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Reuse of waste from the South West of England in alkali-activated cement concrete

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Abstract. The extraction of china clay in the South West of the UK generates waste in a mass ratio of 1:9 for china clay: waste. Currently, part of the coarser waste, "stent" and sand named "china clay sand" (CCS) in this study, is used as building stone or secondary aggregate in concrete and asphalt but the finest waste fraction, called "mica" waste, is used only for the restoration of old quarries. Looking for innovative solutions for the needs of a new Eco-town in the UK, and with regard to uses commercially applicable to construction and of low environmental impact, the china clay waste is being studied as an aggregate in alkali-activated cements (AAC).

Aiming to replace primary aggregates with wastes in low risk construction materials, a series of AAC concrete based on a 50% Ground Granulated Blastfurnace Slag (GGBS) and 50% Fly Ash (FA) blend and an equivalent Portland concrete series were produced. In the mixes the primary aggregate was steadily replaced by forms of the waste and tests in compression showed a decreasing trend in strength accordingly. The two series of concrete follow approximately the same ratios of decrease although in absolute values the AAC series reached higher range of strengths on the 28 day compared to the Portland series. While the use of CCS did not have any negative impact, the addition of mica decreased the strength up to 25% more.

Introduction

In 2011 the production of kaolinite in the UK was 1,290,000 tonnes [1] which corresponds to over 11,000,000 tonnes of waste. Though the waste has several forms, the main three are: "stent" which is large fragments of unaltered granite up to 2 m diameter; "china clay sand" (CCS), the smaller fragments which result from the fragmentation of the overburden and the processing for the separation of kaolin; and, "mica" (M) which results after the use of the hydrocyclones [2] and has maximum particle size just over 0.5 mm.

Approximately 20% of stent and china clay sand are used every year as secondary aggregate, while mica waste is only used in mine reclamation. Stent is broadly considered reliable as a coarse aggregate in concrete and asphalt and has been used in several projects, some of large scale as the construction of the A30 Bodmin to Indian Queens dual carriageway [3], the One Coleman Street in the city of London [4] and the Aquatic Centre, Handball Arena and the Stadium built for the 2012 London Olympics [5]. After processing, the china clay sand can conform to BS EN 12620 Grade 0/4 (MP) [6] as aggregate for concrete. Although the concrete using that sand conforms to the BS 8500 and BS EN 206-1 [4], to date it has not been widely used due to its high water demand [4]. Mica mineral in the free form is considered disadvantageous [7], as it increases the water demand and so increases required cement content to achieve a specified strength. Previous studies [8,9] have shown that even low contents of free mica in the aggregate can cause significant decrease to the strength of Portland cement concrete. For that reason the mica waste is not used as a secondary aggregate in conventional Portland cement concrete.

As part of a broader research on the use of the china clay waste in sustainable construction, this paper investigates the suitability of using the waste in AAC concrete. Geopolymers, as known in their generic name, is an alternative to Portland cement with lower CO_2 emissions [10]. A previous paper of this project [11], looking at the performance of the waste in AAC mortar, showed that the increase of the water demand was the main reason for the reduction in the compressive strength of the test mortars using mica and china clay sand. Other authors have looked at the kaolin waste from Brazil with a focus on altering the leftover kaolinite to metakaolin to use it as binder [12-14]. However, that cannot apply to the waste of the UK china clay production, as it does not contain high amounts of left-over kaolinite as present in the waste from Brazil.

Experimental work

Materials. The mineral composition of the waste is shown in Table 1. Although it varies between different batches, the results show that the waste is largely comprised of inactive minerals. The stent and CCS used in this study were supplied by Aggregate Industries. In Table 2 some physical properties of the aggregates are reported. The Mica was supplied by Imerys Ltd in Cornwall.

Table 1 Mineralogical analysis by X-Ray diffraction.

Constituents (wt%)	Kaolinite	Mica	Quartz	Feldspar	Schorl
Mica (M)	8	9	50	22	11
China Clay Sand (CCS)	4	9	58	21	8

Table 2 Aggregate properties.

