

A Preliminary Investigation into Geopolymer Cement Mortar's Suitability for Providing Resilient Highway Solutions

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ABSTRACT

Despite local and national road authorities striving to provide motorists with a durable and safe infrastructure environment, one in six UK roads are currently classed as being in poor condition. In terms of safety, Department for Transport statistics continue to report high numbers of road fatalities; 1,780 in 2015, representing a 3% increase from the previous year. As such, research focused on developing resilient and cost effective planned/preventative highway maintenance solutions remains highly topical. Reported in this paper is research aimed at developing high performance, low impact solutions for both highway repair and skid resistance enhancement. A metakaolin/alkali silicate-based geopolymer cementitious mix design investigation is initially reported, providing key fresh and mechanical material properties such as setting time and compressive/flexural strength. Using favourable mix designs, the paper presents an assessment of geopolymer cement mortar's suitability as a highway repair material. To this end, wear and skidding resistance characteristics of potholes repaired with geopolymer cement concrete is reported, with initial findings suggesting excellent performance levels. Finally, the paper examines the potential use of a geopolymer cement mortar-based artificial aggregate as a cost-effective alternative to calcined bauxite for high friction surfacing applications. The results of this phase of the work show potential for geopolymer application, although ongoing optimisation research is required.

Keywords: Geopolymer cement; road maintenance; permanent road repair; high friction surfacing.

INTRODUCTION

Well maintained, safe and fully functional highway infrastructure is central to global economic competitiveness. Despite this fact, infrastructure assets are routinely overlooked in terms of investment, modernization and technical advancement, with significant social and economic implications. In the UK, for instance, the economic impact of infrastructure quality levels falling short of other developed economies is predicted to be around £90 billion by 2026 (CECA, 2013). In terms of the UK highway infrastructure network alone, the estimated one-time maintenance catch-up cost of rectifying this situation is estimated to be £12.06 billion (ALARM, 2017). This figure reflects the fact that more than one in six UK roads are reported to be in poor structural condition and with less than five years of life remaining. Defects such as potholes are prevalent; 1.7 million were repaired in England and Wales alone during 2016 at a cost of £102.3 million (ALARM, 2017). With the cost of repairing defects such as potholes around a third more when undertaken reactively rather than proactively, planned programmes of highway repair are preferable for maintaining agencies (ALARM, 2017).

Geopolymer cement-based materials have a potential role to play in future road repair and

upgrade programmes given their established environmental and performance credentials (McLellan et al., 2011; Davidovits, 2013; Banah, 2014), as well as the emergence of codes covering their properties and use (BSI, 2016). Indeed, previous research investigating the use of geopolymer cement-based products in patching or road repair solutions has generally yielded positive findings. This work has predominantly focused on mechanical properties of geopolymer cement mortar or concrete properties such as compressive and bond strength (Alanazi et al., 2016; Zanutto et al., 2017), however, and limited work investigating performance of materials exposed to live or accelerated simulated trafficking exists currently.

Concurrent to a need for effective highway repair solutions, maintaining appropriate pavement friction levels at critical locations is central to the safe and uninterrupted flow of traffic on highway infrastructure. In the U.S., for instance, despite horizontal curves making up only 5% of all highway miles, more than 25% of fatal crashes occurred at these locations in 2008 (FHWA, 2016). High friction aggregate surfacing is proven internationally as a means to significantly reduce accidents and casualties at critical locations such as curves, steep gradients and intersections (Gorell et al., 2016; NCHRP, 2016). The material used almost exclusively worldwide for high friction surfacing is

calcined bauxite; a quarried natural material requiring high temperature pre-processing. As commercial sources of calcined bauxite are limited to China, Guyana and India, high associated economic and environmental costs make finding an alternative attractive. While research into competing hard-wearing natural aggregates such as sandstone, limestone, granite and basalt (Woodward and Friel, 2017), as well as industrial bi-products such as steel slag (Shui, 2017) have yielded positive results, these materials generally do not perform as well as calcined bauxite and are restricted to less demanding, non-high friction, environments.

