Effects of limestone powders on alkalinity, pore structure and physiological characteristics of planting concrete from sulfoaluminate cement

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Abstract: Limestone powders generated during the production of machine-made sands were widely used as supplementary cementitious material in making concrete, which affected concrete properties. In this paper limestone powders were added to prepare low-alkali planting cementitious material. Its alkalinity, compressive strength and fluidity were investigated to evaluate their suitability for planting concrete. Water permeability coefficient of planting concrete was investigated to make clear pore connectivity. The physiological characteristics, such as root length and relative water content of leaves, of plants grown in the planting concretes were analyzed to investigate their effects on plant growth. The results indicated that limestone powders had no effect on the alkalinity of PCMs at the early hydration ages of 1d and 3d. But the 28d alkalinity of PCM with 20wt.% limestone powder decreased to 9.67 because they reacted with CH from clinker hydration and anhydrite. Adding of limestone powders into PCMs contributed to the increase of fluidity of PCMs, but too high fluidity caused that the pores in the bottom of concrete were blocked and water permeability coefficient was decreased. The water permeability coefficient of concrete with 20wt.% limestone powders was the highest of 17.9mm/s. At 20d after sprouting root length and relative water content of leaves of plants in concrete with 20wt.% limestone powders were 11.8% and 3.2%, respectively, higher than that in concrete without limestone powders. But much more than 20wt.% limestone powders caused too high fluidity and holes at the bottom of planting concrete blocked, such as concrete with 30wt.% limestone powders, so most plants died in it.

Key words: planting concrete; aggregate gradation; pore structure; physiological characteristics

1 Introduction

Due to the official restrictions of the exploitation and utilization of natural sands, machine-made sands had drew more and more attentions [1,2]and gradually replaced natural sands in making concrete and other cement-based materials [3-6]. During the production of machine-made sands, large amount of limestone powders were generated. For instance, over 10 million tons of limestone powders were generated in China every year [7]. Too many limestone powders accumulated on site were well known to be able to pollute the earth, the water and the environment nearby[8]. So it was necessary to expand the comprehensive utilization rate of limestone powders.

Recently, limestone powders as supplementary cementitious material were used in cement and concrete industry and its effect on properties of cement/concrete was studied. Gokce found that limestone powders could improve the compressive strength and chloride migration coefficient of cement[9]. Elmoaty et al. used 5wt.% limestone powders to replace cement and achieved high compressive and tensile strength for concrete [10]. Lothenbach B and Péra J discovered that limestone powders could influence the hydration of cement because carbonate reacted with C_3A and modified the Ca/Si ratio of C-S-H gel [11, 12]. Laure used limestone filler instead of quartz filler to accelerate the early hydration of sulfoaluminate cement and shorten the initial setting time [13]. Wang found limestone powder prompt the second exothermic peak of SAC to occur earlier and shorten induction period [14]. So limestone powders could play an active role during the hydration of cement and were possible to decrease the alkalinity of hydration phases.

Planting concrete as a kind of ecological concrete was conducive to prevent soil erosion and desertification [15,16]. But high alkalinity of the traditional planting concrete severely limited its application. The pH value of planting concrete cannot be too high for plants growing. The appropriate pH values suitable for plants growing were between 8 and 10.The alkalinity of planting concrete mainly came from the hydration phase of cement. But the pH value of hydrated Portland cement was up to about 13[17-19], making it inappropriate for making planting concrete. Taylor and Calvo once tried to use silica fume, slag and fly ash to reduce the alkalinity of Portland cement, but the pH value was still on or above 12[20,21]. So Portland cement cannot be simply used to make planting concrete. Yan prepared porous eco-concrete using SAC replacing Portland cement, and found that the alkalinity of porous eco-concrete was slightly higher than 10 [22]. It was explained that the main mineral component of sulphoaluminate cement was calcium sulphoaluminate which hydrated to produce ettringite but not calcium hydroxide. Though the alkalinity of planting concrete was significantly reduced by partially replacing Portland cement with SAC, this level of alkalinity was only suitable for some alkali-resistant plants to grow.

