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Research paper

Recycling and reusing of waste fresh cement mortar through the dormancy-awakening method

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Abstract: This study develops the dormancy-awakening method for recycling and reusing of waste fresh cement mortar. Sucrose (SU, $C_{12}H_{22}O_{11}$) is utilized as the dormancy agent to delay cement hydration, which can prolong the storage time of the waste fresh cement mortar. Aluminum sulfate (AS, $Al_2(SO_4)_3$) and calcium formate (CF, $C_2H_2O_4Ca$) serve as awakening agents to resume cement hydration. The results show that the addition of 0.1% SU in fresh mortar blocks cement hydration for the first 24 hours. AS and CF accelerate the cement hydration process and shorten the setting time. The combined use of AS and CF can further accelerate cement hydration, leading to the normal setting time of cement. The setting time can be flexibly controlled by using dormancy agent and awakening agents. Moreover, the awakened cement mortar has smaller volume of harmful pores compared to normal mortar. The addition of awakening agents can improve elastic modulus and packing density of the hardened mortar according to nanoindentation analysis. Compared to the normal mortar, the compressive strength of awakened mortar is enhanced by 21.0% and 18.3% at 3 days and 28 days, respectively. This study develops the method for recycling and reusing waste fresh cement mortar by using conventional admixtures.

Keywords: dormancy, awakening, setting time, hydration, compressive strength

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1. Introduction

The acceleration of the construction industrialization process has led to a year-on-year increase in concrete consumption. Ready-mixed concrete is widely used in construction and building engineering, especially in China. Some fresh concrete is often discarded due to the long-distance transportation or expiration before use [1]. The annual production of commercial concrete is approximately 2 billion tons in China with waste concrete accounting for approximately 1% to 1.5%, resulting in the massive amount of waste concrete reaching around 20 to 30 million tons [2]. The primary disposal method for waste concrete relies on landfill or direct storage in the open air. This not only occupies land, but also pollutes the environment, which has adverse effects on the ecosystem and human health [3].

The key to improving the recycling and utilization rates of fresh concrete waste lies in controlling its setting time and hydration process, which can be achieved by adding chemical admixtures [4]. Yuan et al. [5] proposed the “dormancy-awakening” treatment approach to delay the hydration of waste concrete. This approach involves using hydration inhibitors to delay hydration, and then adding awakening agents at the appropriate time to recover hydration, which can achieve flexible recycling and utilization of waste concrete. Sun et al. [6] adopted to add aluminum sulfate to sulfoaluminate cement paste containing citrate, which eliminated the retarding effect of citrate. Reiter et al. [7] proposed to use mineral admixtures to awaken concrete in “dormancy” state. The mineral admixtures can effectively eliminate the retarding effect of polycarboxylate superplasticizers on cement hydration and achieve normal setting of concrete. Pang et al. [8] found that the retarding effect of nitrilotris(methylene)triphosphonate (NTMP) was mainly due to the formation of calcium phosphonate precipitates from dissolved calcium ions in cement. These precipitates adhered to the surface of cement particles and inhibited hydration. Adding sodium hexametaphosphate can dissolve the precipitates and eliminate the retarding effect of NTMP.

This study introduces the “dormancy-awakening” method for recycling and reusing fresh cement mortar waste. The sucrose (SU) acts as a dormancy agent, while aluminum sulfate (AS) and calcium formate (CF) serve as awakening agents. SU is widely available and inexpensive, with strong retarding effects on cement hydration, making it an extensively used cement retarder. Unlike synthetic retarders, SU is a natural, biodegradable substance, offering a more eco-friendly alternative. Furthermore, using SU contributes to the treatment of sucrose-containing waste generated by the food industry [9]. For instance, the Guangxi region annually processes 80-85 million tons of sugarcane, producing approximately 2.5 million tons of sucrose-containing waste [10]. Utilizing SU as a dormancy agent thus supports waste valorization and sustainability. Young et al. [11] found that the SU can adsorb on the aluminate phase and solubilize the ionic group $[\mathrm{Al(OH)}^{3-}]$ through chelation, which accelerates the hydrolysis of C_3A. On one hand, this delays the precipitation of hydration products, such as $Ca(OH)_2$ and C–S–H. On the other hand, SU adsorbs on the small amount of generated C–S–H and $Ca(OH)_2$, hindering their growth. A few studies concluded that SU can prevent further nucleation of $Ca(OH)_2$ and inhibit the hydration of C_3S and C_2S [12, 13]. Aluminum sulfate (AS), an alkali-free compound, promotes cement hydration and enhances both early and late strength. As an eco-friendly early strength agent, it is primarily used in alkali-free accelerators and minimizes risks of corrosion and alkali-aggregate reactions [14]. When added to cementitious materials as an early strength agent, AS improves mechanical properties and mitigates alkali-aggregate reactions of cementitious materials [15]. The incorporation of AS promotes early strength formation in cementitious materials by improving hydration reactions, crystal nucleation and particle dispersion [16,17]. This enhances the early strength of cementitious materials, which is suitable for applications requiring rapid strength development. Furthermore, AS improves the viscosity and prevents water secretion, which is advantageous for applications requiring lower fluidity, such as for pouring vertical structures. This helps maintain the desired shape and stability of fresh concrete [18]. Calcium formate (CF), a byproduct of polyester polyol production, serves as an ideal organic early strength agent. Compared to other early strength agents, CF is safer and more environmentally friendly than calcium chloride, which poses a risk of steel reinforcement corrosion [19]. Formate ions effectively penetrate the hydration layer that forms around these silicate phases of C_3S and C_2S and destroy the protective film of C_3S, leading to accelerated the hydration of cement clinker [20]. Moreover, formate ions promote the decomposition of unhydrated cement particles and accelerate the formation of C–S–H gel and AFt. This effectively improves the early compressive strength of cementitious materials [21].

