Performance and Microanalysis of Cement Asphalt Mortar with Admixture of Coal Fly Ash

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Abstract

In this study, cement asphalt mortars prepared with three different cementitious material were systematically investigated: C1 ordinary Portland cement, C2sulfoaluminate cement, C3 (sulfoaluminate: ordinary Portland cement: fly ash=3:6:1) according to the technical indices of cement asphalt mortar for Chinese high speed railway (CRTS II). The C2 CA mortar shows early strength due to the early hydration process between the sulfoaluminate cement and water while the workability is not as excellent as C3 group which not only shows great performance in physical and mechanical properties but also has a good fluidity and workable time to meet the requirement of CRTS II. Through the microstructure analysis, it was found that cement asphalt mortar is a porous structure and the hydration between cement and free water happened at the early age while an integrated formed amorphous gel play an important role in the strength development of the CA mortar as the strength development to 28 days.

Keywords: Cement asphalt mortar, Performance, CRTSII, Fly ash, Microanalysis

1. Introduction

The nonballast slab track is an advanced track structure with many high performance properties, such as a low maintenance requirement, a long service life and the reduction of structure height (Esveld, 1999).Japanese National Railways started the research on slab track in 1970s' and 1244 km long was applied for high speed passenger lines until 2007 (Koyama, 1997; Takai, 2007).In the recent years, China also launched its high speed railways plan with fast growing speed with the sophisticated slab track technology. Right now, 6552 km high speed passenger lines in China is well used and more than 10,000 km new high speed passenger lines is to be completed in the future (China ministry of railway, 2010).The cement asphalt mortar (CA Mortar) is composed of cement asphalt emulsion, sand and several chemical admixtures (Yang, *et al.*, 2010; Torri, *et al.*, 1975; Makoto, *et al.*, 1995; Ryoichi, *et al.*, 2005). It usually applied to the Slab track structure for the high speed railway, as a layer injected between the reinforced pre-stressed concrete slabs (Esveld, 2003).There are two types of CA mortar exist, one with a low elastic modulus and strength used in shinkansen slab track in Japan and the other with a high elastic modulus and strength used in the Bogl slab track in Germany.Both CA mortars were introduced in China and used in the construction of high-speed railway (Wang, *et al.*, 2011). The two temporary technical indices of cement asphalt mortar were issued for Chinese high speed railway: CRTS I with low elastic modulus and CRTS II with high elastic modulus. CRTSII specification is widely used in the Chinese rapid developed railway construction and its performance requirements are listed in table 1. Besides the requirement on the mechanical strength, the fluidity and self-compacted ability are common requirement for CA mortar due to the non-vibrating involvement of this construction technology.

Due to the high workability of cement asphalt mortar with various constituents of different densities it is necessary to evaluate the different parameters of cement asphalt mortar.In the last decade, some investigations were performed on the components and physical properties of CA Mortar, polymers and fine sand were introduced to improve the fluidity of the CA mortar (Jin, *et al.*, 2006; Zuo, *et al.*, 2005). And the viscoelasticity feature of CA mortar, setting time and rheological behavior was studied by (Wang, *et al.*, 2008a; Wang, *et al.*, 2008b). However, few studies has been reported the CA mortar with adjusting constituent of fly ash regarding to the specification as CRTS II. In this paper, as a new technical note, a design of CRTS II type Cement asphalt mortar with fly ash constituentis introduced and the experiment method was also first time detailed described for the convenience of the scientific workers and policy makers as reference. Besides that, systematically microanalysis was also conducted to illustrate the mechanism if the hydration mechanism and morphological characterization of the introduced CA mortar.

2. Material and Method

In this test, the test follows the technical specification of CA mortar for CRTS II nonballast slab track (Chinese railway specification, 2008).

2.1 Material

Anionic asphalt emulsion was introduced in this experiment and the properties were listed in table 2 and three types of cementitious materials were introduced in this experiment, one was ordinary Portland cement C1 and another two is fast hard sulfoaluminate cement C2 and blended cementitious material C3 (sulfoaluminate: ordinary Portland cement: fly ash=3:6:1). The properties of the cementitious materials were listed in Table 3. Also the commercial air entrainment, superplastizer, alumina power was introduced as the following recipe as each batch in this experiment (Table 4).

2.2 Method

2.2.1 Test Method of Workability of Cement Asphalt Mortar

Firstly, place aglass plate 400mm(±2mm)×400mm(±2mm)horizontally.Secondly, put the cylinder (inner diameter is 20mm±1mm; height is 190mm±2mm)in the center of glass plate vertically and add mixed cement asphalt mortar into cylinder until it reaches the upper edge. Thirdly, lift the cylinder vertically up quickly about 15±2cm, and hold for 10s. Press the stopwatch at the same time to record the time whenthe spread diameter of cement asphalt mortar is 280mm. The test result is shown as the average of two diameters which are vertical to each other (accuracy 5mm) and the time when divergence is 280mm (accuracy 1s).