In this paper limestone powders were added to prepare low alkali planting cementitious material(PCM). The alkalinity, the compressive strength and the fluidity of low alkali PCM were studied to evaluate the properties of planting concrete. The physiological characteristics of plants, such as root length and relative water content of leaves(LRMC), were analyzed to investigate the effects of planting concrete on plant growth. So this paper would provide data and theoretical basis for the research of limestone powders, as SCM, in the field of planting concrete with low-alkali PCM.

2 Raw material and experimental method

2.1 Raw materials

2.1.1 SAC clinker

The SAC clinker used in this paper was produced by China United Cement Qufu Co., Ltd. The chemical compositions of the clinker are presented in Table 1.

Table1 Chemical compositions of the SAC clinker (wt.%)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2	LOSS
clinker	10.22	29.03	2.32	44.04	1.63	10.01	2.42	0.53

2.1.2 Anhydrite

Industrial-grade anhydrite employed in this research came from Qufu, China. Its residue on 75 mm sieve was less than 5wt.%.

2.1.3 Limestone powders

Limestone powders in industrial grade utilized in this research came from Qufu, China. Its residue on 75mm sieve was less than 5wt.%. The chemical compositions of the limestone powders are listed in Table 2.

Table 2 Chemical compositions of limestone powders(wt.%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_5	Loss
0.49	0.58	0.25	54.68	0.54	0.043	0.01	43.14

2.1.4 Coarse aggregates

Coarse aggregates with particle sizes of 19.0-26.5mm were adopted for making SAC concrete in this study. Their stacking density was 2710 kg/m^3 and crushing index was 8.7%.

2.2 Measurement methods

2.2.1 Alkalinity

Alkalinity of PCM was measured according to the method taken by Lianfang Li as shown as in Fig.1[23]. For such purpose, epidermis of a specimen with 20mm×20 mm×20 mm cubes was removed and the specimen was then ground into powders able to pass through 0.08 mm-size sieve. Then the ground powders were soaked in water with 10 times of their quantity for 1h. After that the solution was filtered. PH value of the filtrate was taken as alkalinity of PCM investigated as shown as in Fig.2.

Fig. 1 Sample processing

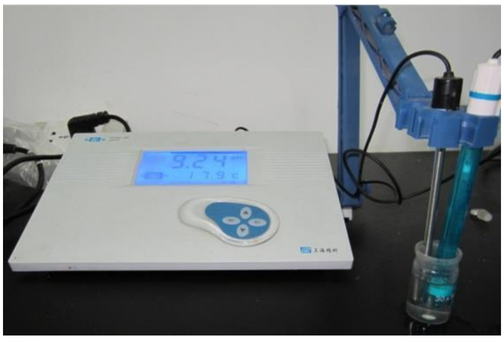


Fig. 2 PH meter for alkalinity measurement

2.2.2 Compressive strength

Compressive strength of PCM paste was determined according to GB 20472-2006 [24]. After cured at the standard condition of 20±2℃and ⩾95% relative humidity (RH) for 24 h the cubes were removed from steel moulds and then cured at the same condition until the day of testing.

2.2.3 Fluidity

Fluidity of PCM was determined according to GB/T 2419-2005 [25]. The water/PCM ratio was 0.5.

2.2.4 Water permeability coefficient

The water permeability coefficient of porous concrete was determined in accordance with JCI Test Method for Permeability of Porous concrete (draft), Technical Committee Report on Eco-Concrete[26]. The test equipment employed in this study for such purpose was showed in Fig. 3. The water permeability coefficient was calculated by using the following equation (1):

$$K_T = \frac{H \times Q}{h \times A \times \Delta t} \times \frac{\eta_T}{\eta_{15}} \quad (1)$$

Where K_T: permeability coefficient, cm/s; H: length of a specimen, cm; Q: amount of discharge water at a time interval Δt, cm^3; h: height of water head, cm; Δt: time interval, s; A: area of cross section of the cylindrical specimen, cm^2; η_T and η_{15}: the viscosity of water at the test temperature (T℃) and the reference temperature 15℃, respectively.

