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Effect of Shrinkage Reducing Admixture on the Strength and Shrinkage of Alkali Activated Cementitious Mortar

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Abstract. The effect of a shrinkage reducing admixture (SRA) on the mechanical properties and drying shrinkage of a proprietary alkali activated cementitous material (AACM) was investigated. Five AACM mortar mixes were prepared. SRA replaced the liquid activator at a dosage of 0%, 1%, 2%, 4% and 7%. The liquid/binder ratio was 0.38. The samples were cured in water. The flexural and compressive strengths of all mixes were determined at 1day, 2 days, 7 days and 28 days and the drying shrinkage was determined up to 80 days. The results show that SRA reduced the shrinkage of AACM mortar by up to 69% after 80 days at 7% dosage. However, SRA also reduced the compressive and flexural strengths of AACM mortars. Increasing dosages of SRA reduced the compressive and flexural strength while recording less shrinkage. Regardless of the dosage of SRA, a unique relationship exists between flexural strength and compressive strength, which correlates with the data of previous research. The AACM mortar maintained strength of over 43MPa (greater than 75% of the control mix at 0% SRA dosage) at 7% SRA dosage, which is classified as high strength in accordance with British Standard PAS 8820:2016.

1. Introduction

Alkali activated cementitious material is developing significantly as a global sustainable material for the construction industry. Alkali activation is the chemical reaction between a solid aluminosilicate precursor and an alkaline activator which produces hardened products [1, 2]. The main precursors used for producing alkali activated materials are industrial by products which are high aluminates such as granulated blast furnace slag, fly ash and natural clays (metakaolin) [3].

The drying shrinkage is a key factor causing the early age cracking of mortar. There are many causes of shrinkage such as materials constituents, curing methods, etc. Previous research has revealed that the characteristics of the hydrated calcium silicate gel and pore size distribution have a direct effect on drying shrinkage [4, 5]. Kutti [6] stated that the alkali activation of slag produced two main hydration products, a C–S–H gel and a Si-rich gel. The latter consists of higher uncombined water content that is eliminated during the drying process, causing substantial shrinkage and, therefore, microcracking.

The shrinkage can be reduced by using low liquid activator/slag ratio, low activator concentration or high aggregate/slag ratios [7]. There are also some possible solutions to reduce the shrinkage such as using of polypropylene fiber [8] or admixtures [9]. The effect of shrinkage reducing admixtures (SRA) has been studied in Portland cement systems [10-14], where they decrease capillary stress in pore water, which in turn reduces cement paste shrinkage. However, the effect of SRA on the mechanical properties and dry shrinkage of alkali activated slag has not been fully investigated. This paper reports the investigation on the effect of a shrinkage reducing admixture on the strength and shrinkage of a proprietary AACM developed by Sheffield Hallam University [15] and produced under licence by C-Probe Systems Ltd, UK.

2. Experimental Programme

The test programme was planned according to the British Standard for AACMs, PAS 8820:2016 [16].

2.1 Material and mix composition

Five AACM mortar mixes were prepared. The binder /sand ratios were kept constantly for all mixes. The mix proportions were 1:1:0.38 for AACM binder: sand: liquid respectively. The liquid is defined as the total of shrinkage reducing admixture (SRA) and liquid activator. Five different dosages of SRA (0%, 1%, 2%, 4% and 7% by weight of binder) replaced the liquid activator, so that the liquid/ binder ratio remained constantly for all mortar mixes. The mix proportions are presented in Table 1.

Table 1. Mixture proportion of AACM mortar

Sample ID	AACM binder (kg)	Sand (kg)	SRA (kg)
0%SRA	5.5	5.5	0
1%SRA	5.5	5.5	0.055
2%SRA	5.5	5.5	0.110
4%SRA	5.5	5.5	0.220
7%SRA	5.5	5.5	0.385

2.2 Sample preparation and curing

The samples of dimensions 40x40x160 mm were cast in steel moulds. After casting, all samples in the moulds were covered by plastic sheets and left in the laboratory (20^{o}C, RH 65%) for 24 hours. Then, all the samples were demoulded and cured in water at 20^{o}C. The shrinkage samples were cured in water for 7 days before recording the first reading (datum) as detailed in section 2.3.