2.2.2 Test Method of Fluidity of Cement Asphalt Mortar

Put the wetted funnel (as figure 1) on the funnel stand and make sure the axis of funnel should be perpendicular to the ground. Then place1Liter of cement asphalt mortar into funnel slowly and homogeneously and block off funnel mouth with finger. After that, loosen fingerand press stopwatch at the same time to record the demanding time when the mortar in funnel flows away completely.

2.2.3 Test Method of Separation Rate of Cement Asphalt Mortar

Pour CA mortar into testing mold (Φ50mm×50mm) and scrape and cover the surface of testing mold with film, then move the mold into standard curing room. After de-moulding in 24 hours, keep the mold in the room for 7 days. Then move the mold into the curing room where the temperature is 20±2ºC, and humidity is 60%±5% and keep curing for 28 days. When the mortar age is 28 curing days, divide it from the middle, weight out the mass in unit volume with balance. And the spread rate is calculated by the following formula:

$$Separation\ rate = \frac{(\text{Mass bottom halve} - \text{Mass Top halve})}{(\text{Mass bottom halve} + \text{Mass Top halve})}$$

2.2.4 Test Method of Air Content of Cement Asphalt Mortar

Clean the inside of air entrainment barrel (figure 2) and wet it slightly and inject cement asphalt mortar, scrape by using scraping straightedge, and cover it with lid. Then open water valve and drain valve and add water through water valve. When the flowing current from drain valve does not contain air bubbles, close water and drain valve. Add air through air-entrapping valve and make sure the pointer at the red line. Open operating valve and read the air content when indicating value is stable.

2.2.5 Test Method of Expansion Rate of Cement Asphalt Mortar

Freshly mixed CA mortar was poured into a 250ml flask, and the depth of initial depth after casting and 24 h depth after casting were measured by vernier caliper with a precision of 0.02mm. And the expansion rate for CAM is determined by the following formula:

$$Expansion\ rate = \frac{\mathrm{H\ (24\ hour\ casting) - H(Initial\ casting)}}{\mathrm{H(Initial\ casting)}}$$

2.2.6 Test Method of Mechanical Property of Cement Asphalt Mortar

40 mm×40 mm×160 mm specimen bars were casted for mechanical property test and cover the surface of testing model with film, and then move the model into standard curing room. The specimens demoulded after 24 hour were cured first at 20±1 ºC and 95% relative humidity for 7days. After that, the specimens are transferred to cuing condition 20±1 ºC and 65% relative humidity for the remaining ages. The compressive and flexural strength was tested at 1, 7, 28 day curing ages.The experiment of strength test of mortar should comply with relevant provisions in Chinese standard GB/T17671.

2.2.7 Microanalysis

The microstructures of cement-asphalt pate were observed by a Philips XL30 FEG Scanning Electron Microscope (SEM) with energy-dispersive X-ray microanalyses.

3. Results and Discussion

3.1 Mechanical Properties

Figure 3 and 4 illustrate the development of strength of the cement asphalt mortar. As in Figure 3, the cement asphalt mortar mixed with difference cementitious material shows different compressive strength properties. The group C2 and C3 mixed with different portion of sulfoaluminate cement have related higher compressive strength than the group C1 mixed with ordinary Portland cement. At 1 day curing age, the C1 group only has 1.6 MPa in compressive strength development, which does not satisfied with the requirement in CRTS II requirement (higher than 2 MPa at 1 day curing age)as shown in table1. While the C2 and C3 groups reaches 3.2 MPa and 2.8 MPa respectively. When 3 day of curing age, the compressive strength of C1 is 7.3 MPa which still does not meets with the CRTS II requirement (higher than 10.0MPa at 3 day curing age). However, the compressive strength of C2 and C3 developed well and satisfy with the entire CRTS II requirement at different curing ages, and it reaches to 11.7MPa and 10.5 MPa at 3 day curing age respectively. And it is interesting that C2 and C3 has almost similar compressive strength at 28 day curing age, although the C3 only contains 60% of sulfoaluminate cement compared with the cementitious material of C2. It can be refereed that sulfoaluminate cement shows better performance than OPC in compressive strength development at the early age when they applied as cement asphalt mortar. As for the flexural strength development, it shows similar pattern with the compressive strength development. In Figure 4, it can be found that C2 has the highest flexural strength at each specific curing age, however, C3 still performs well to meet the CRTS II requirement while C1 does not able to reach one of the flexural requirement at different curing age.

