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Flow Performance of Hybrid Cement Based Mortars

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Abstract**—**The workability of hybrid alkaline cements is a field of knowledge that still needs further research efforts. This paper reports experimental results of 32 hybrid cement mixes regarding the joint effect of sodium hydroxide concentration, the use of a commercial superplasticizer and a biopolymer on the flow and compressive strength performance. The results show that the use of commercial admixtures led to a slightly increase in the flow of mortars with lower sodium hydroxide concentration.

Keywords**—**Waste reuse, fly ash, waste glass, hybrid cement, biopolymer, polycarboxylate, flow.

I. Introduction

HYBRID cements involve the activation of industrial wastes with alkaline activators, usually composed by hydroxide, silicate, carbonate or sulfate leading to co-precipitation of two gels (C-S-H + N-A-S-H) [1], [2]. These materials have a particular ability for the reuse of several types of wastes [3], [4]. Therefore, the valorization of fly ash and waste glass in hybrid cement would have obvious environmental benefits. Workability is an important engineering property in the construction industry just because lower workability requires higher compaction energy. Hybrid alkaline cements usually use viscous activators that are associated with low workability performance. The superplasticizers that are currently used by the Portland cement (OPC) industry show little or even no effect when used on AACB mortars [5]. Others reported a slight improvement on workability but at the expense of a reduction on compressive strength [6], [7]. Others showed that the workability depended on the mix design composition [8], [9]. More recently, Jang et al. [10] noticed that polycarboxylate-based superplasticizer showed a retarding effect on alkali-activated fly ash/slag mixtures. Therefore, the purpose of this paper is to understand how the composition of hybrid cements based on fly ash and waste soda lime silicate glass and two commercial superplasticizers influences its workability and also its mechanical strength.

II. Experimental

A. Materials and Design

The raw materials used for the preparation of the hybrid cement mortars were fly ash (FA), calcium hydroxide (CH), fine aggregate, milled glass (MG), and sodium hydroxide solution. The FAFA was obtained from The PEGO Thermal

Power Plant in Portugal and it was classified as class F according to ASTM-C618 standard. The CH used in this study had a commercial name of Lusical H100 and chemical composition of $Ca(OH)_2 \geq 93\%$ and $MgO \leq 3$. Waste soda lime silicate glass was provided by the use of glass bottles that were ground for one hour in a ball mill. The density of the MG was 1.27 g/cm^3. Solid sodium hydroxide was obtained from commercially available product of ERCROS, S.A., Spain, were used to prepare three solutions with different concentration (4M and 12M). The chemical composition of the sodium hydroxide was composed of 25% Na_2O and 75%H_2O. The NaOH mix was made one day prior to use in order to have a homogenous solution at the time of mortar preparation. A sand/binder ratio of 4 was used. The sand was used as inert filler provided from the MIBAL, Minas de Barqueiros, S.A. Portugal. Two commercial supersplasticizers supplied by BASF and SIKA were used. Its content was 0.1% of the binder weight. One is a polycarboxylate-based admixture, and the other one is a lignosulfonate-based. Two activator/binder ratios were used (0.4 and 0.5). Table I shows the compositions of the 32 mortars

B. Production and Testing

In the batching process of the mortars, FA, fine aggregate, CH, and MG were mixed for 2 min. Then, the combination of sodium hydroxide and water reducer agents were added and again mixed for 5 min. The workability of the mortars was assessed by using a truncated conical mould and a jolting table according to the EN 1015-3 [11]. The workability of mix compositions was assessed by using relative slump in percentage, which was computed based on the following equation,

$$\Gamma p = ((\frac{d}{d_0}) - 1) \times 100 \tag{1}$$

where, Γp is the relative slump, d is the average of two measured ortigonal diameters of the paste spread, and d0 is the bottom diameter of the conical cone and considered to be 100 mm. For compressive testing, the mortars were cast into cubic molds (50×50×50 mm^3. After 24 hours, specimens were demolded and cured for 28 days at ambient temperature of laboratory with average temperature of 27 ºC and 70% HR. The cubic specimens were assessed under compressive load with a constant displacement rate of 0.30 N/mm^2.s, based on the ASTM C109 recommendation [12]. The compressive load was measured with a load cell of 200 kN capacity.

III. Results and Discussion

Figs. 1 and 2 show the compressive strength and flow performance for references mixtures according to sodium hydroxide concentration and water/binder ratio.

