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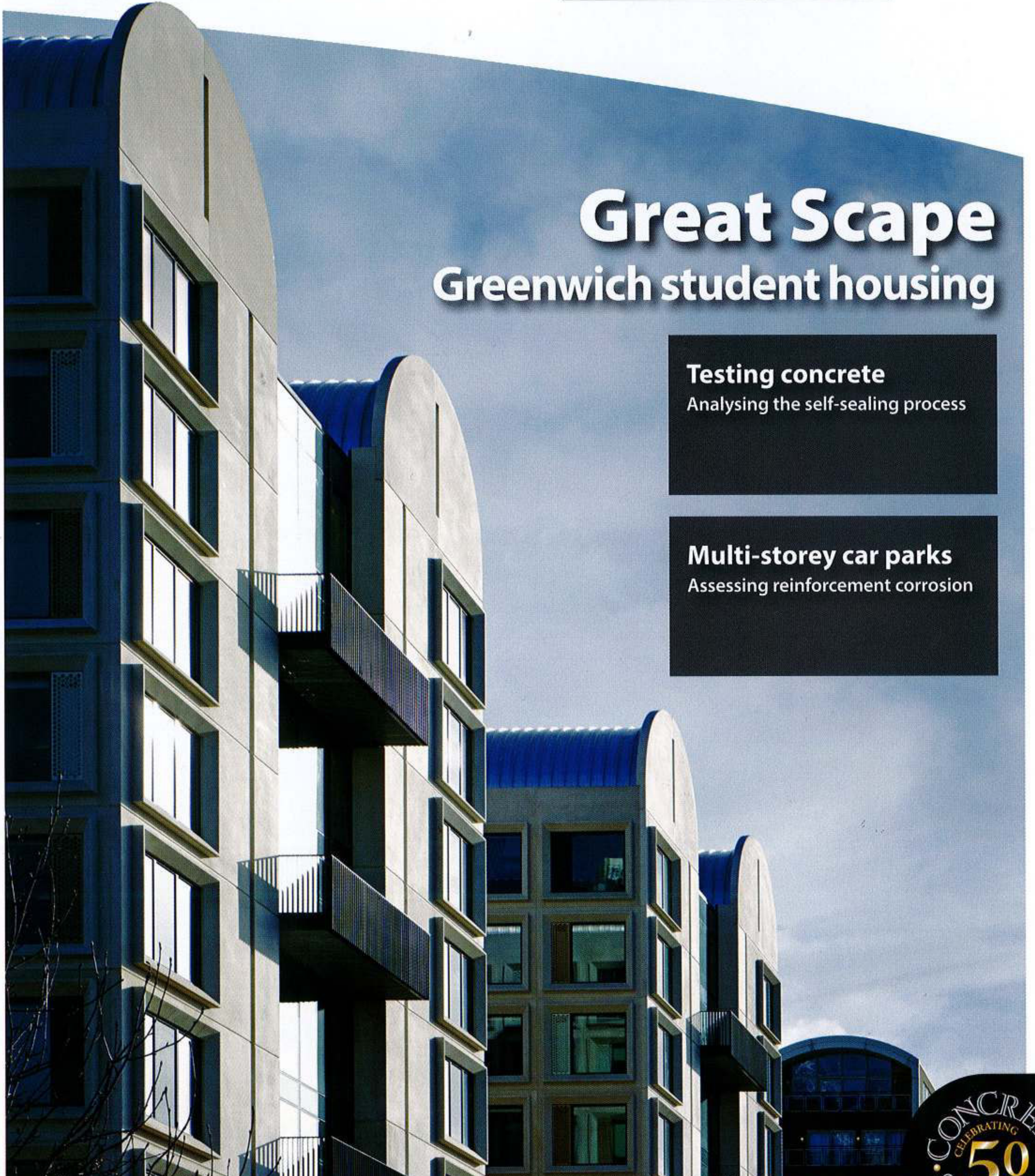

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Testing concrete
Analysing the self-sealing process

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CONCRETE SOCIETY CELEBRATING 50 YEARS

Characterisation of low-carbon AACM concrete and mortar

__Graeme Jones__ of __C-Probe Systems__ and __Paul Lambert__ of __Mott MacDonald__ discuss the testing of alkali-activated cementitious materials (AACM) for sustainable low embodied carbon concrete repair, strengthening, protection and new-build applications in the construction sector.

