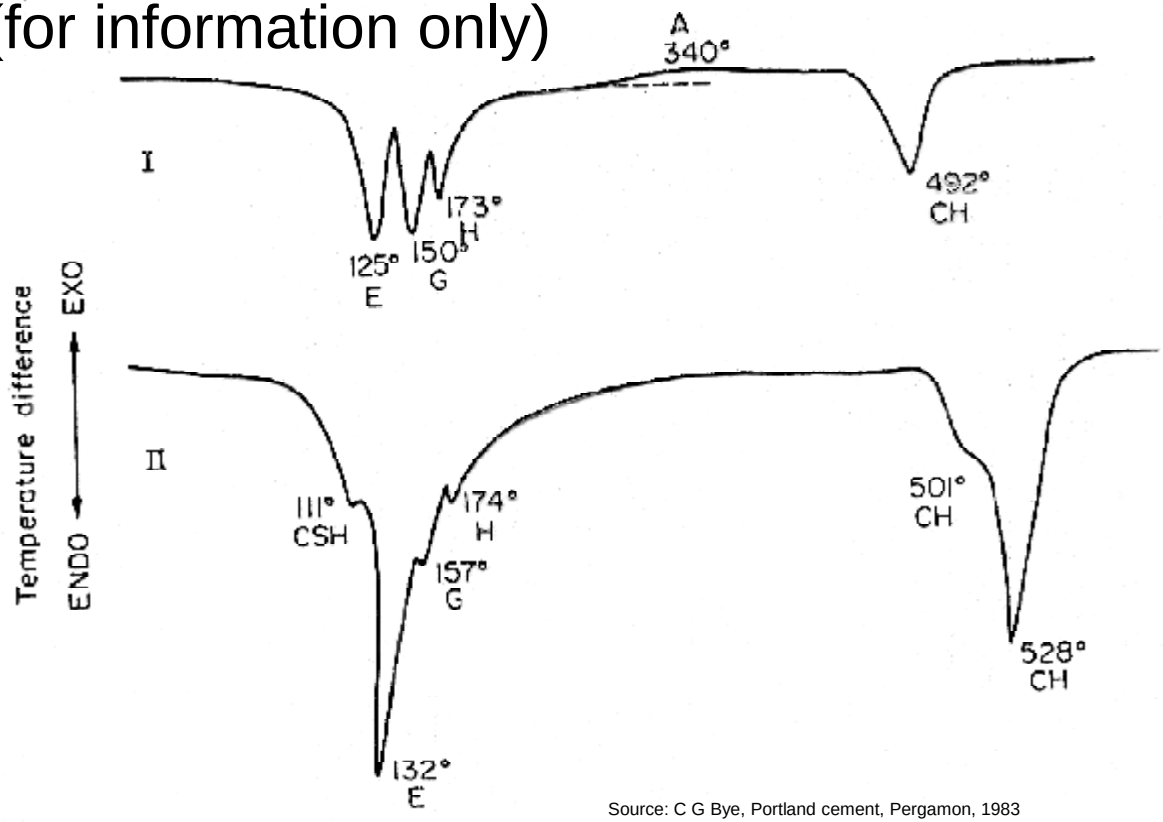
Hydration
Measurement Techniques

- **Lime content in hydrating cement**
- **Chemically bound water content**
- **Heat evolved during hydration**
- **Specific gravity of the hydrating paste**
- **Residual unhydrated cement**

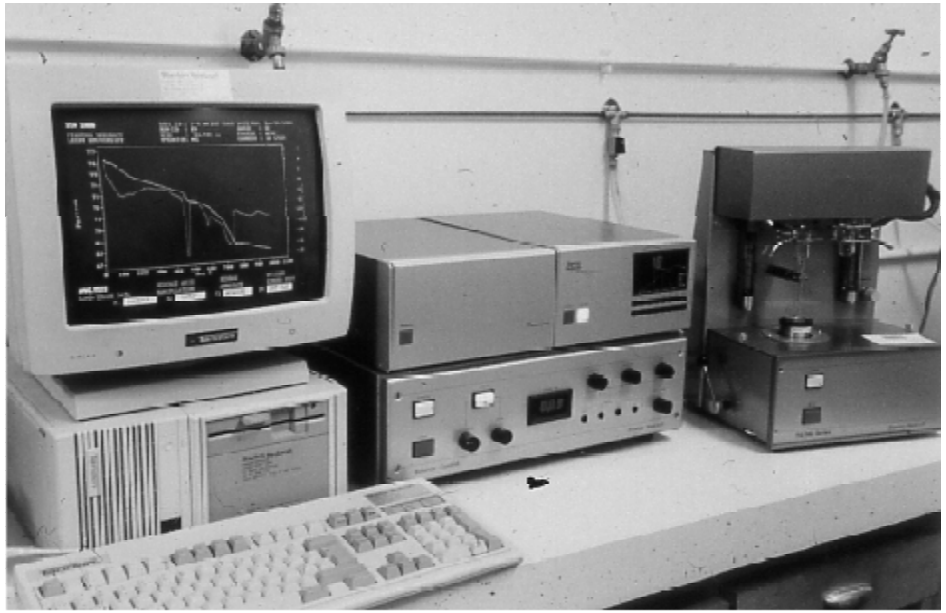
DTA (for information only)