3.2 Workability and Fluidity

There are two sets of test toevaluatethe workability of the cement asphalt mortar and it is necessary to satisfy both of the requirementsfor workability acceptance. For the mortar as fresh slurry just mixed out of the machine, the requirements are as follow: D5 (the spread diameter of the slurry is higher than 280mm), and the time duration of the slurry spread to the diameter at 280 mm needs to be controlled under 16 s as T280-D5; when the slurry stored in ambient condition for 30minutes, the requirement of the spread diameter of D30 still needs to be higher than 280mm while the T280-D30 should be less than 22s. From Figure 5 and 6, we can easily found that D30 of C2 is only 268 mm, which means C2 could not be selected for application due to the lack of workability. However, C1 and C3 meet each specific requirement on these two sets of test. In C3, the fly ash was added to increase the flowability of the slurry. In some previous studies, the fly ash addmixture can increase the consistency of the slurry due to the round sphere of the fly ash particle (Katz & Kovler, 2004). As shown in Figure 7, it is obvious that the fluidity of C3 has only 87.3 s when all the material flow through the funnel while the C1and C2 has 97.5s and 109.8 s respectively, which means that the C3 indeed has better fluidity than C1 and C2.Figure 8 and 9 illustrate the workability test and fluidity test of C3.

3.3 Separation, Expansion, Air content and Density

Separation and expansion is also important to evaluate the stability for the cement asphalt mortar. In Figure 10, the separation rate of three test groups was presented and the separation rate of C1 reached 3.28% that is higher than the 3.0% as the upper limitation in the requirement. The separation rate of C2 and C3 are 2.37% and 2.42% respectively. This is might due to hydration speed of three different cementitious materials; the sulfoaluminate cement usually shows rapid hydration process rather than the OPC. Because the separation is usually caused by gravity depositing of the material, when they are in slurry status, and the early hydration will shorten the duration of the cement asphalt mortar in slurry status, this means it might reduce the time for gravity depositing of the material. However, the rapid hydration also causesanother problem that is the expansion of the material, and Figure 11illustrates the expansion test results of three groups. It is obviousthat the expansion rate of C 2 (2.2%) has much higher expansion than C1 (1.3%), this is because the early hydration process of sulfoaluminate cement often generates higher expansion than the OPC at the 24 hours. Therefore, in order to meet the CRTS II requirement, C3 is determined as the optimal solution when the workability and mechanical properties are also taken into consideration. In table 5, the air content and the density of the three groupsare listed and it shows that all of them fall into the acceptable range according to the requirement.

4. Microstructure

The SEM morphologies of C3 hydrating at different curing ages are shown in Figure 12to 15. Figure 12 to 14illustrate the hydration product of C3 after 1, 7 and 28 day respectively. In Figure 12, the needle-like ettringite structure is widely found, it can be deduced that most of the hydration process of the cementititous material happened in the first day. The consumption of the free water during the hydration can promote the connection and breaking of asphalt spheres, because the free water consumption by physical adsorption of the cementitious material is very limited (Wang, *et al.*, 2011). In the 7 days, the breaking of asphalt spheres were almost finished and it was found that most of the formed cement asphalt structure stuck to the surface of the hydration product of cementitious material at the early age. On the 28th day of curing age, as shown in Figure 14, it is interesting to findthat the cement asphalt was formed as binder sticking to the fall ash sphere, these amorphous gel on the particles' surface plays important roleon the strength development of the cement asphalt mortar. Figure 15shows another image of C3 at 28 curing age in different scale; it is found that the microstructure of the whole cement asphalt mortar is a porous structure. The holes in cementitous asphalt mortar are generally equally distributed which provides the structure with an excellent potential to afford the inner crack of the material.

5. Conclusion

(1). In this test, cement asphalt mortars prepared with three different cementititous material were compared: C1 ordinary Portland cement, C2 sulfoaluminate cement, C3 (sulfoaluminate: ordinary Portland cement: fly ash=3:6:1). The C2 CA mortar shows early strength due to the early hydration process between the sulfoaluminate cement and water while its workability is not as excellent as C3 group which not only shows great performance in physical and mechanical properties also has an good fluidity and workable time to meet the requirement of CRT II.

(2). The fly ash admixture in the C3 group increased the consistency of the cement asphalt mortar slurry. In this case, the separation rate and expansion rate are relative lower than the C2 group. However, the separation rate of C1 reached 3.28% that is higher than the 3.0% as the maxima in the requirement of CRTS II. Thus, C3 is the optimal design in this whole set of test.

(3). Microanalysis illustrates that CA mortar is a porous structure and the hydration between cement and free water happened at the early age to form ettringite structure. It later formed amorphous gel that might play an important role in the strength development of the CA mortar.