Against this background, this paper reports findings from a preliminary research programme aimed at assessing the potential of geopolymer cement-based materials to offer resilient highway infrastructure solutions. Work initially focused on identifying favourable geopolymer mixture proportions based on fresh and mechanical performance (Phase 1), followed by assessment of their suitability for rapid pothole repair (Phase 2) and high friction road surfacing (Phase 3) applications.

MATERIALS AND EXPERIMENTAL METHODS

Materials

This study focused on the application of BanahCEM; a commercially available, calcined clay-based, geopolymer cement system produced in Northern Ireland. BanahCEM is based on kaolinic clay layers exposed at existing basalt quarries in Northern Ireland and identified as suitable alumino-silicate precursor for geopolymerisation (McIntosh and Soutsos, 2014). In manufacture, this clay is calcined at 750°C and then ground to a fine powder. When mixed with a potassium silicate solution (approximately 55-60% potassium solids), geopolymerisation occurs forming a cementitious binder similar in nature to that of an ordinary Portland cement concrete (McIntosh and Soutsos, 2014). Ground granulated blast-furnace slag was also used as a binder material in Phase 2 of the study. Sourced from ECOCEM Ireland, the powder had particle sizes ranging from 0.1-40 µm and a relative density of 2.95. Locally sourced concreting sand was used as fine aggregate in the production of mortar specimens.

Material characterization

Material characterization was undertaken using standard SEM (low vacuum Hitachi S3200N equipment operated at 25kV) and XRD (Bruker D8 Discover Diffractometer) apparatus. A salicylic acid/methanol (SAM) extraction method (Kim, 2012) was additionally used to determine calcium-containing compounds present in geopolymer materials. This method involved producing solutions containing 20 g of salicylic acid ACS reagent and 300 ml of ≥99.9%

HPLC grade methanol. A 2.5 g of powder sample was mixed with 150 ml of SAM solution, using a Sigma Aldrich MSC basic stirring plate and plastic magnetic stirrers, for two hours at an ambient temperature of 17±1.5 °C. The mixture was then allowed to settle and filtered using a vacuum pump, Buchner flask and funnel and two pieces of Sigma Aldrich Grade 2 filter paper. The residue was washed with methanol and dried overnight at 100 °C, after which the residue mass was recorded.

Fresh and mechanical properties

In terms of fresh properties, mixes were assessed for setting time and flow to ensure compliance with typical pavement repair material requirements. Testing was carried out according to BS EN 196-3 (2005) and BS EN 1015-3 (1999) respectively. Compressive and flexural strength testing was carried out using 50 mm cube and 40x40x160 mm prism test specimens respectively in accordance with BS EN 1015-11 (1999). Specimens were cast in steel moulds and wrapped in polythene sheet to retain moisture during initial hardening and curing phase. After 24 hours, specimens were de-moulded and stored at an ambient temperature of 20±2 °C until testing.

Simulated road surface wearing

Simulated wear testing of both rapid pothole repair and high friction aggregate specimens was carried out using an accelerated road test machine in accordance with Appendix H of TRL Report 176 (Nicholls, 1997). The test involved exposing 275x275x40 mm test specimens comprising 10 mm stone mastic asphalt (SMA), to a pair of loaded (5 ± 0.2 kN) standard pneumatic-tyred car wheels repeatedly passing over the specimens' surface in a circular motion at a rate of 10 revolutions per minute. As well as revolving, the loaded wheels moved 160±25 mm laterally across specimens in a cycle taking 1-10 minutes. Undertaken at an ambient temperature of 20±2 °C to replicate slow-speed, high friction traffic loading, pothole repair specimens (Phase 2) and high friction aggregate specimens (Phase 3) were exposed to 2,000 and 20,000 wheel-passes respectively.

