

【DESCRIPTION】**【Invention Title】**

METHOD FOR OPTIMIZING STRENGTH DEVELOPMENT OF ULTRA-HIGH STRENGTH CONCRETE

5 **【Technical Field】**

The present invention relates to methods for optimizing strength development of ultra-high strength concrete, and more particularly, to methods for optimizing strength development of ultra-high strength concrete that are capable
10 of optimizing the strength development of the ultra-high strength concrete in the same mixture design with the same mixing materials as each other.

【Background Art】

With the popularity of super high-rise buildings,
15 recently, much interest in ultra-high strength concrete has been increased. Through the application of the ultra-high strength concrete, the sections of elements like columns, beams and so on can be reduced to decrease the frame costs, and furthermore, a substantially large internal space is
20 ensured to provide efficient space utilization.

The ultra-high strength concrete means hardened concrete from which the development of the compressive strength of more than 120MPa is obtained. The ultra-high strength concrete is made by adopting cement, silica fume,
25 blast furnace slag fine powder, fly ash, and gypsum as binders and mixing the materials with a low water-binder ratio. Recently, the mixture design of extremely high strength concrete with the compressive strength of 200MPa has been proposed.

30 On the other hand, since the ultra-high strength concrete has a low water-binder ratio, the mixing materials are not mixed well, and thus, the concrete does not obtain

the compressive strength development as designed. Even though the mixing is conducted to have a given designed strength, it is hard to mix the mixing materials, which causes the development of the strength lower than the given
5 designed strength thereof. In the same manner, also, the 200MPa ultra-high strength concrete with an extremely low water-binder ratio has the development of the strength lower than the given designed strength thereof.

【Disclosure】

10 **【Technical Problem】**

Accordingly, the present invention has been made in view of the above-mentioned problems occurring in the prior art, and it is an object of the present invention to provide methods for optimizing strength development of ultra-high
15 strength concrete that are capable of improving the problems in the strength development of the ultra-high strength concrete with a low water-binder ratio in conventional practices, thereby optimizing the strength development of the ultra-high strength concrete in the same mixture design with
20 the same mixing materials as each other.

【Technical Solution】

To accomplish the above object, according to a first aspect of the present invention, there is provided a method for optimizing strength development of ultra-high strength
25 concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that the mixture design of
30 the ultra-high strength concrete is conducted with a slump flow of 850 ± 50 mm.

To accomplish the above object, according to a second aspect of the present invention, there is provided a method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that the mixture design of the ultra-high strength concrete is conducted with an air content between 1.0% and 2.0%.

To accomplish the above object, according to a third aspect of the present invention, there is provided a method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that dry-mixing of the gravels and the silica fume is conducted for 20 to 40 seconds in the mixing process of the ultra-high strength concrete, and mixing of the other mixing materials is conducted.

To accomplish the above object, according to a fourth aspect of the present invention, there is provided a method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that final mixing of the water is conducted for 150 to 200 seconds in the mixing process of the ultra-high strength concrete, and after conducting a stationing operation where the mixing operation

stops for 200 to 400 seconds, mixing is conducted for 150 to 200 seconds.

To accomplish the above object, according to a fifth aspect of the present invention, there is provided a method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that self-compacting casting of the ultra-high strength concrete is conducted.

To accomplish the above object, according to a sixth aspect of the present invention, there is provided a method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that wet-curing is conducted for 14 to 28 days after the casting of the ultra-high strength concrete and air dry-curing is then conducted.

【Advantageous Effect】

According to the present invention, there are provided the methods for optimizing strength development of ultra-high strength concrete having the following advantages.

First, the strength development of the ultra-high strength concrete can be optimized in the same mixture design with the same mixing materials as each other, through appropriate methods, that is, the mixing method, the adding order of the mixing materials, the casting method, and the curing method, which are simple and advantageously applicable to the construction site.

Second, the strength development of the ultra-high strength concrete can be optimized so that if an ultra-high strength concrete building is constructed with the ultra-high strength concrete according to the present invention, a high degree of stability of the building can be expected through the optimization of the strength development thereof.

【Description of Drawings】

FIG.1 is a graph showing the compressive strength properties of ultra-high strength concrete in accordance with slump flows.

FIG.2 is a graph showing the compressive strength properties of the ultra-high strength concrete in accordance with air contents.

【Best Mode for Invention】

The present invention proposes six methods for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less.

In the following embodiment, it was checked that the compressive strengths of the ultra-high strength concrete according to the six methods were improved. Through the six methods, therefore, it is understood that the strength development of the ultra-high strength concrete can be optimized, and further, if the six methods are applied at the same time, the strength development thereof can be more increased. Especially, the six methods are advantageously applicable in case of extremely high strength concrete of more than 200MPa.

(1) Previous dry-mixing

Before mixing materials are mixed in a concrete mixer, gravels and silica fume are first put and dry-mixed for 20 to 40 seconds, and the other mixing materials are then mixed to the mixed materials. This allows the silica fume to be
5 evenly distributed and coated on the surfaces of the gravels to increase the pozzolanic reaction of a transition zone (the boundary surface between cement and gravels), thereby improving the attachment capability between the gravels and the cement paste. Through the dry-mixing results for 30
10 seconds according to the embodiment of the present invention, it was found that the compressive strength of the ultra-high strength concrete was increased.

