

ALKALI-ACTIVATED CEMENT MORTARS CONTAINING RECYCLED CLAY-BASED CONSTRUCTION AND DEMOLITION WASTE

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The use of clay-based waste as an aggregate for concrete production is an amply studied procedure. Nonetheless, research on the use of this recycled aggregate to prepare alkaline cement mortars and concretes has yet to be forthcoming. The present study aimed to determine: the behaviour of this waste as a pozzolan in OPC systems, the mechanical strength in OPC, alkali-activated slag (AAS) and fly ash (AAFA) mortars and the effect of partial replacement of the slag and ash themselves with ground fractions of the waste. The pozzolanic behaviour of clay-based waste was confirmed. Replacing up to 20 % of siliceous aggregate with waste aggregate in OPC mortars induced a decline in 7 day strength (around 23 wt. %). The behaviour of waste aggregate in AAMs mortars, in turn, was observed to depend on the nature of the aluminosilicate and the replacement ratio used. When 20 % of siliceous aggregate was replaced by waste aggregate in AAS mortars, the 7 day strength values remained the same (40 MPa). In AAFA mortars, waste was found to effectively replace both the fly ash and the aggregate. The highest strength for AAFA mortars was observed when they were prepared with both a 50 % replacement ratio for the ash and a 20 % ratio for the aggregate.

INTRODUCTION

The construction industry generates large volumes of waste. In 2012, over 2.5 million tonnes of waste were generated in Europe, 33 % of which (819 million tonnes) was construction and demolition waste (C&DW) [1]. This situation has prompted the adoption of a series of regulations in Spain to minimise the concomitant environmental impact. Waste management in general is governed by Act 22/2011 [2]. Construction and demolition waste management is addressed more specifically in Royal Decree 105/2008 [3], which aims to further its reduction as an alternative to stockpiling in landfills and foster appropriate valorisation so as to reduce the consumption of natural resources. In addition, national C&DW management plans (Spanish initials, PNCRD) have been instituted. The specific objectives of the second such plan, covering the period 2008-2015, include waste reduction, reuse, recycling, valorisation and elimination. It also sets out the measures to be adopted and sources the respective funding [4]. Similarly, a European directive requires Member States to introduce measures as required to ensure the re-use, processing, recycling and other valorisation operations of at least 70 wt. % of non-hazardous C&DW by 2020.

According to the "Construction and Demolition Waste" specifications sheet published by the Spanish Ministry of the Environment in 2009 [5], 54 % of domestic C&DW consists of clay-based materials, which are

classified in the European List of Waste [6] as non-hazardous industrial waste.

Whether consisting of clay-based or sanitary ware factory rejects or of construction and demolition waste, these clay-based materials can be reused in the construction industry in very different ways.

Many studies have confirmed the viability of using clay-based waste as a sub-base in road construction [7-9]. It can also be used as a pozzolan in Portland cement manufacture [10, 11] and as an alternative raw material in the preparation of cement raw mix [12-14]. The presence of clay-based waste as a partial replacement for cement at rates of up to 30 % has beneficial effects on the mechanical strength and durability of the end materials.

Puertas et al. [12-14] studied and quantified the effect of the total replacement of clays and the partial replacement of limestone in portland raw mixes with this waste (up to contents of 15 wt. %). The clinkers and cements obtained met the physical, chemical and mechanical requirements laid down in European legislation. These authors also assessed belite cements (with C_2S contents of over 50 wt. %) prepared with clay-based waste and the mineral pair $CaF_2/CaSO_4$ [15]. The abundance of boron in this ceramic waste was observed to favour the stabilisation of high temperature C_2S polymorphs. Isothermal conduction calorimetric studies showed that the belite cements obtained developed heat of hydration values and heat flows comparable to those of portland cements with greater alite phase contents.

Moreover, clay-based waste, composed primarily of Si and Al oxides, may potentially respond to alkaline activation. Alkali-activated or alkaline cements are alternative binders with amply discussed energy and environmental advantages [16, 17]. In 2006, Puertas et al. [12] studied the alkaline activation of clay-based waste. Those studies showed that feldspars were the phases most readily activated and that the activator concentrations had to be higher than 6 M. Other authors [18-20] have also analysed the use of clay-based waste as materials for preparing alkaline cements. Reig et al. [18] reported that red clay brick waste could form alkali-activated pastes and mortars with 7-day compressive strengths on the order of 30 MPa when the activating solutions used were NaOH and sodium silicate.

