Scientific paper

The Effect of $Al_2(SO_4)_3$ on Compressive Strength in SLU Based on Ternary Binder System

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Abstract

The early flexural and compressive strengths of fast setting self-levelling underlayment (SLU) formulations based on a ternary system can be severely affected by the selection of accelerator, its quantity, and chemistry. Besides design complexity, it is predicted that the current lithium resources will not be sufficient to meet the increasing demands from other markets and lithium prices are expected to increase. It is necessary to search for a new raw material that gives the same performance to prevent the possibility of a supply shortage in the construction sector. In this study, ternary system accelerated with aluminum sulphate was comprehensively investigated in comparison with commonly used accelerators. The aim is to provide early strength by using aluminum sulphate in the ordinary Portland cement (OPC)-rich SLU formulation based on the ternary systems instead of traditional accelerators while obtaining cost saving solutions. For this purpose, fresh mortar properties and strength test were carried out according to EN 13813 and results were verified by monitoring hydration reactions over time by powder x-ray diffraction (PXRD) and Fourier transform infrared spectroscopy (FTIR).

Keywords: Self-levelling underlayment; accelerator; aluminum sulphate; fast setting; compressive strength; hydration reaction

1. Introduction

Self-levelling underlayment (SLU) mortar is mainly used to get rid of uneven surface and obtain a smooth surface. In general, this application is a surface preparation process performed before carpet, parquet, PVC, ceramic tile etc. coatings.[1–3] With the help of gravity, its consistency provides to spread by itself on the ground without any vibration.[1,2] It can be used both indoors and outdoors, and even on floors subject to heavy traffic such as shopping centers, industrial areas and depots.[3] In many of these areas, it is desired to complete the work rapidly to open the area for usage or make ready for the other operation such as application of topcoat on it within a few hours.

While traditional screeds are designed based on Ordinary Portland Cement (OPC), new generation SLUs are usually composed of three hydraulic binders which are calcium aluminate cement (CAC), OPC and calcium sulphate (CS). These designs, which are called ternary binder systems, provide important properties such as shrinkage compensation, accelerated setting time, high-early strength, dimensional stability during the hydration period.[1,3] Although it has many advantages, these designs can be complex at all stages, from raw material selection to raw materials dosages and their combinations. Designing the ideal binder combination, selecting the compatible accelerator type for the selected retarder, and choosing suitable plasticizer for the system are known difficulties of SLUs. In cementitious screeds, polycarboxylates and melamine sulfonates as plasticizers, lithium carbonate and lithium sulphates as accelerators, citric acid and tartaric acids as retarders are examples of known additives. However, the selection and combination of these chemicals, whose compatibility of each other can be related to the ionic charge density of formula, is very important in terms of meeting the requirements of application and mechanical properties of the formulation.[4]

The hydration mechanism of this ternary system is also quite complicated. Before explaining this mechanism, it is useful to look into the reactions of both OPC and CAC with water. The reaction mechanism of OPC is as follows.[5,7]

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH \qquad (1)$$

$$2C_2S + 4H \rightarrow C_3S_2H_3 + CH \qquad (2)$$

$$C_3A + CSH_2 + 10H \rightarrow C_4ASH_{12} \qquad (3)$$

$$C_3A + 3CSH_2 + 26H \rightarrow C_6AS_3H_{32} \qquad (4)$$

$$C_4ASH_{12} + 2CSH_2 + 16H \rightarrow C_6AS_3H_{32} \qquad (5)$$

The CAC chemical reaction in its basic form for ettringite formation is as follows.[8]

$$6Ca^{2+} + 6Al(OH)_4^{-} + 3(SO_4)^{2-} + 26H_2O \rightarrow 3CaOAl_2O_3{\cdot}3CaSO_4{\cdot}38H_2O \qquad (6)$$

C_3S and C_2S, which are the main phases of cement, form amorphous C–S–H and crystalline portlandite products due to hydration. As a result of the reaction of the C_3A phase with gypsum and water, two different hydration products in crystalline are formed either high (Ettringite-$C_6AS_3H_{32}$) or low in (C_4ASH_{12}) sulphate. C_4ASH_{12}, containing 12 molecules of water, is in a metastable state. If there is enough gypsum in the environment, it reacts again to form ettringite in a stable state. Since both hydration products contain high amount of water molecules in their structures, they can cause an expansion in the product.[5,7]

CAC is special type of cement in the sense that it is used to produce cementitious binders with different properties. CAC, OPC and/or CS mixtures are applied in a wide variety of areas with their mixtures formed at different rates. In such mixes, CAC contribute unique technical properties such as adjustable setting time, fast setting, fast drying and shrinkage compensation. In this study, a system dominated by OPC (OPC-rich) was studied.

