Analysis of Fine Sulfoaluminate Cement by Strength and Thermogravimetric Analysis

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Sulfoaluminate cement (SAC) was considered as an eco-friendly material due to its less carbon emissions during its production. To date, no studies have been done to analyze fine SAC properties. If the carbon dioxide emissions can be controlled and fine SAC cement can be produced in a very short time by using a ball mill for 30 minutes then it will be a very economical and environmentally-friendly choice. Therefore, this research explores the influence of fine SAC at an average diameter of 2.5µm under partial replacement in conventional cement. The particle size was calculated by Malver master size 2000 analyzer according to ASTM E2651-10. The mortar compressive and flexural strength tests were performed according to ASTM C348-02 and ASTM C349-18 on conventional SAC and fine SAC partial replacement in conventional SAC. The weight losses and mass compositions were also analyzed with the help of thermogravimetric analysis (TGA) according to ASTM E1142-15. In addition, the accelerated carbonation for 2 hrs and also sulfate attack effects were also analysed. It is concluded from experiments that fine SAC partial replacement at 20% under conventional SAC results in effective structure.

Introduction

A sulfoaluminate cement (SAC) has less carbon emissions during its production stage and as termed as eco-friendly material as compared to ordinary Portland cement [**1**]. The rate of development strength is also more than ordinary Portland cement [**2,3**]. The past results exhibit that ettringite and gibbsite are two main hydration products in SAC which contributes to rapid strength gain in SAC cement. SAC cement also shows good porosity [**4,5**]. The influence of nanomaterials has been done before and concludes in good mechanical and durability properties in SAC cement composites. The finely produced cement is much finer and has a steep grading curve than ordinary cement. They are especially suitable for the injection of rock and soil, but also nowadays they are used for filling and scrubbing concrete cracks. Improved compressive strength of cement by the use of ultra-fine cement as a blend has been achieved before [**6**]. It is emphasized that by maintaining optimum content of nanomaterials in cement composites the durability and mechanical efficiency can be achieved [**7-9**]. Moreover, the reactive additives in construction materials are also found to be useful [**10**].

Thermogravimetric analysis (TGA) is usually used as a tool to explain the hydration products, weight losses, carbonation, and nanomaterials effect. It is found to be very helpful to analyze engineering materials. TGA helps in identifying various phases present in the concrete, like portlandite, calcite, C-A-H, C-A-S-H, etc. Most often CH content is measured to check the hydration reaction i.e. if CH content has reduced that means it has been used up in the hydration reaction. These various phases break down at different temperatures to release chemically bound water in the case of hydration products and CO_2 in the case of calcite. This release of chemically bound water and CO_2 helps in identifying the various phases present.

Carbonation and sulfate attack are the two most vulnerable attacks for concrete structures. The carbonation of concrete is one of the main reasons for the corrosion of reinforcement. Carbonation is a mechanism by which carbon dioxide from the air penetrates into pores into concrete and then reacts with calcium hydroxide to produce calcium carbonate. The conversion of $Ca(OH)_2$ into $CaCO_3$ by CO_2 results in reduced shrinkage of cement composites. Carbonation is one of the main factors to enhance corrosion. CO_2, which exists in an atmosphere that can penetrate into concrete can reduce its alkalinity. Most of the time the sodium sulfate causes the attack to structures cause to producing expansion, leaching, spalling, loss of mechanical strength and deterioration of structures.

In this research, the SAC cement is used to reduce carbon dioxide emissions and to attain good mechanical and microstructure features. Fine SAC cement was prepared and was mixed in partial percentages in SAC conventional cement to attain good durability features. In this study, the fine SAC cement was prepared to have an average diameter of 2.5 µm [**11**]. The compressive and flexural strengths were analyzed. The durability features such as accelerated carbonation and sulfate attack were also analyzed. TGA and strength analysis was done to analyze strengths, hydration products, and mass losses.

Experimental

Materials

Sulfoaluminate cement is used in this study. Its composition is shown in **Table 1**. To make mortar in our research, the sand used is China ISO Standardized Sand in accordance with ISO679 EN196-1, produced by Xiamen ISO Standard Sand Co., Ltd. Sand is natural and silica sand with more than 98% of the sand being rounded and silica. The total density of sand is 2667.58 kg / m^3 by a true density meter. SAC was ground in a planetary ball mill (Retsch Co., Germany; Model No.: PM 100) for 30 min to attain an average particle size of 2.5 µm. The Particle sizes are shown in **Fig. 1.**

Table 1. Chemical composition of SAC cement.

	CaO	Fe_2O_3	SiO_2	MgO	Al_2O_3	SO_3	Loss
SAC	41	2.6	8.5	2.5	36	9.1	0.8

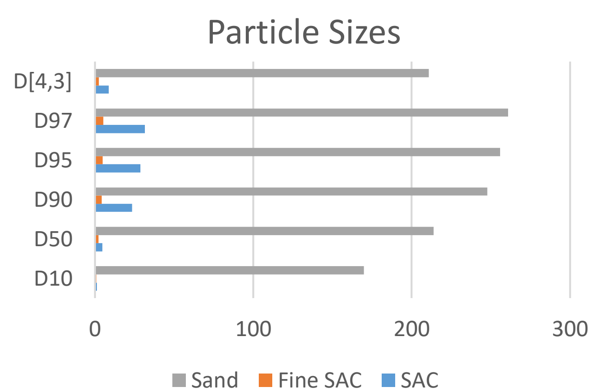

Fig. 1. Particle sizes of Sand, SAC, Fine SAC.

