

# Alkali-Activated Cements and Concretes – Durability Testing to Underpin Standardisation

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## ABSTRACT

*Alkali-activated cements, including 'geopolymer' materials, are now reaching commercial uptake in the UK and elsewhere, providing the opportunity to produce concretes of good performance and with reduced environmental footprint compared to established technologies. The development of performance-based specifications for alkali-activated cements and concretes is ongoing in many parts of the world, including in the UK where the world-first British Standards Institute (BSI) Publicly Available Specification PAS8820:2016 has been published to describe these materials and their utilisation. However, the technical rigour, and thus practical value, of a performance-based approach to specification of novel cements and concretes will always depend on the availability of appropriate and reliable performance tests. This paper will briefly outline the requirements of PAS8820, and discuss the activities of RILEM Technical Committee 247-DTA in working to validate durability testing standards for alkali-activated materials, bringing scientific insight into the development of appropriate specifications for these materials.*

**Keywords:** alkali-activated cementitious materials; durability; testing methods

## 1.0 INTRODUCTION

If the world is to meet its designated and agreed targets for the reduction of emission of atmospheric pollutants, including but not limited to carbon dioxide, it is essential that every industry sector contributes effectively to reduction of emissions. Established technologies will need to be reassessed, and supplemented with newly developed and/or existing alternatives, to meet demand in a way which enables and underpins global sustainable development (Meyer 2009; Habert *et al.* 2010; Flatt *et al.* 2012; Scrivener *et al.* 2016; Miller *et al.* 2018).

Concrete is the world's most widely used material, and probably also the most misunderstood. The erroneous stereotype of concrete as a 'low-tech', dirty, grey material, used to produce unattractive, inexpensive structures, has pervaded much of global society (Boch *et al.* 1999). However, concrete provides reliability and dignity in housing and infrastructure to developing and developed areas of the world, underpinning the modern built environment. The value of the global construction materials market will exceed €1000 billion by 2020 (Statista 2017), more than 13% of global GDP (Reuters 2011). The basis of this enormous contribution is concrete produced from Portland cement, but this comes at an environmental cost: around 8% of global CO<sub>2</sub> emissions are due to the manufacture of the 4 billion tonnes of cement used each year (Olivier *et al.* 2012; Scrivener *et al.* 2016), and this figure is increasing as other areas of society

decarbonise while cement demand grows (Provis 2014).

Production of 1 tonne of Portland cement releases ~800 kg of CO<sub>2</sub>, and over half of this emission is due to the decomposition of limestone during manufacture of cement in a kiln at ~1400°C. This process is already operated in industry at a very high thermal efficiency, so it is unlikely that the full scope of necessary savings can be achieved simply by updating and improving the current established processes. Important work is being conducted in the improvement of high-volume Portland cement blends (Scrivener *et al.* 2016), but if the broader construction materials sector is to play its part in the decarbonisation of modern society, it is essential that all possible options are explored and developed to the greatest degree possible (Imbabi *et al.* 2012). This will include blended Portland cements (Scrivener *et al.* 2018), cements based on innovative clinker types (Gartner and Sui 2018), as well as non-clinker based cements such as alkali-activated materials ("AAMs") (Provis 2018). The latter will be the main focus of this paper; these cements are further developed in an industrial sense than most of the other non-Portland systems proposed for high-volume industrial deployment, and are now in the early stages of the standardization process in a number of jurisdictions.

It should also be noted that it is essential not only to use better cements, but also to use cements better: unless concretes can be designed for durability (Hooton and Bickley 2014) and without excessive cement content (Wassermann *et al.* 2009; Damineli

*et al.* 2010; Damineli and John 2012). If cement cannot be used efficiently to make high quality concretes, much of the underpinning work in cement design would be wasted. Nonetheless, and given that improvements are needed at every stage of the process from raw materials via cements to concretes, it is essential that new and innovative cements are developed, tested and validated.

In the future toolkit of cement technologies required to meet emissions targets, there will not be a 'one size fits all' solution that replaces existing technology in a global context. A large amount of research has been dedicated to blended Portland cement-based concrete based on the proposal that this is, on a global average and considering raw materials availability, the only class of materials that can be deployed at sufficient scale to meet industry needs (Scrivener 2014; Provis 2015; Scrivener *et al.* 2018).