Issues of sustainability in construction and the drive to reduce CO_2 emissions are increasingly impacting on the choice of construction methods and materials. With their key role in most construction works, Portland cements – as used in grouts, mortars and concrete products – are an obvious area to target for possible full or partial replacement with potentially lower energy alternatives.

AACMs, such as geopolymers, show great promise as viable alternatives to Portland cements for use in concrete and mortar product formulations. These alternative binders can deliver equivalent and, in some instances, significantly better, characteristics with respect to compressive strength, adhesion, fire, chemical and mechanical resistance as reported by Mangat and Lambert(1).

Characterisation and durability data for a binder of this type have been obtained from work undertaken at Sheffield Hallam University over the past 20 years, through the support of C-Probe Systems and European research funding.

Alternative binders

This family of alternative binders consists of inorganic cements manufactured predominantly from recycled materials and industrial by-products in blended formulations designed to suit the working characteristics of the end product. When mixed with alkaline activators, these blends form the AACM binder that, together with conventional aggregate and reinforcement, produces concrete and mortar repair formulations for use on-site and in precast construction.

Once mixed and dependent upon the formulation, the Si-Al rich mix partially dissolves to form an amorphous gel. This is then triggered in the presence of calcium to form a crosslinked framework forming a cement phase of calcium silicate hydrates, calcium aluminosilicate hydrates and polysialate polymeric links. These reactions reduce the free water content and generate high alkalinity, resulting in materials with enhanced performance features such as tolerance to extremes of temperature, greater chemical resistance and avoidance of alkali–aggregate reaction. This can be achieved without any loss of the physical and mechanical characteristics associated with Portland cement-based materials and provides a hardened material with the benefits of ceramics and the versatility of concrete.

For an AACM concrete assessed in accordance with PAS 8820:2016(2,3), typical performance characteristics are as shown in Table 1.

Table 1 – Characteristics of AACM concrete

Property	Value (MPa)
Early compressive strength, 2d	34.0
Early compressive strength, 7d	49.0
Standard compressive strength, 28d	60.5
Early flexural strength, 2d	4.4
Early flexural strength, 7d	5.4
Standard flexural strength, 28d	6.4
Early tensile splitting strength, 2d	3.3
Early tensile splitting strength, 7d	4.0
Standard tensile splitting strength, 28d	4.9

Figure 1: AACM tunnel ring segments precast by Shay Murtagh Precast with steel fibres in the mix design.

On the basis of more extensive testing, there appears to be a correlation between binder content and strength. Figures 2 and 3 show the effect of increasing binder content on the compressive and flexural strength of AACM concrete.

Increasing the binder content has the effect of increasing the compressive and flexural strength. The linear relationship allows the simple formulation of a range of products from low-strength pointing mortars to high-strength concrete repair materials in addition to mixes suitable for precasting applications.

Shrinkage

Shrinkage, whether drying or autogenous, appears to be compensated for within the

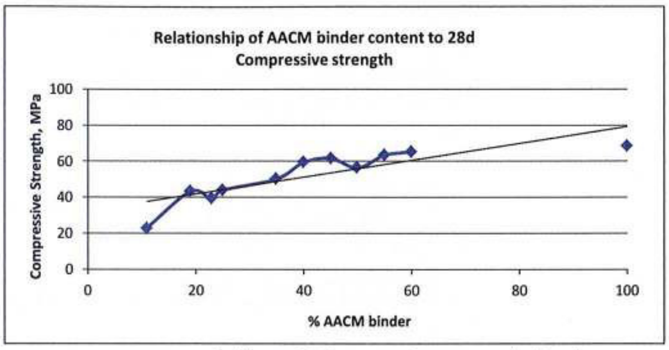

Figure 2: Compressive strength development with increasing binder content.

