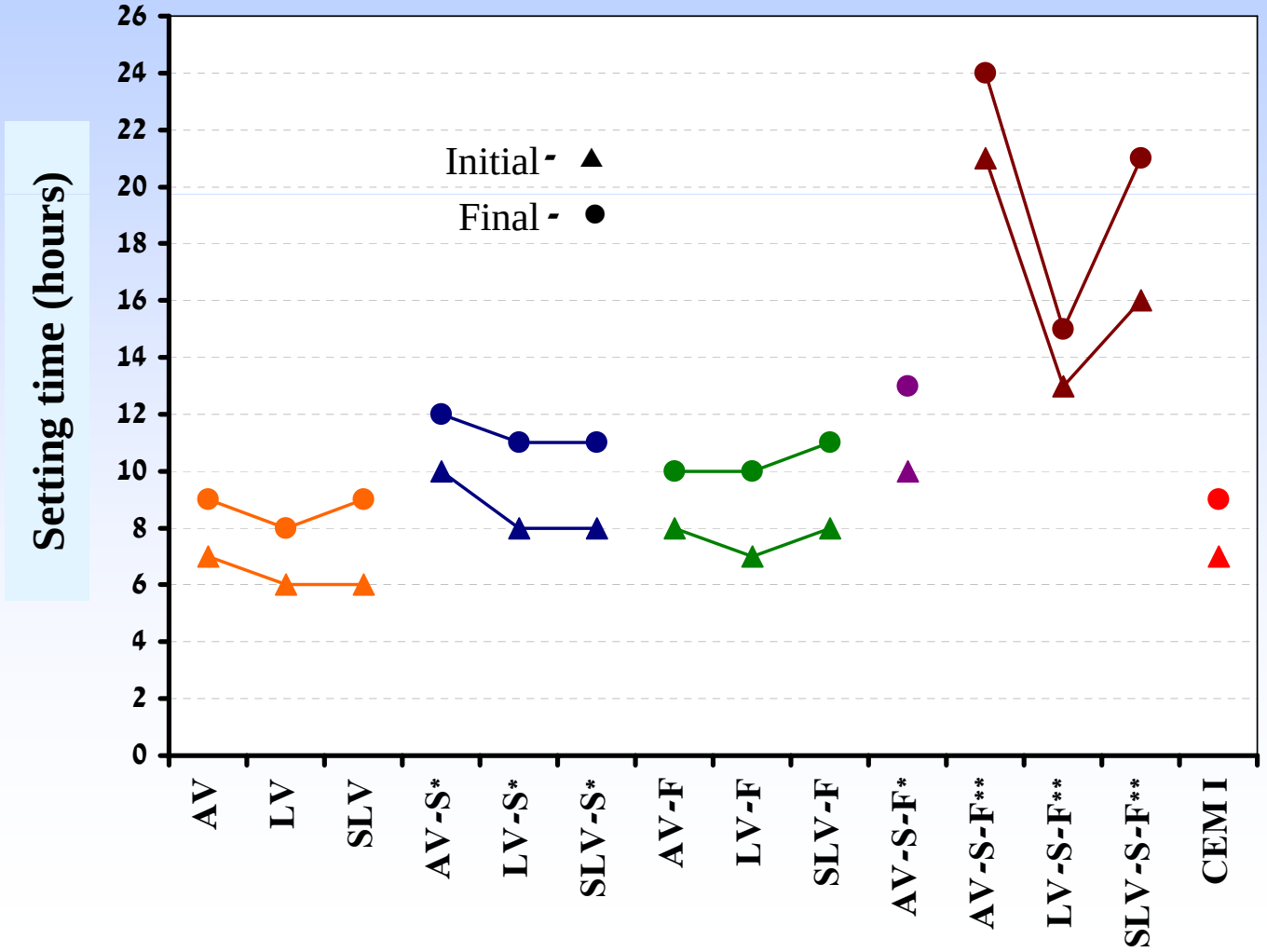

Slump (mm)
200
180
160
140
120
100
80
60
40
20
0
AV
LV
SLV
AV-S*
LV-S*
SLV-S*
AV-F
LV-F
SLV-F
AV-S-F*
AV-S-F**
LV-S-F**
SLV-S-F**
CEM I

