



Geopolymers prepared from DC plasma treated air pollution control (APC) residues glass: Properties and characterisation of the binder phase

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ABSTRACT

Air pollution control (APC) residues have been blended with glass-forming additives and treated using DC plasma technology to produce a high calcium aluminosilicate glass (APC glass). This has been used to form geopolymer–glass composites that exhibit high strength and density, low porosity, low water absorption, low leaching and high acid resistance. The composites have a microstructure consisting of un-reacted residual APC glass particles imbedded in a complex geopolymer and C–S–H gel binder phase, and behave as particle reinforced composites. The work demonstrates that materials prepared from DC plasma treated APC residues have potential to be used to form high quality pre-cast products.

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1. Introduction

The air pollutions control systems at energy from waste (EfW) plants burning municipal solid waste (MSW) produce granular air pollution control (APC) residues. These are a hazardous waste with an absolute entry in the European Waste Catalogue (19 01 07*), and they contain fly ash, excess lime, carbon, relatively high concentrations of volatile heavy metals and soluble salts, particularly leachable chlorides. They also contain trace levels of organics including dioxins and furans.

DC plasma technology provides a sustainable treatment for APC residues that meets the aims of the EU waste policy as it is a recycling/recovery option higher in the waste management hierarchy than alternative options [1,2]. In the DC plasma treatment process APC residues are combined with glass-forming additives and melted to produce inert APC glass [2].

There is increasing interest in developing sustainable construction products which contain recycled materials. Reuse of APC glass would have significant economic and environmental benefits, and

would help to make DC plasma treatment of APC residues commercially attractive. Previous work has investigated the use of APC glass in glass-ceramics [3,4] and sintered ceramic tiles [5].

Geopolymers are synthetic aluminosilicates consisting of silica (SiO₄) and alumina (AlO₄) tetrahedra, linked by shared oxygen atoms [6]. Their formation is based on the chemistry of alkali-activated inorganic binders and involves the chemical reaction of geopolymeric precursors, such as aluminosilicate oxides with alkali poly-silicates, to form polymeric Si–O–Al bonds [7]. The negative charge of Al³⁺ in four-fold coordination is balanced by the presence of positive ions such as Na⁺, K⁺ and Ca²⁺ in framework cavities [8]. The empirical formula of geopolymers is therefore:



where M is a cation such as Na⁺, K⁺ or Ca²⁺, z is 1, 2 or 3, and n is the degree of poly-condensation.

Geopolymers are associated with low CO₂ emissions compared to Portland cement [9]. Using APC residue glass to form a geopolymer would provide a low-carbon emission reuse option that does not involve thermal processing.

The microstructure and properties of geopolymers are determined by the raw materials used, and they can have high early

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Table 1
Chemical composition of APC glass.

Oxide	Composition (wt%)
Na ₂ O	2.88
MgO	2.31
Al ₂ O ₃	14.78
SiO ₂	41.10
P ₂ O ₅	0.77
K ₂ O	0.03
CaO	32.59
TiO ₂	1.19
Mn ₃ O ₄	0.23
Cr ₂ O ₃	0.06
Fe ₂ O ₃	4.07
Cl	2.5

compressive strengths, low shrinkage, rapid or slow setting, good acid resistance and fire resistance, and low thermal conductivity [10–12]. The use of APC glass in geopolymers results in geopolymer–glass composites in which residual APC glass particles act as rigid inclusions in a geopolymer matrix [13].

The presence of calcium in geopolymer systems can result in the formation of calcium silicate hydrate (C–S–H) gel and Al substituted C–S–H gel, and these are reported to decrease porosity and increase the strength of geopolymers [14–25]. This coexistence of geopolymer gel and hydration products has also been observed in alkali activated fly ash–Portland cement blends [26]. Recent research on the effect of alkalis and Al in C–S–H gel has confirmed that the structure is modified by alkali metals and Al [27,28]. The formation of a geopolymer phase or C–S–H gel is determined by the chemical and mineralogical composition, the physical properties of the aluminosilicate and Ca sources, the alkalinity of the activator and the percentage Ca in the system [17–19,22,24].

