Sustainable Technology Research Centre

Dr Anton Fried describes the research activities currently being undertaken by the Concrete and Masonry Research Group at Kingston University's Sustainable Technology Research Centre

The Civil Engineering department at Kingston University undertakes its research activities under the umbrella of the Sustainable Technology Research Centre. At present a wide range of projects examining masonry, concrete, slope instability and energy conservation are being undertaken within the centre. Of particular interest to structural engineers are the masonry and concrete aspects of the work which are summarised in this article. In addition to research, consultancy activities are undertaken at the behest of industry

Masonry research and consultancy

Masonry research is undertaken in purpose built laboratories which house specialist masonry and mortar testing equipment which includes wallette testing equipment conforming to BS EN 1052-2:1999 Methods of Test for Masonry – Part 2, a full scale wall testing rig as indicated in Fig 1, a freeze-thaw chamber (also for use with other materials), and traditional unit and mortar testing facilities. Further, detailed chemical and physical examination of masonry can be undertaken using equipment and techniques which include, a Simple Polarising Microscope, Scanning Electron Microscope, Raman microscope, Electron Micro-Probe Analysis, X-ray diffraction, X-ray fluorescence, Inductively Coupled Plasma Mass Spectrometry, Thermogravimetric and differential thermal analysis.

Research and consultancy currently underway or recently completed includes:

- The properties of low density Aircrete products.
- Low density thin joint Aircrete blockwork under concentrated loading
- The impact of thin joint construction on the strength and durability of solid dense concrete block masonry
- Unreinforced masonry basements
- The properties of masonry mortars including thin joint and lime mortars. (two projects)
- Transverse laterally loaded walls constructed using thin joint mortar
- The procurement of pre-fabricated brickwork
- The thermal properties of a variable aspect ratio cavity wall
- The effect of clay fines in aggregate on the properties of mortar
- Chemical analysis of masonry materials to assist in the understanding of bond.

Fig 1. Crack pattern of a failed solid dense concrete block wall constructed using thin joint mortar

To give a flavour of the work being undertaken some of these projects are briefly described below.

Low density Aircrete

Low density Aircrete is used in mainland Europe, particularly Germany but not in the UK and in order for this material to be adopted by the UK market, design and specification guidance appropriate to UK conditions is necessary. Consequently an EPSRC research programme has been approved whose objectives are to pick up on the need to adjust UK design procedures to reflect developments in the structural Eurocode 6[3] and the supporting CEN TC 125 standards. Opportunities exist to improve productivity by using low density aircrete masonry walls as this material improves the efficiency of construction, the light units being easily manhandled and readily cut, shaped and chased. Their low density (typically 350kg/m^3) and high air content provide excellent thermal insulation which assists in meeting the proposed changes to Part L of the Building Regulations, thereby addressing the key environmental need to reduce the consumption of carbon based energy. Whether their structural performance and durability are sufficient is being determined in this programme.

Fig 2 shows a typical tensile flexural failure for a low density aircrete B-wallette using thin layer mortar whilst Fig 3 illustrates compressive strength development of two different thin layer mortars up to 28 days.

A second study into this material examines in detail how low density Aircrete performs under concentrated loading. The impact of different variables will be determined using physical testing and mathematical modelling using Finite Elements, further expanding the knowledge base of this material. Recommendations on design procedures will be made using the findings from this programme after existing guidance has been appraised.

The impact of thin joint masonry construction on the strength and durability of solid dense concrete block masonry

Two industrial companies have recently approached Kingston University requesting testing work be undertaken to determine the properties of thin joint glued solid dense concrete block masonry for new UK markets. Whilst the use and benefits of thin joint Aircrete walls are known to the UK industry, both in Europe and the UK forming walls using solid dense concrete block masonry with thin joint construction has not been widely undertaken. Potential new markets for this material include using fair faced blocks to build corridor and similar walls in hospitals, schools, universities and other such buildings, prefabricating walls in factories for use in cladding and domestic property applications and utilising the enhanced flexural strength of this material to produce unreinforced solid dense concrete block masonry basements below domestic properties.

