Current building materials research

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Introduction

Research into the mechanisms of decay and treatment of historic building materials is the province of Architectural Conservation Branch within English Heritage's Science & Conservation Services Division. Its extensive programme of scientific testing and development, worth now more than £0.5 million, is organised through agreements and contracts with over 15 national and international groups of collaborators, consultants, and contractors, and employs indirectly more than 30 specialists on 18 rolling projects in the service of better building conservation.

Most of the projects are of two to five years duration and involve a substantial amount of time spent on the painstakingly slow protocols often required to establish scientific facts. For example, field assessment and monitoring of deterioration processes often entail several years of observation and measurement to account for seasonal variations in microclimates that may instigate the cause rather than the symptoms of decay. Laboratory analysis and experimentation follow and site trials and development then take place before details can be synthesised, written up, and made known to the widest possible audience. The perceived delays can be frustrating for the specifiers and conservators out in the field, who desperately need the latest state-of-the-art advice to save a monument in the most sensitive and sensible way. We heard of one case, for example, where a keen conservation officer in a local planning authority made it a condition of listed building consent that an architect specify mortar mixes for the repair of a Grade II building, 'in accordance with the findings of English Heritage's technical research'. But our work on mortars, as readers will see below, is not yet finished.

Figure 1 Mortar samples on the Building Research Establishment exposure site

Unfortunately, proper scientific methods just cannot be rushed. Materials placed in an accelerated weathering chamber, for example, need first to be prepared, cured, weighed, and measured on calibrated machinery, and the processes repeated many times if the results are to have statistical accuracy. And even then, artificial chambers never actually replicate exactly external conditions of exposure. The research teams are as keen as anyone to broadcast their findings as quickly as possible. But they are necessarily concerned to check the quality and standard of results first because of the high profile nature of the work and because of the ethical, technical, and economic impact policy recommendations will have subsequent to the research. This is why they make known their interim results first to their technical and scientific peers for the purpose of corroboration.

These are important steps that sometimes make part of English Heritage's work seem slow. But the welfare of our historic building stock in the next century and beyond is important enough for us to make sure we get things right – especially if we are to give the best possible technical advice and make materials and processes a condition of our grant support.

Set out below, then, is a short summary of current work in progress. Where findings have been reported or published to date, this is indicated. It is intended that all work will be

published when tests are complete and results are finalised. We are not able to discuss our current findings on a one to one basis until the work is complete. Technical advice to local authorities and to historic building owners and their professional advisers remains the responsibility of the regional teams in our Conservation Group and they will be happy to help as resources permit.

AC1 Smeaton project on historic mortars durability

This research is investigating the effects of additives to lime-based mortars in terms of durability and workability (Fig 1). Phase I of the project is completed and results have been published in the newsletter of the British Building Limes Forum, in Europe in EUREKA, Eurocare's Eurolime newsletter, and in the Bulletin of the Association for Preservation Technology.[1] Phase II tests have recently been completed and are at present being evaluated.

Both exercises give indications that small quantities of cement (ie less than a proportion of 1:3:12 of cement : lime : sand) are unexpectedly likely to have a detrimental effect on the durability of the mortar. It was also found that High Temperature Insulation (HTI) powder, which English Heritage has advised specifiers and conservators to use for over ten years, is not the constant reactive pozzolan we had assumed. Its qualities appear to vary by batch and its effectiveness may need to be more thoroughly tested before universal application.

More importantly, information has been gained regarding some of the properties affecting the behaviour of lime mortars modified by the addition of crushed brick or tile. If the bricks are fired at under or around 850 degrees centigrade, and are of certain (as yet unknown) clay types, then the resultant dust can act as a highly reactive pozzolan assisting initial set and increasing durability especially if the dust forms a significant proportion of the mix. In order to find pozzolanic material that will match the appearance of a wide range of historic mortars, the testing programme has also included yellow and white vitrified clay materials with some success.

The larger particles of brick and tile in mortars seem to act as porous particulates, which assist durability. The pores capture air in the original mix and may therefore entrain carbon dioxide to assist early carbonation of the lime binder. The air gaps act as an insulant to the cold and the voids may permit both salt and ice crystals to grow in wet and winter conditions without rupturing the body of the material.

These findings, if confirmed with statistically relevant repeat testing in the next phase of the project, will alter the technical advice we give in English Heritage publications.

