Research Article

Wu Zhao, Jing Yang*, Wenjun Zhao and Chi Yang

Experimental study on the influence of mixing time on concrete performance under different mixing modes

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Abstract: To study the influence of different mixing times on the performance of concrete under vibration mixing and conventional mixing, C40 and C60 are selected in this paper to verify the influence of mixing time of 60, 75, 90, 105, and 120 s on the compressive strength and durability of concrete comparing vibration mixing and common forced mixing. The results show that the early strength of concrete is more significantly improved in 3 and 7 day; the strength with vibration mixing for mixing 105 s in each age is higher than that of conventional mixing at 120 s; under the condition of guaranteed strength, the mixing time of at least 15 s can be reduced. The strength of C40 concrete with vibration mixing has a peak value with the corresponding mixing time of 105 s, and the rapid growth stage of compressive strength is 15 s earlier than that of conventional mixing. For all mixing time, the electric flux of vibrated concrete is significantly smaller than that of forced concrete, and the change rate is generally above 10%; compared with conventional mixing for 120 s, the durability of C40 and C60 concrete increases by 11.8 and 11.1%, respectively, at the time of vibration mixing for 105 s. It was found that under the same mixing time, the compressive strength of concrete with vibration mixing method is higher than that of conventional mixing. In a certain range, the durability of concrete can be improved by prolonging the mixing time.

Keywords: concrete, vibration mixing, mixing time, compressive strength, durability

*** Corresponding author: Jing Yang,** School of Construction Machinary, Chang'an University, Xi'an 710064, China, e-mail: 1529564372@qq.com
Wu Zhao: School of Construction Machinary, Chang'an University, Xi'an 710064, China; Key Laboratory of Construction Technique and Equipment of the Ministry of the Education, Xi'an, Shaanxi, 710064, China, e-mail: zhaowu@chd.edu.cn
Wenjun Zhao, Chi Yang: School of Construction Machinary, Chang'an University, Xi'an 710064, China

1 Introduction

With the continuous progress of China's scientific and technological innovation level in railway, the high-speed railway has become an important symbol of China's scientific and technological innovation. With the increasing amount of concrete used in railway construction, the requirements of concrete quality and preparation efficiency are higher and higher. Under the premise of ensuring that the concrete quality meets the construction requirements, the concrete production quality and efficiency shall be continuously improved to reduce unnecessary resource and energy waste in the construction, to achieve the purpose of improving the construction quality and efficiency.

As an important parameter in the preparation of concrete, mixing time directly affects the uniform distribution of cementitious materials, which not only affects the interface transition zone structure of fresh concrete but also has an important impact on the mechanical properties and durability of hardened concrete [1]. Ngo et al. studied to reduce the energy consumption of the concrete mixing process by optimizing the mixing time. The research results show that by optimizing the mixing time, energy consumption is reduced by about 17% in comparison with the traditional mixing process. Productivity gains are significantly marked by obtaining a reduction in average mixing time of 32% [2]. Yunfen et al. measured the strength distribution of different parts of C30, C40, C50 concrete under different mixing times and discussed the influence of mixing time on the uniformity of the strength of concrete mixed with a polycarboxylic acid water-reducing agent. The results show that the mixing time is too short to make the cementing material in the concrete mixture disperse unevenly, and the concrete strength is low; appropriately extend the mixing time to disperse the constituent materials uniformly and improve the compactness and strength of the concrete, but too long mixing time reduces the mixing. The workability of the compound increases the air content and reduces the compactness and strength of concrete [3]. Zeyad et al. carried out a study on the effect of mixing time and water reducer content on the performance of self-setting concrete. Results showed that compared with the slump flow under 15 min mixing time, the 30, 60, and 90 min increase in mixing time reduced slump flow by 6, 19, and 27%, respectively [4].

To solve the problems of the above-mentioned ordinary forced mixing equipment, eliminate the microscopic unevenness of the concrete, improve the mixing efficiency, and reduce the waste of resources and a series of problems. The research team of Feng Zhongxu's research group puts forward a new theory of vibration mixing, which integrates mechanical vibration into the forced shear mixing process to achieve a combined motion form of vibration and mixing [5]. By transmitting the vibration effect to the mixing mixture, the forced shearing and pushing mixture is also in a flutter state, which can not only effectively break up the agglomerated cementitious material but also distribute it better and accelerate the cement hydration reaction process. In addition, vibration stirring accelerates the diffusion rate of the hydration products on the surface of the particles under the action of vibration energy, so that the cement slurry material and the aggregate are more fully bound, the formed interface bonding strength is higher, and the concrete particles are more compact. Sufficiently, improve the performance and quality of concrete [6].

The industrial test research of 1 m^3 vibrating mixer for C20 concrete was carried out by Liangqi et al. [7]. The results showed that vibrating mixer could effectively shorten the mixing time by 20% when compared with conventional mixing, and the concrete strength can be increased by more than 20% under better mixing time. Yang et al. [8] studied the influence of vibration mixing on the chloride corrosion resistance of C60 high-strength concrete by testing the chloride penetration resistance coefficient. The results showed that vibration mixing can improve the uniform distribution of the internal pore structure of concrete through improving the homogeneity of concrete, and it appears to improve the chloride ion permeability of concrete, so as to has a great improvement on the durability of concrete. Yunshi et al. [9] studied the effect of mixing time on workability and compressive strength of HPC under vibration mixing. The results show that vibration mixing can reduce the plastic viscosity of concrete, and the compressive strength of concrete at all ages is still significantly improved after 40 s of reduction of mixing time. Zhongxu et al. [10] used vibration mixing to improve the strength and other properties of concrete. The results showed that vibration mixing can significantly improve the compressive strength and mixing efficiency of concrete. Zheng et al. [11] studied the influence of different vibration mixing parameters on concrete slump, cohesion, water retention, compressive strength, and its dispersion coefficient. The results showed that the strength of concrete is in direct proportion to the vibration power and vibration time, and the increase of vibration time can increase the strength of concrete, in addition, the dispersion coefficient will also be reduced.

Vibration mixing technology can strengthen the concrete mixing process through mechanical action. As a new mixing technology, it can effectively improve the uniformity of concrete on macro and micro levels and improve the concrete mixing quality and efficiency [12].

In this paper, vibration mixing and conventional mixing are used to study the influence mechanism of different mixing times on the compressive strength at 3, 7, 28, and 56 day and electric flux at 56 day of C40 and C60 concrete, so as to explore the optimum mixing time and mixing method without damaging the performance of concrete, laying a foundation for promoting the wide application of vibration mixing technology in railway projects.

2 Mechanism of vibrating and mixing

The traditional mixing mechanism includes the gravity diffusion mechanism and the forced shear diffusion mechanism. Through the shear process of the mixture, the traditional mixer can make the fresh concrete reach the macroscopic uniformity, but the cement hydration reaction is not complete and the cement particles agglomerate in the microscopic aspect, thus affecting the properties of the fresh concrete and the hardened concrete [13].