This study aims to develop the dormancy-awakening method for recycling and reusing waste fresh cement mortar. The hydration process is characterized by testing the setting time, X-ray diffraction (XRD) and thermogravimetric analysis (TGA) of cement paste. Mercury intrusion porosimetry (MIP) is used to characterize the pore structure distribution. In addition, nanoindentation test is conducted to characterize the micromechanical properties of hardened cement paste and the packing density of hydration products.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (OPC) was used as the binder for cementitious materials. The chemical composition of OPC is depicted in Table 1. River sand with apparent density of 2550 kg/m^3 and fineness modulus of 2.16 was used as fine aggregates. The SU, CF and AS were of analytical purity grade.

Table 1. The chemical compositions of the OPC

Compositions	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Ti_2O	P_2O_5	Others
Oxide content (wt%)	64.92	21.15	5.92	3.15	0.83	0.57	0.26	0.19	3.01

2.2. Mix proportions and specimen preparation

Table 2 presents the mix proportions of cement mortar in this study. All mortar samples were prepared with the constant water-cement ratio of 0.5. The SU dosage was 0.1% of the mass of cement. The notation AS (X) and CF (X) signify the sucrose content of 0.1%, AS mass content of X%, and CF mass content of X%. For example, AS2.5CF1 refers to 2.5% of AS and 1% of CF added in SU dormant cement mortar. SU was initially dissolved in water and thoroughly mixed to form the SU solution, which was subsequently blended with cement and sand using a mixer for 4 minutes. The mixture was cured under standard conditions as per ASTM-C511 (2021) (temperature: 23±2°C, relative humidity > 95%) for 12 hours. The AS and CF were subsequently added and mixed for additional 4 minutes before being cast into 50 mm×50 mm×50 mm cubic molds. The specimens were then cured under standard curing conditions until reaching the respective ages of 3 days, 7 days, and 28 days.

Table 2. Mix proportions of cement mortars (kg/m^3)

Groups	Water	Cement	River sand	SU	CF	AS
CTRL	300	600	1300	0	0	0
SU	300	600	1300	0.6	0	0
AS2	300	600	1300	0.6	0	12
AS2.5	300	600	1300	0.6	0	15
CF1	300	600	1300	0.6	6	0
CF1.5	300	600	1300	0.6	9	0
AS2CF1	300	600	1300	0.6	6	12
AS2CF1.5	300	600	1300	0.6	6	15
AS2.5CF1	300	600	1300	0.6	9	12
AS2.5CF1.5	300	600	1300	0.6	9	15

2.3. Test methods

2.3.1. Setting time test

In accordance with ASTM-C191 (2021) specifications, tests were conducted in the controlled curing room, meticulously maintained at room temperature of 23±2°C and relative humidity exceeding 95%. The cement pastes were prepared in a manner identical to the mortars with the exception that no fine aggregates were included.

2.3.2. Hydration heat test

The hydration heat of cement was tested using the isothermal calorimeter. For each sample, the 50 g of cement was added to the test cup, and the 25 g of water or solution was added in the test cup. The test cup was then placed on the vibration table and vibrated for 1 min to ensure thorough mixing of water and cement. The well-mixed cement paste was place into calorimeter for 72 hours at constant temperature of 23℃. During this period, the heat flow and accumulated hydration heat were automatically recorded.

