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CHEMICAL WEATHERING OF CONCRETE IN SUB-TROPICAL AND TROPICAL REGIONS

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CHEMICAL WEATHERING OF CONCRETE IN SUB-TROPICAL AND TROPICAL REGIONS*

by

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ABSTRACT

Concrete structures in sub-tropical and tropical regions are usually subjected to leaching action of neutral (rain) water in cycle with drying and high temperatures.

Considerable volume of research work has been carried out assessing durability of concrete in aggressive environments (acid attack, salt solutions etc.) but long term quality control of concrete durability in tropics is generally badly defined. In order to fill this gap, an accelerated weathering test intended to evaluate durability of concrete under "normal" conditions of exploitation in tropical and sub-tropical regions is proposed, and some of the investigation techniques discussed.

INTRODUCTION

In a Guide to Durable Concrete, reported by ACI Committee 201 in a December 1977 issue of the Journal of the American Concrete Institute, a summary of the most common factors affecting concrete durability is given, as follows:-

FACTORS INCREASING DETERIORATION	FACTORS DECREASING DETERIORATION
Higher temperatures	Lower water-cement ratios
Alternate wetting and drying	Lower absorption
Increased fluid velocities	Lower permeability
Poor consolidation of concrete	Proper cement type (in some circumstances)
Poor curing of concrete	
Corrosion of reinforcing steel	

In tropical and sub-tropical regions, nearly all concrete structures are subjected to conditions of high temperature and alternative wetting and drying. They may, of course, in addition be subjected to the aggressive action of organic or inorganic acids, alkaline solutions, salt solutions (e.g. sea water) etc...

The object of this research is to provide a method for determination of different rates at which various types of concrete will deteriorate under exposure to the alternative cycles of wetting (leaching corrosion) in hot climatic conditions.

The basic conditions of this type of reaction are reported by several researchers including Mills (1), Chatterji and Jeffery (2), in chapter 4 by Biczok (3) and by Gutt (4).

TEST METHOD

In order to create conditions of repeated cycles of tropical rain (washing specimen with warm distilled water) a slightly modified version of Pedro's (5) technique used in the experimental study of the geochemical weathering of silicate minerals was adopted.

The apparatus consists of a Soxhlet Extractor (British Standard 2071), a heating mantle and recording thermometers with a continuous readout of vapour and liquid temperatures. A schematic diagram of the apparatus and relevant simulation of various ambient conditions is shown in Fig. 1. The specimen is placed in a filter paper thimble to prevent undissolved solids from being siphoned into the flask.

The "eluviate" zone consists of two parts:- above and below the "water-table". By selecting a specimen of appropriate dimensions the process of

