Experimental Study on the Effect of Mixing Time on the Performance of High Strength Concrete

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Abstract. To solve the problem of concrete quality caused by non-standard mixing time of high-strength concrete and improve the durability life of concrete structures, based on the working performance and mechanical properties of concrete, effect of mixing time on the workability and strength was studied. In this paper, for high-strength concrete with water-binder ratios of 0.31 and 0.38, the mixing time was 120 s, 160 s, 180 s and 240 s. The effects of different mixing times on the fluidity, cohesion and water retention of high-strength concrete and the compressive strength of 28 days were studied. The test results show that the appropriate mixing time benefits the working performance of concrete and the development of concrete strength. Based on the workability and mechanical properties of concrete, the mixing time of concrete with a water-binder ratio of 0.38 is 160 s, and the mixing time of concrete with a water-binder ratio of 0.31 is 180 s. To ensure the excellent uniformity, compactness, workability and mechanical properties of concrete, the mixing time should consider the slump and the water-binder ratio of concrete. For concrete with a water-binder ratio of 0.31 to 0.38, the mixing time can change from 180 to 160 s.

Keywords: Mixing Time · Water-Binder Ratio · Workability · Admixture

1 Introduction

Concrete mixing quality is mainly controlled by mixing method, feeding sequence and mixing time. To make the concrete mixture uniform and the mixing time appropriate, Germany first issued the national industry standard DIN1045. However, the concrete homogeneity and mixing time have not been precisely defined. At present, forced mixing is often used in on-site construction. 45–120 s is selected as the mixing time of concrete. The main reason is that too long a mixing time will lead to the bleeding of concrete, affecting its workability, strength, and durability. If the mixing time is longer, the composition of the mixture will be uneven, the homogeneity will be good, the honeycomb will appear inside the structure, and the phenomenon of pockmark will appear

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on the surface [1, 2]. Therefore, a specific internal relationship exists between the uniformity of concrete mixing and bleeding. As shown in Fig. 1, the uniformity of concrete and the development process of segregation exceed the optimal mixing time, and the concrete will begin to segregate. After the concrete reaches a specific mixing time, there will always be a time point for the best mixing quality. On the graph, the position of this point is determined by the sum of mixing and segregation [3]. Zheng Donghao et al. [4] believed that the uniformity of the concrete mixture was the best when the mixing time was 90 s. Ren Changxi [5] believes that the mixing time has little effect on the air content of the concrete mixture. When the mixing time is between 90 s and 120 s, the slump and workability of the concrete are the best. Yang et al. [6] used a double spiral concrete mixer to test the influence of mixing time and mixing rate on the strength and uniformity of concrete. Through comparative analysis, it was found that better quality concrete could be obtained when the mixing speed of concrete was between 1.6~ and 1.8 s and the mixing time was between 85~ and 95 s. He et al. [7] used the discrete element analysis software EDEM to simulate the material mixing process. Rong Xin of Chang'an University established a mathematical model to characterize the workability, and the optimal mixing time of concrete was between 90 s and 110 s by comparing the established mathematical model with the traditional slump test [8]. Fang [9] modified the VC value and strength performance of concrete with different consistency, and determined that the concrete performance was the best when the mixing time was 120 s.