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Table 1. Property index requirements of cement asphalt mortar

No.	Project		Unit	property index requirements
1	Temperature of mixture		℃	5-35
2	Workability(1)		/	$D_5 \geq 280$mm,$t_{280} \leq 16$s; $D_{30} \geq 280$mm,$t_{280} \leq 22$s
3	Fluidity		s	80-120
4	Separation		%	≤3.0
5	Expansion rate		%	0-2.0
6	Air content		%	≤10.0
7	The mass per unit volume		Kg/m³	≥1800
8	Flexural strength	1d	MPa	≥1.0
		7d		≥2.0
		28d		≥3.0
9	Compressive strength	1d	MPa	≥2.0
		7d		≥10.0
		28d		≥15.0

Note (1): D_5 indicates the spread of mortar as slurry when it just prepared; D_{30} indicates the Spread of mortar stored for 30 minutes after mixing preparation; t_{280} indicates the time when the CA mortar reaches the distance of 280mm.

Table 2. Properties of anionic asphalt emulsion

Density	Sieve test	Penetration	Storage stability 5d	Residue by distillation
(g/cm^3)	(%)	(25 ºC)	(%)	(%)
1.09	0.09	79	2.2	62

Table 3. Physical properties of cementitious material

Technical index		unit	C1	C2	C3
Sieve test (mm)	1.18	%	100	100	100
	0.6		98	97	98
	0.3		56	61	68
	0.15		49	53	48
	0.075		42	40	44
Setting time	Initial set	min	144	30	67
	Final set		201	54	89
Compressive strength	1 d	MPa	18.9	39.6	30.7
	7 d		24.5	50.4	45.9
	28 d		49.6	52.8	50.1

Table 4. Recipe design of cement asphalt mortar of each batch

Cementitious material	Sand	Asphalt	Superplastizer	Air entrainment	Al Power	Water
600g	900g	280g	1g	0.2g	0.05g	160g

Table 5. Air content and density of CA mortar

	C1	C2	C3
Air content (%)	5.3	6.2	5.7
The mass per unit volume(Kg/m^3)	1975	2012	1988

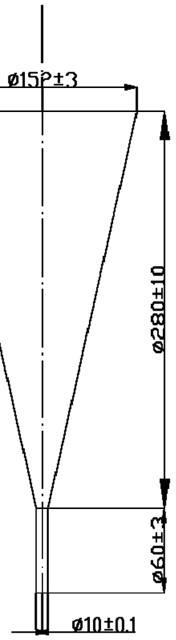

Figure 1. The schematic diagram of funnel. (From Chinese railway specification (2008).)

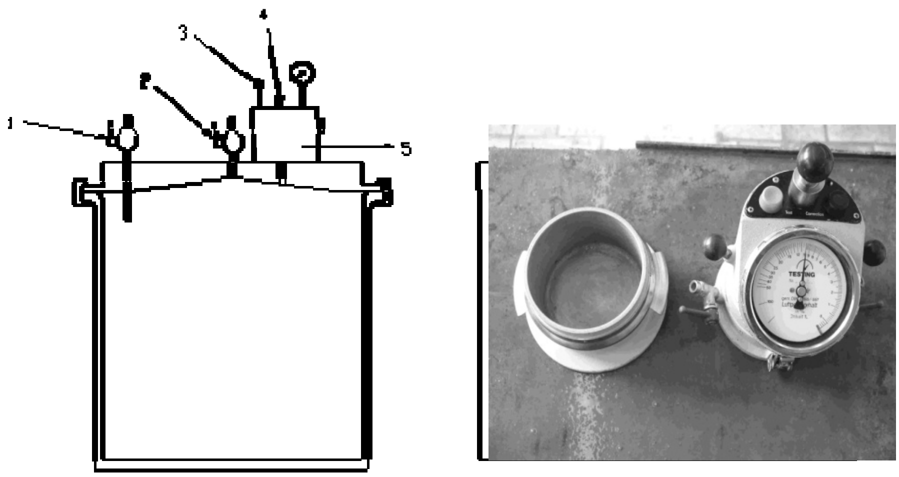

Figure 2. Air Content Measurer (1-water valve;2-drain valve;3-air valve;4-operating valve;5-air chamber) (From Chinese railway specification (2008).)