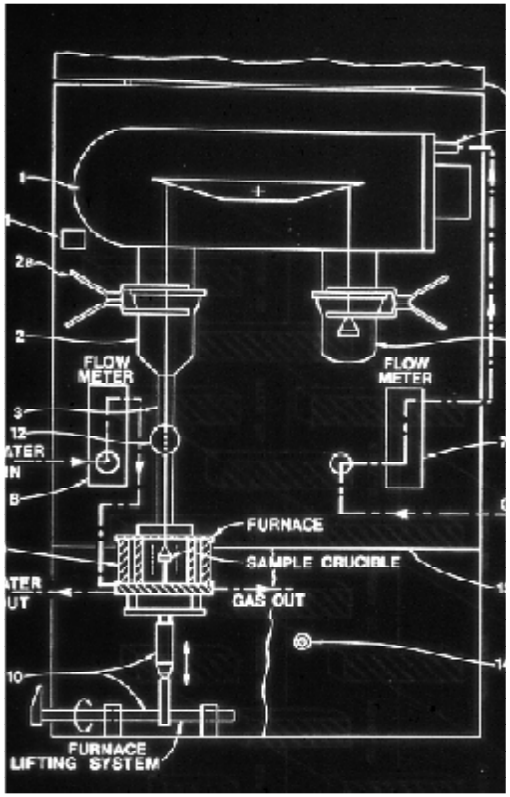


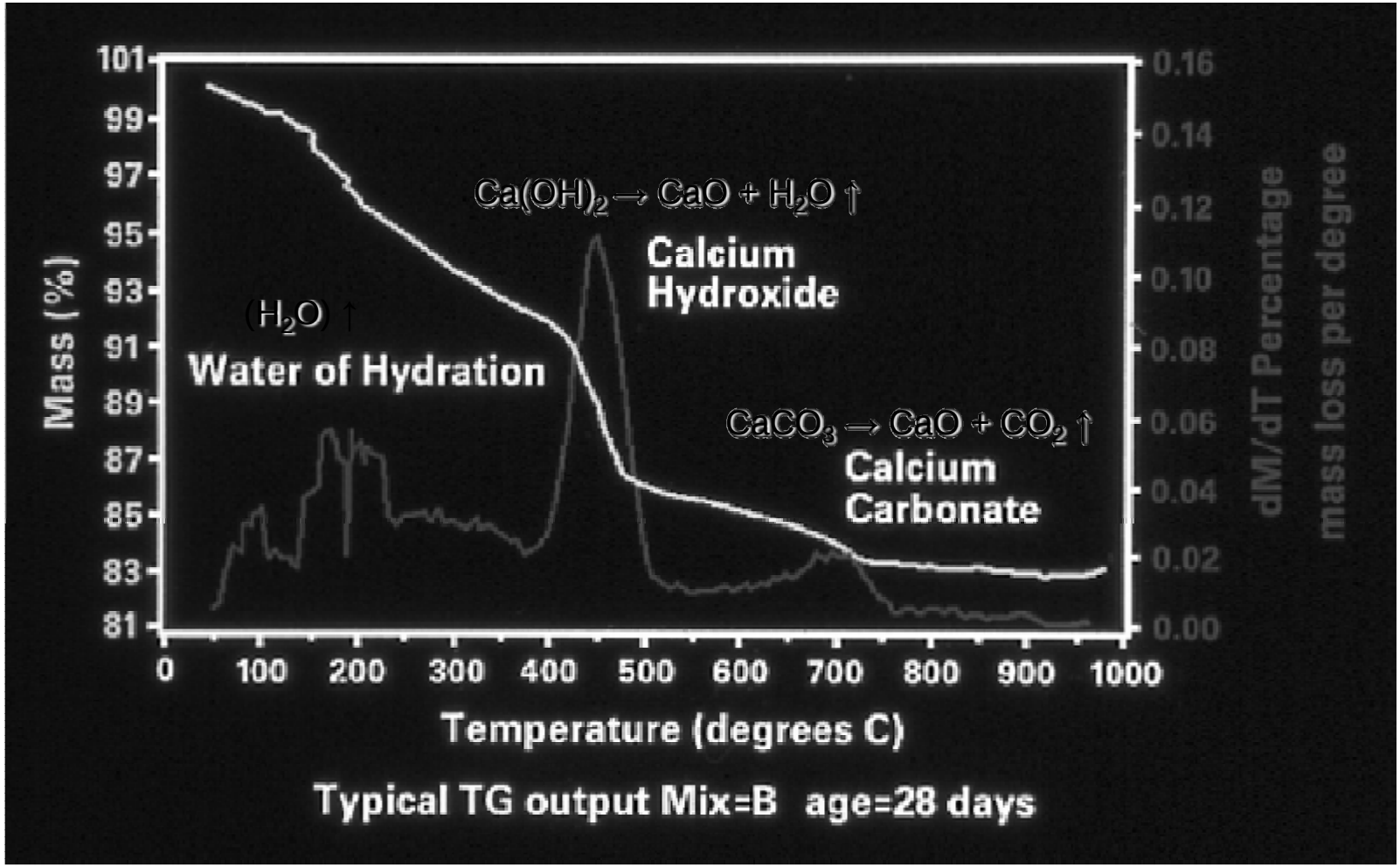
Source: C G Bye, Portland cement, Pergamon, 1983