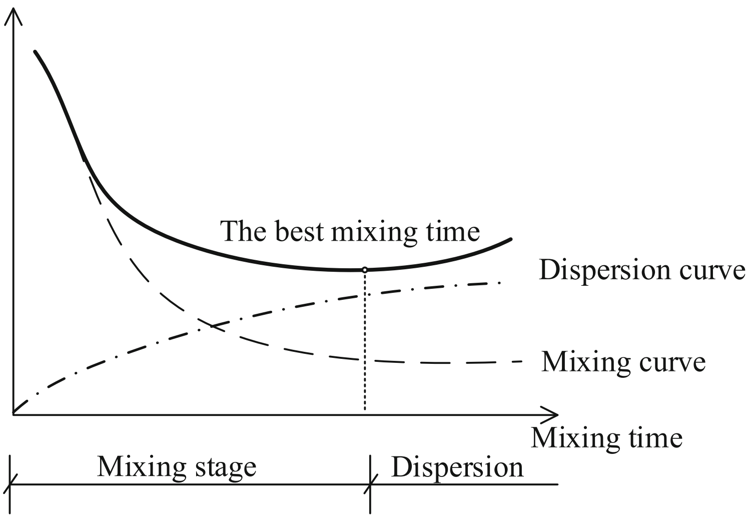

Fig. 1. Curve of mixing process

Ngo [10] designed a method to calculate concrete's shortest mixing time (stabilization time) based on the mixer's power and reduced the energy consumption by 17%. The 'Technical Specification for Concrete Durability Quality Control of Hong Kong-Zhuhai-Macao Bridge' stipulates the shortest continuous mixing time according to the mixer model and capacity, as shown on Table 1.

Table 1. The shortest continuous mixing time of concrete

Mixing machine type	Mixer capacity (L)	The shortest continuous mixing time (min)
Forced (non-vertical)	≤1500	2.5
	>1500	3.0

The mixing time of ordinary concrete is in the range of 90 s–120 s, and the performance of concrete is the best. However, for concrete with high strength and a small water-binder ratio, it is easy to cause insufficient mixing, leading to uncompacted concrete pouring and insufficient strength. To solve the problem of concrete quality caused by the non-standard mixing time, based on the working performance of concrete such as slump and workability, the influence of mixing time on the working performance, mechanical properties and crack resistance of concrete was studied.

2 Test Scheme

2.1 Raw Materials

Raw materials used in the test process: Gravel, limestone, particle size 5–25 mm, cement grade PII42.5, the manufacturer is Yingde Conch Cement Co., LTD., water reducing agent 3301C-HM03, Sika (Jiangsu) Building Materials Co., LTD., first-class fly ash, provided by Zhuhai Yuezhu Environmental Protection Technology Development Co., LTD., slag powder for S95 type, Provided by Zhuhai Yueyufeng Steel Co., LTD.

2.2 Test Methods

The mixing equipment and methods used are different in the concrete mixing process, and the mixing time may also be different when the concrete has the best working performance. The optimum concrete mixing time with different mix ratio designs is also different. For concrete designed with different water-binder ratios, the same HJS-60 horizontal double-axis forced mixer was used to carry out the mixing test, as shown in Fig. 2, and the mixing time required to achieve the best working performance was studied.

Fig. 2. HJS-60 horizontal double-axis forced mixer.

Two mix ratios of w/b = 0.31 and 0.38 were selected, and the mix ratio is shown in Table 2. When the mixing time was 120 s, 160 s, 180 s and 240 s, the working performance, fluidity, cohesiveness and water retention of concrete were observed. At the same time, specimens with the size of 100 × 100 × 100 mm were poured and maintained for 28 days to test the strength of concrete.

Table 2. Mix proportion ratio of concrete

Number	Water-binder	Cement	ground slag	Fly ash	Sand	Stone	Water	Superplasticizer
1	0.31	350	130	0	702	1098	150	4.8
2	0.38	155	90	120	769	1106	140	3.65

3 Test Results

3.1 Influence of Mixing Time on Working Performance

According to the test data analysis in Figs. 3, 4 and Table 3, the concrete with a water-binder ratio of 0.31 and 0.38 has a segregation phenomenon and poor cohesion without water retention when mixing for 120 s. With the increasing mixing time, the cohesion in the range of 120 s–180 s gradually increases, and the cohesion of concrete worsens after mixing for 240 s. The cohesiveness and liquidity achieves the best when the mixing time is 180 s.

