3rd European Symposium on Engineering Ceramics

3RD EUROPEAN SYMPOSIUM ON ENGINEERING CERAMICS

Edited by

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Preface

This volume is the proceedings of the 3rd European Symposium on Engineering Ceramics, held in London, 28–29 November 1989, under the auspices of IBC Technical Services Ltd. The Symposium sessions were chaired by Eric Briscoe, who also introduced the Symposium with the very appropriate review 'Ceramics in Europe'.

The term 'engineering ceramics' is commonly taken to mean a group of special high-strength and heat-resistant ceramic materials developed almost exclusively for the advanced internal combustion engine of the next century. It is not always fully appreciated that high grade fine microstructure ceramics both of the oxide and of the non-oxide classes, whether they be termed engineering, fine, special, advanced, structural or technical, have been supporting a large number of diverse and profitable industries over many decades. Indeed, in some respects these materials can be regarded as natural developments from the long-established refractories field, and the distinction between an engineering ceramic and a refractory can become blurred, as the contribution in this volume on 'Nitride Bonded Carbide Engineered Ceramics' shows. It is of significance that in Japan, for example, much development work in the engineering ceramics field was initiated by the refractories industries, seeking to diversify possibly but doing so on the basis of long experience in the refractories area.

The main objective of this Symposium was to help engineers and designers to assess the present state of the field of engineering ceramics. The programme was intended to be low-key, factual, balanced and critical. To achieve this objective a team of speakers from the engineering ceramics industries and closely associated laboratories, each member a widely respected authority in his own area, was invited to present accounts of specific materials and applications, and related development work. The majority of the twelve invited contributions to the programme placed emphasis on current applications, but in doing so drew attention to recent background developments in order to provide guidance to the avenues likely to be of importance for the near-term future. It was not the intention to concentrate on the more spectacular applications in the engine component area, though these were not ignored. Nor was it intended that points of scientific detail would be examined in depth; there are many other occasions in the scientific meeting calendar providing ample opportunity for this approach. This programme, it was hoped, would provide participants with broad over-views interwoven with illustrations of specific applications and materials' development programmes.

The two-day Symposium took a selected group of subjects and materials for a critical review on the basis of a broad European perspective. It is hoped that the selection presented in this volume will provide a balanced guide to the subject of engineering ceramics. Oxides and non-oxides are reviewed, as are the newer composites, and the now maturing transformation toughened zirconias. There are reflective contributions on how successful production processes can be developed, as well as forward-looking overviews of new processing methods. Established applications of ceramics in the important areas of wear and abrasion resistant materials are also reviewed, taking in established uses in powder and slurry handling, and the newer ceramic bearing area. Very broad reviews of developments in supporting funding for work on the engineering ceramics in Europe, and on recent developments in 'fine' ceramics in Japan were presented by Eric Briscoe and by Keiji Matsuhiro respectively.

The assumption is made that the reader of this proceedings volume is scientifically educated, but non-specialist, and wishes to bring him or herself up-to-date on selected aspects of the subject of engineering ceramics through a structured series of authoritative reviews. This description of a reader can be applied equally to the materials technologist, or company director, and the undergraduate or post-graduate student whose programme includes treatment of the structural or engineering ceramics. Many of the contributions are extensively referenced, and serve as a guide to wider reading.

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Ceramics in Europe — An Overview

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1. INTRODUCTION

This is the third conference of this title spanning some 5 years. In giving the Opening Address I will, no doubt, raise as many questions as explanations for the apparently low level of additional exploitation relative to the considerable input in terms of research and development (R and D) expenditure. It is, however, not uncommon for many decades to pass before new or improved materials find their way into common engineering use. The transistor was originally conceived in the 1930s and it required the impetus of national defence crises worldwide to push its development into sophisticated products; development costs were 'lost'. Development of the transistor into cost-effective civil products for wider use was therefore given a 'free investment'.

