A Study on the compatibility between accelerators and cement

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Abstract. The microcosmic and macroscopic methods were used to study the compatibility between accelerators and cement. The test results show that the environmental temperature, the water requirement of the normal consistency of the cement, the C3A content, the gypsum content, the alkali content and the 1 day heat of hydration have decisive influences on the compatibility between accelerators and the cement. By testing the compositions and properties of various cements, the relationship between various factors and the compatibility between cement and accelerators is established, which provides theoretical support for the engineering application of accelerators.

1. Introduction

With the large-scale development of the western region and the promotion of the Belt and Road policy, China has accelerated the construction of expressways and railways. The construction of mountain tunnels has increased significantly, which has promoted the rapid growth of shotcrete production[1]. Shotcrete is an important part of the initial support system of a tunnel. The fine aggregate concrete mixed with accelerators is sprayed onto the excavated rock surface by a concrete sprayer and quickly condenses. After layered spraying many times, it can reach the required thickness and form a "flexible support layer" to improve the stability[2] of surrounding rock. With the promotion of shotcrete technology, the amount of accelerators produced has increased greatly. In 2015, China's annual production of accelerators reached 800,000 tons; and in 2017 it exceeded 4.067 million tons[3]. The market has a huge demand for accelerators, which will bring new opportunities for the development of the accelerators.

There are many problems in the application of accelerators. China is a country with a vast land, the construction environment temperature and seasonal temperature differences are relatively large. The setting time of accelerators will change with the temperature. This brings challenges for us to effectively control the quality of shotcrete projects[3]. Meanwhile, China’s cement production is large, with many production enterprises and a wide range of source materials, as a result of which, the mineral compositions and chemical compositions of the cements produced are different. With the large differences in the amount of accelerators and the setting time required for different cements, these lead to prominent compatibility problems between accelerators and the cements, which reduces the efficiency of shotcrete production. The variance of setting time will bring potential safety hazards to production and construction, and limit the wide application of shotcrete[4]. Therefore, it is necessary to systematically analyze and study the compatibility of accelerators and cement. Based on the physical properties, chemical and mineral components of cement, this paper studies the factors affecting the compatibility between accelerators and cement, and provides theoretical guidance for the practical engineering applications of accelerators.

2. Materials and the test methods
2.1. Materials

2.1.1. Cements. This paper selects 9 kinds of cement of different brands in different regions, all of which are Portland cements with strength grade of 42.5. The main chemical compositions of the cements are shown in Table 1.

| Cement     | Fe₂O₃ (%) | Al₂O₃ (%) | SiO₂ (%) | CaO (%) | MgO (%) | SO₃ (%) | K₂O (%) | Na₂O (%) |
|------------|-----------|-----------|----------|---------|---------|---------|---------|----------|
| Fujian MF  | 3.11      | 5.29      | 25.56    | 52.31   | 1.18    | 3.87    | 1.02    | 1.45     |
| Guangdong JD | 3.49   | 5.64      | 13.77    | 48.36   | 2.35    | 4.13    | 0.63    | 1.96     |
| Chongqing JD | 2.51   | 4.41      | 22.28    | 60.12   | 1.36    | 2.93    | 0.54    | 0.72     |
| Guizhou HS | 3.99      | 5.22      | 22.98    | 53.14   | 2.56    | 4.08    | 0.87    | 0.99     |
| Zhejiang NF | 3.36     | 2.81      | 23.44    | 56.30   | 2.72    | 3.41    | 0.51    | 1.54     |
| Henan SJ   | 3.14      | 4.28      | 22.96    | 49.45   | 3.06    | 4.40    | 0.85    | 1.58     |
| Guizhou JD | 2.11      | 4.31      | 24.66    | 50.91   | 3.12    | 3.62    | 0.97    | 1.60     |
| Fujian RF  | 4.70      | 4.64      | 26.62    | 50.48   | 1.22    | 4.22    | 0.46    | 1.54     |
| Fujian HS  | 3.78      | 4.44      | 21.50    | 47.76   | 2.78    | 3.22    | 0.69    | 1.76     |

2.1.2. Accelerators. Two accelerators produced by KZJ New Materials Group Co., Ltd are selected---Point-SN (II) and Point-SN (III). Point-SN (II) is a low alkali liquid accelerator and Point-SN (III) is an alkali-free liquid accelerator. The homogeneity indices of the two accelerators are shown in Table 2.

| Accelerator | Solid content(%) | Density( kg/m³) | pH | Alkali content(%) |
|-------------|------------------|----------------|----|-------------------|
| Point-SN(II) | 50.05            | 1.405          | 13.50 | 10.8             |
| Point-SN(III) | 55.20           | 1.455          | 2.50  | 0                |

2.1.3. Sand. Standard sand conforming to GB/T17671-1999 "Method of testing cements-Determination of strength".

2.1.4. Water. Water that meets the requirements of JGJ63-2006 "Standard of water for concrete".

2.2. Test method

2.2.1. Setting time of cement pastes. The tests of the setting time of the cement pastes are conducted in accordance with GB/T35159-2017 "Flash setting admixtures for Shotcrete ".