However, it is essential to note that the overall global perspective is not actually the *average* of a large number of local scenarios, but rather it is the *sum* of a large number of local scenarios. In many of these local regions and contexts, the availability of suitable precursors for alkali-activated cements (e.g. fly ash in countries with a high dependency on coal for electricity generation, or clays or slags in other locations) is high (Bernal *et al.* 2016; Criado *et al.* 2017), and activators can be sourced at appropriate scale to enable AAMs to be produced and used in a meaningful way. This is not the case in every location worldwide, but there are enough locations where this is a truly attractive local option to justify investment and interest in research and development into these materials as part of the global toolkit of cementitious materials that are available for selection and use in sustainable construction.

## 2.0 PATHWAYS TO STANDARDISATION

For this and other reasons, there is significant ongoing interest in the development of standards and specifications for alkali-activated cements and concretes (Van Deventer *et al.* 2013; Kavalerova *et al.* 2014; Ko *et al.* 2014; Hooton 2015; van Deventer *et al.* 2015; Provis 2017). As a world-leading step in this direction, the British Standards Institute has released a Publicly Available Specification, PAS 8820:2016 (British Standards Institute 2016), which defines a performance-based testing approach, allowing the use of innovative materials without imposing a prescriptive set of restrictions on cement selection or mix design as is the case in the current British Standards for concrete, e.g. BS 8500 (British Standards Institution 2012).

In PAS 8820:2016, it is specified that a candidate alkali-activated concrete should be tested in parallel with a reference concrete designed to meet the requirements of the established British standard BS 8500 for the intended exposure class. The candidate alkali-activated material must "*meet or exceed the*

*performance of the reference concrete in each case, within testing precision.*" Some of the subtleties inherent in this statement will be addressed in more detail below.

This parallels to some degree the Equivalent Durability Procedure (European Committee for Standardization (CEN) 2013b) which is applied in many European nations (not including the UK) alongside the EN 206 concrete standard (European Committee for Standardization (CEN) 2013a); in PAS 8820, the reference material is a concrete which exceeds the basic mix design requirements specified in BS 8500 for the design exposure class, cover depth and service life (i.e. 8 MPa higher in compressive strength and 0.02 units lower in water/cement ratio than the basic limits), but with the added specification in PAS 8820 that the reference concrete should also be produced to '*maximise chemical similarities*' between the two concretes. This would, in a practical sense, often be achieved by using as high a fraction as possible of the same supplementary cementitious constituent as is used in the alkali-activated concrete. This is intended to bring the chemically-controlled aspects of degradation of the two materials as close as possible to parity.

Such a performance-based approach, applied at both cement and concrete levels, is significantly more constrained than the (extremely broad) approach to performance-based standardisation embodied in ASTM C1157 (ASTM International 2017a), which contains only very limited restrictions and requirements in cement testing (with set numerical pass/fail criteria rather than the use of comparative performance testing) and does not extend to a concrete level. There are clear advantages and disadvantages to both pathways; the PAS 8820 approach has the advantage that it is necessarily a conservative philosophy in terms of requiring high material performance through the use of a well-performing reference concrete, while still allowing for innovation. The comparative method also avoids the need to carry out a suite of tests to set required minimum performance levels in each of a large set of tests, for each exposure class in which the materials might be used; this would be time-consuming and costly.

However, the use of the reference concrete method does implicitly embody the assumption that a given measured performance level in a specific laboratory test can translate to a similar level of field performance, when comparing Portland-based and alkali-activated concretes. This may not necessarily be the case, particularly for accelerated testing methods in which the test conditions applied to the alkali-activated concretes are significantly different from the natural exposure environment, e.g. accelerated carbonation at very high CO<sub>2</sub> concentrations (Bernal *et al.* 2012), or electrically accelerated chloride testing where the chloride movement is inferred from charge passed or other

electrical properties (Bernal *et al.* 2014). This class of tests, described by Scherer as ‘*overload tests*’ (Scherer 2012), must always be applied with great care and based on a fundamental understanding of the physicochemical processes that actually control material degradation and failure. Otherwise, it is very possible that an accelerated test in fact ends up asking the wrong question – and a correct answer to the wrong question may turn out to be more damaging or misleading, in terms of practical material application – than even a partially correct answer to a better-posed question. Ongoing work in RILEM Technical Committee 247-DTA, including a recently-concluded round robin testing programme which has assessed the validity of different durability testing methods in the analysis of alkali-activated concretes, is intended to underpin and improve the ability to select the most appropriate tests; see the next section of this paper for further discussion.