AC2 Masonry consolidants

Following on from the field reviews of the long term Brethane alkoxysilane consolidant trials, last year's programme concentrated on assessing field observations and on attempting to establish laboratory-based methods for proving exactly where and in what condition residual consolidating material remains in weathering subject stone (Fig 2).

Figure 2 Brethane consolidation treatment

Results have shown that masonry consolidants work, not as preservatives for all time but as a means to slow down decay. The consolidants themselves decay and this discovery will require future research into the methods needed for possible retreatment of treated stone.

However, it has proved exceedingly difficult to assess scientifically exactly what is happening within the treated stone. Though we do not yet have a complete explanation,

field observations indicate that Brethane appears to work better in limestones than within sandstones, which are composed of material more chemically similar to it. But in silica-bound stone matrices it is proving very difficult to find, let alone quantify, how the consolidant has been performing. Experiments are, therefore, underway to detect the treatment boundaries in cores taken from treated sites.
A draft interim report has been produced by the consultants at the Building Research Establishment (BRE), and we are now working with the scientists to produce a rounded and useful document for publication. Verbal interim reports have been made through lectures to the Society for the Protection of Ancient Buildings and to the English Heritage/Cathedral Architects Conference held in London last March. We have also contributed data from the research to the Getty Conservation Institute's international review of the needs for future work on stone treatments which is being coordinated by Dr Clifford Price at the Institute of Archaeology, University College, London.

AC3 & 4 Floor wear and tile pavement decay

This work seeks to find benign and efficient ways of measuring the rate of wear, decay, and erosion in historic floors, especially of encaustic tile pavements (Fig 3). It is also concerned with the definition of decay mechanisms with a view to ameliorating their effects.

Figure 3 Monitoring of tile pavements at Westminster Chapter House; Dr Timothy Yates, BRE

Long-term field monitoring on the English Heritage estate through several winter seasons is now revealing new and important data. First of all, the various trials of frost protection measures for exposed tile pavements all gratifyingly appear to work. However, the chief threat to external pavements now appears to be not from salts or freezing but instead from heat – from differential thermal movement in the clay bodies during the summer months. The results, thus, represent something of a reversal of our common perceptions.
Additional observations are now taking place. We have developed a lexicon and mapping system to describe decay mechanisms and, at Westminster Chapter House, have carried out cleaning trials.
An interim paper and poster was presented to the UNESCO/RILEM International Stone Conservation Conference in Paris and a more detailed lecture was given to the English Heritage/Cathedral Architects Association Conference in March 1994.

AC5 Polishable limestone decay

Purbeck marble and other polishable limestones are the subject of another long-term monitoring programme set up with sensors at several cathedral sites, where climatic conditions are being recorded regularly and analysed. Laboratory work complements the activity and is helping us to understand the decay processes and rates of erosion of this difficult material.
A literature review and preliminary assessment of the causes of Purbeck limestone decay have been completed and the findings presented to an invited audience at a Study Group seminar at Norwich Cathedral in 1993. The wetting/drying cycles and expansion and contraction of the clay minerals, solubility of part of the surface matrix and the staining of pyrites all play their part in the deterioration of the stone. But the effect of polishing on the durability of the material is still not well understood. Photomicrographs have been made from the Sedgewick Collection of marbles in Cambridge to gain a technical context for the work and samples taken for analysis from the shafts removed (with the Cathedral Fabric Commission's blessing) from Chichester Cathedral.

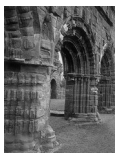

Figure 4 Typical sandstone decay patterns

Connections with technical casework have become possible and the cathedral architects at Norwich, Chichester, Salisbury, and Rochester are sending us details of their own assessment work and treatment trials. Preliminary steps have been taken to help Norwich Cathedral bid for additional research funds from the Getty Grant Programme, and we are seizing the opportunity fed to us by the treatment tests at Salisbury, where students from the Department of Conservation Sciences at Bournemouth University are evaluating cleaning systems and consolidants on the material.

The present contract with the BRE is to continue monitoring at five cathedral sites (including Salisbury) until March 1996. Laboratory tests will continue to help the classification of available polishable limestones and also to compare the different types of Purbeck marble.

The work will also include an assessment of the performance of historical and modern surface treatments on both new and old Purbeck marble samples. Thin sections from the Sedgewick Collection will, we hope, enable us to produce the definitive text book on the Polishable Building Stones of the British Isles in the not too distant future.

The continued monitoring and laboratory work are essential if meaningful progress is to be made in fully understanding the reasons for the decay of polishable limestones. So far there is little direct evidence to determine which of the many theories are most applicable to the phenomena observed. Only when this is achieved can effective remedial treatments be confidently recommended for future conservation programmes.

