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Concrete Materials and Structures Research

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Abstract: *This article provides an overview of some of the current research into concrete materials and design of concrete structures being carried out at the University of Bath. Three main areas of research are described: the performance of concretes made with low carbon cements, the use of flexible fabric formwork and the resistance of concrete structures to blast and impact. Concrete research at the University of Bath is carried out within the Building Research Establishment (BRE) Centre for Innovative Construction Materials. The Centre, formed in 2006, is a joint collaborative partnership between BRE Ltd and the Faculty of Engineering and Design at the University of Bath. The centre conducts research, development and consultancy in the fields of innovative and sustainable construction materials. The Centre currently has 10 full-time academic staff, three postdoctoral researchers and around 30 postgraduate researchers. The range of research activities carried out by the group covers the use of natural materials (timber, straw bales, rammed earth, natural fibre composites), unfired masonry, lime based materials, geotextiles, recycled materials, advanced composites and low carbon cements. Much of this research is carried out in collaboration, not only with the BRE but also with a wide range of other industrial partners.*

Keywords: *University of Bath*

I. INTRODUCTION

Low Carbon Concretes

Recognising the contribution of cement to carbon emissions worldwide, there are been significant interest in the use of cementitious systems that are inherently less CO2 intensive than Portland cement. Examples of such cements are: calcium sulfoaluminate cements, supersulfated cements, alkali-activated cements, magnesia-based cements and phosphate-based cements. Whilst there has been much fundamental research into the mechanisms by which these cements work, there is a considerable shortage of data relating to the performance of concrete made with these cements; particularly when subject to environmental conditions typical of that in the UK It is possible that the development of performance-based standards may be critical to the acceptance of these cements in the UK, and to this end research is being carried out within the Centre to investigate low carbon cement concretes with the performance requirements for a range of industry significant applications, and compare these with the current Portland composite cement alternative. Calcium sulfoaluminate cements (CSAC), widely used in China, have been imported into the UK for use as expansive cements in providing shrinkage and early-age thermal crack control, water tightness and chemical prestressing. CSAC are produced by burning limestone and fly ash (or bauxite) at 1200-1250ºC; 200-250ºC lower than required to create Portland cement, with 18-25% by mass of gypsum interground with the clinker during cooling. Although not currently produced in the UK, there are no technological reasons why they could not be. Research at Bath is investigating the use of CSAC in combination with additions to produce performance similar to that of UK composite cements but with lower embodied CO2 (ECO2); through optimisation of physical and chemical processes. Example additions include fly ash, flue gas desulfurization gypsum and limestone fines. Whilst the novel use of CSAC may have some benefits, supersulfated cements (SSC), which have many similarities to CSAC, have been widely used in the UK in the past; and are now being used commercially in large scale projects in parts of Europe. SSC, for which a new European standard (BS EN 15743) will soon be released, are produced through the judicial blending of ggbs, gypsum and additional constituents that essentially act as a catalyst. Depending on the additional constituents used, the ECO2 emissions for

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SSC are approximately 45 to 90 kg/t; in the order of 90% lower than that of Portland composite cements. Research is investigating whether SSC meeting BS EN 15743 can be achieved using UK.

As an example of the general concept, Figure 1 shows the effect of water/cement ratio on cube strength and initial surface absorption (a property related to permeability) for CSAC and SSC concretes with comparable behaviour to that of a IIIA concrete (50% PC/50% ggbs). Using the approximate figures for ECO2 of the constituent materials, the ECO2 of the resulting concretes can be calculated. Based on interpolation of the data, it can be calculated that equivalent cube strength and initial surface absorption to that of a control IIIA concrete (w/c ratio = 0.45), can be achieved with ECO2 in the order of 80% and 20% lower, when using SSC and SCAC, respectively (Figure 2); for the particular materials and mix proportions used in this research However, given that CSAC and SSC produce concretes that have inherently lower alkali reserves, concerns are understandably raised with respect to their resistance to carbonation. Indeed accelerated carbonation tests in accordance with the draft EN standard show these concretes to lose alkalinity more rapidly than that of Portland composite cement concretes. To achieve equal performance to IIIA concrete with respect to XC environments, concretes made with these cements will require lower w/c ratios, reflected in higher ECO2; estimates are given in Figure 2. However, this is tentative, as no SSC concrete with equivalent carbonation resistance to the control IIIA concrete has been observed in the research to date. On-going research is therefore investigating the potential for using fillers effectively to reduce the porosity and permeability of CSAC and SSC concretes further, and other aspects of durability, including chloride binding. Aligned with this, understanding of the underlying physical and chemical processes that drive performance is being derived through analytical studies. A further area of research, being carried out in close collaboration with the BRE, is investigating the use of alkali-activated concretes, the binder component of which constitutes a blend of fly ash and ggbs activated by an alkali-silicate solution [1]. The main aim of the project is to address concerns that use of these binders in concrete may lead to damaging alkali-silica reaction (ASR). Research is still at a relatively early stage, but the initial results appear to suggest that the reactive alkaline constituents of the activator are bound within the hydrate phases at early age. Subsequently, few free alkalis remain within the system for a significant period, and consequently no ASR has been reported to date.