Initial flexural strength results are encouraging indicating the characteristic flexural strength of dense concrete walls formed using thin joint technology are as much as 3.5 times greater than equivalent walls built using conventional mortar. Results suggest wall panels are behaving as plates, with failure occurring within the block rather than by mortar joints debonding as is common with typical masonry failures. Fig 1 shows the crack pattern of a full sized wall after testing. Fig 4 indicates the failed surface of a small specimen and clearly shows failure is

Fig 2. Typical failure of a low density Aircrete B-wallette using thin layer mortar

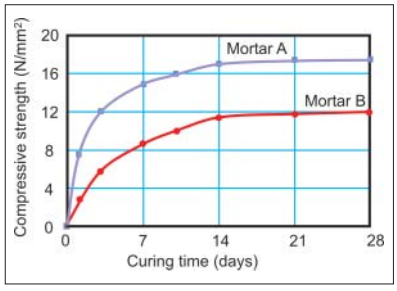

Fig 3. Compressive strength development of two different thin layer mortars

Fig 4. Failure of a B-wallette indicating thin joint is stronger than solid dense concrete blocks

within the concrete block and not along the joint.

Unreinforced masonry basements

Basements were once very common in domestic building in the UK, but following the First World War, when large numbers of 'Homes fit for Heroes' were built, basements were largely omitted. Land at that time was relatively cheap and techniques for producing low cost basements for mass housing largely undeveloped.

Nowadays, many of today's housing developments are, of necessity, on poor ground. This often results in the need for deep foundations where considerable excavation is required. In such circumstances the provision of a basement is often cost effective. But until recently, the use of basements in the UK was inhibited by the lack of comprehensive design guidance of the type now included in the Approved Document *Basements for Dwellings*[1] This document provides excellent design guidance but the absence of an economic design procedure for plain masonry is a severe limitation because plain masonry walls or unreinforced concrete would in many situations be more cost effective than other solutions.

To address this deficiency design procedures for plain masonry basements have been developed. The design information is currently being further developed for inclusion in an updated version of the Approved Document.

Mortar for masonry

One researcher in this field has close involvement in the development of new European Standards for products and test methods. Through this work it became apparent that the tests used for the determination of many of the properties of mortar were inadequate. They produce numbers and values, and these are often used for comparison, but it is generally unclear what basic properties were being measured. The situation obtained particularly in respect of the plastic as opposed to the hardened properties. This has already led to the development of a much improved test to determine the setting time characteristics of mortars which is easier to use and measures definite and precise parameters. Further outcomes should enable more of the existing tests to be validated and recommendations on alternative tests that are better able to fulfil the function of quantifying the properties and requirements of mortar in an objective and reproducible way.

Building on the findings of the first programme, a second evaluation of mortar properties is underway. In this, the effect of mortar on the strength and durability properties of masonry is being investigated.

The need for this is due to changes that have occurred to the materials used to produce mortar and alterations to the regulations governing mortar over the last few years. Further, mortar manufacture in recent years has been extended to embrace traditional site mixing, ready blended bagged products, lime sand mixes, ready mixed retarded mortar, and site hopper mixed mortar. Evaluating the new manufacturing techniques and the changes to the materials has proved to be difficult to achieve in a consistent way, and there is an urgent need for further work. In addition, the mandate for the production of the new European Standards for masonry called for bond between units and mortar to be addressed as a key performance requirement and as this has not been achieved the development of bond and flexural strength across a range of masonry units for both traditional and new mortar types reflecting the recent changes highlighted above will be investigated.

Transverse laterally loaded walls constructed using thin joint mortar.

BS 5628: Part 1:1992[2] includes a design method for laterally or wind loaded wall panels. These walls are widely used in industry as cladding panels, the gable end walls to factory buildings and in domestic properties. Their design is based on the yield line method although masonry is perceived of as a brittle material. However there are reasons which indicate the yield line method may be appropriate with conventional masonry but this is not the case with thin joint glued masonry which is likely to require an elastic approach. This programme of research will examine existing methods of analysis and recommend an appropriate method of design for thin joint glued masonry.