The use of clay-based waste as an aggregate for concrete production is a well-known and amply studied procedure [21-26]. Given the composition of this material, it favours concrete performance and durability, as substantiated by its compliance with national and international concrete specifications. Nonetheless, research on the use of recycled aggregate to prepare alkaline cement mortars and concretes has yet to be forthcoming. The present study aimed to determine the pozzolanicity of this material in OPC systems and the mechanical strength of mortars made with alkali-activated slag and fly ash, using variable proportions of clay-based aggregate. The effect of partial replacement of the slag and ash themselves with finely ground fractions of the waste was also explored. Performance of these materials was compared to portland cement behaviour throughout.

EXPERIMENTAL

Materials: characterisation of clay-based waste

The materials used in this study included CEM I 52.5R portland cement (OPC) furnished by Grupo Cementos Valderrivas (cement plant at Madrid, Spain), a vitreous blast furnace slag (SL) furnished by ArcecorMittal (steel mills at Oviedo, Spain), a fly ash (FA) from coal combustion at the Puente Nuevo power plant (province of Ciudad Real, Spain) and clay-based waste (C) consisting of hollow brick taken from a construction site.

XRF was conducted of all the materials on a PHILIPS PW 1404/00/01 to determine their chemical composition. The reactive silica content of the clay-based waste was ascertained as described in [27]. The percentage of the vitreous phase in the slag was determined by polarised transmitted light microscopy using the Hooton and Emery method [28], while the vitreous phase of FA and clay-based waste content was found by attacking the sample with 1 % HF as described by Fernández et al. [29]. The findings are given in Table 1.

The clay-based waste (C) comprised primarily Si and Al oxides, with a vitreous phase on the order of 60 %.

OPC, vitreous slag and fly ash mineralogy were characterised as described in previous references [30-32].

The original (C) and fired (at 1000°C) (Cc) clay-based waste were characterised using XRD and FTIR. The diffraction patterns and IR spectra are reproduced in Figures 1 and 2, respectively.

The halo beginning at $2\theta = 20^\circ$ on the XRD patterns (recorded with a Bruker AXS D8 Advance diffractometer) confirmed the high amorphous phase content in this clay-based waste. The main crystalline phases identified in sample C were as follows (Figure 1a): quartz (SiO_2), muscovite ($\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$), hematite (Fe_2O_3), calcite (CaCO_3), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and a sodium aluminosilicate hydrate ($\text{Na}_2\text{Al}_2\text{Si}_x\text{O}_z \cdot 2\text{H}_2\text{O}$). This composition is similar to findings described by other authors for clay-based waste [18, 33, 34] (Sample Cc (clay-based waste fired at 1000 °C) (Figure 1b) also contained quartz (SiO_2) and hematite (Fe_2O_3), although the diffraction lines for gypsum were absent and a new phase, anhydrite (CaSO_4), was identified. While no signals for sodium aluminosilicate hydrate were found, lines attributed to a phase formed during its calcination, anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), were observed [33].

Table 1. Chemical composition of the materials.

	OPC %	SL %	FA %	C %
SiO_2	20.51	35.34	54.42	57.21
Al_2O_3	5.37	13.65	26.42	18.60
CaO	57.05	41.00	3.21	5.38
Fe_2O_3	2.10	0.39	7.01	4.97
CO_2	–	–	–	3.60
K_2O	1.44	–	3.02	3.45
MgO	3.86	4.11	1.79	3.31
SO_3	6.37	–	0.01	1.32
Na_2O	0.64	0.01	0.59	1.09
TiO_2	0.16	–	–	0.77
P_2O_5	0.13	–	–	0.16
MO	–	–	–	0.07
SrO	–	–	–	0.03
CuO	–	–	–	0.02
ZnO	–	–	–	0.02
MnO	0.02	–	–	–
SO_3	–	0.06	–	–
S^{2-}	–	1.91	–	–
LoI*	2.35	2.72	2.19	3.60
TOTAL	100.26	99.83	99.44	100.00
IR**	0.26	0.64	0.78	78.74
Reactive silica (%)	–	–	43.66	30.25
Vitreous phase	–	99.00	61.08	59.00
Blaine ($\text{m}^2 \cdot \text{kg}^{-1}$)	481	325	202	–

