A New Addition Agent for Grouting Material Strengthening

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ABSTRACT

C-S (Cement-Sodium Silicate) grout is commonly used as one of grouting materials for ground consolidation and water sealing in mining, tunnelling and other geotechnical engineering.

But it can not be used in permanent engineering because of its lowered long-age strength, bad durability and dry shrinkage. Based on a series of tests and research works, a new addition agent for grouting material strengthening has been presented for eliminating the C-S grout's shortcomings.

By use of the agent, C-S, grouts long-age strength can be maintained and good durability of the material is obtained whereas a little expansion of sample pieces has been shown instead of shrinkage. Some results of the tests and research work on the new addition agent for grout strengthening are introduced in this paper.

INTRODUCTION

Grouting has widely been applied in the engineering of dams, tunnels, foundations and other geotechnical engineering works as an important means for ground consolidation, waterproofing and sealing.

It is an especially important innovation for weak rock tunnelling and can be taken as an effective measure for treatment of existing leaking tunnel linings.

One of the keys to the grouting process is choosing the right grouting material. Nowadays, C-S (Cement-Sodium Silicate) material is used in most cases of ground grouting for water stopping or ground improvement. In competition with other chemical injection material the advantages of C-S material are low price, easy obtainability and non toxicity. At the same time, the C-S material is gel time controllable and has good groutability in comparison with cement grouts. Nevertheless, C-S material too easily shrinks. In three months or half a year after grouting its strength gradually reduces and can be completely lost finally even in water.

Wetting-drying test and freezing-thawing test carried out in the laboratory shows that after two cycles of wetting-drying or freezing-thawing tests there are fissures appearing in test samples and these samples gradually collapse.

For the purpose of overcoming the shortcomings of C-S material which are mentioned above, a new addition agent for C-S material strengthening is submitted based on results of component research, laboratory tests and theoretical analysis.

PROPERTIES OF STRENGTHENED C-S

By the use of a new addition agent, the strengthened C-S material's linear and volume shrinkage rate can probably be reduced to zero (or a slight expansion) whereas C-S grout's advantages such as good groutability, being gel time controllable, are maintained.

The long term strength of strengthened C-S material is steadily developed and no peak value appears in the time dependent curve.

Good durability of strengthened C-S material has been shown by freezing-thawing tests and wetting-drying tests. The number of cycles withstood for strengthened C-S material samples is 15 ~ 20 times greater than that for common C-S (unstrengthened) material.

A series of laboratory tests have been carried out to show the properties of strengthened C-S material.

Gel time

The use of the addition agent caused no influence on gel time of C-S grout. For the strengthened C-S grout the gel time can be controlled within the range of 2' ~ 30' by adding retardar and within range of 20" ~ 2' by changing water-cement ratio just as for common C-S grout.

The relationship between water-cement ratio and gel time of strengthened C-S (ZP in Figure 1) is shown in comparison with that of common C-S (D in Figure 1).

Strength

Compressive strength is obtained by unconfined loading tests. The scale of cubic samples are 2x2x2 (cm) and 4x4x4 (cm).

Figures 2, 3 and 4 show time dependent strength properties for strengthened C-S and the unstrengthened one respectively.

Values of compressive strength at ages of 3, 7, 28, 90, 180, 360 and 720 days are shown on the Figures (curing in water).

It is obvious that in the case of using the addition agent the strength of C-S samples are developed steadily and in the case of unstrengthened C-S (noted by letter D) after 3 ~ 6 months compressive strength reduces rapidly until it is completely lost and then the sample collapses.

Freezing-thawing test

Referring to some test standards we take 24 hours as a cycle time. The range of temperature variation is -25°C ~ 15°C. Number of cycles is taken as 20.

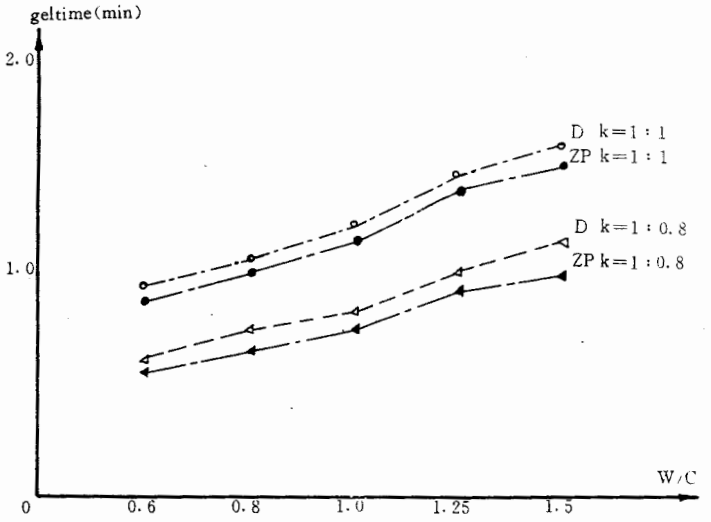

Figure 1. Relationship between gel time and water-cement ratio
K-cement-sodium silicate proportion (in volume)