Differential Thermal Analysis of Samples of Ordinary Portland Cement Paste Hydrated for 5 minutes (I) and 16 hours (II). Endotherms .for the dehydration of: E - ettringite; G - gypsum; H - calcium sulphate hemi-hydrate-CH - calcium hydroxide; CSH - calcium silicate hydrates; A -weak exotherm for the crystallisation of anhydrite ($CaSO_4$). The temperatures found for the peaks are particularly dependent on the sample (size, packing and composition) and the equipment used

Thermogravimetry (TG)







(Source: Cabrera & Lynsdale, L'Industria Italiana Del Cemento 7-8, 1996)

Reactions

- ***Up to about 400 °C, weight loss is due to structural water from silicate and aluminate phases***
- ***At 400 - 500°C***

  $Ca(OH)_2 \rightarrow CaO + H_2O \uparrow$
- ***At 650- 750 °C***

  $CaCO_3 \rightarrow CaO + CO_2 \uparrow$
- ***Atmospheric carbonation***

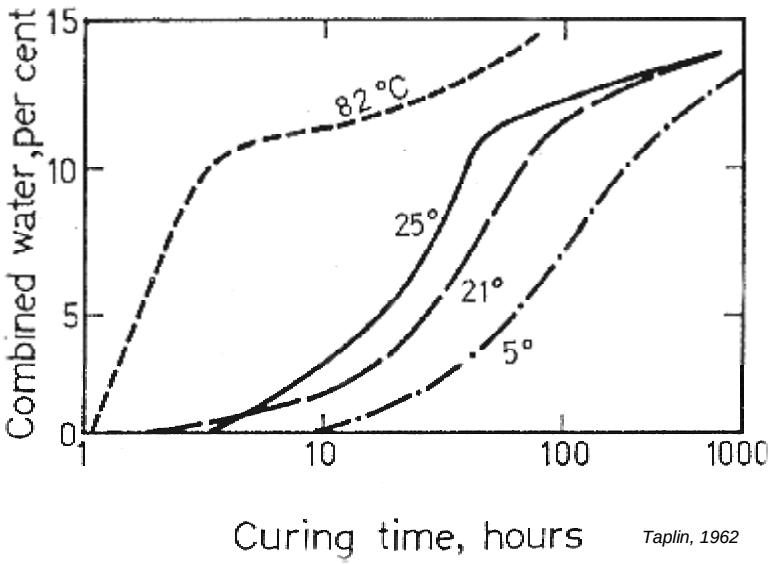
  $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Degree of Hydration

$$DH(at\ \text{age}\ n) = \frac{Ca(OH)_2(\text{at age n})}{Ca(OH)_2(\text{for fully hydrated paste})} \times 100$$

