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Concluding Assessment of Future Development

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Concluding assessment of future development

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The contributions to the conference are reviewed with the aim of identifying their potential influence on the development of hydraulic cement science and technology in the 1990s.

The high-technology–low-volume innovations presented are emphasized because they point towards future efforts in this direction.

Most of the contributions commented upon are related to the basic materials, the processing characteristics and the performance behaviour of concrete and cement paste. The availability of fly ash and slag is referred to because it is encouraging more determined research.

The need for more concern about R. & D. systems as means to transform research into reliable technology, accessible to the practising engineer and labour forces, is stressed.

Introduction

The presentations and discussions confirm that the Royal Society has chosen an appropriate time to arrange this symposium on the development of science and technology of hydraulic cements in the 1990s. It is interesting to learn what science and research currently have to offer for improvements in technology because they are urgently needed now, and will be needed during the forthcoming decades for rehabilitation work, the reduction of investment costs in building and construction and the improvement of labour motivations. Improvements are also needed for social development in the 'third world', where there are many instances that demonstrate that conventional hydraulic cement technology does not meet the demand for the production of reliable, cost-effective buildings and construction works. One may also, from the contents of the contributions, sense concern about the restructuring of science and research itself, an issue that was discussed in the U.S.A. in the *1977–1980 National Materials Advisory Board study* (N.M.A.B. 1980) referred to by J. P. Skalny.

It is apparent that for there to be significant impact in our societies from the realization of the technology opportunities presented requires larger and more coherent R. & D. projects than those done now, and in particular clearer strategy and short term initiatives regarding effective R. & D. planning and management, appropriate science and engineering education and co-operation between universities and industry. The science education aspects are particularly important, because it is tempting for engineers and cement-based industries to rely upon university involvement in trouble-shooting and research during the present economic constraints, rather than acquiring the competence for front-line competitiveness by themselves. Therefore, the creation of a large number of brilliant, outspoken students, to question much of what has been said at this and similar preceding meetings, is needed to make substantial improvements in the performance of the 8–10 Gt of cement products referred to. Consequently, further elucidation of the educational issues seems commendable.

I wish to stress that it is the engineers who face the challenge to gain public confidence in the reliability of the research, when it is to be applied as a technological development.

High-technology–low-volume innovations

The present symposium is surely the first in the history of cement and concrete to devote a section of its programme to high-technology–low-volume innovations with hydraulic cements. This is definitely a pointer towards the future, and amidst the present, general recession and low morale in many heavy industries it is encouraging and admirable that two high-technology innovations presented have emerged from Great Britain. They both have their origins in co-operation between university and public research on the fundamental side, and large corporations outside the cement and concrete community on the technical–commercial side. They are namely the alkali-resistant glass-fibre reinforced composites, presented by A. J. Majumdar, and the MDF cements, presented by J. D. Birchall *et al.* Both inventions are the result of a willingness to take financial risks in a period with severely constricted markets.

It is interesting that the result of an equally daring example of innovative spirit, the silica fume based D.S.P. products, is presented from one of the smallest countries present, by L. Hjorth.

Each of these materials is about ready for rigorous feasibility testing in the markets. At present they demonstrate commendably the determined coherence of systematic R. & D. as described in educational works by the European Industrial Research Management Association and by the Industrial Research Institute in the U.S.A.

Low-technology–high-volume development

The fundamental urgency of cement based technology development can adequately be categorized as demands on improved basic materials, processing, and concrete performance behaviour.

Basic materials

The technology of cement-making has been impressive and has kept ahead of the cement-using technologies throughout its development, since the British Aspdin patent no. 5022 of 1824. The presentations by W. A. Gutteridge & C. D. Pomeroy, G. R. Long. G. W. Groves, G. K. Moir, and, in some ways, also that by J. P. Skalny & G. Frohnsdorff are those among the contributions that are most oriented towards the cement itself, though inadvertently the authors support the judgement that radical changes of cement raw materials, composition and manufacture technology are not waiting 'around the corner'. This seems justified because the cement industries have seen considerable innovations during the last 20–30 years, and today with pre-heater and precalciner kilns, alkali by-pass, computerized on-line process monitoring, etc., are well prepared to meet even considerable technology improvements among the cement uses.