2.3.3. Compressive strength test

The compressive strength of cement mortar specimens was determined following the ASTM-C109 (2024). The testing involved using 50 mm cubic specimens subjected to uniaxial compressive loading at the rate of 0.5 kN/s after curing periods of 3 days, 7 days and 28 days. Each test group consists of three specimens and the average value derived from these specimens used to represent the compressive strength.

2.3.4. XRD analysis

The mineral composition of the 3 days and 28 days cement paste samples was analyzed using a Smartlab SE X-ray diffractometer set to 40 kV and 40 mA. Scans were performed from $2\theta = 5^\circ$ to 80° at a consistent rate of 5° per minute.

2.3.5. TG analysis

The thermal stability of paste samples at different ages (3 days and 28 days) was meticulously evaluated using Q5000 IR thermogravimetric analyzer under the nitrogen atmosphere. By incrementally heating the cement paste samples from 30°C to 800°C at a rate of 20°C/min, distinct differences in the thermal decomposition behavior were observed.

2.3.6. MIP test

After compressive strength test, the undamaged regions of the specimens were selected for MIP test. The undamaged part was carefully cut into the sample with side length of about 20 mm. The pore structure was meticulously conducted using the advanced capabilities of the MicroActive AutoPore V9600 Mercury Intrusion Porosimetry analyzer.

2.3.7. Nanoindentation test

The micromechanical properties of hardened cement paste were characterized using nanoindentation. After curing for 28 days, the cement paste sample were encapsulated in epoxy resin within cylindrical capsules with a diameter of 30 mm. Once the epoxy resin capsules cured, the samples were polished using the automatic grinding and polishing machine. Indentation test was conducted in an area of 100 × 100 µm, with indentations spaced 10 µm apart in an 11 × 11 grid. The use of the Hysitron TI-950 triboindenter allowed for precise control of the testing conditions, ensuring reliable and reproducible results. The specific loading and unloading protocol with maximum load of 1 mN. This maximum load was attained by nine loading steps in order to reduce the creep effect. At the last step, the maximum load was held for 2 seconds and unload to zero for 5 seconds. The load and displacement data were recorded at the last unload process. The stiffness was calculated by the last unloading segment of each indent. The elastic modulus of each test was measured according to the Oliver and Pharr method [22].The packing density (ηi) of hydration phases is measured using the following Eq. (2.1):

$$\eta_i = 0.5\left(\frac{M_i}{m_s} + 1\right) \tag{2.1}$$

where, m_s refers to the indentation modulus of nonporous of C–S–H solid, m_s is consistently set to 62.5 GPa. This value corresponds to the elastic modulus of 60 MPa [23]. M_i refers to the indentation modulus of each point on indentation area.

3. Results and discussions

3.1. Setting time

Figure 1 illustrates the effect of awakening agents' dosages on the dormant period of cement paste. The initial and final setting time of control group were 342 min and 510 min respectively. After adding 0.1% SU, the initial setting time extended to 1339 min and the final setting time was prolonged to 2100 min. This confirms that SU can effectively inhibit the hydration of cement. The addition of AS and CF significantly reduced the setting times as the dosage increased. At the AS dosage of 2%, The initial and final setting time of control group were 448 min and 714 min respectively. When the dosage was increased to 2.5%, the initial setting time decreased by 24 min and the final setting time decreased by 74 min. As the CF dosage increased from 1% to 1.5%, the initial setting time was reduced by 118 min and the final setting time was reduced by 150 min. The combined use of AS and CF further decreased the setting time. With the dosage of 2.5% AS and 1.5% CF, the initial setting time was 85 min and the final setting time was 310 min. This indicates that the cement hydration is recovered by adding AS and CF in dormant cement paste.