	Stent	China clay sand 0/4	Mica
Apparent Particle Density (Mg/m^3)	2.67	2.68	2.71
S.S.D. Particle Density (Mg/m^3)	2.61	2.67	2.65
Water absorption (%)	1.3	1.1	1.5
L.O.I (%)	2.1	1.03 - 1.6	1.79
Classification to Alkaline Silica Reaction	Low	Low	-
Type of Deposit:	Igneous		
Aggregate type:	Granite		

Table 3 Chemical analysis of precursors by X-Ray fluorescence.

Constituents (wt%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI
GGBS	35.15	13.07	0.28	39.6	8.47	0.17	0.14	0.51	0.66	0.44	-	0.97
FA	49	23.5	8.7	2.4	1.4	0.8	3.06	0.87	-	-	1.1	4.4

The GGBS used was supplied by the Hanson Heidelberg cement group (Port Talbot works), whilst Cemex provided the 450-S type of FA. The chemical composition of FA and GGBS are given in Table 3. The Portland series was produced using CEM I 52.5N by Cemex.

The alkaline solution was mixed using a 50% NaOH solution (Sigma Aldrich) and a Na_2SiO_3 solution which was prepared using 50% spray-dried powder (Tennants Distribution Ltd. , Na_2O= 27.05, SiO_2 =53.5 and H_2O= 19.45 wt.%) and 50% H_2O. The activator contains more water than the water in the NaOH and Na_2SiO_3 solutions as noted in Table 4. Distilled water was used in all mixes.

Concrete. First, a Portland cement conventional concrete design was used based on the BRE guide for concrete mixes [15]. According to the design, 32% of the total aggregates are fine, of which half is sand 0/4 and half is fines. Since the target application for AAC concrete is blocks, the mix was designed to be of 0-10mm slump (class S1, conducted in accordance to BS EN 12350-2:2009 [16]; classes defined in BS EN 206:2013 [17]). The cement to water ratio (C/W) was set at 0.47 resulting in 383kg/m^3 Portland cement and 180kg/m^3 water.