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TABLE I
MIX COMPOSITIONS (KG/M^3)

Mix composition	FA	CH	MG	NaOH	Sand
80FA_10CH_10MG_4M_0.5A/B	377	47	47	236	1884
75FA_10CH_15MG_4M_0.5A/B	350	47	70	233	1864
70FA_10CH_20MG_4M_0.5A/B	328	46	92	230	1844
80FA_10CH_10MG_12M_0.5A/B	377	47	47	236	1884
75FA_10CH_15MG_12M_0.5A/B	350	47	70	233	1864
70FA_10CH_20MG_12M_0.5A/B	328	46	92	230	1844
80FA_10CH_10MG_4M_0.5A/B_0.1% Poly.	377	47	47	236	1884
75FA_10CH_15MG_4M_0.5A/B_0.1% Poly.	350	47	70	233	1864
70FA_10CH_20MG_4M_0.5A/B_0.1% Poly.	328	46	92	230	1844
80FA_10CH_10MG_12M_0.5A/B_0.1% Poly.	377	47	47	236	1884
75FA_10CH_15MG_12M_0.5A/B_0.1% Poly.	350	47	70	233	1864
70FA_10CH_20MG_12M_0.5A/B_0.1% Poly.	328	46	92	230	1844
80FA_10CH_10MG_4M_0.5A/B_0.1% Ligno.	377	47	47	236	1884
75FA_10CH_15MG_4M_0.5A/B_0.1% Ligno.	350	47	70	233	1864
70FA_10CH_20MG_4M_0.5A/B_0.1% Ligno.	328	46	92	230	1844
80FA_10CH_10MG_12M_0.5A/B_0.1% Ligno.	377	47	47	236	1884
75FA_10CH_15MG_12M_0.5A/B_0.1% Ligno.	350	47	70	233	1864
70FA_10CH_20MG_12M_0.5A/B_0.1% Ligno.	328	46	92	230	1844
80FA_10CH_10MG_4M_0.4A/B	385	48	48	193	1928
75FA_10CH_15MG_4M_0.4A/B	358	48	72	191	1908
70FA_10CH_20MG_4M_0.4A/B	330	47	94	189	1888
80FA_10CH_10MG_12M_0.4A/B	385	48	48	193	1928
75FA_10CH_15MG_12M_0.4A/B	358	48	72	191	1908
70FA_10CH_20MG_12M_0.4A/B	330	47	94	189	1888
80FA_10CH_10MG_4M_0.4A/B_0.1% Poly.	385	48	48	193	1928
75FA_10CH_15MG_4M_0.4A/B_0.1% Poly.	358	48	72	191	1908
70FA_10CH_20MG_4M_0.4A/B_0.1% Poly.	330	47	94	189	1888
80FA_10CH_10MG_12M_0.4A/B_0.1% Poly.	385	48	48	193	1928
75FA_10CH_15MG_12M_0.4A/B_0.1% Poly.	358	48	72	191	1908
70FA_10CH_20MG_12M_0.4A/B_0.1% Poly.	330	47	94	189	1888
80FA_10CH_10MG_4M_0.4A/B_0.1% Ligno.	385	48	48	193	1928
75FA_10CH_15MG_4M_0.4A/B_0.1% Ligno.	358	48	72	191	1908
70FA_10CH_20MG_4M_0.4A/B_0.1% Ligno.	330	47	94	189	1888
80FA_10CH_10MG_12M_0.4A/B_0.1% Ligno.	385	48	48	193	1928
75FA_10CH_15MG_12M_0.4A/B_0.1% Ligno.	358	48	72	191	1908
70FA_10CH_20MG_12M_0.4A/B_0.1% Ligno.	330	47	94	189	1888

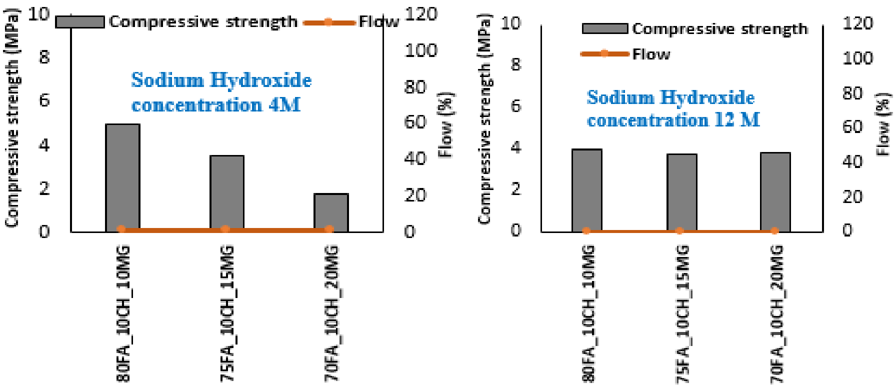

Fig. 1 Compressive strength versus flow for reference mixtures with three sodium hydroxide concentrations (4 M and 12M) and two water/binder concentrations: A/B=0.4