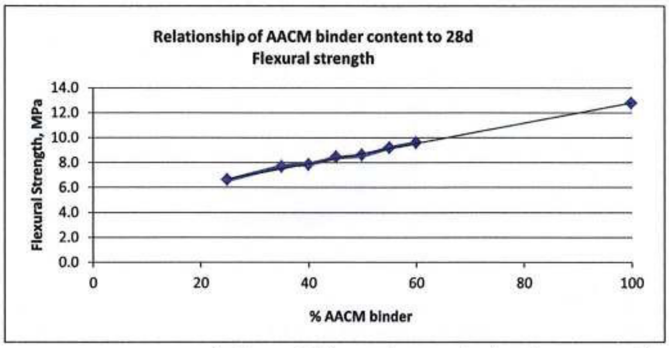

Figure 3: Flexural strength development with increasing binder content.

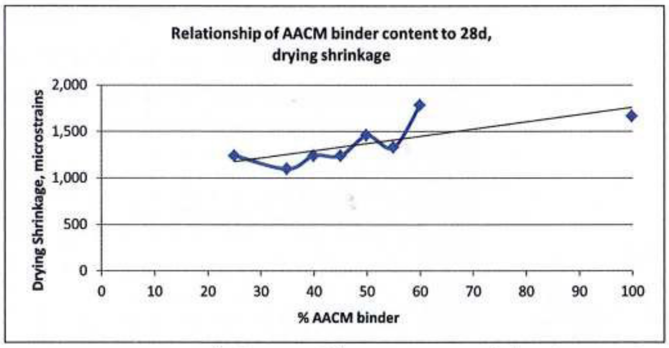

Figure 4: Effect on measured shrinkage with increasing binder content.

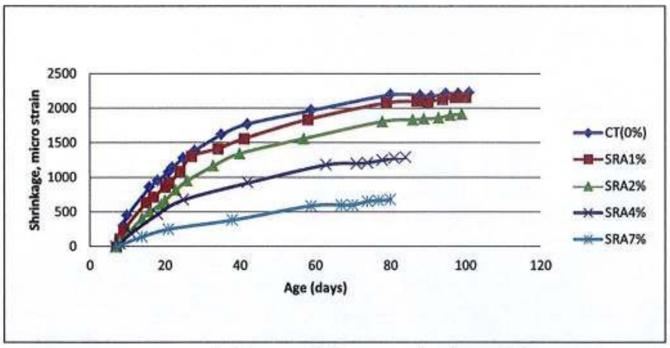

Figure 5: Effect on shrinkage of increasing SRA content in AACM concrete (CT refers to a control sample).

Figure 6: Concrete apron repair with AACM patch material after 12 months' exposure to weather and traffic.

hardened material. Figure 4 shows the effect of increasing binder content on the increase in micro-strain obtained from AACM mortar prisms. The measured micro-strain value might be expected to result in cracking of the mortar sample; however, even after 112 days when the measured value flattens out, the samples were still in good condition with no sign of cracking.

The micro-strain value can be controlled by adding shrinkage-reducing admixture (SRA) as shown in Figure 5, where increasing the SRA content from 0 to 7% results in a marked decrease in the measured shrinkage value. However, once again, no sample showed any signs of cracking, leading to the presumption that the material itself shrinkage-compensates on hardening.

Figure 6 shows the application of the material as a concrete repair mortar, used within an unreinforced parking apron after 12 months' service. The AACM mortar remained intact and well bonded, with no visible cracking around the perimeter or within the body of the repair.

Developments in the use of electrically conductive AACM have also seen the material used as a cathodic protection anode. Being able to tailor the compressive strength to suit the application means that applications for both heritage steel-frame buildings and reinforced concrete structures can be undertaken using the same basic material but with differing binder formulations to suit each purpose.

