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Recent Advances in ASR Test Methods and Understanding Mitigation Mechanisms, Part 1

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Relations between ASR expansion and average water content in mortar bars exposed to dry ambient atmospheres

By

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Introduction

✱ Moisture in concrete is strongly held by the cement paste phase, and so expansion does not always occur even if much ASR gel has been produced.

✱ Moisture distributions within mortar specimens exposed to dry ambient atmospheres depend on their size.

Objective of this study

The objective of this study is to reveal relationship between critical average water contents below which ASR expansion do not occur, and equilibrium water contents in mortar bars exposed to ambient atmospheres with various values of relative humidity.

Materials

- Reactive aggregate:
  - ∗ Calcined flint (C.F.) (Lafage Cement Ltd)
    Reduction in alkalinity: 70 mmol/l,
    Dissolved silica: 1063 mmol/l
- Non-reactive aggregate: Japanese standard sand
- Alkali content of cement: 0.53% ⇒ 1.2% (added NaOH)(JIS)

Experimental procedures

- Initial curing : > 95% R.H., 40℃ ⇒ about 0.1% Exp.

Saturated salt solutions		Equilibrium relative humidity
NaCl	↔	74.7% (≒ 75%)
$(NH_4)_2SO_4$	↔	79.9% (≒ 80%)
KCl	↔	82.3% (≒ 82%)
KNO_3	↔	89.0% (≒ 90%)
Water	↔	>95%

- Atmosphere of 70% R.H. : mechanically controlling

Hilsdolf Equation*

- **Equilibrium water content (W_e) at a given R.H. value**

$$W_e = C[0.18mX + Y(W_oC^{-1} - 0.36m)] \quad (1)$$

X, Y: Coefficients depending on R.H. value

- **Average water content (W_t) at a given time**

$$W_t = W_e + \bar{U}(W_o - W_e) \quad (2)$$

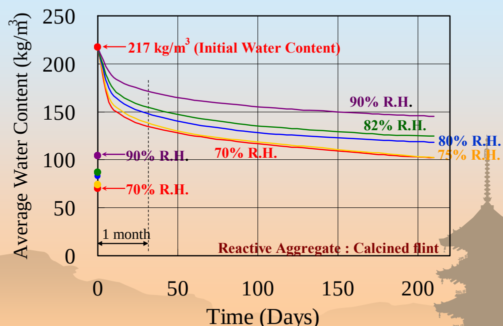
where average moisture concentration ($\bar{U}$):

$$\bar{U} = \exp[-\alpha(t/\bar{l}^2)1/3] \quad (3)$$

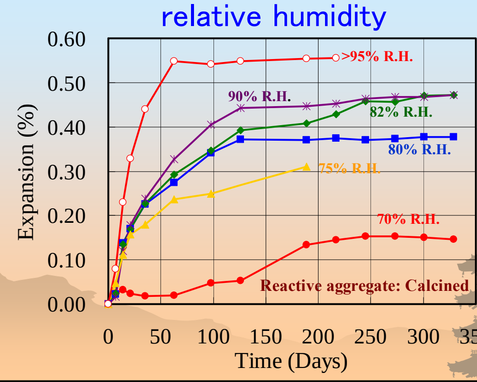
$$\alpha = 1.75 \times 10^{-2}\sqrt{1-\phi}\,[1 + 15(W_0C^{-1} - 0.40)^2]/m_a \quad (4)$$

* Hilsdolf, H.K., A method to estimate the water content of concrete shields", Nucl. Eng. Des., 6, 251-63, 1967.

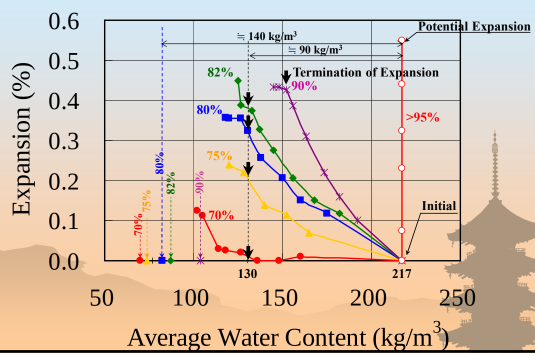
Reduction in average water content with time



Expansion curves at various values of relative humidity



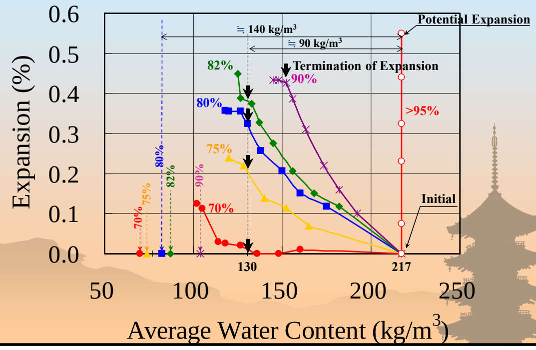
Average water content vs. expansion relations



Causes of sensitive response of expansion to relative humidity

- Vapor sorption of ASR gels drastically increase with increasing relative humidity over about 80% R.H..
- Internal stresses induced in mortar bars influence overall expansions

Average water content vs. expansion relations



Kelvin equation

$\ln p/p_0 = -2 \upsilon V/rRT$

p/p_0 : relative humidity

r : radius of pore

Critical pore size

Relative humidity (%)	Pore size (nm)
89.0	16.7
82.3	10.0
79.9	8.7
74.7	6.7
70.0	5.4

Classification of pore sizes

✱ Medium capillary pores: 50 ～ 10 nm

✱ Small capillary pores: 10 ～ 2.5 nm

(S. Mindess & J.F. Young, "Concrete", Prentice-Hall, Inc., N.J.,1981)

Conclusions

(1) An apparent critical relative humidity below which ASR expansion did not occur, was between about 70% and 75% in ASTM mortar bars.

(2) Expansion was very sensitive to moisture distribution within mortar bars.

(3) ASR gels in mortars appear to have expanded by absorbing water in relatively large capirally pores.