AC6 Sandstone decay

This programme is attempting to define and explain the decay systems in sandstones in the United Kingdom with a view to preparing appropriate treatments.

Our work has articulated the fact that there are seven generic types of sandstone, each with its own sensitivities. We have searched for, tested, articulated, and adopted a lexicon and mapping system to describe the relevant decay mechanisms – based on one of the international attempts (Fig 4). We have produced a draft literature review and held a technical seminar on the subject at the BRE. An interim report on the research was also presented to the United Kingdom Institute for Conservation at its meeting in Lichfield last year.

AC7 Anti-graffiti barriers

This research is attempting to assess whether wax-based anti-graffiti barriers, and their regular removal and reapplication, can be recommended for use to protect friable historic masonry (Fig 5).

A viable test method had to be established that could objectively assess the colour and textural changes to surfaces before and after coating, attack, cleaning, and retreatment. This has produced an inventive use of a standard colour meter together with a computer presentation to reveal comparative contour changes.

Figure 5 Graffiti removal from brick masonry

Preliminary field trials were also made in conjunction with the treatment manufacturer in Watford and in the city of Bath with the cooperation of the local planning authorities. The

start of the work has been reported in a poster and in the conference proceedings of Historic Scotland's International Masonry Cleaning Conference in Edinburgh in 1992.

Figure 6 Typical fire damage

ACS Structural fire protection

Phase I activity has established the standard performance in fire of historic panelled timber doors. Facsimile doors have been tested to the British Standard in attempts to gain at least half hour fire resistance. Various methods of upgrading have also been employed.
After peer review by fire engineers, the results will be written up and final illustrations made for publication (Fig 6). The document's production has been delayed since first announcements were made because of the need for one vital extra set of tests on a new and heavily promoted line of intumescent wallpapers.
Tests show that almost 20 to 25 minutes can be gained for an historic panelled door if it is carefully dismantled and rebuilt with subtle amendments to its design, including the bedding of intumescent strip in the tenons between panels and frame, the secret cross nailing of the panels to the frames, and the placing of intumescent strip in the edges of the door.

Figure 7 Slaking lime on site

We have also started to prepare an ancillary document for publication in association with the pamphlet on panelled doors entitled *The fire engineering approach to fire safety in historic buildings*. This will help to explain how and why this methodology can be applied, and adopt relatively weak passive fire protection measures (such as the upgrading of historic doors not quite to British Standard) and yet still achieve the necessary integrity of the fire safety protection overall.

AC9 Lime and lime treatments

This project is seeking to characterise all currently available building limes in the United Kingdom, including foreign imports, hydraulic limes and blends, etc (Fig 7). A draft directory of building limes has been produced and is being reviewed for publication. The next stage will be to collect scientific data or samples for analysis, so that the chemical constituents of the limes and their likely performance can be included in the report.
A second part of the project involves a review of sites treated with the 'lime method' (lime watering, lime repairs, and lime shelter coating) in an attempt to determine the long-term efficacy of this treatment (Fig 8). Future work may involve related laboratory or field trials following on from the work of Dr Price at the BRE.[2]
We have already been promised the cooperation and assistance of the Mortar Producers Association and of the smaller manufacturers, and there is potential to form international industrial alliances for research in order to win EC research grants to extend the work.

AC10 Underside lead corrosion

This is a long-term programme to determine the many parameters affecting underside lead sheet corrosion (Fig 9).

In 1993/4, we set up the national Condensation Corrosion Forum, which represents all research interests in the field and a substantial body of resourcing aligned to our own modest project.

Figure 8 Statue after lime treatment, west front, Wells Cathedral

During the first two-year phase of research, a test rig was set up to simulate corrosion parameters identified in the laboratory. Special lead coupons were also designed and put out on live sites to further accumulate data from real situations, which confirmed the idiosyncratic behaviour of lead as a result of very small variations in conditions. The work also confirmed that acetic acid from oaken roofs can reemerge even after very long periods in well-seasoned timbers to cause problems for metal sheet roof coverings. Finally, the research showed that plywood decking under sheet roofing can act as a moisture storage area if leaks permit water ingress. These results were presented at the English Heritage/Cathedral Architects Association conference in March 1994.

The second phase of research has just begun both in the laboratory and on various test sites. A state-of-the-art summary of progress will be published shortly. Results will eventually be fed into specifications on our own estate and into grant aid policy.