This work follows from previous research [13] in which novel geopolymers prepared using APC glass were described. The effect of processing parameters on geopolymerisation of APC glass was examined. In the present paper the properties of optimised APC glass geopolymers and the formation of a complex binder phase are investigated in detail. This provides new insight and information on the potential applications of this material and the link between the final geopolymer composite properties and microstructure.

2. Materials and methods

2.1. Materials

Glass produced by DC plasma treatment of APC residues was supplied by Tetronics Ltd. (Swindon, UK) in the form of a coarse granular material with <2 mm particles. These were then milled to form a fine powder (TEMA Machinery Ltd.) with a broad particle size range, with all particles <200 μm. The chemical composition of APC glass is presented in Table 1. This shows that the composition (wt%) in terms of major oxides was SiO₂ (41.1%), CaO (32.6%) and Al₂O₃ (14.8%).

Sodium silicate solution (VWR, Lutterworth, UK) containing 26.5 wt% SiO₂, 8.5 wt% Na₂O and 65 wt% H₂O and a density of 1310 kg/m³ was used. NaOH (Fisher Scientific, Loughborough, UK) and distilled water were used to form the activating solution.

2.2. Preparation of samples and characterisation

Sample preparation involved mixing the APC glass powder with the activating solution. This was prepared by dissolving NaOH pellets in water and allowing the solution to cool to room temperature before adding the required amount of sodium silicate solution. The Si/Al ratio was 2.6, the solid to liquid ratio was 3.4 and the sodium hydroxide concentration in the activating solution was 6 M. The

activating solution was thoroughly mixed with the APC glass powder for 10 min in a 5 litre mortar mixer. The resulting paste was cast into rectangular moulds (80 mm × 25 mm × 25 mm) on a vibrating table to reduce air voids. The samples were covered with glass slips, de-moulded after 24 h, wrapped in cling film to inhibit water evaporation and cured at room temperature.

APC glass geopolymers were characterised for unconfined compressive strength (UCS) at a loading rate of 300 kPa/s on four samples of each composition. The bulk density and porosity of the APC glass geopolymer samples were determined by mercury porosimetry (Micromeritics AutoPore IV 9500). Bar specimens (60 mm × 8 mm × 6 mm) were cut from APC glass geopolymers for three-point flexural strength testing, with one surface of each bar ground and polished and the adjacent edges chamfered prior to testing on a 30 mm span, using a cross-head speed of 0.5 mm/s (Hounsfield H5KS, Salfords, UK). The modulus of elasticity was calculated using the ultrasonic pulse velocity method [29]. Thermal conductivity was measured using a TT-TC Probe (ThermTest Inc.) which provides a non-destructive thermal conductivity test based on the Mathis modified hot-wire technique [30]. Freeze/thaw resistance was determined using the method described in ASTM standard C 1262–05 [31]. Three test samples were subjected to 92 freeze/thaw cycles, with the cumulative mass loss of the samples given as a percentage of the initial mass.

The chemical resistance of APC glass geopolymer was determined according to the method described in BS EN 1344: 2002 [32]. APC glass geopolymers were ground and sieved to between 500 and 800 μm. The required amount of sample (~100 g) was then treated with boiling sulphuric and nitric acid (75 ml of 10% sulphuric acid and 25 ml of 10% nitric acid) for 1 h in a round bottom flask, fitted with a reflux condenser. After treatment the residue was rinsed to remove the acid, dried to constant mass, and re-weighed. Results are expressed as the loss in mass of the sample as a percentage of the original mass, with the test performed in duplicate. Leaching of heavy metals from APC glass geopolymer was evaluated using the EU compliance leaching test for granular waste (BS EN 12457–4), on particles less than 10 mm using a liquid to solid ratio (L/S) of 10 L/kg, with water as the leachant [33]. The eluate was vacuum filtered and elemental analysis of leachates completed using inductively coupled plasma atomic emission spectroscopy (ICP-AES, Varian Vista-Pro, Australia).