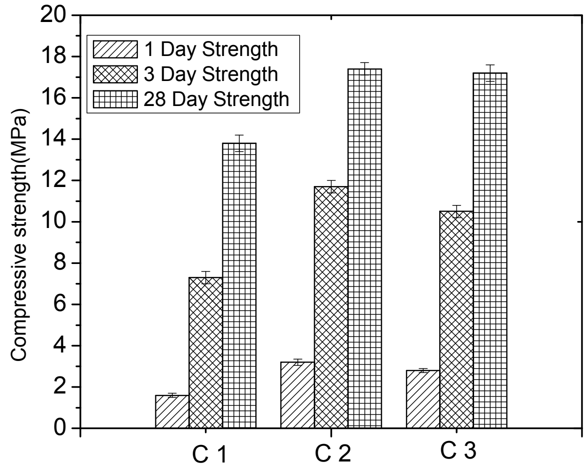

Figure 3. Compressive strength test of CA mortar

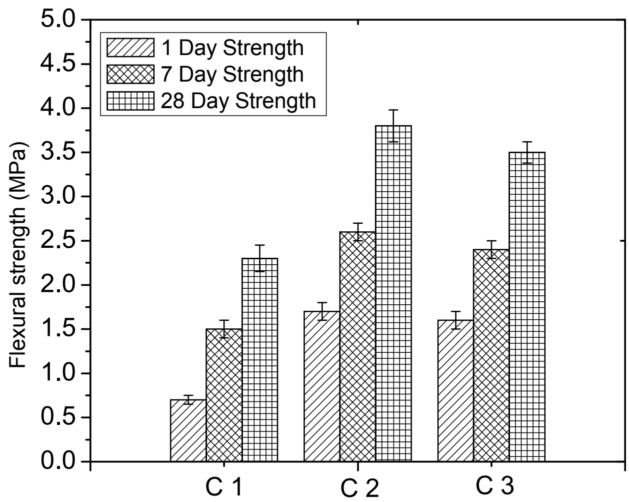

Figure 4. Flexural strength of CA mortar

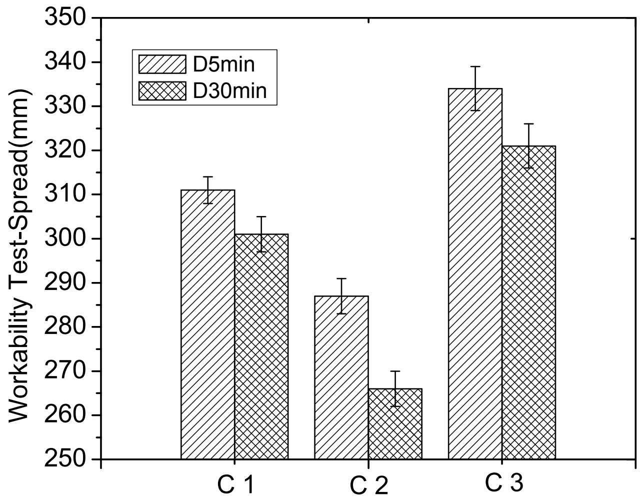

Figure 5. Worability (Spread test) of CA mortar

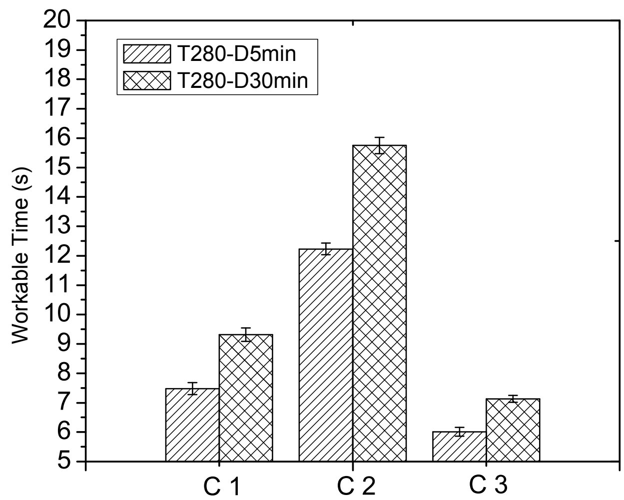

