Pergamon

Cement and Concrete Research 33 (2003) 73–76

CEMENT AND CONCRETE RESEARCH

Investigation on pozzolanic effect of perlite powder in concrete

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Received 18 April 2001; accepted 9 July 2002

Abstract

The pozzolanic effect of perlite powder (PP) added to concrete can be determined quantitatively with strength indices: specific strength ratio (*R*), index of specific strength (*K*), and contribution percentage of pozzolanic effect to strength (*P*). Besides compressive strength, these indices indicate that perlite powder has a high pozzolanic effect and is an active mineral admixture (MA) for concrete.

Keywords: Perlite powder; Pozzolanic effect; Concrete; Specific strength; Fineness

1. Indices of pozzolanic effect

Analytical methods of determining the pozzolanic effect of active mineral admixtures (MA) in concrete have been quantified by a few in the past [1]. Pu Xincheng [2] considered that concrete strength originated entirely from cement hydration without any mineral admixture. When a mineral admixture was added to concrete, its strength consisted of two parts, one came from cement hydration, and the other from pozzolanic effect of the mineral admixture. Therefore, he introduced some indices to quantitatively determine the pozzolanic effect of a mineral admixture.

1.1. Specific strength ratio (R)

R is a concept, a ratio of the contributions to concrete strength from unit cement and unit mineral admixture, and it can be expressed by:

$$R = f/q \tag{1}$$

here, *f* is the concrete compressive strength (MPa), *q* is the cement or mineral admixture percentage of the cementitious materials (CM).

Alternatively, R_C expresses the contribution of unit cement to concrete strength without any mineral admixture, while R_M expresses the contribution of unit mineral admixture to concrete strength, and R_P is the contribution of the pozzolanic effect to concrete strength due to mineral admixture, expressed by the equation:

$$R_P = R_M - R_C \tag{2}$$

1.2. Index of specific strength (K)

K is the ratio of R_M to R_C, and it can be calculated by the formula:

$$K = R_M/R_C \tag{3}$$

1.3. Contribution of pozzolanic effect to strength (P)

P is the percentage value of the contribution of pozzolanic effect to concrete strength, and it can be written as:

$$P = (R_P/R_M) \times 100\% \tag{4}$$

2. Experimental investigations

2.1. Material

The cement used in the concrete was a rapid hardening Portland cement, whose strength grade was 525 by the

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0008-8846/03/$ – see front matter
PII: S0008-8846(02)00924-9

Table 1
Grading of aggregates

	Crushed limestone					Sand					
Size (mm)	>31.5	>25.0	>16.0	>5.0	>2.5	>5.0	>2.5	>1.25	>0.63	>0.315	>0.16
Amount (wt.%)	0	3	52	95	100	13.2	29.4	36.3	50.8	79.0	98.7

Table 2
Chemical composition of perlite (wt.%)

SiO_2	Al_2O_3	Fe_2O_3	MnO	Na_2O	K_2O	TiO_2	CaO	MgO	P_2O_5	H_2O	Loss
76.89	10.51	2.48	0.04	0.80	8.25	0.07	0.12	0.06	0.03	0.31	0.64

Chinese standard (GB177-1992), which defines its compressive strength to be over 52.5 MPa at 28 days under standard curing conditions.

The fine aggregate used is midcoarse river sand of fineness modulus 2.61. Crushed limestone of 25 mm maximum size was used as coarse aggregate. Their grading was shown in Table 1.

The superplasticiser used was a naphthalene type of high-range water-reducing admixture (HRWRA), which could reduce about 20% water in concrete.

Perlite powder (PP) was added to concrete as a mineral admixture through cement replacement by an equal amount. Perlite is a natural volcanic siliceous rock from Jinxi County, Jianxi Province, P.R. China. Table 2 lists its chemical composition.

2.2. Concrete mixture proportions

Table 3 gives the mixture proportions of concrete in the present experimental work. The fresh concrete had