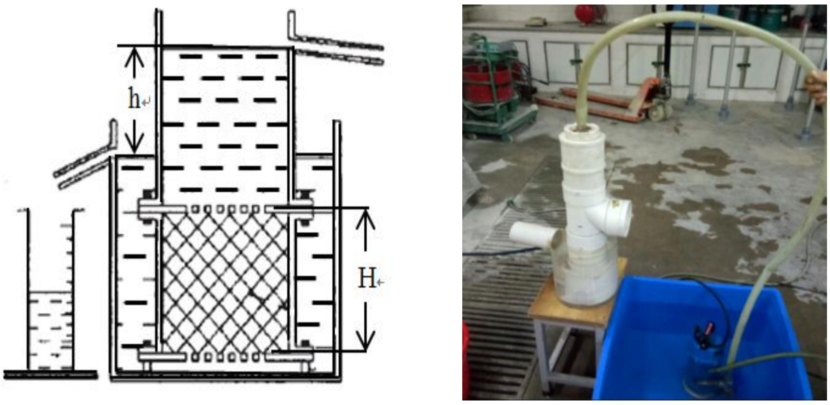


Fig. 3 Water permeability test equipment for planting concrete

2.2.5 Root length

When the specified planting age reached, the concrete with plants was removed from the soil and the integrity of the root system was tried to maintain. Then the concrete was washed with water to remove the soil. At last the concrete was broke, the plant with roots was taken out and the length of the roots was measured using a ruler. Fig. 4 showed the measurement of root length in planting concrete.

Fig. 4 The measurement of root length

2.2.6 LRWC

The fresh weight method was employed to test LRWC of the plants grown in planting concrete[27]. To do so, first fresh leaves were harvested and weighted (with the weight denoted as Wf). Then the leaves were immersed in water for 24 h, and weighted again (with the weight denoted as Wt) after being taken out and toweled down. Finally, the toweled-down leaves were put into a 105℃ environment for 0.5h to kill cell tissues and then continued to be dried at 80℃ till a constant weight (denoted as Wd) was reached. The LRWC was calculated as following:

$$LRWC = (Wf - Wd) / (Wt - Wd) \times 100\% \quad (2)$$

2.3 Experimental Design

The proper alkalinity was required by planting concrete to avoid hurting roots. In this research limestone powder and anhydrite were added into SAC clinker to gain low-alkali PCM for making planting concrete. Gypsum could react with calcium sulphoaluminate in clinker to adjust the setting time and improve strength. The details of PCM were shown in Table 3. At the same time limestone powder might affect the fluidity of PCM to blocked pores of planting concrete, water permeability coefficient and physiological performance were investigated. The proportion of planting concrete was showed in Table 4. The aggregates and fresh concrete were showed in Fig.5 and Fig.6, respectively.

Table 3 Proportions of PCM (wt.%)

Batch	Gypsum	Limestone powders	SAC clinker
B0	40	0	60
B1	30	10	60
B2	25	15	60
B3	20	20	60
B4	15	25	60
B5	10	30	60

Table 4 Mixing proportions of planting concrete (Kg/m^3)

Content	Aggregate	PCM	Water	Retarder
Amount	1538.60	311.20	62.24	3.11

Fig.5 Aggregates

Fig.6 Fresh concrete

3 Results, analysis and discussion

3.1 Alkalinity

Fig. 7 shows the alkalinity of PCM with limestone powders. It can be found that limestone powders had no evident effect on the alkalinity of hydrated PCM at the ages of 1d and 3d. At the hydrated age of 1d, the pH values of the PCM s with limestone powders varied in a narrow band from 10.83 to 10.88, which were very close to 10.85 of B0. This is because limestone powders did not participate in early hydration and the alkalinity of PCM was controlled by the clinker. Therefore, they had no effect on the alkalinity of PCM.