2.2.2. Water requirement of normal consistency of cements. The tests of the water requirement of normal consistency of the cements are conducted in accordance with GB/T1346-2011 "Test methods for water requirement of normal consistency, setting time and soundness of the portland cement".

2.2.3. Heat of hydration of cements. The tests of the heat of hydration of the cements are conducted in accordance with GB/12959-2008 "Test methods for heat of hydration of cement".

2.2.4. Chemical compositions of the cements. The tests of the chemical compositions of the cements are conducted in accordance with GB/T176-2008 "Methods for chemical analysis of cement".

3. Experimental results and discussion

3.1. Ambient temperature

The High-and-low-temperature Laboratory constructed by KZJ New Materials Group Co., Ltd was used for the test. Studying the compatibility of the two accelerators with Fujian Runfeng Cement at different temperatures while keeping the other conditions constant. The test results are shown in Figure 1.
3.1. Relationship between ambient temperature and setting time.

In Fig. 1, the setting times of the two accelerators both decrease first and then stabilize with the increase of temperature. When the temperature is in the range of 0~15℃, the changes of setting times are more obvious—the higher the temperature is, the better the effect of quick-setting is. When the temperature is higher than 15℃, the changes of setting times with temperature are gentle. It shows that the lower the ambient temperature, the less compatibility between the accelerator and the cement. As the ambient temperature drops, the reaction between the accelerator and the cement slows down, and the setting of the cement is slowed down.

3.2. Water requirement of normal consistency of cement

All other things (conditions?) being equal, adjust the content of the accelerators and control the initial setting times of the cements to be equal. Then study the effect of the water requirement of normal consistency of cement on the compatibility between the accelerators and the cements. The test results are shown in Figure 2.

3.3. C3A content in cement

All other things being equal, adjust the content of the accelerators and control the initial setting times of the cements to be equal. Then the effect of the C3A content in the cements on the compatibility between the accelerators and the cements was studied. The test results are shown in Figure 3.
Figure 3. Effect of C₃A content in cement on the compatibility of accelerators and cements

In Fig. 3, as the content of C₃A increases, the dosages of Point-SN(II) and Point-SN(III) both decrease. It shows that the compatibility of Point-SN(II) and Point-SN(III) with cement is better with the increase of the C₃A content. The higher the content of C₃A, the more minerals involved in cement hydration, which promotes the formation of ettringite in cement and forms network structure between cement particles, resulting in a shorter setting time.

3.4. Gypsum content in cement

All other things being equal, adjust the content of the accelerators and control the initial setting times of the cements to be equal. Then the effect of gypsum content in cement on the compatibility between the accelerators and the cements was studied. The test results are shown in Figure 4.

Figure 4. Effect of gypsum content in cement on the compatibility between the accelerators and the cements

In Fig. 4, as the content of gypsum increases, the dosages of Point-SN(II) and Point-SN(III) both increase. It shows that the compatibility of Point-SN(II) and Point-SN(III) with cement is less with the increase of the gypsum content. This is because cement generally meets the requirements of setting time by adjusting the content of gypsum. The higher the gypsum content is, the longer the setting time is. Thus it is necessary to increase the dosage of accelerators to accelerate the setting of the cement.

3.5. Alkali content in cement

All other things being equal, adjust the content of the accelerators and control the initial setting times of the cements to be equal. Then the effect of alkali content in cement on the compatibility between the accelerators and the cements was studied. The test results are shown in Figure 5.

Figure 5. Effect of alkali content in cement on the compatibility between accelerators and cements

In Fig. 5, as the content of alkali increases, the dosages of Point-SN(II) and Point-SN(III) both decrease. It shows that the compatibility of Point-SN(II) and Point-SN(III) with cement is more with the
increase of the alkali content. The lower the alkali content in cement, the slower the hydration exothermic rate and the longer the setting time. Thus it is necessary to increase the dosage of accelerators to make the setting time meet the requirement.

3.6.1 Day hydration heat of cement

All other things being equal, adjust the content of the accelerators and control the initial setting time of the cements to be equal. Then the effect of 1 day hydration heat of cement on the compatibility between the accelerators and the cements was studied. The test results are shown in Figure 6.

![Figure 6](image)

Figure 6. Effect of 1 day hydration heat of cement on the compatibility between accelerators and cements

In Fig. 6, as the 1 day hydration heat increases, the dosages of Point-SN(II) and Point-SN(III) decrease. It shows that the compatibility of Point-SN(II) and Point-SN(III) with cement is more with the increase of the 1 day hydration heat. The higher the 1 day hydration heat, the more severe the hydration reaction, the shorter the setting time of the cement, and the lower the content of the accelerator.

4. Conclusions

(1) The lower the ambient temperature is, the less the compatibility between the accelerator and the cement.
(2) The higher the water requirement of normal consistency of the cement is, the more the compatibility between the accelerator and the cement.
(3) The higher the content of C_3A in the cement is, the more the compatibility between the accelerator and the cement.
(4) The higher the gypsum content in the cement is, the less the compatibility between the accelerator and the cement.
(5) The higher the alkali content in the cement is, the more the compatibility between the accelerator and the cement.
(6) The higher the 1 day hydration heat of the cement is, the more the compatibility between the accelerator and the cement.

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