* LoI: loss on ignition, ** IR: insoluble residue

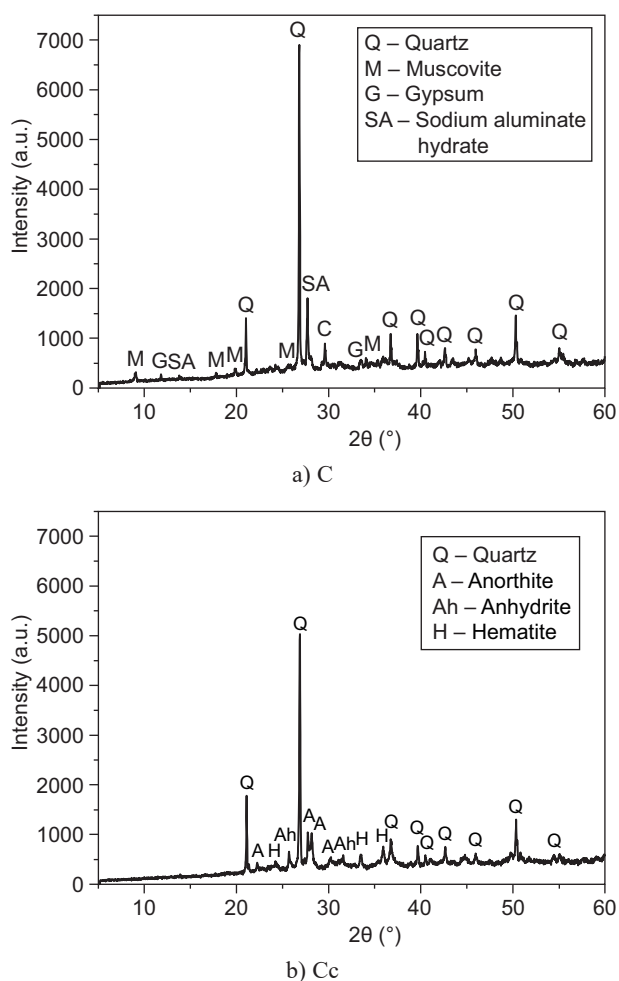


Figure 1. XRD patterns for clay-based waste: a) C and b) Cc.

The FTIR spectra were obtained by analysing KBr pellets containing 1.0 mg of a sample of clay-based waste in 300 mg of KBr on an Nicolet 6700 FTIR Thermo Scientific spectrometer. The spectra were recorded after running 64 scans in the 4000 - 400 cm^{-1} range. The series of bands at frequencies of 1120 - 1000 cm^{-1} (Figure 2) is characteristic of T–O and T–O–T (T = Si, Al) bond vibrations. More specifically, the highest frequency band

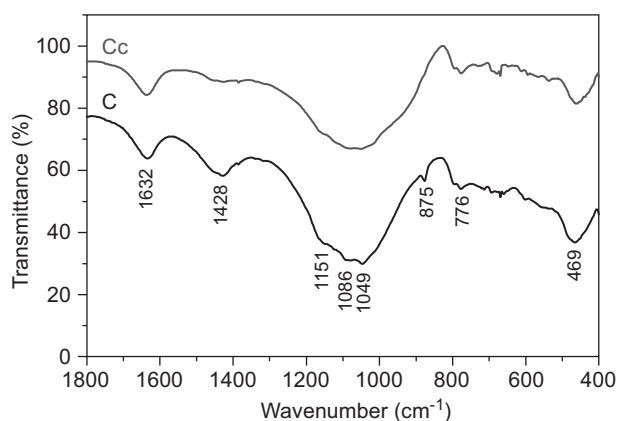


Figure 2. FTIR spectra for wastes C and Cc.

(~ 1100 cm^{-1}) is associated with T–O bond stretching vibrations in the aluminosilicate phases comprising the waste. The band at 780 cm^{-1} , in turn, was attributed to the ν_1 (Si–O–Si) vibrations generated in the quartz present, and the one at around 584.5 cm^{-1} to the Al–O bond vibrations typical of aluminosilicates [34-36]. The presence of sulfates was confirmed by vibrations in the 1120 - 1160 cm^{-1} region. The FTIR findings, in short, verified the XRD results.

Table 2 lists some of the physical properties of the waste studied (C), with a comparison to standard siliceous sand (99 % quartz material) (S) as described in European standard EN 196-1 [37]. Water absorption and bulk density were determined as per European standard EN 1097 [38]. An analysis of the findings showed that while clay-based waste and siliceous sand had similar densities, water absorption was ninety times greater in the former.

Table 2. Standard siliceous sand (S) and waste (C). Water absorption and bulk density.

	S	C
Water absorption (%)	0.07	6.52
Bulk density (g m^{-3})	2.64	2.53

Clay-based waste pozzolanicity

Samples C and Cc were tested for pozzolanicity as per European standard EN 196-5 [39]. Cements containing 30 % waste (with a particle size of under 45 μm) and 70 % of the OPC used in this study (see Tab. 1) were prepared. Hydroxide and calcium oxide concentrations were determined in 2-, 8- and 20-day samples.

The possible pozzolanicity of C and the effect of its presence on mechanical strength development, in turn, were tested with two types of mortars: OPC with siliceous aggregate (OPC-S) and mortars containing clay waste (C) (particle size < 45 μm) at a 20 % replacement ratio (OPC/C (80:20)-S).

