Effect of three-step mixing technology based on vibratory mixing on properties of high-strength concrete

Kaiyin Zhao¹, Lijun Zhao*, Shanshan Liu¹, Jinru Hou¹

¹ Key Laboratory of Highway Construction Technology and Equipment of Ministry of Education, Chang’an University, Xi’an 710064, China
E-mail: zhaolj@chd.edu.cn

Abstract: A large number of experimental studies have shown that both vibratory mixing and multi-step mixing processes can improve the workability of concrete and improve the strength and durability of high-strength concrete (HSC). In this paper, for C60 HSC, two kinds of mixing methods: conventional compulsory mixing and vibratory mixing, two kinds of mixing technology: one-step mixing technology and three-step mixing technology are used to carry out contrast test. The purpose is to study the influence of mixing method and mixing technology on the performance of HSC. The research results show that compared with the one-step mixing technology, the three-step mixing technology can significantly reduce the plastic viscosity of the concrete, improve its fluidity, and significantly improve the compressive strength at the age of and after 28 days and 56 days under the condition of the conventional compulsory mixing and the vibratory mixing. And the study found that the most suitable mixing method and mixing technology for C60 HSC are vibratory mixing method and three-step mixing technology.

Key words: vibratory mixing; HSC; three-step mixing; mixing technology

1. Introduction

Because of its high strength, small deformation and good durability, HSC has been widely used in high-rise building structure, large-span bridge structure and some special structures, which is more suitable for the development of modernization than ordinary concrete. A large number of experiments

*Corresponding author. E-mail: zhaolj@chd.edu.cn

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[1-5] show that the vibratory mixing and three-step mixing technology can improve the performance of HSC, but how to combine the two methods has not been studied yet. Therefore, in order to study the effects of different mixing methods and technologies on the performance of HSC, two kinds of mixing methods (conventional compulsory mixing and vibratory mixing) and two kinds of mixing technologies (one-step mixing technology and three-step mixing technology), were combined and compared various scheme tests. The results show that both under the condition of the conventional compulsory mixing and the vibratory mixing, compared with the one-step mixing technology, three-step mixing technology can significantly reduce the plastic viscosity of concrete, improve its fluidity, and obviously enhance the compressive strength of HSC at 28 days and 56 days, and vibratory mixing method and three-step mixing technology are the optimal combination of mixing method and mixing technology.

2. Experiment details

2.1. Equipment and Materials

The test mixer was a 60L twin-shaft vibrating mixer (No vibratory mixing and Vibratory mixing).

(1) P.O52.5R ordinary Portland cements;

(2) The poly carboxylate superplasticizer with high water reduction rate is selected in this experiment. The dosage is 0.7~1.8%, and 1.3% is selected;

(3) The coarse aggregate includes two grades in 5~10mm and 10~20mm. In this experiment, the amount of each of the two materials is calculated according to 10~20mm : 5~10mm = 6 : 4.

2.2. Mix proportion design

The compressive strength grade of HSC is designed as C60, the sand ratio is 33%, and the water-cement ratio is 0.33. According to the raw material test results, the design ratio of HSC is shown in Table 1.

| Materials | Water (kg/m³) | Cement (kg/m³) | Fly ash (kg/m³) | Water reducer (kg/m³) | Coarse aggregate (kg/m³) | Fine aggregate (kg/m³) |
|-----------|---------------|----------------|----------------|-----------------------|--------------------------|-----------------------|
| Amount    | 165           | 500            | 0              | 5                     | 1229                     | 606                   |
| Mix proportion | 0.33         | 1              | 0              | 0.01                  | 2.458                    | 1.212                 |

2.3. Mixing methods

As a kind of effective method to strengthen the concrete mixing process, vibratory mixing is the most representative of the research done by Professor Feng Zhongxu of Chang’an University in China. The research group has done a lot of experimental research on the influence of vibratory mixing on concrete performance [3][8-10]. The research found that: (1) vibratory mixing can significantly increase
the air content of concrete; (2) vibratory mixing can improve the interface between cement stone and coarse aggregate and the morphology of cement hydration slurry in concrete, so that its strength and durability can be greatly improved.

In this paper, HSC is mixed by vibratory mixing and conventional compulsory mixing. The effects of different mixing methods on the performance of HSC are compared and analyzed. The vibration parameters are selected as shown in Table 2.

| Number | Amplitude/mm | Vibration acceleration/g |
|--------|--------------|--------------------------|
| 1      | 0            | 0                        |
| 2      | 0.82         | 4                        |
| 3      | 0.82         | 8                        |
| 4      | 1.36         | 4                        |
| 5      | 1.36         | 8                        |

2.4. Mixing technology

The one-step mixing technology and the three-step mixing technology are adopted in this experiment. Under the same raw material and mixing ratio, the performance of fresh concrete and the compressive strength of concrete after 28 days and 56 days were compared and analyzed between the two mixing technologies.

The one-step mixing technology is that cement, water, water reducer, coarse aggregate and fine aggregate are added at the same time. The mixing time is 150 seconds.