Factors affecting Hydration

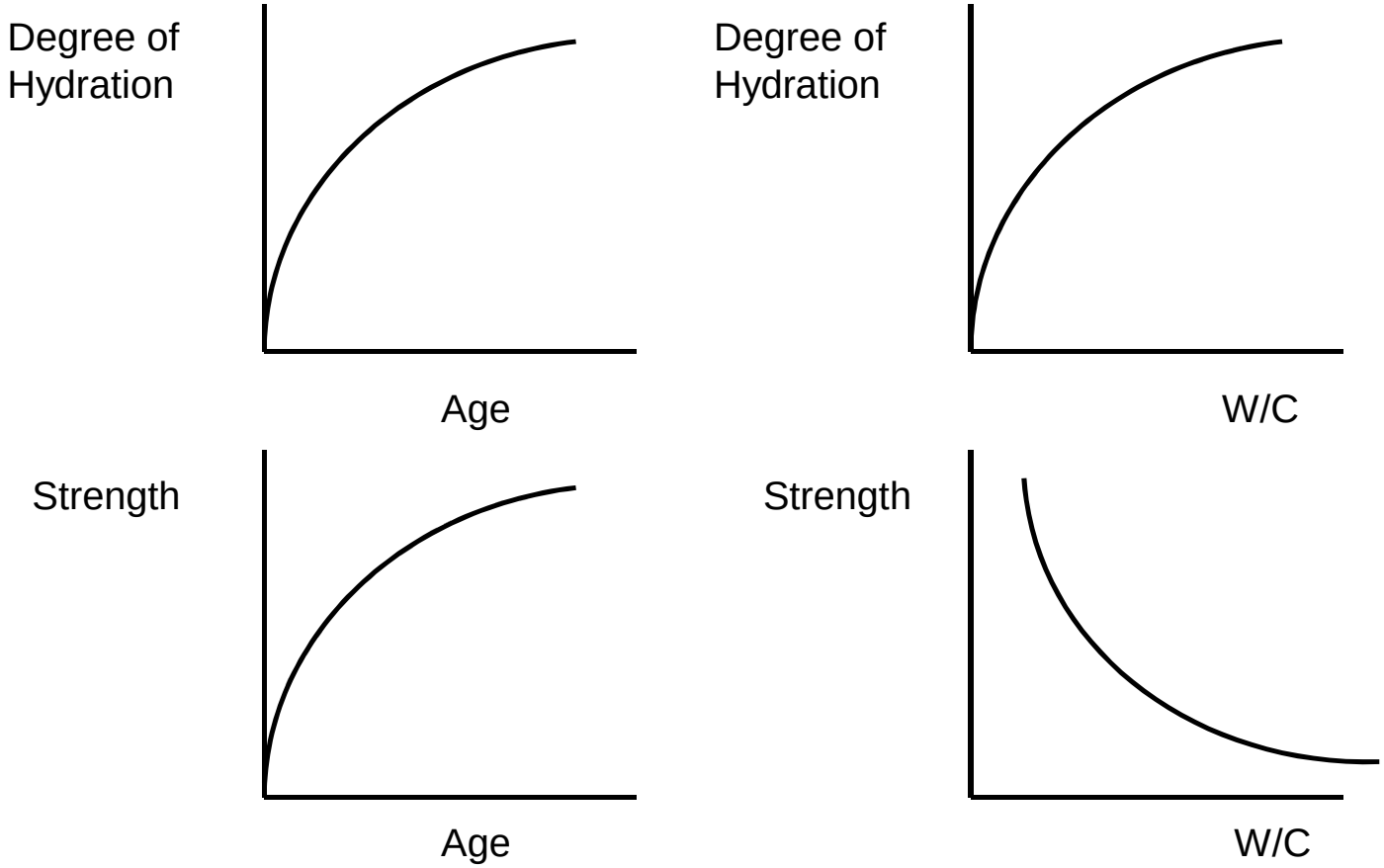
- **Cement composition**
- **Fineness of cement**
- **Water / cement ratio**
- **Curing**
- **Ambient conditions**
  - **Temperature**
  - **Relative humidity (for hydration to proceed relative humidity (RH) needs to be above 80%)**
- **Admixtures e.g. retarders and accelerators**