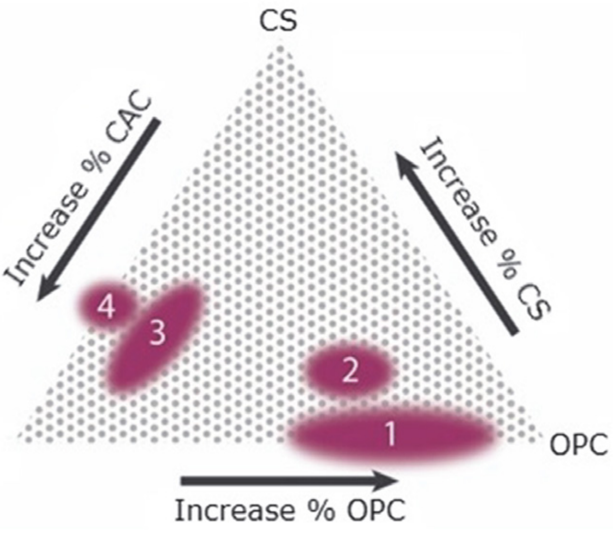

Figure 1. The pseudo ternary system of CAC–OPC–$CaSO_4$. Adapted from ref [9]

Such typical mixtures can be described by their positions in the pseudo ternary system CAC–OPC–CS. Figure 1 illustrates representative examples of four primary systems exhibiting distinct behaviors as the binder composition is varied from position 1 to position 4.

The binder composition is tailored to suit the intended application of the samples. Position 2 corresponds to the ternary system utilized in this study, characterized by its key features: early-age strength, fast setting, and rapid hardening.

Aluminates from OPC and CAC react with sulphates from the CS phase. The rapid hardening produced in OPC/CAC mixtures is mainly due to the formation of ettringite. [3] CAC or CS, which are present at different rates, also change the reaction mechanisms. In the first moments of hydration, ettringite formation dominates the reaction. The hydrates formed in OPC/CAC mixtures depend on the content ratios of the two cements. For low amounts of CAC (< 20%), the C–S–H gel is the predominant hydrate and exists in the form of alumina, ettringite, monosulfoaluminate or C_4AH_x. It has been reported that metastable hydrates C_2AH_8 and CAH_{10} were not detected for these mixtures. Therefore, the conversion of these phases to C_3AH_6 is negligible. On the other hand, when the amount of OPC is less than 20%, the hydrates obtained are typical products of normal CAC. The development of hydrates between these two boundaries is complex and C_2ASH_8 type aluminosilicates are thought to be formed. When CS is completely consumed, CA reacts with ettringite to form monosulfoaluminate.[10,12]

Besides, the reaction mechanism in ternary systems is as described above, the water solubility of aluminum sulphate is another issue. It has been proven in many scientific studies that Al^{3+} ions rapidly transform into $[Al(OH)_4]^-$ aquo-complex in the alkaline medium that develops after mixing, and then react with $SO4^{2-}$ (provided by both accelerator and solubility) and Ca^{2+} ions. It is also known that the accelerator begins to form ettringite immediately after contact with cement and water.[13]

As detailed in the hydration mechanism, achieving the optimal product design in ternary systems relies on the precise interaction of multiple additives at their optimum levels. In recent years, the growing interest in fast-curing product designs has brought attention to the effects of setting time accelerators on the hydration mechanism and their relative differences. However, challenges have arisen in the supply of lithium carbonate, the most widely used additive for setting time acceleration in formulation designs. Additionally, with increasing demand, a significant rise in its price is anticipated in the coming years.

The growing global emphasis on clean energy sources and electric vehicles, driven by heightened awareness of reducing greenhouse gas emissions, is expected to significantly increase the demand for lithium. Global market findings indicate that the electric vehicle sector currently accounts for approximately 45% of lithium demand, a figure projected to rise to 80% by 2030. Despite increased production capacity, current lithium output is expected to fall short of meeting the growing demand, leading to anticipated price increases in the coming years.[14–16] In addition to these recent developments, lithium and its derivatives are widely used across various industries, including construction chemicals, ceramics, glass, electronics, electricity, industrial greases, metallurgy, silicon, nano-welding, air filters, optics, and rocket launchers. Moreover, lithium has become a critical component in the development of industrial products, particularly batteries for electronic devices and electric vehicles.[17]

While the expectation for an increase in lithium demand is rising rapidly, it is known that Turkey does not have a lithium source or any reserves with economic value.[14] Although there are important developments in the field of lithium extraction and lithium-ion battery production in Turkey and other countries, it is not foreseen that a rapid result will be obtained in the short term.[18] Considering the changing world dynamics, proximity to local raw materials and supply will gain more importance in the future in the construction chemicals industry. In addition, the search for an alternative raw material that can give the same performance and offer more economical solutions will help to solve the main problem. As it is known that Turkey imports lithium carbonate, the fact that its market share will increase in different areas in the future and this will require the search for substitute and more sustainable raw materials.[17]

For all these reasons, finding innovative raw materials as substitutes for setting time accelerators, particularly in place of lithium carbonate, has become an increasingly important issue. In this article, the effect of aluminum sulfate on performance in ternary systems is comparatively examined, considering both the proximity to local raw materials and the opportunity for optimization from a more innovative perspective.