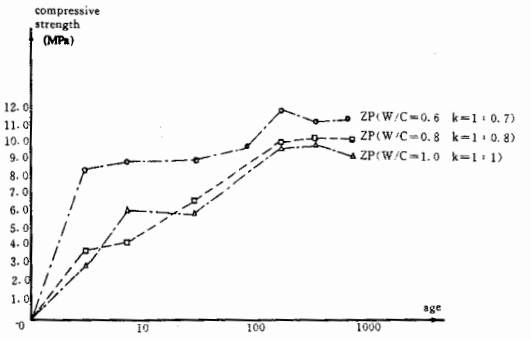

Figure 2. Time-dependent properties of unconfined compressive strength
test on 4x4x4 (cm) cubes
(for strengthened C-S)

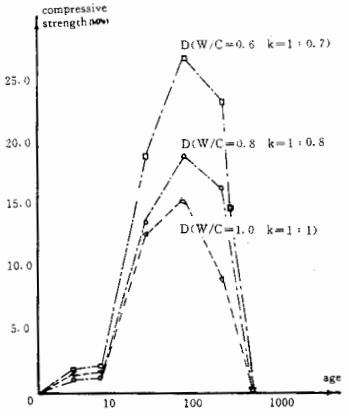

Figure 3. Time-dependent properties of unconfined compressive strength test on 4x4x4 (cm) cubes (for common C-S)

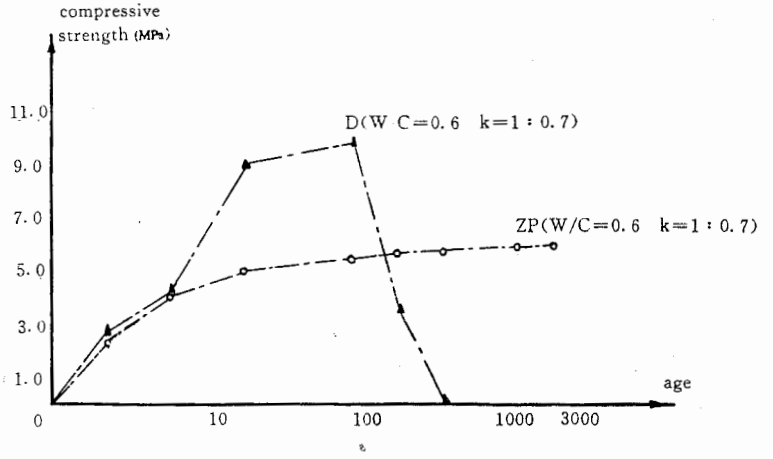

Figure 4. Tests on 2x2x2 cm
D-common C-S
ZP-strengthened C-S

In order to understand the effects of each component samples tested are divided into four groups:

ZP - using addition agent
Z - using addition agent without foaming component
P - without accelerator
D - common C-S

Results of test (Table 1,2) shows that samples of group ZP have the highest resistance to frost-thaw changes.

After bearing 20 freezing-thawing cycles no sample defects were observed. For both group Z and group P resistance to frost-thaw is reduced to a certain degree. For group D (common C-S), some slight fissures appeared immediately after 1 ~ 2 cycles. And then, samples were full of cracks after 3 ~ 4 cycles. Finally, after 5 ~ 6 cycles, the sample completely collapsed into small blocks even powder.

In Tables 1, 2 and 3 intactness of samples are described as follows:

α - intact sample
β - with some fissures
γ - collapsed
δ - cracked into powder

In the tables the changes of sample weight and strength are also shown.

It can be seen that for the strengthened C-S compressive strength and the weight of sample are only slightly reduced after bearing freezing-thawing tests. And for the unstrengthened C-S samples, such data can not be obtained as samples have collapsed completely.

Wetting-drying tests

24 hours are also taken in wetting-drying tests as cycle time and the range of moist variation is 60% ~ 90%.

Samples tested are divided into two groups for comparison to each other.

ZP - using addition agent
D - common C-S

The tests show (Table 3) that just after the first wetting-drying cycle in samples of D group some slight fissures appeared. After the third cycle the samples were full of cracks and then the sample can collapse after 5 ~ 7 cycles. After 10 cycles they can be pulverized into powder.