As a starting point, the philosophy used in the construction of PAS 8820:2016 was to use non-accelerated tests (e.g. chloride diffusion testing by ponding; carbonation under natural conditions) wherever possible. This does bring the intrinsic disadvantage that such tests are slow, taking at least several months of exposure before samples can be analysed and performance levels determined. However, there is an intrinsic trade-off between ‘fast’ and ‘correct’ in the design of durability testing methods to appropriately represent natural exposure which would take place over a period of decades or more (Pommersheim and Clifton 1985). The now-withdrawn ASTM Standard Practice E632-82, describing a methodology by which accelerated tests of building materials may be designed, includes the exhortation to “*take care to ensure that extreme levels of degradation factors do not result in degradation mechanisms that would not be experienced in service*” (ASTM International 1982). Although that standard is no longer in force, its advice remains both current and salient, particularly when considering tests that involve acceleration of chemically-induced degradation by increasing concentrations of aggressive agents to a degree which may change the fundamental thermodynamics and phase relationships that control the degradation process itself (Glasser *et al.* 2008; da Silva *et al.* 2009; Bernal *et al.* 2012; Bernal *et al.* 2015).

For materials suppliers and clients who do have a strong preference for preferred alternative test which is faster and/or more convenient, PAS 8820 offers the scope for various accelerated methods to be selected and used in place of the specified tests, by mutual agreement between all parties. However, the need to conduct comparative tests against a reference concrete is retained in all such cases.

As noted above, a further point to consider in the practical implementation of a comparative testing programme such as this, is the precise definitions of the concepts of ‘*meet or exceed*’ and ‘*testing*

precision’ as they relate to the reported material performance (or, more precisely, specimen performance) under application of each of the tests. Although some testing methods, particularly those published by ASTM International, include explicit statements of ‘precision and bias’ as defined in ASTM E177 and C670 (ASTM International 2014; ASTM International 2015), this is not universally the case, and where such information does exist, it is usually based on results obtained for samples based on plain Portland cement mixed and cast under very controlled laboratory conditions. A recent French multi-laboratory study (Ait-Mokhtar *et al.* 2013) using a very large number of samples cast from single batches of industrial concrete based on a CEM III (according to EN 197-1 (European Committee for Standardization 2011)) high-slag cement showed degrees of scatter in test results which are much higher than those defined in ASTM test methods, for example a coefficient of variation in 28-day compressive strength of 11.3% (Ait-Mokhtar *et al.* 2013), compared to the value of 5.0% given in ASTM C39 from an inter-laboratory test of lab-cast Portland cement concretes (ASTM International 2018).

The situation becomes even more complex for durability tests for which precision and bias statements do not exist in the standard documents (e.g. ASTM C1543 for chloride ponding (ASTM International 2010), NordTest NT Build 492 for chloride migration (NordTest 1999), or the draft European standard DD CEN/TS 12390-10 for relative resistance to accelerated carbonation (European Committee for Standardization (CEN) 2007). In such cases, the material producer and the specifier must agree on what is meant by ‘equivalent’ when the performance levels of candidate and reference specimens are compared according to each particular test. This may require more extensive replicate testing programmes and statistical analysis to be conducted, to define the within-laboratory and between-laboratory precision achieved for each test for each particular type of concrete. An explanatory note in the text of PAS 8820:2016 states that there is an “*absence of extensive data describing the correspondence between laboratory test results and field performance*”, and that “*there is a clear and direct need for such data to be... made available*” (British Standards Institute 2016). This is self-evident, yet doubtless labour-intensive and potentially costly, so unfortunately such an exercise has not yet been undertaken by the research or industrial community who are active in this area.