AC11 Timber decay and moisture ingress

This project completed its third and final stage in 1993/4, assessing the interrelationships between environment, fungi, and beetles in cathedral roof spaces with special respect to moisture ingress.

The second annual interim report was produced and its executive summary presented to the English Heritage/Cathedral Architects Association conference earlier in the year.

High points of the year's field inspections and testing were: the discovery of two species of spider as significant natural predators for the deathwatch beetle; the recognition of the relative inefficiencies of both smoke bomb and so-called mayonnaise paste delivery systems for the treatment of beetle infestations in old oak; and the realisation that our remedial systems generally must also harm our natural allies in the battle against beetles.

The results from this work are to be assembled in a book to be published by E and FN Spon in November 1995. Through a partnership arrangement, Historic Scotland has provided 50% of the publishing costs.

Figure 10 Acid cleaning of sandstone, Edinburgh

Further investigation of these complex interrelationships will be carried out through funding from the European Commission as a collaborative venture between English Heritage and its consultant Dr Brian Ridout, Birkbeck College (London), University College Dublin, and the TNO (The Netherlands).

AC 12 Masonry cleaning

This project aims to update our assessments of currently available masonry cleaning systems in the United Kingdom so as to establish policies and guidelines towards them (Fig 10).

Working with English Heritage, consultants have reviewed and redrafted the cleaning sections of British Standard Code of Practice for the Cleaning and Surface Repair of Buildings (BS CP 6270 Pt I: 1982). A review is also underway of English Heritage's policy

documents and their attitude towards soiling and cleaning. The final objective of this phase of the project is to produce a priority list of cleaning problems where additional research might assist in making recommendations to specifiers and practitioners.

Figure 9 Underside lead corrosion

Our work was broadly promoted at Historic Scotland's International Stone Cleaning Conference held in Edinburgh, and we have contributed details from the research to the international inquiries being made by the Getty Conservation Institute into treatment processes and research needs for the turn of the century.

AC 13 Fire safety in cathedrals

In March 1994, our consultants from the Warrington Fire Research Consultancy (London) completed their two-year study of the fire safety provisions in cathedrals, measured in the light of the recommendations in the Bailey Inquiry Report following the fire at Windsor Castle.

After numerous site visits and meetings with the Ecclesiastical Insurance Group surveyors, cathedral fire safety committees, and local fire brigades, a draft final report has been submitted to peer review and final revisions to the text are now being made before publication. The recommendations are too detailed to be mentioned here in full but, following acceptance by English Heritage's Cathedrals and Churches Advisory Committee recently, there will be a change in grant aid policy towards support for active fire safety measures including the appointment of specialist fire engineering advice.

Notable findings include the general view that passive fire protection measures to save the buildings are nearly all well underway, but that the roles of cathedrals now as places of public assembly are generally overlooked and personal safety has been a relatively low priority.

Figure 11 Terracotta damaged through inappropriate cleaning and patch repair, Edinburgh

The report also drew English Heritage's attention to the likely impact upon cathedrals and churches of the Home Office's draft Fire Precautions (Places of Work) regulations. Steps are now in hand to make representations to ministers on the problems so highlighted.

AC14 Terracotta decay and conservation

This two-year project seeks to better understand the special sensitivities of architectural terracotta to soiling, decay, and treatment so as to devise better cleaning systems for the material (Fig 11).

The first phase, started last year, involves a cooperative agreement with the Postgraduate Historic Preservation Programme of the University of Pennsylvania, USA. Outputs will include preliminary research findings regarding the effects of various cleaning systems on terracotta surfaces and substrates and an international literature review on terracotta decay and conservation.

The work was presented at a national Architectural Ceramics Conference set up by English Heritage and the United Kingdom Institute for Conservation and held at the Ironbridge Institute at Telford, Shropshire in September 1994. Proceedings from the event will be published shortly.

AC 17 Stained glass

This two and a half year project in three phases seeks to discover the factors affecting the durability of mastics, lead cames, and Paraloid B72 adhesive in stained glass repair and conservation.

Phase I has been completed and involved a literature review and general search of industrial data in relation to the modern use of butyl mastics. An draft report is presently under review by our internal clients before publication.

Phase II commenced with a search of parallel research in the field of lead sheet roofing corrosion, where metallurgical studies involving crystallography in the rolling, extrusion, and casting of lead and the amendment of copper contents in alloys all prove to be contributing factors but not essential parameters in the atmospheric decay and structural performance of the material.

