Discussion on the Citation of Accelerator Standards and Testing Methods

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Abstract: As several standards are available for the accelerator test, the influence of different
standards on accelerator test result was studied. Results showed that cement components and
cement type had a significant effect on the accelerator test results. In addition, the impact of
different batches of benchmark cement and w/c ratio on accelerator test results was investigated.
Moreover, reasons of benchmark cement affected the test results of accelerator was analyzed.
Standards for accelerator testing and principles of selection of standards were also discussed in
this paper.

1. Preface
Accelerator is one of widely used concrete admixtures in tunnels and mining projects [1]. Accelerator has
three generations of product changes [2]: powder accelerator, liquid alkaline accelerators, and liquid
alkali-free(low) accelerator, respectively. The first generation of accelerator is an alkaline powder with
fast-setting agent which is mixed with aluminum-oxygen clinker, soda ash, quicklime, etc. The second
generation is a liquid alkaline accelerator with alkali metal carbonate and aluminate as the main
components. Both of these two generations accelerators have the shortcomings of large rebound of
shotcrete, strength loss in the later stage in terms of time [3], poor air in the limited construction condition,
and had adverse effects on the health of construction workers [4]. In order to improve the accelerator
performance, the third generation accelerator is developed with liquid and alkali-free(low) property. The
main accelerator market is dominated by liquid alkali-free accelerator in China at moment, but powder
and liquid alkaline accelerators are still in use.

To standardize the application of accelerators, China has established a series of national and industry
standards for accelerators. The State Administration of Building Materials Industry published the first
accelerator standard: JC477-1992 "Flash setting admixtures for shotcrete". The standard was aimed at
the provisions of powder accelerators that were mainstream products in the market at that time. In the
21st century, after liquid alkaline accelerators entered the market, the Chinese Academy of Building
Materials Science (hereinafter referred to as CBMI) revised JC477-1992 standard and published JC477-
2005 "Flash setting admixtures for shotcrete". With the emergence of alkali-free accelerators in the
market, CBMI has launched a new standard, GB/T35159-2017 "Flash setting admixtures for shotcrete". At the same time, relevant ministries and commissions in China have promulgated relevant standards for accelerators.

The promotion and application of accelerators was benefited by the revision and development of related standards. But some problems were found in the practical applications. For example, the test methods are various with different standards, and the type of cement used for testing are not same. This paper presents experimental study on verification by referring to standards, and explores the possible reasons. At the same time, this article also discusses the questions about standard citation in the actual engineering projects.

2. Raw materials
Cement: benchmark cement and engineering cement.

The benchmark cement is PI42.5 Portland cement produced under the supervision of China Building Materials Institute.

Engineering cement is PO42.5 Portland cement with the brand of Yingde Conch, Fengkai China Resources, Guizhou Conch, Chongqing Huaxin, Southwest Delong, Datian Red Lion, and Southwest Lijiang.

Sand: Standard sand produced by China ISO Sand Co., Ltd.

Accelerators: Liquid alkali-free accelerator produced by Guangzhou Institute of Building Science Co., Ltd (GIBS);
Liquid alkali-free accelerator produced by a Shenzhen manufacturer;
Liquid alkali-free accelerator produced by a Yunnan manufacturer;
Liquid alkali-free accelerator produced by a Shanxi manufacturer.

Table 1 shown the homogeneity index of the accelerator of the mentioned manufacturers.

| Manufacturer       | product status | Density (kg/m³) | Slild content/% | Alkali content /% | Chloride /% | Recommended dosage /% |
|--------------------|----------------|----------------|-----------------|-------------------|-------------|----------------------|
| GIBS               | Transparent liquid | 1.36 | 42.3 | 0.5 | 0.02 | 6-8 |
| A Shenzhen manufacturer | Transparent liquid | 1.32 | 44.5 | 0.7 | 0.05 | 6-8 |
| A Yunnan manufacturer | Milky white liquid | 1.38 | 45.0 | 0.6 | 0.01 | 6-8 |
| A Shanxi manufacturer | Transparent liquid | 1.35 | 48.8 | 0.8 | 0.06 | 6-8 |

3. Test method
Setting time and 1-day compressive strength: Refer to JC477-2005 "Flash setting admixtures for shotcrete" and GB/T35159-2017 "Flash setting admixtures for shotcrete".