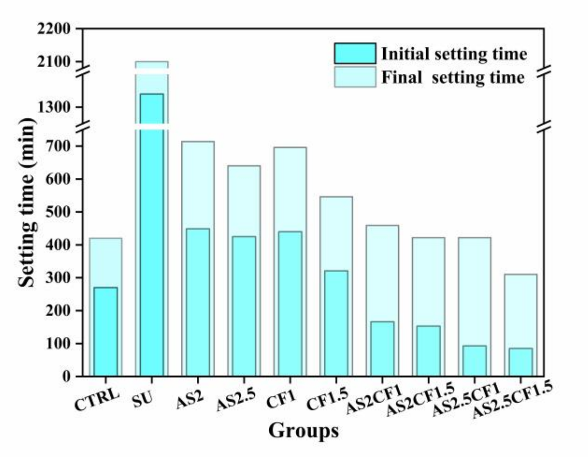
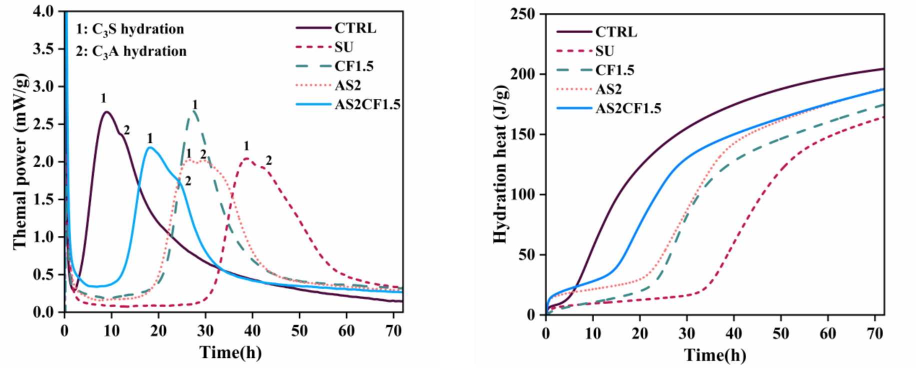


Fig. 1. The setting times of cement pastes

3.2. Hydration heat

The thermal power and hydration heat of cement are presented in Fig. 2. Two exothermic peaks can be observed in Fig. 2(a), which are attributed to the hydration of C_3S and C_3A, respectively. For the CTRL group, the first exothermic peak and second exothermic peak are observed at 9.0 hours and 12.1 hours. When SU is used, the time required to attain the first exothermic peak extends to 39.6 hours. This suggests that the SU can significantly delay cement hydration, which can be confirmed by the results of setting time. The cement hydration is hardly increased at first 30 hours, indicating that cement hydration can be blocked and the cement paste is in the dormant state. When AS or CF is added to the dormant cement paste, the exothermic peaks appear around 30 hours. This suggests that the hydration reaction of cement is accelerated by adding AS or CF. Compared with the AS2 group, the CF1.5 group has higher exothermic peak. The first exothermic peak is higher and even covers up the second exothermic peak. For the AS2CF1.5 group, the exothermic peaks appear around 20 hours, indicating that the dormant cement can be awakened by using AS and CF. Compared to the CTRL group, the awakened cement paste has lower exothermic peaks and accumulated hydration heat. Lower exothermic peak and increase in heat release time can lead to more uniform hydration of cement particles, which are beneficial for improving the compressive strength and reducing the autogenous shrinkage of cementitious materials [24].



(a)

Fig. 2. The hydration of cement paste: (a) Thermal power, (b) Accumulated hydration heat

3.3. Compressive strength

Figure 3 presents the influence of awakening agents on the compressive strength of cement mortar. The CTRL group exhibited compressive strengths of 21.8 MPa, 25.4 MPa, and 34.9 MPa at 3, 7, and 28 days, respectively. The SU group exhibited lower compressive strength at 3 days compared to the control group. This attributes to the addition of SU, which delayed hydration and induced the “dormant” state of cement mortar. This retarding effect is eliminated after 7 days. Upon the addition of awakening agents, the compressive strength shows the increasing trend with the dosage of awakening agents. The single-component awakening agent (AS2) can enhance the mortar compressive strength by 15.0%, 16.1%, and 2.2% at 3, 7, and 28 days, respectively. Similarly, SC1.5 group shows the 9.7%, 10.6%, and 12.5% enhancement at 3, 7, and 28 days, respectively. Among the dual-component activators, AS2CF1.5 presents the highest compressive strength compared to other groups. This formulation increased the compressive strength by 21%, 25.7%, and 18.3% at 3 days, 7 days, and 28 days, respectively, suggesting that AS2CF1.5 is the optimal group in this study. The dissolution of AS elevated the SO_4^{2-} concentration in the liquid phase, promoting C_3A hydration and accelerating AFt formation. This accelerates the setting and hardening of cement paste, resulting in the improvement on compressive strength of cement mortar at early age [25]. CF supplied Ca^{2+} to the cement mortar, which can facilitate the formation of hydration products, such as C–S–H gel and $Ca(OH)_2$. This leads to the enhancement of early strength of the mortar [20]. The incorporation of AS and CF not only eliminates retarding effect of SU on cement hydration, but also shows higher compressive strength compared to the cement with single-component awakening agent.