Vibration mixing technology is to impose vibration at the same time as forced mixing and strengthen the concrete mixing process through mechanical action [14]. In the mixing device, mechanical vibration is applied to strengthen the displacement and shear action of the mixture, so that the mixture can realize two kinds of movements in the mixing drum, i.e. convection and circumfluence movement, accelerate the cement hydration reaction, break the agglomeration of cement particles, to make the fresh concrete reach the uniformity of macroscopic and microscopic, improve the interface transition area of the concrete, and improve the workability of the concrete, mechanical properties, and durability [15]. In addition, vibration mixing can also eliminate the low-efficiency mixing area caused by the structure of mixing equipment, shorten the mixing time, reduce the cement consumption,

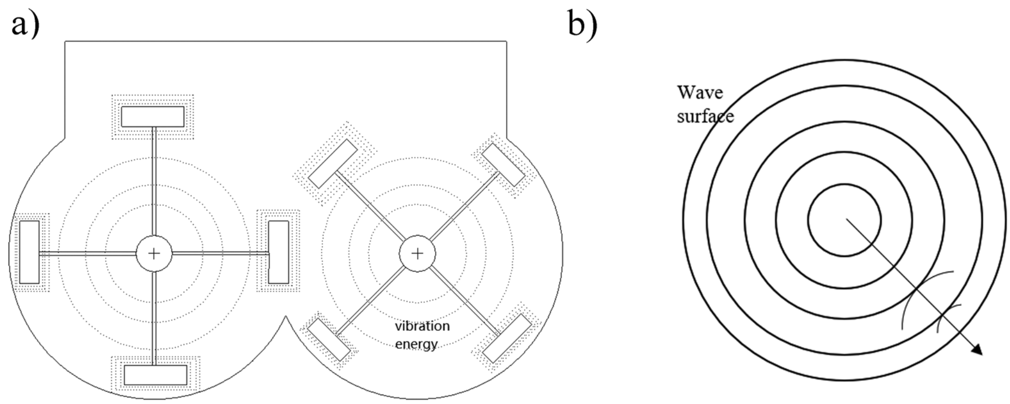


Figure 1: Schematic diagram of vibration energy transmission of double horizontal shaft vibration mixer: (a) distribution diagram of vibration and (b) vibration wave surface energy propagation.

and improve the production efficiency of concrete [16]. The energy transmission diagram of the double horizontal shaft vibration mixer is shown in Figure 1.

2.1 Breaking mechanism of cement particle agglomeration caused by vibration mixing

It is generally believed that the mechanical properties of cement paste are mainly determined by the progress of cement hydration reaction under the condition of water-cement ratio determination. During the conventional mixing, some cement particles agglomerate to form a flocculation unit, which does not participate in the reaction, seriously affecting the mechanical properties of concrete.

After the external exciting force is added, the vibration wave is transmitted among materials, and the shear and convection movement times between materials are increased. The energy absorbed by the vibration wave is in the flutter state, the agglomeration state between particles is destroyed, the aggregates that did not participate in the hydration reaction are dispersed, and they are combined with water molecules to participate in the reaction. The hydration area of cement particles increases and the hydration reaction will be more thoroughly, it creates a way to improve the strength of hardened concrete, as shown in Figure 2.

2.2 Influence mechanism of vibratory mixing on the interface transition zone

The interface transition zone exists in a small area near the surface of the concrete coarse aggregate, and the strength of the hardened cement paste and the interface transition layer determine its mechanical properties [17–19]. Under normal mixing, the material surface tends to adhere to dust that is more hydrophilic. After combining with water, a water film is formed on the surface of the aggregate. The cement particles are passively away from the surface of the aggregate, and the hydration reaction at the surface is less. Therefore, less CSH gel is generated at the interface, and another hydration product $Ca(OH)_2$ crystal will be arranged at the interface. However, the interface energy of $Ca(OH)_2$ crystal is low, the ability to adsorb on the surface of aggregate is weak, and many tiny cracks will be formed [14]. As shown in Figure 3(a), under conventional mixing, the C–H coarse crystals are arranged directionally on the interfacial transition layer and the contact layer and the aggregate surface are mostly arranged in hexagonal shaped C–H crystals, and the intermediate layer is distributed with large ettringite acicular crystals (AFt, AFm) and a few C–S–H gels. During the vibration and mixing process, the dust

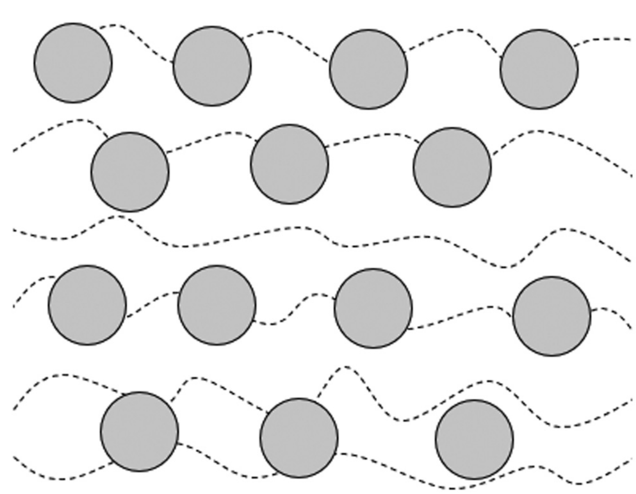


Figure 2: Uniform dispersion of cement particles.

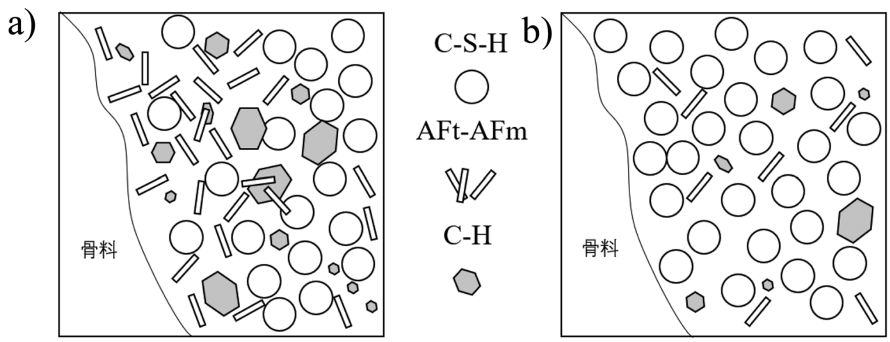


Figure 3: Concrete interfacial transition zone model: (a) common mixing interface transition zone and (b) vibratory mixing interface transition zone.

and water film on the surface of the aggregate will have a certain amplitude. The dust will continue to fall off and the water film will be destroyed. The clean aggregate surface will quickly contact with the water and wet, and the cement particles will quickly adsorb and participate in the hydration. At this time, the CSH gel with high interface energy is fully formed at the aggregate surface, as shown in Figure 3(b), and it is firmly adsorbed on the aggregate surface. As the hydration reaction continues, the CSH gel at the interface increases. The more glue, the larger the interface with the aggregate, the denser the concrete and the higher the strength.