Three-step mixing technology used in this paper is an improved multi-step mixing technology. The improvement idea is derived from a new method used by Hu Guiling [6] for mixing asphalt mixture, as shown in Figure 1. Three-step mixing technology is that coarse aggregate, 30% water and 30% water reducer are added leading to the formation of a thin water film on the surface of coarse aggregate during the first step of mixing. At the second step of mixing, cement is added slowly (feeding duration is 10 seconds) leading to the surface of the wet stone wrapped evenly by the cement. At the third step of mixing, the remaining water, water reducer and fine aggregate are added to complete the concrete mixing process. The specific process is shown in Figure 2.
3. Test results and discussions

3.1. The rheology of fresh concrete

Figure 4 show the relationship between Plastic viscosity and Vibration acceleration under different amplitude.

Figure 5 Relationship between Yield stress and Vibration acceleration under different amplitude

Figure 4 show the relationship between yield stress of HSC and vibration acceleration at different amplitude. Analysis of the test results found that vibration mixing can significantly reduce the yield stress and plastic viscosity of concrete compared with ordinary mixing. Compared with the one-step mixing technology, the three-step mixing technology does not reduce the yield stress of the HSC, which is related to the amount of water used in the third mixing process. The reason for this result is that the water addition amount in the third step is 70%, the 70% water added time is shorter, and another reason is that a large amount of water is easily leaked in the batch mixer, resulting in the lower water distribution uniformity. Figure 5 show that compared with the one-step mixing technology, three-step mixing technology reduces the plastic viscosity of the HSC, which is reduced by 25.9%.

Studies [12] have shown that the yield stress and plastic viscosity of HSC are related to unit water consumption. In this experiment, the slump of the three-step mixing technology is reduced because of the reduction of the unit water consumption, which leads to the increase in the yield stress. However, the "shell-forming" process of the cement-coated stone method increase the amount of slurry between the aggregates, and the internal movement of the concrete is more easy, which greatly reduces the plastic viscosity of the HSC and improves the fluidity.
3.2. The air content of fresh concrete

As shown in Figure 6, the vibratory mixing can increase the air content of the HSC, and as the vibration acceleration increases, the concrete gas content quickly increases to a maximum value (up to 2.5%), and as the vibration acceleration continues to increase, the air content of the HSC decreases. Studies have shown that [13-14] gas content plays an important role in the durability of concrete, especially for freezing. Figure 6 shows that both vibratory mixing method and three-step mixing technology can increase the air content of HSC. And the air content is the highest and durability is the best when the amplitude is 1.36 mm, the vibration acceleration is 4 g and the mixing technology is three-step mixing technology.

3.3. Compressive strength of HSC

The standard test block of 100 mm × 100 mm × 100 mm was prepared by the one-step mixing technology and the three-step mixing technology, then the standard curing was carried out, and the compressive strength test was carried out separately. The test results are shown in Tables 3.

| Table 3. Compressive strength test results |
|-------------------------------------------|
| Mixing technology | Mixing method | Compressive strength of hardened concrete at 28 days | Compressive strength of hardened concrete at 56 days |
| | | Amplitude /mm | Vibration acceleration/g | f/Mpa | Cv | f/Mpa | Cv |
| One-step mixing technology | Conventional compulsory mixing | 0 | 0 | 60.76 | 0.067 | 63.84 | 0.066 |
| | Vibratory mixing | 0.82 | 4 | 64.57 | 0.111 | 72.27 | 0.061 |
| | | | 8 | 66.38 | 0.064 | 77.34 | 0.096 |
| | | 1.36 | 4 | 61.15 | 0.106 | 75.45 | 0.125 |
| | | | 8 | 63.46 | 0.076 | 77.16 | 0.123 |
| Three-step mixing technology | Conventional compulsory mixing | 0 | 0 | 63.52 | 0.081 | 68.14 | 0.088 |
| | Vibratory mixing | 0.82 | 4 | 65.07 | 0.079 | 74.73 | 0.055 |
| | | | 8 | 66.55 | 0.088 | 75.45 | 0.097 |
| | | 1.36 | 4 | 67.86 | 0.036 | 77.94 | 0.041 |
Figure 7 shows the relationship between the compressive strength and the coefficient of variation and the vibration acceleration of HSC at 28 and 56 days.

1) Figure 7 (a) shows that compared with the one-step mixing technology, three-step mixing technology both increased the compressive strength of concrete at 28 days and 56 days by 2.9% ~ 10.9% under the condition of the conventional compulsory mixing method and the vibratory mixing method.

2) Figure 7 (b) shows that under conventional compulsory mixing method, the coefficient of variation of compressive strength of three-step mixing technology at 28 days and 56 days are greater than those of one-step mixing technology; under vibration mixing method, the coefficient of variation of compressive strength of three-step mixing technology can be reduced at 28 days and 56 days. And when the amplitude is 1.36mm, the vibration acceleration is 4g, the coefficient of variation is the smallest.

4. Conclusion

1) Under the conventional compulsory mixing method, compared with the one-step mixing technology, the three-step mixing technology can obviously reduce the plastic viscosity of HSC, improve its fluidity, workability, and significantly improve the compressive strength of HSC at 28 days and 56 days.

2) Under the vibratory mixing method, compared with the one-step mixing technology, the three-step mixing technology obviously reduces the plastic viscosity and improves the
fluidity of concrete, and the compressive strength of HSC at 28 days is obviously improved. The optimum vibration parameter is that the vibration acceleration is 4g, the amplitude is 1.36mm.

(3) The yield stress of HSC (HSC) is not reduced by the three-step mixing technology either in the conventional compulsory mixing method and in the vibratory mixing method, which is related to the leakage of water in the mixer and the unit water consumption in every step, which needs to be further verified by a large number of subsequent tests.

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