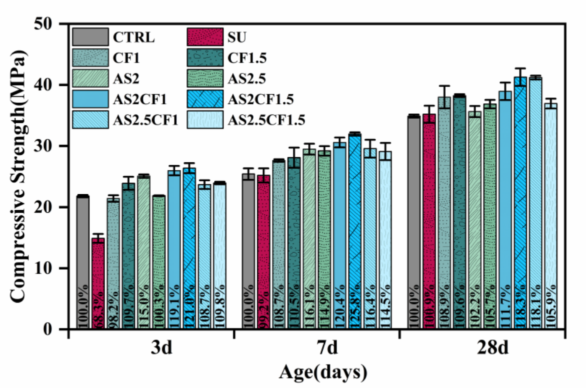
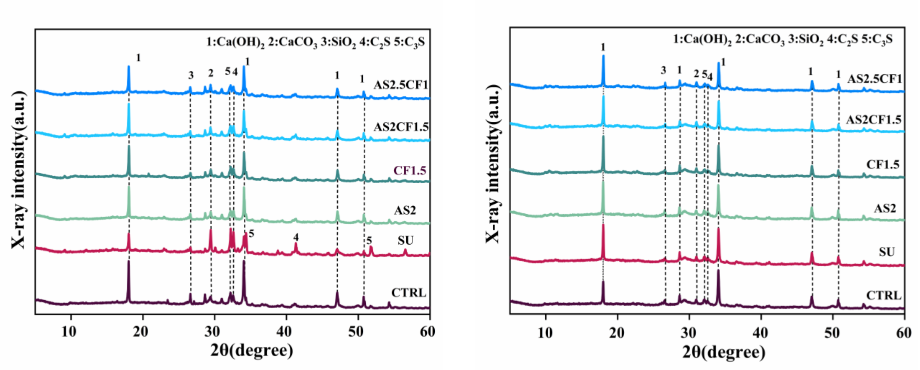


Fig. 3. Compressive strength of cement mortar

3.4. Hydration products

Figure 4 shows the XRD patterns of samples at 3 and 28 days. It is evident that the primary compounds with strong diffraction peaks in the CTRL group are $Ca(OH)_2$, $CaCO_3$, C_2S, and C_3S. The addition of activating agents did not introduce any new diffraction peaks, suggesting that no novel hydration products were formed. The C–S–H gel possesses an amorphous structure, and the quantities of AFt and AFm formed are relatively minimal, thus no significant diffraction peaks are observed in the XRD patterns [26]. As depicted in Fig. 4(a), the intensity of the $Ca(OH)_2$ diffraction peak in the SU group is significantly reduced, indicating that sucrose addition inhibited the early hydration of the cement paste. The diffraction peaks of C_2S and C_3S are most prominent, suggesting that the degree of hydration is low at 3 days. Following the addition of activating agents, the diffraction peak intensities of C_3S and C_2S decreased, while the $Ca(OH)_2$ diffraction peak intensity increased. This indicates that the awakening agents significantly enhanced the early hydration of C_3S and C_2S in the sucrose- doped cement paste [27]. The $Ca(OH)_2$ diffraction peak intensity of the dual-component activating agent surpasses that of the single-component, suggesting that the dual-component agent can further accelerate the hydration rate of the sucrose-doped paste. Fig. 4(b) shows the XRD patterns of cement paste at 28 days. The intensity of the $Ca(OH)_2$ diffraction peak increased with the reduction on the diffraction peak intensities of C_2S and C_3S. The $Ca(OH)_2$ diffraction peak intensity of SU group is slightly higher than in the other groups, suggesting that SU inhibited early cement hydration but facilitated hydration in the later age. Since the XRD results cannot accurately characterize the content of hydration products, TGA analysis was performed.



(a) (b)

Fig. 4. XRD patterns of cement paste: (a) 3 days, (b) 28 days

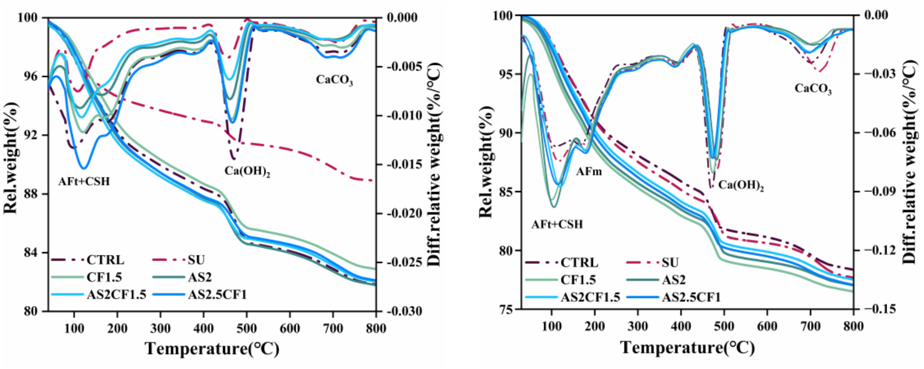
Figure 5 shows the TG-DTG curves of samples at 3 and 28 days. The DTG curves reveal four main endothermic peaks: the first peak corresponds to the dehydration of AFt at 40–150°C; the second peak arises from the dehydration of AFm at 160–200°C; the third peak is related to the dehydroxylation of $Ca(OH)_2$ at 420–550°C; and the fourth peak is attributed to the decomposition of low-crystalline or amorphous $CaCO_3$ at 600–800°C. Table 3 provides the comprehensive quantitative analysis of hydration products in various paste samples. The presence of $CaCO_3$ is attributed to the carbonation of $Ca(OH)_2$, which is a common occurrence when $Ca(OH)_2$ is exposed to CO_2 in the air. The $Ca(OH)_2$ content can be determined using Eq. (3.1):

