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Newlands, Moray; Jones, Roderick; McCarthy, Michael; Dyer, Thomas; Csetenyi, Laszlo; Jozwik, Maciej

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Developing low-carbon concrete technology at Dundee

The Concrete Technology Unit (CTU) at the University of Dundee is working on a diverse range of projects with important end applications. Moray Newlands, Rod Jones, Mike McCarthy, Tom Dyer, Laszlo Csetenyi and Maciej Jozwik report.

Ongoing work with the Mineral Product Association (MPA), UK Quality Ash Association (UKQAA), Scottish Research Partnership in Engineering (SRPe) Innovate UK's Knowledge Transfer Partnership (KTP), Rock Solid Processing and Historic Environment Scotland is focused on the development and performance of low-carbon binders and aggregates for concrete. Separately, the CTU facilities and analytical skills are helping shape maintenance strategies for historic palaces and abbeys.

Manufactured pozzolans

The CTU is exploring the production of pozzolanic materials using hydrothermal techniques. Waste materials, plus a largely reusable alkaline activator, when combined with water in an autoclave and heated to temperatures of less than 200°C, are able to produce zeolites and similar compounds. These materials readily undergo a pozzolanic reaction in the presence of lime, leading to a contribution towards strength. While the temperatures involved mean the energy demand is relatively low, significant reductions are not realised as easily as might be anticipated: water has a high specific heat capacity, meaning that a large amount of energy is needed to raise its temperature.

As a result, much of the development work at Dundee has explored the extent to which water content, temperatures and manufacturing time can be reduced as much as possible. Suitable waste materials being explored include anything rich in silicates and aluminates, for example, lagoon fly ash, glass powder, clays unsuitable for calcining and incinerator bottom ash. Viable manufacturing techniques have now been established and the material's performance as a binder is being characterised.

Stockpile fly ash for use in concrete

With the gradual retirement of coal-fired power stations, there has been a growing interest in the use of stockpile fly ash for concrete. Stockpile storage areas exist, as supply has often exceeded demand, with estimates indicating that there is more than 100 million tonnes of material in the UK[(1)]. This represents a research area receiving increasing attention in recent years, where the effects of stockpile storage on fly ash properties have been identified. Processing, using drying/de-agglomeration and a range of techniques (particle size reduction/separation and carbon removal), shows that improved material performance, depending on the method used, is achievable[(2)].

Work funded by the UKQAA and SRPe is currently focusing on concrete durability, examining the main deterioration processes that can occur in structures, under both accelerated and normal-type exposure conditions. A particular aspect of this includes fly ash properties relevant to its use in air-entrained concrete[(3)] to resist freeze–thaw scaling. Studies on both laboratory-moistened and stockpile fly ash, covering foam index, specific surface area (SSA), dye adsorption and air contents in mortar have been carried out. These gave reductions in foam index, dye adsorption and increases in SSA and air content (at a fixed air-entraining admixture (AEA) dose) in mortar with wet storage, compared with dry fly ash. It appears that physical and chemical changes in fly ash with wet storage influence the effects observed. Processing (by drying and milling), which breaks down agglomerates and particles in fly ash, was found to give increases in AEA demand (by foam index). Research is on-going in this area, including studies on concrete and associated freeze–thaw scaling resistance.

Rapid assessment of low-carbon cements

Understanding the performance potential of low-carbon binders continues with work in progress, guided by the MPA and BRMCA, to examine the impact of elevated curing temperatures, towards providing a rapid assessment of a range of cement combinations now available to engineers and producers. As reported previously, the project showed that approximately 21 days of elevated temperature curing gives strength equivalent to 90-day standard cured concrete.

