Potentials of calcined clay as a pozzolan

Kalcinált agyag puccolános anyagként való használatának lehetőségei

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Abstract

Calcined clay (CC) is a promising pozzolan recently attracting research attention globally. Various investigations have shown the desirable attributes of the material as a Supplementary Cementitious Material (SCM) in cement concrete systems. This paper captures the compressive strengths impact of calcined clay-Portland cement (CC-PC) as binders in both concrete and soil systems. Grade 20 concrete cubes were prepared and tested; adopting five CC-PC binder blends obtained by replacing PC with CC at 0(control), 5, 10, 15, and 20%; designated as PC100, PC95, PC90, PC85, and PC80, respectively. Similarly, four CC-PC binder blends PC100(control), PC75, PC50, and PC25 were adopted to stabilise samples of A-2-6 lateritic soils at increasing content of 0, 2.5, 5, 7.5, 10% of the soil's weight. Results show that compressive strengths of the concrete samples increase with cement replacement. PC80 impacts the highest strengths with 7, 28 and 56-day strength activity indices (SAIs) of 174.7, 126.0 and 144.9%, respectively. In soil stabilisation, unconfined compressive strength (UCS) of the soil was found to increase with binder contents (2.5% to 10%) for the four binder designations. Compared to control (PC100), the PC75, and PC50 binders were better stabilisers with 7 and 28-day SAIs ranging between 105 and 275%, respectively. From the results, for applications across concrete and soil stabilisation works, CC has been shown to be a potential supplementary material for mitigating carbon emission without compromising on strength enhancement.

Keywords: calcined clay, compressive strength, binder blends, cement concrete, soil stabilisation

Kulcsszavak: nyomószilárdság, kötőanyag keverékek, beton, talaj stabilizálás

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1. Introduction

The need for reduction in carbon footprints has continued to be a front-burning discussion in environmental sustainability. In response to this, research efforts have been geared towards finding eco-friendly, cost-effective alternatives to Portland cement, which contributes about 10% of carbon emission globally [1-2]. Moreover, considering the likelihood of increased cement demands (especially in developing countries), possible supplements should have an appreciable level of commercial availability to meet up with these demands.

Calcined kaolin clay (calcined clay, CC) has been reported as a promising supplementary binder in civil engineering works. It has been regarded as reactive and its production eco-friendlier than cement's [1-4]. This paper documents the comparative performances of CC in cement concrete and soil stabilization works. The idea is to project the broader view of the applicability of this pozzolan across different civil engineering uses.

2. Materials and methods

Raw kaolinite clay was obtained from a deposit reported to have abundance of the material with the kaolinite mineral content being as high as 95% [5]. Chemical properties are also typical of kaolin clay [6]. The clay was milled and calcined 700°C for 1 hour based on the previous findings of the authors [6]. The calcined samples sieved using 90μm sieve to have samples whose fineness compares closely with cement.

The work was executed in two stages. The first was to use calcined clay (CC) in cement concrete. CC-PC concrete cubes of grade 20 were prepared with ordinary Portland cement (PC) grade 32.5, CC and aggregates (fine and coarse aggregates in line with standard [7]). Five sets of 150mm concrete cubes were produced and designated as PC100, PC95, PC90, PC85, and PC80; corresponding to replacement of Portland cement (PC) with CC at five levels of 0%, 5%, 10%, 15% and 20% respectively. The samples were tested for their compressive strengths at increasing curing ages. The sprinkler curing method was applied to simulate a typical curing technique at construction sites. The concrete cubes were uniformly sprayed twice daily (sunrise and by sunset) with water to obtain thin films of water round them.

The second stage was to stabilise samples of fine-grained (A-2-6) lateritic soils using four CC-PC blends designated as PC100, PC75, PC50 and PC25; corresponding to PC replacement levels of 0%, 25%, 50% and 75% respectively. Each blend was applied at 0%, 2.5%, 5%, 7.5% and 10% of the soil's weight, respectively; the 10% limit considered as adequate in line with [8]. The soil-stabiliser mixes were compacted, cured and tested for the unconfined compression strength (UCS).