3 Experimental study

This test was carried out in the on-site laboratory on the base of Yanliang-Airport Intercity Railway Project–Jinghe Extra Large Bridge Project. The concrete marks selected in the test were C40 pier concrete and C60 beam concrete of Jinghe Bridge. The concrete mix ratio was designed according to the construction standard of railway concrete. The effects of mixing time on the mechanical properties and durability of concrete under different mixing ways were verified by a series of tests on a testing machine.

3.1 Raw materials

The raw materials selected during the test are the same as those used in the actual production of the project.

3.1.1 Cement

C40 uses P·O 42.5 (low alkali) Portland cement produced by Jidong Development Jingyang Building Materials Co., Ltd, and C60 for P·O 52.5 (low alkali) Portland cement produced by Shaanxi Shengwei Building Materials Group Co., Ltd. The physical and mechanical properties of cement are shown in Table 1.

3.1.2 Fine aggregate

C40 concrete fine aggregate uses natural sand from Wugong County Jintiesha Stone Factory which is medium sand with a fineness modulus of 2.8. C60 concrete adopts the middle sand of Yangxian Jinding Mining Development Co., Ltd with a fineness modulus of 2.8.

3.1.3 Coarse aggregate

C40 concrete coarse aggregate adopts continuous graded coarse aggregate with nominal diameter of 5–10 mm,

Table 1: Physical properties of cement

Cement specifications	Standard consistency water consumption/%	Specific surface area/ (m^2/kg)	Density/ (g/cm^3)	Initial setting time/min	Final setting time/min	Stability	Breaking strength		Compressive strength	
							3 day	28 day	3 day	28 day
42.5	28.0	328	3.01	193	294	Qualified	5.3		28.0	
52.5	28.6	339	3.01	158	212	1.0	5.5	9.4	30.7	63

Table 2: Main technical indexes of fly ash

Serial number	Test items	Technical requirements		Test index	
		Grade I	Grade II	Grade I	Grade II
1	Fitness/%	≤12.0%	≤25.0%	3.80	23.10
2	Water demand ratio/%	≤95.0%	≤105.0%	93.00	99.00
3	Loss on ignition/%	≤5.0%	≤8.0%	1.44	4.74
4	Free calcium oxide content/%	≤1.0%	≤1.0%	0.78	0.78

10–20 mm, and 16–31.5 mm produced by Jidong Development Jingyang Building Material Co., and C60 concrete is 5–10 mm, 10–20 mm continuously graded crushed stone produced by Xixia Jinhui Building Materials Co., Ltd.

3.1.4 Fly ash

C40 concrete uses Class II fly ash produced by Weihe Thermal Power Plant of Datang Shaanxi Power Generation Co. Ltd., and C60 concrete uses Grade I fly ash from Shaanxi Zhengyuan Fly Ash Comprehensive Utilization Co., Ltd. The main technical indicators of fly ash are shown in Table 2.

3.1.5 Mineral powder

C60 concrete uses S95 fly ash produced by Hancheng Leiyong Powder Co., Ltd.

3.1.6 Water-reducing agent

All water-reducing agents adopt ART-001 retarding type water-reducing agent produced by Shanxi Aorite Building Material Technology Co., Ltd. Its main performance indicators are shown in Table 3.

3.2 Mix ratio design

The mix ratio of this test is designed according to the railway concrete construction standard. The specific mix ratio is shown in Tables 4 and 5.

3.3 Testing program

The test is divided into two groups according to the mixing method. QZ group is conventional mixing, and ZD group is vibration mixing. The mixing parameters of the two groups of tests are the same except for the mixing time.

According to the stipulation of "Concrete Structure Engineering Construction Code" (GB50666-2017) [20] requesting the minimum time for concrete mixing (60 s), the mixing time is taken in this test to be five levels: 60, 75, 90, 105, and 120 s. In this test, the one-time feeding method was adopted as the sequence of fine aggregate-cement-fly ash-coarse aggregate, and water and water reducer were added at the end. The dry mixing time was stipulated for 30 s [21].

For each group of tests, a 150 m × 150 × 150 mm standard cube test block and a round cake with a diameter of 100 mm × 50 mm were made of fresh concrete

Table 3: Main performance indexes of water reducing agents

Serial number	Test items	Skills requirement		Detection indicator	
		C40	C60	C40	C60
1	Water reduction rate/%	≥20.0%	≥25.0%	28.0	34.0
2	Air content/%	≤3.0%	≤3.0%	2.6	2.6
3	Air content change over time in 1 h/%	—	0.5	−0.2	
4	Bleeding ratio/%	≤20%	0	0	
5	Pressure bleeding ratio/%	≤90%	54	47	
6	Slump change over time in 1 h/mm	≤60%	20	35	
7	7 day compressive strength ratio/%	≥125%	≥140%	158	147

Table 4: C40 concrete mix proportion and material dosage (kg/m^3)

Materials	Cement	Fly ash	Fine aggregate	Coarse aggregate			Water	Water reducing agent
				5–10	10–20	16–31.5		
Dosage/m^3	293	126	686	217	543	325	155	4.19

Table 5: C60 concrete mix proportion and material dosage (kg/m^3)

Materials	Cement	Fly ash	Fine aggregate	Mineral powder	Coarse aggregate		Water	Water reducing agent
					5–10	10–20		
Dosage/m^3	400	50	50	667	356	830	140	7.50

mixed at different mixing times. Each group needs to make three blocks. After curing in the standard curing room for a certain age, the compressive strength of the cube test block in 3, 7, 28, and 56 days is tested. After curing the round cake test block for 56 days, the electric flux is tested after treating the test block according to the measurement procedure. The standard of electric flux is shown in Table 6.

3.4 Testing equipment

The mixing equipment used in this test is a Detong double horizontal shaft vibration mixer (DT60ZBW). The mixer can realize two kinds of mixing methods: conventional mixing (without vibration) and vibration mixing (with vibration) [23]. The internal schematic diagram of the mixing host is shown in Figure 4.