Fractured surfaces were gold coated before examination by scanning electron microscopy (SEM, JEOL JSM 5610LV). Surfaces polished to a 1 μm surface finish and carbon coated were also examined (JEOL-JSM-840A).

The binder phase in APC glass geopolymers was characterised using the salicylic acid/methanol (SAM) selective extraction method. This test was developed to dissolve alite, belite and free lime from cement clinker. It has previously been used in geopolymer research and the results have shown that salicylic acid–methanol dissolves calcium silicates, while the geopolymer network structure and the un-reacted materials remain unaltered [17,24,26,27,34]. Measuring the amount of SiO₂ in the initial material and the solid residue provides an indication of the amount of SiO₂ that is fixed either as C–S–H gel or geopolymer gel. Si, Al and Ca in the initial sample and the solid residues were determined by ICP-AES analysis. The initial sample and the solid residue were analysed by FTIR spectroscopy to identify changes in structure of the APC glass geopolymer after SAM selective extraction. FTIR (Magna-IR 560 Spectrometer E.S.P., Nicolet) provides information on the chemical bonds in geopolymers and identifies products formed during geopolymerisation. Samples were ground to a fine powder and pellets prepared with the addition of KBr.

The crystalline phases in APC glass geopolymers and solid residues were analysed by XRD (Philips PW1700) using CuKα radiation and a secondary graphite crystal as mono-chromator.

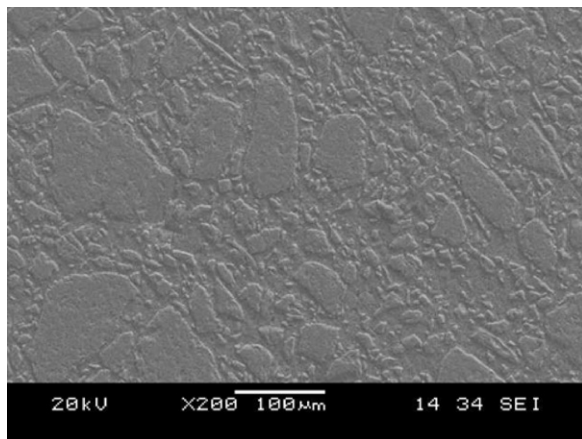


Fig. 1. SEM image of polished surface of APC glass geopolymer.

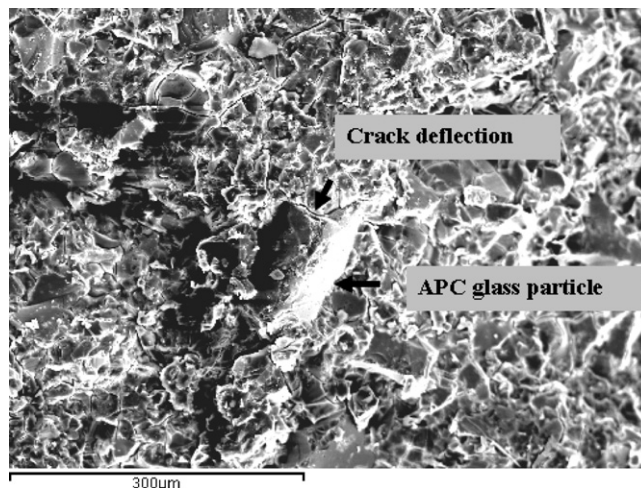


Fig. 2. Fracture surface of APC glass geopolymer sample after 3 point bending strength test.

3. Results

3.1. Properties of APC glass geopolymers

A polished surface of APC glass geopolymer is shown in Fig. 1. A significant volume of residual APC glass particles was encapsulated in a geopolymer derived matrix phase. The properties of APC glass geopolymers investigated in this research and various commercial products are presented in Table 2. The term geopolymer cement in Table 2 refers to fly ash based geopolymers or rock based geopolymers which harden at room temperature [8]. The values presented for concrete refer to a typical concrete mix containing 10–15% cement, 60–75% aggregates and 15–20% water [35].