Today there are other pressures to achieve unique solutions to what have now become engineering problems, as a result of intense international industrial competition and the consumer demand arising from the much higher standard of living available to a larger part of the world. Significantly, governments worldwide recognise that intervention on a national scale is necessary to support innovation in materials on account of the huge costs and uncertainties. Some 'bean counters', if I may use a term understood by those of us who are not accountants, will naturally have more difficulty than others in understanding the commercial wisdom of expenditure for which no short-term high return certainty is assured. Consequently funding or long term and speculative R and D in materials development is not likely to be carried out quickly enough, or indeed at all, unless the financial burdens and risks are shared by the taxpayer. Even where science and technology is admired, government pays to ensure modern and competitive industry to support its citizens in the long term.

It seems that a crisis of one kind or another is needed to catalyse action. The dramatic rise in oil prices in the 1970s was undoubtedly such a catalyst for the industrial nations to develop economies in the use of oil-related consumption devices; governments worldwide co-ordinated such initiatives and provided significant financial support.

Prior to the oil price crisis, there was another catalyst, of an environmental nature, for an engineering solution requiring enhanced properties of materials; the impending 1970 Clean Air Act in the USA. In this case there was an acceleration of work on ceramics as a potential solution to environmental needs, to reduce the vehicle exhaust generated 'smog', of Los Angeles in particular. It has taken a long time for Europe to get to grips with the same fundamental problem, but the need to do so is now with us.

As long ago as the early 1950s, the then UK Ministry of Supply funded the development of silicon nitride for 'undisclosed' reasons. Subsequently in 1956 the UK Admiralty Materials Laboratory at Holton Heath commenced the development of a silicon nitride internal combustion engine requiring no liquid cooling. The size of the investment made is not revealed, but in terms of R and D investment on the new high temperature and strong ceramics it was probably significant in world terms at that time.

Other initiatives, spurred on by quadrupled oil prices, followed rapidly and were aimed at significantly improving the thermal efficiency of the internal combustion engine. The development of the 'adiabatic', or minimum heat loss, engine became the worldwide target, and this required materials with properties not possessed by metals.

2. INTERNATIONAL PROGRAMMES AND GOVERNMENT FINANCIAL SUPPORT

A summary of the programmes in the UK and USA is given in Figs 1 and 2.

Some idea of the size of investment in the USA is shown in Fig. 3 and that of the UK and EEC in Fig. 4, which takes us through the period up to today, apart from developments which are more or less classified or

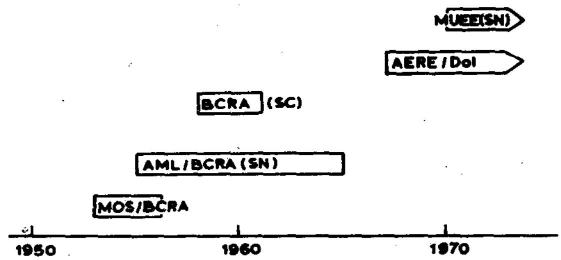

Fig. 1. Government support for ceramics R and D — UK.