Flexible fabric formed concrete

One of the key attributes of concrete, which invariably goes unexploited, is its mouldability. Coupling this with the desire to use materials efficiently and responsibly, there is the potential to optimally design the shape of reinforced concrete elements. However, the difficulty until now has been how to actually construct an optimised structural element. By moving beyond the confines of conventional rigid formwork, fabric formwork has the means to allow these optimal structures to be built, creating a new and exciting architectural aesthetic. Whilst techniques for creating these fabric formed structures have been developed there is a lack of design rigour which prevents these structures being used in practice. Structural analysis, detailing and optimisation approaches required to make this technique viable have still to be resolved. This has been the focus of ongoing research at Bath in recent years. In particular the research has focused on the construction of optimised beams (Figure 3). Such beams can result in up to a 50% saving in concrete compared to a conventional rectangular beam, minimising both resources and dead weight [2]. However, one of the key problems with this approach is preventing shear failure. Not only is it difficult to quantify the shear capacity of a non-rectangular, non-prismatic section using conventional approaches, but it is also difficult, physically, to provide shear reinforcement in a complex, variable section beam. Various approaches to both these problems are currently under investigation. Use of fibre reinforced polymer reinforcement, mesh reinforcement, fibre reinforced concrete and prestressing are also all being looked at in order to improve efficiency, constructability and performance [3]. The key issue of optimisation and analytical modelling of the beam has also been examined, with new computational techniques having been developed to define the shape of a fabric formed beam (Figure 4), rather than relying on empirical formulations developed previously, giving enhanced flexibility to the design approach [4].

Concrete structures under blast and impact

Concrete, being an essentially brittle material has the potential to react catastrophically to impulsive loads of the sort caused by explosive blasts or impact events. Research has begun at Bath looking at the behaviour of reinforced concrete columns under such loading in order to develop an understanding of how and when mitigation strategies should be implemented. In particular the use of fibre reinforced polymers to wrap and strengthen concrete columns is being examined (Figure 5). This follows on from a previous study of the confining effects of FRP on large-scale rectangular concrete columns [5]. The new study uses an energy approach to analyse the structural response of concrete columns to an impulsive load, turning input energy into kinetic energy of the column together with initial elastic strain energy and subsequent dissipation of energy through various mechanisms [6]. The energy dissipative mechanisms of FRP wrapped columns benefit from both the confinement of the concrete, increasing ductility of the concrete in compression, and the shear enhancement provided by the FRP, preventing brittle shear failure from occurring. Furthermore, the FRP wrap limits spalling and ejection of shattered concrete particles. Other energy dissipation mechanisms are also evident, such as microcracking, requiring a damage mechanics type approach to be developed. All this is done based upon strain-rate enhanced material properties, although this is difficult to accurately quantify for concrete, due to its non-homogeneity and triaxial stress behaviour. Preliminary analyses for FRP confined concrete columns demonstrate the benefits of the approach. A set of tests are planned in the near future to help validate the model further and provide greater detail into some of the energy dissipation associated with various damage mechanisms.

II. CONCLUDING REMARKS

The aim of the BRE Centre for Innovative Construction Materials is to promote research into new construction materials and explore innovative ways of using existing products in modern, sustainable building design. The on-going research on concrete materials and structures highlighted in this paper are delivering innovative, practical and sustainable solutions to the issues facing the cement and concrete sectors, through use of novel cements, appropriate constituent materials selection, innovative forming techniques and use of complementary reinforcing materials. As these technologies mature, designers will need to embrace them in order to maintain their competitive advantage and sustainability credentials.

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