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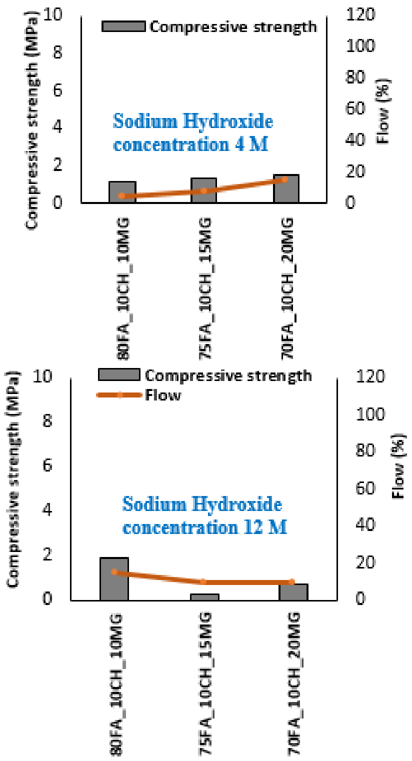

Fig. 2 Compressive strength versus flow for reference mixtures with three sodium hydroxide concentrations (4 M and 12 M) and two water/binder concentrations: A/B=0.5

The results show that the reference mixtures with an activator/binder (A/B=0.4) show no flow at all being unsuitable for construction purposes. This is independent of the sodium hydroxide concentration and the waste soda lime silicate glass content. When the water/binder ratio increased to 0.5, a minor increase in the flow is noticed. Again, it seems that the composition and the sodium hydroxide concentration do not play a relevant role in the flow. The fact is that this study used a sand/binder ratio of 4, which may help to explain the low flow results. Other authors use a sand/binder ratio of just 2.2 because higher valued greatly reduce the flow [9]. For A/B=0.5, all mixtures show a compressive strength below 2 MPa, which has not value for construction purposes. The reduction of the activator binder shows a maximum compressive strength of almost 9 MPa for mixture with 10% replacement of FA by waste soda lime silicate glass and a sodium concentration of 8 M. The reason may lie on the fact that, for low sodium hydroxide concentrations, the main hydration product formed is a CSH gel [13]. This compressive strength level is enough for renders or masonry units.

Mixtures with a sodium concentration of 4 M show decreased strength with the replacement of FA by waste soda lime silicate glass. However, when the sodium concentration of 12 M is used, the compressive strength is not influenced by the waste soda lime silicate glass content. The flow and compressive strength for mixtures with 0.1% polycarboxylate admixture are shown in Figs. 3 and 4, while the data for mixtures with lignosulphonate are shown in Figs. 5 and 6. The results show that the polycarboxylate was not capable to induce flow for mixtures with A/B=0.4. However, the mixtures with a water/binder ratio of 0.5 and 20% waste glass showed almost 40% flow. A flow reduction is noticed for higher sodium hydroxide concentration. These results are not in agreement of the other authors [14] who noticed a reduction on workability for polycarboxylates. The lignosulphonate shows a similar behavior. While the lignosulphonate admixture works based on electrostatic repulsion, the polycarboxylate admixture in addition to electrostatic repulsion benefits from the steric repulsion produced by lateral ether chains on the molecule of the modified lignosulphonate admixture [15].

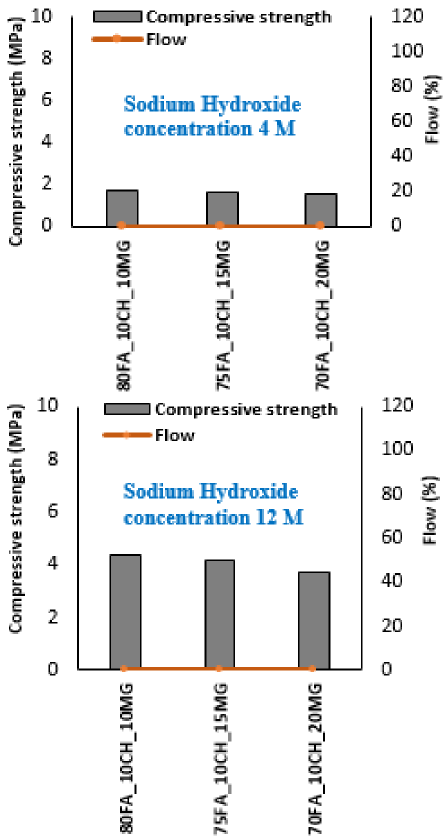

Fig. 3 Compressive strength versus flow for 0.1% Polycarboxylate mixtures with three sodium hydroxide concentrations (4 M, above 12 M) and two water/binder concentrations: A/B=0.4

As to the mechanical performance mixtures with an activator/binder of 0.5 no strength increase was noticed with the exception of the mixture with 10% replacement of FA by waste soda lime silicate glass and a sodium concentration of 4M. As to the ones with the reduced activator/binder ratio, some compressive strength decrease is noticed. Other authors suggest that this compressive strength reduction may be due to the fact that those admixtures are not stable on high basic media [16].