Clay-based waste as a raw material for preparing alkali-activated materials

Prismatic specimens (1 × 1 × 6 cm) were moulded with the 8 M NaOH (N)-activated C and Cc (particle size < 45 mm) pastes to analyse the aptness of clay-based waste for use in the preparation of alkali-activated materials. These pastes were then compared to two others: one made with 4 % Na_2O waterglass (Wg)-activated vitreous slag with a silica modulus ($\text{SiO}_2/\text{Na}_2\text{O}$) of 1.2 and the second with 8 M NaOH (N)-activated fly ash. Tests were also conducted on blends of clay-based waste (C) and vitreous slag (SL) or fly ash (FA) at replacement rates of 80:20 and 50:50. Table 3 lists the composition of the blends prepared and respective labels.

Table 3. Paste preparation: conditions.

	Binder (wt. %)			Alkaline solution		Solid/Liquid	Curing conditions
	SL	FA	C	NaOH	Wg		
CN	–	–	100	X	–	0.45	H
CcN	–	–	100	X	–	0.55	H
SLWg	100	–	–	–	X	0.38	HC
FAN	–	100	–	X	–	0.25	H
SL/C(80:20)Wg	80	–	20	–	X	0.40	HC
SL/C(50:50)Wg	50	–	50	–	X	0.45	HC
FA/C(80:20)N	–	80	20	X	–	0.30	H
FA/C(50:50)N	–	50	50	X	–	0.35	H

Curing conditions: H: 99 % RH and $85 \pm 2^\circ\text{C}$ in the first 20 h and $> 90\%$ RH and $20 \pm 2^\circ\text{C}$ for the remainder; HC: 99 % RH and $20 \pm 2^\circ\text{C}$ throughout.

The 7-day pastes were tested for mechanical strength on an Ibertest Autotest 200/10 hydraulic press as specified in European standard EN 196-1 at a rate of $2\,400\text{ N/s} \pm 200\text{ N/s}$.

Mortar preparation

OPC mortars

OPC mortars were prepared with the non-fired clay-based waste (C), which was used to replace the aggregate. For this purpose, waste C was ground and subsequently sieved to a particle size distribution comparable to the distribution in standard sand (S) [40] given in Table 4. The aggregate: binder ratio in all the mortars prepared was 2:1

The aggregate substitutions of the siliceous sand (S) by clay-based waste (C) were 100 and 20 %. A further variable studied in the mortars was the state of the clay-based waste: normal (dC) or saturated in water/alkaline solution to prepare the mortar (wC) when they were used as aggregates. The solid/liquid (S/L) ratio in the mortars

Table 4. Particle size distribution of standard siliceous sand (S).

Sieve mesh size (mm)	(wt. %) retained
2.00	–
1.60	8.88
1.00	26.49
0.50	31.13
0.16	24.07
0.08	9.25
Receiver	0.18

was varied to ensure a pre-established slump measured on the spread table described in Spanish standard UNE 83-811-92 [41]. Table 5 lists all the OPC mortars prepared.

Mortars were cured in a climatic chamber at 99 % relative humidity and $20 \pm 2^\circ\text{C}$ for the first 24 hours. The specimens were subsequently removed from the moulds and kept in the climatic chamber, submerged in water, until the test age. All samples were tested for bending and compressive strength at 2, 7 and 28 days.

Alkaline mortars

Alkaline mortars were also prepared with the non-fired clay-based waste (C), but here the waste was used to replace both the binder and the aggregate. As in OPC pozzolanic mortars, when replacing the binder the particle size used was consistently under $45\ \mu\text{m}$ and when the siliceous aggregate (S) was replaced, the particle size distribution of C was the same as S (Table 4). The aggregate: binder ratio in all the mortars prepared was 2:1

The replacement ratio for the alkaline binders (slag or fly ash) was 50 %. The standard aggregate was replaced by clay-based waste (C) at rates of 100 and 20 % of the dC (normal) and wC (saturated in the liquid used in each case) siliceous sand, respectively, as described for the OPC mortars. Lastly, in some mortars both binder and aggregate were replaced by clay-based waste (50 % for the binder and 20 % for the aggregate). The solid/liquid (S/L) ratio was determined as required to reach a preestablished slump, as described in item 2.4.1 [41]. Table 6 lists all the mortars prepared.

Table 5. OPC mortar preparation: conditions.

	Binder (wt. %)		Aggregate (%)			Liquid	S/L	Curing conditions
	OPC	C < 45	S	dC	wC			
OPC-S	100	–	100	–	–	H ₂ O	0.44	HC
OPC-dC	100	–	–	100	–	H ₂ O	0.80	HC
OPC-wC	100	–	–	–	100	H ₂ O	0.54	HC
OPC-S/dC (80:20)	100	–	80	20	–	H ₂ O	0.52	HC

Curing conditions: HC: 99 % RH and $20 \pm 2^\circ\text{C}$ throughout.