4. Results and discussions

4.1. The differences of testing standards
Accelerator testing standards and technical specifications, as well as the main differences in testing methods were summarized in table 2.

It can be seen from table 2 that in the current accelerator standards, there are two main differences for the setting time test. First, two types of cement were used for the test: benchmark cement or engineering cement. Second, the w/c ratio of cement paste test is 0.35 or 0.4.
| Standard         | Issuing agency | Type of cement | Cement content/g | w/c | Initial setting time/s | Final setting time/s |
|------------------|----------------|----------------|------------------|-----|------------------------|---------------------|
| JC477-2005       | NDRC           | Benchmark cement | 400              | 0.4 | $\leq 300$ (Second class) | $\leq 720$ (Second class) |
| GB/T35159-2017   | AQSIQ, SAC     | Benchmark cement | 400              | 0.35 | $\leq 300$             | $\leq 720$          |
| JGJ/T 372-2016   | MoHURD         | Benchmark cement | 400              | 0.35 | $\leq 180$            | $\leq 720$          |
| DL/T 5100-2014   | NEA            | Engineering cement | 400              | 0.4  | $\leq 300$            | $\leq 720$          |
| DL/T 5778-2018   | NEA            | Engineering cement | 400              | 0.35 | $\leq 300$            | $\leq 720$          |
| JT/T 1088-2016   | MOT            | Benchmark cement | 400              | 0.35 | $\leq 300$ (Second class) | $\leq 720$ (Second class) |

4.2. The influence of cement type on setting time and compressive strength

The mechanism of alkali-free accelerator for fast setting and improving early strength is that the calcium ions were consumed once fast-setting agent reacted with gypsum and calcium hydroxide in the cement, which greatly shortened induction period of tricalcium aluminate (C3A) and tricalcium acid (C3S), promoted the hydration of C3S, released large amount of calcium ions, and increased the combined water amount, therefore, large amount of hydrated calcium silicate gel and ettringite were generated. With ettringite continuous formed, cement paste lost fluidity quickly and reached the initial and final setting time, and early strength was also improved [5].

![Fig.1 The results of different sources of accelerators with engineering cement and benchmark cement](image-url)
With large amount of practical applications, we found the results were various with different source of cements even test under the same condition, which may due to the different raw materials or processes of production. And the difference was more obvious especially for benchmark cement. Fig.1 shown the results of different sources of accelerators with engineering cement and benchmark cement.

Fig.1 shown that the setting time and 1-day compressive strength results were different with two types of cement mixed with accelerators under the same condition. The setting time and 1-day compressive strength were met the standard requirements when engineering cement was used, while benchmark cement failed to meet the requirements.

The benchmark cement is PI 42.5 type cement which is produced under the supervision of the China Building Materials Institute, and new batch of benchmark cement is usually produced every 1 to 3 months. Huge differences between different batches of benchmark cement was found after monitored different batches of benchmark cements in past two years. Fig.2 shown the results of benchmark cement mixed with accelerators in past two years.

![Fig.2 Results of benchmark cement mixed with accelerators in past two years](image)

It can be seen from Fig.2 that the quality of benchmark cement fluctuated in the past two years. Although the benchmark cement was supervised by the China Building Materials Institute, the cement manufacturers were different, and raw materials and formulation of cement were not same among the manufacturers or not same time, which lead to large impact on the results of accelerators.

Firstly, the different mineral components in cement will affect the detection structure of accelerant, in addition, cement in the production process of necessary additives will also have a great impact on the detection results of accelerant. Not only can different cement production units not guarantee that the cement mineral composition and the type and amount of additives used are the same, but even the same production unit cannot guarantee that.