$$m_{\text{total CH}} = \frac{74}{18}\Delta m_{\text{CH}} + \frac{74}{44}\Delta m_{\text{CaCO}_3} \tag{3.1}$$

where: $m_{\text{total CH}}$ represents the total weight loss of the $Ca(OH)_2$, Δm_{CH} and Δm_{CaCO_3} represent the mass losses of the $Ca(OH)_2$ and the $CaCO_3$, respectively.

Figure 5(a) reveals that the peaks of AFt and AFm in awakened cement paste are not prominent at 3 days, suggesting that the awakening agent facilitated the formation of a greater amount of AFt while inhibiting its transformation to AFm. At the age of 28 days, the broadening of the AFt peak and the pronounced AFm endothermic peak indicate that the activator effectively promoted the conversion of AFt to AFm. The two-component awakening agents exhibited the synergistic effect in the early stages by depleting C_3A and enhancing AFt formation, which consumed substantial amounts of Ca^{2+} and further promoted the hydration of C_3S and C_2S, thus increasing the degree of cement hydration [27, 28].

Table 3 shows the mass loss of hydration products based on TG-DTG results. In the SU group, the total mass of $Ca(OH)_2$ at 3 days is lower than in the CTRL group but higher at 28 days, indicating that SU initially delayed the cement hydration reaction but subsequently promoted hydration at later age. With the addition of awakening agents, the contents of AFt



(a) (b)

Fig. 5. TGA curves of cement paste:(a) 3 days, (b) 28 days

and $Ca(OH)_2$ both increased, suggesting that more hydration products can be formed by using AS and CF. However, the total mass of $Ca(OH)_2$ in awakened cement is lower than in the CTRL group at 28 days, indicating that the awakening agents initially accelerate cement hydration but do not promote the C_2S and C_3S hydration at later age. Table 3 also indicates the mass loss of AFt and AFm increases with the addition of dual-component awakening agents. The increase in mass content of AFt and AFm suggests that awakening agents can promote the C_3A hydration.

Table 3. Contents of hydration products composite cement pastes

Ages	**Groups**	**Mass loss (%) related to the decomposition of**				**Total $Ca(OH)_2$ (%)**
		AFt	AFm	$Ca(OH)_2$	$CaCO_3$	
3d	CTRL	4.19	3.48	3.55	2.16	18.23
	SU	3.18	1.34	1.40	2.04	9.20
	AS2	4.18	3.52	2.45	2.19	13.74
	CF1.5	3.91	3.74	2.85	2.11	15.26
	AS2CF1.5	4.84	3.29	2.39	2.28	13.65
	AS2.5CF1	4.74	3.59	2.56	2.35	14.49
28d	CTRL	5.36	4.21	3.52	2.48	18.46
	SU	5.64	4.67	3.39	2.71	18.51
	AS2	7.74	4.66	3.25	1.71	16.22
	CF1.5	8.38	4.55	3.39	1.69	16.80
	AS2CF1.5	7.00	4.82	3.09	2.04	16.14
	AS2.5CF1	7.36	4.83	3.05	2.09	16.06