Bleeding



Bleeding rate exhibited similar trends

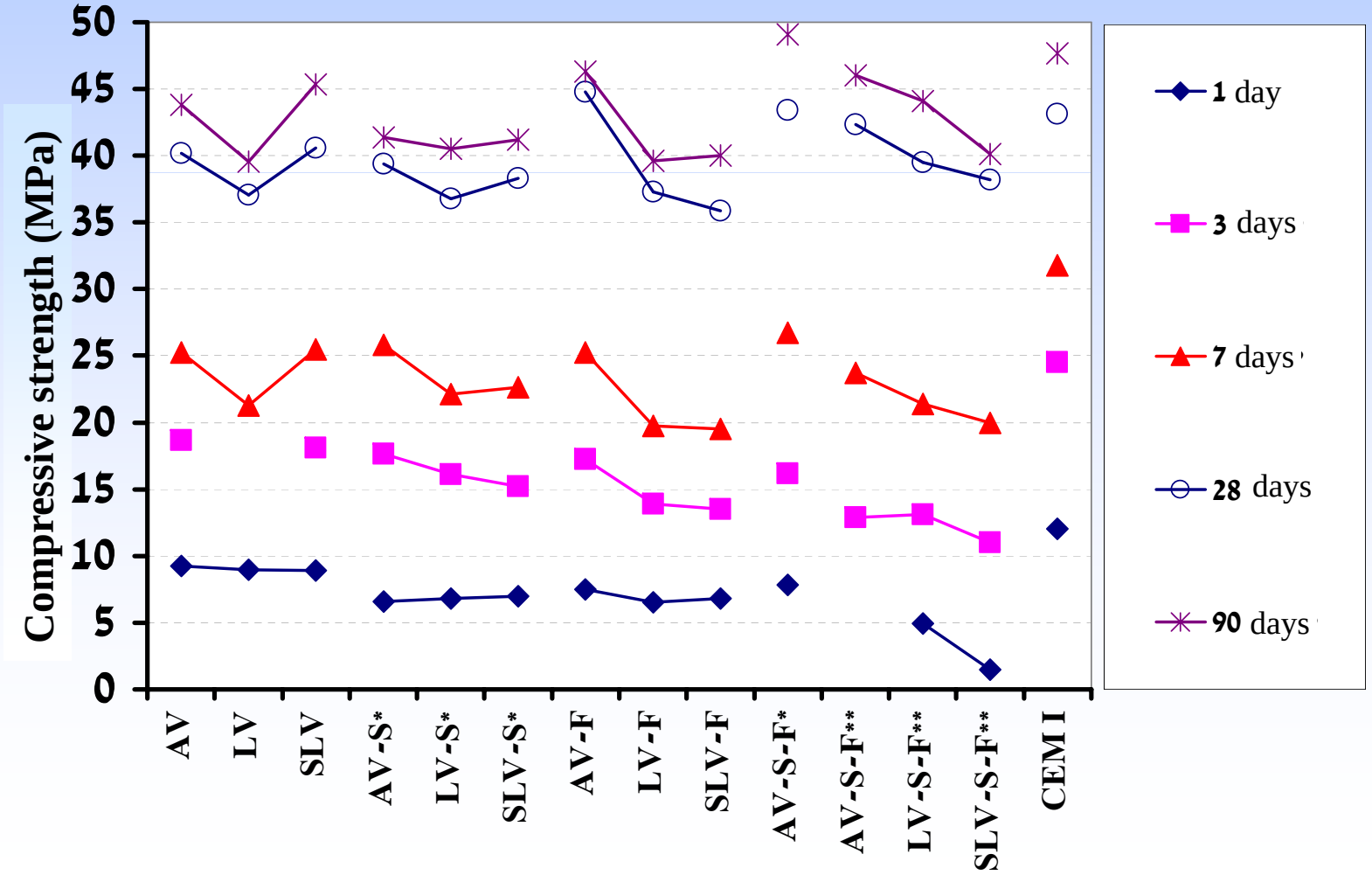