### 3.0 SELECTION AND DESIGN OF TESTS

To obtain a useful answer in any field of endeavour, it is obviously essential to first ask the correct question. However, this principle is in many cases lost in the design and application of accelerated durability test

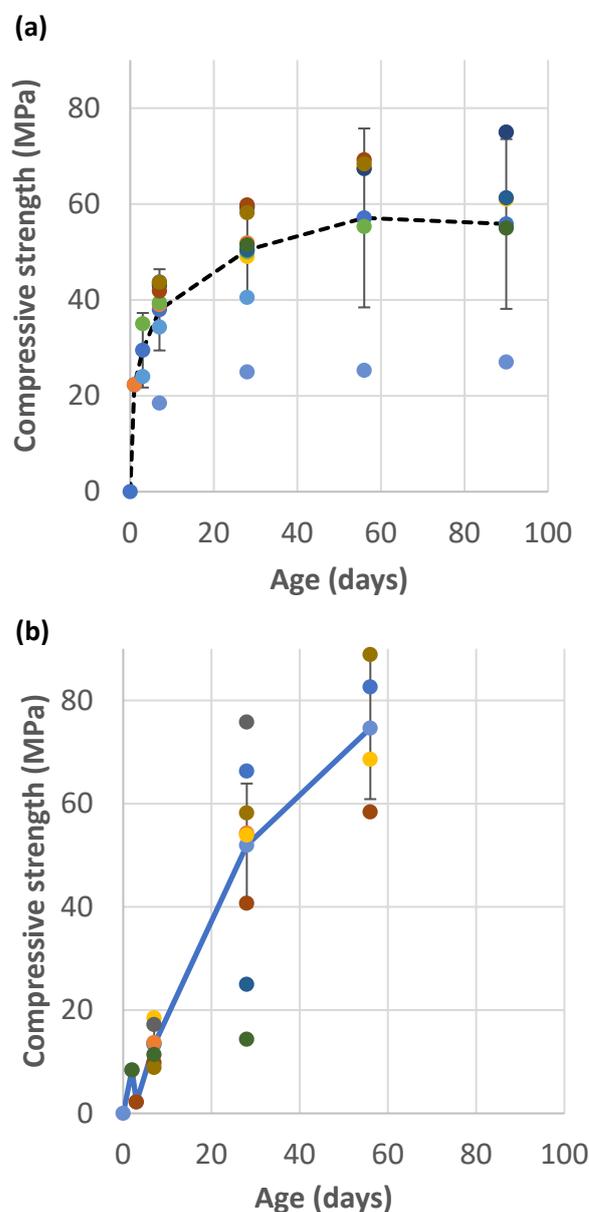
methods, where unanticipated – and sometimes perverse - outcomes can be reached when specifying cements or concretes based on tests that do not replicate appropriately the conditions in which the materials are intended to serve (Page 2012). Note that ‘appropriately’ is used here rather than ‘accurately’, as no accelerated test can ever accurately represent service conditions in all ways. However, with knowledge regarding which ways, and to what extent, the test conditions diverge from reality, the test outcomes can be interpreted and understood, then used to provide meaningful recommendations even if there are aspects of the physics, chemistry or engineering of the test itself which diverge from what would be experienced in service. This is the entire basis of accelerated testing: how can exposure to damaging environments be accelerated to an accessible laboratory timescale, while still providing useful, and useable, information to guide materials selection?

For the specific case of alkali-activated concretes, this question has been addressed during the past 5 years through a round-robin testing programme conducted by RILEM Technical Committee 247-DTA. Through this programme, an interlaboratory comparison of various accelerated and non-accelerated durability tests has been undertaken, investigating the methods that are available for the analysis of chloride ingress, sulfate attack, carbonation, alkali-silica reaction, and freeze-thaw/frost-salt processes in alkali-activated concretes. Selected test methods were applied to concretes produced from alkali-activated binders based on blast furnace slag, on fly ash, and on calcined clay, each activated by sodium silicate solution, and with the precursor powders each sourced from a single source and shipped to all test participants. For the slag-based and fly ash-based mixes, concretes were designed with intended ‘high’ and ‘moderate’ performance levels, to define whether the testing methods were able to distinguish between these different mixes. The focus of the work was not to identify which alkali-activated material is better under given conditions, or to prove anything in particular about the durability of the materials themselves (as generic, simple mix designs were intentionally used in all cases). Rather, the focus is to ‘test the tests’, and to understand whether standardised accelerated methodologies designed for Portland cement-based concretes can give meaningful outcomes when applied to these non-Portland materials.