3.5. Pore structure

To elucidate the pore structure distribution of cement mortar, MIP test was conducted on CTRL, SU, AS2, CF1.5, and AS2CF1.5 samples at 28 days. The corresponding results are illustrated in Fig. 6. Pores are classified according to their diameters into four distinct categories [29]: harmless pores (Region I, less than 10 nm), less harmful pores (Region II, 10–100 nm), harmful pores (Region III, 100-1000 nm), and highly harmful pores (Region IV, more than 1000 nm). Fig. 6 shows the consistent distribution of large pores (> 100 nm) across all groups. The pore size for each group is predominantly concentrated within the range of 10-100 nm, which corresponds to less harmful pores. In comparison to the CTRL group, the SU group shows the reduced modal pore size. This reduction can be attributed to SU's capacity to refine AFt crystals and subsequently fill cement pores [30]. The introduction of the awakening agents results in the reduction in the modal pore size, leading to the refinement of the pore structure. The AS2CF1.5 group exhibits an intermediate modal pore size, falling between those observed in the AS2 and CF1.5 groups. This observed phenomenon can be attributed to the dual-component activator's ability to accelerate cement hydration. This acceleration leads to the generation of substantial hydration products, which effectively fill the pores and reduce the pore size of cement mortar. Fig. 7 provides a comprehensive illustration of the volume fractions across four pore types, including the volume fractions of less harmful pores, harmful pores and highly harmful pores. In the CTRL group, less harmful pores account for 44.7% of the total pore volume, while harmful pores comprise 29.8%. The SU group demonstrates the 4.6% reduction on the volume of highly harmful and harmful capillary pores, compared with the CTRL group. As a result, the 28 days compressive strength of the SU group exhibits the slight improvement over that of the control group. The volume of highly harmful and harmful capillary pores is reduced when the awakening agents is used in dormant cement mortar. The AS2CF1.5 group shows the 5.6% reduction in the volume fraction of these pores.

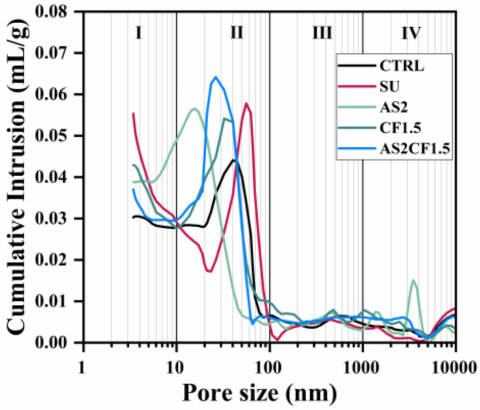


Fig. 6. Pore size distribution of cement mortar at 28 days

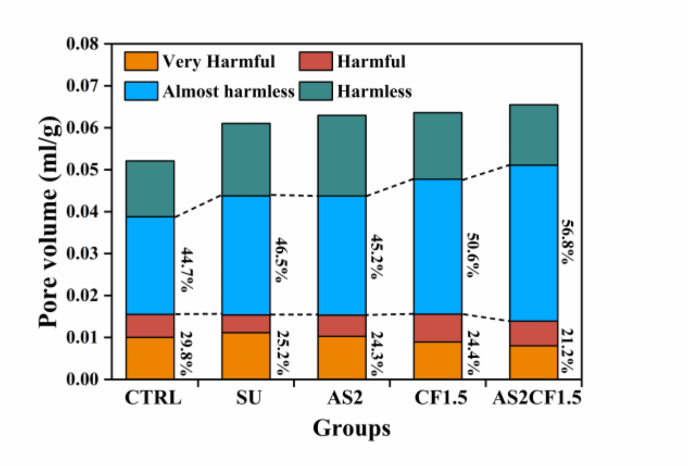
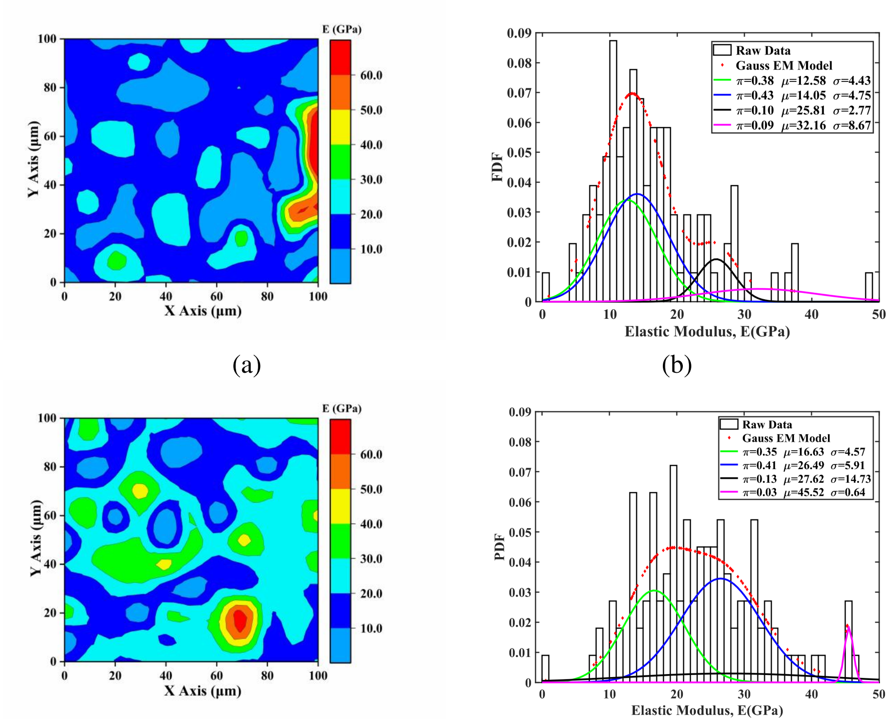