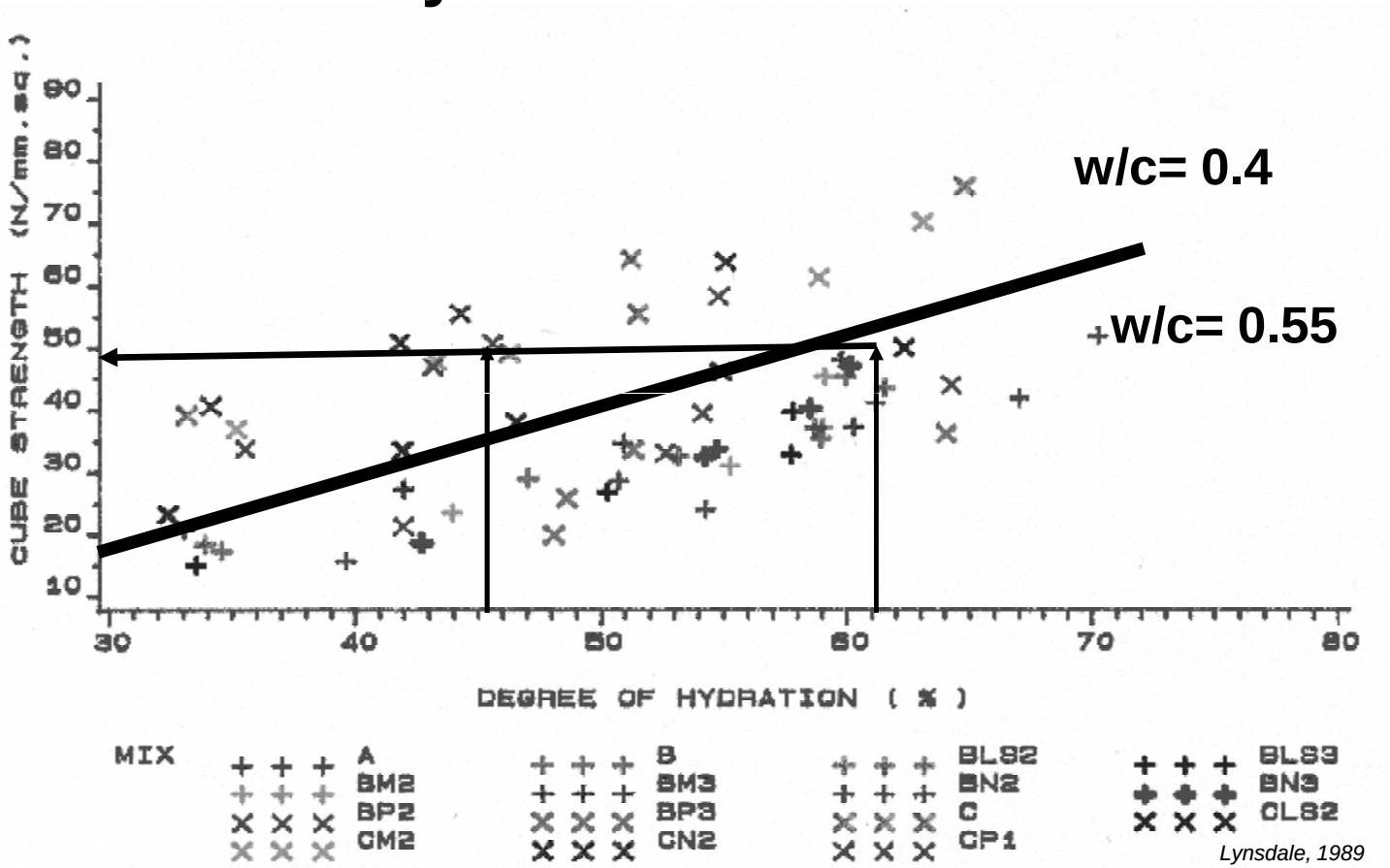
Taplin, 1962

Significance of Hydration and W/C on Microstructure and Strength Properties of Concrete