At the hydrated age of 28d with the increase of limestone powder content the alkalinity of PCM changed evidently. When limestone powder content was lower than 20wt.%, their alkalinities were lower than that of B0. The pH values of B1 and B3 decreased by 0.8% and 2.1%, respectively, compared with that of B0, which was attributed to that limestone powders were activated by CH from hydrated clinker with the reaction presented as Equation (2). When limestone power content was more than 20wt.%, the alkalinity increased to a pH value higher than 10. At this time because anhydrite content was too low to realize the reaction of Equation (2), too much CH still existed to increase the alkalinity of SAC. So it can be concluded that a proper amount of limestone powders can decrease the alkalinity of PCM.

$$3(3CaO \bullet 3Al_2O_3 \bullet CaSO_4) + 3(CaSO_4 \bullet 2H_2O) + 2CaCO_3 + 3Ca(OH)_2 + 92H_2O \rightarrow$$

$$2(3CaO \bullet Al_2O_3 \bullet 3CaSO_4 \bullet 32H_2O) + 2(3CaO \bullet Al_2O_3 \bullet CaCO_3 \bullet 11H_2O) + 5(Al_2O_3 \bullet 3H_2O) \tag{2}$$

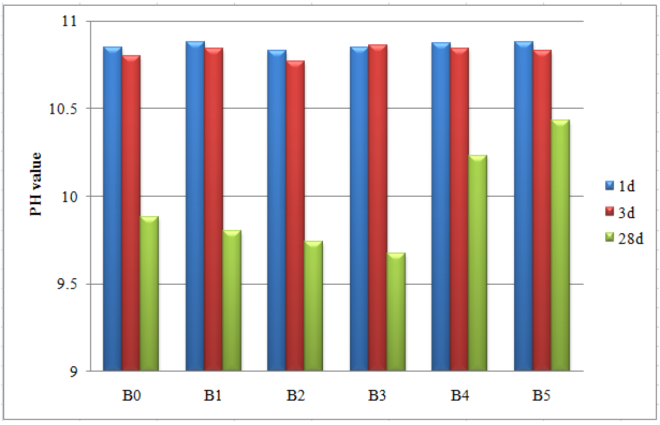


Fig. 7 Alkalinity of PCM with limestone powders

3.2 Compressive strength

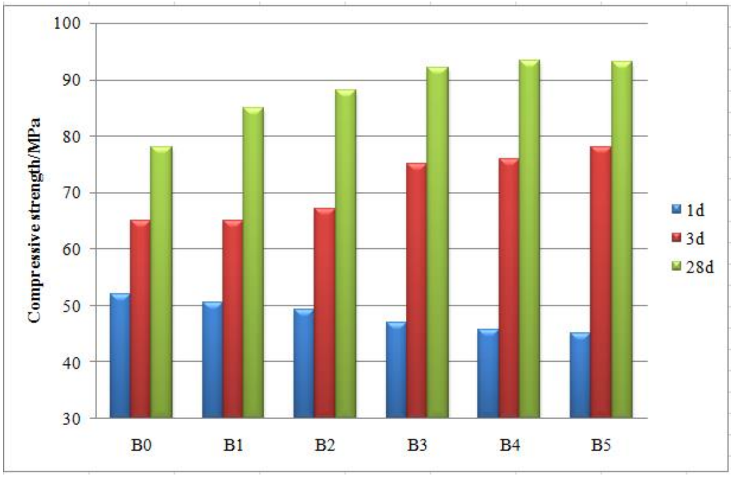


Fig. 8 Compressive strength of PCMs with limestone powders

Fig.8 presents the compressive strength of PCMs with limestone powders. It could be seen that with the extension of cured age compressive strength of PCM increased steadily and was evidently affected by the added amount of limestone powders. With the increase of limestone power content the 1d compressive strength of PCMs with limestone powders was decreased and lower than that of B0. 1d compressive strengths of B1 and B5 had decreased by 2.9% and 13.3%, respectively, compared with that of B0, suggesting that inert limestone powders hindered the connection of hydration products from SAC, and consequently reduced compressive strength of PCMs with limestone powders.

With the increase of limestone power content, the 3d and 28d compressive strengths of PCM exhibited an opposite varying trend. The 3d compressive strengths of B1 and B5 had increased by 0.2% and 20.0% than that of B0 , respectively. The 28d compressive strengths of B1 and B5 increased by 9.0% and 19.2%, respectively, compared with that of B0, which is attributed to that limestone powders participated in the reaction with anhydrite and CH and produced the hydrate($3CaO \cdot Al_2O_3 \cdot CaCO_3 \cdot 11H_2O$) which contributed to strength development of PCM. The result of 28d compressive strength was in accordance with that of 28d alkalinity.

