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A developed technology for wet-ground fine cement slurry with its applications

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Abstract

In order to reduce grouting costs, a new preparation technology for wet-ground fine cement (WFC) was developed. After grinding by this method, the maximum size of cement particles in slurry is not bigger than 40 μm and the medium size (50% by weight) is less than 10 μm; thus, the slurry can be used to inject a rock body with micro-fissures. This newly developed grouting technology with the special gear-grinder has been used successfully in some hydropower projects in China such as Wan'an Project in Jiangxi province and the Three Gorges Project in Yichang city.

Keywords: Grout; Workabilities; Wet-ground fine cement (WFC); Mechanical properties; Grinding

1. Introduction

As the most commonly used grout material, ordinary Portland cement (OPC) has many advantages such as high strength, high durability, nonpoison and low cost. But OPC can only be used to inject rock masses, in which breadth of fissure is bigger than 0.2 mm, because there are some large particles which maximum size is more than 80 μm [1]. When the water/cement ratio of slurry is over 2:1, it is difficult to be injected into micro-fissures due to bad stability and bleeding. At the same time, because of bleeding and shrinkage of set grout, the viscous strength between hardened cement and grouted rock decreases, resulting in a new seepage route. To grout rock masses, especially that with micro-fissures, OPC cannot meet the requirements of projects, so developing fine or superfine cement has become increasingly important [2–4].

Since 1980s, many kinds of superfine cement have been produced in several countries. Although they have many advantages such as limited or no bleeding, high compressive strength and good injectability as chemical materials, the high price (over US$250 per ton) hinders their large-scale usage.

2. Preparation of fine cement

2.1. Grinding method

Nowadays, there are two ways to produce fine cement: dry-grinding and wet-grinding. The former means to grind directly OPC or clinker into fine cement in factories by some types of grinder, for example, ball mill, vibration mill, Raymond mill, mixing mill or air-blow mill. Some performance regulating additives often are added into the mills. However, it is uneconomical to prepare fine cement by these mills because cement particles with big specific surface area and high surface energy tend to aggregate, so it is necessary to apply superfine classifier to separate timely qualified fine cement. Usually, dry-grinding fine cement has a high fineness (the maximum particle size is below 20 μm, medium size below 5 μm and specific surface area over 1000 m^2/kg), but there are some special requests about package and storage, which resulted in a high cost.

Wet-grinding was firstly reported in Japan to prepare slurry of fine cement (called WMC method). OPC was ground by a drum attrition mill to decrease the particle

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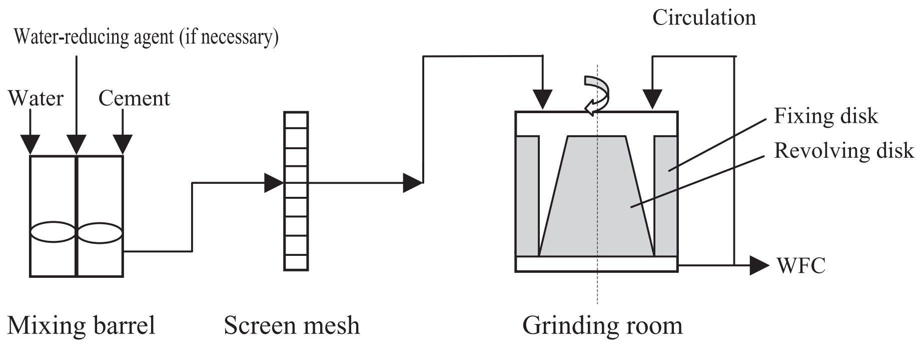

Fig. 1. A schematic representation of the wet cement grinder.

size in grouting fields. The longer milling time is, the finer cement is. By omitting package and storage designed especially for fine cement, WMC technology had been applied in many grouting projects. To inject rock masses with micro-fissures of the Three Gorges Project in China, we have begun to develop wet-grinding of cement since the end of 1980s. After analyzing the advantages and disadvantages of WMC method, a new type of wet-grinder for fine cement has been developed to inject rock masses that breadth of fissure is range from 0.05 to 0.2 mm.