Figure 6. Workable time test of CA mortar

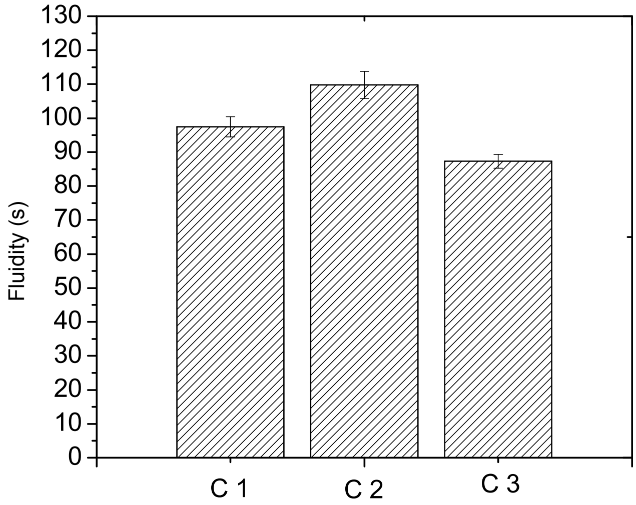

Figure 7. Fluidity test of CA mortar

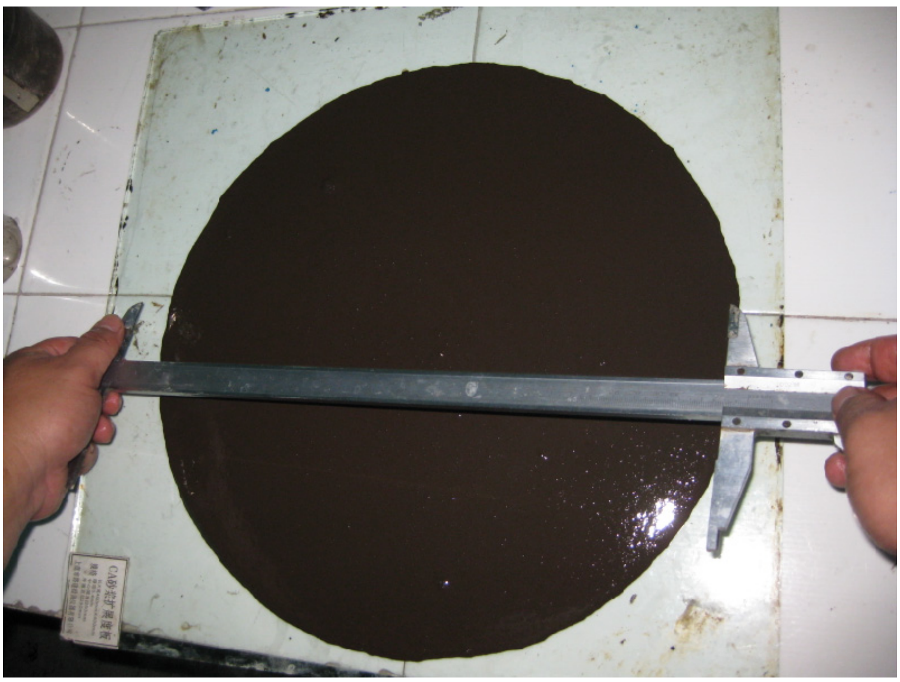

Figure 8. Workability test of CA mortar C3

Figure 9. Fluidity test of CA mortar C3

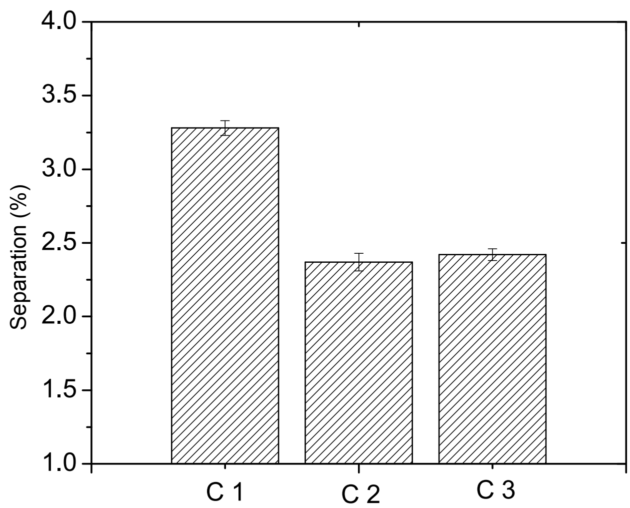