3.3 Fluidity

The fluidity of PCM with limestone powders is presented in Fig.9. It can be seen that limestone powders contributed to the increase of the fluidity of PCM. Compared to B0 the fluidities of B1 and B5 had increased by 5.9% and 21.6%, respectively. Anhydrate not only reacted with calcium sulphoaluminate, but also hydrated into dihydrate gypsum. In comparison, limestone powder took no chemical reaction and its specific surface area was close to that of anhydrite. So when limestone powders partially replaced anhydrate, they consumed less added water than anhydrite would do. Therefore limestone powders could reduce water requirement of PCMs and consequently increased the fluidity of PCMs at the same W/C ratio.

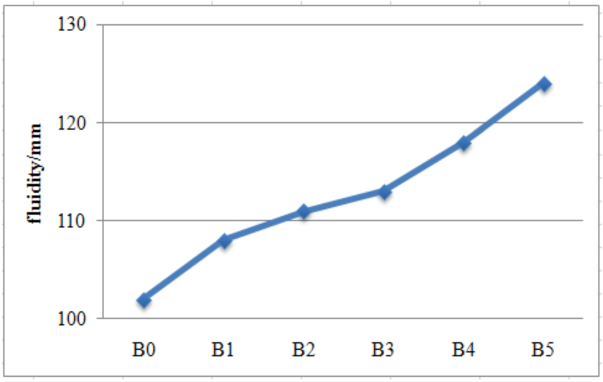


Fig. 9 Fluidity of PCM with limestone powders

3.4 Water permeability coefficient

In general, the porous structure, especially connected pore structure, of concrete can be characterized by its permeability coefficient. Fig.10 presents water permeability coefficient of planting concretes. It can be seen that the water permeability coefficient of B1 with 10wt.% limestone powders was close to that of B0 without limestone powders. The water permeability coefficients of B1 and B3 had increased by 0.6% and 6.5%, respectively, compared with that of B0. But the water permeability coefficient of B5 was as low as 14.9mm/s which was 11.3% less than that of B0. It can be found from Fig. 5 that with the increase of limestone powder content water permeability coefficient increased first and then decreased. With the increase of limestone powder content to 20wt.% the water permeability coefficient was the highest to 17.9mm/s. At this time the surface of aggregates was fitly coated by slurry and the bottom of concrete B3 was not blocked as shown in Fig.11(a). But when keeping increasing limestone powder content the fluidity of PCM was too high (i.e. increased to 118mm (seen in Fig. 9) corresponding to that of B4), and the pores in the bottom of concrete were blocked (see Fig. 11(b)). At that moment the water permeability coefficient decreased. So a proper amount of limestone powders is beneficial to improve both the water permeability and the pore connectivity of planting concrete.

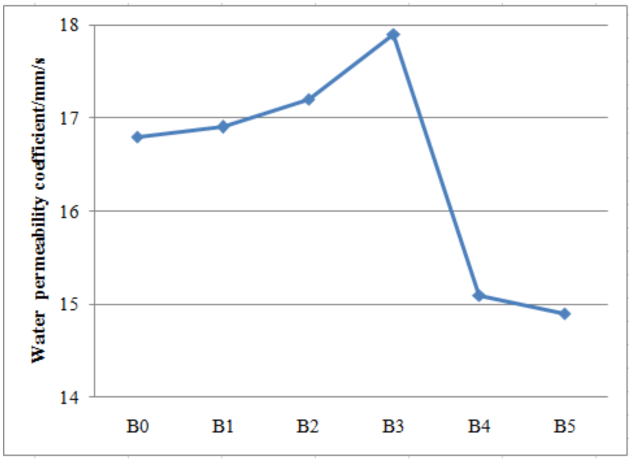
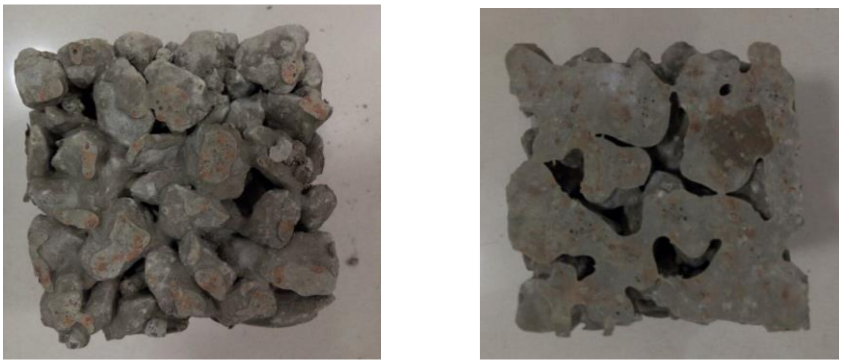