4 Results and discussion

4.1 Effect of mixing time on compressive strength of concrete

The homogeneity of fresh concrete can affect the internal structure of hardened concrete, thus directly affecting the compressive strength and durability of hardened concrete. The length of mixing time plays a decisive role in whether the mixture can achieve macroscopic and microscopic homogeneity. The mixing time is too short, the cement particles can only reach the macroscopic homogeneity; there still exists the agglomeration phenomenon on the microscopic level, and the aggregate cannot be fully wrapped by the fine aggregate and the cement product. However, Yunshi et al. [24] conducted a vibration mixing experiment on high performance concrete. The results show that when the stirring time is 160 s, compared with the stirring time of 120 s, the compressive strength at 3, 7, and 28 days decreased by 1.4, 9.8, and 4.7%. Therefore the mixing time is too long, it will produce segregation phenomenon and reduce the quality of the fresh concrete. Lifang et al. [25] believed that the excessively long mixing time would affect the concrete intensity and strength uniformity are unfavorable, it is advantageous to choose a suitable mixing time to improve the homogeneity of concrete. And research by Hou Yunfen and others also showed that the mixing time is too short, the cementitious material in the concrete mixture is unevenly dispersed, and the concrete strength is low [3].

Therefore, the appropriate mixing time directly affects the compressive strength of concrete. The compressive strengths results of 3, 7, 28, and 56 day of concrete standard test blocks with 60, 75, 90, 105, and 120 s mixing time under different mixing methods are shown in Figure 5,

Table 6: Concrete electric flux evaluation index [22]

Electric flux/C	>4,000	2,000–4,000	1,000–2,000	500–1,000	<500
Recommendations on durability levels	Poor	Poorer	Better	Good	Very good

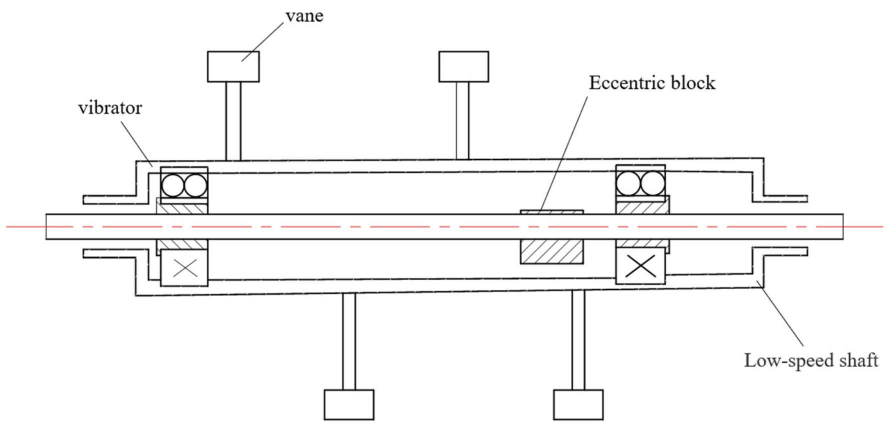


Figure 4: Diagram of mixer.

where QZ means conventional mixing and ZD means vibration mixing.

It can be seen from Figure 5 (a) and (b) variation trend of strength at each age that, within the time range studied in this paper, the compressive strength of concrete changes significantly under different mixing times.

With the increase of the mixing time, the compressive strength of each age of concrete in forced mixing mode shows a gradual increase trend; for C40 concrete, the compressive strength of each age with vibratory mixing has a peak value where the mixing time corresponds to the compressive strength value is called the peak time. When the mixing time exceeds the peak time of 105 s, the compressive strength of each age will show a downward trend. Yang [22] proved that the compressive strength of machine-made sand concrete increased first and then decreased with the increase of mixing time in the research on optimization of working parameters of machine-made sand concrete vibration mixing. For C60, the compressive strength of each age increases gradually with the increase of mixing time, and there is no obvious peak of compressive strength. The reason is that high-performance concrete is more difficult to mix evenly than ordinary concrete, and it takes more mixing time to mix evenly [23]. With the increase of mixing time, the early strength of vibrating mixing concrete was obviously improved. The compressive strength of concrete increased with the age increase trend under the two mixing methods. It is worth noting that, whether it is C40 or C60 concrete, the compressive strength value of concrete at each age of vibration mixing is significantly higher than that of conventional mixing concrete.

The strength increase rates of vibration mixing compared with that of forced mixing in different time periods were analyzed. For C40 concrete, the maximum strength increase rates of vibration mixing were 9% (3 day), 5.7% (7 day), 6.1% (7 day), 9.8% (3 day), and 5.9% (7 day) when the mixing time was 60, 75, 90, 105, and 120 s, respectively. From the results of concrete strength of each age, the strength improvement rate of vibration-

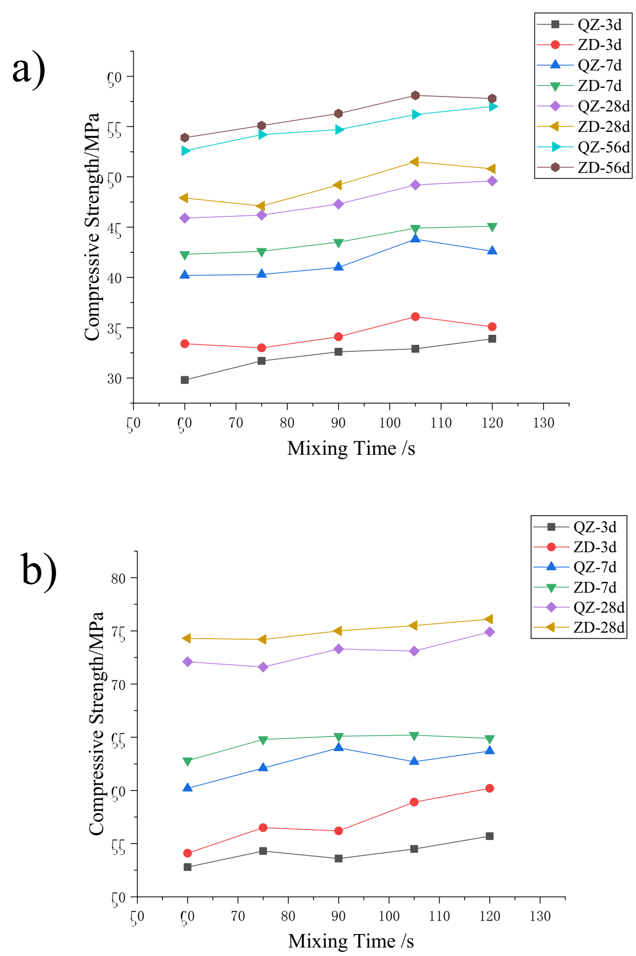


Figure 5: Concrete strength changes with mixing time. (a) C40 concrete compressive strength with time and (b) C60 compressive strength change curve with time.

mixed C40 concrete is between 5 and 10% at most, the early strength increase rate of vibration-mixed concrete is relatively higher, and the most obvious increase ages are generally concentrated in the early strength of 3 and 7 day, and the concrete strength improvement slowed down with the increase of age.