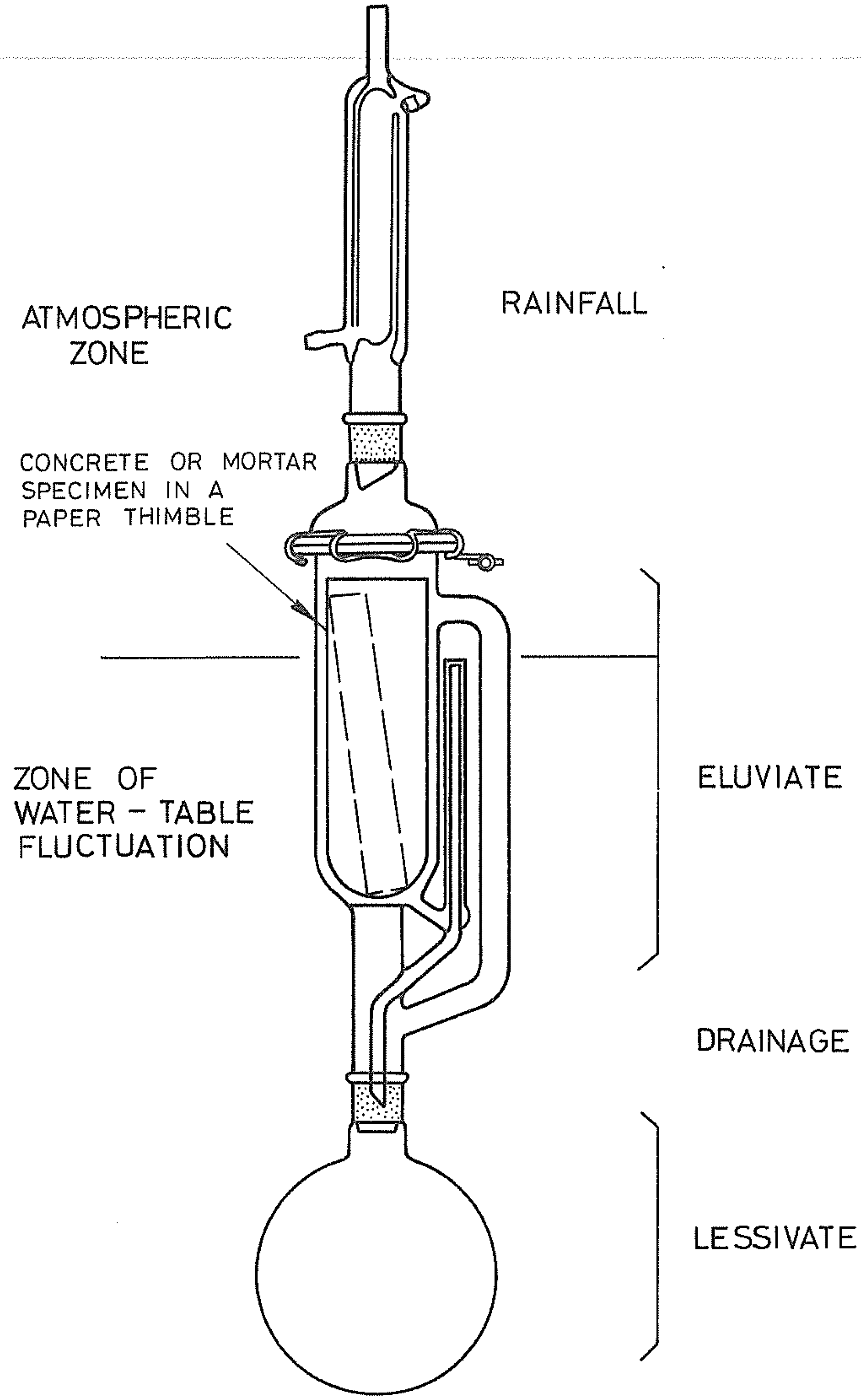
ATMOSPHERIC ZONE
RAINFALL
CONCRETE OR MORTAR SPECIMEN IN A PAPER THIMBLE
ZONE OF WATER – TABLE FLUCTUATION
ELUVIATE
DRAINAGE
LESSIVATE

Fig. 1

weathering in the zone of "water-table fluctuation" only or (in the case of a larger specimen) partial exposure to the "atmospheric zone" can be reproduced.

Chemical, mineralogical and physical changes of specimens with time provide a qualitative measure of the weathering process. Periodical chemical analyses of reflexing water provide information of the type and the rate of leaching corrosion. The rate of concrete deterioration can be expressed by means of a mathematical model of the type proposed by Prudil (6).

ANALYTICAL TECHNIQUES

Change in the chemical composition of a specimen and the rate at which dissolved chemicals are removed from concrete can be done using conventional wet analysis, e.g. Australian Standard (A.S. 1315-73, ASTM C114-77) British Standard (B.S.) 4550: Part 2: 1970, South African 734-755 series etc...

