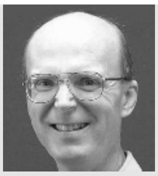
Proceedings of the Institution of Civil Engineers
Construction Materials 163
May 2010 Issue CM2
Pages 57–60
doi: 10.1680/coma.2010.163.2.57

Paper 1000003
Received 08/01/2010
Accepted 18/01/2010

Keywords:
concrete technology & manufacture/ recycling & reuse of materials/waste management & disposal



Peter Claisse
Professor of Construction Materials, Coventry University, UK

Mark Tyrer
Research Manager, Minerals Industry Research Organisation, and Visiting Professor, Coventry University, UK

Stephen Coupe
Research Manager and Renewable Energy, Hanson Formpave, and Lecturer in Environmental Sciences, Coventry University, UK

Institution of Civil Engineers

Briefing: How to research and publish new concrete ingredients

P. Claisse MA, PhD, CEng, FICE, M. Tyrer MSc, PhD, FGS, FIMMM and S. Coupe BSc, PhD, MCIWEM

1. INTRODUCTION

Almost half of the papers submitted to this journal involve the use of a secondary material as a component of a cementitious mix. This is not unusual – the same proportion has been observed from papers submitted to the Sustainable Construction Materials conference scheduled for 2010. The published literature now includes papers that describe tests on the inclusion of hundreds of different materials in concrete.

The reasons for this are easy to understand. The introductions to many papers often comment on carbon dioxide emissions from cement manufacture. Added to this are the environmental impacts of the extraction of the raw materials needed for cement manufacture and, most significantly, aggregate. Finally, there are rising disposal costs of the materials that are to be diverted to make concrete. The combination of these factors presents a compelling environmental and economic case for replacing the traditional components of the mix and acts as a driver from regulators as manufacturers are forced to improve practice. The risks, however, are also very evident. New materials may cause production problems or premature failure of a finished product. The reputation of a company could be destroyed from a media story such as 'Householder finds faults because company builds houses with waste instead of proper materials'. A health scare would be even more damaging, whether or not it has any real scientific basis. These risks combine to discourage companies from making the significant capital investments that are needed.

Indeed there are few signs that significantly increasing amounts of novel waste materials are being used in concrete. In Europe some progress has been made with the approval of new types of blended cements, but these generally only include types of materials such as pulverised-fuel ash and blast furnace slag that have been used in concrete for at least 80 years. In the USA, the combination of emission controls on coal-burning power stations and concerns about trace toxins in the ash itself is making it difficult even to maintain existing levels of use.

As an academic, it is easy to blame industry for this situation. In the UK, we often imply that the construction industry is 'very conservative', 'risk averse' and 'reluctant to invest in new ideas' and suggest that there will be more progress elsewhere. In this briefing, the opposite assumption is discussed: that perhaps the problem lies in published research. Industry often sees academia as an 'ivory tower', unconcerned about the long-term results of innovation. This discussion is intended to provide a contribution to the 'environmental debate' and also to inform future editorial policy.

The paper is divided into two sections: the research project and the publication. It is assumed that normal scientific rigour, such as adequate tests on control samples and error bars on graphs, will be applied, so this is not discussed.

Terminology is important when wastes are involved. In this paper the word 'material' is used to describe material that is received from a waste producer, although it is acknowledged that it is often better to use the term 'secondary material'. Once the material has been used or mixed or processed in some way, the result can be described as a product and is thus, hopefully, exempt from the mass of regulation that covers the transport and handling of wastes. Simply mixing two wastes together may produce a product that is not classified as a waste.

2. THE RESEARCH PROGRAMME

2.1. Research objective – products and applications

The objective must define the product that is to be marketed and the application for which it will be used. The intended product may be a 'grey powder'. It may also be a concrete, a mortar or even a stabilised soil. Experience has shown that proposing a product that looks like a waste for general use in concrete is unlikely to succeed. If it is ground up and mixed to look like a grey powder it will be far more acceptable to producers. Fortunately, experience has shown that grinding and mixing many combinations of waste minerals results in a grey colour.