There are, as yet, unanswered challenges in the potential development of the utilization of about 500 million tons of fly ash and blast-furnace slag per year, not merely for greater use of these materials, but also for more effective access to the hydraulic energy inherent in them. Incidentally, when Professor Birchall says that the uses of cement 'have been restricted by the low tensile strength and fracture toughness of hardened cement paste' – this is true – but with some modifications. The total cement use in the world was about 25 million tons in 1920, is about 850 million tons now, and the demands, seen socially, are such that during the 1990s we will approach 2000 million tons. Consequently, the restrictions referred to have been and are of limited effect.

Processing

It appears from all the contributions that the processing of concrete and cement products has not been the sole aim for the presented research, nor has it been used as the most important criterion for predictions regarding application of the research results in technology in engineering and industrial practice. It seems that the scientific community considers further clarification of the fundamental nature of the hydration reactions and their basic structure formation phenomena desirable, before the consensus aims at more practical development.

Despite apparently unsettled discrepancies about some of the fundamental aspects of cement hydration, the eight papers by R. G. Ottewill, D. D. Double, G. W. Groves, M. Regourd, P. Pratt, J. E. Bailey & C. J. Hampson, G. K. Moir and L. J. Parrott all fit into the 'concrete processing' category. They illuminate, expressed in simple terms, 'how the stuff gets stiff and gains strength and longevity'.

M. Regourd made some very interesting remarks about the modifications of surfaces of clinker minerals and slag, which take place as soon as they are mixed with water; millions of workmen and engineers are awaiting more guidance on how these discoveries can lead to improved monitoring of workability in concrete making. L. J. Parrott's observations are compatible and emphasize that pore structure is formed early during hydration. This points to the need for supplementary theoretical studies of the effects of vibration and chemical admixtures. R. H. Ottewill's contribution in its entirety is dealing with workability, if considered from an engineering viewpoint, though few civil engineers would recognize the characteristics in the presentation without further guidance. Other contributions also probably include observations of similar significance. However, the emphasis seems to be on the hydration chemistry and on its related morphology and submicroscopic structure in cement paste.

J. E. Bailey & C. J. Hampson are exploring the 'yellow area' on the hydration map of aluminate phases. I do hope that the alumina-ferrite phases will also be covered in these studies, as there are many unsolved problems in using cements with high–low C_3A against low–high $C_2(A, F)$ content. I do wonder if the alumina phases really come out entirely as fibrous $C\bar{S}A$ hydrates. The optical microscope does not reveal that, and recent work (Komarneni *et al.* 1982) suggests Al-ion exchange capability in alumina-hydrate phases. Thus, in concrete, there may be many different pathways for Al during performance conditions.

P. Pratt is one of the few authors to discuss fly ash. That is very timely because so much new empirical research is being published that nobody can really assess the fundamental nature of fly ash hydration – its kinetics and thermodynamics – and without this knowledge money will be wasted and failures will occur.

The advance of the basic knowledge since physico-chemical methodology was forcefully brought to bear, about 40 years ago, is formidable, has admirably and steadily been updated by the development of modern instrumentation, and will be used in any future development towards greater manufacturing effectiveness and improved quality assurance for cement uses. Notwithstanding this advance, there are two issues requiring more attention if the further basic studies of hydration are to become useful for progress in technology, these are rheology and curing. Fibre reinforced composites, MDF cement and D.S.P.-type materials do represent conscious application of basic rheology. Concrete, in contrast, is largely made with, at best, crude modelling of its behaviour during mixing, transport and placement, if any model is used at all. Development in this area is urgently needed, even in current concrete practice. Concrete has, during the last 10–20 years, been made a reacting system, significantly sensitive to variations in materials and to changes in operation conditions. And skilled workmen must frequently perform wonders when monitoring workability with but little background of explanatory research.

Most current hydration research deals with systems reacting at room temperatures. Until 30–40 years ago concrete did experience slow temperature rises to 30–40 °C during the curing phase, and a slow decline to ambient temperatures in the temperate climatic regions, so that the room temperature modelling was justified. Much contemporary concrete reaches 80 °C or higher temperatures within 24 h of casting and rapid subsequent cooling down to ambient temperatures is enforced. No concrete or cement products are cured at constant room temperature. Only test and research specimens are processed this way. There are numerous studies to show that at curing temperatures above 50–60 °C, the permeability and porosity of cement paste become considerably increased, and ultimate strength is decreased. And there are numerous incidents to justify the view that much current and forthcoming repair work on concrete buildings and structures is due to high curing temperature deterioration of the concrete.