Spectrophotometric Analysis of Cement: A.S. 1378-1972 (U.V. range) yields faster results, with the X-ray fluorescence being the fastest, giving analytical precision comparable to that obtained by wet chemical methods for most elements. The accuracy however, progressively decreases for the elements with lower atomic numbers. Alkalis are conveniently analysed using flame photometry or atomic absorption spectroscopy. Most of the above techniques are summarised by Klemm et al (7) and in the second chapter of Ramachandran (8).

Changes in Mineralogy of a specimen can be determined using X-ray Diffraction techniques. The method is well established and has been extensively covered in the literature (7) (8) (9) (10) (11) (12).

Petrographic studies traditionally rely on light microscopy as a principal investigative method, but the use of Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM) are employed more and more frequently in this field of research (7) (9) (13) (14). These methods can be readily applied to study the effects of chemical weathering on the products of hydration and can be supplemented by the Differential Thermal Analysis (DTA) (7) (8).

Physical changes can be detected by means of Optical or Scanning Electron Microscopy, although special techniques are often required (15).

Concretes containing chemical admixtures (e.g. A.S. 1478 and A.S. 1479 or ASTM C494) do require additional instrumentation techniques for proper analysis. These include Infrared Spectrophotometry (16), Paper and Gas Chromatography (17). An outline of hardened concrete analyses for admixture type and quantity is given by Rixom (18), in chapter six of his book.

Changes in mechanical properties can be evaluated by non-destructive methods, such as dynamic modulus of elasticity (B.S. 1881.5; 4408 or ASTM C215; C597 and E317), change in the Ultrasonic Pulse Velocity (B.S. 4408.5 or ASTM C597) or by destructive (compression, tension etc...) tests.

Special test methods designed to measure aggregate-cement bond (19) can give an indication of the effect of weathering or chemical and mechanical bond in concrete.

DISCUSSION

As with any accelerated test method, one of the main questions to be answered is the relationship of a test cycle to the equivalent time span for an in-situ structure.

The simplistic approach is probably to assume that each Soxhlet cycle is equivalent to a hot tropical shower. This takes care of the cyclic effect of wetting, but does not account for the intensity and duration of the rainfall.

An alternative is to develop an empirical function, relating the rate of weathering under the test conditions (6) to the in-situ weathering rate, expressed in geochemical terms, similar to the formulae proposed by Corbel (20) or Groom and Williams (21).

Another important aspect of an accelerated test interpretation is dependence of solubility of concrete constituents on temperature, pH, solvent purity etc. Water is one of the best solvents known to humanity, perhaps closest to being the "universal solvent" of which alchemists dreamed. All chemical substances present in concrete have a finite solubulity in water, but the degree of solubility varies with water purity, temperature etc.

For example, solution of CaO and $Ca(OH)_2$ decreased with temperature (Fig. 2) and increases with higher sugar concentrations (e.g. polysaccharate type admixture) (22). Solubility of alumina, for example, is highly pH dependent, although to a lesser degree (Fig. 3). However, Morey et al (24) reported that solubility of amorphous silica and quartz is virtually pH independent in the pH range from 2 to 8.

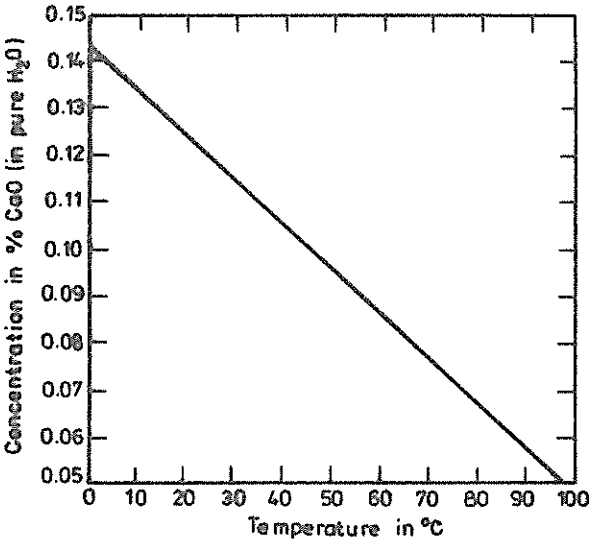

Fig. 2 Solubility of pure CaO at different temperatures (from Boynton).

