The effect of Al$_2$(SO$_4$)$_3$ + Li$_2$CO$_3$ + C$_6$H$_{15}$O$_3$N compound early strength agent on the early mechanical properties of concrete

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Abstract. The effect of Al$_2$(SO$_4$)$_3$ + Li$_2$CO$_3$ + C$_6$H$_{15}$O$_3$N compound early strength agent on the early mechanical properties of concrete is studied in this paper, the microanalysis was carried out by SEM scanning electron microscope. The results showed that Al$_2$(SO$_4$)$_3$ + Li$_2$CO$_3$ + C$_6$H$_{15}$O$_3$N composite early strength agent had very significant enhancement effect. The flexural strength of concrete reaches 7.9MPa for 8 hours, and the compressive strength is 43.06MPa, which is increased by 648% and 259% respectively, compared with those without the early strength agent.

1. Introduction

As a traditional admixture, early strength agent can significantly improve the early setting and hardening of concrete, and then rapidly enhance the early mechanical properties of concrete, so as to meet the needs of practical engineering. There are some defects in both organic or inorganic early strength agent separately mixed into concrete, such as the commonly used organic triethanolamine. Because of its small amount of mixing, the early strong agent triethanolamine is not easy to control and has different effect on different kinds of cement systems, so it is generally not added alone$^{[1-2]}$. Sodium sulfate, as a commonly used inorganic salt early strength agent and mixed with concrete, is prone to salting out, which not only affects appearance, but also has potential threat to alkali aggregate reaction of sodium ions in solution$^{[3]}$. The compound early strength agent can reduce the adverse effect of various substances to concrete as much as possible while giving full play to the advantages of various early strength agents, and fully display the superposition effect of all early strength agents$^{[4]}$. The compound early strength agent is one of the main directions of the development of the early strong agent industry, and it is also the main subject of the research of early strong agent. Therefore, the effect of compound early strength agent on the early mechanical properties of concrete is studied by combining inorganic and organic early strength agents.

2. Experimental materials and experimental methods

2.1. main material of test

- Cement: the cement used in the experiment is the P•O42.5 cement produced by Yatai group in Jilin province.
Table 1. Physical mechanical properties of cement

| Type of cement | Standard consistency% | Density g/cm³ | Specific surface area m²/kg | Setting time/min | Flexural strength/MPa | Compressive strength/MPa |
|----------------|------------------------|---------------|------------------------------|------------------|-----------------------|--------------------------|
| P•O42.5        | 27.0                   | 3.15          | 350                          | 240              | 5.2                   | 26.1                     |
|                |                        |               |                              | 320              | 8.4                   | 47.0                     |

- Silica fume: the chemical composition of silica fume (SF) is shown in table 2, and the physical properties of silica fume are shown in table 3.

Table 2. Chemical composition of silica fume

| SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SiO₃ | Na₂O | K₂O | MnO | ZnO |
|------|-------|-------|-----|-----|------|------|-----|-----|-----|
| 90.35| 1.04  | 0.92  | 0.76| 0.25| 0.58 | 0.58 | 0.24| 0.32|     |

Table 3. The physical properties of silica fume

| Density (g/cm³) | Active index (%) | Specific surface area (m²/g) |
|-----------------|------------------|-----------------------------|
| 2.35            | 86               | 17.8275                     |

- Quartz sand: the quartz sand used in this experiment is different in size distribution. The particle size of coarse sand is mainly between 2.36 and 4.75mm. The size of middle sand is mainly between 1.18 and 2.36mm, and the diameter of fine sand is mainly between 0.6 and 1.18mm. The distribution of the quartz sand is shown in table 4, and the physical performance parameters are shown in table 5.

Table 4. Grading distribution of quartz sand

| Particle size (mm) | Accumulative sieve residue (%) |
|--------------------|-------------------------------|
| 4.75               | 0.0%                          |
| 2.36~4.75          | 87.6%                         |
| 1.18~2.36          | 97.6%                         |
| 0.6~1.18           | 98.0%                         |
| 0.3~0.6            | 99.3%                         |
| 0.15~0.3           | 99.5%                         |
| Screen bottom      | 100.0%                        |

Table 5. Physical properties of quartz sand

| Aggregate type     | Stacking density (kg/m³) | Apparent density (kg/m³) | Voidage (%) |
|--------------------|--------------------------|--------------------------|--------------|
| Coarse aggregate   | 1573.5                   | 2564.1                   | 38.6         |
| Medium aggregate   | 1477.7                   | 2604.2                   | 43.3         |
| Fine aggregate     | 1416.6                   | 2673.8                   | 47.0         |

- Admixture: polycarboxylic superplasticizer is provided by Shenyang Huayin environmental protection material Co., Ltd., the water reducing efficiency is 20%. Compound early strength agent: Al₂(SO₄)₃, Li₂CO₃, C₆H₁₅O₃N.

