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Communication

Strength improvement in Portland cement-based boards

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1. Introduction

The aim of this research was to increase and, if possible, to double the bending strength of Portland cement-based board products by chemical additions, while simultaneously improving processability. The chemicals under investigation were metakaolin (Metastar 501, ECCI) and two polymers: hydroxypropylmethylcellulose (HPMC15,000, Celanese) and a cationic polymer based on a dimethyl diallyl quaternary ammonium salt (DP2-6569, Allied Colloids). It is known that metakaolin can enhance the strength of concrete [1,2] and high-performance mortars [3], and its chemical effects have been investigated [4,5]. A composition of cement board was selected to be representative of existing products, but simplified to allow understanding of the strengthening mechanisms. No reinforcing fibre was included in the formulation in order to examine the fundamental matrix strength. Also, the test samples here were not autoclaved except to show that autoclaving produced further improvements as additional calcium silicate hydrates were generated. The intention, including the use of a new plastic processing production route, was to improve both processability and properties of cement boards to allow more economic production of products in more intricate and beautiful forms with improved strengths, leading to thinner sections and new applications.

2. Background

Existing Portland cement board products of the type under investigation are currently made using the Hatschek process, which involves removing water from a slurry under vacuum to form cement sheets. The resultant boards are then hydraulically compressed prior to high-pressure steam autoclaving. Although this process is well established and largely understood, it has a number of disadvantages including a high water usage during manufacturing, and a slow moulding step, while producing relatively low-strength material. The work presented here is based on a different production route utilising plastic mixing that introduces more shear into the powder mix, thus aiding compaction. In this process, the correct amount of water is added to the powder ingredients (no water is removed after compaction) and the composition is plastic mixed, rolled, and extruded or moulded to produce a wider range of product forms than the Hatschek process, to give improved strength properties. It is known that the bending strength of cement boards made by this method can be as high as 80 MPa when better compaction is achieved [6–10], an order of magnitude better than current Hatschek products. Of course the major problem of this plastic process is the polymer additive needed to achieve the required rheology of the mix. This can be expensive, prone to degradation, and a smoke hazard in fire situations.

3. Methods

A control formulation containing Portland cement obtained from Castle Cement (Clitheroe, Lancashire, UK) and complying to BS12 (1996), water, mica, and ground silica was used, in the proportions 48.7:37.5:20.8:50.5, based on an existing cement board product formulation. The mica and silica were supplied by a manufacturer of Hatschek-based boards (Cape Boards, Uxbridge, Middlesex, UK). The mica was found to have a mean particle size of $\sim$0.5 μm; and the silica had a mean particle size of 14 μm with a surface area of 1.02 m^2/g [measured by Brunauer-Emmett-Teller (BET)]. To the above formulation an aqueous slurry containing metakaolin plus any polymer additions was added. The water/solids (w/s) ratio, excluding metakaolin and polymers, remained constant at 0.31 throughout the process.

The slurry was prepared by milling the metakaolin (ECC Metastar 501) in water on an Eiger Torrance Mini Motor-mill 250 (Eiger Torrance Ltd., Warrington, Cheshire, UK) for 30 min with various polymer additives. The proportions of metakaolin and polymer in the mill were varied to study the effects on product processability and final strength properties.