Rapid repair test sample preparation

Potholes were simulated in the 275x275x40 mm simulated road surface wearing specimens by removing material using a hammer and chisel to form roughly circular defects with rough, sloped sides and approximate volumes of 0.00104 m³. The defects were designed to satisfy reported minimum dimensions of potholes as defined by over 60% of local authorities in England and Wales (ALARM, 2011). Each defect was filled with geopolymer cement mortar to the same level as the original slab surface. Compaction was achieved using a steel tamping rod followed by 20 seconds of compaction

using a vibrating table. Excess mortar was removed using a hand trowel and no further surface texturing was applied. The repaired slabs were covered with a polythene sheet to retain moisture. After 24 hours at 20 ± 2 °C, the polythene sheets were removed and the specimens stored, uncovered, for a further six days before accelerated wearing tests were carried out. Air curing was selected, as this method is likely to reflect in-situ curing applications for pothole repair material.

Skid resistance and polished stone value testing

High friction aggregate specimens (Phase 3) were prepared by evenly dispersing and bonding 1-3 mm aggregates to the surface of the 275x275x40 mm simulated road surface wearing specimens. Aggregate particles were bonded using a 2 mm-thick layer of commercially available two-part epoxy resin binder that was allowed to cure for 24 hours before excess material was removed using a wire brush. Specimens were assessed periodically for skid resistance value (SRV) and mean texture depth in accordance with industry guidelines (RRL, 1969; BSI, 2010). High friction aggregate specimens were also subjected to the PSV test described in BS EN 1097-8 (2009), albeit modified to assess the aggregate size range under investigation (1-3 mm) rather than the standard aggregate size range recommended (10-14 mm). Geopolymer aggregates were bonded onto blank epoxy resin moulds using a 2 mm-thick layer of Araldite two-part epoxy glue. As per the standard method, samples were subjected to two, three-hour polishing cycles comprising the addition of coarse emery grit and fine emery corn respectively. Friction test values were measured prior to testing and at one-hour intervals thereafter, followed by measurement of the modified polished stone value after testing.

PHASE 1

Mixture proportions

Based on previous research (Rangaraju and Pattnaik, 2008) undertaken to identify material properties and values influencing the compatibility of parent pavement structures and subsequent repairs, nine geopolymer cement concrete mixtures were initially considered to assess the effect of varying powder, activator and water content on performance. As shown in Figure 1(a), the range considered for each aforementioned variable was 450-550, 300-400 and 50-60 kg/m³ respectively, with one variable being changed while the other two remained at the middle content level. Fine aggregate contents were adjusted in each case to maintain constant volume. Mixing in accordance with guidance provided by Banah UK (Banah, 2011) involved using a motorised table-top mixer to blend the powder and alkaline activator initially, followed by addition of fine aggregate.

Fresh and mechanical performance

Initial and final setting time ranges for the nine geopolymer mortar mixes were 44-295 and 75-390 minutes respectively (Figure 1(b)). While appropriate for standard mortar applications, this level of performance was recognised as insufficient for rapid-setting patch materials where minimum recommended strength levels are typically required after 2 hours (McDaniel et al, 2014). According to flow characteristics given in BS EN 1015-6 (1999), mix 1 was classed as a stiff mortar (<140 mm), mixes 2 and 5-11 as plastic mortars (140-200 mm), and mixes 3 and 4 as soft mortar (>200 mm) (Figure 1(b)). The Manual of Contract Documents for Highway Works (2016) mandates class C37 (minimum 7 and 28 day compressive strengths of 32 and 37 MPa respectively) for concrete road surfacing material. As shown in Figure 1(c), all of the geopolymer mixes considered exceeded this, with 7- and 28-day compressive strength ranges of 54-69 and 54-77 MPa recorded respectively for the nine mixes considered. Furthermore, the flexural strength of mixes 1, 3, 4, 7 and 8 exceeded the minimum laboratory-based value of 2.4 MPa proposed for rapid-setting patch materials (McDaniel et al, 2014).