2. Materials, Methods and Standards

2. 1. Materials

OPC (CEM I 42.5 R) was obtained from Akcansa, cement producer in Turkey. CAC that composed mainly of the calcium aluminate phase was supplied from IMERYS Aluminates which is a French industrial company. The third binder, CS anhydrous with high purity, was obtained from Saint Gobain (France). The silica sand used as filler was obtained from a local producer. The clay content and size distribution of the sand used are very critical as they would affect the performance and application properties (quartz 99.7 wt%, 0.3% feldspathoid as impurity, particle size < 1 mm). The other filler used in the formula is calcite, and it was obtained from Etna Maden, one of the local calcite producer in Turkey. (calcite 99 wt%; containing dolomite 0.7 wt% and quartz 0–1 wt% as impurities, particle size < 0,1 mm). Hydroxy Ethyl Cellulose was used as a rheology agent to increase workability, adjust viscosity and resistance to segregation. Vinyl Acetate/Acrylic Copolymer was used as a re-dispersible polymer powder to increase performance. According to product design, performance can be evaluated as flexibility, abrasion resistance, adhesion strength, durability and sometimes surface quality. Polycarboxylate-based powder plasticizer was used as a superplasticizer in the formula. Lithium carbonate and aluminum sulphate were setting accelerator additives. Tartaric Acid was evaluated as a setting retarding additive. These accelerators and retarders are found together in the formulation and work with a harmony for the ideal setting time. Hydrophobic ester mixture in powder form was used as defoamer.

2. 2. Characterization

To ensure homogeneity of the formulations by mixing the materials a Collomix Shaker (Germany) was used. Powder X-ray diffraction (PXRD) analysis was conducted to characterize the raw materials and determine the hydrated phases as the hydration reaction progressed by using the Philips PANalytical X'Pert-Pro X-ray diffractometer with Cu Kα radiation with a 40 mA and 30 kV. For all samples a scanning range of $2\theta = 5–70$ at a step size of 0.02° were used. Fourier-transform infrared spectroscopy (FTIR) measurements of the conditioned powder and hydrated product were conducted using a Perkin Elmer Spectrum 100 series device with ATR mode. C–S–H, which is one of the hydrated phases that gives binding property to the cured sample, cannot be seen in the PXRD analysis because of its amorphous structure; therefore, the presence of this phase was determined using FTIR. The morphology of the samples was determined by using of scanning electron microscopy (SEM), Zeiss EVO LS 10. Viscosity value of fresh mortars was measured using Brookfield brand, RVDV-II+PX model viscometer. The setting times of the fresh mortars were followed using the Matest E044N Automatic Vicat Device. Utest UTCM 6431 Compression and Flexural Strength tester, measuring range compression; 10–250 kN/flexural: 1–1.5 kN was used to determine the Compression and Flexural Strength values of hydrated specimens. Nabertherm brand L 9/12 P320 model furnace was used in the range of 25–1200 °C with a heating regime of 10 °C/min to perform the aluminum sulphate calcination. TA Instruments-Waters LLC brand Discovery Series-Model 650 thermal analyzer was used to verify the effectiveness of the calcination process.

2. 3. Test Methods and Standards

2. 3. 1. Test Methods

The EN 13813:2002 standard is the primary standard that specifies the requirements for screed materials used in internal floor construction. It defines performance limits and requirements for consistency, setting time, abrasion resistance, shrinkage, and both compressive and flexural strength for both fresh and hardened screed materials. This study, however, focuses specifically on the analysis of early flexural and compressive strength. These parameters are critical for evaluating the material's performance during the early curing stages, which directly influence the durability and long-term stability of the floor.

2. 3. 2 Compressive and Flexural Strength Test

The self-levelling screed samples were prepared in accordance with the EN 13892-1 standard and subjected to flexural and compressive strength test in accordance with the EN 13892. The samples prepared in the appropriate water ratio* were poured into (40 mm × 40 mm × 160 mm) steel prism molds lubricated with mold oil after viscosity measurement. Since the product is self-leveled, vibration is not applied against collapse. The samples were then covered with a glass plate and stored at 95 % ± 5 RH and 20 ± 2 °C for 6 h and 24 h to provide high humidity conditions. After 6 and 24 hours, the samples were removed from the molds and subjected to flexural and compressive strength tests. In these tests, three prisms are prepared for each trial and each prism is subjected to a flexural test at first. Then, each of broken parts of this prism is loaded until failure occurs, the maximum compressive strength observed and recorded the average of them. Tests were carried out according to EN 196-1 using an automatic compression/flexural strength testing machine with a loading speed (50 ± 10) N/s for flexural strength, (2400 ± 200) N/s for compressive strength. During the test, the ambient conditions were around 22 °C and 60% RH.