The round-robin work of RILEM TC 247-DTA is nearing its conclusion, but the following findings obtained to date are worthy of note:

### 3.1 Strength and workability in round-robin testing

Figure 1 shows that there is, according to the results of this RILEM round robin test, significant variability in strength and in workability between alkali-activated concrete mixes produced using the same binder chemistry but different aggregates.



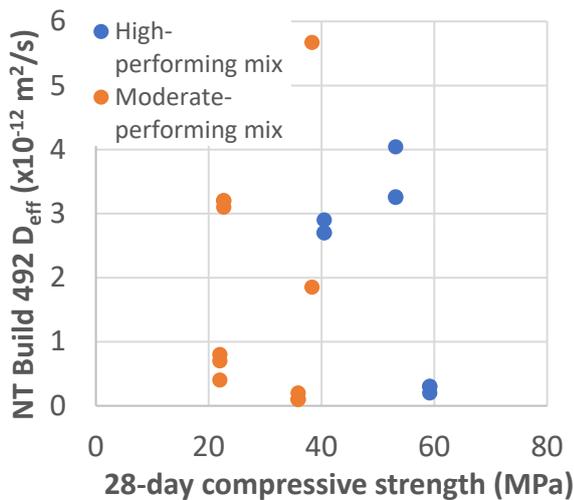
**Fig. 1.** Compressive strength test results from participating laboratories in the RILEM TC 247-DTA round-robin test: (a) one of the concrete mixes based on ground granulated blast furnace slag; (b) one of the concrete mixes based on fly ash

In each case in Fig. 1, each individual point represents a single sample, colour-coded by the

identity of the lab that conducted the test. All concretes in each set have the same binder composition and mix design, but were produced with locally available aggregates, targeting as similar a grading curve as was feasible. The dashed line represents the mean of all results received, with error bars showing one standard deviation either side of this mean. In each case, a small number of laboratories reported zero strength results as they found the mixes to be unworkable for casting (due to poor rheology for one lab testing the slag-based mix; due to flash setting for one lab testing the fly ash-based mix); these results are not shown.

### 3.2 Chloride

The deviation in strength results between laboratories does not appear to have translate directly into differences in performance levels in durability tests, which in many cases relate more closely to basic mix design parameters than to strength. Figure 2 highlights this for the case of accelerated chloride migration coefficients determined for two different alkali-activated blast furnace slag concretes, which clearly do not correlate to the compressive strength results obtained for the same concretes in the same laboratories.



**Fig. 2.** Correlation (or lack thereof) between 28-day compressive strength and 28-day effective chloride migration coefficients obtained from the NordTest NT Build 492 electrically accelerated method (NordTest 1999), for two different alkali-activated concretes based on ground granulated blast furnace slag, in four different laboratories, in the RILEM TC 247-DTA round-robin test programme

In fact, for the slag-based mixes in this test programme, the mixes designed for ‘moderate’ performance (and thus with lower compressive strengths) on average outperformed the higher-strength mixes in both the chloride diffusion and migration testing, possibly because higher strength was achieved in this instance through the use of a higher paste volume. Although the majority of

prescriptive standards and codes conflate (explicitly or implicitly) the ‘quality’ of concrete as measured by compressive strength and by durability, this has for some time been known to be incorrect and misleading; it is worthwhile to recall the comments of Neville in this regard, “*strength and durability are two separate aspects of concrete: neither guarantees the other*” (Neville 2001). In that paper, Neville noted that 28-day compressive strength and durability probably ran well in parallel for concretes produced up to 1970, but less so since then; the extension of the definition of ‘concrete’ to include alkali-activated materials produced without the addition of Portland cement means that the relationships deviates even further from the simple historical assumption that strength and durability must run hand-in-hand, as evidenced by the results of this RILEM round-robin test.