The research objective must clearly state the chosen application. Few new products for use in concrete will be suitable for the full range of uses of Portland cement. Many may only be suitable for controlled low-strength materials or possibly masonry blocks. This will reduce their economic value but will probably still be worth pursuing because low-strength products have numerous applications including house foundations and road sub-bases. Indeed, it could be argued that very large amounts of 'structural grade' cement are wasted on these uses.

It is unlikely that a secondary mineral will be suitable for use in concrete as a complete or almost complete replacement for cement without the addition of further secondary materials.

Figure 1 shows a schematic arrangement for the potential application of a number of materials of variable composition. The laboratory research should provide data for the operation of the flow control that determines the mixture proportions.

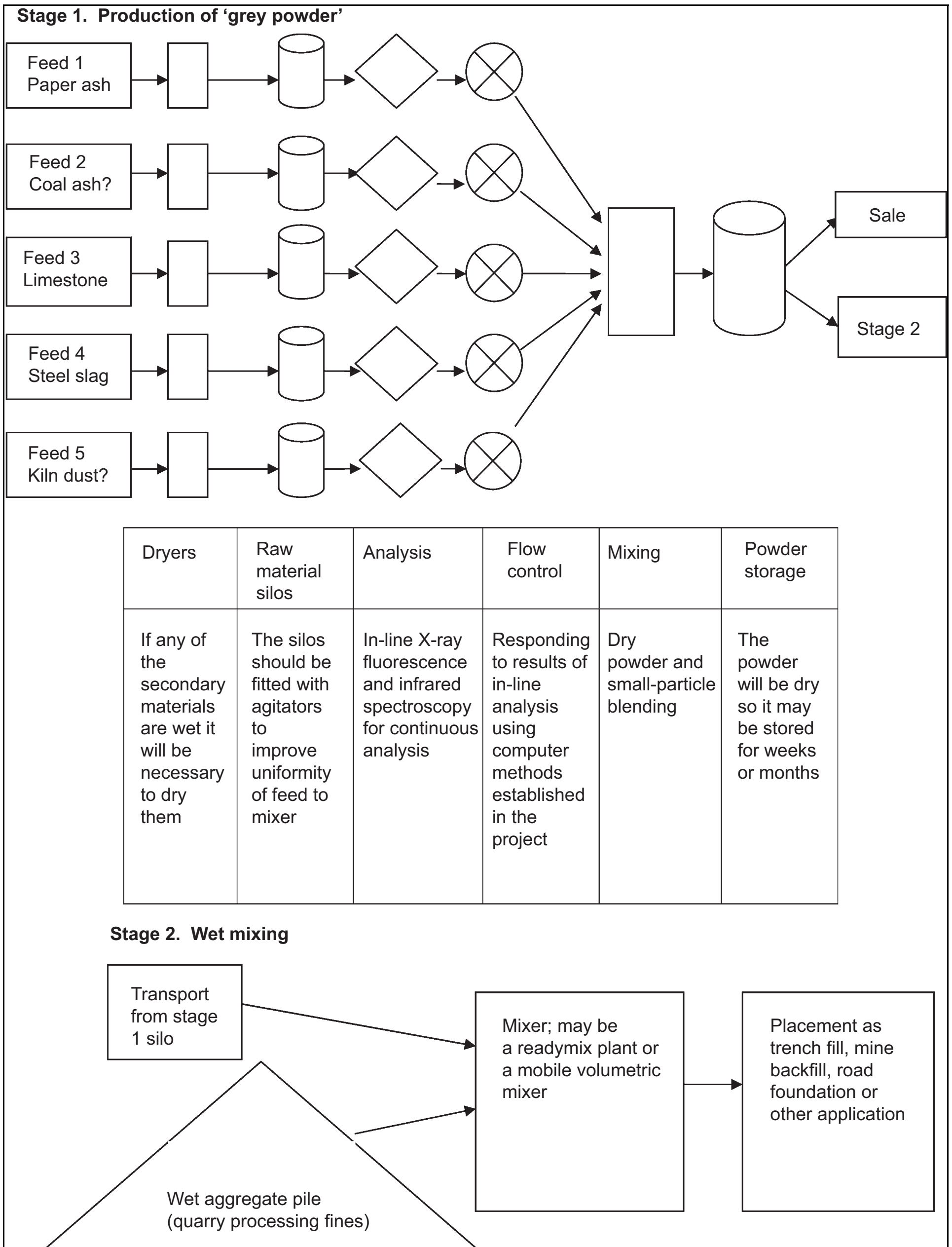
The basic objective of the research must be to investigate the use of the chosen material with a view to either dismissing it as unsuitable or promoting its application. Both these options must remain open and researchers should not be penalised for negative results. This is a risk for industry – spending money on a negative result is hard to justify but is an inevitable risk in genuine research. Such results are of use and should be published. It is not the purpose of this note to discuss research funding and its influence on areas of work, but clearly it must not bias the interpretation of results.