2. 3. 3. Initial and Final Setting Time

The performance of the setting time accelerator was evaluated by measuring the initial and final setting times of the samples according to EN 196-3. All equipment and samples were maintained under controlled laboratory conditions, ensuring that the ambient humidity was no lower than 50%. The conditioned samples were prepared with the correct water-to-cement ratio using a mortar mixer in accordance with EN 196-1. The self-levelling screed samples were placed on a lightly oiled baseplate, without the application of excessive compression or vibration. Air bubbles in the sample were removed by lightly tapping the plate. Excess material was leveled off. The tests were performed using an automatic Vicat machine. The initial setting time was defined as the time elapsed from zero time to when the distance between the needle and the baseplate was (6±3) mm. The final setting time was determined when the needle first penetrated only 0.5 mm into the specimen.

2. 3. 4. Flowability Measurements

The fluidity test was carried out according to the EN 12706 standard. A ring with a diameter of (30 ± 0.1) mm and a height of (50 ± 0.2) mm was placed in the middle of a flat glass plate. The inside of the ring was filled with the prepared sample. The ring was immediately removed and the sample spread on the glass plate was released. After waiting for 45 seconds the spreading diameter of the sample was measured along two vertical axes and recorded as mm. This process was also carried out at the 15th minute and the spreading diameter of the sample was also measured at that time.

2. 3. 5. Viscosity Measurements

The viscosity of the product samples was measured using a Brookfield Viscometer. This was one of the preliminary tests conducted to determine the optimal water ratio and ensure that all product samples were within the same viscosity range. Measurements were taken using spindle 5 at a speed of 10 rpm. Based on the fluidity test results, the viscosity range determined for the products was 4500–5500 cPs.

2. 4. Sample Preparation

First, to eliminate batch-to-batch fluctuations in the raw materials, a sufficient quantity of fresh materials for the entire study was separated and stored from the same batch. All formulations were then prepared using these materials.

In this study, the main formula, which will be used to examine the effect of aluminum sulfate as an accelerator, is rich in Ordinary Portland Cement (OPC). Its composition is shown in Table 1. The formula is based on a ternary system containing OPC, Calcium Aluminate Cement (CAC), and Calcium Sulfate (CS). The maximum particle size of this formula, which includes fine calcite and coarse silica sand as fillers, is less than 1 millimeter. The total organic content of this formula, which contains an accelerator, retarder, re-dispersible polymer powder, cellulose ether, defoamer, and superplasticizer, is approximately 2.0%.

Table 1. The main SLU formulation used in this study.

Component	**wt. %**
OPC, CEM I 42.5 R	22.00–26.00
CAC	3.00–6.00
Anhydrite	2.00–4.00
Silica Sand, Coarse < 1 mm	38.00–45.00
Calcium Carbonate, Fine < 0,100 mm	18.00–26.00
Re-dispersible Polymer Powder	0.70–1.40
Rheology Modifier, Cellulose Ether	0.07–0.20
Superplasticizer, Polycarboxylate Ether	0.07–0.15
Accelerator, Lithium Carbonate	0.07–0.15
Retarder, Tartaric Acid	0.06–0.18
Defoamer, Hydrophobic Ester	0.08–0.20

(*) Appropriate water ratio was determined by viscosity measurement and flowability tests.

Table 2. Experiment Set

Component, wt.%	Reference	Sample-1	Sample-2	Sample-3	Sample-4
Lithium carbonate	0.07–0.15	0.00	0.00	0.00	0.00
Lithium sulphate	0.00	0.07–0.15	0.00	0.00	0.00
Aluminum sulphate	0.00	0.00	0.07–0.15	0.14–0.30	0.21–0.45

In the trials, lithium carbonate in the main formulation was replaced with aluminum sulphate at different dosages while other raw materials were kept constant. In addition to these trials, lithium sulphate, one of the traditional accelerators, was also tried in the experimental set at the same dosage instead of lithium carbonate. All the details of the formulations are presented in Table 2.

These designed formulations were prepared to 2.5 kg by a single operator and mixed in a shaker for 8 minutes to achieve homogeneous mixture. Then, by adding appropriate water ratio to dry mix formulations SLU mortars were prepared to have similar viscosities. Setting times and flowing values of them were observed. After the fresh mortar tests, samples for the flexural and compression strength, which were the performance tests, were prepared and samples left to cure in the standard conditions. In order to be sure of the accuracy of the data, these formulas were prepared in the same way three times and these tests were carried out in three repetitions.

Simultaneously with the formulations and performance test sample preparations, advanced analyses studies were carried out for raw materials. In the XRD analyzes and literature reviews, it was found that aluminum sulphate can contain a high amorphous content.[19]

The high amorphous content made it difficult to accurately quantify the with the Rietveld method and required different characterization methods to be studied. Gravimetric sulphate determination method was used to detect aluminum sulphate, but it was decided that it was not a sustainable test method due to its long waiting time, inability to give definite results and it may vary according to the person making the determination. From the literature it was observed that the aluminum sulphate structure decomposed into alumina with temperature.[20–22]

The powder X-ray diffraction analyses (PXRD) analyzes were performed on the samples before and after calcination and the comparative diffractogram is given in Figure 2. In the PXRD analysis before calcination (black line in Figure 2), a less crystalline structure can be seen. At the same time, the sample had a more crystalline structure after calcination (red line in Figure 2). Rietveld analysis determined that the sample after calcination contained a significant weight percentage of aluminum oxide resulted from the decomposition of aluminum sulphate.