Fig. 7. Pore volume distribution verse sizes

3.6. Nanoindentation analysis

Nanoindentation tests were conducted on cement pastes from the SU and AS2CF1.5 groups. The resulting contour maps and deconvolution analyses of their elastic modulus are presented in Fig. 8. The elastic modulus is categorized into seven color-coded regions, ranging from low to high values: light blue regions (< 10 GPa), dark blue regions (10-20 GPa), cyan regions (20–30 GPa), green regions (30–40 GPa), yellow regions (40–50 GPa), orange regions (50–60 GPa), and red regions (> 60 GPa). Fig. 8(a) and (b) show that the elastic modulus of SU group. The elastic modulus values are mainly in the range of 10-20 GPa. The average elastic modulus of SU group is 16.30 GPa on the indent area. The elastic modulus contour map for AS2CF1.5 group paste exhibits higher elastic modulus than the SU group. The elastic modulus is predominantly concentrated in the range of 10–35 GPa, as depicted in Fig. 8(c) and (d). The average elastic modulus of the AS2CF1.5 group is 21.49 GPa, which is 31.8% higher than that of the SU group. This is the main reason for compressive strength improvement of the AS2CF1.5 group.

Figure 8(b) and (d) show the deconvolution results based on the elastic modulus data. Based on increasing elastic modulus values, the gel phase can be categorized into four phases: porous phase (PP), low-density (LD) C–S–H, high-density (HD) C–S–H and calcium hydroxide (CH). Fitting parameters for these phases are also provided. The fitting parameters encompass the volume fraction (π), mean value (μ) and standard deviation (σ) of the calculated elastic modulus for each hydration phase. Table 4 summarizes these results. The results reveal that the incorporation of awakening agents leads to an increase in the average elastic modulus for these four phases. The awakening agents addition resulted in the reduction of porous phase from 0.38 to 0.35 and LD C–S–H from 0.43 to 0.41, while increasing HD C–S–H from 10% to 13%. Consequently, pack density is increased from 0.638 to 0.654. This significant improvement suggests that the incorporation of awakening agents effectively densified the microstructure of hardened cement paste.



(a) (b)

(c) (d)

Fig. 8. Contour maps and deconvolution results of the SU and AS2CF1.5: a) elastic modulus mapping for SU, b) elastic modulus deconvolution of SU, c) elastic modulus mapping for AS2CF1.5, d) elastic modulus deconvolution of AS2CF1.5

Table 4. Packing density of different phases

Groups	**PP**		**LD C–S–H**		**HD C–S–H**		**CH C–S–H**		**Overall**
Volume	Mean	Volume	Mean	Volume	Mean	Volume	Mean		
SU	0.38	0.61	0.43	0.62	0.10	0.72	0.09	0.77	0.638
AS2C1.5	0.35	0.64	0.41	0.75	0.13	0.74	0.03	0.87	0.654

4. Conclusions

This study explores the recycling and reuse of fresh cement mortar waste by utilizing dormancy and awakening agents. The main conclusions of this study are as follows:

1. The 0.1% dosage of SU significantly delayed hydration of cement and setting time of cement paste by inhibiting the hydration of C_3S and C_3A. The inclusion of SU prolonged the setting time by approximately fivefold.

2. The addition of AS and CF can eliminate the retarding effect of SU and accelerate cement hydration. The combined use of AS and CF was more effective than their individual use in reducing setting time. These activating agents can restore the normal setting and hardening of dormant cement mortar.
3. The awakening agents can reduce the harmful porosity of cement mortar. Importantly, the elastic modulus and bulk density are significantly enhanced by incorporating awakening agents. More than 18% improvement in compressive strength can be achieved by using awakening agents in dormant cement mortar.

The AS and CF composite awakening agents not only enables the normal hydration and hardening of dormant cement, but also improves the compressive strength of cementitious materials. Further performance improvements can be obtained by optimizing the concentration and type of dormant and awakening agents, which can achieve more flexible control over the dormancy-awakening process. More work will be carried out in the future.

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