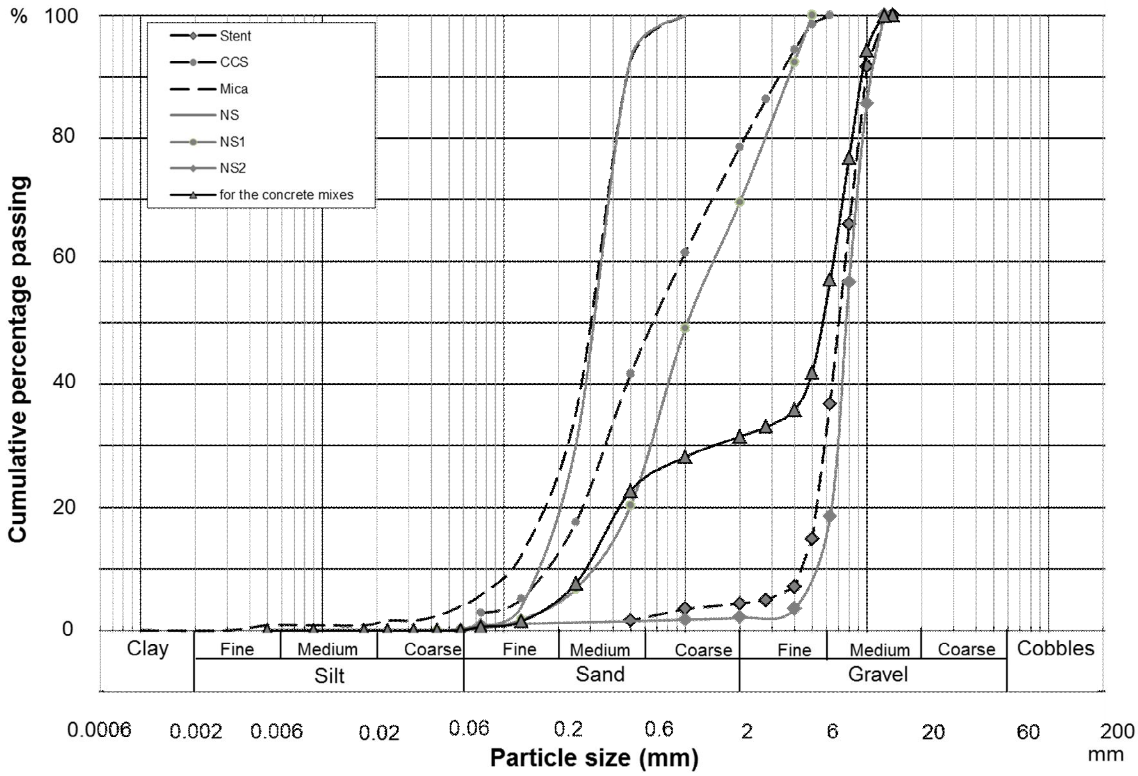

Fig. 1 Particle distribution of the coarse aggregate, sand and fines used in this study, as raw materials and combined.

To mix the equivalent AAC mixes the binder was calculated as equal in weight (563kg/m^3) and the aggregate composition did not change. The molar ratio in the alkaline solution was 1Na_2O: 1.00SiO_2: 33.71H_2O. The aggregates were used dry, rather than saturated surface dry. The mix design is presented in Table 4.

The control specimens of the two series (mix “a”) make use of regular coarse aggregate (Mendip rock, NS2), sand (Malborough sand, NS1) and fines (quartzitic builders sand, NS). To investigate the impact of the different forms of the waste in the mix, the primary aggregate was gradually replaced. The particle size distribution of all the aggregates used in this study is in Fig. 1.

The trial mixes of the Portland series had very poor workability while the AAC mixes were significantly more workable due to the rheological properties of FA in concrete. As the decided particle distribution of the aggregate was gap graded (fig.1) the very dry trial mixes could not give good consistency in compressive strength, hence it was decided to add extra water to reach 70-80mm in the slump test (falling in class S2 although the design was for Slump class 1). The higher water content and slump class were used as previous tests on binders and mortars showed that at lower water contents the AAC did not harden, probably because of poor dissolution.

The specimens were tested in compression after 7 and 28 days. The binder was mixed separately for 5 minutes and then added to the coarse aggregate in a pan mixer. The already blended fines and sand were then added. The last ingredient to be added was the extra water required for workability. The pan mixer was run for approximately 5 minutes until a homogeneous mix was formed. If the slump was less than 70-80mm the material would be further mixed with more water for 1 minute. The fresh concrete was cast in 100mm cubic moulds, compacted in 4 layers each receiving 25 blows. Triplicate specimens were used for every test.

Table 4 Concrete design for the two series of cement binder.

		Composition (in kg/m^3)			
PORT. BINDER	Portland		383.0		
	H_20		180.0		
AAC BINDER	GGBS		174.3		
	FA		174.3		
	H_2O added in the binder		127.9		
	NaOH solution		23.0		
	Na_2SiO_3 solution		63.4		
		Mixes			
		a	b	c	d
CONCRETE	NS2	1249.2			
	NS1	293.9	293.9		
	NS	293.9	293.9	293.9	
	Stent		1249.2	1249.2	1249.2
	CCS			293.9	293.9
	M				293.9

Results and Discussion

The compressive strength of the samples is summarized in Fig. 2. The standard errors of the mean which are noted on the columns are of small scale which indicated the reliability of the results.

Compared to the control specimens (mix “a”) all the test specimens gave lower compressive strength. The results in general show a common trend: a decrease for the use of stent and CCS (mixes “b” and “c”), although being broadly used as secondary aggregate, and a further decrease for the use of M (mix “d”). While on day 7 the performance of the Portland and the AAC series is similar, on the 28th day the AAC series has gained significantly more strength compared to the slightly improved Portland series. The common trend between the two series and the fact that on the 28 day the strength of mixes “b” and “d” of the AAC series is approximately the same with the control mix of the Portland series (46MPa) means that the stent and CCS can well replace primary aggregate when combined with a suitably formulated AAC binder.