Extrapolation of the room temperature projection of the kinetics of cement hydration to deal with the temperature variation of the hydration process is so much more rewarding, because in some countries fully computerized systems for monitoring curing are in operation for design and construction work. Danish concreting guidelines for winter and highway construction specifications are examples.

Recent research (see, for example, Regourd 1980; Bamforth 1980; Wesche & Schubert 1982; Roy & Idorn 1982) has demonstrated the significant beneficial effects of heat on the hydration of fly ash and slag, accompanied by its moderation of the temperature development during Portland cement hydration in blended cements. Altogether, the state of affairs and the progress of research on cement hydration presented at this symposium are promising to supply a broader basis for monitoring development of concrete processing in engineering and industry within a few years, if made to include adequate progress of knowledge on rheology of fresh cement paste mortars and concrete, and realistic approaches to the kinetics of hydration. This will leave 'the room temperature syndrome' behind as a historically justified relic of the pre-industrial era.

Concrete performance behaviour

There are four contributions in this category to consider, namely those by R. W. Davidge, K. Kendall, A. J. Howard & J. D. Birchall, and D. J. Hannant *et al.* Until the superplasticizers became available a few years ago, preceded by many years of theoretical research by P. A. Rehbinder and workers, 'ceramic' strength of cement paste was a vision beyond insurmountable obstacles, except for very special laboratory procedures, as referred to by L. Hjorth. The introductory contributions to this conference do show remarkable achievements for overcoming the barriers. The field of knowledge presented by R. W. Davidge, K. Kendall, and also by D. J. Hannant *et al.*, comes much closer to integrated applications than before. Once again, slag, fly ash and silica fume do contribute to increased density, and to higher proportions of ultrafine pores in cement paste. Recent work (Short & Page 1982) is of interest in this connection.

Considering fibrous composites, it is a striking development in technology that, owing to lack of timber, about 50% of all river barges and boats in China are now made of ferrocement. They serve a very large part of the national transportation system for 1100 million inhabitants. Do not assume that urgent needs in developing nations will wait for accomplishments in basic research if overwhelming social problems are at stake!

In some respects these four papers bridge the initial distinction of practice between high and low technology development, because they do illuminate that the properties that are now believed to sell high-technology cement-based products are desirable, though less easily attainable; also for voluminous concrete bodies and elements. *Density, porosity, toughness and deformability are all, in small and large bodies, decisive parameters of strength and stress transfer capability.*

Research should not overlook that the same parameters are important for the longevity of the materials, provided that basic materials' compositions and processing have assured a long term convergence of the reacting systems towards thermodynamic equilibrium under the given exposure conditions.

Conclusions

The outlined prospects for the hydraulic cements and cement uses are probably expected to be what industry and engineering, at the present especially, will want as a basis for their technology development in the 1990s. If research planning with the objective to satisfy such requirements is in conflict with strong desires in the science oriented community for research to make progress in basic knowledge *per se*, then a period with turbulent, dialectic development of the research is predictable. Maybe, out of necessity, this is the most fruitful way to progress in the near future. But whichever course we see emerging, the proceedings of this symposium are likely to become an influential source of information on essential fragments of the entirety. Thus, the Royal Society's approach should be truly rewarding to everybody concerned.

References

Bamforth, P. B. 1980 *Proc. Inst. civ. Engrs.* **69**, 777–800.
Komarneni, S., Roy, D. M. & Roy, R. 1982 *Cem. Concr. Res.* **12**, 773–780.
Regourd, M. 1980 In *Proc. 7th Int. Congr. Chem. Cem., Paris*, vol. 2, III. 105–III. 111. Paris: Éditions Septima.
Roy, D. M. & Idorn, G. M. 1982 *J. Am. Concr. Inst..* **79**, 444–457.
Short, N. R. & Page, C. L. 1982 *Silicates Industriel* **10**, 237–240.
The Status of Cement and Concrete R. & D. in the United States 1980 Paper NMAB-361, (117 pages). The National Research Council.
Wesche, K. & Schubert, P. 1982 In *Proc. Symp. Nat. Mater. Res. Soc. Annual Meeting, Boston*, pp. 225–232.

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