Figure 10. Separation rate test of CA mortar

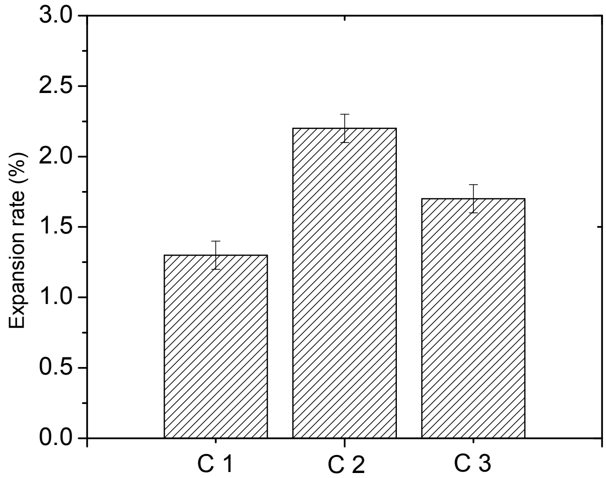

Figure 11. Expansion rate test of CA mortar

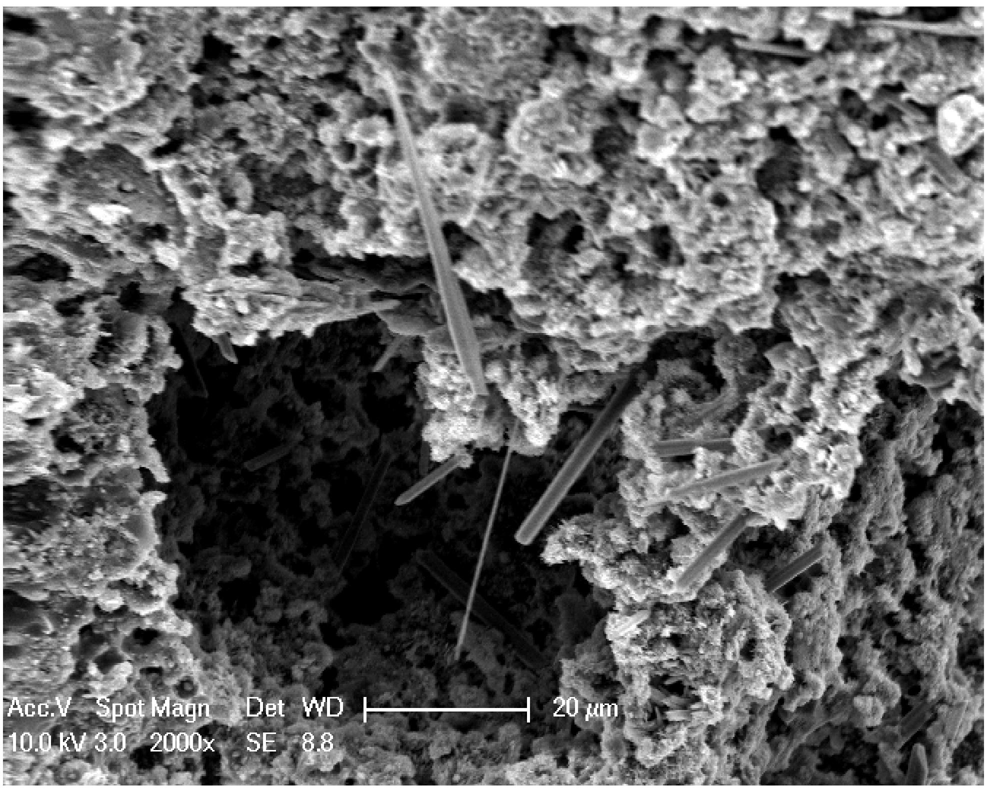

Figure 12. SEM image of C3 at 1 day curing age (2000X)

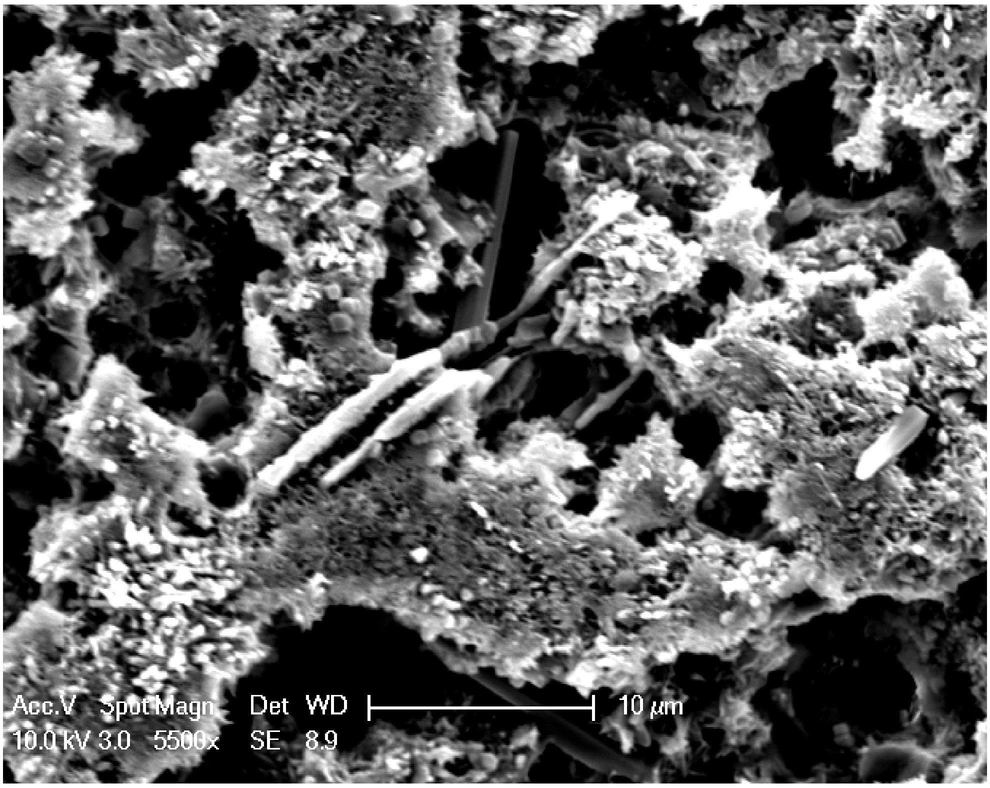

Figure 13. SEM image of C3 at 7 day curing age (5500X)