Characterization of OPC, CAC and CS samples used as components of Ternary Binder System was performed using PXRD analyses and Rietveld method (**), and contents are given in Table 3. For the determination of amorphous phase in samples after calcination, external standard method was carried out and it was confirmed that there was no amorphous phase after calcination. According to the Rietveld analysis performed after calcination, the impurity values were calculated, and the obtained mass loss values were also confirmed by thermogravimetric analyses.

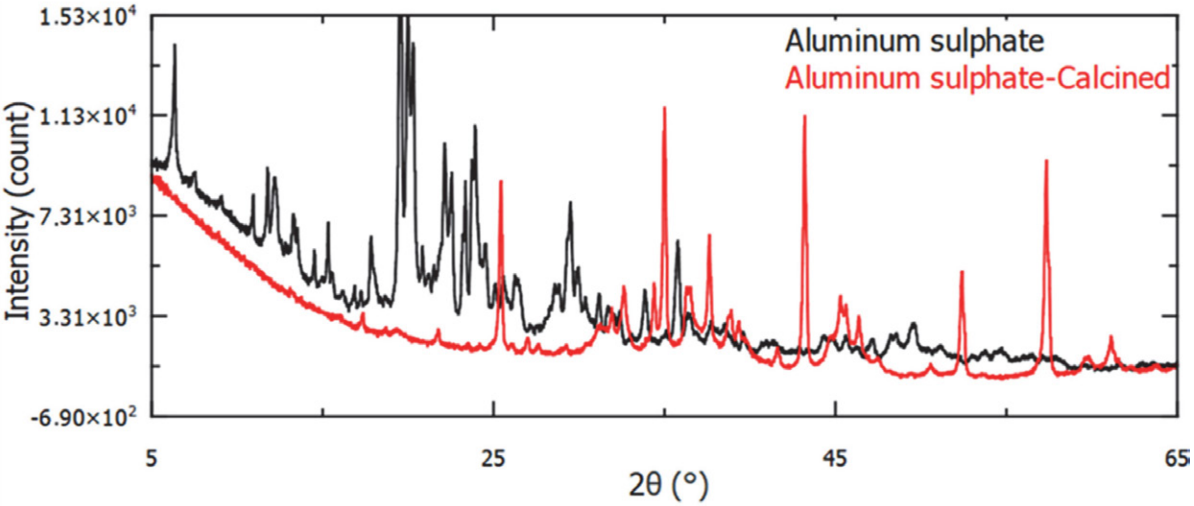

Figure 2. PXRD data of aluminum sulphate before and after calcination.

Table 3. Chemical composition of the OPC, CAC and Anhydrite

Component	OPC	CAC	Anhydrite
Gypsum	2.6		0.9
Hatrurite	69.2		
Anhydrite			98.2
Brownmillerite	12.1	17.9	
Bassanite	1.1		0.9
Larnite	10.0		
Calcium sodium aluminate titanate	2.4		
Quartz			
Calcite	0.8		
Dolomite	0.8		
Periclase	0.9		
Krotite		63.8	
Mayenite		3.8	
Gehlenite		3.1	
Calcium Titanate		4.3	
Hematite		1.4	
Spinel		5.6	

(**) The standard deviation is around ± 5%

At the end of 6 hours curing time, the prepared prisms were taken out of the mold and subjected to flexural and compressive test according to EN 13892. In order to examine the hydration follow-up, parts of the samples from the compression test were taken, XRD and FTIR analyses were carried out quickly without any reaction stops. Completing the analyses in a very short time after the compression test is very important in the examination of the rapid hardening products. The study was repeated in the same way at the end of 24 hours and 7 days curing time.

3. Results and Discussion

3. 1. Fresh Mortar Test Results

Fresh mortar tests (water ratio (wt%), viscosity, flowing, workability, initial and final setting time value) were conducted after mixing the dry mix mortar samples with water. The flowing performance of the samples was quite similar to each other. Other results for all the prepared samples are presented in Table 4.

All samples were evaluated within the appropriate viscosity range established for the product design, and no significant differences in water demand were observed. However, when lithium carbonate, lithium sulfate, and aluminum sulfate were used at the same dosage in formulations, lithium carbonate and lithium sulfate exhibited similar water ratios. In contrast, recipes containing aluminum sulfate showed a slight increase in water demand as the dosage increased. To maintain the same viscosity range, the water ratio was accordingly adjusted.

Upon examining the initial and final setting times, no significant differences were observed between the Reference, Sample-1, Sample-2, and Sample-3. However, Sample-4 exhibited a notably delayed final setting time compared to all other trials and the reference. Another key observation was that the time between the initial and final setting for Sample-1 and Sample-2 was very short, ranging from 5 to 10 minutes. This rapid water loss and phase change in such a short period is undesirable for the product. In contrast, the Reference and Sample-3 showed more consistent results, with the difference between the initial and final setting times being more controlled. These findings indicate that aluminum sulfate can function as an accelerator in the ternary system, similar to lithium carbonate, although its optimal dosage may be approximately double that of lithium carbonate.