For C60 concrete, when the mixing time of C60 concrete was 60, 75, 90, 105, and 120 s, the highest increase rate of compressive strength of vibration mixing is up to 4.4% (7 day), 4.2% (7 day), 4.9% (3 day), 8.1% (3 day), and 8.1% (3 day), respectively. From the results of concrete strength of each age, the strength improvement rate of vibration mixing C60 concrete is up to about 8%, and C60 concrete has a higher rate of early strength improvement under the same condition of vibration mixing, which is consistent with the trend of compressive strength of C40. Jiansheng [26] and others confirmed that the strength of concrete with different mix ratios of vibration mixing is generally more than 10% higher than that of traditional forced mixing. The strength increase rate obtained by the two tests is roughly equal.

A point worth noting is that the strength increase rate of C40 concrete with vibratory mixing increased most significantly at 105 s but not at 120 s, Compared to the conventional mixing for 120 s, the strength increase rate of vibratory mixing at 105 s on 3, 7, 28, and 56 day were 6.5, 5.9, 3.9, and 2.0%, respectively. It is indicated that vibratory mixing can reduced the mixing time without decreasing the strength, but increasing the strength. This is because during forced mixing, there is still agglomeration of cement particles existed. Vibration can exert vibration energy on material particles, which is more conducive to material diffusion, thereby destroying agglomeration and making cement hydration reaction more sufficient. At the same time, the dispersion of the agglomerated cement is equivalent to the addition of more cementitious materials, thus plays a role in reducing the water-binder ratio and further enhancing the strength of concrete.

Compared with C40 concrete the strength improvement rate of C60 concrete with, vibratory mixing is not too obvious. The reason is that, with the decrease of the water-binder ratio, the amount of C60 concrete cementing material increases. The amount of C60 concrete used in this paper reaches 500 kg/m^3.

Therefore, the sufficient amount of cement allows cement mortar to fully wrap coarse aggregate and fill in the void structure of concrete, although vibration mixing improves the strength of concrete to a certain extent, the effect of vibration mixing on the strength of C60 concrete is not obvious due to the sufficient amount of cementing material.

The compressive strength test standard is the average strength $\bar{R}$, standard deviation σ, and dispersion coefficient C_v. The calculation formula is as follows:

$$\bar{R} = \frac{1}{n}\sum_{i=1}^{n} R_i, \tag{1}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(R_1 - \bar{R})^2}{n-1}}, \tag{2}$$

$$C_v = \frac{\sigma}{\bar{R}}. \tag{3}$$

In the formula: n – the number of groups of concrete time; R_i – compressive strength of the i group of specimens, MPa; the $\bar{R}$ value represents the overall level of concrete strength.

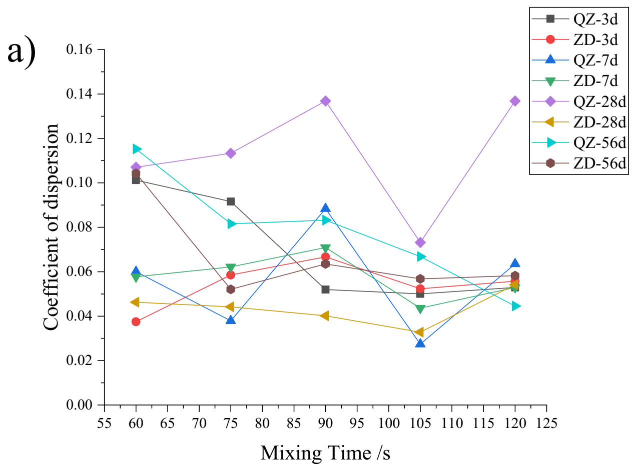
When $\bar{R}$ is higher, σ and C_v are smaller, and the concrete quality is better. As can be seen from Figure 6, for C40 concrete, when the age of 3, 7, 28, 56 day forced mixing and 7, 28 day vibration mixing, the mixing time is 105 s when the dispersion coefficient is low, concrete. The quality is better. For C60 concrete, when the age is 3, 7 day forced mixing and 3, 7, 28 day vibratory mixing, the dispersion coefficient is lower when the mixing time is 105 and 120 s. In summary, it is preliminarily determined that C40 is compressive. The optimal stirring time under high intensity is 105 s, and the optimal stirring time under C60 compressive strength is 120 s.

In different mixing time periods, concrete strength changes are different. The strength changes of concrete in different mixing time periods with the change of mixing time are summarized in the same Figure 7.

Make a contrastive analysis of the concrete strength variation rates under different mixing methods as shown in Figure 6(a)–(d), we can know:

The change rate of 7 and 28 day compressive strength of C40 concrete with forced mixing is relatively stable, and the fluctuation of other stages is relatively large. The strength of C40 concrete has achieved rapid growth in 90–105 s. The strength change rate of vibrating mixing C40 concrete is stable in each time period, and it is in a stable state of improvement. The strength of concrete increases rapidly in the stage of 75–90 s.

The rate of change of compressive strength of C60 concrete subjected to forced mixing fluctuates greatly. The two stages of rapid strength growth are 60–75 s and 105–120 s, respectively, and the increase amplitude of the former is higher than that of the latter. The compressive strength of vibration mixing C60 concrete is in a more stable state of increase, and the compressive strength of C60 concrete is growing rapidly in the two stages of



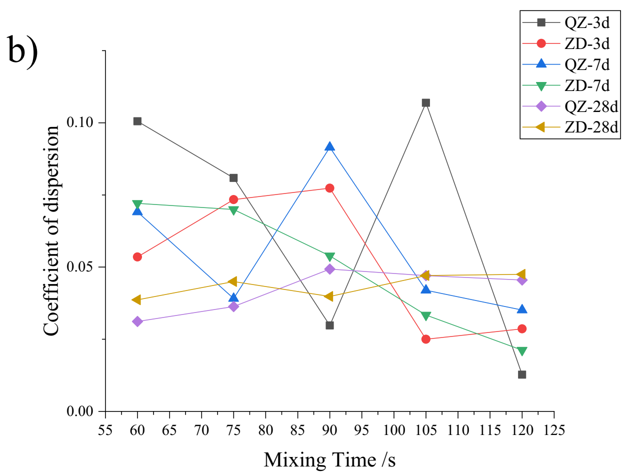


Figure 6: The influence of age and mixing time on the dispersion coefficient of concrete compressive strength: (a) C40 dispersion coefficient variation curve with time and (b) C60 dispersion coefficient variation curve with time.

60–75 s and 90–105 s, and the increase of the former is higher than that of the latter.

Due to the vibration strengthening effect, the position migration and exchange frequency of materials are accelerated, and the cement hydration reaction is accelerated. Xiong et al. [27] also confirmed this in preparation of high strength lightweight aggregate concrete with the vibration mixing process. Chaoyang [28] studied the effect of vibration mixing on the strength of concrete. The results show that vibration mixing can significantly accelerate and promote the hydration reaction of cement, making the concrete test block more compact, thereby increasing the strength of concrete. It is shown that the rapid growth stage of the strength of the vibration mixing concrete is earlier than forced mixing. which is reflected from the strength growth rate that the concrete strength increases faster than that of forced stirred concrete.

