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RE4 Project

REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

D4.5 Development of alkali activated binder from ceramic CDW Public summary of deliverable	
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Introduction

When used as recycled aggregates, bricks and tiles are considered to be lower performing compared to recycled mineral aggregates or even pieces of mortar, although the performance of the latter depends on the cement type used. To improve their recycling potential, within the remit of the RE^4 project, waste bricks and tiles was separated from the construction and demolition waste (CDW) stream and recycled to be used as a binder, much like Portland cement is used as a binder in concrete. Indeed, bricks and tiles, made of clay, when thermally activated, can react in an alkaline medium to form a stable binder. These types of binders are typically referred to as alkali activated binders in which a precursor, here ground waste bricks and tiles, react with the activating solution containing an alkali (Na_2O or K_2O). Several precursors can be used, but all differ in chemistry. As such, to optimize performance, the chemistry of the activating solution must be adapted to the precursor used. Presented here is the work carried out on alkali activated waste bricks and tiles mortars, determining the most suitable activating solution chemistry to maximize strength development.

Amount of brick & tile waste in CDW

The constituents of 2 sources of construction and demolition waste, one from a recycling site from Northern Europe, the other from Southern Europe, were manually sorted to determine their relative proportions. The Northern and Southern European CDW sources were found to contain 14% and 27% by weights of brick and tiles respectively that could be recycled as a binder. As such, the amount can vary greatly. Still, the amount that can be recycled can be significant – almost half the project target (65% recycled) if only the Southern fraction is considered.

Preparation of the brick & tile precursor

The separated bricks and tiles were collected and manually broken into pieces no bigger than 10 mm in size. The crushed pieces were then ground into a fine powder to prepare mortars with – see Figure 1 and Figure 2.

Figure 1 - Manually Sorted Brick and Tile Waste

Figure 2 - Ground Brick and Tile Waste

Preparation of the activating solution

The activating solution was made by blending two alkaline solutions – sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Different solution compositions were prepared by varying the amounts and proportions of the two solutions. The mass ratio of sodium oxide (Na_2O) M+, i.e. the amount of Na_2O in the system, varied from 4.5% up to 11.5% by weight of precursor. The alkali modulus, or the Na_2O to SiO_2 ratio, varied from 0.5 to 1.5. Each activating solution was then tried to optimize strength.

Preparation of Mortars

The wet ingredients, which include the activation solution plus added water, were first mixed manually. The amount of water added was decided to fix the water to solids ratio (W/S) at 0.37. Note that 'solid' here includes the precursor (ground brick and tile) plus the sodium and silicon oxides (Na_2O and SiO_2) from the activating solutions.

Mortars were prepared by weighing 500 g of ground brick and tile powder into a mortar mixer to which the wet ingredients were added while continuously mixing. After 30 second of mixing, 1375 g of sand was added gradually and the fresh mortar was mixed thoroughly. The fresh binder was then poured into 50 mm cube moulds and cured at 70°C until testing. A finished cube is shown in Figure 3.

Figure 3 – Cured 50 mm Mortar Cube Made with Brick and Tile Waste

Further specimens were prepared to assess the impact of ground granulated blast furnace slag (GGBS) on strength, with it substituting up to 80% of the ground bricks and tiles. The impact of water content on strength, by increasing in increments the W/S from 0.37 up to 0.45, was also assessed.

Influence of Alkali Content (M+)

Figure 4 shows the influence of the alkali content (M+) on strength for a fixed alkali modulus (AM), cured for 28 days at 70°C.

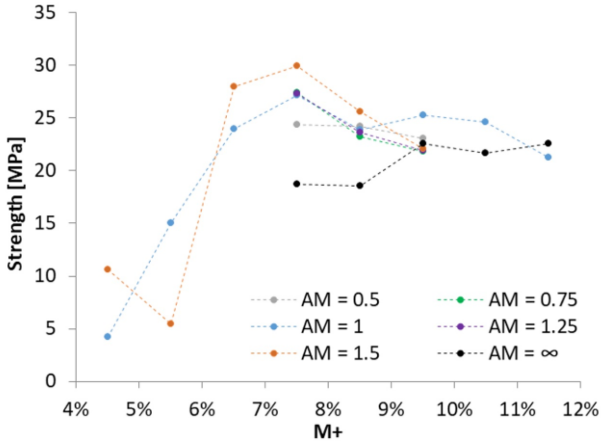

Figure 4 – Influence of M+ for a Fixed AM on Strength

At low alkali contents (M+ ≤5.5%), strength remained low. Strength then increased with M+, up to 7.5%, before dropping again at higher M+ values. The only mix that increased in strength with M+ beyond an M+ = 7.5% were the mixes prepared only with NaOH as the activator (AM = ∞). Mortar cubes reached an ultimate strength of 30 MPa with an activating solution prepared with an M+ of 7.5% and an AM of 1.5.