Table 6. Alkaline mortar preparation: conditions.

	Binder (wt. %)			Aggregate (%)			Liquid	S/L	Curing conditions
	SL	FA	C < 45	S	dC	wC			
SL-S	100	–	–	100	–	–	Wg	0.54	HC
SL-dC	100	–	–	–	66.6	–	Wg	0.79	HC
SL-wC	100	–	–	–	–	100	Wg	0.64	HC
SL-S/dC (80:20)	100	–	–	80	20	–	Wg	0.60	HC
SL/C (50:50)-S	50	–	50	100	–	–	Wg	0.66	HC
SL/C (50:50)-S/dW (80:20)	50	–	50	80	20	–	Wg	0.66	HC
FA-S	–	100	–	100	–	–	NaOH	0.34	H
FA-dC	–	100	–	–	100	–	NaOH	0.65	H
FA-wC	–	100	–	–	–	100	NaOH	0.50	H
FA-S/dC (80:20)	–	100	–	80	20	–	NaOH	0.40	H
FA/C (50:50)-S	–	50	50	100	–	–	NaOH	0.50	H
FA/C (50:50)-S/dC (80:20)	–	50	50	80	20	–	NaOH	0.50	H

Curing conditions: H: 99 % RH and 85 ± 2°C in the first 20 h and at > 90 % RH and 20 ± 2°C for the remainder; HC: 99 % RH and 20 ± 2°C throughout.

Alkali-activated slag (AASL) mortars were cured in a climatic chamber at 99 % relative humidity and 20 ± 2°C for the first 24 hours. The specimens were subsequently removed from the moulds and stored in the climatic chamber until the test age. The activated fly ash mortars (AAFA) were cured for the first 20 hours at 85 ± 2°C and > 90 % relative humidity to prevent possible carbonation. After removal from the moulds, they were stored in a climatic chamber at 99 % relative humidity and 20 ± 2°C until tested.

All samples were tested for bending and compressive strength at 7 days and selected samples were tested at 2, 7 and 28 days.

RESULTS AND DISCUSSION

The findings for the waste itself (pozzolanicity and response to alkaline activation), as well as for the mortars prepared using it as recycled aggregate or binder are discussed below.

Clay-based waste pozzolanicity

Further to the [OH⁻] and [CaO] ion concentrations (mmol/l) given in Table 7 and Figure 3, found with the Frattini test [39], both C and Cc proved to be pozzolanic

Table 7. [OH⁻] and [CaO] ion concentrations for clay-based waste (mmol litre⁻¹).

	Ion concentration (mmol·litre ⁻¹)			
	2 days	8 days	20 days	
C	[OH ⁻]	56.5	57.25	58.25
	[CaO]	9.05	7.8	5.25
Cc	[OH ⁻]	56.5	55.25	58.5
	[CaO]	9.75	7.29	5.45
Pozzolanic	NO	YES	YES	

after the eighth day. Although the standard specifies that if an 8-day sample is compliant it need not be tested after 15 days, here the tests were conducted again after 20 to verify the data.

Figure 4 shows that in mortars containing 20 % ceramic waste C as a pozzolanic addition to cement, which would be equivalent to CEM-II AV category cement as per the classification in European standard EN-197-1 [42]; mechanical strength was slightly lower than in mortars where a 100 % OPC binder was used. More specifically, the 2-, 7- and 28-day compressive strength values were 19, 17 and 15 % lower, respectively, in the waste-containing mortars. These findings show that the pozzolanic reaction and concomitant C-S-H gel formation generated by the waste contributed to mechanical strength because at all ages, the reduction in strength was smaller than the waste-for-cement replacement ratio (20 %). To put it another way, the strength activity index was greater than 1 at all the ages studied Comparable findings have been reported for other types of clay-based waste [22].

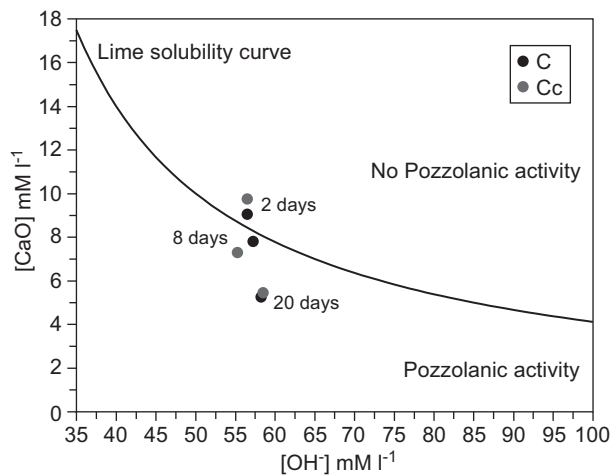


Figure 3. Pozzolanicity test.