From the above analysis, it is known that vibratory mixing can increase the compressive strength of all ages and accelerate cement hydration. The main reason is that the mixture particles have a certain amount of energy under the action of vibration and flutter. And then making the sticky connection between materials is not very easy, the agglomerated particles change from the agglomerate state to the uniformly dispersed state, which creates conditions for the cement hydration reaction and hydration reaction more fully, thus it creates favorable conditions for increasing compressive strength of hardened concrete.

4.2 Influence of mixing time on concrete durability

From Figure 8(a) and (b) C40, C60 concrete electric flux change trend, with the extension of the mixing time, the concrete electric flux value showed a decreasing trend, Under the forced mixing mode, the electric flux of C40 and C60 concrete at 120 s is decreased by 31 and 22.6% respectively, in comparison with that at 60 s. Under the vibration mixing mode, the electric flux of C40 and C60 concrete at 120 s is decreased by 24.9 and 22.4%, respectively, comparing with that of 60 s, It illustrates that within a certain range prolonging the mixing time can effectively improve the durability of concrete.

It can be seen from Figure 8(c) that the electric flux value of vibrating mixing concrete in each mixing time is significantly lower than that of forced mixing concrete, and the change rate is generally above 10%. For C40 concrete, the maximum rate of change of electric flux was 17.4 and 13.4% at 60s and 105 s. For C60 concrete, the maximum rate of change of electric flux at 90 and 105 is 15.6 and 14.1%, and the electric flux of vibrating mixing concrete remained stable after 105 s. Yang [22] proved that the mixing time is not uniform when the mixing time is short, and the concrete test block after hardening has poor density and weak resistance to ion erosion. When the mixing time is appropriately increased, the electric flux has been significantly reduced. With a very significant decrease, the concrete is relatively uniform in both the micro and macro perspectives. Continue to increase the mixing time, the electric flux will increase, and excessive mixing will cause the concrete to separate and layer, and the test block's ability to resist ion erosion becomes weak.

Comparing the electric flux of C40 concrete with vibration mixing for 105 s and forced mixing for 120 s.

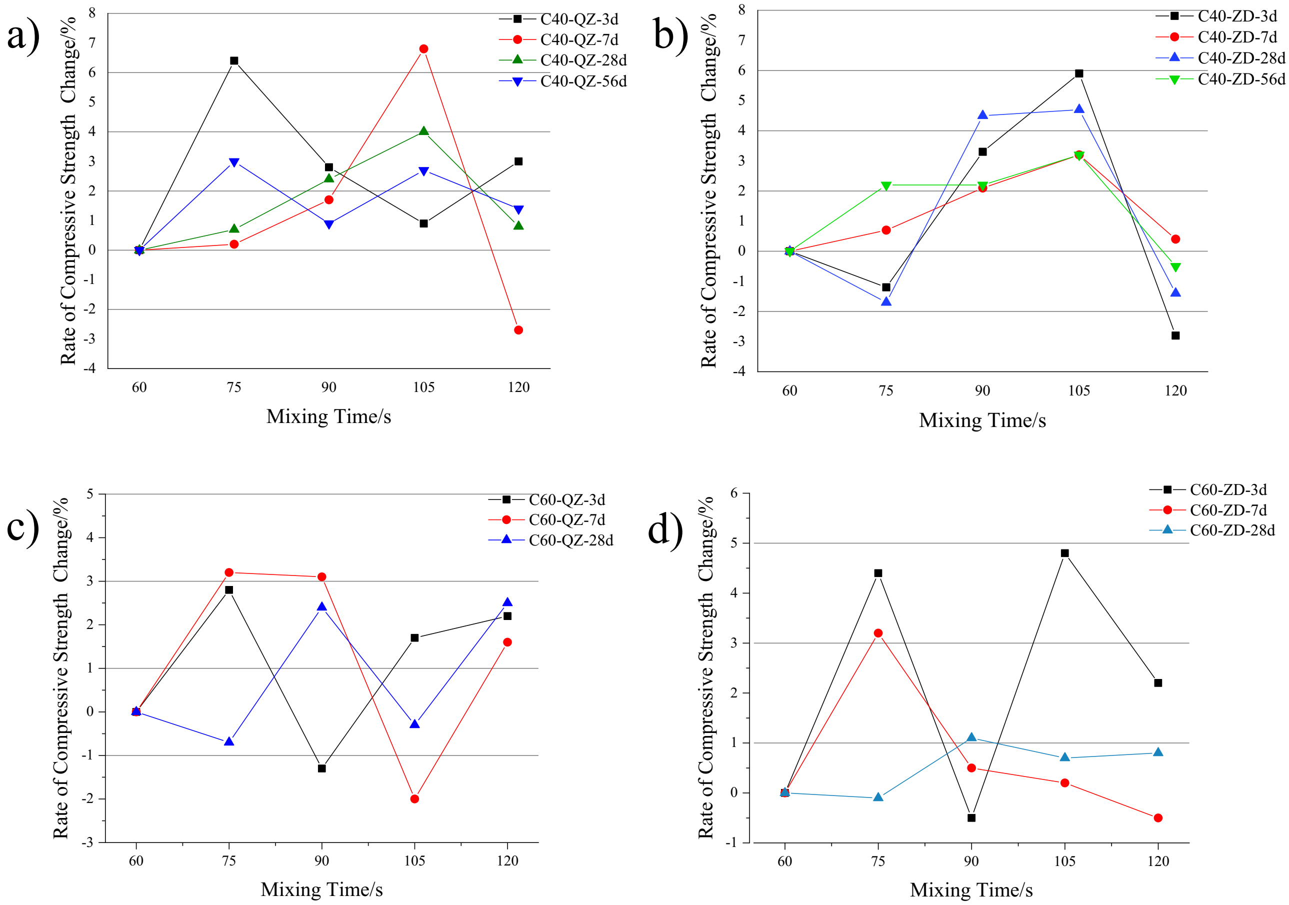


Figure 7: The change rate of concrete strength. (a) Forced mixing C40 concrete strength change rate. (b) Vibrating mixing C40 concrete strength change rate. (c) Forced mixing C60 concrete strength change rate. (d) Vibration mixing C60 concrete strength change rate.

The increase rate of vibration mixing durability was 9.0%. Comparing the electric flux of C60 concrete with vibration mixing for 120 s and forced mixing for 120 s, the increase rate of vibration mixing durability was 11.1%. Vibration mixing can effectively improve the durability of concrete, the analysis of reasons are as follows: vibration has a certain air entrainment effect. Vibration can destroy the water film on the surface of the aggregate to eby allow more air to enter the concrete, and at the same time, the high-frequency vibration can damage the big air bubbles inside the concrete that can reduce the number of large pores and optimize the pore structure to effectively improve the interface transition zone on the micro-level, make the interface bond tightly and reduce micro-cracks and pores. This is reflected in the improvement of concrete durability. Changhui [29] has carried out a study on the influence of vibration mixing parameters on the air content of concrete, and the results show that when the vibration parameters are selected appropriately, the air content of fresh concrete generally reaches about 3.5%, which is higher than that of ordinary mixed concrete, and is close to the range of air content generally required for air-entrained concrete (3 to 6%). And, the strength is generally higher than that of ordinary mixed concrete. This shows that vibration mixing can not only improve the air content and distribution of concrete but also increase the strength of concrete.