Degree of Hydration & Strength: Influence of Age & W/C

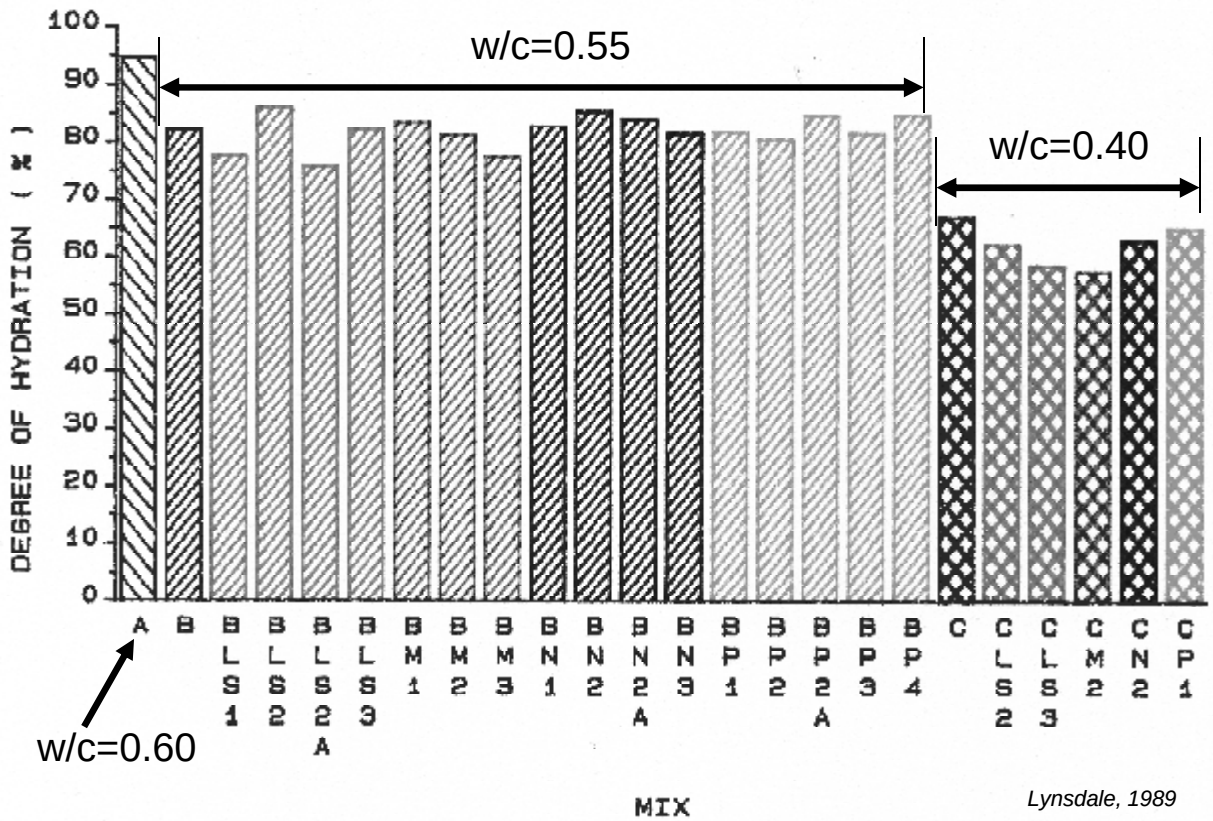


Compressive strength, degree of hydration and w/c



Lynsdale, 1989

Degree of hydration calculated from measurement of calcium hydroxide content using TG for various mixes at age = 28 day



Lynsdale, 1989

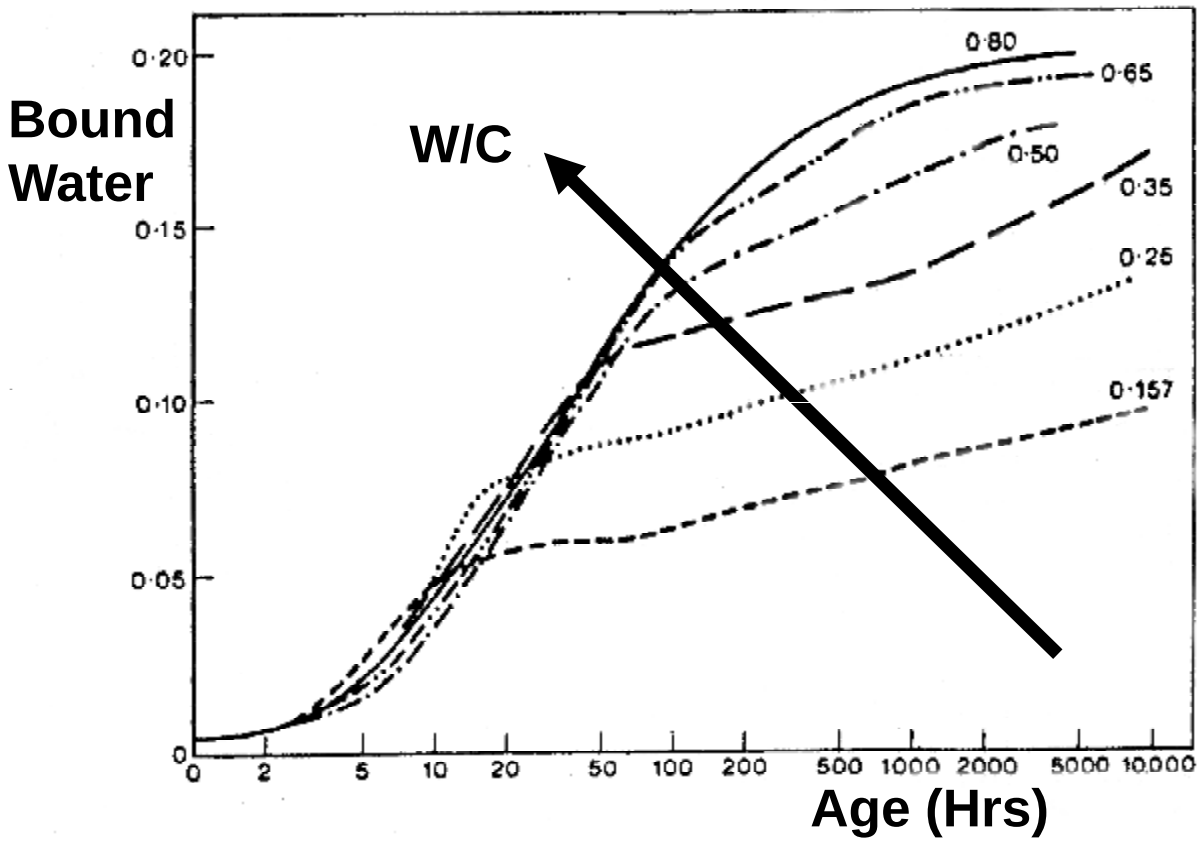
The Influence of Age & W/C on Degree of Hydration