2.2. Mechanical principle

Wet cement grinder is a new geared mill based on colloid mill that used to grind juice and medical materials, a special long-axis motor that rotates at 3000 rpm drives the grinder. The slurry premixed in a barrel is forced to crush into interspaces between the fixing disk and revolving disk, then by the combining forces of friction, impact, shear, centrifugal and high-frequency vibration, cement particles are pulverized and dispensed quickly. Ground slurry suspends in the form of single particle and has high stability. Because there are some advantages such as simple structure, practical usage, light weight, low energy consumption and low cost that is only 1/4–1/3 of fine cement by dry-grinding and, without milling medium requirements in the milling procedure, this wet-grinder has been used in many grouting fields (Fig. 1).

2.3. Technical parameters

2.3.1. Cement fineness

According to Grouting Theory and Practice, there is a relation among the degree of injectability, the breadth of fissure and particle size as follow:

$$M = b/D \geq 3$$

Where M is the degree of injectability, b is the breadth of fissure (μm) and D is the maximum particle size (μm). If the breadth of fissure of rock masses is 0.05–0.2 mm, then particle maximum size of grouting cement should be under 40 μm and medium size below 10 μm.

Some studies have showed that cement strength is mainly attributed to cement particle that size ranges from 3 to 30 μm. The highest compressive strength can be seen when the content of particle that size is below 10 μm is about 50%. Considering the energy consumption and the desired properties of cement, finer cement is usually unnecessary.

2.3.2. Cement output

Fineness of cement and output of the grinder are mutually restrictive. In order to grind finer cement and get higher output, a larger milling machine is necessary. Usually, grout acceptance is limited when fine cement is being injected and grouting is a slow circulation process, the designed output of the wet cement grinder is 20 l/min (when the water/cement ratio is 0.6:1).

Table 1
Particle size distribution of cement before and after grinding

	Size distribution of cement particle (μm...%)							D_{50} (μm)	D_{97} (μm)
	0–10	10–20	20–30	30–40	40–60	60–80	80–		
OPC (before grinding)	32.36	15.56	14.99	12.66	12.48	8.92	3.03	21.39	80.28
WFC (after grinding)	51.92	25.97	14.71	5.21	2.18	0	0	9.63	38.45

(1) OPC = ordinary Portland cement, WFC = wet-ground fine cement.
(2) Water/cement ratio is 0.6:1, content of water-reducing agent is 1.0% and milling time is 3 min.
(3) Cement particle size is measured by photo-homology settlement meter typed NSKC-1A.

Table 2
Performances of wet-ground cement slurry

Item/water–cement ratio		0.6:1	1:1	2:1	3:1	5:1
Setting time (h:min)	OPC	7:54	8:35	9:14	10:10	11:30
	WFC	6:50	7:07	8:50	10:45	12:13
Bleeding ratio (%)	OPC	10.0	27.2	54.3	75.0	81.6
	WFC	1.6	21.8	50.2	67.6	79.6
Viscosity (MPa s)	OPC	400	52.0	13.0	5.6	2.0
	WFC	410	57.5	15.0	7.0	2.5
Compressive strength (MPa, 7 days)	OPC	29.0	23.2	17.8	15.0	13.3
	WFC	26.1	16.7	11.8	7.6	5.2
Impermeability strength (MPa, 7 days)	OPC	2.8	0.4	0.4	0.3	0.2
	WFC	3.4	1.0	0.6	0.4	0.2

(1) Room temperature is 20 ± 2 °C and no water-reducing agent.
(2) Viscosity is measured by revolving viscometer and impermeability strength is measured by mortar permeability meter ranging 0–4.0 MPa in accordance with Experiment Standards of Hydraulic Concrete (No. SD105-82).

2.3.3. Service life

Because of the high hardness of cement particles, it is necessary to coat surfaces of the fixing and revolving disks with materials of higher abrasion resistance and corrosion strength. By chemical and heating combined treatment, surface hardness of the milling disks can be much increased. After grinding 100 tons cement, there is no observed abrasion on both disks.

3. Performances of wet-ground fine cement (WFC)

3.1. Fineness of cement

Some tests have showed that the maximum size (indicated by D_{97}) of cement particles decreases with grinding time, just as medium size (D_{50}) does 3 min before, while 3 min later, medium size is unchanged. When the water/cement ratio is 0.6:1, particle size distributions of cement before and after grinding are listed in Table 1.