2.3 Flexural and compressive strength

The flexural and compressive strengths were determined in accordance with BS EN 196-1: 2005 [17]. The three point bending test method was used to determine the flexural strengths. The two halves of the broken prisms from the flexural strength test were used to determine the compressive strengths of mortar. The strength measurements of AACM mortar were made at 1, 2, 7 and 28 days age. Each result of flexural strength and compressive strength was the average value of three specimens and six specimens respectively.

2.4 Drying shrinkage

The drying shrinkages of different compositions of AACM mortar mixes (Table 1) were determined according to BS ISO 1920-8:2009: Testing of concrete - Part 8: Determination of drying shrinkage of concrete for samples prepared in the field or in the laboratory [18]. Prism specimens of 160mm length and cross section 40x40 mm were cast and demoulded after 24 hours. Two demec points were attached on each face of the prism at a gauge length of 100 mm to measure the distance (strain) between the demec points with an extensometer. The samples were then cured in water at 20^{0}C. The samples were removed from water at 7 days after casting, dried with a cloth and the first (datum) strain reading was taken with a demec extensometer. The shrinkage specimens were then cured in air at 20^{0}C, 65% RH. Subsequent shrinkage readings were taken with the extensometer up to 80 days. The shrinkage strain and time relationships were plotted.

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3. Results and discussion

3.1. Flexural and compressive strength

The flexural strength and flexural strength activity index of all samples are shown in Table 2 and plotted in Figure 1. The flexural strength activity index is defined as the ratio (in percent) of flexural strength of the SRA replacement sample to the corresponding control sample (0%SRA). Similarly, the compressive strength and compressive strength activity index of all mixes are shown in Table 2 and plotted in Figure 2. The compressive strength activity index is defined as the ratio (in percent) of compressive strength of the SRA replacement sample to the corresponding control sample (0%SRA).

Table 2. Flexural strength and compressive strength of AACM mortars

Sample ID	Flexural strength (MPa) (Flexural strength activity index)				Compressive strength (MPa) (Compressive strength activity index)			
	1 day	2 days	7days	28 days	1 day	2 days	7 days	28 days
0%SRA	3.72 (100)	5.36 (100)	7.73 (100)	8.25 (100)	20.79 (100)	28.64 (100)	44.68 (100)	57.90 (100)
1%SRA	3.00 (80)	4.79 (89)	6.92 (90)	7.63 (92)	17.76 (85)	25.49 (89)	40.36 (90)	50.62 (87)
2%SRA	3.28 (88)	4.70 (88)	7.35 (95)	7.98 (97)	16.04 (77)	26.13 (91)	36.96 (83)	52.52 (91)
4%SRA	3.76 (101)	5.74 (107)	7.27 (94)	7.31 (89)	19.13 (92)	27.21 (95)	37.46 (84)	47.03 (81)
7%SRA	3.80 (102)	5.07 (95)	5.86 (76)	6.96 (84)	18.11 (87)	21.09 (74)	32.59 (73)	43.20 (75)

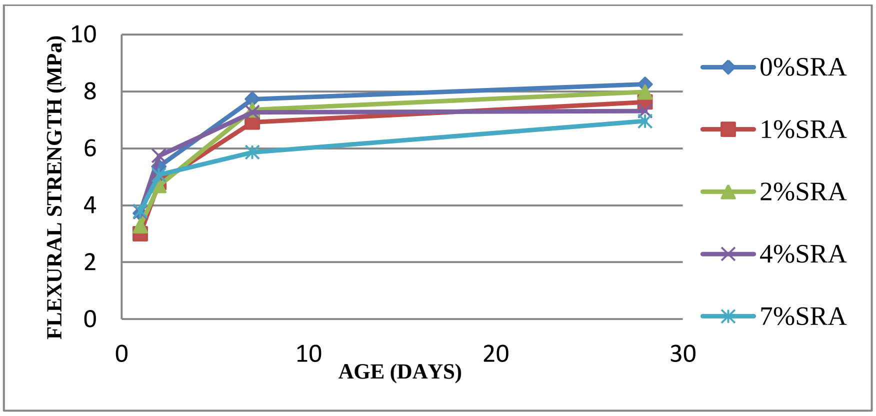

Figure 1. Flexural strength of the mortar samples.