$$DH(\%) = 191.6 - 67(\text{w/c})^{-0.5} - 55.2(\text{age})^{-0.33}$$

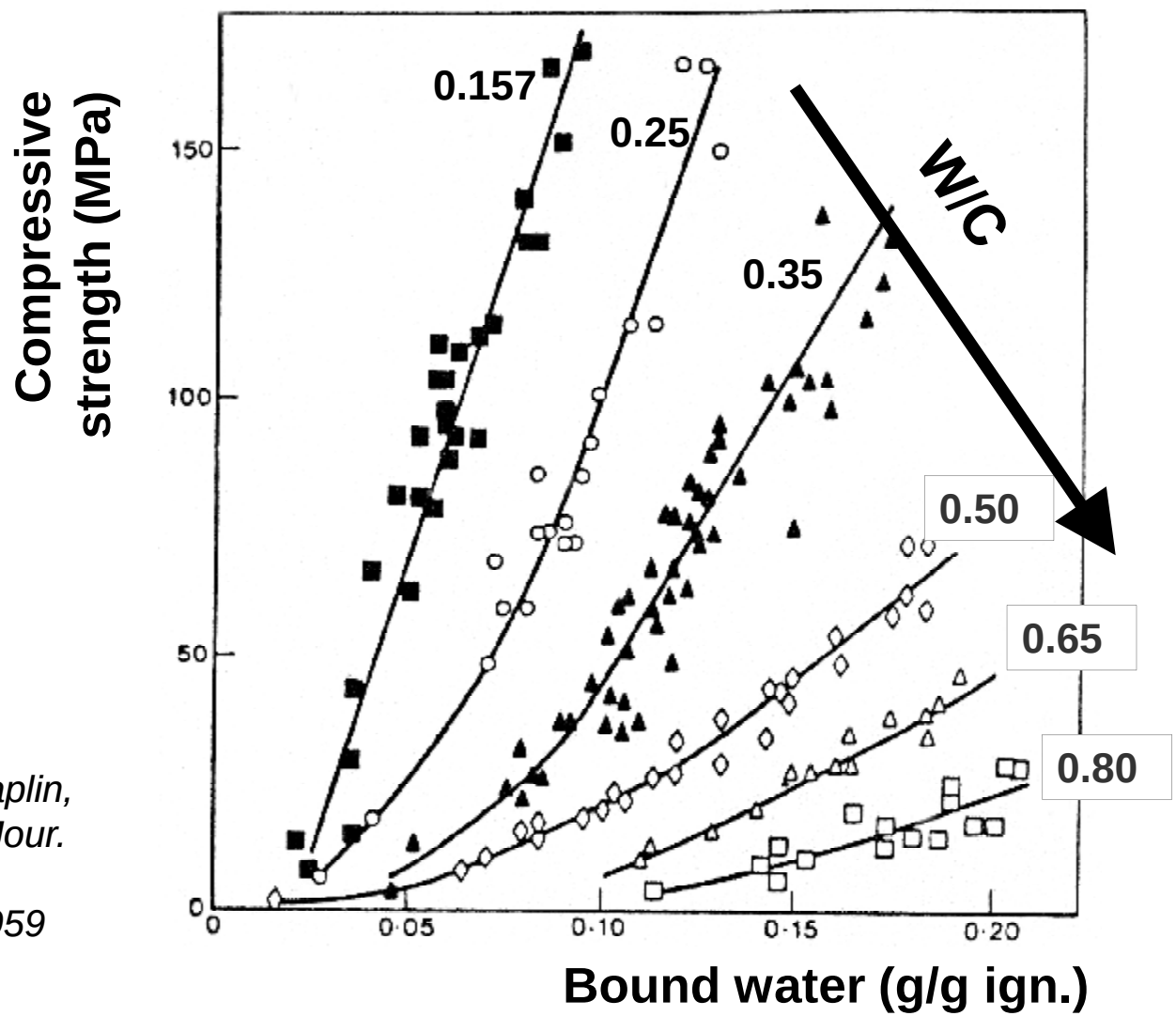
Coefficient of determination $R^2 = 0.933$
Standard deviation = 4.6
Coefficient of variation = 6.9