2.2. experimental method

2.2.1 concrete mix ratio parameters
In this experiment, the water cement ratio is 0.28, silica fume content was 10%, cement sand ratio is 0.5 (coarse sand, medium sand, fine sand mixing ratio is 1.2:1.01:0.9), the water reducing agent is a cementitious material quality of 3 per thousand, compound early strength agent dosage: C₆H₁₅O₃N (0.04%) + Al₂(SO₄)₃ (2%) + Li₂CO₃ (1.6%). Concrete mix ratio is shown in Table 6.

| Water (g) | Cement (g) | Silica fume (g) | Coarse sand (g) | Medium sand (g) | Fine sand (g) | Water reducing agent (g) |
|-----------|------------|----------------|----------------|----------------|---------------|-------------------------|
| 196       | 630        | 70             | 540            | 455            | 405           | 4.2                     |

2.2.2 the procedure and process of experimental operation
Firstly the powder of compound early strength agent is added into concrete mixing material, and the powder is well stirred, which is beneficial to the powder of early strength agent to be more evenly dispersed in concrete, and then C₆H₁₅O₃N liquid in the compound early strength agent is added into the mixing water and stirred in the concrete mix together with the mixing water. Then the mixed mixture is loaded into the 40 x 40 x 160mm triad die, and the mold is put into the concrete curing box. The curing condition is used for the standard maintenance. After 4-5 hours of maintenance, the mold is removed and the specimen is maintained for 8 hours.

3. Experimental results and analysis
In this experiment, the effect of composite early strength agent on the early mechanical properties of concrete was investigated. Therefore, the experiment was based on 8 hours of compressive strength and flexural strength. The results obtained by the test are shown in Table 7.

| Experimental groups | Compressive strength (MPa) | Flexural strength (MPa) |
|---------------------|----------------------------|------------------------|
| Without early strength agent | 12.00               | 0.12                   |
| Adding early strength agent    | 43.06               | 7.90                   |

It is not difficult to find out from Table 7 that the effect of C₆H₁₅O₃N + Al₂(SO₄)₃ + Li₂CO₃ early strength agent on the early mechanical properties of concrete is very significant. The curing time of this experiment is much shorter than the general maintenance time, the degree of hydration of cementitious materials in ordinary concrete is lower in such a short curing time, basically no cementation effect. It is difficult to establish the internal structure of concrete and therefore, the flexural strength of concrete is only 0.12MPa after 8 hours of maintenance. While adding C₆H₁₅O₃N + Al₂(SO₄)₃ + Li₂CO₃ combined with early strength agent, the strength of concrete is greatly improved, the flexural strength of 8h reaches 7.9MPa, and the compressive strength is 43.06MPa.

Figure 1. Section map of test block
By observing the internal section of the test block, as shown in Fig. 1, the concrete block mixed with compound early strength agent is denser than the unfilled ones, and the internal porosity is
smaller, and the pore radius is smaller. Lithium carbonate is a strong base and weak acid salt, and aluminum sulfate belongs to strong acid and weak base salt, therefore, when they are added to water at the same time, they will produce mutually promoted hydration reaction and produce lots of bubbles. These bubbles play the role of air entraining agent to some extent, making the bubbles larger in the concrete mixture less, reducing porosity and pore radius, and improving the compactness of the mixture.

Through SEM scanning electron microscope, specimens in the experimental group were observed. We can see from fig. 2, in 8 hours short maintenance time, the inner structure of concrete blank in the experimental group is littered with a lot of unhydrated cement particles and voids filled unhydrated cement particles is relatively loose, causing the concrete flexural strength is low. It is clearly observed from fig. 2 that the hydration degree of the inner matrix of concrete mixed with compound early strength agent is relatively high, and the internal structure is more dense. Because lithium ion has a smaller radius and strong polarization effect, it shortens the hydration induction period, accelerates the formation of calcium sulfoaluminate crystal and accelerates the condensation speed significantly. Therefore, the early strength agent of $\text{C}_6\text{H}_{15}\text{O}_3\text{N} + \text{Al}_2(\text{SO}_4)_3 + \text{Li}_2\text{CO}_3$ can greatly accelerate the hydration process of the matrix in a short time. The compound early strength agent has a certain air entraining effect, which makes the internal porosity decrease, the compactness increases, and the early mechanical properties have a remarkable strengthening effect.

4. Conclusion

- The early strength agent of $\text{C}_6\text{H}_{15}\text{O}_3\text{N} + \text{Al}_2(\text{SO}_4)_3 + \text{Li}_2\text{CO}_3$ has enhanced the mechanical properties of concrete, especially the increase of flexural strength;
- The early strength agent of $\text{C}_6\text{H}_{15}\text{O}_3\text{N} + \text{Al}_2(\text{SO}_4)_3 + \text{Li}_2\text{CO}_3$ can not only accelerate the setting and hardening process of cementitious materials, but also have a certain air entraining effect and improve the density of concrete.

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