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Hydration process and rheological properties of cementitious grouting material

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HIGHLIGHTS

- The additives can change the hydration rate and reaction time.
- The grout has high initial fluidity and time-varying behavior.
- The grout has shorter setting time and higher final strength than common.
- The mechanism of each stage is explained by using hydration model.

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ABSTRACT

Grouting reinforcement is an effective technique for wide cracks of slope and complex formation. But the geological problems make them difficult to be filled as grouting materials easily run out before it solidified. To solve the issues, a new type of cement paste is developed, namely SJP grout (S-Sichuan, JP-Jinping), which is made up of cement and SJP additives. In this paper, the influence of the SJP additives on the early hydration process is investigated by hydration heat. The influence on the rheological and harden properties are investigated by viscosity and compressive strength. The results establish that the additives can adjust the cement hydration. It can effectively change the rate of hydration and extend the hydration time. The hydration degree of cement is improved directly. On its rheological properties, the grout has a high initial fluidity and time-varying behavior on viscosity. Pumpable time can adjust from 10 to 60 min and the final strength of the solidified grout is 15–25% higher than of common cement grout. Then this paper discusses a hydration model for SJP grout. The hydration model is divided into five stages of hydration and explains the reaction of every stage.

1. Introduction

In the Himalaya mountain range in western China strong topographic relief, high geo-stresses and complicated geological conditions are the cause of problems due to deep open cracks in rock slope masses. Engineering treatment of such cracks has been a major problem for engineers working on the major hydropower projects along Jinsha river, and in the Yalong river basin. Fig. 1 shows a deep and open crack caused by relaxation and unloading at the left bank of Jinping-1 hydropower station. The deep cracks are roughly parallel to the almost vertical valley slope. They have a maximum crack opening ranging from tens to hundreds of centimeters. The cracks threaten the stability of the high slopes and the water tightness of the dam foundations and abutments.

To solve the problems of geological bodies, the grouting technology is usually used in reinforcement and anti-seepage engineering. On account of the grout can cement loose and fill the cracks, that will effectively improve the stability and anti-permeability of geological bodies [1–4]. The grouting materials are all Portland cement and cement-based material. Cement paste is a heterogeneous system, made of water, cement and soluble chemical admixtures, so it shows different properties with different admixtures. Numerous researchers [5–7] agree that the performance of the composites mentioned is highly dependent on the kind of the admixtures and dosage. Neat cement grouts have a long flow time (namely pumpable time must be possible for 5–7 h), long initial setting time and strength grows slowly. This leads to strong leakage out of the wide open cracks and poor quality of sealing, which does not meet the engineering requirements for the reinforcement. Adding accelerating admixture can make the grout solidified quickly, such as waterglass and calcium chloride etc [8,9], which can increase the cement hydration rate during early ages [10].

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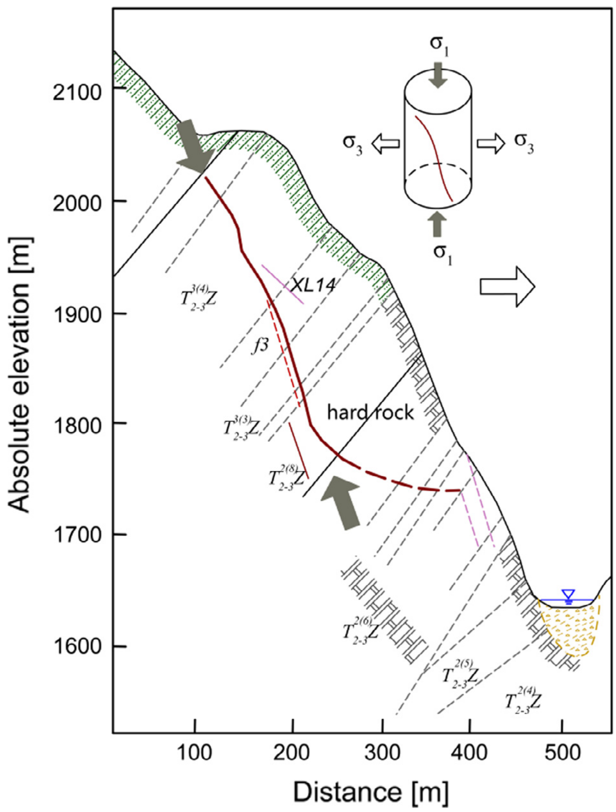

Fig. 1. Steep slope with large open fracture on left bank of Jinping-1hydropower station.