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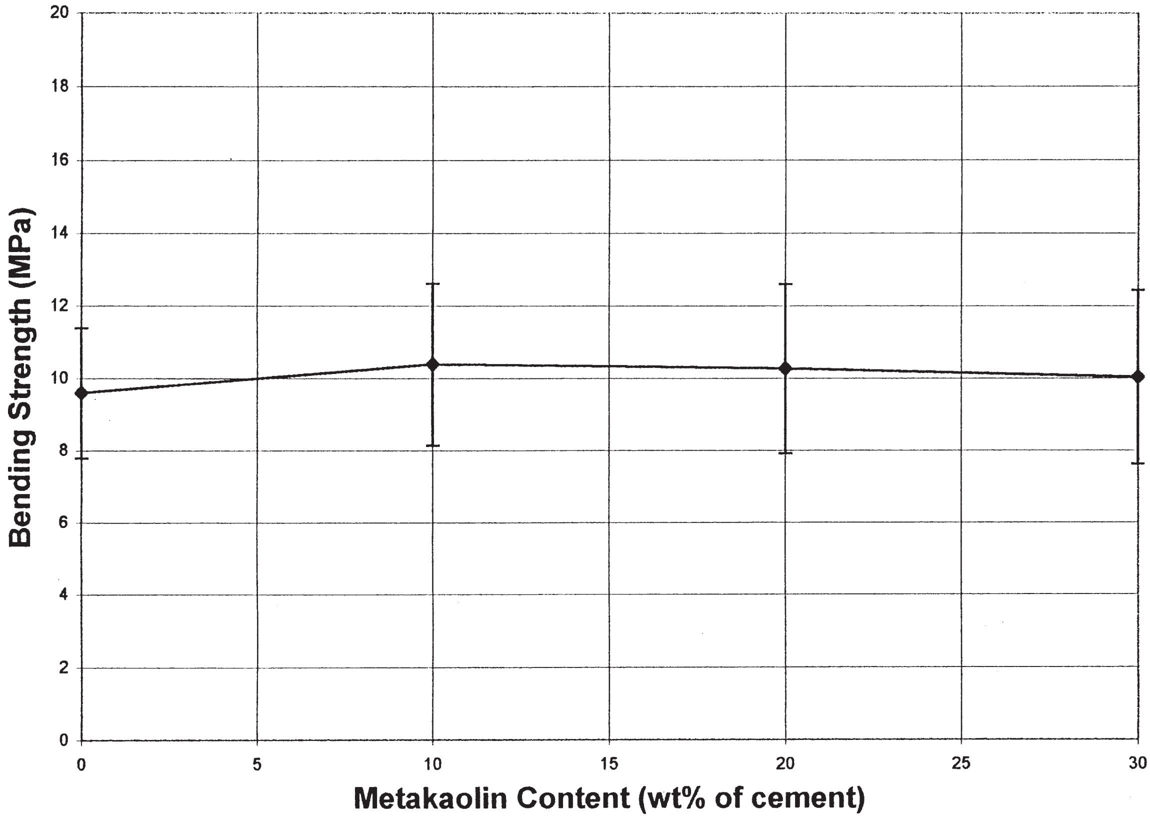

Fig. 1. Strength of Portland cement boards containing silica, mica, metakaolin, and water.

To prepare the cement board composition, the appropriate amounts of dry powder ingredients were placed into a beaker and dry mixed. The milled slurry, which had a milky appearance, was poured into a Z-blade mixer; the dry powder mix was added gradually, until it had all been mixed in. A Z-blade mixer was used to ensure thorough homogenisation. After mixing for 30 min, the contents were transferred to a sealable plastic bag. The material was flattened out somewhat in the bag to an area of 200 cm^2, sealed with damp tissue to maintain high humidity, and then hydraulically pressed at 2 tonnes overnight between steel plates.

After removal from the press, the material was left in the bag to cure for 7 days, then the board was removed from the bag and transferred to a curing tank maintained at 65% relative humidity at room temperature. Boards were left to dry to constant weight in the tank, taking typically 4 to 5 days. They were then transferred to a 50°C oven for 24 h, followed by 24 h at 100°C.

Strips of material of 6 to 10 mm in width were cut from the dried boards with a diamond wheel. These were then subjected to three-point bend tests, 20 such tests being carried out for each formulation.

4. Results

The first result demonstrates that the addition of metakaolin to the board marginally increased the bending strength in the absence of polymer. Fig. 1 shows the bending strength of the boards vs. metakaolin content. The control samples, with zero metakaolin, showed a strength of 9.6 ± 1.80 MPa. There was a small increase when metakaolin was added but the scatter also rose slightly because the rheology of the mixes was poor, leading to variable defect sizes in the board samples. As the quantity of metakaolin was raised, the size of these defects was clearly seen to increase.

There were two benefits of adding polymer-dispersing agents to the bead mill: first, the bead milling of the metakaolin was improved as the clay particles became dispersed to give a lower viscosity, and second, the rheology of the cement board mix was improved by the polymer additive. Fig. 2 shows the strength of cement boards containing metakaolin and dispersing polymer additions. The strength increases were substantial. But more importantly, the scatter of results was diminished because the rheology of the cement board mix was better in the presence of polymer.