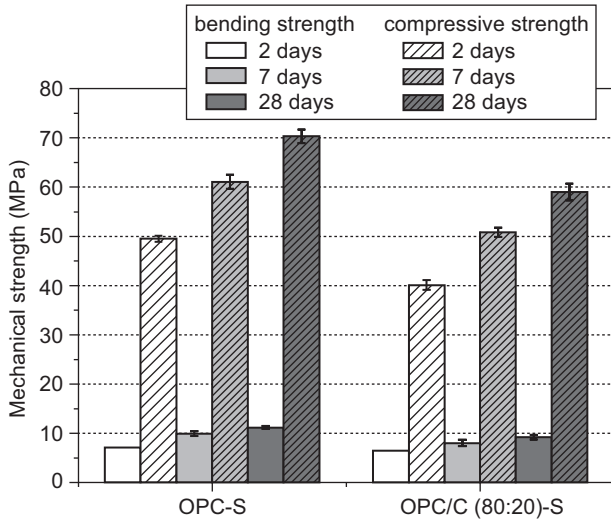


Figure 4. Two-, 7- and 28 day mechanical strength in OPC-S and OPC/C (80:20)-S mortars.

Clay-based waste as a raw material for preparing alkali-activated materials

Figure 5 shows the bending and compressive strength findings for the clay-based waste pastes tested to ascertain their response to alkaline activation. According to the graph, both compressive (8 - 10 MPa) and bending (around 1 MPa) strength values were low in CN and CcN pastes. This apparent indication of scant response constitutes anomalous behaviour whose explanation calls for further research.

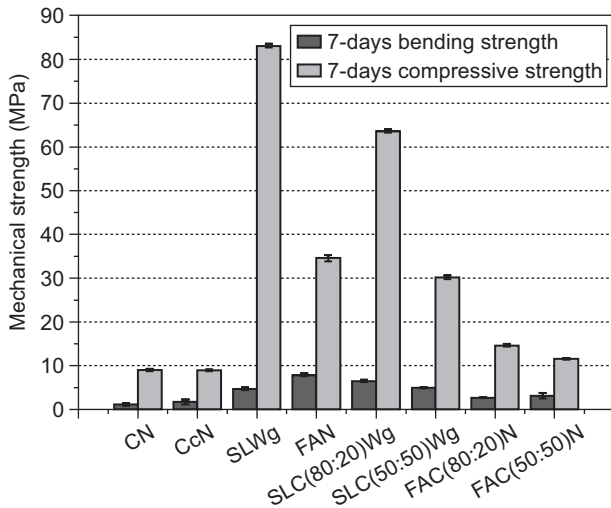


Figure 5. Bending and compressive strength in 7 day pastes.

As expected, the best 7-day results, with values of upward of 80 MPa, were obtained for slag when alkali-activated alone. When it was replaced with clay-based waste C, strength declined by 23 and 63 % at replacement ratios of 20 and 50 %, respectively: i.e., the effect of this waste was not beneficial.

The alkali-activated fly ash pastes, in turn, developed 7-day compressive strengths on the order of 35 MPa. Replacing the fly ash with waste C had no beneficial effect on mechanical strength either, with 57 and 66 % reductions when the replacement ratios were 20 and 50 %, respectively. Other authors have reported comparable findings [12, 18, 19, 20, 43]. Inasmuch as activating conditions (liquid/solid ratio, activator nature and concentration, testing age) clearly impact geopolymer strength development [44], however, direct comparisons of these to other authors' results is difficult. The optimal activating conditions must be determined for each clay-based waste, depending on its nature, chemical composition and vitreous content.

When waste C was blended into the slag or ash, the resulting pastes consistently required greater amounts of mixing liquid. Figure 6 graphs the relationships between liquid/solid ratio and 7-day compressive strength for all the pastes studied. Since by itself the clay-based paste had negligible (< 10 MPa) mechanical strength, no appreciable effect was observed in this sample. In contrast, the ratio had a very visible effect on alkali-activated slag pastes: an increase in waste C led to a rise in the liquid required for a given consistency, along with a substantial decline in strength. The findings for the fly ash pastes occupied the middle ground between these two extremes.