Sampling

Fluidity must be tested for an adequate water-cement ratio for the preparation of mortar according to ASTM C1437. The cement-sand ratio of 1:3 is assumed. The water-cement ratio is taken as 0.55 to preserve fluidity at 180-220 mm in order to produce a thick mixture and good workability. The mortar and paste samples are prepared to have fine SAC cement partial percentages at 10, 20 and 30% in conventional SAC cement.

After hydration of 7 days, the samples are placed in the carbonation chamber for accelerated carbonation for 2 hrs. And also samples are placed in 5% Na_2So_4 solution for 1 month to analyze sulfate attack.

Methodology

Strength

In compliance with ASTM C348 & C349 flexural and compressive strengths [**12,13**]. of samples at 7 days were evaluated respectively.

Thermogravimetric analysis

The cement paste has been analyzed after hydration in accordance with ASTM E1142-15 with the thermogravimetric test (TGA) [**14**]. Mettler-Toledo machine examined various weight losses regarding from 50 to 960 centigrade for samples.

Results and discussion

Strength

The compressive and flexural strength test shown in **Fig. 2** shows the influence of fine SAC cement. It must be focused that flexural and compressive strength at 7 days for SAC 20% fine partial replacement sample shows good strength. SAC 20% shows a 30% increase in flexural strength while a 16% increase in compressive strength as compared to conventional SAC. Also, after a carbonation attack for 2 hrs. the 20% SAC sample shows higher strengths. More than 20 % fine replacement sample shows less strength due to the agglomeration of cement particles. SAC cement shows a good effect on strength after the carbonation attack.

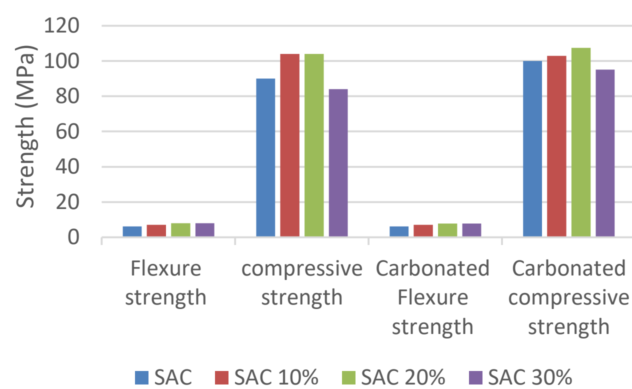

Fig. 2. Strength comparison by the influence of fine cement.

In the sulfate attack, the samples are placed in water for 28 days and also other groups for samples are placed in 5% Na_2SO_4 solution for 28 days. The results and coefficient resistance factor was also evaluated based on the flexural strength test shown in **Fig. 3**. All the factors result in K >1 which shows good resistance to sulfate attack while SAC 20% contributes more strength development.

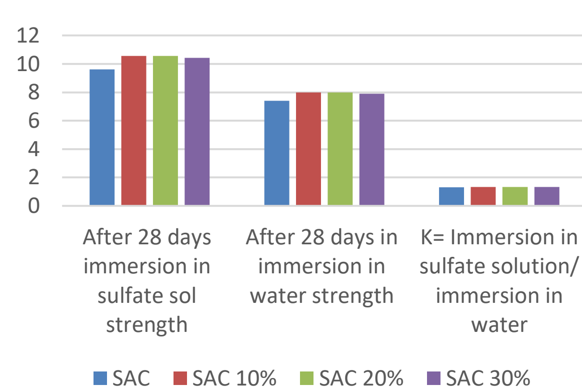

Fig. 3. Flexural strengths and resistance coefficient of samples under sulfate attack.

Thermogravimetric analysis

Total Mass loses from TG curve was calculated for samples it shows that 20% SAC cement replacement show fewer loss masses and less expansion in masses as exhibited to carbonation and sulfate attack. The mass losses for all samples are shown in **Fig. 4**. Samples of SAC may include: ettringite (100–150ºC), AFm monosulphates (60-200ºC), strätlingites (130-240ºC) and AH_3 (250–280ºC) [**15**]. Fine SAC cement can be seen as helping to increase strength through the formation of more ettringite. Because its compositions are not measured as a TGA curve by overlapping peaks.