Figure 1 shows that at early age the flexural strength of AACM mortar is more than 3MPa at 1 day and more than 4.7MPa at 2 days regardless of the dosage of SRA replacement of liquid activator. At 28 days age the flexural strength of AACM mortar is about 7MPa regardless of the dosage of SRA replacement. Table 2 shows that at 1 day the flexural strength of 1%SRA and 2%SRA samples reduced compared with the control sample (0%SRA). The flexural strength activity index values of 1%SRA and 2%SRA are 80% and 88% respectively. However the flexural strengths of 4%SRA and 7%SRA increased slightly compared with the control samples (0%SRA). The flexural strength activity index values of 4%SRA and 7%SRA are 101% and 102% respectively. Similar trends occur with flexural strengths at 2 days age. The flexural strength activity indexes of 1%SRA, 2%SRA and 4%SRA are 89%, 88% and 107% respectively, however the flexural strength activity index of 7%SRA reduced to 95%. Although the 1%SRA and 2%SRA reduced early age flexural strengths, these were still maintained at over 80% of the control samples (0%SRA). At 28 days age, reduction in flexural strength was recorded for all mortar samples with SRA replacement. The flexural strength activity index values of 1%, 2%, 4% and 7%SRA are 92%, 97%, 89% and 84% respectively. It shows that at later age (28 days), an increasing dosage of SRA replacement causes more reduction in flexural strength, although these flexural strengths are still maintained above 84% of the control sample even with 7% of SRA addition.

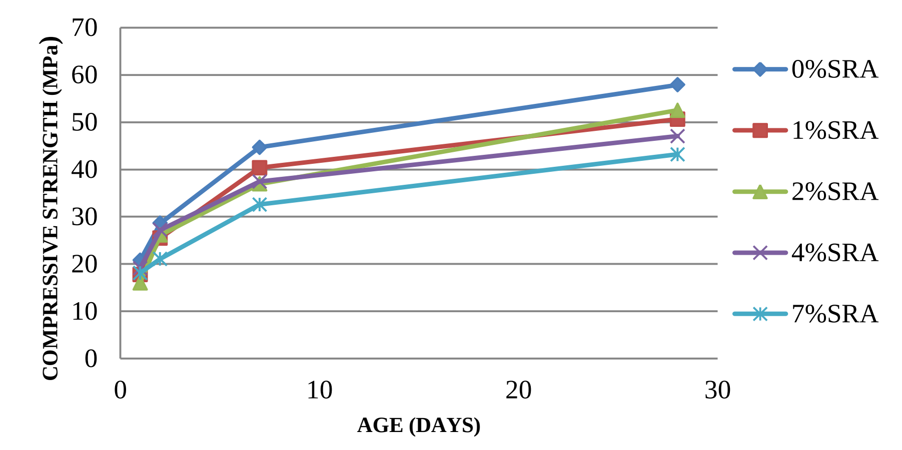

Figure 2. Compressive strength of the mortar samples.

Figure 2 and Table 2 show that at early age (1 day) the compressive strengths of all AACM mortar mixes reduced with increasing SRA content, similar to the case of flexural strength. The compressive strength activity index values of 1%, 2%, 4% and 7%SRA mixes are 85%, 77%, 92% and 87% respectively. Similar to the flexural strength, the compressive strengths of 4% and 7%SRA mixes were higher than that of 1% and 2%SRA mixes at 1 day. At 2 days the compressive strengths of SRA replacement samples reduced compared with the control mix (0%SRA), the 7%SRA mix showing the most reduction with the compressive strength activity index being 74% compared with 89%, 91% and 95% for 1%, 2% and 4%SRA mixes respectively. At later age of 28 days, the compressive strength again reduced compared with the control sample (0%SRA), giving the compressive strength activity index values of 87%, 91%, 81% and 75% for 1%, 2%, 4% and 7%SRA respectively. However, the compressive strength of all SRA mixes still remained greater than 75% of the control samples at 28 days. Regardless of the dosage of SRA the compressive strengths of AACM mortar are more than 16MPa, 21MPa, 32MPa and 43MPa at 1, 2, 7 and 28 days respectively, classifying as 42.5R in accordance with PAS 8820:2016 [17]. The compressive strengths of AACM mortar without SRA gained a high value of nearly 58MPa at 28 days age.