It is known from the above analysis that the electric flux of concrete under vibration mixing is smaller than that of conventional mixing. The main reason is that the particles of cementitious materials in concrete are evenly dispersed under vibration and mixing, and the cement hydration reaction is complete and rapid. At the same time, the number of capillary holes is sharply reduced and the number of micro-capillary holes is increased due to the vibration, thus reducing the possibility of free water molecules remaining in concrete space. During the curing of the specimen, the excess water inside the concrete is inevitably evaporated. If there are few free water molecules, it is not easy to form a water loss channel,

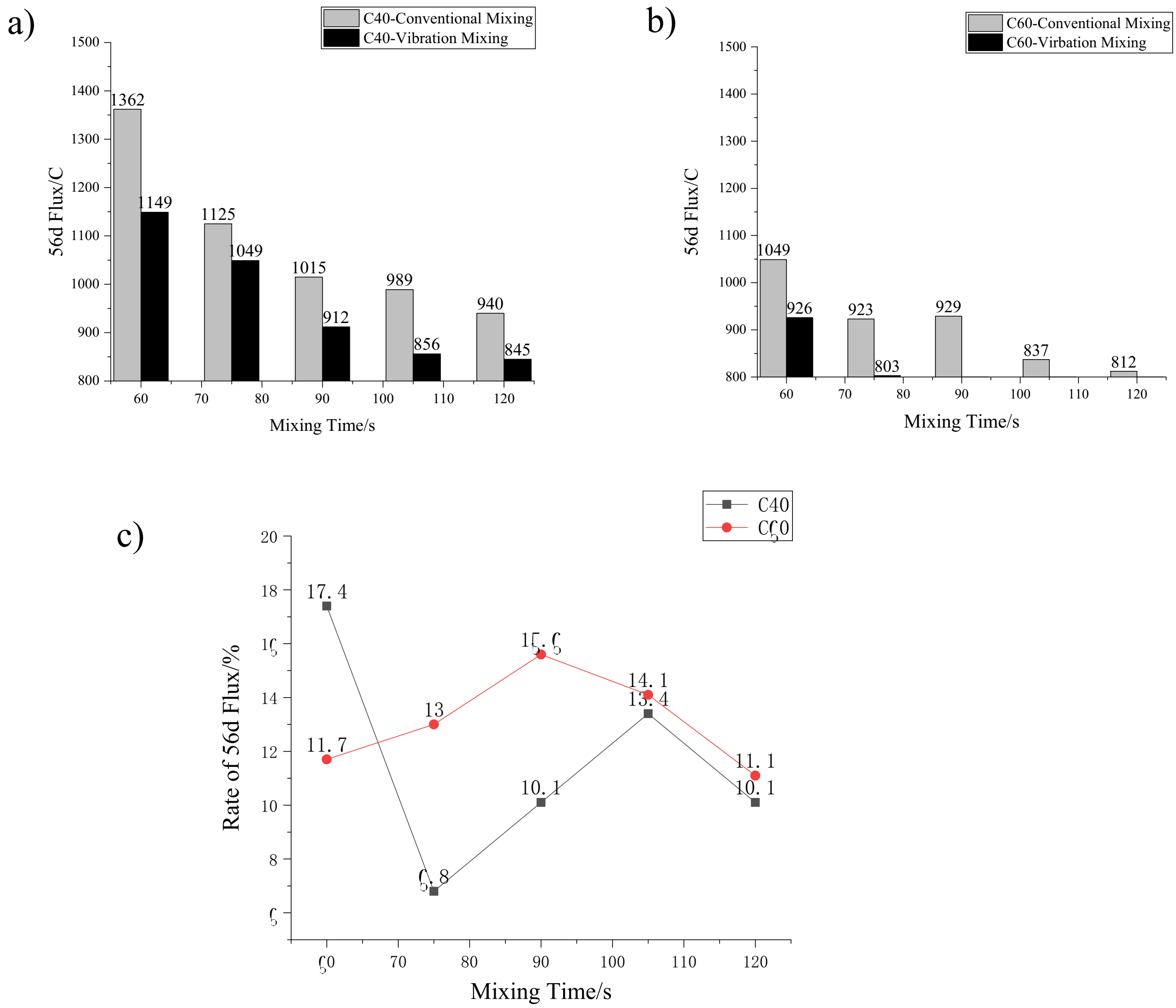


Figure 8: Comparison of the variation trend of electric flux between the two mixing modes. (a) Change trend of the electric flux of C40 concrete. (b) Change trend of C60 concrete electric flux. (c) Rate of change of concrete electric flux compared to conventional mixing.

which effectively improves the anti-permeability of the concrete and the durability of the concrete.

5 Concrete industry machine test

Power function fitting is performed on the intensity of 3, 7, 28, and 56 days, expressed by the formula as

$$y = ax^b,$$

as reported in Figures 9 and 10. The above equation is an exponential function, where b is exponential and a is the coefficient. In the formula, x represents age and y represents concrete strength that changes with age. The specific values of a, b parameters in each curve after nonlinear curve fitting are shown in Figure 9. It can be seen from Figures 9 and 10 that the strength of vibratory mixing concrete at each age is significantly higher than that of forced mixing concrete. In the Jinghe Extra Large Bridge Project, the forced mixing takes 120 s mixing time. Therefore, in the following analysis, the strength of the vibrating mixing concrete is compared based on the strength of the forced mixing 120 s. Figure 11 shows the piers and bridges made in the Jinghe Bridge Project.