Table 3
Concrete mixture proportions

No.	Series	Mineral admixture		W/CM	Amount of every material in concrete (kg/m^3)						Compressive strength (MPa)		
		Fineness (residue%)	Mix (%)		Cement	MA	Fine AG	Coarse AG	Water	HRWRA	3 days	28 days	91 days
1	1		0	0.30	500	0	560	1207	150	5	51.2	61.6	62.5
2		0.0	10	0.30	450	50	560	1207	150	5	47.3	71.6	85.8
3		2.2	10	0.30	450	50	560	1207	150	5	49.8	70.6	79.2
4		5.6	10	0.30	450	50	560	1207	150	5	47.7	76.3	78.9
5		10.2	10	0.30	450	50	560	1207	150	5	44.8	71.5	78.6
6	2	2.2	15	0.30	425	75	560	1207	150	5	50.1	77.4	83.8
7		2.2	20	0.30	400	100	560	1207	150	5	40.6	61.4	83.6
8		2.2	25	0.30	375	125	560	1207	150	5	36.4	64.0	73.9
9		2.2	30	0.30	350	150	560	1207	150	5	39.0	66.0	77.3
10		2.2	40	0.30	300	200	560	1207	150	5	32.3	59.9	67.7
11	3	0		0.36	450	0	620	1208	162	4	37.9	59.5	62.4
12		5.6	10	0.36	405	45	620	1208	162	4	41.5	70.5	74.1
13		0		0.34	450	0	620	1208	153	4	45.8	62.0	72.2
14		5.6	10	0.34	405	45	620	1208	153	4	46.5	65.0	79.8
15		0		0.32	450	0	630	1210	144	5	42.0	53.6	69.6
16		5.6	10	0.32	405	45	630	1210	144	5	38.1	65.1	69.1
17		0		0.30	500	0	630	1210	150	5	44.2	59.3	61.8
18		5.6	10	0.30	450	50	630	1210	150	5	46.0	61.9	63.5
19		0		0.28	500	0	640	1212	140	6	49.8	73.9	71.3
20		5.6	10	0.28	450	50	640	1212	140	6	58.0	77.6	82.7
21		0		0.30	534	0	614	1074	160	5	54.5	73.3	83.9
22		13.2	10	0.30	481	53	614	1074	160	5	56.1	75.3	79.6
23		0		0.27	565	0	593	1113	153	6	60.8	84.5	91.0
24		13.2	10	0.27	508	57	593	1113	153	6	64.3	87.7	96.1

Table 4
Indices of pozzolanic effect with mixed content of PP (28 days)

No.	Mineral admixture (%)	Cement (%)	Compressive strength (MPa)	R_M (MPa)	R_P (MPa)	K	P (%)
1	0	100	61.6	0.62	0	1	0
3	10	90	70.6	0.78	0.15	1.27	19
6	15	85	77.4	0.91	0.30	1.48	32
7	20	80	61.4	0.77	0.15	1.25	20
8	25	75	64.0	0.85	0.24	1.39	28
9	30	70	66.0	0.94	0.33	1.53	35
10	40	60	59.9	1.00	0.38	1.62	38

excellent workability, and the slump was more than 20 cm. Compressive strengths of concrete cubes at 3-, 28-, 91-day standard curing (exposed at temperature of about 20 °C and relative humidity above 90%) were reported in Table 3.

3. Results and discussion

3.1. Variation of pozzolanic effect with mineral admixture content

The mix proportions of concrete were presented in No. 1, 3, and 6–10 of Table 3. The indices of pozzolanic effect are summarized in Table 4. In this table, it is observed that the best ratio of MA to CM was 15% for standard compressive strength of concrete at 28 days, that is, when the strength was the highest; but indices of pozzolanic effect such as R_M, R_P, K, and P improved with mix percentage of MA in the discussed range except for one, and relation between these indices and the mix percentage was nonlinear. The variation was plotted, and it was shown in Figs. 1 and 2.

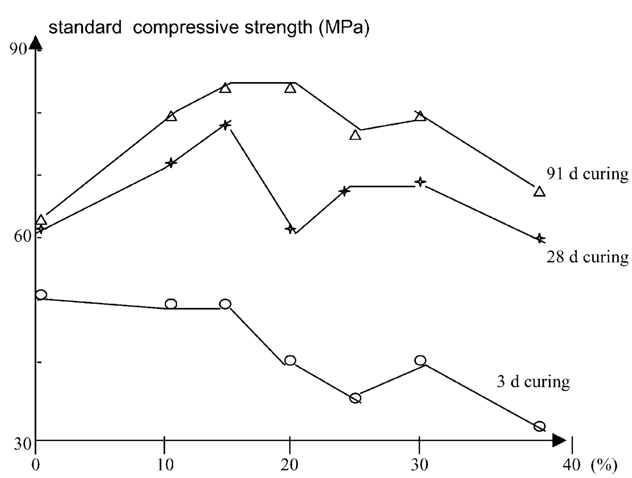

Fig. 1. Change in strength versus mix percent of perlite powder.

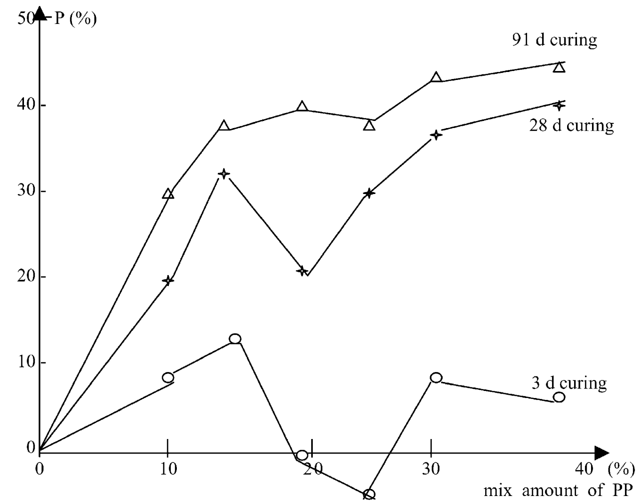

Fig. 2. Variation of P (contribution of pozzolanic effect to strength) versus mix percent of perlite powder.