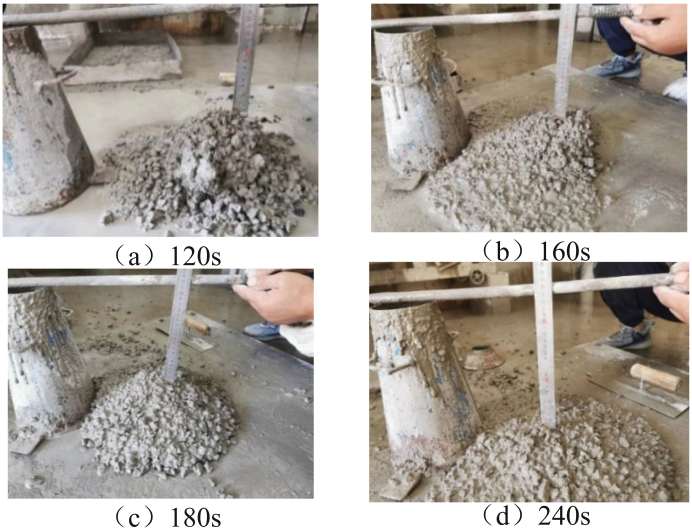

Fig. 3. Slump of concrete at different mixing time (Water-binder ratio 0.31)

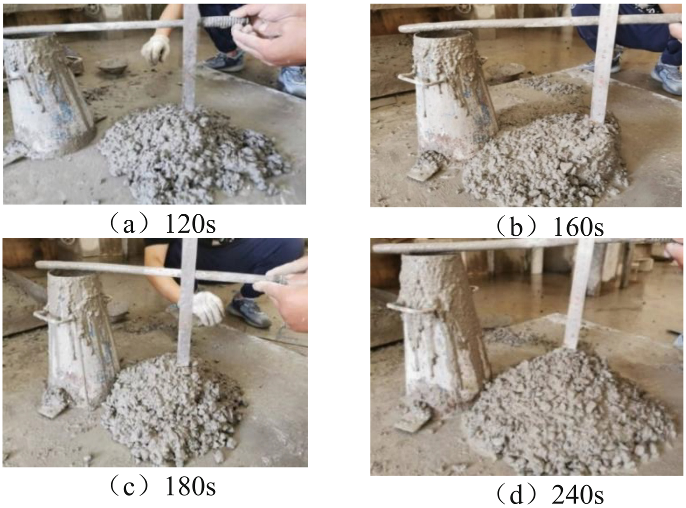

Fig. 4. Slump of concrete at different mixing time (Water-binder ratio 0.38)

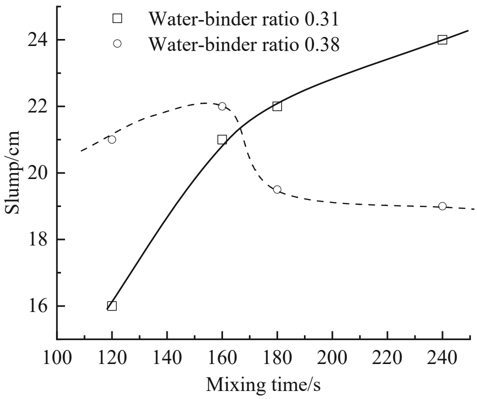

Fig. 5. The relationship between the slump and the mixing time

Table 3. Workability of concrete with different water-binder ratio at different mixing time

Water-binder ratio	Mixing time/s	Slump/mm	Stickiness	Water-retaining property	Cohesiveness
0.31	120	160	mid	no	poor
0.31	160	210	superior	no	range
0.31	180	220	superior	mickle	good
0.31	240	240	superior	no	fair
0.38	120	210	mid	no	poor
0.38	160	220	superior	no	fair
0.38	180	195	superior	no	good
0.38	240	190	superior	no	fair

As shown in Fig. 5, according to different mixing time (120 s, 160 s, 180 s, 240 s), the concrete resistance to segregation, bleeding performance and cohesion. Analysis of the influence of concrete quality, such as concrete strength and dispersion, shows that concrete with the water-binder ratio of 0.31 and 0.38 has better concrete workability in the range of 120 s to 180 s, and the concrete workability become worse after mixing 240 s. The cohesiveness of the two kinds of water-binder ratio concrete reaches its best when the mixing time is 180 s. The results show that the concrete with the water-binder ratio of 0.31 and 0.38 has the best workability, water retention and cohesiveness at 180 s.