More recently, the project has compared the microstructure and pore solution of these concretes with different curing conditions across different water:cement (w/c) ratios and cement types (CEM II/B-V, CEM II/C-M(S-L), CEM VI (S-V) and CEM VI (S-L)). Figure 1 shows an example of SEM images for a CEM II/B-V at equivalent maturity, highlighting the similarity in qualitative microstructure. Similarities were also seen quantitively in measured total porosity of the concretes (small differences of around 2.5% between standard and accelerated curing) and size distribution of the pores, particularly at w/c ratios of 0.4 and 0.5. The project is now determining the influence of the pore structure and chemistry from standard and accelerated curing on durability performance of concretes including carbonation and chloride resistance.

IBAA as low-carbon aggregate

Work is continuing via the collaborative KTP with Dutch partner Rock Solid Processing and a local concrete processer, Collier. With the recent appointment of the KTP Associate, a comprehensive overview of the local and national market is underway as well as a review of the processing capabilities at two sites in Scotland (Goathill Quarry and Lower Melville Wood). Incinerator bottom ash (IBA) from several municipal solid waste incinerators across Scotland (including Aberdeen, Dundee, Grangemouth and Dunbar) is being processed on-site with ferrous and non-ferrous metals separated and bottom ash graded into size fractions for use in various end product markets (Figure 2).

Work is ongoing at the processing sites and in Dundee to examine the incinerator bottom ash aggregate (IBAA) characteristics with a view to monitoring variability of the incoming IBA from various sources and the influence of processing techniques on 0/4, 4/10 and 10/20 aggregate size fractions. Over the coming months, the project will be examining the effect of coarse IBAA variability and replacement level on key fresh concrete properties such as slump, flow and compactability, as well as plastic and hardened density. In addition, a parallel project is determining potential outlets for fine fractions (<2mm) of IBAA alongside rigorous environmental testing to ensure compliance with Scottish Environment Protection Agency standards.

Analysis of historic structures

Working with Historic Environment Scotland, the CTU is also using its specialist analytical skills and techniques in mercury intrusion porosimetry (MIP), and computed tomography (µCT), typically used to assess concrete micro-structure, by facilitating ongoing strategic planning for conservation work at Linlithgow Palace, Arbroath, Jedburgh and Kelso Abbeys. Sampling, testing and analysis techniques are being used to determine porosity of stonework to assess their condition and potential durability performance against wetting/drying and freeze–thaw conditions. A section from the arched entrance to the Great Hall in Linlithgow Palace was investigated to map its porosity at various depths. The results were compared with those of stone samples from Arbroath and Jedburgh. Mercury intrusion porosimetry was used, with further analysis of any additional debris undertaken by X-ray diffraction.

In general, a lower porosity within the stone gives better resistance to environmental weathering effects, which often also coincides with greater strength. Differences were noted for the Linlithgow stone compared with those from Arbroath and Jedburgh, with the latter more compact. Material at the exposed surfaces also had lower porosity compared with the bulk indicating weathering processes contributing to blocking of surface pores.

Conservation work at Kelso Abbey in Scotland is also using these techniques to evaluate whether Swinton sandstone could be applied as a proxy material where the original stone was missing or deteriorated. Tests on the original stone involved µCT scans of samples (Figure 3), with work underpinned by MIP tests on small fragments. The results revealed that the sandstones from Kelso Abbey and Swinton quarry were similar in terms of their internal structure, implying that they would perform the same way when exposed to the elements.

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3. MCCARTHY, M.J., HOPE, T.A. and CSETENYI, L.J. Wet storage effects on fly ash properties relevant to its use in air-entrained concrete. *Magazine of Concrete Research*, Vol.75, No.3, February 2023, pp.149–162.

[Figure captions]:
[Figure 1]: SEM images of 90-day standard cured CEM II/B-V concrete samples and the equivalent maturity samples cured at 50°C at 0.4 w/c.
[Figure 2]: On-site processing operations of IBA stockpiles to produce IBAA size fractions suitable for use in concrete.
[Figure 3]: µCT scan of sandstone samples from Kelso Abbey.