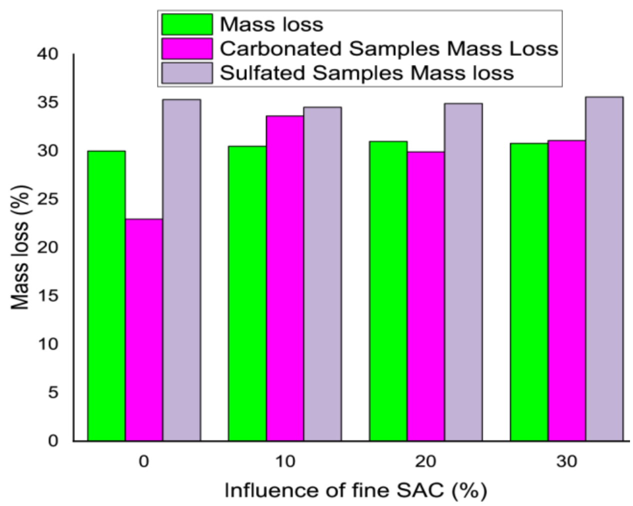

Fig. 4. Mass Loses from TGA.

The results for the DTG curve to compare mass losses of different hydration products are shown in **Fig. 5**. The main components of SAC are shown as ettringite, monosulfate and AH_3 by DTG curves. It is focused that ettringite and monosulfate masses cannot be calculated due to overlapping of peaks. While Gibbsite (AH_3) contents can be calculated. AH_3 under 40 ° C is amorphous and then becomes gibbsite over this temp. The AH_3 contents are 14.93, 15.5, 19.04, 15.9 % for 0, 10%, 20%, and 30% fine SAC cement replacement respectively. More Gibbsite and Ettringite contents are shown by a 20% partial replacement sample [**16**].

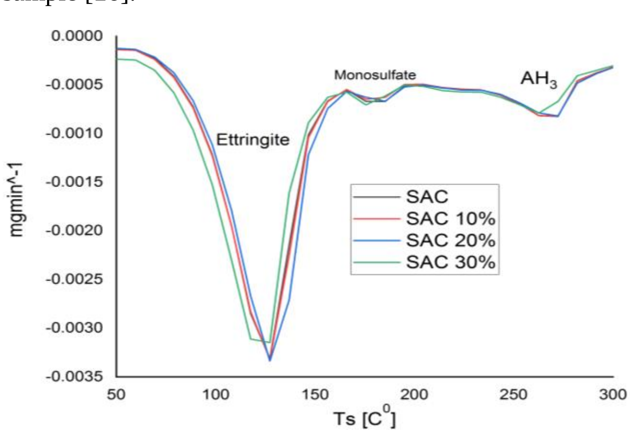

Fig. 5. DTG Curves for SAC partial replacement samples.

After a 2hrs carbonation attack, the TGA results were analyzed as done by previous researches [**17-19**]. In SAC samples, the $CaCo_3$ decomposition ranges are compared by DTG curves. Focusing on **Fig. 6** it clearly shows that less $CaCo_3$ was shown by sample 20% SAC.

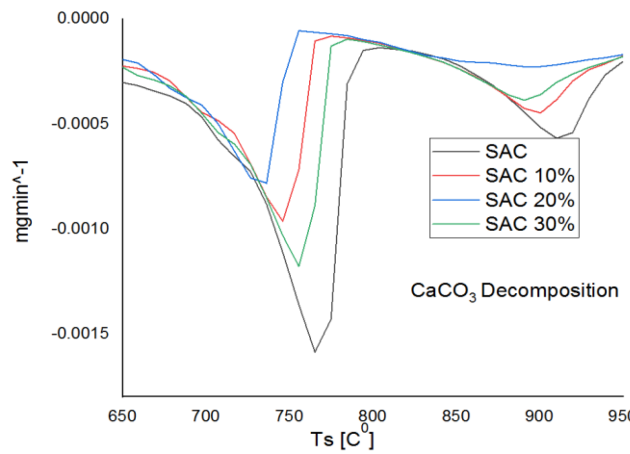

Fig. 6. DTG Curves for SAC Carbonated samples.

From mass expansion, we can calculate the influence of sulfate attack. By focusing on **Fig. 4** it is noted that the samples usually expend after sulfate attack. The mass expansion is calculated before and after immersion [**20**]. The 20% partial replacement sample shows less mass difference between before and after the sulfate attack.

Conclusion

In this study, the effect of fine SAC cement is tested using a wide range of experimental techniques. The amount of fine SAC with an average diameter of 2.5 µm applied in the traditional SAC system at an optimum dose of 20 % which resulted in an increase in the overall strength by 30–35 percent. For traditional SAC cement, the 20 percent substitution of fine SAC with an average diameter of 2.5 µm has produced more ettringite and AH_3 content which leads to the faster development of strength as verified by DTG results. The carbonation and sulfate resistance was also improved. After carbonation less $CaCO_3$ contents were identified by the DTG curve. The less mass expansion and more coefficient of resistance K were also identified in a 20% replacement sample. The modern SAC-fine cement technique for mortar or concrete is found to be useful and can be used in cement and concrete batching plants for future reference.

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Author's contributions

Conceived the plan: JC; Performed the experiments: WSA; Data analysis: WSA; Wrote the paper: WSA. The authors have no competing financial interests.

Keywords

Sulfoaluminate cement, thermogravimetric, sulfate attack, accelerated carbonation.

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