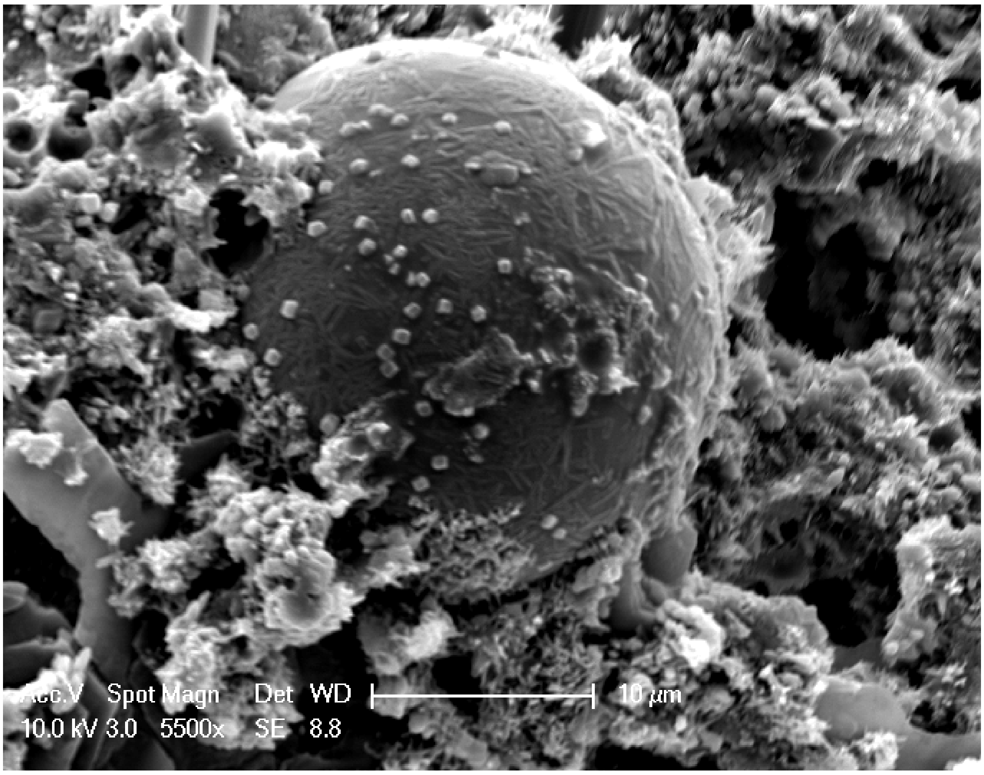

Figure 14. SEM image of C3 at 28 day curing age (5500X)

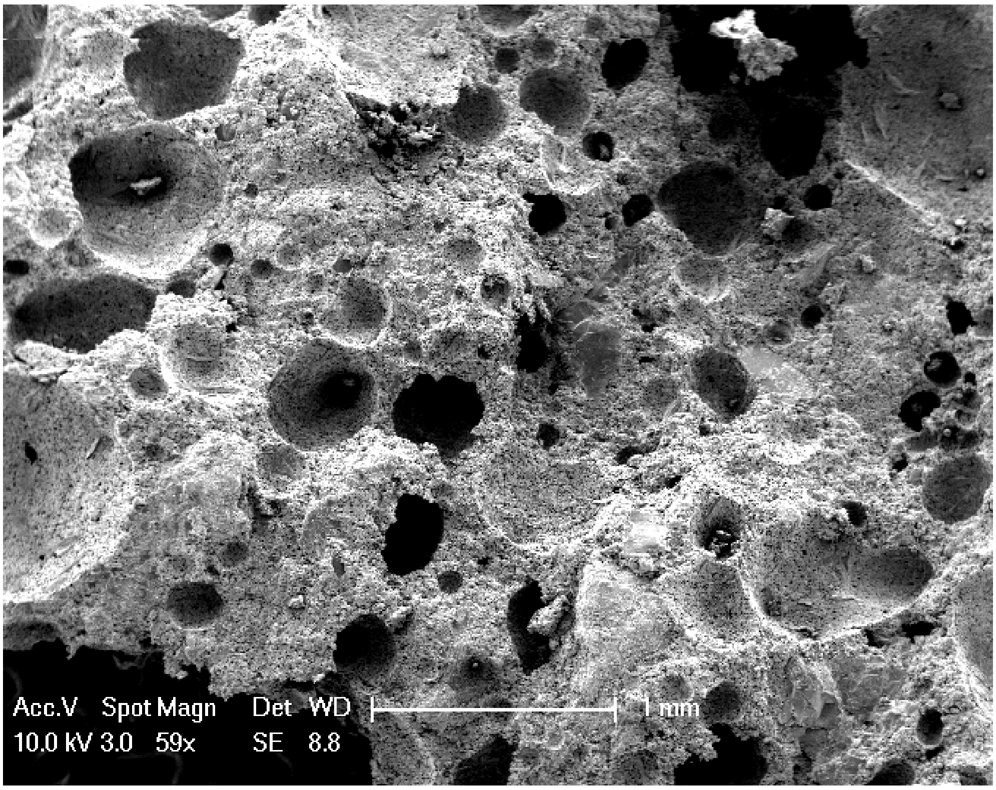

Figure 15. SEM image of C3 at 28 day curing age (59X)