Mix	Mixture proportions (kg/m ³)				Liquid: solids ratio
	Powder	Activator	Sand	Water	
1	500	300	1545	55	0.264
2	500	350	1495	55	0.282
3	500	400	1445	55	0.299
4	450	350	1545	55	0.304
5	500	350	1495	55	0.282
6	550	350	1445	55	0.264
7	500	350	1500	50	0.275
8	500	350	1495	55	0.282
9	500	350	1490	60	0.289

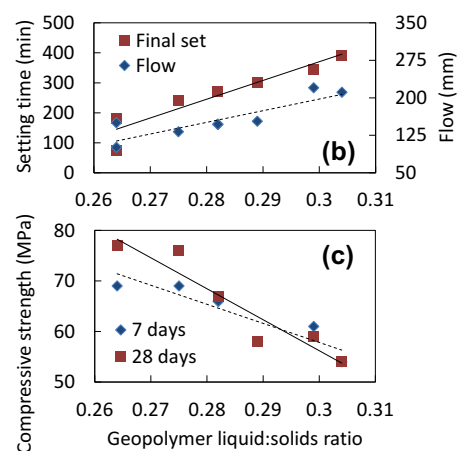


Figure 1. (a) Geopolymer mortar mixture proportions used in Phase 1; Relationship between geopolymer liquid:solids ratio and: (b) fresh mortar properties (flow and final set); and (c) compressive strength (7 and 28 days).

Apparent from Figure 1 is the significant influence of geopolymer liquid:solid ratio (i.e. ratio of the sum of water content in the activator and added water to solid metallic silicate content of the activator and the alumina-silicate powder) on both fresh and hardened properties. Similar to the influence of water:cement ratio for Portland cement-based materials, increasing liquid:solid ratio resulted in increasing flows and setting times, and decreasing compressive strengths. In addition, other factors such as paste to sand content have an effect. An example of this is apparent when comparing mixes 1 and 6. While both had a liquid:solid ratio of 0.264, mix 1 had a lower paste:sand ratio (0.55) and corresponding strength (62 MPa) in comparison to mix 6 (0.66 and 77 MPa); indicating an insufficient quantity of paste in mix 1 to sufficiently fill voids between the sand particles, resulting in poor compaction and interfaces between sand particles and geopolymer paste.

PHASE 2

Mixture proportions & material characterization

Mix 6 was selected for further scrutiny in Phase 2 owing to its optimum compressive (69/77 MPa at 7/28 days) and flexural (2.3 MPa at 28 days) strength in Phase 1. However, as the setting times and rate of strength gain noted for mix 6 were deemed inadequate for rapid repair applications, additional mixes were considered with increasing quantities of calcium-containing materials; an established approach for accelerating geopolymer reactivity (Hunnicut, 2013). In addition to mix 6, three mixes with 40, 50 and 60% by mass replacements of BanahCEM powder with GGBS (labeled 6-40, 6-50 and 6-60% respectively) were prepared in accordance with the same mixing processes as used in Phase 1 (Banah, 2011).

The suitability of binder systems comprising BanahCEM and GGBS was confirmed via XRD analysis of BanahCEM-60% GGBS (this high replacement level being chosen to represent a worst case scenario) powder samples and corresponding geopolymerised pastes prepared at a liquid:solids ratio of 0.264. From Figure 2(d) it can be seen that the amorphous aluminosilica hump between 20-30 2θ identified for the powder sample became more pronounced for the ground paste sample, confirming the presence of additional aluminosilicate gel phases associated with geopolymerisation. Crystalline peaks noted for both sample types can be traced back to the original lithomargic clay-derived metakaolin and correspond with hematite, a form of crystalline iron oxide formed when goethite and magnetite from the raw lithomarge is calcined (Fernandez-Jimenez et al, 2013). For the BanahCEM/70% GGBS paste sample, two new peaks are apparent at 26.6 and 29.4 2θ , which from previous research can be linked to calcium

aluminium silicate hydrate (C-A-S-H) gel phases more commonly associated with alkali-activated cements than geopolymers (Temuujin et al, 2009; Van Deventer, 2015). However, the broad hump between 20-38 2θ on which the peaks are situated suggests that the C-A-S-H has been formed alongside geopolymeric aluminosilicate gel formation, suggesting a C-A-S-H/ aluminosilicate hybrid gel. This could be caused by non-geopolymerised aluminosilicate and calcium elements leaving the unreacted material to form a C-A-S-H gel when it reacts with any remaining silicate activator. Shown in Figure 2(g) is an SEM micrograph of the control geopolymer cement mortar, which clearly shows a dense, non-crystalline microstructure with well-defined, homogeneous paste-aggregate interface zones typical of geopolymer cement-based materials. As no inconsistencies were noted from this analysis, work progressed to the mechanical testing stage.