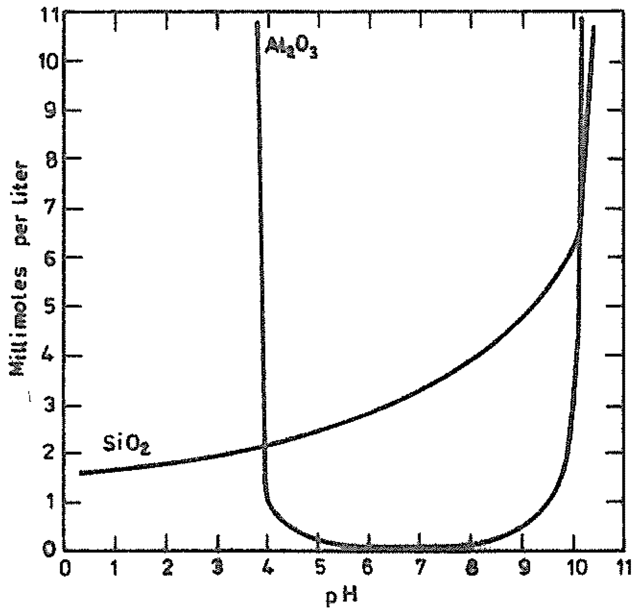

Fig. 3 The solubility of silica and alumina as a function of pH (from Mason).

Hence, the rate of water flow in Soxhlet apparatus can have a considerable effect on the rate of chemical leaching in the weathering test.

Temperature of percolating water depends not only on the rate of flow, but also on the type of condenser used (e.g. Liebig, double surface, coil etc...)

Pedro (5) in his experiments selected the rate of 3 litres per day (calculated as the equivalent to a daily rainfall of 39.4 inches ≃ 10,000 mm) by maintaining distilling flask at a boiling point. The actual temperature of the water percolating through the rock fragments was in the vicinity of 65^{o}C.

Faster rates would increase the temperature (subject to a condenser type) but reduce the alkalinity in the "zone of water-table fluctuation" (Fig. 1).

Slower rates can help in reducing temperature, but pH of the "eluviate" will go up. This can highlight the difference in weathering between the lower part of the test specimen and the section in an "atmospheric zone" subjected to neutral water treatment only.

Some corrections may also be necessary due to the solubility of Pyrex glass, form which Soxhlet extractors are commonly made. Solubility of Pyrex glass crushed to grain size from 300 to 500 micron in size does not exceed 0.01 mg Na_2O per gramme of glass after 1 hour at 100^{o}C. Complete data on Pyrex can be obtained from the manufacturer.

CONCLUSIONS

Proposed accelerated weathering test should provide a convenient method for quality control of durability of concrete subjected to chemical weathering (action of rain water, humidity and CO_2 of air) in hot tropical and sub-tropical conditions.

Test procedure can be modified to simulate a range of ambient conditions of variable temperature, intensity of rainfall and water impurity.

A separate model of concrete behaviour for each specific set of tropical weathering conditions should be developed.

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Professors Welch and Lee are currently supervising the project.

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REFERENCES

1. MILLS, R.H., "Five Monographs on the Hydration of Cement", Department of Civil Engineering, University of Witwatersrand, South Africa, 1965.

2. CHATTERJI, S. and JEFFERY, J.W., "Effect of Weathering on the Reactivity of Commercial Portland Cement", Symposium on Structure of Portland Cement Paste and Concrete, Highway Research Board, Special Report No. 90, Washington D.C., 1966, 254-257.