4.3. The influence of different standards on setting time

The test results were significantly affected by referred standards. Taking standard JC477-2005 "Flash setting admixtures for shotcrete" and GB/T35159-2017 "Flash setting admixtures for shotcrete" as an example, table 3 shown the influence of standards on the setting time by using benchmark cement.

| Production time of cement | w/c | Dosage of accelerator | Initial setting time | Final setting time | Test results | Standard       |
|---------------------------|-----|-----------------------|---------------------|-------------------|-------------|----------------|
| 2020.02                   | 0.35| 7%                    | 1min30s             | 4min10s           | Pass        | GB/T35159-2017 |
|                           | 0.4 | 7%                    | 4min30s             | 13min50s          | Fail        | JC477-2005     |
Table 3 indicated that, w/c ratio, dosage of accelerator were different if referred by different standards in order to meet the standard requirement. When the w/c is 0.4, the accelerator dosage should be 1%-2% higher than the w/c ratio at 0.35. In addition, the lower w/c ratio, the faster the hydration rate of cement.

### 4.4. Discussion on the citation of quick-setting agent testing standards

There are many standards of testing accelerators, all of which lead to different results. Therefore, it is easy to have different opinions on testing method among accelerator manufacturers, project owner, construction unit, supervision unit and inspection unit. Several suggestions to avoid the mentioned problems shown as below.

Relevant ministries and commissions for standard setting judge the contradictions between different levels of standards, and should correct and unify or make corresponding trade-offs between the standards with obvious contradictions. For example, it can be seen from table 5 that, with same accelerator in same dosage, the test results was qualified when referred to GB/T35159-2017 "Flash setting admixtures for shotcrete", while it was failed when referred to JC477-2005 "Flash setting admixtures for shotcrete". According to the "Standards Law of the People's Republic of China", industry standards can be formulated and implemented if national standards and technical requirements are not available. Once national standards are formulated, relevant industry standards should be coordinated. At the same time, we should refer to national standards if there was a conflict between industry standards and national standards.

It should be noted that JC477-2005 "Flash setting admixtures for shotcrete" was compiled before 2005, only alkaline accelerators were available in China market at that time. With the development of the accelerator technology, alkali-free(low) accelerator has developed after 2010, which resulted in GB/T35159-2017 "Flash setting admixtures for shotcrete" published. Therefore, GB/T35159-2017 "Flash setting admixtures for shotcrete" is an update version to the standard of JC477-2005 "Flash setting admixtures for shotcrete". It is highly recommended that JC477-2005 "Flash setting admixtures for shotcrete" should be updated or abolished.

### 5. Conclusions

1. The main difference for using accelerator is formula difference between engineering cement and benchmark cement. In tunnel engineering projects, integration of the project was paid more attention during the testing (including supervision and random inspection), and the quality of the project should be well controlled rather than a formality. It has high practical significance for engineering quality control to use engineering cement for the accelerator test.

2. As benchmark cement has great volatility in the accelerator test, whether it could be used as the standard cement for accelerator test should be further discussed.

3. It is highly recommended to organize accelerator experts to make corresponding corrections to different standards with contradictory opinions, so as to avoid different opinions in actual projects.

| w/c  | dosage | Setting Time | Hydration Rate | Outcome | Standard |
|------|--------|--------------|----------------|---------|----------|
| 0.4  | 8%     | 2min40s      | 5min40s        | Pass    | JC477-2005 |
| 0.35 | 8%     | 1min0s       | 8min0s         | Pass    | GB/T35159-2017 |
| 2020.06 | 0.4  | 8%          | 5min20s        | Fail    | JC477-2005 |
| 0.4  | 9%     | 3min10s      | 9min20s        | Pass    | JC477-2005 |
| 0.35 | 8%     | 2min40s      | 6min10s        | Pass    | GB/T35159-2017 |
| 2020.10 | 0.4  | 9%          | 5min0s         | Fail    | JC477-2005 |
| 0.4  | 10%    | 2min30s      | 8min0s         | Pass    | JC477-2005 |
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