Fresh and mechanical properties

Flow, setting time (initial and final) and compressive strength (3 hrs, 1, 7 and 28 days) results for the GGBS-based mixes considered in Phase 2 are reported in Figure 2(a and b) relative to the performance of control mix 6 (i.e. no GGBS). Clearly from Figure 2(a), the addition of GGBS had a marked influence on fresh mortar properties, with flow levels increasing by 9-15% as the GGBS replacement level increased from 40-60% by mass. Classed as 'plastic mortars' (BSI, 1999), these flow results confirmed levels of workability suitable for small-scale repair applications. A more significant influence of GGBS is apparent from Figure 2(a) in relation to mortar setting times, where GGBS replacement resulted in initial and final setting times on average 85% lower than the non-GGBS control. With final setting times of 30 minutes recorded for all GGBS mixes, this aligns well with the requirement given in Specification for Highway Works clause 946 (2005) for pothole repair materials to have sufficiently hardened to be capable of trafficking without damage after 30 minutes. In terms of compressive strength, Figure 2(b) clearly shows how the GGBS-based mixes obtained significantly higher strengths relative to the control at 3 hours. At 3 hours mix 6 had just achieved final set and yielded a relatively low compressive strength result of 13.3 MPa (17% of its 28-day value). In contrast, all GGBS-based mixes achieved values in the range 31-34 MPa (on average 150% higher than the control mix and 40% of their 28-day values). At 24 hours, a similar but less pronounced trend was apparent (GGBS mixes achieving values in the 53-54 MPa range in comparison to 39 MPa for the control). Conversely after 7 and 28 days, a state of performance equivalence was achieved, with the control mix marginally out-performing mixes 6-40 and 6-50%. Only mix 6-60% out-performed the control in terms of compressive strength at all test ages.