Fig.10 Water permeability coefficient of planting concrete with limestone powders



(a) B3 (b) B5

Fig.11 Images of the bottom of planting concrete with limestone powders

3.5 Physiological performance

The internal alkalinity and pore structure of planting concrete directly determined growth rate of the plants, especially at the early stage of growth. If the alkalinity was too high, the plant would die because of the damage of roots. If the connectivity of pore structure was poor, roots could not quickly reach to the soil under the concrete and then plants would wither and even die due to being lack of nutrients and moistures. Therefore, in this paper, root length and relative water content of leaves were utilized as the index to characterize physiological performances of planting concrete. Tall fescue chosen in this paper was planted in the concrete. The thickness of planting concrete was 10cm. The soil was firstly mixed with seeds and then covered about 2cm in height on concretes.

3.5.1 Root length

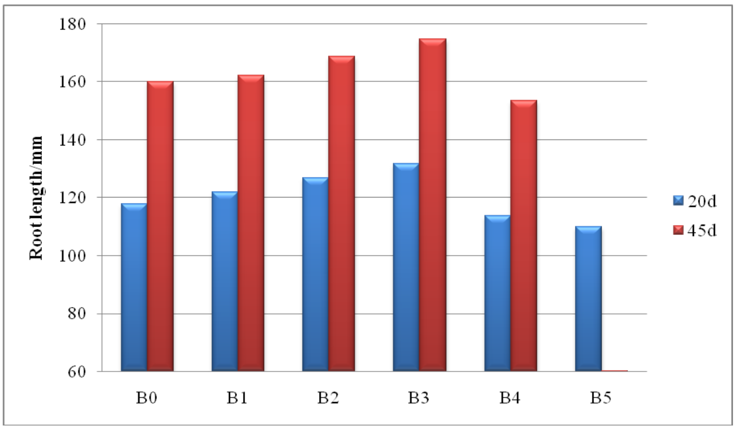


Fig.12 Effects of limestone powders on root length

Fig.12 illustrates the effects of limestone powders on root length of plants grown in concrete. At 20d after sprouting root length of plants in different concretes increased first and then decreased. Root length of plants in B3 reached the highest to 131.7 mm which was 11.8% higher than that in B0. The root length of plants in B5 was 16.5% less than that in B3. Though at that time root length of plants in concrete was higher than 100mm of concrete thickness, because the connected pores inside concrete were tortuous, there were no roots passing though concrete as shown as in Fig.13(the left concrete was B4 and the right was B3). It was concluded that at that time the connectivity of pores was key as shown in Fig.10. It was attributed to the fact that alkalinity of planting concrete affected the growth of roots. The result of root length at 20d after sprouting was in accordance with the alkalinity at cured 28d shown in Fig.7.

Fig.13 Photos of plants in concrete at 20d after sprouting

The root lengths of plants at 45d after sprouting followed the same trend with those at 20d after sprouting. They increased first and then decreased, too. At 45d, the root length of plants in B3 was also the highest which was 9.3% higher than that in B0. The growing rate of plants in B3 was good as shown as in Fig.14(a) and Fig.15(a). Because of too many pastes blocking holes at the bottom of planting concrete B5, most plants died in B5 as shown as in Fig. 14(b) and Fig. 15(b).