3.2. Relationship between flexural and compressive strengths

The relationship between flexural and compressive strength is plotted in Figure 3 for the experimental data of this investigation including summary data of all AACM mortar samples with and without SRA and the results of other researcher [19-21] whose mixes did not contain a shrinkage reducing admixture (SRA). The ratio of flexural strength and compressive strengths of all AACM mortar samples is in the range of 0.14 to 0.24 with the higher ratios occurring at higher dosage of SRA addition. It means that when SRA was added to the mix, the reduction in compressive strength appears to be higher than the reduction in flexural strength. A power relation of summary data with and without SRA of the form $f_f = 0.398 f_c^{0.77}$ fits all data with a coefficient of correlation of R^2=0.99. Where f_f is the flexural strength in MPa; f_c is the compressive strength in MPa; and R is the correlation coefficient of the equation.

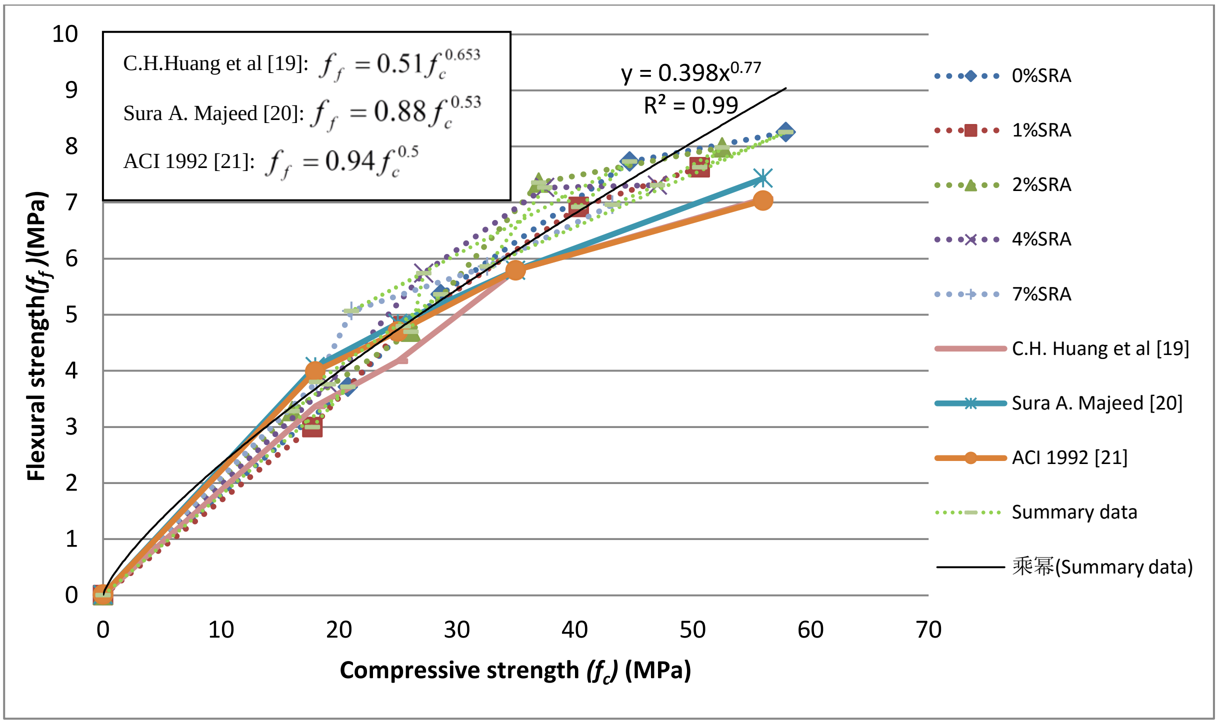

Figure 3. Relationship between flexural and compressive strength of AACM mortar.

