Alkali-Aggregate Reaction and Structural Damage to Concrete

Engineering Assessment, Repair and Management

Geoffrey E. Blight & Mark G. Alexander

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A BALKEMA BOOK

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Author biographies

GEOFFREY BLIGHT

Geoffrey Blight completed his Bachelor's and Master's degrees in Civil Engineering at the University of the Witwatersrand, Johannesburg and his PhD in Geotechnical Engineering at the Imperial College of Science and Technology, London, in 1961. The early years of his career were spent at the South African National Building Research Institute, Pretoria, where he was engaged in research on design, operation and safety of mine waste storage facilities, including waste rock dumps and hydraulic fill tailings storage facilities.

In 1969 Geoff Blight was appointed to the Chair of Construction Materials in the Department of Civil Engineering at Witwatersrand University. The field of study encompassed geotechnical engineering and concrete technology.

In 1978 he was commissioned to study and diagnose the cause of cracking occurring in a series of 15 to 17 year old reinforced concrete structures supporting the Johannesburg motorway system, and diagnosed the cause as AAR. Since then, he has researched and investigated several cases of deterioration by AAR, and has published widely on the subject. He and his co-author, Mark Alexander, spent a number of years in joint research on AAR and other aspects of the durability of concrete.

He was a corresponding member of the committee that produced the British Institution of Structural Engineers' guides on the structural effects of AAR published in 1989 and 1992 and, since 2002, has been a corresponding member of the RILEM Technical Committees TC 106 and TC 191 – ARP which have been investigating various aspects of AAR.

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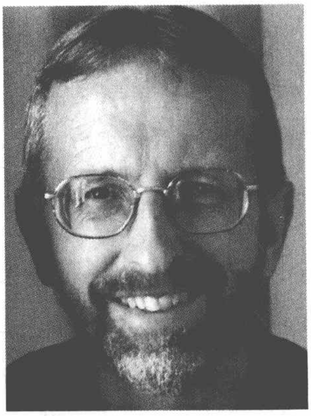
MARK ALEXANDER



Mark Alexander completed his Bachelor's, Master's and PhD degrees in Civil Engineering at the University of the Witwatersrand, Johannesburg and lectured in Construction Materials at Witwatersrand University for several years. In 1992 he was appointed to the Chair of Civil Engineering at the University of Cape Town where he has further developed his interests in concrete durability, including repair and rehabilitation of deteriorated concrete structures. He has published extensively and is active in international scientific circles. He co-authored the Book "Aggregates in Concrete" published by Taylor and Francis in 2005. He is currently Vice President of RILEM* and is scheduled to assume the RILEM Presidency in 2012.

* Reunion Internationale des Laboratoires et Experts des Materiaux.

Acknowledgements

The authors wish to salute the many engineers and scientists who have contributed to the understanding that we have of the AAR phenomenon in 2010, 70 years after it was first formally described by T.E. Stanton in the U.S.A. in 1940. We particularly acknowledge the great early contributions in the 1950's and 60's by Harold Vivian in Australia, Sydney Diamond in the U.S.A. and Gunnar Idorn in Denmark. In our own country, Bertie Oberholster led the field with his early investigations of the unexplained cracking of concrete structures in the Western and Eastern Cape Provinces. There are many other pioneers in the field that we have not mentioned, but we salute them all.

We also thank all the engineers and scientists who in later years, up to the present, have taken the trouble to share their experiences and ideas on combating and preventing the effects of AAR, thus adding to the pool of common knowledge of the subject. We particularly want to thank the co-authors of our papers on AAR. It was the efforts of all those mentioned above that made the writing of this book possible.

In Geoff Blight's case, the City Engineer and Deputy City Engineer of Johannesburg, Eric Hall and John Stewart, as well as the consulting civil engineer, Wally Schutte first involved him, in 1978, in this fascinating field. He thanks them for doing so.

Mark Alexander in his formative years as a young researcher, was most fortunate in having Geoff Blight, first as a supervisor and then as a colleague in the enabling environment at Witwatersrand University. No one could have wished for a more supportive and stimulating supervisor! He is very grateful for the opportunities then afforded him.

Both authors have had the good fortune to enjoy the support of dedicated and outstanding technicians. At the University of the Witwatersrand, Bob van der Merwe, Frans Wiid and Bob Anderson were indispensable to the success of our research. At both Witwatersrand and Cape Town, in addition to lab staff, many students have assisted from time to time in investigating various aspects of AAR. One of these was Yunus Ballim, who went on to become head of Civil Engineering and is now Deputy Vice-Chancellor of the University of the Witwatersrand. We are grateful to Yunus for his enthusiasm and support for writing this book.

We thank Alex Elvin, Professor of Civil Engineering at the University of the Witwatersrand, for contributing Section 4.8.6 on recent developments in instrumentation.

Maryanne Kelly prepared the diagrams and patiently made the seemingly endless changes, additions and deletions that were part of the process.