3.2. Mechanical properties and Young's modulus of elasticity

APC glass geopolymer exhibits high compressive strength (~110 MPa after 28 days curing), which is much higher than the strength of typical hardened concrete (~30 MPa) [36], and higher than most geopolymer cements [8]. Flexural strengths of the APC glass geopolymer show similar behaviour to concrete, and are typically 10–15% of the compressive strength [37]. The flexural strength of APC glass geopolymers is 10.5 MPa which is ~10% of the compressive strength. This value is lower than flexural strength values observed for glass and commercial tiles [5,36]. After 3-point bending testing, the APC glass geopolymer samples developed surface cracking but did not break into separate pieces indicating high fracture toughness. The SEM micrograph of a fractured surface presented in Fig. 2 shows that cracks do not pass through un-reacted APC glass particles but are deflected around them. The geopolymer–glass composite structure results in a high strength material with increased fracture surface energy because of toughening involving crack deflection, typical of particle reinforced ceramics [38].

Data presented in Table 2 show that Young's modulus is higher in glassy and ceramic materials [5,36] and lower in concrete and geopolymer cements [8,36]. The Young's modulus of APC glass geopolymer is close to the values reported for concrete [36].

3.3. Porosity and bulk density by mercury porosimetry

APC glass geopolymers have comparable density to concrete and higher density than geopolymer cements, 2.3 g/cm³, 2.4 g/cm³ and 1–1.9 g/cm³, respectively [8,36]. They also have lower open porosity (5.5%) compared to concrete (15%) [36] and geopolymer cements (15–30%) [8].

3.4. Thermal conductivity

The thermal conductivity of APC glass geopolymer samples was ~0.9 W/Km which is higher than the value reported for geopolymer cements of 0.2–0.4 W/Km [8]. The thermal conductivity of APC glass geopolymer is similar to concrete which ranges between 0.8 and 1.3 W/Km [36].

3.5. Chemical resistance

Chemical resistance of APC glass geopolymer was evaluated according to BS EN 1344: 2002 using sulphuric acid and nitric acid. The weight loss of APC glass geopolymer samples was <0.1%, showing that the material has good acid resistance. The value reported for geopolymer cements is similar but is based on a different test method [8]. APC glass geopolymer was boiled in a solution prepared with 75 ml of 10% sulphuric acid and 25 ml of 10% nitric acid while in the test used for geopolymer cements the material was immersed in a 5% sulphuric acid solution [8]. Nevertheless, both materials exhibit very good resistance to acid attack.

3.5.1. Freeze/thaw resistance

Freeze/thaw tests were performed on APC glass geopolymer according to ASTM C 1262-05. Samples were subjected to 92 freeze/thaw cycles. The water was changed every ten days and the sample residue in the water was also collected. Residue weight was measured at every collection interval and the weight loss for each sample is presented in Fig. 3. W_{initial} is the initial weight of the samples which according to ASTM C 1262-05 is calculated using the following equation:

$$W_{\text{initial}} = W_{\text{final}} + W_{\text{residue}} \quad (2)$$

After 92 freeze/thaw cycles an average weight loss of 2% was determined. Significant weight loss occurs during the first 60 cycles after which no further weight loss was observed. The highest weight loss was observed in the first 30 cycles and the amount of residue decreased with increasing cycles. Peeling was observed on the surface in contact with water.

The freeze/thaw resistance reported for geopolymer cements (<0.1%) [8] is lower than the values obtained for APC glass geopolymers (2%) but a different test has been used. APC glass geopolymers were subjected to 92 freeze/thaw cycles while the standard used for geopolymer cements required just 12 cycles.

Table 2
Properties of APC glass geopolymers, APC glass materials and other commercial products.