3.3. Drying shrinkage

The drying shrinkage of all AACM mortar mixes with and without SRA is presented in Figure 4. Each result presented is the average value of three specimens with 6 readings. It is clear that SRA reduced drying shrinkage with increasing dosage of SRA. At 80 days the drying shrinkage of all mortar mixes were 2194, 2079, 1835, 1274 and 679 microstrain for 0%, 1%, 2%, 4%, 7%SRA respectively. The shrinkage of AACM mortar reduced by 5.2%, 16.4%, 41.9%, and 69.1% when 1%, 2%, 4% and 7%SRA (by weight of binder) were used to replace the liquid activator.

At 28 days, the drying shrinkages of all mortar samples with and without SRA are 1390, 1302, 956, 680 and 330 micro strain representing reductions of 6.3%; 31%, 51%, and 76% with 1%, 2%, 4% and 7% replacement by SRA. In comparison, the flexural and compressive strengths of SRA samples at 28 days were reduced by less than 15% and 25% respectively. It can be said that depending on the purpose of AACM application, we can select the reasonable dosage of SRA so that meeting the required strengths and reducing of shrinkage preventing surface cracking. It was also observed that after 80 days, the surfaces of all AACM samples were still in very good condition without any sign of cracking on the surface.

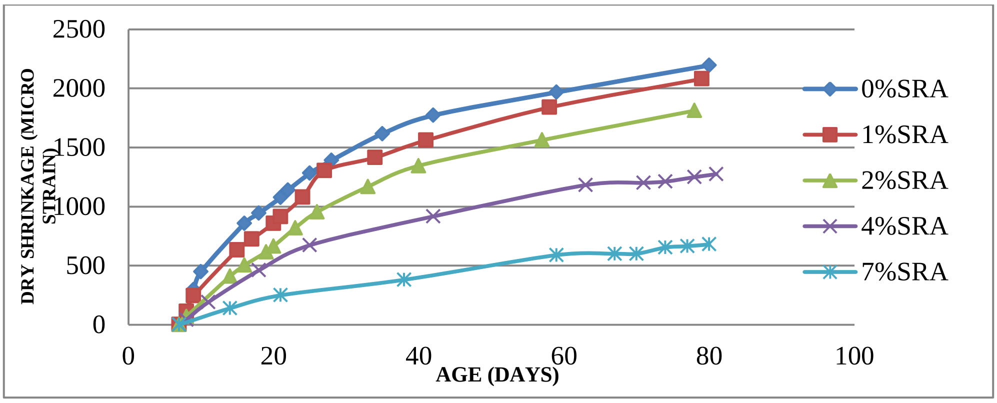

Figure 4. Shrinkage of AACM mortar.

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4. Conclusions

Based on the results reported in this paper, the following conclusions can be made:

- The shrinkage reducing admixture (SRA) significantly decreases the drying shrinkage of AACM mortar while still maintaining its strength.
- The drying shrinkage is reduced by 76% at 28 days and 69% at 80 days with 7% of SRA (by weight of binder) addition to the AACM mortar mixes.
- The surfaces of AACM samples (with and without SRA) were still in very good condition without any signs of cracking after 80 days.
- SRA reduces both the flexural and compressive strength of AACM mortar. These reductions at 28 days are less than 15% and 25% for flexural and compressive strength respectively with 7% of SRA content.
- Regardless of the dosage of SRA, the flexural and compressive strengths of AACM mortar exceed 7MPa and 44MPa respectively at 28 days. These values are considered as high strength and classified as 42.5R according to British standard PAS 8820:2016.
- The flexural strength (f_f) and compressive strength (f_c) of AACM mortar are related by the following equation $f_f = 0.398 f_c^{0.77}$ with a coefficient of correlation of R^2=0.99.
- The microstructure of AACM mortar samples (with and without SRA) should be investigated in future researches.

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