Setting time



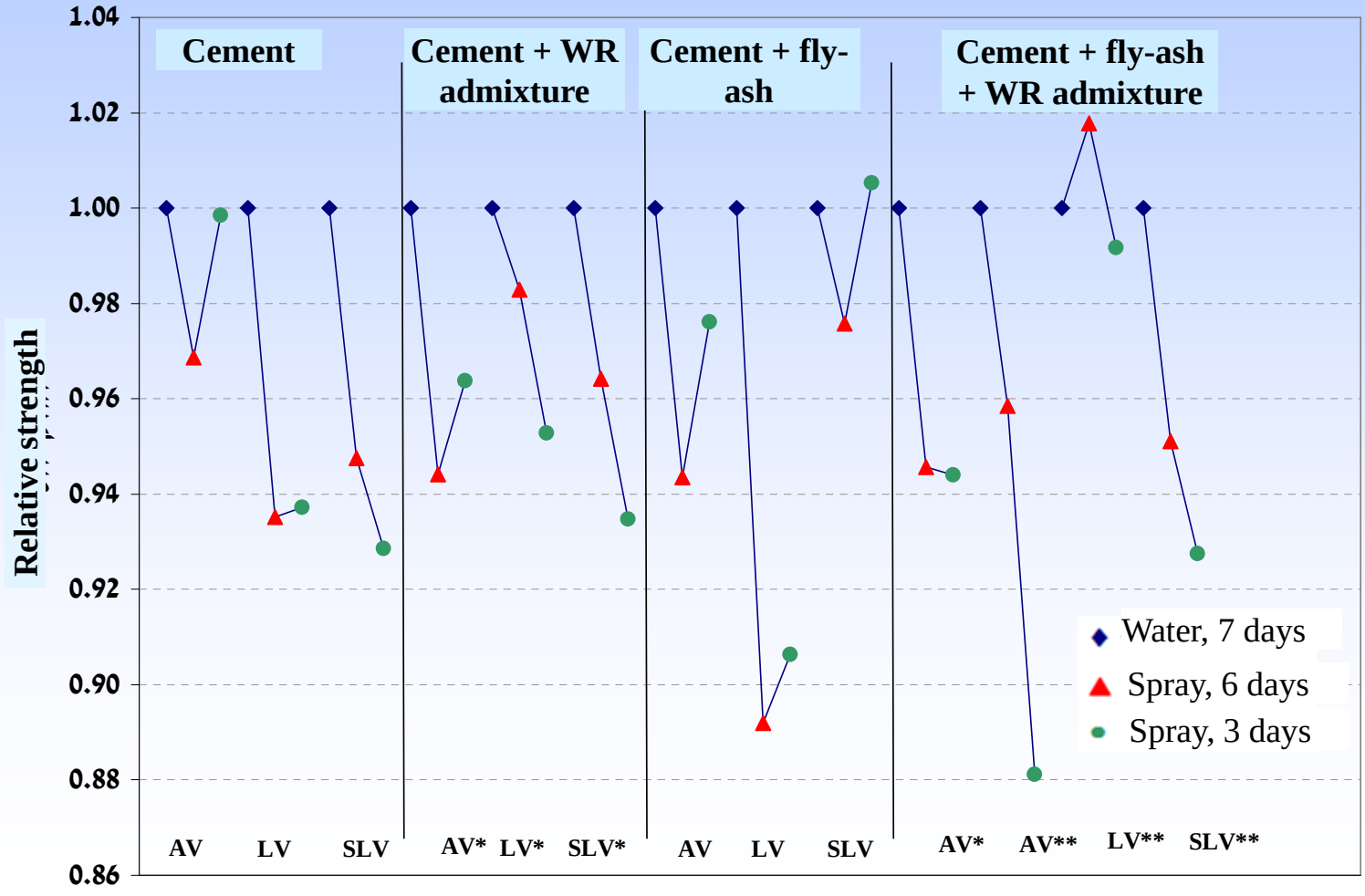
Results:

Hardened concrete

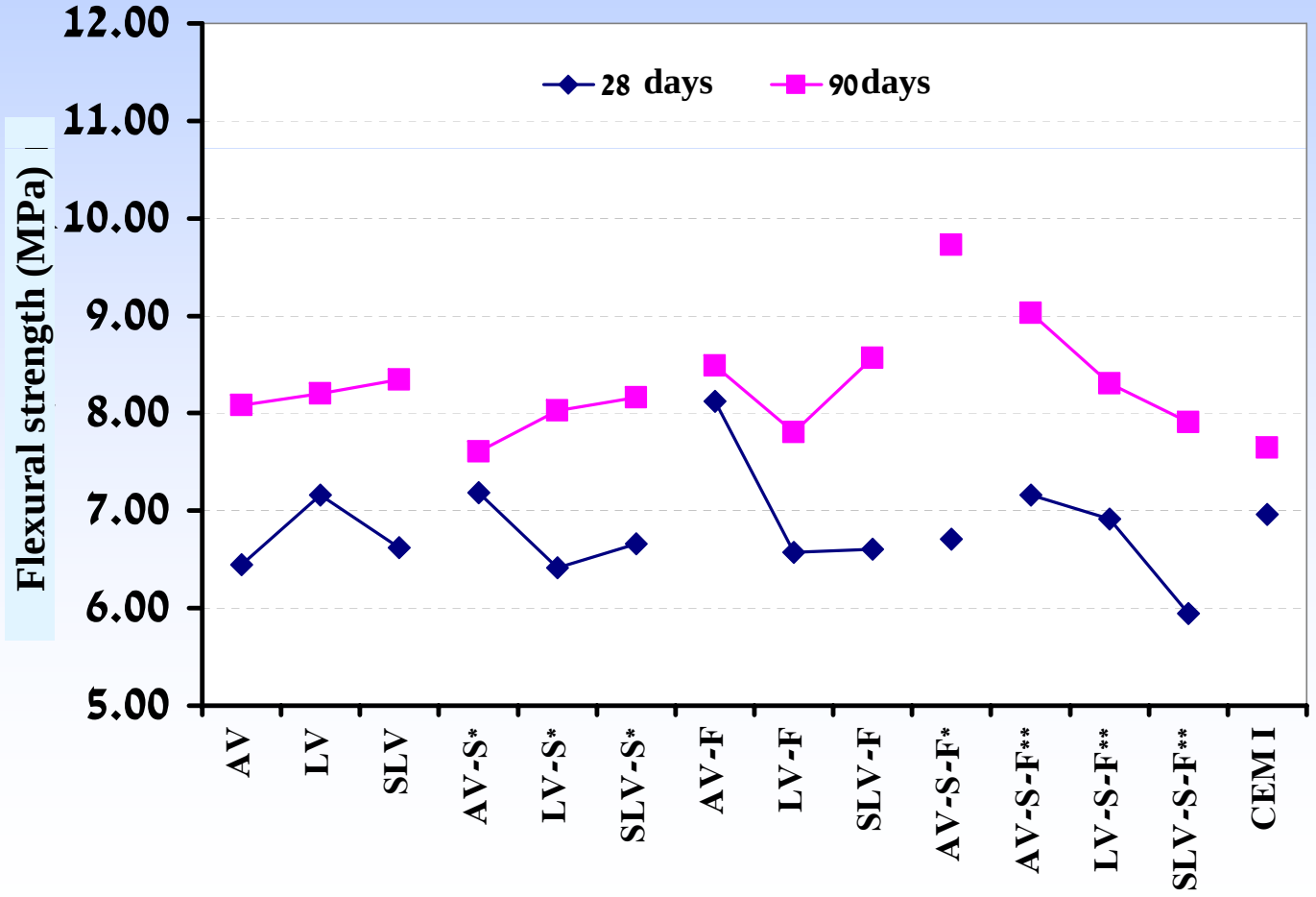
Compressive strength



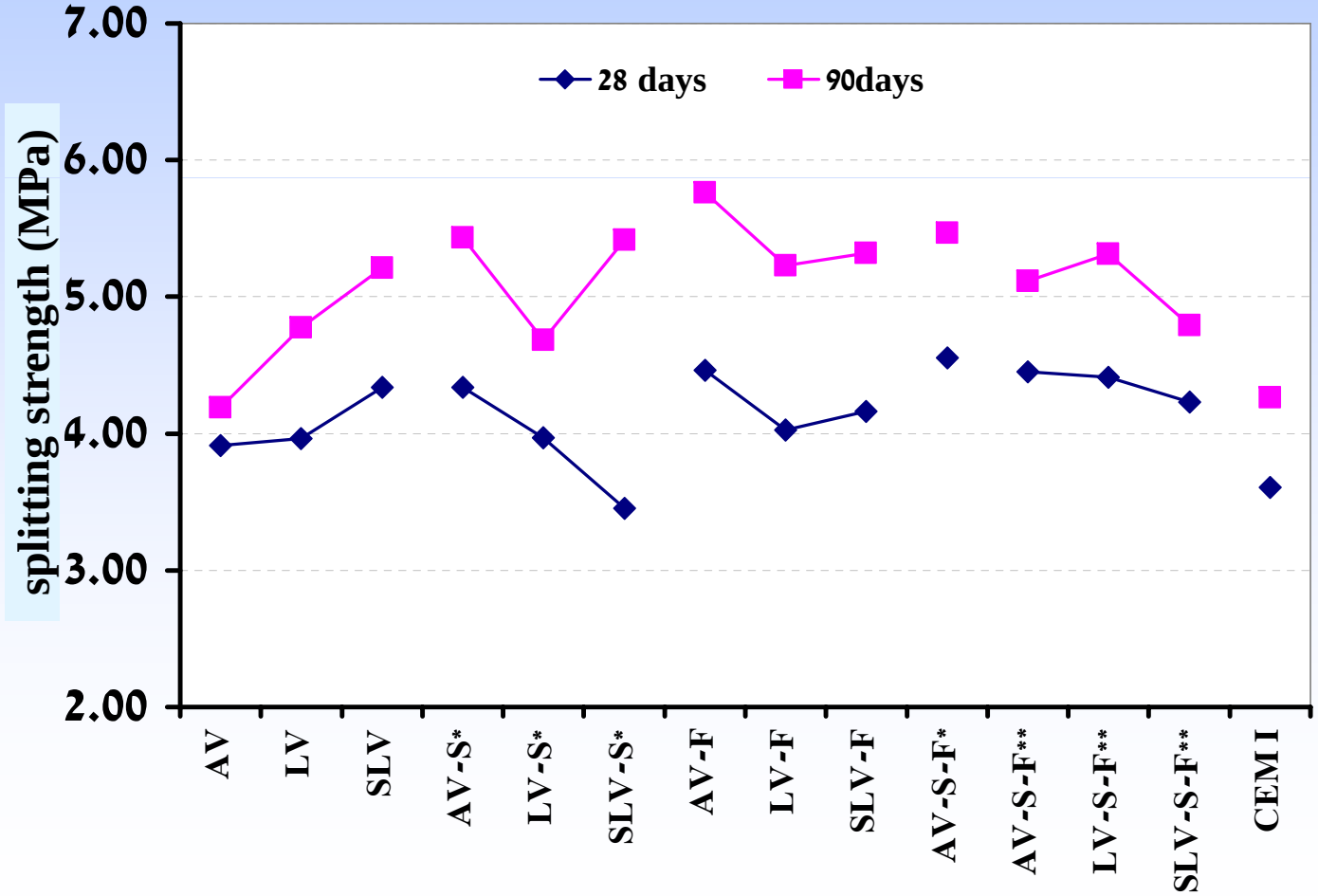
Effect of curing regime on compressive strength