Materials	Density (g/cm ³)	Open porosity (%)	Water absorption (%)	Compressive strength (28 days) (MPa)	Flexural strength (MPa)	Young's modulus (GPa)	Chemical resistance (%)	Freeze/thaw mass loss (%)	Thermal conductivity W/K m
APC glass geopolymer	2.3	5.5	11	110	10.5	32	<0.1	2	0.96
Concrete [36]	2.4	15	–	30	2	20	–	–	0.8–1.28
Bricks [36]	2	–	–	100	10	50	2	–	–
Tiles ^a [5]	2.4 ^b	–	2–14.5	–	1.6–53	38	–	–	–
Glass [36]	2.5	0	–	320	40	70	–	–	–
Geopolymer cements [8]	1–1.9	15–30	–	>90	10–15	>2	<0.1	<0.1	0.2–0.4

^a Values refer to a range of tiles including floor tiles, wall tiles, vitrified tiles and porcelain tiles.

^b Porcelain tiles.

Table 3
Results of the leaching test from optimum APC glass geopolymer.

Element	mg/kg	Element	mg/kg	Element	mg/kg
Al	13.28	Fe	<DL	Pb	<DL
As	<DL	K	2.16	Si	41.48
Ba	<DL	Mg	<DL	Ti	<DL
Ca	4.96	Mn	<DL	Zn	<DL
Cd	<DL	Na	1067	Zr	<DL
Cr	0.18	Ni	<DL		
Cu	<DL	P	0.33		

Elements in italics are included in Waste Acceptance Criteria. WAC limits: As, 0.5 mg/kg; Ba, 20 mg/kg; Cd, 0.04 mg/kg; Cr, 0.5 mg/kg; Cu, 2 mg/kg; Ni, 0.4 mg/kg; Pb, 0.5 mg/kg; Zn, 4 mg/kg.

3.5.2. Leach testing

APC glass which was the starting material for the production of APC glass geopolymers is inert, as previously reported [2]. The results of leaching tests performed on APC glass geopolymers are presented in Table 3. There is negligible heavy metal leaching from APC glass geopolymers. Cr has very limited leaching (0.18 mg/kg), but all values were well below the WAC for inert waste landfill. Significant leaching of Na (1067 mg/kg) occurred, as this was the main component in the activating solution used to prepare the APC glass geopolymers.

3.6. Characterization of the binder phase

APC glass geopolymers are not pure geopolymers but a composite material consisting of un-reacted APC glass particles and a binder phase [1]. Data indicate that the binder phase contains geopolymer and amorphous C–S–H gel. The amorphous nature of these phases makes it impossible to identify the presence of

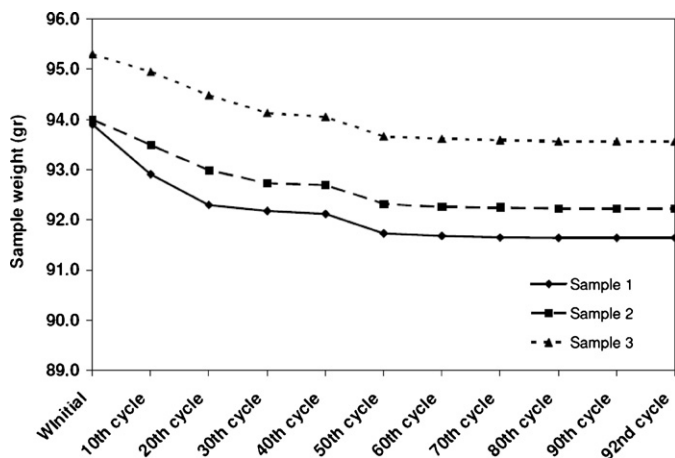


Fig. 3. Weight loss of three APC glass geopolymer samples subjected to freeze/thaw test.

amorphous hydrations products. Salicylic acid and methanol (SAM method) dissolves free lime and C–S–H that exist in the structure, but it does not affect geopolymer network and un-reacted APC glass particles. ICP analysis of the initial geopolymer and the solid residue together with XRD and FTIR analysis are necessary to identify different components in the material. The weight change between the initial sample and the solid residue after the SAM method indicates the percentage of material in the form of calcium containing products such as lime or C–S–H gel. The APC glass geopolymer was tested in duplicate and weight change data are presented in Table 4.