The chloride diffusion and migration tests applied in this testing programme (NordTest methods 443 and 492, respectively) generally appeared to give trends that align well with each other. However, the ASTM C1202 “rapid chloride penetration test” (ASTM International 2017b) is not at all recommended for application to alkali-activated concretes as it gives scattered and unreliable results, as exemplified by the data presented in Table 3.

**Table 3.** ASTM C1202 charge passed results obtained in three different laboratories for multiple replicate samples of two different alkali-activated concretes based on alkali-activated slag, designed for ‘moderate’ and ‘high’ performance levels, measured at different ages.

Design mix performance level	Age (days)	Charge passed (C)
<b>Lab B</b>		
Moderate	28	221
Moderate	28	214
Moderate	28	216
<b>Lab C</b>		
Moderate	28	416
Moderate	28	631
Moderate	28	783
Moderate	56	673
Moderate	56	583
Moderate	56	547
High	28	1061
High	28	864
High	28	1115
High	56	959
High	56	831
High	56	863
<b>Lab K</b>		
Moderate	28	1261
Moderate	90	1292
High	28	3956
High	90	2607

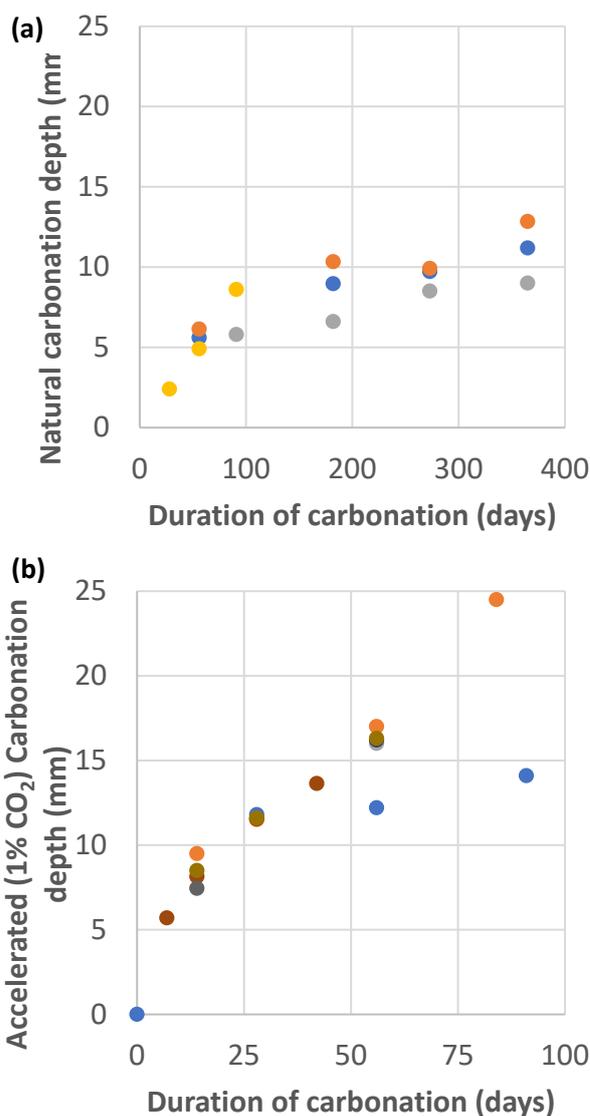
The results in Table 3 do not show any consistency in trends or values between labs, beyond the fact that the 'high performance' alkali-activated slag concrete mix, which has both a high paste volume and also a high activator dose, appeared to allow more charge to pass than did the concrete of moderate performance. This shows that the higher alkali mobility related to the very high ionic strength in the pore solution of the high-performing concrete has led to a clear difference in the C1202 test results. However, other than this, there is not any evidence of useable information in the data presented in Table 3; the results for a single sample (28-day, moderate performance) vary by a factor of 5 between laboratories, multiple replicates tested in one laboratory have almost 100% difference between lowest and highest values obtained, the refinement of pore structure with ageing that is known to take place in alkali-activated slag paste (Provis *et al.* 2012) is not reflected in the charge-passed data, and the high-performing mix was found by lab K to have performance falling in the 'moderate to high' charge passed region, which contrasts with the low to very low migration and diffusion coefficients determined for this concrete by both NordTest methods that were applied. For these reasons, the validity of the ASTM C1202 test as applied to alkali-activated concretes should be called into serious question.