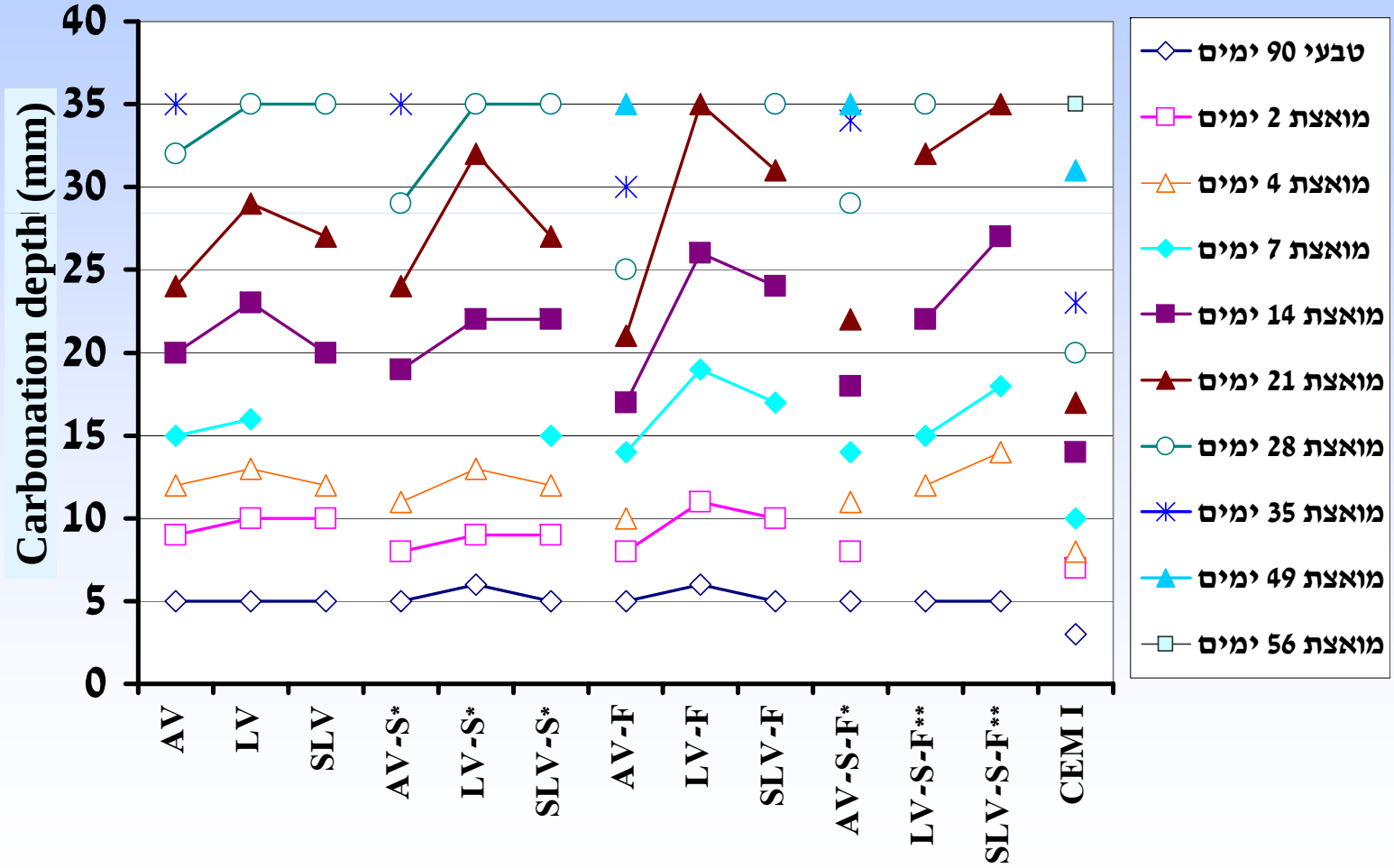
Flexural strengths



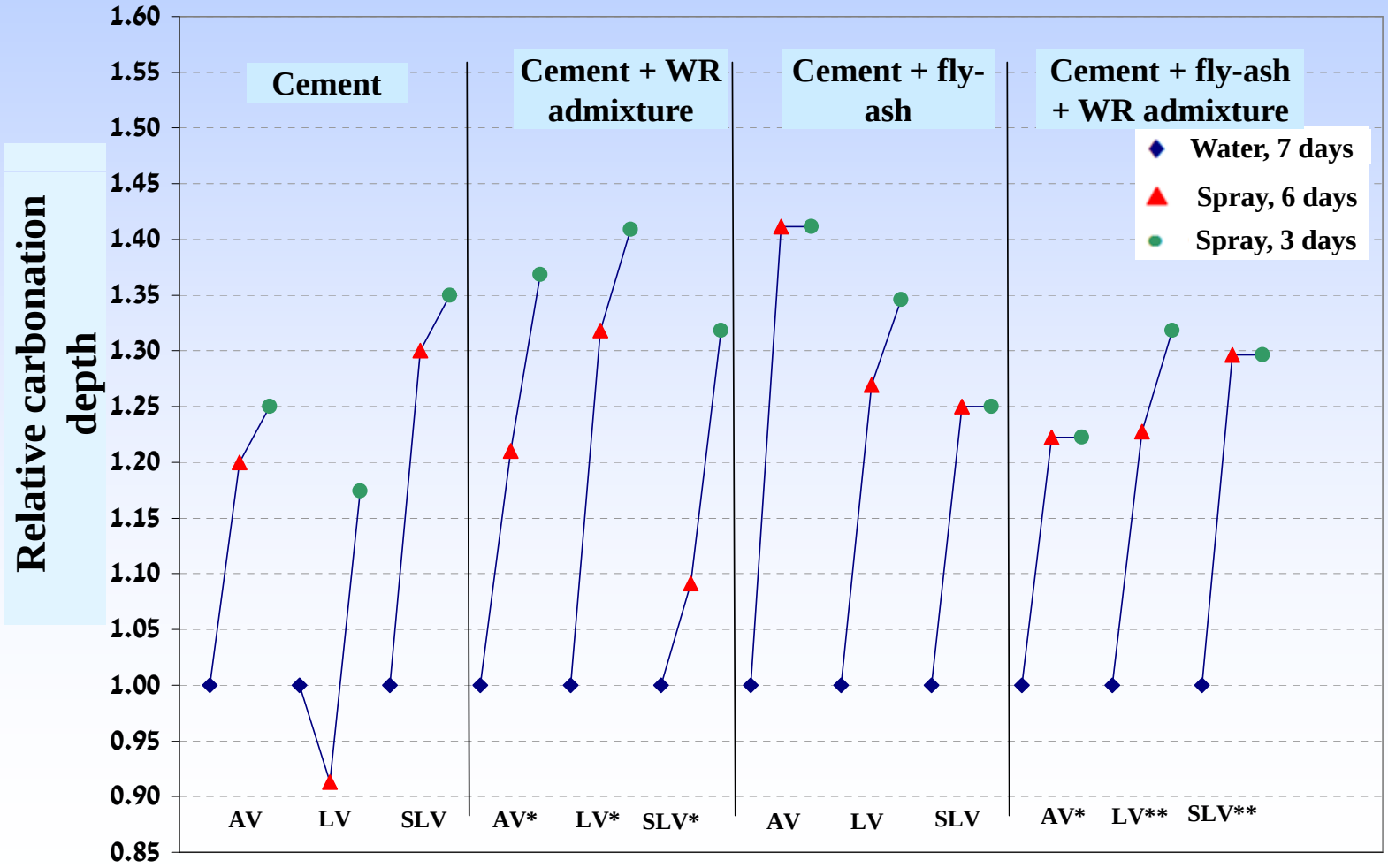
Splitting strengths



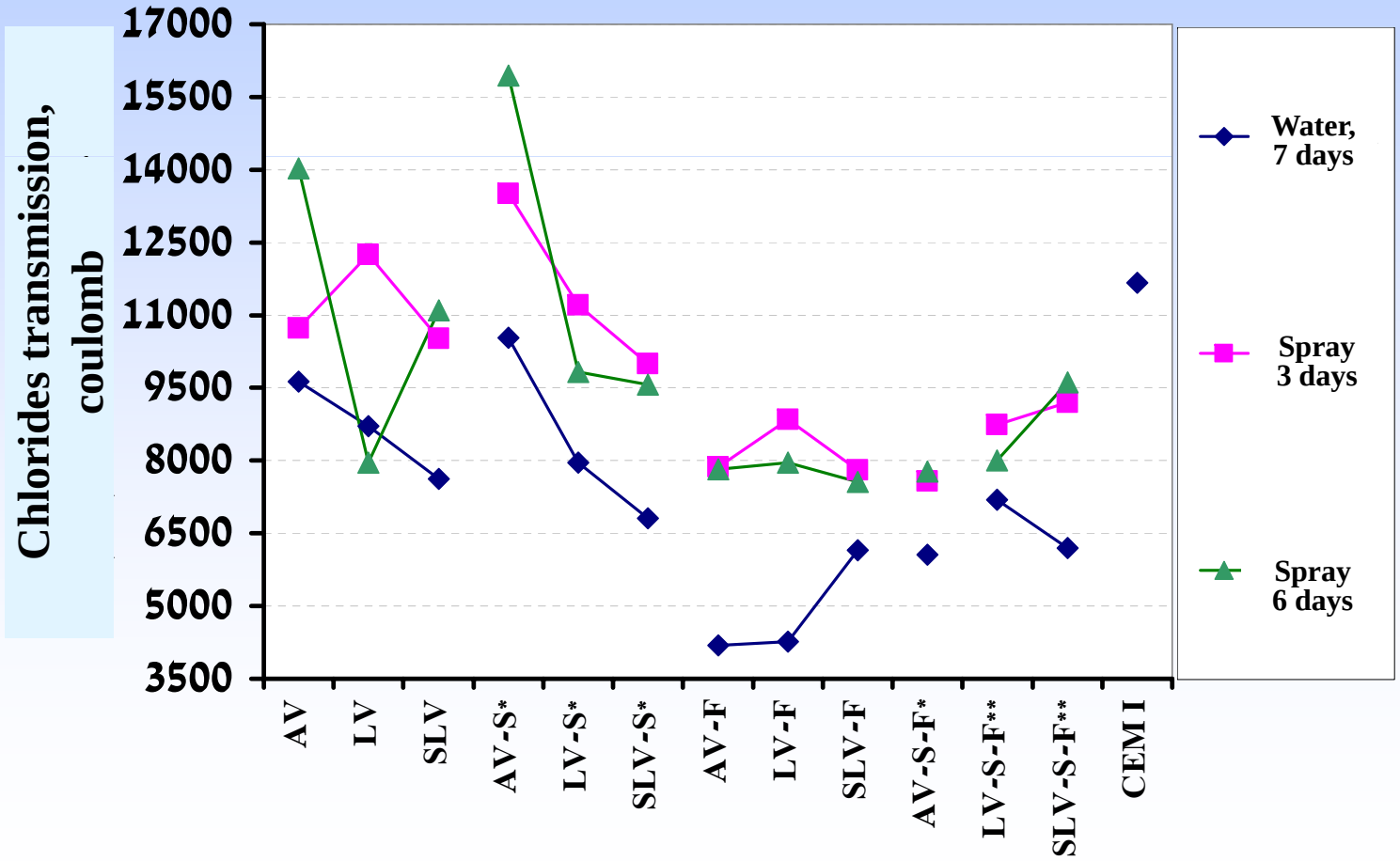
Carbonation, standard curing



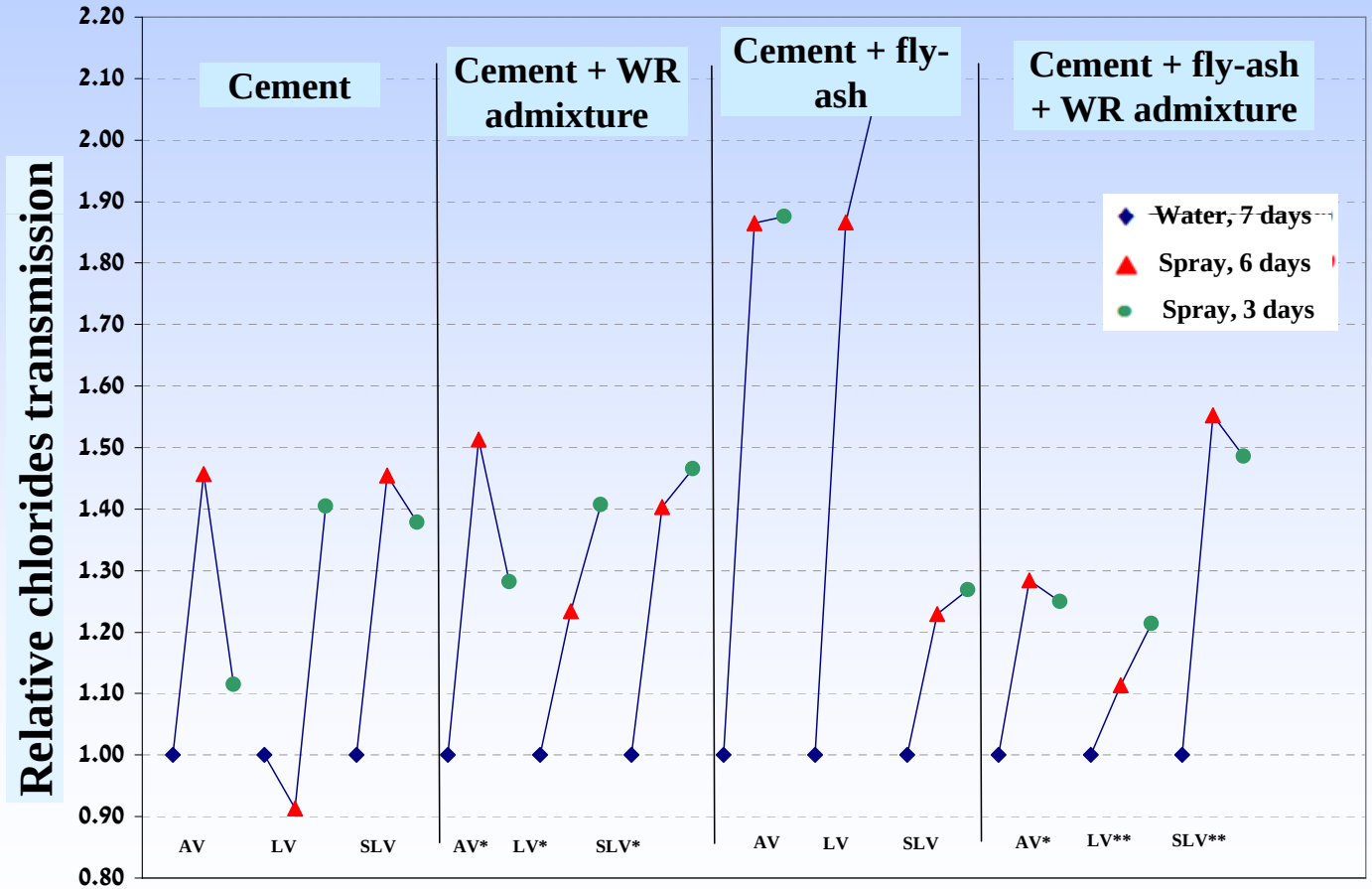
Carbonation- effect of curing



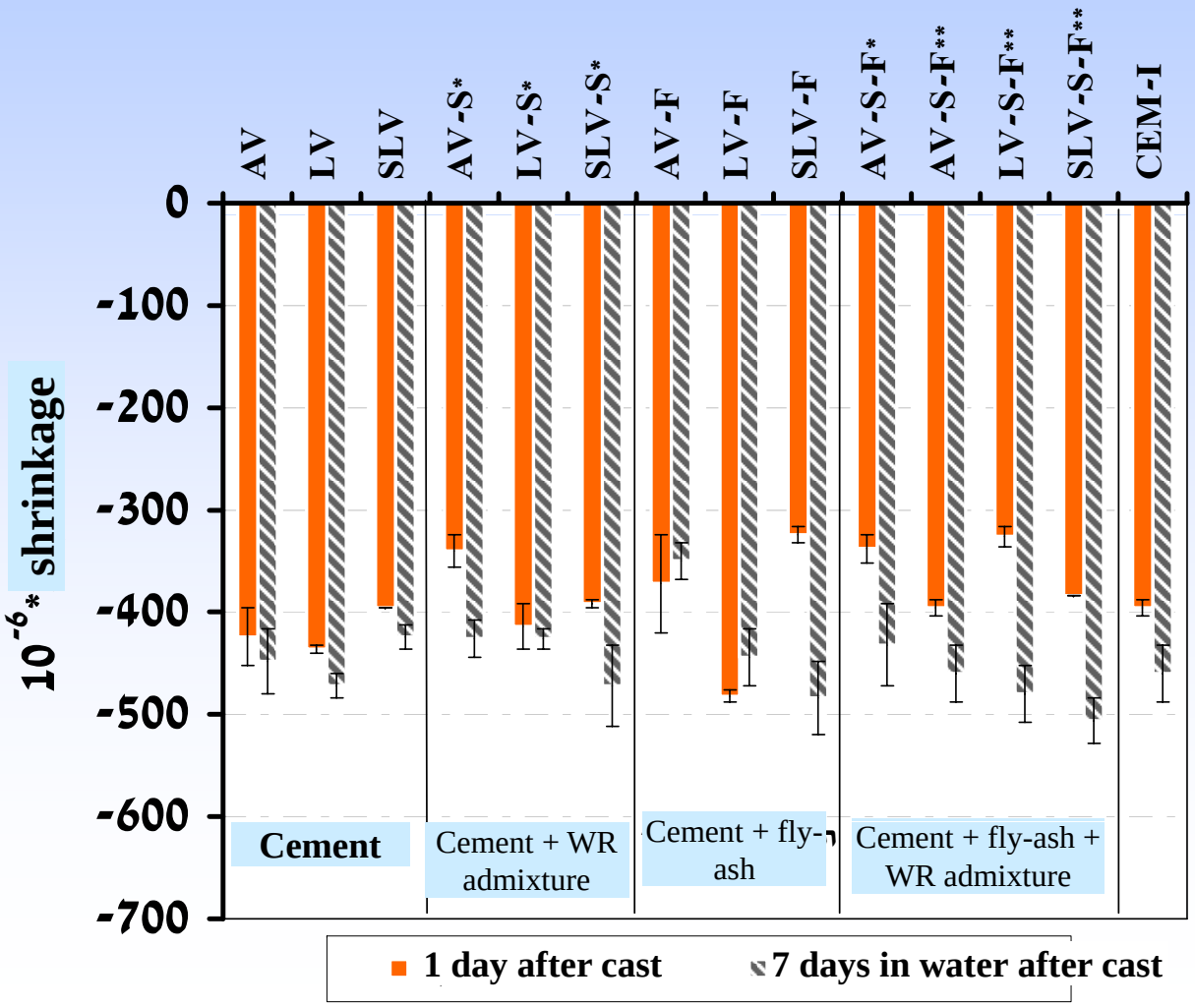
Chlorides transmission



Chlorides transmission-effect of curing



Drying shrinkage



Conclusions

- Larger surface area of the blended cement led to increased water demand or reduced slump. This could be controlled by proper use of water reducing admixtures.
- Setting time of the blended cement was shorter, but not as much as seen of the neat cement paste.
- Bleeding has reduced with the use of the blended cements

Conclusions (cont.)

- The compressive strength of concretes with blended cements was somewhat lower. Mainly when fly-ash was used.
- One day compressive strength was quite similar with all concretes, except for concretes with fly-ash and WR admixture.
- Tensile strength was sensitive to mixes containing fly-ash and WR admixture. 90 days tensile strength improved in the presence of the blended cements.

Conclusions (cont.)

- Carbonation rate of concretes with blended cements was larger. LV cement was more sensitive.
- Chloride penetration decreased in concretes containing blended cements

Conclusions (cont.)

- Proper adaptation of the admixtures to the chemical and physical properties of the cements is of special importance for their efficient use in concrete.

Disclaimer: the above mentioned conclusions are applicable to the cements tested in this study only.

Thank you

Haifa