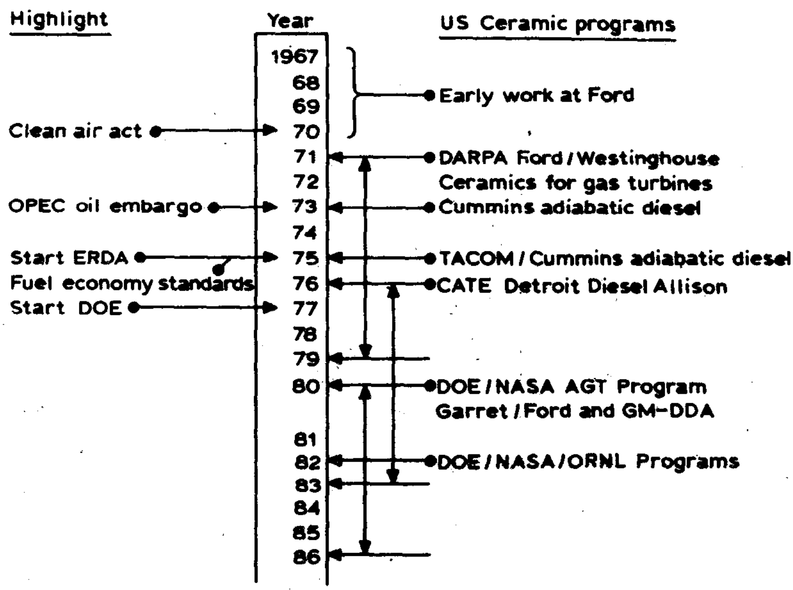

Fig. 2. Highlights and related US ceramic programmes.

commercially sensitive. The acronyms describing the projects were no doubt designed to confuse the 'competition' and with the passing of time some of us, though familiar with the derivations at the time, are now also confused with regard to the very obvious! (One has to forgive some lightheartedness, as a sense of humour is an advantage when tackling what were then 'impossible' tasks, some of which remain as intractable today.)

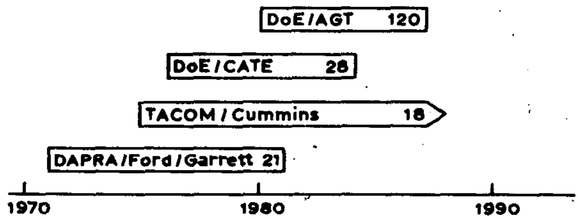

Fig. 3. Government support for ceramics R and D — USA.

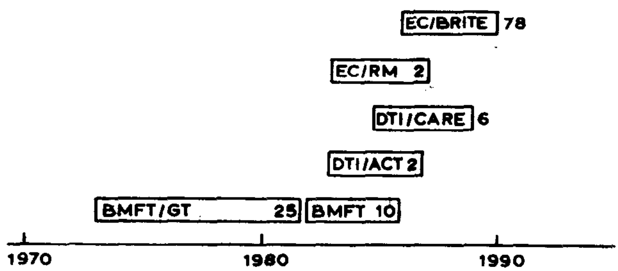

Fig. 4. Government support for ceramics R and D — Europe.

Today the latest European engineering ceramics programmes are principally those of the combined BRITE/EURAM programmes, and indirectly that of EUREKA (but there are many purely national programmes such as the UK CARE programme which finishes this year). The latest Commission of the European Communities initiative extends across the whole materials range and the split between the essential components is not settled. However, it is possible that the ceramics content over 3 years might be some £17 M, if one divides the sum available by three. Factors of policy and the quality of applications also have to be taken into account of course. That sums of this size are considered to be strategically necessary for the competitiveness of Europe can be taken as implying that there are many solutions still required and that it is important to achieve the remaining important objectives. This Symposium will address itself to some of those issues. However, let us not assume that the further development of engineering ceramics is a task for Europe alone. Japan has had a series of well-conceived and managed programmes under the aegis of MITI funding and as we may hear from a distinguished speaker from NGK, Japan currently has substantial funding of a ceramic component gas turbine

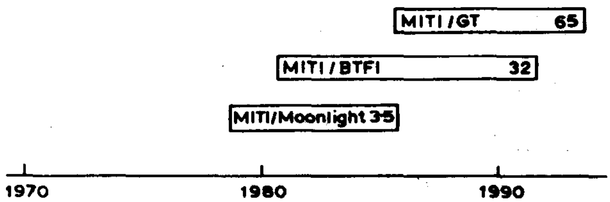

Fig. 5. Government support for ceramics R and D — Japan.

of automotive size. Some of us will recall the Rover gas turbine which ran at Le Mans in the early 1970s. Sadly this may be yet another example of a British innovation killed off by short term policies. Figure 5 relates to Japan.