### 3.3 Carbonation

Figure 3 shows the test results obtained for the 'moderate' performance alkali-activated slag concrete under natural and accelerated (1% CO<sub>2</sub>) carbonation exposure. In this section, all samples were cured under sealed conditions for 28 d prior to the start of carbonation exposure, and this curing period is not included in the 'duration of carbonation' time shown in the graphs.

The reproducibility of these results is very good considering that (a) the strengths differed significantly between participating laboratories (Figure 2), and (b) Figure 3a includes natural carbonation data collected under both indoor and sheltered outdoor conditions. For comparison, Aït-Mokhtar *et al.* determined coefficients of variation of 12-37% in accelerated (50% CO<sub>2</sub>) carbonation data from industrial single-batch blended Portland cement concretes (Aït-Mokhtar *et al.* 2013) under controlled laboratory conditions.

Accelerated carbonation testing at 1% CO<sub>2</sub> appears to be a good compromise between achieving realistic chemical effects in alkali-activated concretes - and thus trends that compare to natural carbonation - and reaching a useful test result in an accessible timeframe. The trends in carbonation rates between each pair of concrete mixes (i.e. concretes produced with the same precursor and different design performance levels) at 1% CO<sub>2</sub> were consistent with the expectations based on the mix designs, and also

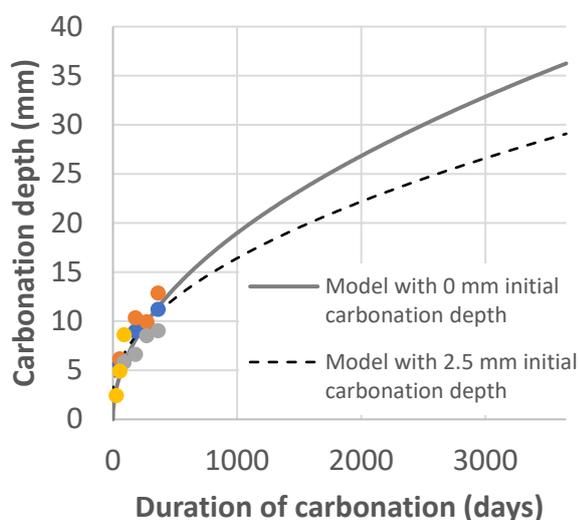


**Fig. 3.** Carbonation depths measured for the alkali-activated slag concrete designed for 'moderate' performance, under (a) natural and (b) accelerated (1% CO<sub>2</sub>) conditions. As in Figure 1, each colour represents results reported from a particular laboratory

with the rankings based on natural carbonation data. Tests for natural carbonation conducted under outdoor conditions raise further questions (and the need for more detailed investigations) regarding the link between exposure to unsheltered weather conditions (e.g. rain that can wash alkalis out from the concretes) and carbonation rates.

The natural carbonation data also appear in some cases to show an initial 'skin' of carbonated material that appears as a non-zero carbonation depth at time zero, which needs to be taken into consideration when fitting mathematical relationships to predict future carbonation depths. If a model is fitted using the assumption of a zero initial carbonation depth, the data would appear to indicate a significantly greater carbonation depth after several years in service, than would be predicted if a non-zero initial carbonation

depth is used in calculations. This is shown in Figure 4, where the same data as in Figure 3a (for up to 1 year of natural carbonation) are re-plotted along with two simple square-root time models (i.e. assuming pure diffusion control): one assuming zero initial carbonation depth, and the other with an initial carbonation depth of 2.5 mm based on curve-fitting to the experimental data. This shows a difference of ~8 mm in the predicted carbonation depth after 10 years, based simply on this difference in the assumptions about any carbonation taking place before the start of the test period (i.e. during casting and curing). This result shows that it is imperative to carefully consider this early time period when formulating any service life prediction models for alkali-activated concretes, which appear to be prone to skin carbonation at early age (i.e. in low-maturity samples).