3. BICZOK, I., "Concrete Corrosion, Concrete Protection", Akademiai Kiado, Budapest, 1972.

4. GUTT, W.H., "Chemical Resistance of Concrete", Concrete, 1977, 11 (5), 35-37.

5. PEDRO, G., "An Experimental Study of the Geochemical Weathering of Crystalline Rocks by Water", Clay Minerals Bulletin, 1961, 26, 266-281.

6. PRUDIL, S., "Model of Concrete Behaviour in Aggressive Environments", Cement and Concrete Research, January 1977, 7 (1), 77-84.

7. KLEMM, W.A., SKALNY, J., HAWKINS, P., COPELAND, L.E., "Cement Research: Boon or Boondoggle?", Rock Products, 1977, February 56-63, and April, 156-170.

8. RAMACHANDRAN, V.S., "Calcium Chloride in Concrete, Science and Technology", Applied Science Publishers, London, 1976.

9. YAMAGUCHI, G., TAKAGI, S., "Analysis of Portland Cement Clinker", Proceedings of the Fifth International Symposium on The Chemistry of Cement, Tokyo, 1968, Session 1-3, Part I, 181-225.

10. SELIGMANN, P., GREENING, N.R., "Studies of Early Hydration Reactions of Portland Cement by X-Ray Diffraction", Highway Research Record No. 62, Washington D.C., 1964, 80-105.

11. HANDY, R.L., "Quantitative X-Ray Diffraction Measurements by Fast Scanning", ASTM STP No. 395, Analytical Techniques for Hydraulic Cements and Concrete, 1966.

12. SAZLAR, S.L., "Automated Method of Determining Tricalcium and Dicalcium Silicate Phases in Portland Cement Clinder by X-Ray Powder Diffractiometry", Indian Concrete Journal, December 1977.

13. ERLIN, B., "Methods Used in Petrographic Studies of Concrete", ASTM STP No. 395, Analytical Techniques for Hydraulic Cements and Concrete, 1966.

14. GRATTAN-BELLOW, P.E., QUINN, E.G. and SEREDA, P.J., "Reliability of Scanning Electron Microscopy Information", Cement and Concrete Research, May 1978, Vol. 8, 333-342.

15. DERUCHER, K.N., "Application of the Scanning Electron Microscope to Fracture Studies of Concrete", Building and Environment, 1978, 13 (2), 135-141.

16. HIME, W.G., MIVELAZ, W.F., and CONNOLLY, J.D., "Use of Infrared Spectrophotometry for the Detection and Identification of Organic Additions in Cement and Admixtures in Hardened Concrete", ASTM STP No. 395, Analytical Techniques for Hydraulic Cements and Concrete, 1966.

17. WEXLER, A.S., "Determination of Acetate Additions in Cement by Gas Chromatography", ASTM STP No. 395 (etc. as in (16)).

18. RIXOM, M.R., "Chemical Admixtures for Concrete", E. & F.N. Spon Ltd., London, 1978

19. ALEXANDER, K.M., WARDLAW, J., GILBERT, D.J., "Aggregate-Cement Bond, Cement Paste Strength and the Strength of Concrete", Proceedings of the International Conference on The Structure of Concrete and Its Behaviour Under Load, C. & C.A., London, September 1965.

20. CORBEL, J., "Erosion en Terrains Calcaires", Ann. Geogr., 1959, 68, 97-120.

21. GROOM, G.E., and WILLIAMS, H., "The Solution of Limestone in South Wales", Geog. Journ., 1965, 131, 37-41.

22. BOYNTON, R.S., "Chemistry and Technology of Lime and Limestone", John Wiley & Sons, 1967.

23. MASON, B., "Principles of Geochemistry", John Wiley & Sons, 1966.

24. MOREY, G.W., FOURNIER, R.O., and ROWE, J.J., "The Solubility of Amorphous Silica at 25^{o}", Journal of Geophys. Research, 1964, 69, 1995-2002.