The procurement of prefabricated brickwork masonry

In recent years there has been increased attention paid to the need for improvements in the construction process and quality achieved on site. With the number of skilled masons falling rapidly, alternatives to masonry construction are once again receiving attention and the prefabrication of brick elements provides a way of achieving the high quality and standards required along with improved working conditions. The programme included an experimental investigation into the feasibility of using thin joint construction as a means of enabling prefabrication.

The thermal properties of a variable aspect ratio cavity wall

Cavity walls are widely used in the construction of low-rise dwellings. The primary function of such wall construction is to increase thermal resistance while affording a barrier to water infiltration. Several design guides, including 'CIBSE'[4], provide data for prediction of the thermal resistance of cavity walls of varying internal geometries. However, 'U-value' coefficients provided in these guides do not allow for the heat transfer variations of convective airflows in cavities of different aspect ratio and are usually based on the thermal performance of the inner skin[5,6]. The guides consider conduction and radiation as the main heat transfer modes. Although much work has been done in the field of convective cavity flow, the particular application to thermal resistance of a mortar jointed masonry cavity wall has received little attention to date. This project examines this problem.

The effect of clay fines in aggregate on the properties of mortar

Within Europe the harmonisation of standards for aggregates has resulted in a suite of new and modified aggregate test methods and a reappraisal of specification limits through the work of the European Committee for Standardisation (CEN) Technical Committee (TC) 154. The acceptance in many countries, particularly France and The Netherlands, that fines quality is more significant than fines quantity has led to the drafting of test methods to assess the harmfulness of fines. The methylene blue dye test, a quantitative test method for clay fines, and the Sand Equivalent test for fines content are currently draft European Standards and their use is included in the new European Standard for aggregates for mortar being drafted by Sub-committee 1 of technical Committee 154.

Information gathered on fine's content and fine's quality has led to concerns that following European guidelines would demand onerous restrictions on harmful fines that would prejudice the use of what may be perfectly satisfactory materials traditionally used by bricklayers in the UK. This project investigates and makes recommendations on this.

Chemical analysis of masonry materials to assist in the understanding of bond

Detailed investigations into the chemical nature of the constituents forming the bond between masonry units and mortar are necessary to enable properties, particularly flexural strength to be optimised. To achieve this an interdisciplinary approach which includes both the users and material scientists is needed. Analytical techniques which better define the chemical-mineralogical features of the materials and enable the nature, shape and size of different constituents of units and mortars to be determined will assist in improving material use and productivity for the industry.

To achieve this, investigations into masonry and concrete properties are currently underway which will enable a study of mineral phases and chemical compounds in these materials using a suite of techniques. These include, a simple

Polarising Microscope, Scanning Electron Microscopy, Raman microscope, Electron Micro-Probe Analysis, X-ray diffraction, X-ray fluorescence, Inductively Coupled Plasma Mass Spectrometry and Thermogravimetric and differential thermal analysis.

Concrete research and consultancy

Kingston University has been undertaking masonry investigations for many years. To broaden and diversify the research base, over the last three years, work to determine the feasibility of using re-cycled materials as aggregate in concrete has been developed. To achieve this, a specialist freeze-thaw chamber was purchased for use in the sustainability area of research and carbonation tanks to accelerate the effect of carbonation on concrete have been procured. In addition, microscopical investigations into the chemical nature of concrete are undertaken as well as the usual wet, dry and non-destructive concrete tests.

Current concrete research includes the following projects. Firstly, three projects are underway to examine the feasibility of using recycled materials as aggregate in new concrete. In the first, the performance of concrete constructed using Ordinary Portland Cement but with old concrete crushed to form the coarse aggregate is being studied whilst in the second similar programme, instead of OPC, binary cements are being investigated. In the third programme, recycled glass as a replacement for aggregate in concrete is being examined. A fourth project to develop a design approach for unreinforced concrete in domestic basements has been completed which complements the work being undertaken into unreinforced masonry basements.