The results show that ~60% of the initial APC glass geopolymer was insoluble and can be attributed to un-reacted APC glass particles and the geopolymer network. The remaining ~40% passed in the liquid phase is attributed to soluble calcium-containing products such as free lime and C–S–H gel.

The APC glass geopolymer and the SAM solid residue were analysed using ICP-AES for Si, Al and Ca content, and the results are presented in Table 5. The Ca percentage in the insoluble residue is lower than the Ca percentage in the initial geopolymer. During the selective chemical attack, phases containing soluble Ca pass into the liquid phase causing the observed decrease in Ca percentage in the solid residue. Moreover, the percentage of Si increased, as the insoluble material is a mixture of un-reacted APC glass particles and geopolymer. ICP-AES results also confirmed the design Si/Al ratio of 2.6 that was used in the preparation of the geopolymers.

Based on the composition and quantity of APC glass geopolymer and solid residue from SAM methods, the quantities of Si, Al and Ca were calculated for the initial APC glass geopolymer, the insoluble residue and the soluble material. The results are presented in Table 6. For the soluble material the amounts presented were

Table 4
Weight change of geopolymer samples subjected to salicylic acid/methanol (SAM) selective extraction method.

	Sample 1	Sample 2
Initial sample weight (g)	4.96	5.06
Insoluble solid residue weight (g)	2.86	3.09
Soluble material in the liquid phase (g)	2.10	1.97
Insoluble material (%)	57.7	61.1
Material in the form of soluble Ca containing products (%)	42.3	38.9

Table 5
ICP analysis results for optimum APC glass geopolymer and insoluble solid residue of SAM method.

	Al (wt%)	Ca (wt%)	Si (wt%)	Si/Al	Ca/Si
APC glass geopolymer	7.69	23.2	19.7	2.6	1.2
Insoluble solid residue	6.85	19.8	20.2	2.9	1.0

Table 6
Al, Si and Ca quantities in APC glass geopolymer samples subjected to salicylic acid/methanol (SAM) selective extraction method.

Samples	Weight (g)	Al (g)	Ca (g)	Si (g)	Al (%)	Ca (%)	Si (%)
Sample 1							
APC geopolymer	4.965	0.382	1.152	0.979	100	100	100
Insoluble residue	2.864	0.196	0.567	0.578	51.3	49.2	59
Soluble material	2.101	0.186	0.585	0.401	48.7	50.8	41
Sample 2							
APC geopolymer	5.056	0.389	1.173	0.997	100	100	100
Insoluble residue	3.088	0.212	0.611	0.623	54.5	52.1	62.5
Soluble material	1.968	0.177	0.562	0.374	45.5	47.9	37.5

calculated from the initial amount on APC glass geopolymer by subtracting the amounts present in the insoluble solid residue:

$$X_{\text{APC geo}} = X_{\text{Insoluble residue}} + X_{\text{Liquid phase}} \quad (3)$$

where X is Si, Al or Ca. Furthermore the percentages of each compound that remained in the solid residue or passed in the liquid phase are included.

It can be observed from Table 6 that ~50% of initial Ca has passed into the liquid phase and was therefore bound to soluble compounds such as free lime and C–S–H, although a significant amount remained in the insoluble residue. Part of the Ca in the solid residue can be attributed to the Ca in the un-reacted APC glass particles and the remainder to the non-hydrated alumino–silicate network which also contains some Ca.

The solid residue from the SAM test was examined by XRD analysis to identify changes in mineralogy due to the selective chemical extraction. Fig. 4 presents XRD data of the initial APC glass geopolymer and the SAM solid residue. It can be seen that both materials are amorphous, with a broad hump around $30^\circ 2\theta$ present in both spectra.

Fig. 5 presents the results of FTIR analysis of the initial APC glass geopolymer and the SAM solid residue. It also presents the FTIR spectrum of the soluble material generated by subtraction of the spectrum of the insoluble residue from the spectrum of the initial APC glass geopolymer, using computer software. The main peak of the insoluble residue, after the selective chemical attack, shifted to higher frequencies compared to the original APC glass geopolymer. The main band of insoluble residue appears at around 1018 cm^{-1} , while for APC glass geopolymer it appears at 976 cm^{-1} . This indicates a higher degree of geopolymerisation in the insoluble residue. The main band of soluble material appears at 968 cm^{-1} , and this is very similar to the main band of C–S–H gel at 970 cm^{-1} .