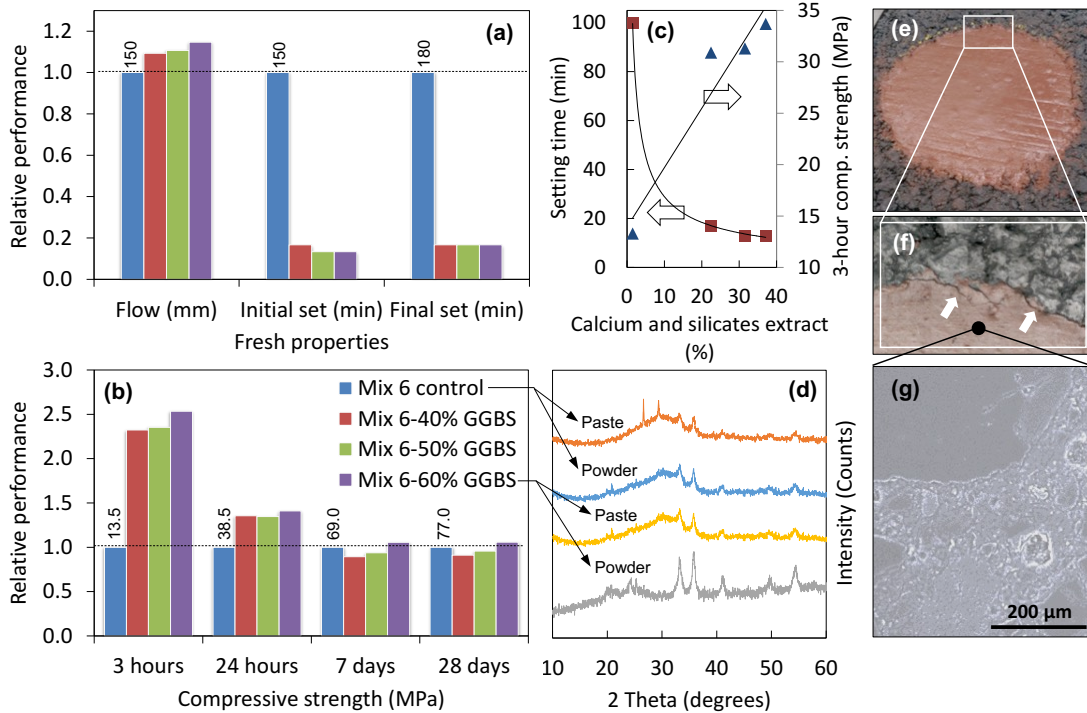


Figure 2. (a&b) Performance of GGBS-based geopolymer mortar mixes relative to a non-GGBS control (mix 6 – see Figure 1(a)); (c) Influence of calcium content on geopolymer mortar setting time and 3-hour compressive strength; (d) X-ray diffraction traces for geopolymer cement powder and paste specimens; (e) Rapid patch repairs test specimen prior to accelerated wear testing; (f) Surface edge cracking of patch repair specimens after exposure to 2,000 wheel passes; and (g) Representative SEM image of BanahCEM mortar specimen.

The positive influence of GGBS on mortar performance was confirmed to be as a result of additional available calcium and silicates in the geopolymer cement matrices (Figure 2(c)). Plotted in this figure are quantities of calcium and silicates within each sample as determined using the salicylic acid/methanol extraction method in relation to both 3-hour compressive strength and initial setting time. Clearly, the level of calcium and silicate impacts both properties significantly, with increasing calcium and silicates content resulting in reduced setting times and increased strength levels; an affect reported to occur due to increased dissolution rates of geopolymer phases causing reactions to occur more rapidly (Hunnicut, W.A., 2013). This work reinforces the potential suitability of GGBS-based geopolymer as a rapid repair highway solution.

Rapid repair performance

Geopolymer cement mortar mixes selected for preliminary assessment in pothole repair applications included control mix 6 and mix 6-60%; the optimum rapid set material in terms of compressive strength. As previously untested material in this test method, it was anticipated that some performance issues would occur due to bond and stiffness incompatibilities between the parent asphalt and geopolymer patch repair. After 2,000 wheel-passes in the accelerated road test machine, however, no surface defects were noted for mix 6 specimens from visual assessments focused on surface cracking, delamination, de-bonding, and

material loss. The only indication of wear was minor shining of the material surface and no measurable decrease in surface texture was recorded. In comparison, the rapid setting repair specimens (mix 6-60%) exhibited some surface and edge cracking after testing (Figure 2(e and f)), indicating potential bond failures between the geopolymer cement mortar and asphalt. While this finding was of concern given the low wheel exposure level used in this study (2,000 in comparison to the maximum 100,000 recommended), the tapered edge profile of the repairs in this study represented a worst-case scenario in terms of material application.

In terms of skid resistance, average values of 41 and 39 were recorded after simulated wear testing for mix 6 and mix 6-60% specimens respectively. While these values represented negligible decreases during testing, these performance level fall short of the minimum required values of 45, 55 and 65 prescribed in RRL Road Note 27 (1969) for: public roads; trunk roads and motorways; and bends and roundabouts, respectively. This finding is not surprising, however, given the lack of surface texturing applied to the patch repairs in this preliminary testing stage. To fully develop solutions suitable for road pavement exposure, ongoing research in this area is focused on geopolymer cement mortar patches with applied surface textures, installed in pothole recesses with vertically cut and cleaned edges, and subjected to 100,000 ± 1000 wheel passes.