(a) B3 (b) B5

Fig.14 Photos of plants in concrete at 45d after sprouting

(a) B3 (b) B5

Fig.15 Photos of roots in concrete at 45d after sprouting

3.5.2 LRWC

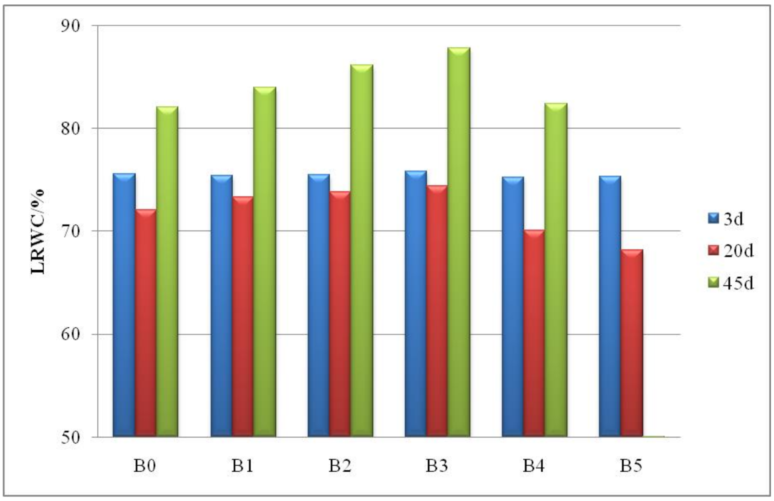


Fig.16 Effects of limestone powders on LRWC

Fig.16 illustrates the effects of limestone powders on LRWC. At 3d after sprouting LRWCs of PCMs with limestone powders changed slightly from 75.2wt.% to 75.8wt.% which were very close to that of B0 without limestone powders, suggesting that plants in all concrete samples had the same growing rate at early ages because of water and nutrients from the same casing soils. LRWCs at 20d after sprouting had a same varying trend with those at 45d. They increased first and then decreased with the increase of the content of limestone powders and were consistent with the variation trend of root lengths as presented in Fig.12. At 20d after sprouting LRWC in B3 was 3.2% and 9.1%, respectively, higher than that in B0 and B5. At 45d after sprouting LRWC in B3 was 6.9% higher than that in B0.

4 Conclusions

Based on the results of this study on effects of limestone powders on pore structure and physiological characteristics of planting concrete with PCM, the following conclusions can be drawn:

(1) Limestone powders had no effect on the alkalinity of PCMs at the early hydration ages of 1d and 3d. But the 28d alkalinity of PCM with 20wt.% limestone powder decreased to 9.67 because they reacted with CH from clinker hydration and anhydrite. When their contents kept increasing the alkalinity increased again for the lack of anhydrite to react.

(2) Because limestone powders hindered the connectivity of hydrates, with their contents increasing the 1d compressive strength decreased. But when the hydration age kept increasing limestone powders reacted with anhydrite and CH and produced additional hydrates which consequently contributed to the strength growth of PCM. The 28d compressive strength of PCM with 30wt.% limestone powders reached as high as 93MPa which was 19.2% higher than that of PCM without limestone powders.

(3) Adding of limestone powders into PCMs contributed to the increase of fluidity of SACs. The fluidity of PCM with 20wt.% limestone powders increased by 5.9% than that of PCM with no limestone powders. And water permeability coefficient of its concrete was the highest of 17.9mm/s. If the content of limestone powders went on increasing, too high fluidity caused that the pores in the bottom of concrete were blocked and water permeability coefficient was decreased. The water permeability coefficients of concrete with 20wt.% and 30 wt.% limestone powders had increased by 6.5% and -11.3%, respectively, than that of concrete with no limestone powders.

(4) Limestone powders effectively reduced the alkalinity and increased the water permeability coefficient of concrete, which improved the plant growth environment. At 20d after sprouting root length and LRWC of plants in concrete with 20wt.% limestone powders was 11.8% and 3.2%, respectively, higher than that in concrete without limestone powders . But much more than 20wt.% limestone powders caused too high fluidity and too many pastes blocking holes at the bottom of planting concrete, such as concrete with 30wt.% limestone powders, so most plants died in it.

Acknowledgments

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