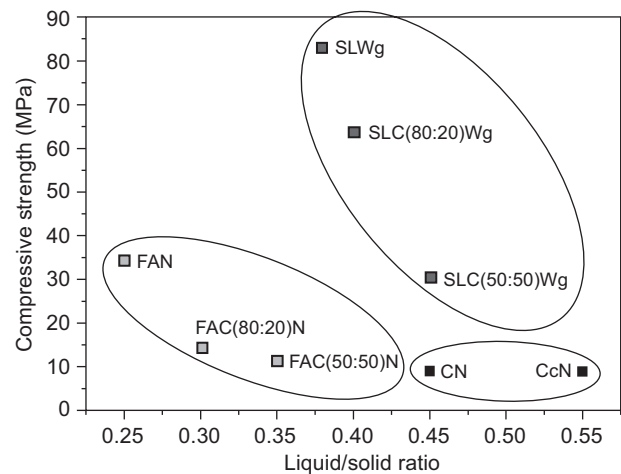


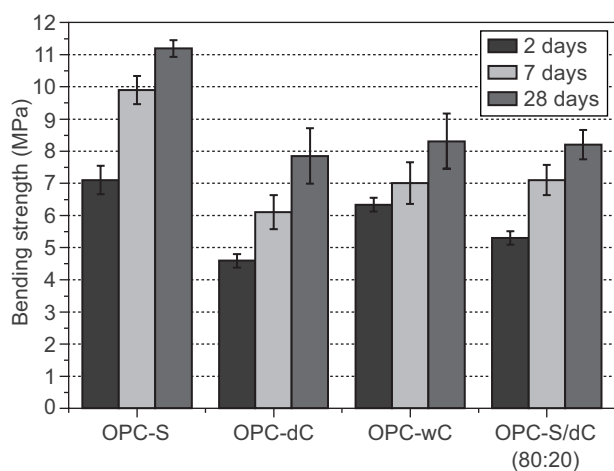
Figure 6. Liquid/solid ratio versus 7 day compressive strength.

Mechanical strength in mortars

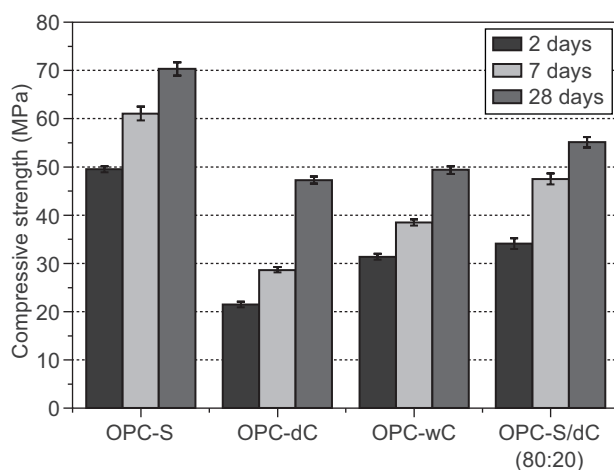
OPC mortars

The mechanical behaviour of all the mortars graphed in Figure 7 shows the effect of replacing the standard siliceous sand with (saturated, wC, or non-saturated, dC) clay-based waste in OPC mortars. Total replacement of the aggregate lowered the 7-day mortar compressive strength by 38 or 54 %, depending on whether or not the waste was water-saturated, an effect associated with the higher water/cement ratio in the non-

saturated material (see Table 5). When the aggregate was partially replaced (80:20), 7-day strength declined by 23 %. These findings were consistent with other studies [26, 45-48], according to which strength declined with rising recycled aggregate percentages in mortars and concrete. The 28-day strength value for mortar made with 20 % clay-based aggregate was 21 % lower than in mortars containing 100 % siliceous sand as aggregate. In contrast to 7-day mortar behaviour, however, the dip in strength was very similar regardless of whether the waste used was saturated or unsaturated. These results show that the clay-based waste can be used as an aggregate in OPC mortars.



a) bending strength



b) compressive strength

Figure 7. Bending (a) and compressive (b) strength in 2-, 7- and 28 day OPC mortars.

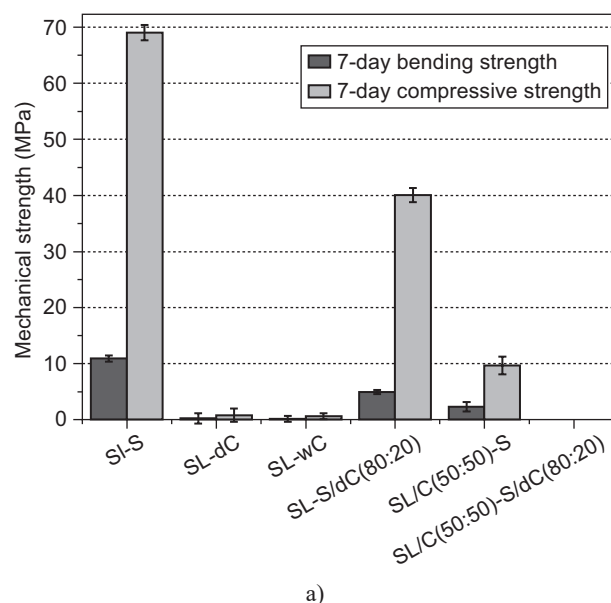
Alkaline mortars

In alkali-activated slag mortars (Figure 8), the clay-based waste had an adverse effect when used as aggregate, whether saturated or otherwise in the activating solution. That effect might be attributed to the absorption of part of the activating solution by the waste, preventing slag activation, although such an explanation