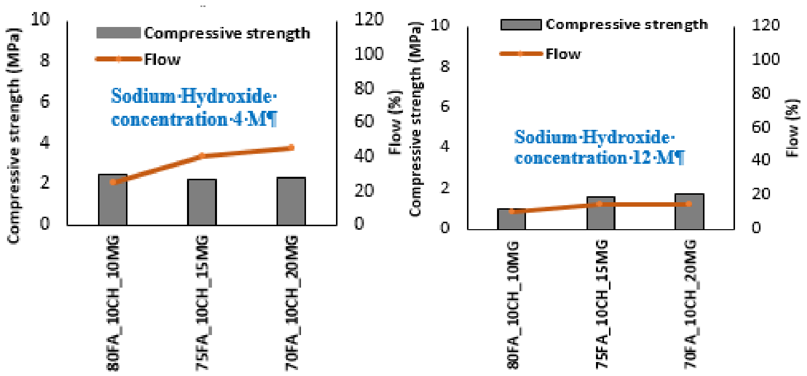

Fig. 4 Compressive strength versus flow for 0.1% Polycarboxylate mixtures with three sodium hydroxide concentrations (4 M and 12M) and two water/binder concentrations: A/B=0.5

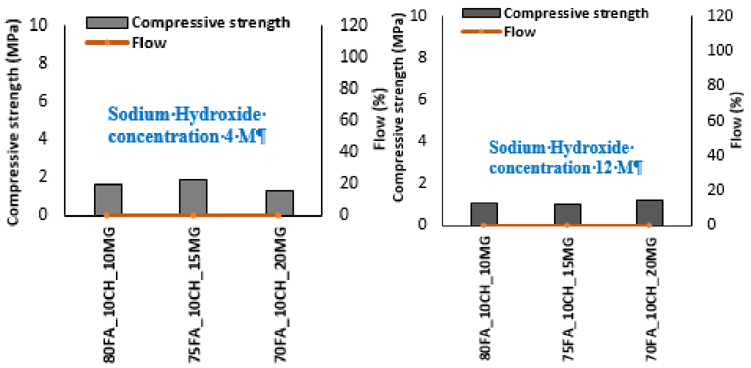

Fig. 5 Compressive strength versus flow for 0.1% Lignosulphonate mixtures with three sodium hydroxide concentrations (4 M and 12M) and two water/binder concentrations: A/B=0.4

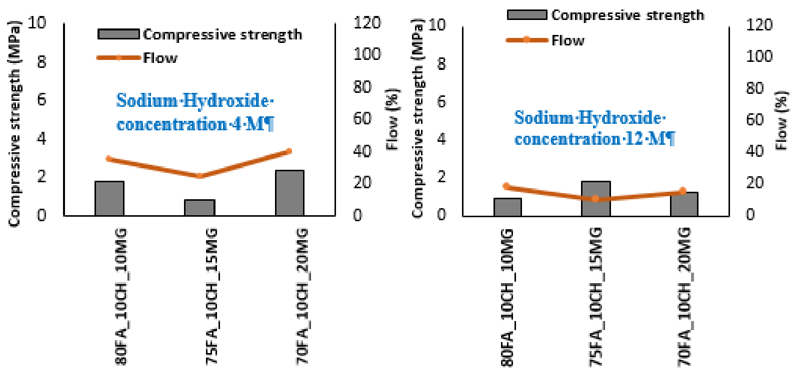

Fig. 6 Compressive strength versus flow for 0.1% Lignosulphonate mixtures with three sodium hydroxide concentrations (4 M and 12M) and two water/binder concentrations: A/B=0.5

IV. Conclusions

The results show that the two commercial mortars demonstrate similar ability to slightly increase the flow of mortars with lower sodium hydroxide concentration, and both are more effective than the biopolymer admixture. A mixture based on 80% FA, 10% CH, and 10% waste soda lime silicate glass showed the highest compressive strength. A compressive strength decrease was noticed concerning the use of the three admixtures that could be due to the fact that those admixtures are not stable in high basic media.

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