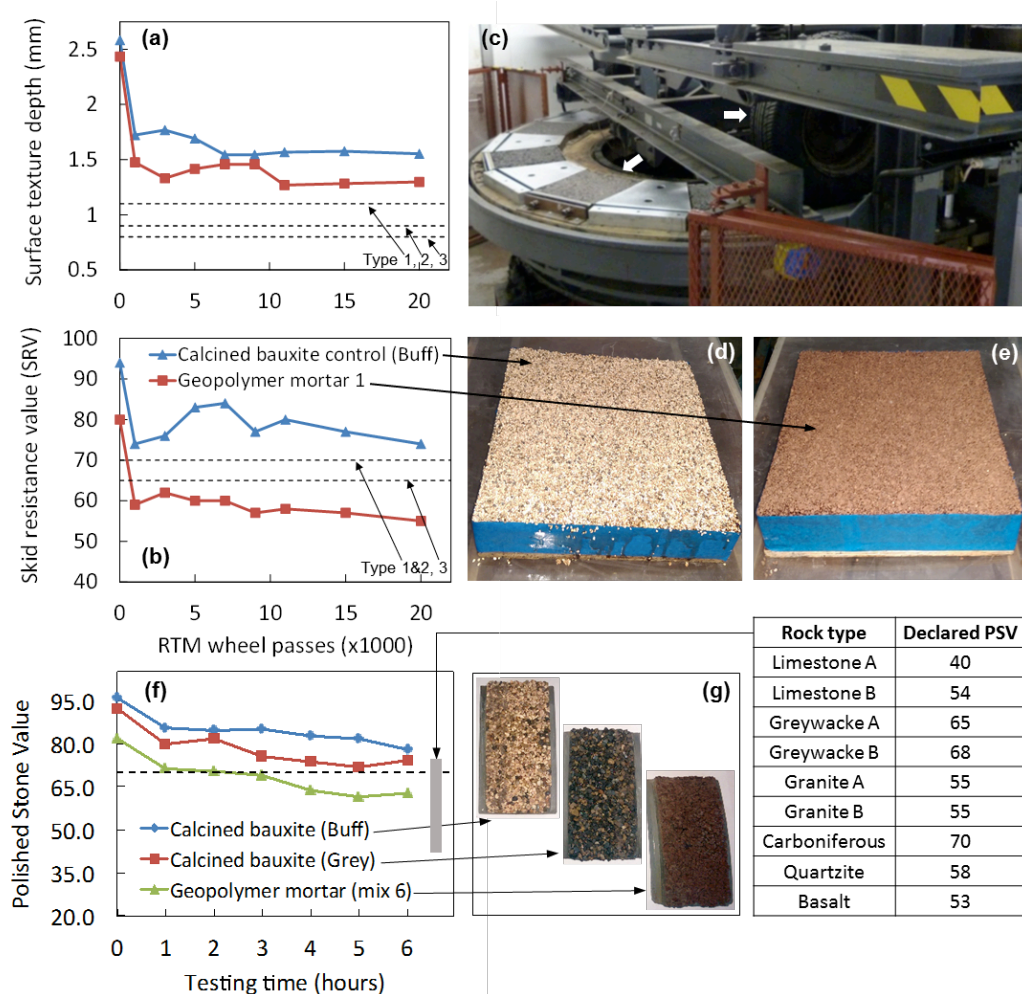


Figure 3. (a & b) Relationships between number of accelerated road test machine wheel passes and texture depth and skid resistance value; (c) Experimental test set up of Ulster University's accelerated Road Test Machine (locations of test specimens and tyres highlighted); (d & e) Images of test specimens prepared using calcined bauxite and geopolymer cement mortar-based high friction aggregates; (f) Relationships between polished stone value and testing time for calcined bauxite and geopolymer cement mortar-based aggregate samples (including published values for natural aggregates (Woodward and Friel, 2017)); and (g) Images of test specimens for polished stone value testing.

PHASE 3

Geopolymer mortar-based aggregate preparation

Geopolymer cement mortar-based aggregates were produced using material recycled from mix 6 specimens used for compressive and flexural strength testing in Phase 2. After mechanical testing, specimens were reduced in size using a jaw crusher and the resulting material sieved in accordance with BS EN 1015-1 (1999) to retain aggregates in the 1-3 mm range. Commercially available calcined bauxite aggregates in the same size range were used as controls. Testing apparatus and example test specimens used for simulated road surface wearing and PSV testing are shown in Figure 3(c, d and e).

High friction aggregate performance

In terms of resistance to simulated wear for both the control and geopolymer specimens, initial values of average texture depth (2.52 and 2.43 mm respectively) and skid resistance (94 and 80

respectively) decreased significantly after 1,000 wheel-passes, with performance levels largely stabilizing thereafter up to 20,000 wheel passes (Figure 3(a & b)). Average texture depth values for the calcined bauxite control and geopolymer mortar specimens decreased from 1.72 to 1.55 mm (9.9% decrease) and from 1.47 to 1.29 mm (12% decrease) respectively between 1,000 and 20,000 wheel passes. With both of these final values exceeding the minimum road surface requirement of 1.1 mm (DMRB, 2006), albeit that this limit relates to 100,000 wheel passes, these provisional findings suggest suitably high levels of geopolymer mortar durability under traffic loading.