3.2. Development of pozzolanic effect with curing time

Tables 4–6 list results of standard compressive strength and indices of pozzolanic effect at 28, 3, and 91 days after standard curing. So do Figs. 1 and 2.

It is clear that compressive strength and indices of pozzolanic effect in concrete increased with curing time. During the early period (3 days of curing), the pozzolanic effect of MA was minimal. The longer the curing time, the greater the contribution of pozzolanic effect of MA to concrete strength. Therefore, curing time is an important factors on the pozzolanic effect of MA for concrete.

3.3. Pozzolanic effect on fineness of perlite

Four fineness types of perlite powder were selected in Table 3. The fineness of perlite powder is shown as percent residue on an 80-μm sieve. Their indices of pozzolanic effect are listed in Table 7.

In general, the difference in concrete strength and pozzolanic effect was not evident, except for fineness of 5.6%,

Table 5
Indices of pozzolanic effect and mixed content of PP (3 days)

No.	Mineral admixture (%)	Cement (%)	Compressive strength (MPa)	R_M (MPa)	R_P (MPa)	K	P (%)
1	0	100	51.2	0.51	0	1	0
3	10	90	49.8	0.55	0.04	1.08	7
6	15	85	50.1	0.59	0.07	1.15	13
7	20	80	40.6	0.51	0.00	0.99	− 1
8	25	75	36.4	0.49	− 0.03	0.95	− 6
9	30	70	39.0	0.56	0.05	1.09	8
10	40	60	32.3	0.54	0.03	1.05	5

Table 6
Indices of pozzolanic effect and mixed content of PP (91 days)

No.	Mineral admixture (%)	Cement (%)	Compressive strength (MPa)	R_M (MPa)	R_P (MPa)	K	P (%)
1	0	100	62.5	0.63	0	1	0
3	10	90	79.2	0.88	0.26	1.41	30
6	15	85	83.8	0.99	0.36	1.58	37
7	20	80	83.6	1.05	0.42	1.67	40
8	25	75	73.9	0.99	0.36	1.58	37
9	30	70	77.6	1.10	0.48	1.77	43
10	40	60	67.3	1.13	0.50	1.81	45

which was better for compressive strength and indices of pozzolanic effect in concrete.

3.4. Variation of pozzolanic effect with water–cementitious material ratio

Table 8 gives the results of strength and pozzolanic effect on W/CM. Nos. 11–14, 17, and 18 shown in the table appeared to decrease strength and pozzolanic effect with W/CM ratio. In general, concrete strength increases with reducing W/CM.

3.5. Change of pozzolanic effect with fine aggregate proportion

Nos. 1, 4, 17, and 18 shown in Table 8 can be compared to study the change on compressive strength and indices of pozzolanic effect due to sand proportion, which is the ratio of sand mass content to total aggregate (sand and stone) mass content. It appears that in order to increase strength and pozzolanic effect, it is preferable to decrease fine aggregate proportion.

Table 7
Indices of pozzolanic effect and fineness of PP (28 days)

No.	MA (%)		Cement (%)	Compressive strength (MPa)	R_M (MPa)	R_P (MPa)	K	P (%)
	Fine	Mix						
1		0	100	61.6	0.62	0	1	0
2	0.0	10	90	71.6	0.80	0.18	1.29	23
3	2.2	10	90	70.6	0.78	0.15	1.27	19
4	5.6	10	90	76.3	0.85	0.23	1.38	27
5	10.2	10	90	71.5	0.79	0.18	1.29	22

Table 8
Indices of pozzolanic effect and fine AG proportion and W/CM (28 days)

No.	MA (%)		Fine AG proportion	W/CM	Compressive strength (MPa)	R_M (MPa)	R_P (MPa)	K	P (%)
	Fine	Mix							
11		0	0.34	0.36	59.5	0.60	0	1	0
12	5.6	10	0.34	0.36	70.5	0.78	0.19	1.32	24
13		0	0.34	0.34	62.0	0.62	0	1	0
14	5.6	10	0.34	0.34	65.0	0.72	0.10	1.17	14
17		0	0.34	0.30	59.3	0.59	0	1	0
18	5.6	10	0.34	0.30	61.9	0.69	0.10	1.16	14
1		0	0.32	0.30	61.6	0.62	0	1	0
4	5.6	10	0.32	0.30	76.3	0.85	0.23	1.38	27

4. Conclusions

The pozzolanic effect of the mineral admixture perlite in concrete was quantitatively investigated through specific strength indices like specific strength ratio (R), index of specific strength (K), and contribution percentage of pozzolanic effect to strength (P).

Similarly, the compressive strength of concrete containing other active mineral admixture like natural zeolite powder [3], condensed silica fume [4], fly ash, blast-furnace slag, rice husk ash, and volcanic rocks can be described through these indices. This study indicates that natural perlite powder has a significant pozzolanic effect and is a good active mineral admixture for concrete.

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