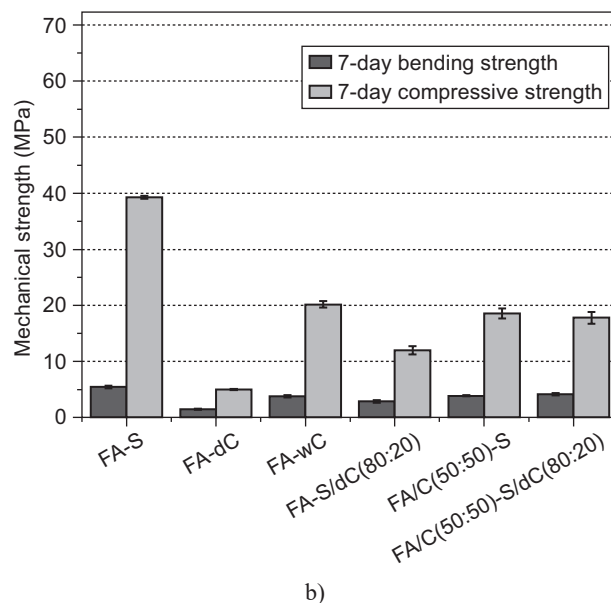
would not apply to the solution-saturated aggregate. The reasons underlying the poor behaviour observed would call for further study.

AASL mortar strength was also low when the siliceous aggregate was partially replaced by the recycled material: compressive strength was 42 % lower in mortars containing 20 % of the recycled aggregate than in the control slag, further confirming the poor performance of clay-based waste in AASL systems. Performance was no better when the waste was used to replace the slag itself, with strength values of 10 MPa or lower when the replacement ratio was 50 %.

Lastly, when both aggregate and binder were replaced, the slag mortars developed no 7-day strength. Here also, the explanation may be found in the absorption of the activating solution by the clay-based waste.



a)



b)

Figure 8. Bending and compressive strength in 7 day mortars.

Moreover, the activating conditions (low activator concentration and ambient temperature curing) were scantily ideal for materials with low Ca contents (such as clay-based waste). The end result was the non-formation of a sufficient amount of reaction or cohesive products for the specimens to harden.

Strength declined less in the fly ash mortars containing saturated than in the materials with non-saturated recycled aggregate, an effect logically associated with the liquid/solid ratio required to prepare the mortars (see Table 6). When the recycled aggregate was saturated, the ratio was lower than otherwise.

The partial replacement of fly ash with clay-based waste proved to have no adverse effect, for the 7-day compressive strength in the resulting mortar was nearly 20 MPa. Moreover, similar strength values were observed when both the binder (ash, 50:50) and the aggregate (80:20) were replaced. These findings confirm that given the chemical and mineralogical composition of clay-based waste, it can act as a binder similar to (albeit less effective than) fly ash and as a partial replacement for aggregate.

Lastly, when alkali-activated fly ash mortars were prepared with 50 % blends of ash and waste and 20-80 % blends of waste and siliceous aggregate, they developed 7-day strength around 20 MPa. Alkali-activated fly ash mortars with no replacements generally exhibit mechanical strength of 20 - 40 MPa [43, 49].

CONCLUSIONS

The conclusions drawn from the present study are listed below.

- The Frattini test showed that clay-based waste (with a chemical composition based primarily on SiO₂ and Al₂O₃) is highly pozzolanic.
- Nonetheless, it does not respond to alkaline activation, nor does it have a beneficial effect on strength when blended with vitreous blast furnace slag or fly ash.
- Such construction waste can viably replace up to 20 % of standard siliceous aggregate in OPC mortars.
- The performance of such recycled aggregate in alkaline cements depends on the nature of the aluminosilicate (slag or fly ash) and the replacement ratio.
- In 7-day alkali-activated vitreous slag mortars containing 20 % recycled aggregate, strength was on the order of 40 MPa. Replacing the slag with clay-based waste had no beneficial effect on mechanical strength.
- In alkali-activated fly ash, clay-based waste may be used to replace either the aluminosilicate (fly ash) or the siliceous aggregate. The optimal replacement ratios in this case were 50 wt. % for the binder and 20 wt. % for the aggregate.

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