Considerable disparity existed between initial skidding resistance values measured for the calcined bauxite control and geopolymer mortar specimens (94 and 80 respectively), indicating that production process optimization is required for the latter in terms of its macro/micro texture. While initial decreases in performance between 0 and 1,000 wheel passes were similar for both aggregate types

(21 and 26% decreases respectively), the initial disparity was reflected in ultimate performance levels recorded (74 and 55 respectively after 20,000 wheel passes). According to HAPAS guidelines (BBA, 2015), this classifies the control as performance Type 1 (≥ 70) and the geopolymer mortar as falling short of Type 2 and 3 (≥ 65).

To investigate relative skidding resistance behavior more comprehensively, modified PSV testing was undertaken using standard test specimens (Figure 3(g)) to assess the performance characteristics of each aggregate type and their polishing susceptibility under traffic loading. Similar to trends noted for SRV, initial average PSV values recorded for geopolymer aggregate was appreciably lower than for the bauxite controls (82 compared to 94) (Figure 3(f)). While decreases in performance thereafter up to six hours of testing were similar for both aggregate types (22 and 19% respectively), the initial disparity was reflected in the ultimate average performance levels recorded (76 and 63 respectively). While geopolymer aggregates fell short of the '68+' classification given in DMRB HD36/06 [2006] for high performance materials, when benchmarked against declared PSV values for hard wearing natural aggregates and years of related research into this field (Woodward and Friel, 2017), it is clear that the prototype geopolymer aggregates assessed show excellent potential for application in this field.

CONCLUSIONS

Presented in this paper are findings from a preliminary research project aimed at assessing the potential suitability of BanahCem geopolymer cement-based materials for use in highway applications. From an initial work phase focused on identifying favorable geopolymer mortar mixes in terms of fresh and mechanical properties, a wide range of performance levels was identified. Compressive strength at 7 and 28 days and flexural strength at 28 days ranged from 54-69, 58-77 and 1.7-3.1 MPa respectively. Based on these results, a material combination with a solid:liquids ratio of 0.264 and average 28-day compressive and flexural strengths of 76 and 3.1 MPa respectively was selected for further investigation (mix 6). The flow and initial/final set of mix 6 was 150 mm and 150/180 minutes, making it generally suitable for a range of engineering applications. In Phase 2 of the research, the suitability of mix 6 as a rapid repair road material was considered. While its level of compressive and flexural strength, as well as flow, was deemed appropriate for this application, its relatively slow setting time was not. Work was subsequently undertaken using 40-60% replacements of BanahCem with GGBS by mass to achieve final setting times within acceptable levels (<30 minutes). The stability of this approach in terms of geopolymerisation was confirmed using XRD

analysis. After 2,000 wheel-passes in an accelerated road test machine, the resilience of a BanahCEM-60% GGBS mix to traffic loading was found to be acceptable when placed in a pre-prepared pothole in asphalt with tapered sides. While texture depth and skid resistance values were below minimum requirements due to the omission of prescribed surface texturing, no surface deformations were noted other than some minor shining of the geopolymer surface. Based on these positive findings, future work will continue to focus on the performance of rapid set geopolymer patch repairs, albeit placed in conventionally pre-prepared straightedge potholes, finished with profiled surface textures, and exposed to higher levels of simulated traffic (100,000 wheel passes). As a high friction aggregate, crushed geopolymer cement mortar exhibited impressive results relative to standardized targets, given the lack of manufacturing process optimization invested at this preliminary stage. Particularly in terms of the modified PSV levels (average of 63) recorded after 6 hours of testing, this research provides a strong platform from which to further investigate suitable alternatives to calcined bauxite. In addition to mechanical performance, potential also exists to optimize the economic and environmental impacts associated with conventional high friction aggregates.

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