4. Discussion

APC glass geopolymers have compressive strengths of 110 MPa after 28 days curing, high density (2.3 g cm^{-3}) and low porosity (5.5%). These properties are comparable to the properties of commercial sintered tiles, high strength concrete and geopolymer cements. The APC glass geopolymer samples subjected to flexural strength test developed cracks at the surface but did not fracture into separate pieces. Micro-structural analysis indicates that APC geopolymers have a heterogeneous microstructure containing un-reacted APC glass particles surrounded by a binder phase. The results suggest a toughening mechanism based on crack deflection [39] as previously proposed [13]. Cracks are forced to change direction when they encounter APC glass particles, and this crack deflection mechanism is similar to that reported in particle reinforced ceramic matrix composites [38,40]. The particle reinforcement associated with the un-reacted APC glass particles is considered to be particularly effective because the bond between the APC glass and the complex geopolymer matrix is expected to

be very strong as they both originate from the same material. Thus an effective load transfer mechanism occurs at the interface.

The thermal conductivity of APC glass geopolymers is similar to the thermal conductivity of concrete, indicating that APC glass geopolymers are not suitable for refractory applications.

Construction materials such as concrete, tiles and geopolymers must be extremely durable. Initial evaluation of the durability of APC glass geopolymer involved testing the chemical resistance and freeze and thaw resistance of samples. The acid resistance test showed that APC glass geopolymers have very good resistance to acid attack as the observed change in weight was <0.1%. This is in accordance with previous research which showed that geopolymers have very good acid resistance [8,41,42], even when Ca is added to the system [25]. It has been reported that geopolymer structures with Si/Al ratio of 1 are more susceptible to acid attack than geopolymers with higher silicon content [43]. APC glass geopolymers have a Si/Al ratio of 2.6 which explains the good acid resistance.

Freeze and thaw resistance of the material was evaluated by subjecting APC glass geopolymer samples to 92 freeze and thaw cycles. A 2% weight change and some peeling of the surface in contact with water were observed. Very good freeze and thaw resistance has been reported for geopolymer cements with a weight change <0.1% [8]. The test used required only 12 cycles while the APC glass geopolymers in this study were subjected to 92 cycles, and this makes comparison of the results difficult.

The leaching test performed for APC glass geopolymers revealed that APC glass geopolymers are inert and do not leach significant levels of heavy metals. Only low concentrations of Si, Al and Ca were detected, which are the main elements in the material. Significantly higher amounts of Na were observed, which originates from the activating solution. Release of heavy metals and other elements from the original APC glass was not observed as they are effectively encapsulated in the geopolymer micro-structure. This was expected as geopolymers have been used in hazardous waste management to encapsulate heavy metals [44–46] and radioactive wastes [47–50].

The results of the selective chemical attack with salicylic acid and methanol provide valuable information on the nature of APC glass geopolymers. The change in weight of APC glass geopolymer, after SAM method, revealed the presence of C–S–H gel in the APC glass geopolymer. Around 60% of the initial material was insoluble, while the soluble material is associated with calcium containing phases such as lime and C–S–H gel [17,24,26,27].

The results showed that only 50% of the Ca in the initial material was soluble which means that a significant amount remained in the insoluble residue. Part of the Ca in the insoluble residue is due to the Ca in the un-reacted APC glass, while the remainder can be attributed to non-hydrated alumino–silicate network containing Ca. This possibility of formation of silica-rich gel containing Ca has been reported previously in the literature [27,51,52]. The FTIR results confirm this possibility, as the main peak for the insoluble residue is at 1018 cm^{-1} , where the main peak occurs for