Lynsdale, 1989

Hydration vs. Age & W/C

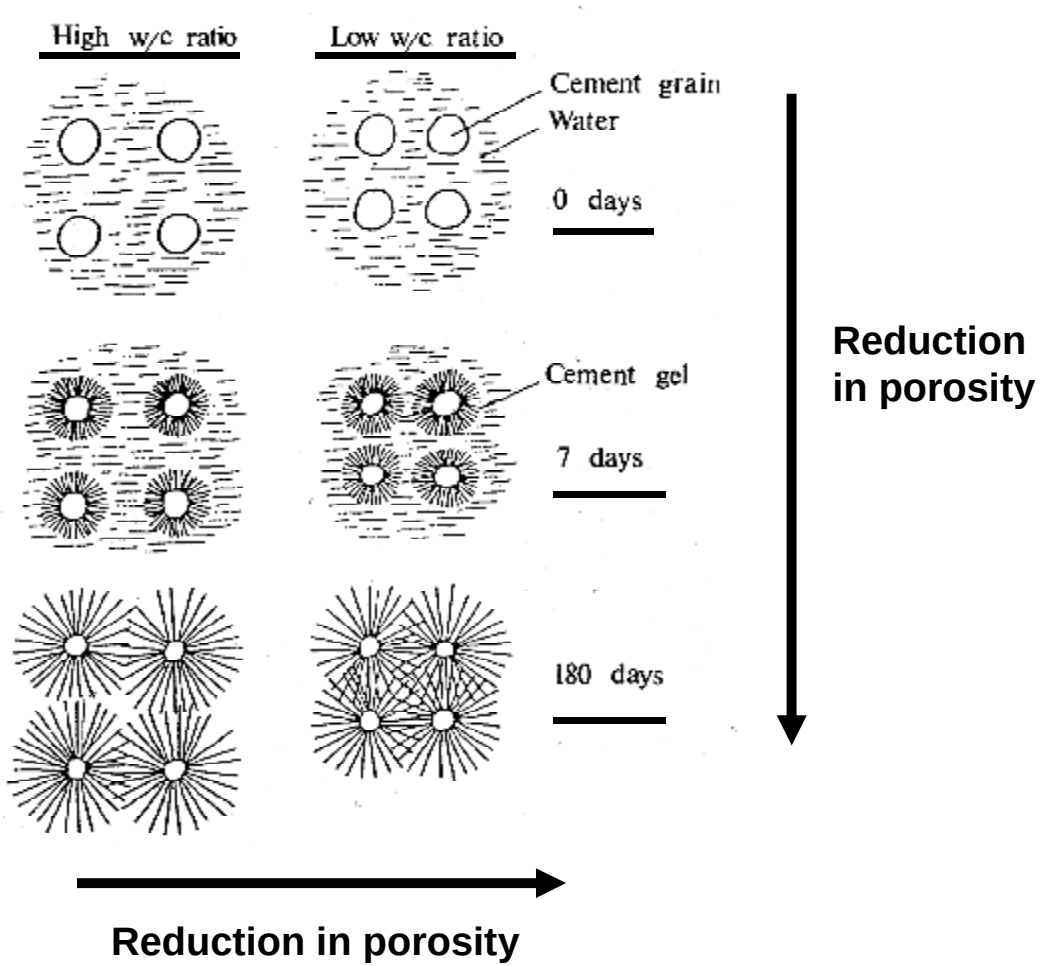


(After J H Taplin, Australian Jour. Of Applied Science, 1959)



After J H Taplin, Australian Jour. Of Applied Science, 1959

Schematic w/c, hydration & porosity



Strength, Porosity & Hydration
Relative significance

- **Example**
  (results by Roy & Gouda, CCR, 1978)

Cement paste samples

Compacted: high pressure, 340 MPa (50,000 psi)

Cured: 250 ˚C

- **Results**

Compressive strength= 660 MPa

Tensile splitting strength= 64 MPa

Porosity= 1-2 (%)

Degree of hydration= 30-35 (%)

Engineering Significance of Hydration

- **Reduction in total porosity ® Higher strength with time (i.e. strength development)**
- **Refinement of pore size ® Reduction of permeability with time**
- **Both effects lead to a more durable concrete**
- **Influence of hydration on concrete is significant at early ages**
- **Influence of hydration on concrete properties is controlled by the water / cement ratio**