We both acknowledge and are extremely grateful for our families' unwavering support.

Geoff particularly thanks his wife Rhona for patiently typing yet another major manuscript from his almost illegible drafts.

Mark likewise acknowledges the patient and unswerving support of his wife Lyn over the years.

Unless otherwise acknowledged, all of the photographs were taken by Geoff Blight.

Geoff Blight
Johannesburg, September 2010

Mark Alexander
Cape Town, September 2010

List of mathematical symbols

ROMAN LETTERS

A	cross-sectional area [mm^2]
B, b	breadths [mm]
c	cohesion of concrete [MPa]
C	compressive force [kN]
or C	structural capacity [stress, force or moment units]
D	structural demand [stress, force or moment units]
D	diameter [mm]
E	elastic modulus [MPa, GPa]
f	direct stress (fy = yield stress) [MPa, GPa]
f(u) or F( )	function of quantity in ( )
H, h	heights [mm]
K	function of Poisson's ratio ν
L, l	lengths [mm]
P	load [kN, MN]
p^{II}	pore water suction [kPa]
P_f	probability of failure [dimensionless]
r	radius of water meniscus [mm or nm]
RH	relative humidity [dimensionless]
s_d	standard deviation [MPa]
T	tensile force [kN]
or T	surface tension of water [N/mm, kPam]
V	ultrasonic pulse velocity [m/s, km/s]
V_u	shear force at failure [N, kN]
W_f	failure load [kN]
$\overline{x}$	mean value

GREEK LETTERS

α	l.c.	alpha	ratio or coefficient [dimensionless]
β	l.c.	beta	ratio or coefficient [dimensionless]
γ	l.c.	gamma	shear strain [dimensionless]

ε	l.c.	epsilon	direct strain [dimensionless, mm/m = 1×10^{-3} = millistrain mm/km = 1×10^{-6} = microstrain]
η	l.c.	eta	viscosity [Pas, kNm/s]
μ	l.c.	mu	micro as in μm = micrometre or με = microstrain
ν	l.c.	nu	Poisson's ratio [dimensionless]
π	l.c.	pi	ratio of perimeter to diameter of a circle [dimensionless]
ρ	l.c.	rho	density or unit mass [kg/m^3 or g/cm^3]
σ	l.c.	sigma	direct stress, strength or pressure [kPa = kN/m^2, MPa = N/mm^2]
or σ			standard deviation of C or D
τ	l.c.	tau	shear stress or shear strength [kPa, MPa]
τ_u, τ_f			shear stress at failure
φ	l.c.	phi	angle of shearing resistance of concrete [degrees of arc]

Contents

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Chapter 1

Alkali-aggregate reaction (AAR) and its effects on concrete – an overview

1.1 AAR AND ITS VISIBLE CHARACTERISTICS

The subject of the book is alkali-aggregate reaction and the structural damage it causes to concrete. The occurrence of AAR has been reported from every continent and both north and south hemispheres. It is a world-wide problem in concrete technology. The emphasis of the book is on engineering assessment, diagnosis and repair. There are many published conference and journal papers dealing with AAR, and the number of authoritative and specialized papers has increased substantially over the past three decades. For example, the number of papers presented to the Fifth International Conference on AAR in Concrete in 1981 was 32. At the 12th International Conference in 2004, 162 papers were presented. However, most of this literature is concerned with scientific rather than engineering aspects of AAR, i.e.: its chemistry, the nature of the various reactions, susceptible minerals, chemical kinetics, and factors influencing them, as well as the prediction of AAR-susceptibility. These scientific studies have been essential for our understanding of the AAR phenomenon and have assisted the cement and concrete industries to improve the performance of cement and aggregates and items made of concrete and to eliminate the use of marginal materials that may be AAR-susceptible.

The effects of AAR on the engineering performance of concrete artifacts and structures – whether of mass reinforced or prestressed concrete has been less well-covered in the engineering literature. At the 1981 AAR Conference, 4 of the 28 papers dealt with engineering aspects of AAR, while in 2004, 45 of the 162 papers were on engineering aspects. Hence not only has the number of engineering-orientated papers increased, but also their proportion (1 in 7 to 1 in 4.2). AAR has the primary effect of damaging concrete and causing some loss of performance in concrete structures, at the very least by the unsightly surface cracking it causes. The challenge to owners and operators of AAR-affected structures is how to assess these structures in terms of their engineering performance and safety, how to repair them and then how to manage the repaired structures. It must be recognised that, ultimately, civil or structural engineers have to assess, repair and manage the ongoing problems of AAR-affected structures. Owners of such structures will require reasonable assurance that their assets will retain their value and remain safe, functional and economic in terms of ongoing repair costs. Therefore, sound engineering knowledge of the mechanisms whereby concrete is damaged by AAR, its effects on the actual performance of concrete structures, as well as on assessment and repair techniques is needed.

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