3. 2. Performance Test Results

Flexural strengths of samples cured for 6 hours, 1 day and 7 days are given in the Figure 3 and compressive strengths are given in the Figure 4.

Upon comparing the 6-hour and 1-day early flexural and compression strengths of the samples, it was found that the Reference, Sample-1, and Sample-3 exhibited very similar results. However, Sample-2 showed slightly lower compression strength after 6 hours of curing compared to the others. On the other hand, after 1 day of curing, Sam-

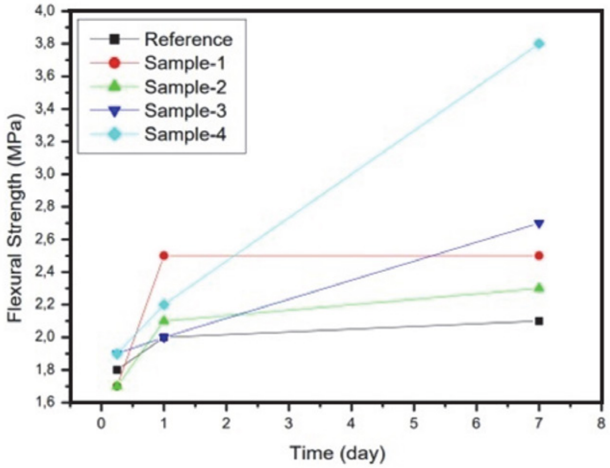

Figure 3. Flexural strength of the samples after curing for 6 hours, 1 day and 7 days.

Table 4. Fresh mortar test results

Test Results	Reference	Sample-1	Sample-2	Sample-3	Sample-4
Water demand, (wt%)	22.00	22.00	22.25	22.50	22.50
Viscosity (sp 05, 10 rpm)	4650	4350	4650	5200	5500
Initial/Final setting time (min)	120/160	140/150	135/140	110/160	160/235

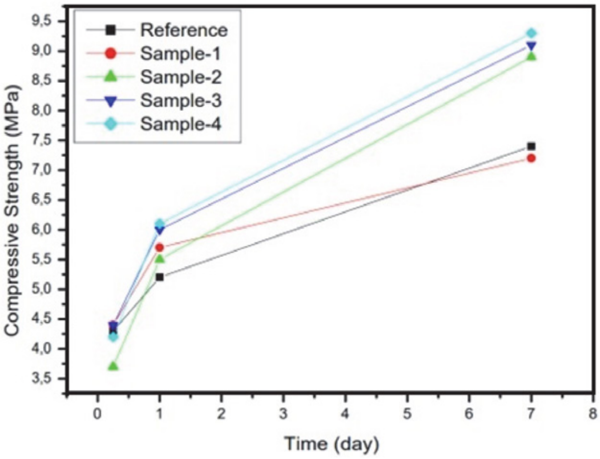

Figure 4. Compressive strength of the samples after curing for 6 hours, 1 day and 7 days.

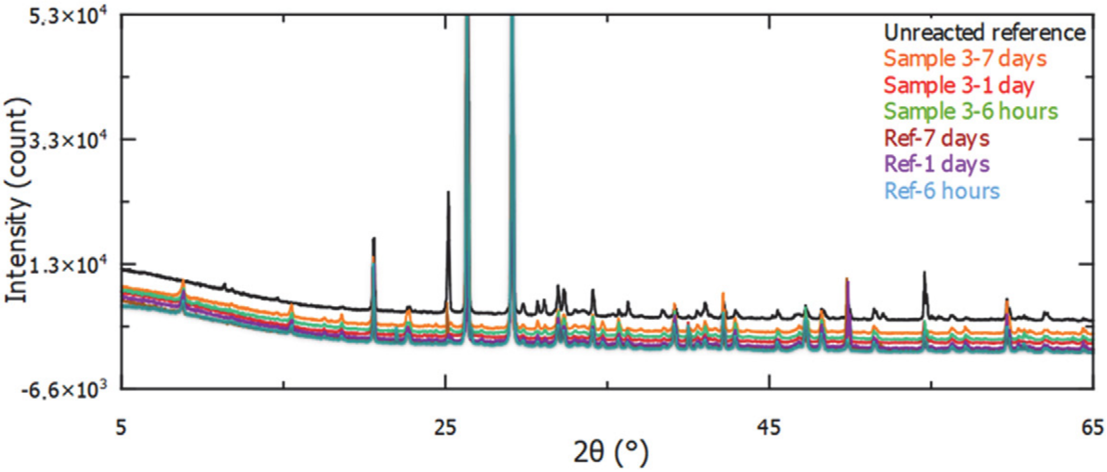

Figure 5. Diffractogram of the results of XRD of Reference and Sample-3 conditioned for 6 hours, 1 day and 7 days.

ple-2 displayed an increase in both flexural and compression strength compared to the Reference and Sample-1.