A more detailed objective will be to determine whether the new product will be as good as current products for the chosen application. This is an objective that should be proven statistically to, say, a 5% significance level.

2.2. The plan of work

The choice of tests to carry out and numbers of samples to use will depend on time and resources, but there are three components that must be present every time – materials characterisation, strength and leaching. These may only be omitted if fully relevant results are obtained from the literature.

One of the main reasons why research does not result in industrial applications is the short-term nature of the research funding that is normally awarded. Many plans include 'long-term monitoring' but this will not be achieved without further funding. This problem is exacerbated by the use of students in carrying out the work. PhD and MSc students generally leave once their degrees have been awarded and it is difficult for supervisors to continue with the work. Plans should therefore



Dryers	Raw material silos	Analysis	Flow control	Mixing	Powder storage
If any of the secondary materials are wet it will be necessary to dry them	The silos should be fitted with agitators to improve uniformity of feed to mixer	In-line X-ray fluorescence and infrared spectroscopy for continuous analysis	Responding to results of in-line analysis using computer methods established in the project	Dry powder and small-particle blending	The powder will be dry so it may be stored for weeks or months

Figure 1. Schematic arrangement of production facilities

not contain unrealistic ideas for work beyond the end of the contract. This is a problem for industry because its view of 'long term' is the period over which the construction project should perform to the guarantee/insurance, which is often decades. No short-term experiment can truly simulate long-term exposure so the best solution is probably to include several different simulation methods in the programme.

2.3. Materials characterisation

Full materials characterisation is needed because it is essential that all work should be repeatable so that another worker in another laboratory should be able to yield the same results. Furthermore, many waste streams are highly variable so a detailed analysis of the material used for testing is always necessary; this must include a full chemical and physical description of the material as well as details of its source. It is also very useful to have an analysis of a number of samples to give an idea of the range of properties in different batches of material. This is especially important in the case of industrial by-products such as combustion residues or slags, the composition of which may change depending on the source of material, seasonal operations or variations in the major product stream.

2.4. Pre-treatment

If a material is not giving good results when used in concrete it can often be improved by washing, calcining and grinding. A discussion of the environmental impact of this should be given. Details of the economic impact may be outside the scope of the work. One advantage of pre-treatment is that it may well result in reclassification of the waste as a product.

2.5. Mixture designs

Mixes with high cement content offer fewer benefits from the use of the waste. High-sulfate mixes may be incompatible with cement so 100% replacement may be necessary as well as giving maximum benefit.

2.6. Types of test sample

If the material is a powder that is being used to replace cement, it should be acceptable to obtain most of the results with small mortar samples (typically 50 mm cubes).

2.7. Storage and archive

Storage of both materials and products under controlled atmospheres (fixed humidity – low or high as appropriate – temperature and low carbon dioxide partial pressure) maximises the time such samples remain representative of the bulk material. It is particularly important to ensure that materials containing lime do not carbonate before use. Producing a small archive of surplus samples of both materials and products costs little and allows re-examination of materials in the light of later interesting results. In many cases, the lead time between a study and commercialisation of a developed product spans several individual projects in a larger programme. The availability of reference samples from earlier phases may add considerably to the confidence with which later decisions are made. The samples will normally be held at the laboratory while the original data from the research should be held by the researcher.

2.8. Strength

This property has been used as a measure of the quality of concrete for over 100 years and is always used as a first indication of both structural performance and durability. If fibres are being used, tensile as well as compressive strength should be tested. It is helpful to readers if strength measurements are related to a conventional unconfined compressive strength determination. The literature abounds with other tests that require recalculation for their interpretation. On occasion, this is not done well, resulting in propagation of errors and misleading or erroneous conclusions.