But it is difficult to control the pumpable time and setting time. Moreover, it has the problems of slower growth of later strength and higher deterioration rate. Therefore it cannot solve the problems of leakage.

To solve the problems of big leakage, uncontrollable and low later strength caused by traditional cement pastes. Authors have carried out research work, since 2006, to find the ways to control the rheological and setting time of the grout and the strength of consolidated body. So a new SJP (S-Sichuan, JP-Jinping) grouting material is developed, which is suitable for the grouting treatment of steep and wide open cracks and solve the problems of leakage of cement grout.

The present work aims to elucidate the impact of the admixtures of SJP materials on the mechanisms affecting the process of cement hydration, rheological properties and mechanical properties. To this end, though the chemical and physical properties, discussed the influence of SJP material on cement paste, and discussed the hydration mechanism of SJP grout, then came up with the hydration model.

2. Experimental

2.1. Material

SJP grout is composed of cement grout (cement + water) and SJP additives. The SJP additives include modified fiber (#1 additive), Calcium-Silicon early strength agent (#2 additive) and acylamide derivatives (#3 additive).

The modified fiber (#1) is mainly a mixture of organic fibers, that consist of 0.5–1.0% of methylcellulose and 1–2% of hydroxy propyl cellulose. The color is taupe and PH is nearly 6–6.5. The calcium-silicon early strength agent (#2) is mainly inorganic salts, including 5–10% of metasilicate, 2–8% of calcium oxide and 0.2–1.0% of monox. The color is white and PH is nearly 10–11. It can provide an alkaline environment for the system of cement paste, that can stimulate the hydration of cement. The last one is acylamide derivatives (#3), including 0.5–1.0% of PAM and sodium 0.2–1.0% of acrylate. Though control the content of #3 can adjust the setting time. The cement used in the present work is an ordinary Portland cement produced by Southwest cement plant, Chengdu, Sichuan, China. The chemical compositions of the cement are given in Table 1.

2.2. Laboratory testing of the SJP grout

2.2.1. Composition of the tested grout samples

To investigate the effect of SJP additives on the hydration process of cement grout, the water-cement ratio and weight percentage of the first additive are fixed, while the second and third additives are mixed in different percentages in the grout. The test samples are cured under at a constant temperature of 20 ± 1 °C with a humidity of 90–100%. The compositions of the different samples are shown in Table 2.

2.2.2. The grout hydration process

According to the Chinese testing procedure GB/T 112959-2008, we used the PTS-12S digital cement hydration testing equipment. The test samples are cured at constant temperature of 20 ± 1 °C, and then tested for a duration of 168 h. Test datum are collected every 1 min and each group samples are duplicate.

Table 1
Composition of the ordinary Portland cement deduced from XRF and XRD analyses.

Oxides	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	SO_3
Mass [%]	20.91	2.77	6.50	0.51	63.12	2.10	2.81

Table 2
Mix proportions of the grout.

No.	W/C	C	$1^{\#}$ [%]	$2^{\#}$ [%]	$3^{\#}$ [%]
1	0.6	1	–	–	–
2	0.6	1	0.33	1.8	1
3	0.6	1	0.33	2	1
4	0.6	1	0.33	2.2	1
5	0.6	1	0.33	2.6	1
6	0.6	1	0.33	2.4	1
7	0.6	1	0.33	2	1.2
8	0.6	1	0.33	2	1.4
9	0.6	1	0.33	2	1.5

Note: W/C-water-cement ratio; Additives 1, 2 and 3 in weight ratios to cement.