Parallel to all these results, when the 7-days flexural and compression strengths of the samples were compared; it was observed that the Reference and Sample-1 gave very close results as in the early flexural and compression strengths. Sample-2, which was thought to have a relatively lower initial reaction response, gave higher flexural and compression results at day 7. It was observed that the flexural and compression strengths increased in parallel in Sample-3 and Sample-4 coded samples, where the aluminum sulphate dosage was doubled or tripled. For this reason, it was thought that lithium carbonate and lithium sulphate form faster ettringite by establishing a more effective connection with the hydrated phases after mixing, but aluminum sulphate was also more effective in increasing the strength in the following periods. However; it was seen that the early strength when the aluminum sulphate dosage was doubled compared to lithium carbonate also increased to the desired performance.

3. 3. Hydration Study Results

In order to observe the hydration reaction in the ternary binder system, the structure of the ettringite and portlandite phases formed as a result of the hydration reaction was followed by PXRD because of its crystalline structure, while the structure of C–S–H, which is another dominant phase, was followed by FTIR due to its amorphous nature. In Figure 5, PXRD diffractograms of 6 hours, 1 day and 7 days hydrated samples of Reference and Sample-3, and unreacted reference sample are given comparatively. Other samples were analyzed under the same conditions after hydration reactions at the same times, and the focus was on the reference and Sample-3, other samples were not detailed because they had similar tendencies. PXRD analyses were not interpreted with the Rietveld method in order not to cause errors due to the amorphous C–S–H phase that formed as a result of hydration. The residual observed depending on the curing time in the formation of ettringite (peak of 9°) confirmed the flexural and compression strength values obtained in both the reference and Sample-3. According to the results of PXRD analyses, although the amount of portlandite with a maximum peak of 18° was the lowest in both reference and Sample-3 at 6 hours, this peak increased as the curing time increased. As stated in the section where the reaction mechanism was explained, first a serious change occurs in the calcium sulphate phase. Anhydrite with a maximum peak of 25.4° was mostly found in the unreacted reference, it decreased rapidly due to the increasing hydration time and reached the minimum level at the end of 7 days. The amount of decrease in CAC was followed by the maximum Krotite peak at 30°. When we looked at the rate of decrease between CAC and OPC, it was observed that the amount of CAC decreased faster than OPC and it was almost consumed at the end of 7 days.[10–11]

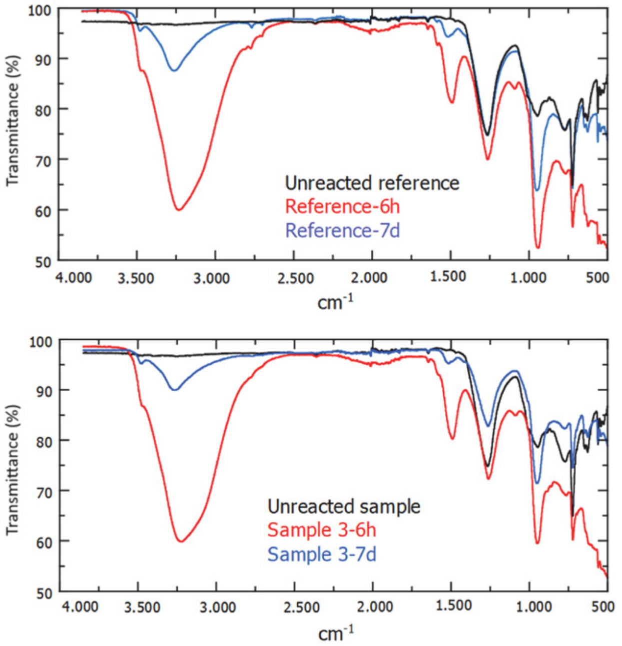

Figure 6. Spectrum of the results of FTIR of reference and Sample-3 conditioned for 6 hours, and 7 days.