2.9. Leaching

Environmental concerns are such that nothing new can be used in construction without a leaching test. It makes little difference if the product is intended for a dry environment because demolition and reuse of the structure must be considered. Also, it makes little difference if it is obvious that the product will not leach. Nothing can be used without a test to a relevant standard. For some products the tests must be even more stringent and include contaminants that do not leach. For example, the limits on toxins in plasterboard (wallboard) are based on the assumption that a child could make a hole in a partition wall and consume the arisings. The highest incidence of asbestos-related disease in the UK is among electricians who drill into walls and breathe in the dust. In choosing a leach test from the many available, the justification should be stated. For example, what range of chemical environments is the material likely to experience during its service life?

2.10. Site trial

A large-scale 'site' trial of the manufacture and use of the product will form a very valuable part of a project but may be difficult to arrange, particularly when the industry is in recession. A site trial could be a trial production run of precast products or mixing a truckmixer full of the proposed mix and pouring it into a trench. A 'live' trial in which the product is actually used (e.g. as part of a road) is best but this is often not achievable. If the trial is not in a live application the challenge is to make it as realistic as possible. Thus, for example, if it is not part of the road it should be located where it will receive some other form of loading.

A trial adds a lot to a project and the resulting publication, but must have defined objectives. The following objectives should be considered.

(*a*) To validate lab results on a larger scale. A site trial is of far more use when carried out in combination with lab work. This objective is particularly vulnerable to time constraints on funding. If the trial is carried out towards the end of a project, the results obtained will only be very short term. If the research has produced models for long-term performance, site validation may be very limited.
(*b*) To demonstrate large-scale methods of production.
(*c*) To provide samples that may be recovered from the trial and returned to the lab for testing.
(*d*) To provide publicity for the project and the application. This includes generating consumer confidence in the method. Site trials will normally provide the best opportunity for photographs, video, etc., which may be used to promote the work. This objective may be the most important.

3. THE PUBLICATION

3.1. Introduction

It is no longer necessary to explain why replacing cement is a good idea. The introduction should give some details of the source of the material, the amount that is available and any factors related to its future supply. Details of the chosen application and the properties required for the application should also be given.

3.2. Review

As with all research, the discovery of results of very similar tests carried out previously does not diminish the value of the work, provided the prior studies are not too common. If a report of similar work is found, the review should focus on the analysis of the materials used.

3.3. Relevance and transferability of results

Too many papers are rejected on the grounds of being over-specific to a single system. Although often well planned, executed and presented, the authors fail to demonstrate the relevance of their work to other materials, systems and processes. This, at best, results in an editor requesting major revision of the manuscript to overcome such shortcomings, but all too often ends in rejection of the paper. It falls on the author to consider who will make use of the results, specifically how the findings may be used in planning or interpreting related studies. This consideration must be made at an early stage of the work and authors should ensure that sufficient measurements are made and reported to allow interpretation by a wide range of readers. Increasing the usefulness of a paper in this way will also pay dividends in generating citations by others. Industrial confidence in research is primarily based on cost, performance, return on investment and good publicity. Anything that is not widely applicable, however novel, will attract little interest.

3.4. Discussion

Discussion should provide a comparison with existing products. If acceptable to the project sponsors, a discussion of the limitations of existing products is appropriate. This can often be negotiated with sponsors; for example, work on a replacement for asbestos–cement board (which is still manufactured in many countries) should correctly discuss problems associated with asbestos. The discussion should not be biased, however. If the new product results in, say, a 20% loss of strength, there is no point in saying that this is not a problem. Similarly, if the proposal is to use sewage sludge ash, an honest discussion of public resistance to it should be included.

The discussion should also include consideration of the methods that should be used to produce and market the product. Any significant required capital investment should be discussed, as should potential problems with environmental or health risks and insurance.

4. CONCLUSIONS

The following components contribute to a strong publication that is likely to lead to industrial application of the results.

(*a*) An informed discussion of the source of the material, including its availability.
(*b*) A physical and chemical analysis of the material, including estimates of the range of values that might occur in the supply.
(*c*) Test results for strength and leaching of the product.
(*d*) A report on a site trial.
(*e*) An unbiased discussion of the problems that may be expected before the product is brought to market.
(*f*) An analysis of the long-term consequences of introducing the proposed technology.