3.2. Workabilities of wet-ground cement slurry

The required performances of a good grout are: high flowability, stability of the suspension, limited or no bleeding, high impermeability and some expansibility at the hardened state. After grinding by the wet grinder, the injectability and stability of the cement slurry have been improved, while flowability is decreased. At normal pressure, WFC slurry has a lower compressive strength than that of OPC due to its low bleeding ratio, which resulted in a high water/cement ratio in set grout. The bigger water/cement ratio is, the more compressive strength decreases. But because of its high fineness, the impermeability of set concrete from WFC is better than that of OPC with the same water/cement ratio [5]. Some performances of slurry at different water/cement ratio are presented in Table 2.

By adding suitable water-reducing agent, the viscosity of WFC slurry has been decreased and slurry flowability has been increased easily. Furthermore, there is a marked improvement in compressive strength. The medium diameter of WFC drastically decreases before grinding for 3 min; after 3 min, it is almost unchangeable but has a increasing slurry temperature and a low compressive strength. So it is necessary to control the grinding time, especially in summer. The optimum time is about 2–4 min. Some results are showed in Table 3.

Microstructure tests showed that [6], when OPC was ground for several minutes, there was a high need for hydration water, quick hydration and more hydration product, which resulted in high slurry viscosity and shortened setting time. But because of smaller pore and lower porosity in hydration product, WFC hardened grout's mechanical properties had been improved greatly.

4. Applications of wet-ground cement

Wan'an hydro project in Jiangxi province, which maximum height of dam is 58 m and dam length is 1104 m, has

Table 3
Grinding times' effects on the performances of WFC slurry

Item/grinding time	0	1 min	2 min	3 min	4 min	6 min	8 min
Temperature of slurry (°C)	20.5	22.0	25.0	27.0	29.5	35.0	38.0
Viscosity of slurry (s)	21.0	20.5	20.0	18.5	18.5	17.7	17.2
Bulk density (g/cm^3)	1.68	1.69	1.68	1.64	1.66	1.58	1.56
Bleeding ratio (%)	0.72	0.80	0.72	1.00	0.60	0.30	0
Initial setting time (h:min)	13:53	13:09	13:11	13:06	11:31	11:11	10:56
Final setting time (h:min)	17:26	16:39	15:51	15:46	14:43	14:26	14:19
Compressive strength (MPa, 3 days)	18.6	24.6	23.7	27.2	26.1	15.2	11.3
Compressive strength (MPa, 7 days)	26.8	32.6	33.6	30.1	32.7	14.8	16.7
Impermeability strength (MPa, 7 days)	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0
Medium diameter (μm)	25.14	17.84	13.06	10.15	9.51	10.51	10.32

(1) Water/cement ratio is 0.6:1, the content of water-reducing agent is 1.0% and room temperature is 20 ± 2 °C.
(2) The viscosity of slurry is measured by standard marsh funnel viscometer.

many rock masses with micro-fissures in seventh and eighth monoliths. It is difficult to inject OPC slurry because of bleeding and condensation. In order to verify the grout effect of WFC, the seventh and eighth monoliths, which have similar geological conditions, were grouted by WFC and OPC, respectively. The grouting method is top down, circuit grouting and grouting pressure ranges from 0.6 to 2.0 MPa. The field experimental results shows that unit acceptance of WFC slurry is 23.6 kg/m, which is over 50% higher than that of OPC slurry in grouting areas with many micro-fissures.

Furthermore, grouting technology of WFC has been widely used in many hydropower projects, such as the Three Gorges Project in Yichang city, Wuqiangxi and Jiangya hydroelection station in Hunan province, Geheyan hydroelection station. Moreover, WFC has also been applied to inject silty layer foundations in coastal areas, for example, Zhuhai airport in Guangdong province and a high-rise building in Shanghai city.

5. Conclusions

(1) After grinding for 2–4 min, OPC can be used to prepare WFC slurry in which maximum particle size is below 40 μm and medium size is 10 μm. Owing to its high injectability, WFC can be used to inject rock masses with micro-fissure, which has been illustrated by some engineering examples.

(2) Compared with OPC, WFC has shorter setting time, less bleeding and lower compressive strength. By adding suitable water-reducing agent, performance of WFC slurry can be greatly improved, but it is necessary to control grinding time in order to have a best mechanical prosperities.

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