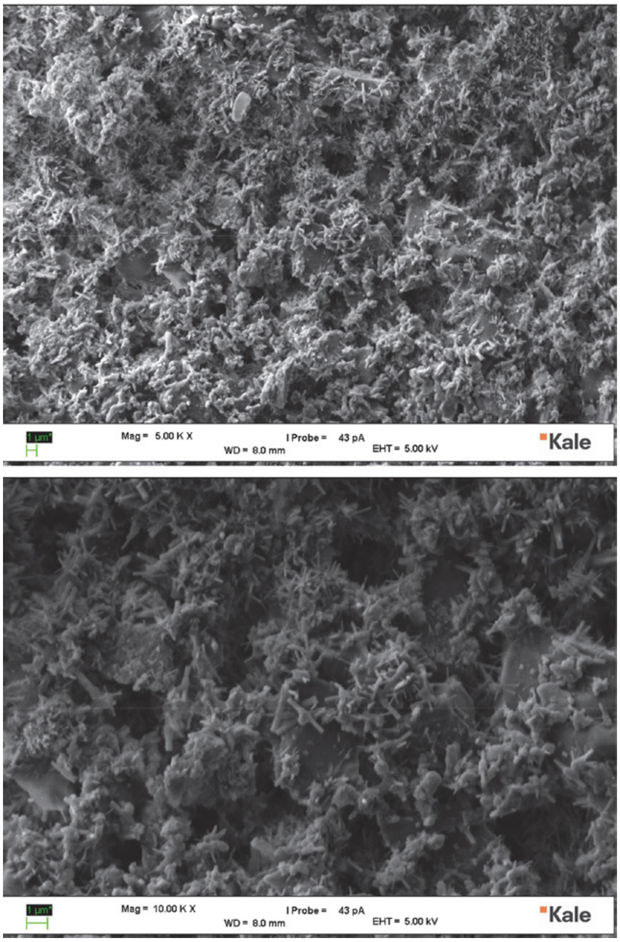

Figure 7. Scanning electron microscopy images of the hydrated sample at 5000X (top) and 10000X (bottom) magnifications.

The reaction progress was followed by FTIR due to the formation of amorphous C–S–H phase and the FTIR spectra of Reference, Sample-3, and Unreacted Reference/Sample-3 are given in Figure 6. Comparing the uncured sample with the samples cured for 6 hours and 7 days, it was seen that stretching vibrations of weak H-bonded OH groups occur at 3700–3500cm^{-1}.[23] The portlandite observed due to the progression of hydration is characteristically determined by the stretching vibrations produced by the dense narrow band, O–H bonds at 3639 cm^{-1}. [24] While the C-S-H phase was not present in the unreacted sample, it started to form with curing and appeared as a characteristic band set centered at ~970 cm^{-1}.[25]

In Figure 7, SEM images of a cured sample are given at 5000x and 10000x magnifications. The needle-like crystal structures in the image belong to ettringite. Portlandite was observed as relatively large crystalline aggregates as hexagonal plate and columnar aggregates. It is known that the C–S–H phase exhibits an extremely low crystallinity.[26,28]

4. Conclusions

Ternary binder system are products consisting of OPC, CAC, calcium sulphate, fillers, and additives such as rheology agent, re-dispersible polymer powder, plasticizer, setting time accelerator, setting time retarder, and defoamer. Self-levelling underlayment (SLU) mortar is mainly used to get rid of rough surfaces and to obtain a smooth surface, and ternary binder systems are mostly preferred for this purpose. In this study, the effect of aluminum sulphate on early and final flexural-compressive strength of these products was investigated. The results provide an understanding of the mechanisms behind the similar strength of SLU systems accelerated with aluminum sulphate. It has been proven that aluminum sulphate can be used as an accelerator substitute for lithium carbonate. The reaction of aluminum sulfate in the initial stages within OPC-rich ternary systems was slower when used at the same dosage as lithium carbonate. For designs requiring early high strength, it is recommended to double the aluminum sulfate ratio. Aluminum sulfate, sourced from a local manufacturer, not only demonstrates comparable performance to lithium carbonate but also provides more cost-effective solutions. A cost analysis of all samples confirmed that aluminum sulfate offers significant cost optimization, both at the reference dosage and at the maximum dosage levels studied. These findings and shared insights will aid in the development and optimization of new setting time accelerators and innovative products. Furthermore, the possibility of utilizing alternative raw materials to replace traditional accelerators, which could face supply challenges in the future, has been highlighted. By carefully tailoring formulation designs, it is expected that product costs can be optimized, thereby contributing to economic sustainability in the construction industry.

5. References

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Povzetek

Zgodnje upogibne in tlačne trdnosti hitrosušečih samorazlivnih izravnalnih mas (SLU), ki temeljijo na ternarnem sistemu, so močno odvisne od izbire pospeševalca, njegovega odmerka in kemije. Poleg zapletenosti procesa njihovega pridobivanja se predvideva, da trenutne zaloge litija ne bodo zadoščale za naraščajoče povpraševanje v drugih industrijah, cene litija pa naj bi se zvišale. Da bi preprečili morebiten primanjkljaj litija v gradbenem sektorju, je nujno poiskati alternativne materiale z enako učinkovitostjo. V tej študiji je bil ternarni sistem, pospešen z aluminijevim sulfatom, celovito raziskan v primerjavi z običajno uporabljenimi pospeševalci. Cilj je doseči zgodnjo trdnost v SLU formulaciji, bogati s portlandskim cementom (OPC), z uporabo aluminijevega sulfata kot alternative tradicionalnim pospeševalcem, pri čemer se hkrati zagotavljajo stroškovno učinkovite rešitve. V ta namen so bile izvedene analize lastnosti svežega malta in testi trdnosti v skladu s standardi EN 13813. Rezultati so bili potrjeni z opazovanjem hidracijskih reakcij skozi čas z uporabo rentgenske praškovne difrakcije (PXRD) in Fourierjeve transformacijske infrardeče spektroskopije (FTIR).