A study of the use of an electrically conductive additive with a range of AACM formulations, demonstrates how an inherently non-conductive material can be modified to act as an impressed current cathodic protection (ICCP) anode. Measurements of electrical resistivity of the material against increasing amounts

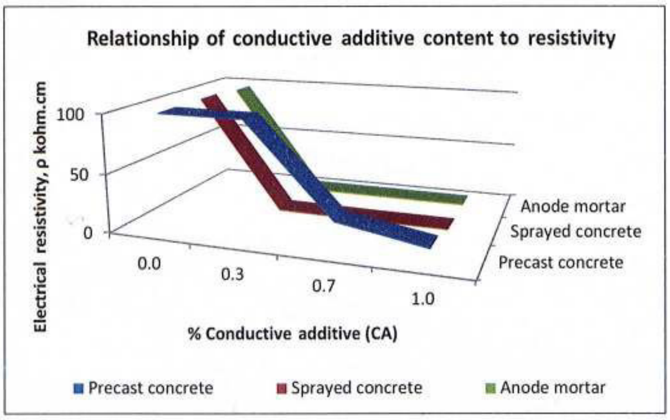

Figure 7: Effect on electrical resistivity of AACM with increasing conductive additive.

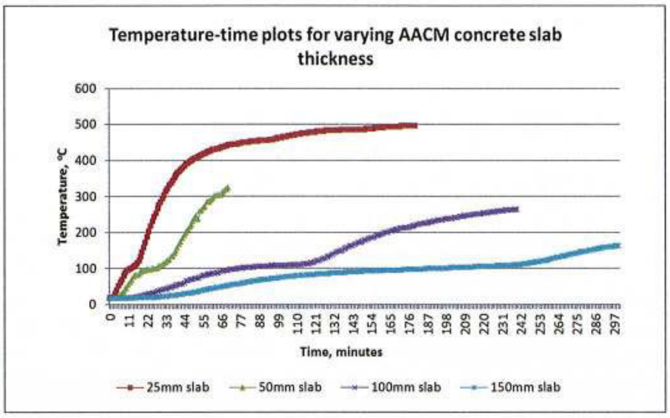

Figure 9: Temperature–time curves for AACM precast slabs of varying thickness.

Figure 8: Front entrance of the Commerce Bank in Kansas City following installation of the AACM geopolymer bed joint anode.

of conductive additive show a significant decrease in the measured resistivity in three AACM anode formulation variants: precast concrete, sprayed concrete and as a mortar. Varying the conductive additive from 0 to 1% within the AACM formulation has a significant effect, as shown in Figure 7.

The unmodified formulation (0%) provides a high electrical resistivity of around 100kohm.cm, dropping to 11kohm.cm for the precast concrete and to around 2kohm.cm for the sprayed concrete anode and anode mortar. This allows the materials to pass the low-voltage protection currents from ICCP applications, as well as enhancing the throw within galvanic anode applications, for example within concrete repair patches.

A number of commercial applications of AACM anode mortar have been carried out, including the use of combination galvanic and impressed anodes at a quayside in North Tyneside and heritage building applications in Leeds, York, Blackpool and Kansas City in the USA. In the Kansas City project, the low temperature tolerance of the AACM mortar was demonstrated by anode mortar application within stone bed joints at ambient temperatures as low as −15°C.

Fire resistance

This material has also been tested for fire resistance. Figure 9 gives temperature–time curves for four AACM precast slabs at 1100 × 1200mm footprint but at four different slab thicknesses. Each slab was tested at 1200°C for up to five hours in accordance with BS EN 1363-1(4). As would be expected, the thicker the slab the lower the heat transference through depth, with the 150mm slab transferring only 140°C to the unexposed side at the five-hour point. No slab disintegrated, although the 25mm slab did break on removal from the test rig.

AACMs offer the possibility of durable and sustainable alternatives to a range of conventional structural materials. Their ability to be modified to deliver specific properties means they can provide combinations of strength, heat resistance, chemical resistance and electrical conductivity, as may be required for both mainstream and niche applications.

Following the publication of PAS 8820(2), there is now a recognised framework within which to specify and demonstrate the suitability of such materials for numerous applications that would have been carried out previously by Portland cement-based materials. ■

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