What then is the scenario that directs the taxpayer's money into the development of materials? We do not have to look further than back at history — the Ages of Man are defined traditionally in terms of materials, from the Stone Age to today, see Fig. 6. On the assumption that there is no better prediction than that arising from hindsight, it is not unreasonable to predict that when looking back at the period 1950–2000 the most influential material classifications will have been ceramics

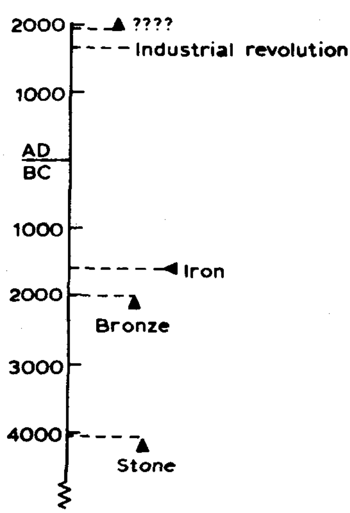

Fig. 6. Materials 'ages'.

and plastics. In terms of solving the most difficult engineering problems, the ceramics age may be just ahead.

The level of commitment by governments to fund Ceramics R and D is in itself an indication of the perceived value to the respective nations in the longer term. It is therefore appropriate to examine the techno/economic details to justify that concern.

Our expert speakers today will present their own version of the case, some with a more commercial emphasis, and others from a purely scientific viewpoint. It is by presenting that essential balance that commercial progress is made. After all, it is by the process of exposing apparently uneconomic scientific discovery to the harsh economic environment of life that real progress is made; one without the other would have left us in the Stone Age. Though the experimenters with a piece of flint producing a spark could not have understood the scientific basis of their discovery, to them it was an important means of survival. Perhaps the same applies today?

3. THE TECHNO/ECONOMIC CASE FOR ENGINEERING CERAMICS

3.1 General Properties: Ceramics Compared with Metals

High values for ceramics:

- compressive strength
- hardness
- stiffness
- corrosion resistance
- retained high temperature tensile strength
- electrical resistivity (some, however, are good conductors).

Low values for ceramics:

- thermal conductivity (with some exceptions)
- specific heat
- coefficient of expansion
- density (some exceptions)
- toughness (but some getting better for example, some zirconia based materials)
- tensile strength.

(But see Section 4 concerning 'specific' properties, for the effect of density.)

3.2 Cost

Competitive cost for simple shapes where unique properties are vital. High cost for complex engineering accuracy for shapes relative to the same metal shape. Re-design for material advantages can change the relative cost. There may be no need to apply protective coats, for example.

3.3 Raw Material Availability

The chemical constituents of materials are generally readily available. Some special components may not be available. Processing costs can, however, be high, but the scale of demand is likely to reduce these.

4. SPECIFIC PROPERTIES

It is not intended to list a comprehensive data bank. For the purpose of this paper it is more useful to make comparisons with other, more commonly used, typical engineering materials. My 5-year old zirconia hammer which knocks 15 cm nails into wood always surprises engineers who look for an explanation other than the simple truth!

Typical properties with which the mechanical engineer will normally be concerned include tensile strength, stiffness, and to an increasing extent, the minimum mass required to satisfy design criteria, that is related to density. To make the comparisons on the above basis, specific properties can be calculated, that is property value divided by density. Figure 7 shows the effect of such calculations on the ranking of some materials.

From the above the following conclusions can be drawn:

a high strength polymer composite is strongest (but has a relatively low maximum operating temperature);

silicon nitride is nearly as strong as mild steel (and can operate at much higher temperature and in composite form is stronger, and tougher).

Other similar calculations show that the flexibility of transformation toughened zirconia approaches that of steel, for example.

Toughness is inevitably the question engineers will raise. Ceramics have a fundamental problem with this property, but some forms of zirconia are as tough as the brittle cast iron and engineers long ago learned how to use this material. Ceramic composites have been made