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Variability of clay in poured earth

Large worldwide consumption of concrete has brought a critical environmental impact to the earth, such as CO_2 emission, energy and resources consumption. Due to these concerns, the construction industry is pushed to propose sustainable construction materials and solutions. Despite the strong interest for earth as building material, providing a number of advantages (local and available raw material, hygrothermal behaviour, etc.), earth constructions are still marginal. The complicated process and the high variability of the raw material are the main limits to its larger expansion and to its industrialization.

Among the techniques recently developed to improve the earth construction, poured earth appears to be the most promising one. This technology, based on the deflocculation/flocculation of clay particles, was used as reference for this study. Through the addition of inorganic dispersants and flocculants in clay paste, only binder in earth material, it is possible to modify clay particle interactions and thus the whole behaviour of the material. Nevertheless, this essential step is not sufficient, as many issues can occur during the scaling up, with the use of raw materials containing different types of clay. Tackling the variability of the clay nature is now the main issue to push this product on the market with robust properties.

The objective of this research is then to investigate the robustness of the poured earth deflocculation, by highlighting the main characteristics of the clay that influences the efficiency of the additives. The results show that the deflocculating action of the additives varies according to the considered type of kaolinite clay. By correlating the mechanical behaviour of the tested materials to the characteristics of the kaolinite clay, it is possible to show that the efficiency of the additives is predominantly linked to the specific surface area of the clay particles, for one given mineralogy.

Introduction

By following exponential population growth, cities stimulate the unrestrained consumption of resources [1], leading to an increase in greenhouse gas emissions; therefore, alternative technologies are crucially needed. As a related problem to city growth, a large amount of excavated earth is produced every year. By observing the flow of materials in cities [2–7], it appears that the main resource is earth from excavation sites. The use of these excavated materials can provide a solution to problems associated with the availability of resources, as earth is the best example of a a closed material flow loop: from excavation site to construction elements [8, 9]. Recently, new strategies have been investigated to develop poured earth without any hydraulic binder. These different approaches all use clay dispersants coming from ceramic industry, mainly sodium hexametaphosphate (NaHMP)) [10–15] to allow the material to flow with a limited amount of water. All these strategies show an increase in the global strength. Thanks to the action of the dispersant, the initially positive edge charges of the clay platelets become negative [12, 14]. Clay particles are not stacked in clusters and, after a certain resting time, become oriented in a face (-)/face (-) arrangement. The sample becomes denser, with less global porosity compared to the non adjuvanted fluid sample, and consequently becoming stronger [10, 13, 14].

However, the increase in the strength differs substantially from one type of clay to another, making this strategy not robust. The objective of this research is then to investigate the robustness of the poured earth process, by highlighting the main characteristics of the clay that influences the efficiency of the additives. The reference additives were tested on four different types of kaolinite, from different sources and with different physical and chemical properties (granulometry, compacity, specific surface area, pH, etc.) and the

Table 1 Main physico-chemical properties of the kaolinite clays studied here

Properties	KL	KB	KZ	KS
D50	1.5	2.1	1.7	1.3
Specific gravity	2.6	2.6	2.6	2.6
PH	6.5	6.5	6	5.5
Surface area (BET; m^2/g)	13	9	7	14
Methylene Blue Value (MBV)	1.25	1.33	0.83	1.42
Chemical analysis by X-ray fluorescence				
SiO_2 (%)	51	51	55	47
$Al2_2O_3$ (%)	35	35	35	38

properties of the mix designed clay pastes at hardened state (compression strength) was determined.

Materials and procedures

Clay

Four different pure kaolinite clays were used in this study, varying by their physical properties: Kaolinite FP 80 (referred to here as KZ) sourced from Dorfner, (Germany), kaolinite Speswhite (referred to here as KS) sourced from Imerys (United Kingdom), kaolinite Polwhite KL (referred to here as KL) and kaolinite Polwhite EB (referred to here as KB) both sourced from Imerys (France). Their respective main properties are gathered in Table 1.