**Fig. 4.** Extrapolation of Figure 3a to predict 10 years' natural corrosion, based on different assumptions about initial carbonation depth, and assuming diffusion control of carbonation rate

### 3.4 Other modes of degradation tested in this round-robin testing programme

For logistical reasons, the other areas of testing in the RILEM round-robin test found fewer participants and less directly comparable data, but some preliminary conclusions can be drawn from these results (which are undergoing ongoing analysis and interpretation), as follows:

Exposure to sodium sulfate did not cause significant expansive damage to any of the materials tested under any of the testing regimes applied, although magnesium sulfate caused some chemical degradation and loss of strength. The definition of the 'zero' point for expansion measurements

In alkali-silica reaction testing, the presence of very high concentrations of alkalis within alkali-activated concretes (and mortars) did not appear to induce any untoward expansive reaction of the aggregates – i.e., aggregates of 'normal' reactivity did not become

problematically reactive in these materials. When known reactive aggregates (e.g. Spratt crushed limestone) were used, some expansion was observed in mortar bar tests and in concrete tests, but probably not exceeding the levels expected for blended Portland cements containing the same aggregates.

Salt scaling tests on non-air entrained alkali-activated concretes showed significant damage, as expected for mixes without designed-in protective air void systems. Freeze-thaw testing in the absence of salt gave better behaviour, but more work is still needed to validate both materials and test methods for the study of this mode of attack in particular.

### 3.5 Overall round-robin test outcomes

The outcome of this round-robin testing programme is largely an exhortation to further analysis, rather than providing definitive answers to any of the core questions posed. The appropriate selection and implementation of accelerated durability testing methods for alkali-activated concretes – and, by the same token, for other concretes such as high-volume blends including some Portland cement along with dominant fractions of supplementary cementitious constituents – remains a work in progress, but it is only through this type of concerted effort that cross-validation of methods can be developed to the point where the community has confidence to use the results to underpin standardisation. This is a challenging and long-term aim, and needs to be extended further to account for multiple simultaneous modes of attack and degradation under truly realistic service environments (Holt *et al.* 2015), but is both a necessary and desirable goal if we are to look toward a future society which has a sustainable supply chain of high-performing, durable infrastructure materials.

## 4.0 CONCLUSIONS

When working to solve a global problem such as atmospheric pollution, it is essential to develop a toolkit of solutions that is as diverse as possible, to enable the most suitable solution to be developed in each specific local scenario and context. It is implausible that alkali-activated materials – or any other single type of alternative cement – will replace the majority of Portland cement usage globally. These materials are certainly promising and are already being deployed at scale in different parts of the world, but the fact that established practices, economies of scale in production, and entrenched industry attitudes strongly favour 'familiar' materials, mean that bulk uptake of a new material will inevitably meet challenges that are beyond the purely technical. However, such challenges should not be seen as an excuse to not pursue the uptake of these materials in the many places, contexts and applications where they can offer desirable performance characteristics, at an affordable cost, from local resources and with an attractive environmental emissions profile. As part

of a global toolkit which is based on appropriate local solutions, alkali-activation clearly offers the opportunity to contribute to meeting societal needs for construction materials, while reducing the environmental footprint of the sector as a whole. When put into appropriate and effective application, alkali-activated materials can offer excellent performance at an affordable cost, and are now being led into standardisation processes to enable and underpin their broader uptake. This standardisation needs to be based on the scientifically sound selection of test methods to assess and classify material performance, and this is a strong prerequisite for any performance-based standardisation process.

The intra-laboratory reproducibility of many tests is excellent, but inter-laboratory comparisons are more problematic, particularly for highly accelerated methods. Longer-term testing gives results that compare better across different participating laboratories in most cases. The present level of knowledge of test methods and their application to alkali-activated concretes does not allow this to be implemented on the basis of encoding particular performance levels into standards and designing materials to meet specific numerical outcomes in given tests. However, work in this regard is ongoing, and in the interim, comparison of test results against the results obtained for Portland cement-based concretes of known acceptable performance under similar exposure conditions may be a largely acceptable (although sometimes time-consuming) alternative.

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