As a result of this rheology improvement in the presence of polymer, the water content in the formulation could be substantially reduced [1]. In the control mix the water:cement ratio had been 0.77. With polymer in the mix, the water:cement ratio was reduced to 0.45, yet the mix was easier to handle and mould than the control. With the reduced water content, the board strength increased still further; for example, with 5% metakaolin and 4% polymer addition (by weight of cement in each case), the board strength rose to 30 ± 3.6 MPa.

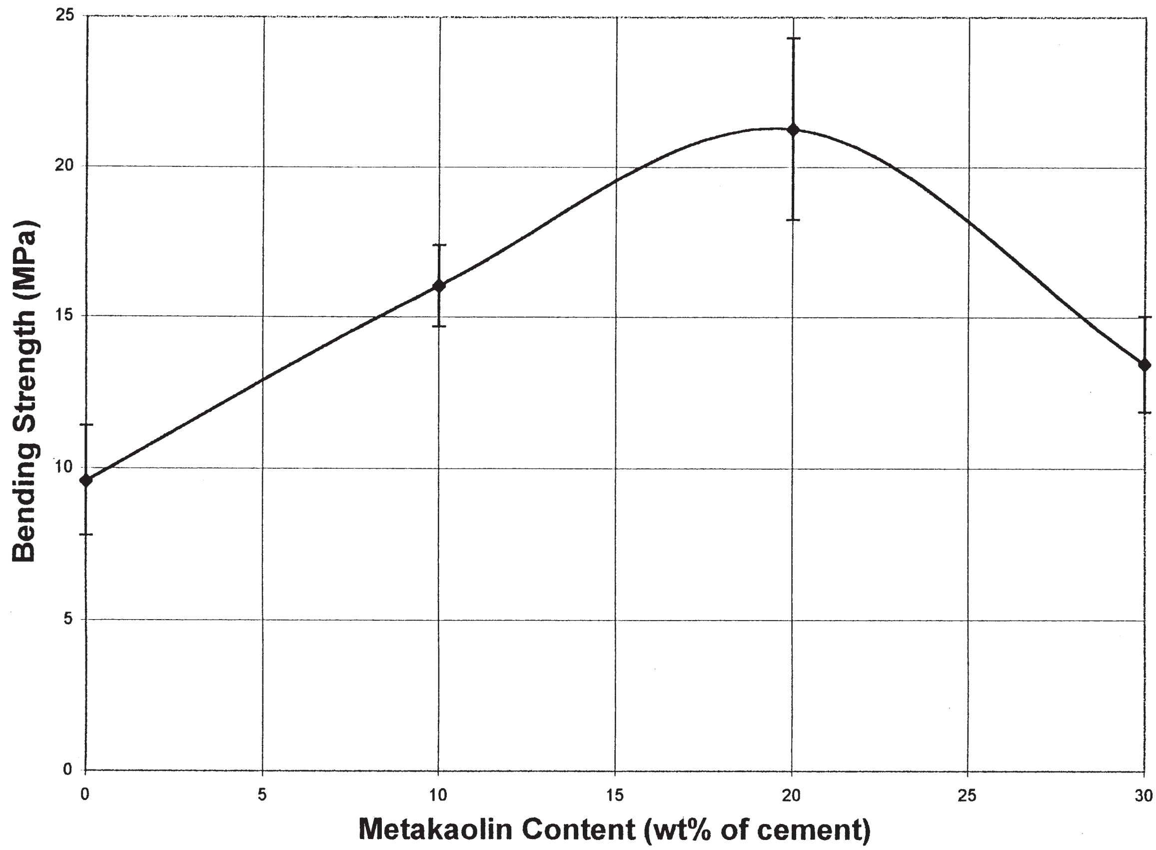

Fig. 2. Strength of Portland cement boards containing silica, mica, metakaolin, polymers, and water.

5. Conclusions

The introduction of metakaolin into the cement board formulation gave a slight increase in bending strength. The problem was the poor rheology of these formulations, leading to variable defect size and large scatter in strength results. Addition of dispersing polymer to the mixes gave improved rheology, reduced scatter, and gave further substantial strength improvement. Such was due to the rheology enhancement that the water content could then be reduced, leading to significant strength increases in the boards.

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