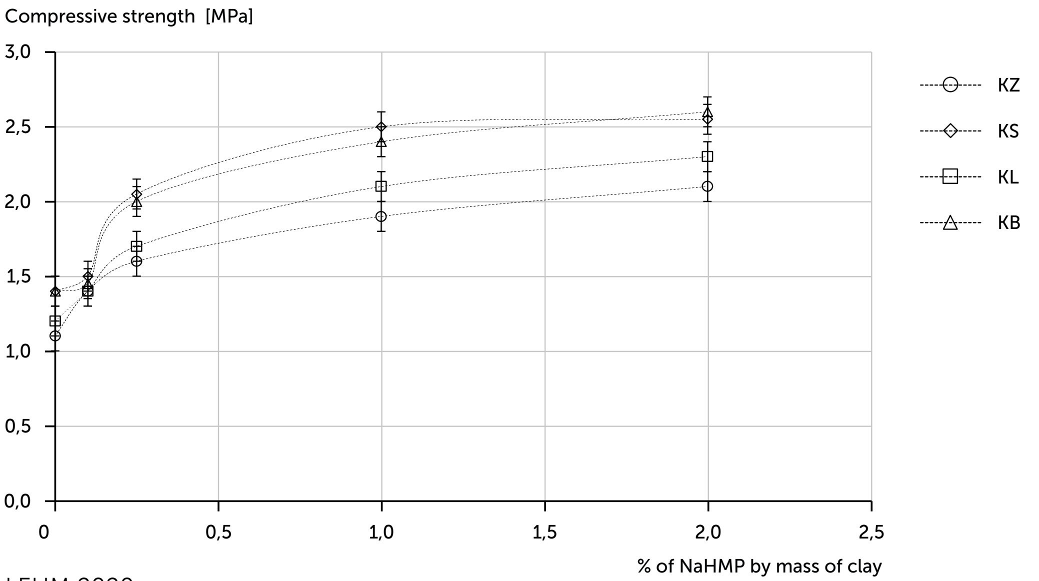
Additives

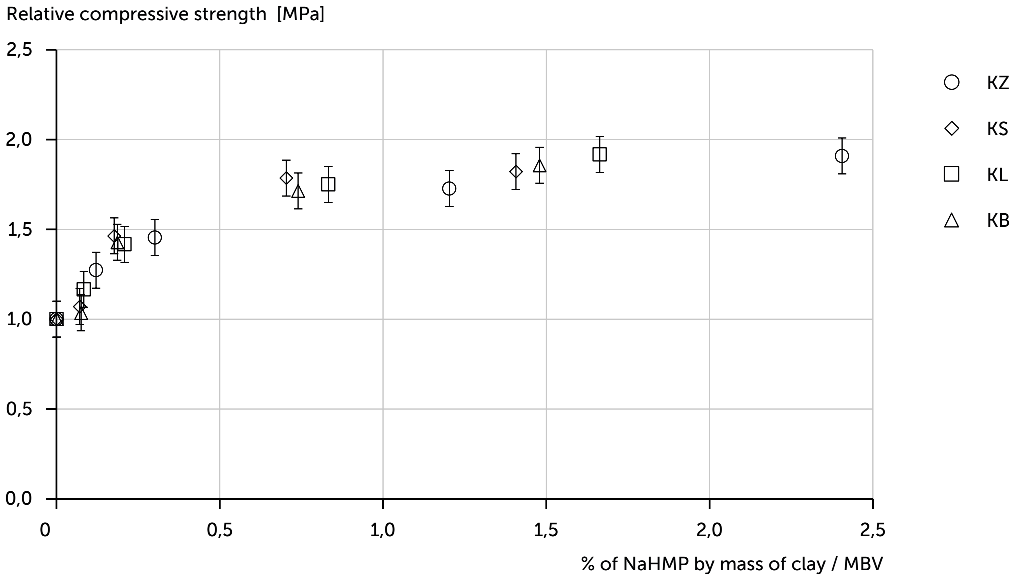
A high-purity sodium hexametaphosphate $(NaPO_3)_6$ (>99.0% pure) in powder form sourced from Fisher Chemical (Reinach, Switzerland) is used as the clay dispersant (referred to here as NaHMP).

