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Alkali Activation of Fly Ash, Metakaolin and Slag Blends: Fresh and Hardened Properties

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Abstract : Alkali-activated materials, particularly geopolymers, have attracted much interest in academia. Commercial applications are on the rise, as well. Geopolymers are produced typically by a reaction of one or two aluminosilicates with an alkaline solution at room temperature. Fly ash is an important aluminosilicate source. However, using low-Ca fly ash, the byproduct of burning hard or black coal reacts and sets slowly at room temperature. The development of mechanical durability, e.g., compressive strength, is slow as well. The use of fly ashes with relatively high contents (> 6%) of unburned carbon, i.e., high loss on ignition (LOI), is particularly disadvantageous as well. This paper will show to what extent these impediments can be mitigated by mixing the fly ash with one or two more aluminosilicate sources. The fly ash used here is generated at the Orlando power plant (Florida, USA). It is low in Ca (< 1.5% CaO) and has a high LOI of > 6%. The additional aluminosilicate sources are metakaolin and blast furnace slag. Binary fly ash-metakaolin and ternary fly ash-metakaolin-slag geopolymers were prepared. Properties of geopolymer pastes before and after setting have been measured. Fresh mixtures of aluminosilicates with an alkaline solution were studied by Vicat needle penetration, rheology, and isothermal calorimetry up to initial setting and beyond. The hardened geopolymers were investigated by SEM/EDS and the compressive strength was measured. Initial setting (fluid to solid transition) was indicated by a rapid increase in yield stress and plastic viscosity. The rheological times of setting were always smaller than the Vicat times of setting. Both times of setting decreased with increasing replacement of fly ash with blast furnace slag in a ternary fly ash-metakaolin-slag geopolymer system. As expected, setting with only Orlando fly ash was the slowest. Replacing 20% fly ash with metakaolin shortened the set time. Replacing increasing fractions of fly ash in the binary system by blast furnace slag (up to 30%) shortened the time of setting even further. The 28-day compressive strength increased drastically from < 20 MPa to 90 MPa. The most interesting finding relates to the calorimetric measurements. The use of two or three aluminosilicates generated significantly more heat (20 to 65%) than the calculated from the weighted sum of the individual aluminosilicates. This synergetic heat contributes or may be responsible for most of the increase of compressive strength of our binary and ternary geopolymers. The synergetic heat effect may be also related to increased incorporation of calcium in sodium aluminosilicate hydrate to form a hybrid (N,C)A-S-H) gel. The time of setting will be correlated with heat release and maximum heat flow.

Keywords : alkali-activated materials, binary and ternary geopolymers, blends of fly ash, metakaolin and blast furnace slag, rheology, synergetic heats
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