For the strengthened C-S samples (ZP group) no change or defect was observed after bearing 10 wetting-drying cycles except for a low water-cement ratio sample in which some slight fissures appeared. Even after 20 cycles the shape of the samples can still be kept.

Both freezing-thawing test and wetting-drying test proved that by the use of addition agent durability of C-S grout can obviously be increased.

Expansion rate measurements

A three-dimensional expansion meter is used for expansion rate measurements. Therefore, the volume expansion rate can be calculated for the cubic sample as follows:

$$\eta = (\Delta x + \Delta y + \Delta z)/a$$

where

η = volume expansion rate
a = size of the cube (side length of the cube)
$\Delta x, \Delta y, \Delta z$ = size changes of a sample in three directions

The result of measurements show (Table 4):

1. For the strengthened C-S samples some expansion can be measured. The expansion rate at age of 28 days and 62 days are shown in Table 4.

2. For the unstrengthened C-S sample the value of volume change measured is negative, that means shrinkage. The shrinkage rate can be 1 ~ 5% complying with different water-cement rate.

In all tests mentioned above viscosity of C-S grout used is 3.2 ~ 4.0 cp, the grout is composed of 425# or 525# Portland cement and sodium silicate at 38 Be'.

A CASE

Laoqingshan water supply tunnel is one of key engineerings of a major irrigation system in Yunnan province, Southwest China.

The tunnel is located in fractured rock ground with some faults intersected. Moreover, the ground is abundant in Karst water.

Full-face pregrouting was operated during the tunnel excavation and in an area of 20 m long, boreholes (mileage DK5 + 355 ~ 375) 43461/hour of leakage, remained even after lining had been completed.

Chemical examination of ground water shows that the ground water is HCO_3^- -C_a^{++} -Mg^{++} contained with 7.5 pH value. No chemical attack should be considered for the material.

Strengthened C-S material is adopted for grouting at the back of lining and into the surrounding rock.

Hole drilling

Near the leakage points on lining surface 10 holes of 0.6 m deep and 0.25 mm are drilled.

Equipment and material

KBY-250 type pump for bi-liquid grouting is adopted.
Cement: 525# Portland
Sodium Silicate: 35Be', modulus 2.4
Cement: Water = 1 : 1 ~ 1 : 0.6
Cement: Sodium Silicate = 1 : 0.8
Additional agent: 5% of cement
Gel time control: 30" ~ 1'00"
Grouting pressure: 0.1 MPa
Grouting rate: 35 l/min

Result

After grouting leakage within the area is reduced from 4346 l/hr to 444 l/hr.

CONCLUSION

1. By use of the strengthening agent the C-S grout's shortcomings can be eliminated. The good durability of the strengthening agent mixed C-S material has been proved by a series of tests.

   Instead of shrinkage a slight expansion has been shown and long age strength can be kept. So, such a strengthened C-S material can be used in permanent engineering works.

2. No environment problem is caused by using the strengthening agent.

3. No unfavourable effect on groutability and gel time control of C-S grout by mixing the strengthening agent, and the grouting operation and equipments do not need to be changed.

4. The production process of the strengthening agent is uncomplicated and its raw material can easily be obtained.

Tab. 1 Results of Freezing-Thawing tests on 4×4×4cm Cubes

group	W/C	K**	intactnes	Number of cycles												Weight change		strength change	
				1	2	3	4	5	6	7	8	9	10	15	20	before	after	before	after
ZP	0.8	1:0.8	α	3*	3	3	3	3	3	3	3	3	3	3	3	280 (g)	270 (g)	13.39 (MPa)	12.924 (MPa)
			β																
			γ																
			δ																
D	0.8	1:0.8	α	9	9	8	7	6	5	4						285 (g)	0	0	0
			β			1	2	3	4	4	6	6	4						
			γ							1	2	2	3						
			δ								1	1	2	9	9				
ZP	1.0	1:1	α	3	3	3	3	3	3	3	3	3	3	3	3	315 (g)	300 (g)	19.60 (MPa)	18.00 Mpa
			β																
			γ																
			δ																
D	1.0	1:1	α	3	3	2										296 (g)	0	0	0
			β			1	1	1											
			γ				2	2	3	1									
			δ							2	3	3	3	3	3				
ZP	0.6	1:0.7	α	3	3	3	3	3	3	3	3	3	3	2	2	260 (g)	250 (g)	8.555 (MPa)	8.166 (MPa)
			β											2	2				
			γ																
			δ																
D	0.6	1:0.7	α	3	1											282 (g)	0	0	0
			β		2	3	3												
			γ					3	3	1									
			δ							2	3	3	3	3	3				