3.2 Effect of Mixing Time on Mechanical Properties

The relationship between the compressive strength of concrete and the mixing time in Fig. 6 shows that the compressive strength increases with the incremental mixing time. In addition to the influence of mixing time, the changing trend of compressive strength of concrete relates to the mix ratio of concrete materials. The compressive strength increases from 54 MPa to 59 MPa (an increase of 9.3%) when the mixing time changes from 120 s to 180 s. The change in compressive strength of concrete with a water-binder ratio of 0.38 is not apparent, and the compressive strength increases from 46 MPa at 120 s mixing to 48 MPa at 160 s mixing (an increase of 4.3%).

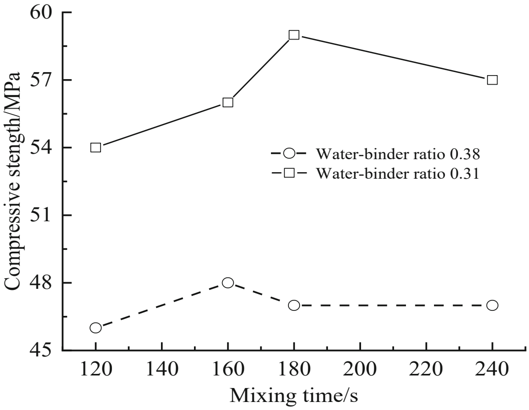

Fig. 6. The relationship between the compressive strength and the mixing time

3.3 Analysis

Because the performance of concrete is not only related to the material itself but also to the mixing time of the material, and the hydration reaction will occur during the mixing process, the change of mechanical properties of concrete will affect the workability of fresh concrete. Therefore, using the same mixer, the mixing time is an essential indicator of workability. The mixing process includes four stages: Stage 1 (about 0–20 s): Due to the lack of water, the particles between the aggregates are seriously staggered due to lack of lubrication. The second stage (about 20 s–70 s): After the contact of water with cement and mineral admixtures, the aggregate particles begin to form agglomerates, and the uniformity of the concrete mixture reaches its best. The water and cement have not fully reacted at this time, so the workability cannot reach the best. In the third stage (about 70–120 s): the lubrication effect of water weakens, and the fluidity and cohesion of concrete begin to increase. The fourth stage (after 120 s): As the hydration continues, the colloid formed by cement, mineral admixtures, and water gradually encapsulates the aggregate, and the workability gradually increases. When the workability of the concrete mixture reaches the optimal value, the colloid and aggregate form a whole of fluidity; if the stirring continues, some particles begin to peel off the concrete mixture, and the colloid will also flow out of the mixture in a liquid state.

Comparing the different mixing time on the working performance of different water-binder ratio concrete. The concrete mixing time of the water-binder ratio of 0.38 is 160 s, and the concrete mixing time of the water-binder ratio of 0.31 is 180 s. The working performance of concrete is the best. With the decrease in the water-binder ratio, the water content in the mixture decreases, and the stirring time should be extended appropriately. From the test process, it is found that not only the mixing time should be controlled according to the slump of concrete, but also the mixing time should be controlled according to the water-binder ratio of concrete. For concrete with a water-binder ratio of 0.31 to 0.38, the mixing time can be controlled between 160 s and 180 s. For concrete with a smaller water-binder ratio, the mixing time should be appropriately increased and verified by experiments.

4 Conclusions

In this paper, concrete with water-binder ratio w/b = 0.31 and 0.38 and mixing time of 120 s, 160 s, 180 s and 240 s were used to observe the working performance, fluidity, cohesiveness, and water retention of concrete. Effect of mixing time on the working performance and strength of concrete with a small water-binder ratio was analyzed. Specific conclusions are as follows:

(1) When mixing concrete with a small water-binder ratio and high strength, the mixing time is between 160 s and 180 s, and the concrete has good workability, water retention and cohesiveness.
(2) To obtain good uniformity, compactness, and good workability of concrete, not only the slump should be considered but also the water-binder ratio of concrete, the water-binder ratio of 0.38 concrete mixing time 160 s, the water-binder ratio of 0.31 concrete mixing time 180 s is more appropriate.
(3) If the mixing time exceeds 240 s, the concrete fluidity is good, but the phenomenon of bleeding begins, which will also affect the compressive strength of the concrete.
(4) The compressive strength of concrete is related to workability, and the concrete strength with better workability, water retention and cohesiveness are more significant.

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