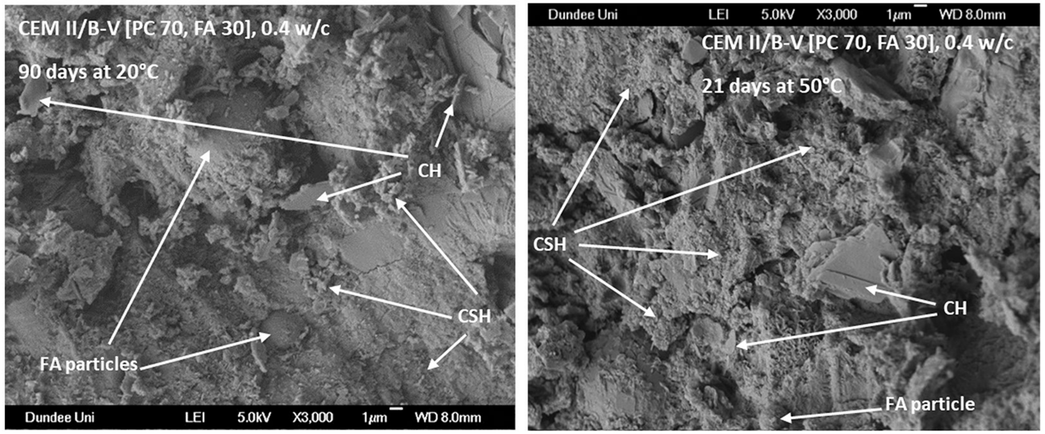

Fig 1 - CTU Dundee Uni.jpg

Fig 2 - CTU Dundee Uni.jpg

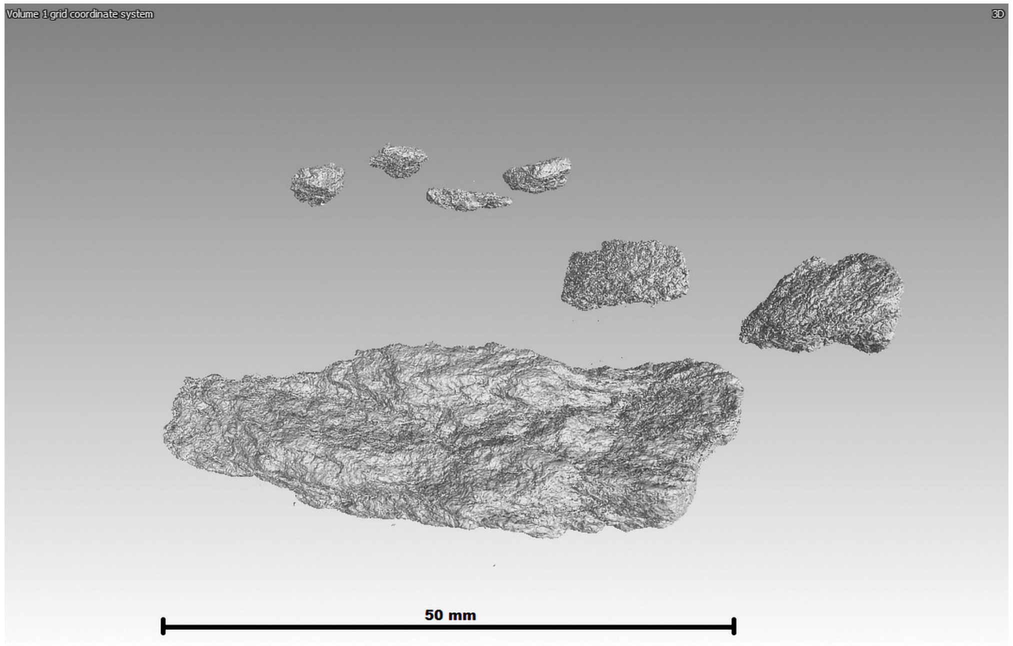

Fig 3 - CTU Dundee Uni.jpg