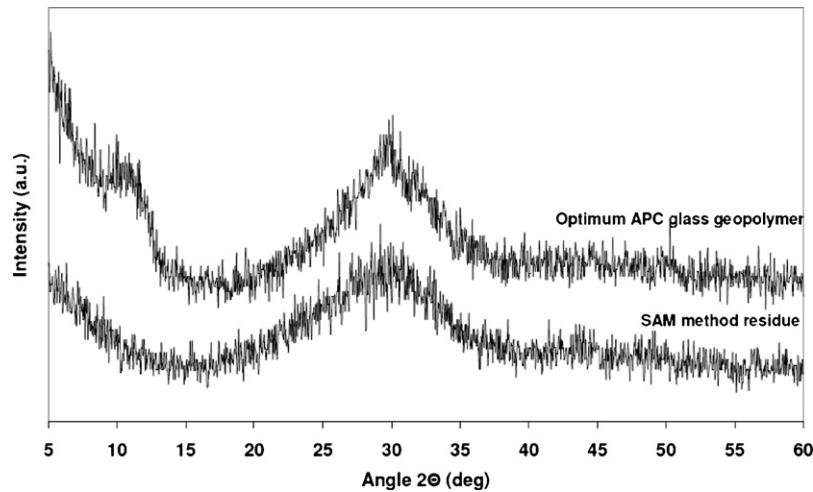


Fig. 4. XRD analysis of APC glass geopolymer and solid residue after SAM method.

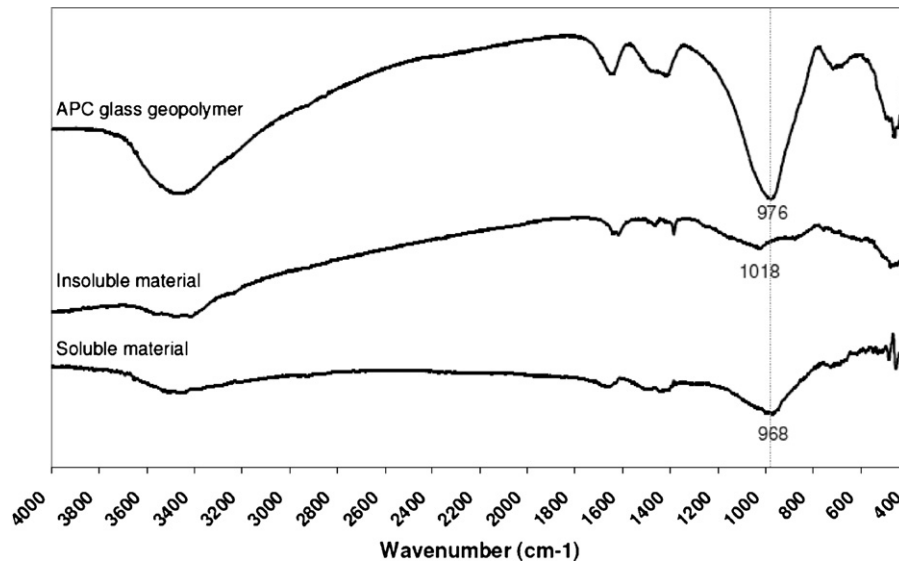


Fig. 5. FTIR analysis of initial APC glass geopolymer, insoluble residue after SAM method and soluble material.

geopolymers [53–55], while the main peak for the soluble material was at 968 cm^{-1} , where the main peak for C–S–H usually occurs [27,28,51,52,55,56].

The results of the SAM method suggest that the APC glass geopolymer contains both an alumino–silicate network containing calcium and C–S–H gel. The composition of the two phases seems to be quite similar and for that reason they cannot be identified using conventional methods such as XRD or SEM/EDS analysis.

5. Conclusions

APC glass geopolymer is not a pure geopolymer, but a composite consisting of a binder phase and un-reacted APC glass particles which act as reinforcement. The binder phase is a three dimensional geopolymeric network that contains C–S–H gel and probably Al modified C–S–H gel. The excellent mechanical properties of APC glass geopolymers can be attributed to these micro-structural characteristics. Geopolymers prepared from the glass derived from DC plasma treatment of APC residues have potential to be used in various pre-cast products such as paving blocks and tiles.

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