* shown in the table are numbers of samplts

** k cement-sodium silicat proportion (in volume)

*** samples are at age of 48 days (Under water curing for 28 days and being tested for 20 days)

Tab. 2 Results of Freezing-Thawing tests on 4×4×4cm Cubes.

group	W/C	k**	intactness	Number of cycles																Weight change		strength change	
				1	2	3	4	5	6	7	8	9	10	12	13	15	17	19	20	before	after	before	after
ZP	1.0	1:1	α	3*	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	284 (g)	280 (g)	10.66 (MPa)	9.80 (MPa)
			β																				
			γ																				
			δ																				
Z	1.0	1:1	α	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	293 (g)	93 (g)	8.943 (MPa)	7.900 (MPa)
			β												1								
			γ													1	1	1					
			δ																1				
P	1.0	1:1	α	3	3	3	3	3	3	3	2	2	2	2	2	1	1	1	1	285 (g)	82 (g)	7.196 (MPa)	
			β								1	1	1	1	1	2	1	1					
			γ																				
			δ														1	1	2				
D	1.0	1:1	α	3	1															298	0	10.76 (MPa)	
			β		2	3	3	2	2	2	1	1											
			γ					1	1	1	2	2											
			δ										3	3	3	3	3	3	3				

* Shown in tab. are numbers of samples

** Cement-Sodium silicate proportion (in volume),

*** Samples are at age of 48 days (under water curing for 28days and being tested for 20days)

Tab. 3 Results of Wetting-Drying tests on 4×4×4cm cubes

group	W/C	k	intactness	Number of cycles																				Weight change		strength change	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	before	after	before	after
ZP	0.8	1 : 0.8	α	3*	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	289 (g)	285	6.717 (MPa)	5.553 (MPa)
			β																								
			γ																								
			δ																								
D	0.8	1 : 0.8	α	3																				345 (g)	0	6.718 (MPa)	0
			β		3	3	3	1	1																		
			γ					2	2	3	1																
			δ								2	3	3	3	3	3	3	3	3	3	3	3	3				
ZP	1.0	1 : 1	α	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	280 (g)	274	9.098 (MPa)	7.891 (MPa)
			β																								
			γ																								
			δ																								
D	1.0	1 : 1	α	3																				355 (g)	0	9.098 (MPa)	0
			β		3																						
			γ			1	1																				
			δ			2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3				
ZP	0.6	1 : 0.7	α	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	296 (g)	293	8.460 (Mpa)	7.474 (MPa)
			β																								
			γ																								
			δ																								
D	0.6	1 : 0.7	α	3																				365 (g)	0	6.761 (MPa)	0
			β		3	1	1																				
			γ			2	2																				
			δ					3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3				

* shown in tab. are numbers of samples

* * k cement-sodium silicat proportion (in volume)

* * * samples ane at age of 48 days (under water curing for 28 days and being tested for 20 days)

Tab. 4 Three dimension expansion of 4×4×4cm cubes

Group	W/C	k	direetion	expansions			ΔV%	age
				Primary	final	Δl		
ZP	0.6	1:0.6	x	0.640	0.651	0.011	1.15%	62天
			y	0.385	0.391	0.006		
			z	0.560	0.589	0.029		
ZP	0.8	1:0.8	x	0.640	0.722	0.118	4.65%	
			y	0.697	0.759	0.062		
			z	0.652	0.658	0.006		
ZP	1.0	1:1	x	0.585	0.606	0.021	1.40%	
			y	0.693	0.722	0.029		
			z	0.421	0.427	0.006		
ZP	1.0	1:0.6	x	0.080	0.105	0.025	1.90%	28天
			y	0.082	0.105	0.023		
			z	0.112	0.140	0.028		
ZP	1.0	1:0.8	x	0.692	0.728	0.035	1.70%	
			y	0.552	0.580	0.028		
			z	0.527	0.532	0.005		
ZP	0.6	1:0.7	x	0.0092	0.098	0.006	0.175%	
			y	0.735	0.736	0.001		
			z	0.174	0.174	0.000		
D	0.8	1:0.8	x	0.324	0.278	-0.046	-4.53%	
			y	0.702	0.590	-0.112		
			z	0.436	0.413	-0.023		
D	1.0	1:1	x	0.537	0.501	-0.036	-1.55%	28天
			y	0.811	0.797	-0.014		
			z	0.604	0.484	-0.120		
D	0.6	1:0.7	x	0.781	0.756	-0.025	-3.875%	
			y	0.849	0.771	-0.024		
			z	0.771	0.665	-0.106		

* Samples are air cured at temperature of 25℃ and moisture of 70%.