It can be seen from Figures 9(a) and (b) that the strength of C40 and C60 concrete increases with the increase of age under forced mixing and vibration mixing. The strength of C40 forced mixing for 120 s is lower than that of vibration mixing for 75 s and vibration mixing for 90 s. The intensity of 90 s mixing is higher than that of vibratory mixing for 75 s; the intensity of C60 forced

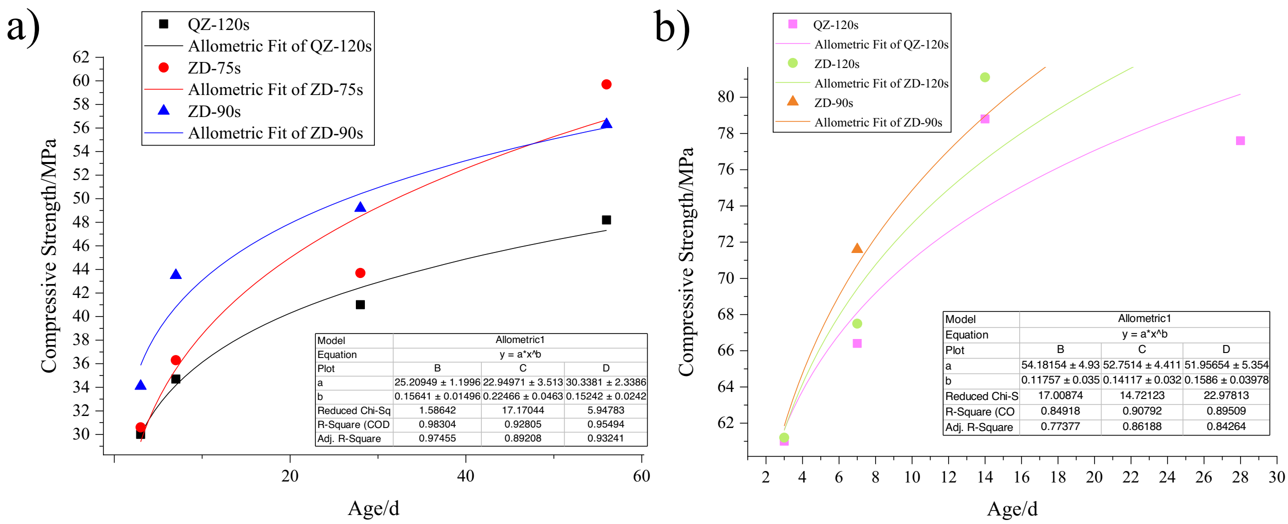


Figure 9: Concrete strength changes with age. (a) C40 concrete compressive strength with age. (b) C60 concrete compressive strength with age.

mixing for 120 s is lower than that of vibratory mixing for 120 s and vibratory mixing for 90 s, and the intensity of vibratory mixing for 90 s is slightly higher than that of vibratory mixing for 120 s. It can be seen that the strength of C40 and C60 concrete in practical engineering applications basically reaches the highest value when vibrated for 90 s. This proves that the above-mentioned vibration mixing can shorten the mixing time and improve the mixing efficiency without damaging the strength.

Analyzing the results of the strength change rate of C40 concrete through Figure 10(a), the strength change rate of the forced mixing 120 s concrete is relatively stable, and the 7 day strength change rate fluctuates greatly, and the strength increases by 15.7%; the vibration mixing 75 s concrete strength change rate is in a stable state of improvement, The strength achieved rapid growth in the 7 and 56 day stages; the vibratory mixing 90 s concrete strength was in the rapid growth stage at 7 day, but the growth rate was lower than the former two at 28 and 56 day.

Analyzing the results of C60 concrete strength change rate through Figure 10(b), the strength change rate of forced mixing and vibration mixing concrete showed a downward trend at 28 and 56 day, and the vibration 120 s and forced 120 s concrete were in a relatively stable increase state from the age to 28 day. The strength of

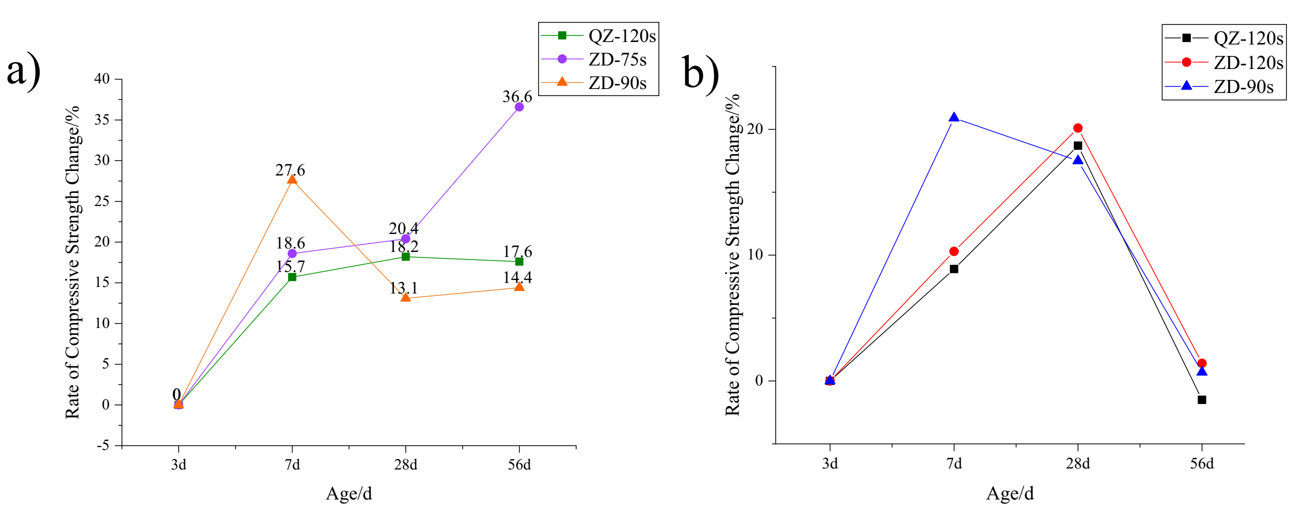


Figure 10: The change rate of concrete strength. (a) C40 concrete strength change rate. (b) C60 concrete strength change rate compared to the 3 day.

Figure 11: The piers and bridges.

vibrated 90 s concrete was in a rapid growth stage at 7 day, and the strength increased by 20.9%, which was significantly higher than the concrete strength of vibrated 120 s and forced 120 s.

6 Conclusions

1. Under the same mixing time, the compressive strength of concrete of all ages under vibration mixing mode is significantly higher than that of conventional mixing mode. In addition, the early strength of concrete is significantly improved under the vibration mixing method, mainly showed in the early 3 and 7 day compressive strength, C40 strength increase rate was between 5–10% at the highest, C60 concrete strength increase rate was around 8%.
2. The compressive strength of the vibratory mixing method at the mixing time of 105 s is significantly higher than that of the conventional mixing concrete at 120 s. Under the condition of ensuring the mechanical properties of concrete, the vibration mixing mode can reduce the mixing time by at least 15 s.
3. Under vibration mixing mode, the strength curve of each age of C40 concrete peaks in the mixing time of 105 s, the period of rapid strength growth is 75–90 s, which is 15 s ahead of the forced mixing. The strength increase rate of concrete is relatively stable under vibration mixing mode.
4. The vibration mixing mode can reduce the electric flux of concrete. Compared with the forced mixing for 120 s, the durability of C40 and C60 concrete is improved by 11.8 and 11.1%, respectively, under vibration mixing mode when they are mixed for 105 s. Under the same mixing mode and the same mixing method, extending the mixing time within a certain range can improve the durability of concrete.

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