3. Results and discussion

Table 1 presents the compressive strengths of the CC-PC concretes. Generally, the strengths of the PC95, PC90, PC85, PC80 specimens were comparable to control's (PC100). These were typical of grade 20 concretes. The PC80 samples produced the highest 28-day and 56-day strengths of 24.36 N/mm² and 28.00 N/mm², respectively. The corresponding strength activity indices (SAIs) were 126% and 144.9%; indicating that the strengths were enhanced with the adoption of CC as cement supplement up to the 20% level. Thus, apart from the potential of reducing dependence on cement and mitigating the associated carbon emissions, strength enhancements are achievable with CC-PC blends.

Binder Designation	7-day strength	28-day strength	56-day strength
PC100	9.06 (100.0%)	19.33 (100.0%)	21.15 (100.0%)
PC95	8.41 (92.8%)	19.29 (99.8%)	22.64 (117.1%)
PC90	9.11 (100.6%)	17.60 (91.1%)	20.00 (103.5%)
PC85	16.00 (176.6%)	20.74 (107.3%)	23.82 (123.2%)
PC80	15.83 (174.7%)	24.36 (126.0%)	28.00 (144.9%)

Note: Strength Activity Indices are presented as a % of PC100

Table 1 Compressive strengths (N/mm²) of the CC-PC concretes
1. táblázat CC-PC betonok nyomószilárdsága (N/mm²)

The results of the UCS are also presented in *Table 2a* and *2b*.At 0% stabiliser content, the 7-day strength (0.8 N/mm²) did not vary significantly from the 28-day strength (0.9N/mm²) since there were no binders whose impact can improve the soil strength. These UCS values are lower than the minimum of 1.8 N/mm² recommended for base course materials for flexible road pavement [9-11]; indicating a weak soil which requires stabilisation. The results show that the binders PC100 (control), PC75 and PC50 successfully improved the strength of the soil above the required threshold.

Binder Designation	Total binder %				
	0%	2.5%	5%	7.5%	10%
PC25	0.80	0.40 (48.8%)	0.55 (45.8%)	0.70 (42.4%)	1.20 (40.8%)
PC50	0.80	2.24 (273.2%)	2.34 (195.0%)	2.59 (157.0%)	3.11 (105.8%)
PC75	0.80	1.50 (182.9%)	3.04 (253.3%)	3.74 (226.7%)	4.64 (157.8%)
PC100	0.80	0.82 (100.0%)	1.20 (100%)	1.65 (100.0%)	2.94 (100.0%)

Note: Strength Activity Indices are presented as a % of PC100; for each binder content

Table 2a 7-day unconfined compressive strength of stabilised soil (N/mm²)
2a táblázat Stabilizált talaj 7 napos nyomoszilárdsága (N/mm²)

Binder Designation	Total binder %				
	0%	2.5%	5%	7.5%	10%
PC25	0.90	0.97 (87.4%)	1.76 (88.9%)	2.13 (83.2%)	3.36 (91.1%)
PC50	0.90	2.97 (267.6%)	3.19 (161.1%)	3.58 (139.8%)	4.47 (121.1%)
PC75	0.90	2.31 (208.1%)	4.63 (233.8%)	4.98 (194.5%)	5.80 (157.2%)
PC100	0.90	1.11 (100.0%)	1.98 (100.0%)	2.56 (100.0%)	3.69 (100.0%)

Note: Strength Activity Indices are presented as a % of PC100; for each binder content

Table 2b 28-day unconfined compressive strength of stabilised soil (N/mm²)
2b táblázat Stabilizált talaj 28 napos nyomoszilárdsága (N/mm²)

The SAIs indicate that PC75 and PC50 can comparatively replace the control (PC100) with satisfactory performances. PC50 presented comparably higher strength while optimum strengths were obtained with PC75. Thus, for soil stabilisation, potential savings of up to 50% in PC usage (by extension, 50% reduction in accruable carbon emission) can be achieved with CC-PC blends, as indicated in the result. The PC25 did also improve strength but at a later curing age.

4. Conclusions

The optimal strengths achieved in adopting CC in concrete and soil stabilisation works indicates possible benefits accruable from adopting this pozzolan in civil engineering works. The material has shown the potential of mitigating carbon emission by replacing cement by as much as 20 to 50%, respectively, depending on the required engineering use and without compromise on strengths.

The details of the mechanism of reaction of this pozzolan, especially in soil-binder systems remain to be fully investigated. This will help capture the reactive phases with the CC based systems. With this, the protocol for the application of CC as binder can be established for stakeholders. Research progress on the durability of the CC-based systems needs be properly documented, as well, in details.

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