Additional work has also been completed on a short study of polycarbonate sheet protection that is commonly used to safeguard valuable stained glass. The study looked at the optical and structural decay mechanisms that affect the sheeting upon long term exposure to ultraviolet light. A draft final report has been submitted for review and the document will be evaluated by internal clients before publication.

Figure 12 Metropolitan Cathedral of Christ the King, Liverpool

AC20 Tile stone roofing

This project is divided into two parts, dealing with the technical and economic issues surrounding the long-term decline in indigenous production and availability of non-metamorphic natural fissile stone roofing (eg Cotswold, Collyweston, and other fissile limestone tiles and the northern sandstone/gritstone flags).

To lend support to local authorities faced with the challenge of imported French limestone tiles, English Heritage is working with the BRE to develop some specific tests that might help to evaluate the comparative long-term durability and aesthetic match in appearance of local and imported products for planning purposes.

With Derbyshire County Council and the Peak Park Planning Board, we are working towards a long term strategy for the continuous supply of Derbyshire flagstones for the local marketplace. Here, English Heritage hopes to act as a catalyst to bring in support for economic and unemployment development by other agencies to the benefit of conservation.

AC21 Mosaic clad concrete

This project, in the early development stage, will bring together a team of building pathologists and mosaic conservators to elucidate how and why glass mosaic cladding decays on modern concrete buildings of the 1950s and 1960s.

The problem has come to light in reviewing the repair and restoration options for the Metropolitan Cathedral of Christ the King in Liverpool (Fig 12). Most of its contemporary equivalents have now been replaced or had their surfaces reclad since they were not considered to be of any historic merit. But our long term treatment systems for buildings of special architectural or historic interest must attempt to retain original cladding systems as part of the conservation ethos. For the moment, English Heritage has accepted the need to overclad Liverpool Cathedral in the hope that our research might subsequently find an answer to the exfoliating mosaic.

Figure 13 New cob construction in Devon

AC204 National sand and aggregates library

This project, undertaken initially as a student exercise, has developed a national reference collection of sands and aggregates for building mortars for English Heritage.
In consultation with the Natural History Museum (Geological Museum) and the National Geological Survey, current regional and national quarries were contacted and supplies of materials donated for assessment. Detailed geological, petrographic, mineralogical, and other analyses were undertaken to profile the materials and the data were loaded into a database.
The collection has now been subdivided to create two collections: one for English Heritage's Headquarters and the other for the Fort Brockhurst training centre. Additional outputs will include descriptions of the work as part of the new travelling exhibition on the maintenance of brick and stonework, 'Making the point'.

AC207 Earthen structures

This study has fostered research and other technical studies regarding the decay and conservation of earthen architecture (Fig 13).
Several meetings were called with national interest groups concerned with the craft and technical and scientific matters in earthen architecture. From these, English Heritage fostered the creation of the Earth Structures Committee of the International Council on Monuments and Sites (UK) (ICOMOS-UK) and encouraged the establishment of the National Centre for Earthen Architecture at the School of Architecture at Plymouth University.
Other outputs include the first national conference on the Conservation of Earthen Architecture at Dartington Hall, Totnes, Devon, the creation of a national travelling exhibition called 'Out of earth', and the publication with ICOMOS-UK and the National Centre for Earthen Architecture of the conference proceedings.

Conclusions

A thorough understanding of building materials and decay processes is critical to the proper repair and maintenance of historic buildings. Through its programme of research, the Architectural Conservation Branch of English Heritage hopes to contribute to the understanding of materials and technology so as to develop benign and effective conservation treatments. Emphasis is placed on applied research which addresses real and timely problems. Our aim is to provide useful results and practical guidelines which will lead to the best possible technical advice and improved standards of practice.

Notes

1. Teutonico, J M, McCraig, I, Burns, C, and Ashurst, J, 1994 The Smeaton Project: factors affecting the properties of lime-based mortars, *Bull Assoc Preservation Technology*, **September**, 32–49. Offprints are available from Sebastian Bulmer, English Heritage, Architectural Conservation Branch, Room 528, 429 Oxford Street, London W1R 2HD; price £10.00 including post and packing.
2. No scientific proof has been found for the evidence of surface consolidation of friable stonework often reported by experienced conservators. See Price, C, Ross, K, and White,

G, 1988 *Further appraisal of the lime technique for limestone consolidation, using a radioactive tracer*, Studies in Conservation, **33**, 178–86.

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