Influence of Alkali Modulus (AM)

The influence of the AM on strength was more modest (Figure 5).

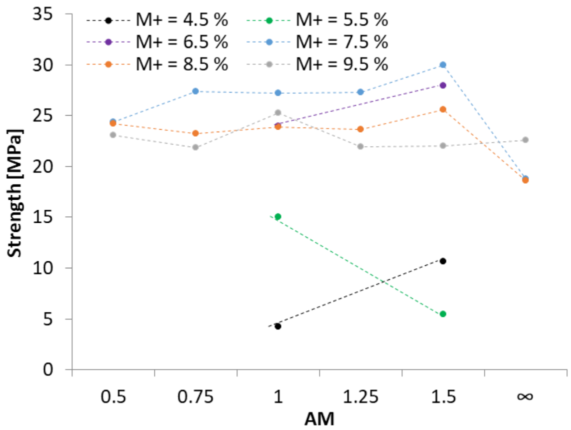

Figure 5 – Influence of AM for a Fixed M+ on Strength

As the AM increased from 0.5 to 1.5, strength was either stagnant or increased by no more than 5 MPa. The strength dropped when AM = ∞, e.g. the mixes containing no Na_2SiO_3 in their activating solution. Again, for mixes prepared with low M+, strength remained low (≤15 MPa).

Influence of GGBS

Blends containing GGBS were prepared with an activating solution with the M+ and AM set at 7.5% and 1 respectively. It was found that the addition of GGBS, even when replacing only 20% by weight of the ground brick and tile, allowed for room temperature curing of the mortar cubes. However, workability had dropped and, to compensate, the W/S ratio was increased to 0.41. The strength data of mortar specimens cured for 28 days is shown in Figure 6. Strength containing no GGBS reached strengths of only 8 MPa. Strength then increased in an almost linear fashion with GGBS content, up to 80 MPa for a mix containing 80% GGBS.

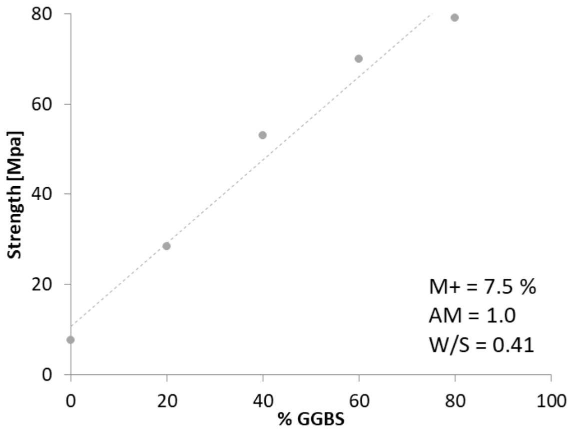

Figure 6 – Influence of GGBS Strength

Influence of W/S on Strength

Figure 7 shows the impact of increasing the W/S of mortars prepared with an M+ of 7.5% and an AM of 1. As the W/S increased from 0.37 to 0.45, strength decreased from 27 MPa down to 20 MPa after 28 days of curing. Simultaneously, the mortar was found to be more workable and compactable.

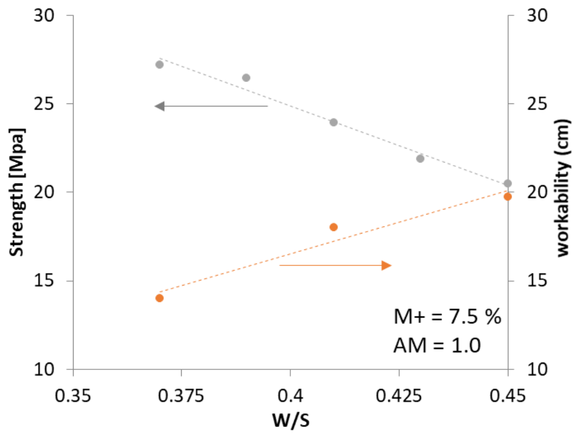

Figure 7 – Influence of Water Content on Strength and Workability

When compacted in a cone of standard size on a plate, with the cone then removed, the mound of mortar spread to a circle 15 cm in diameter at low W/S ratio, and then to a circle 20 cm in diameter at high W/S under the mechanical action of lifting and dropping the plate 15 times.

Summary

- The overall alkali content (Na_2O) was the main parameter controlling strength, and had to be present in sufficient quantity to obtain sufficient strength. Mortars prepared with an M+ = 7.5% were typically the strongest
- The addition of SiO_2, as sodium silicate Na_2SiO_3, also contributed to strength, but to a lesser degree. The performance was optimised with an AM of 1.5
- The addition of GGBS led to an increase in strength with the GGBS content. Additionally, its use also allowed for room temperature curing. However, workability could be adversely affected
- Like mortars prepared with Portland cement, an increase in the water content led to a drop in strength and an increase in workability

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