Important is the issue of the use of extra water to achieve the required workability. Although this issue is not going to be analysed in detail in this paper, table 5 presents the extra water added in the mixes to achieve the required slump as it is has some relevance to the outcome strength. Initial research [11] was focused on mortars and has shown that the use of M results in the drop of strength compared to a mortar using standard sand. It was suggested that was due mainly to the increase in water demand, caused by the use of the M, which was much finer than the standard sand used, rather than any mineralogical factors.

Table 5 Extra water in the mixes to reach 70-80mm slump (in % of the total water in the binders).

	Mixes			
	a	b	c	d
Portland series	12%	37%	40%	40%
AAC series	5%	15%	15%	23%

Taking into consideration that the decrease due to the use of mica (difference between mixes “c” and “d”) according to fig.2 is 11% for the Portland series (same amount of extra water used, table 5) and 23% for the AAC series (while mix “d” used more extra water), it is suggested that M could be used in small quantities to replace a material with similar particle size distribution (Fig. 1) as builders sand with small decrease of the strength.

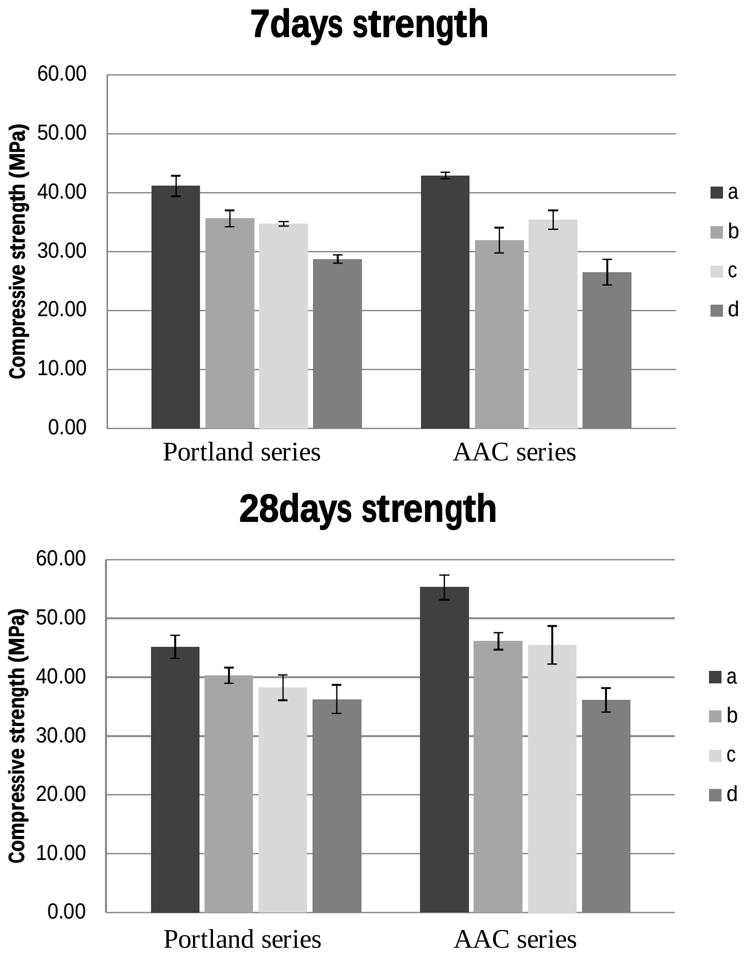

Fig. 2 Results of the compression strength on the 7 and 28 day.

Conclusions

The compressive strength of concrete using china clay waste was investigated in this paper. Two types of binder were mixed: Portland as control mix and an alkali-activated based on a GGBS and FA blend. The results show that replacing fine quartzitic sand in the mixes with stent, CCS and M waste gradually impairs the compressive strength, up to 36% with M only inducing a 5-25% decrease. The effect of the sand replacement was greater on the AAC series than the Portland series. Durability issues are not addressed in this paper, although they play an important role and they are under investigation in an on-going project.

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