Sample preparation

Compressive strength measurements were performed on clay mortars to study the effect of NaHMP according to the type of kaolinite used. To compare the results obtained from different measurements, the Water to Clay ratio (W/C) was kept constant at 0.65 and the solid mass fraction was kept constant at 83% (23wt% of fine sand 63-200 µm and 60wt% of normalized sand 0-2 mm). All dosages are expressed as the percentage of the mass of clay. Only the dosage of the dispersant was varied from one sample to another. The tested clay mortars were prepared using the following mixing procedure: deionized water was mixed with dry mix components previously homogenized (NaHMP in powder form, clay and sand) for 2 min at low speed and for 2 minutes at high speed with an automatic mortar mixer. All the samples were prepared at room temperature (23 ± 0.1°C).

01 Compressive strength of the different clay samples prepared with increasing amount of dispersant





02 Relative compressive strength (ratio between ratio between the compressive strength of the clay mortar containing NaHMP and the compressive strength of the clay mortars without NaHMP) as a function of the ration between NaHMP dosage and MBV for the four kaolinite clays.

Directly after the mixing stage, a standard prismatic formwork with of dimensions 40×40×160 mm [16] was filled with the clay mortar. Samples were dried for three days at ambient air conditions (23 ± 0.1°C), demolded and put into the oven at 50°C until weight stabilization.

Results and discussion

In Figure 1, the compressive strength of the samples is plotted as a function of the dosage of NaHMP by mass of clay. As a general observation, for all tested earth pastes, the compressive strength increases with the addition of NaHMP. This behavior is ascribed to the mechanism of action of the dispersant, which modify the clay interactions. Indeed, these results confirm that the microstructure and rearrangement of the clay particles due to deflocculation is the main driver of the increase in strength. Prior studies on the deflocculated clay proposed a preferential orientation and interaction between clay particles after deflocculation [10, 13]. The authors suggested that a transition from a house-of-card (HoC) structure or interaction from face (-)/edge (+) to a lamellar structure with a face (-)/face (-) interaction. The lamellar structure after drying may increase the strength due to a higher contact surface between clay particles, while the size of the clay flocs decrease. However, when considering each clay mortar behavior in detail, from the addition of 0.1 wt% of NaHMP, the increase in strength is not similar depending on the studied kaolinite. The clay structure, linked to the nature of clay, does not seem to be the only parameter that affect the action of the dispersant on the compressive strength.

Indeed, by plotting the relative compressive strength (i.e. ratio between the compressive strength of the clay mortar containing NaHMP and the compressive strength of the clay mortars without NaHMP) of the four kaolinite as a function of the ratio between the NaHMP dosage and their MBV, a correlation can be found. The MBV, directly linked to the specific surface area (SSA) of the clay particles and to their adsorption capacity via their charges [17], appears as a key parameter controlling the efficiency of the additive in terms of strength.

Conclusion

In this study, the influence of sodium hexametaphosphate as mineral dispersant on the compressive strength of different type of kaolinites was studied. Even if the tested clays belong to the same family of clay in terms of structure, they exhibit different behavior at hardened state. However, even if raw data are highly different between the four studied kaolinites, a relationship between the mineralogy data and the mechanical response can be found. These results allow a better understanding on how to tackle the earth variability for the development of a robust poured earth product. With the extension of this study to other types of mineralogy (illite, montmorillonite, etc.), some mix design guidelines to be used for the up scaling of the technology could be defined.

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