Construction and demolition waste recycling project I. Examination of ordinary Portland Cement (Portland Cement Class 42.5)

This project demonstrated the suitability of recycled aggregate for use in a range of concrete applications but only using Portland Cement, through laboratory research and field trials in order to address escalating costs in capturing aggregates and disposing of construction and demolition waste. The findings verified that the BSI draft specification (BS 8500[7]) is adequate and appropriate for intended uses, and provides suitable guidance for re-cycled aggregates. A full scale site trials confirmed that coarse Recycled Aggregate (RA) can be used successfully in a range of concrete applications. (Fig 5).

To achieve the outcomes, the aggregates were characterised, suitable concrete mixes which contain RA were developed by investigating a range of blends of natural and RA in trial mixes, full scale demonstrations including a variety of structural and paving elements which include coarse RA were built, assessed and are being monitored over the long term and finally, technical papers, workshops and a technical skills workshop have been run.

Fig 5. Full scale construction using recycled aggregates for heavy duty concrete pavement application

Construction and demolition waste recycling project II. Examination of binary cements which include pulverised fly ash, silica fume and ground granulated blast furnace slag

This project set out to demonstrate the suitability of recycled aggregate for use in a range of applications in which binary cements were used. Hence the advantages of re-using aggregate as well as using wastes materials in cement are addressed. The aims of this project are similar to those above so are not repeated.

Specifically the research examines the suitability of recycled aggregates for use in concrete with blended cements (PC/PFA, PC/silica fume, PC/GGBS). New European standards for concrete and aggregates in concrete allow the use of recycled aggregates and by-products such as PFA, Silica fume and GGBS combined with Ordinary Portland Cement and the findings will confirm their suitability.

The development of simple 'deemed to satisfy' *in situ* concrete basements for dwellings

At the time of this research the Approved Document *Basements for dwellings*[1] gave overall design guidance on basements for dwellings in the U.K. This guidance allows the walls of basements to be constructed of reinforced masonry or reinforced concrete, the designs being in conformance with BS 5628: Parts 1[2], 2[8] and 3[9] (masonry walls) and BS 8110: Parts, 1[10], 2[11] and 3[12] and BS 8007[13] (concrete walls). Further guidance for inclusion in an Approved Document on unreinforced masonry basements had also been produced resulting in the anomalous position whereby domestic basements in concrete need to be designed to BS 8110: Parts, 1, 2 and 3 and BS 8007 with the consequent high levels of reinforcement but masonry basements may be unreinforced. The Ready Mix Concrete Buraeau (RCB) has questioned the need for such high reinforcing levels in shallow domestic basements made of concrete and this project sets out to examine the feasibility of utilising unreinforced or lightly reinforced concrete in these situations and to produce the relevant guidance for inclusion in an 'Approved Document'.

The findings have been written into a document which will be forwarded to BRAC (Building Regulations Advisory Committee) in February 2005 who will advise as to their appropriateness for inclusion into an Approved Document (AD). With BRAC's approval the document will be forwarded to the ODPM for public comment. se

REFERENCES

1. Approved Document: *Basements for dwellings*. Crowthorne. British Cement Association. 1997. p 82
2. BS 5628: Part 1. *Structural Use of Unreinforced masonry*, 1992, British Standards Institution
3. Eurocode 6: *Design of Masonry Structures – Part 1-1: General rules for buildings – Rules for reinforced and unreinforced masonry*, ENV 1996-1-1, Comite European de Normalisation, June 1995
4. 'CIBSE' guide, Section A3, *Thermal Properties of Building Structures*
5. 'Thermal insulation of airspaces' *Trans. A.S.M.E.,* 1955
6. Cheesewright, R.: 'Distribution of temperature and local heat transfer rate in turbulent natural convection in a large rectangular cavity' *Proc. 8th. Int. Heat Transfer Conf.,* San Francisco, USA
7. BS 8500, British Standards Institution
8. BS 5628: Part 2, British Standards Institution
9. BS 5628: Part 3, British Standards Institution
10. BS 8110: Part 1, British Standards Institution
11. BS 8110: Part 2, British Standards Institution
12. BS 8110: Part 3, British Standards Institution
13. BS 8007, British Standards Institution