(2) Stationing

When water is finally mixed after the other mixing
15 materials have been dry-mixed in the concrete mixer, the mixing operation is conducted for 150 to 200 seconds, and next, a stationing operation where the mixing operation stops for 200 to 400 seconds is conducted. After that, the mixing operation is conducted again for 150 to 200 seconds, and the
20 mixed materials are discharged from the concrete mixer. This allows the initial hydration reaction to be accelerated and improves the compacting capability of concrete. Through the stationing operation according to the embodiment of the present invention, it was found that the compressive strength
25 of the ultra-high strength concrete was increased.

(3) Slump flow control

The slump flow of the ultra-high strength concrete has a close relation with the strength. That is, the higher the slump flow is, the higher the compacting property of the
30 ultra-high strength concrete is advantageously. Accordingly, the slump flow of $850\pm50\text{mm}$ is provided in the embodiment of the present invention. If the slump flow is less than

850±50mm, the compacting property is deteriorated to cause the compressive strength to be lowered, and contrarily, if it is over 850±50mm, the separation of the mixed materials may occur. After checking the relation between the slump flow and the strength in the mixing process of the ultra-high strength concrete with a compressive strength of 200MPa in the embodiment of the present invention, it was found that the highest strength development occurred with the slump flow of 850±50mm. On the other hand, the slump flow is controllable by means of appropriate adjustment of amounts of various chemical agents (water reducing agent, flowing agent and so on) added, which give no influence on the mixture design of the concrete.

(4) Air content control

The air content is controlled 2.0% and less. The air content is inversely proportional to the strength, so that the smaller the air content is, the higher the strength of the ultra-high strength concrete is advantageously. After checking the relation between the air content and the strength in the mixing process of the ultra-high strength concrete with a compressive strength of 200MPa in the embodiment of the present invention, it was found that the development of compressive strength was optimized in the air content of 2.0% and less. On the other hand, the air content is controllable by means of appropriate adjustment of amounts of various chemical agents (foaming agent, antifoaming agent and so on) added, which give no influence on the mixture design of the concrete.

(5) Self-compacting casting

If the fluidity of concrete is good, self-compacting casting is conducted. In case where vibration compacting is performed by using a vibrator, material segregation or air

content increment occurs to cause the strength reduction. It was in the embodiment of the present invention found that the strength development in the self-compacting casting is better than that in the vibration compacting casting. Especially, if the slump flow of $850\pm 50\text{mm}$ is provided, good fluidity is made to allow the self-compacting casting to be conducted.

(6) Wet curing

After casting, the ultra-high strength concrete is wet-cured for 14 to 28 days and then air-dried. If the water inside the ultra-high strength concrete is dried due to the low water-binder ratio, an amount of water needed for hydration reaction may be insufficient. Therefore, there is a need for preventing the water inside the concrete from being evaporated at the time when the hydration reaction occurs actively, and in the embodiment of the present invention, the ultra-high strength concrete is wet-cured for 14 to 28 days after casting. If the wet curing is kept longer than the proposed period of the present invention, however, the strength may be decreased, and accordingly, the wet curing for 14 to 28 days is most preferable.

【Mode for Invention】

Hereinafter, the strength properties of the ultra-high strength concrete according to the methods of the present invention will be explained. In this case, however, the embodiment as will be described below just explains the present invention, and the scope of the invention is not defined thereby.

[Embodiment] Strength properties of ultra-high strength concrete according to the methods of the invention

1. Experiment method

The influences on the compressive strength by experimental variable were checked with the same mixing ratio

of 200MPa ultra-high strength concrete in the following Table 1. The experiments were performed in the state where the other conditions except the respective experimental variables were the same as each other.

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Table 1

Ultra-high strength concrete mixing

W/B	S/a	Unit Weight (kg/m ³)						
		W	OPC	Silica Fume	Blast Furnace Slag	Gypsum	Sand	Gravel
12.5%	35%	150	660	240	240	60	392	736

10 2. Experiment result

(1) Strength properties of ultra-high strength concrete in accordance with mixing condition

The strength properties of ultra-high strength concrete in accordance with mixing condition were obtained as listed in Table 2. As listed, it was found that the compressive strength of the ultra-high strength concrete was improved if the gravels and the silica fume were first dry-mixed.

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Table 2

20 Strength properties of ultra-high strength concrete in accordance with mixing condition

Division	Compressive strength(MPa)		
	7 days of age	28 days of age	91 days of age
General dry-mixing	150.4	184.5	198.7
First dry-mixing of gravels and silica fume for 30 seconds	155.8	194.4	207.1

(2) Strength properties of ultra-high strength concrete in accordance with the existence of stationing

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The strength properties of ultra-high strength concrete in accordance with the existence of the stationing operation in the mixing of water were obtained as listed in Table 3. As listed, it was found that the compressive strength of the ultra-high strength concrete was improved if the stationing operation was conducted.

Table 3

Strength properties of ultra-high strength concrete in accordance with the existence of stationing

Division	Compressive strength (MPa)		
	7 days of age	28 days of age	91 days of age
No stationing	144.1	170.3	191.6
Mixing for 180 seconds and after stationing for 300 seconds, mixing for 180 seconds	147.3	174.9	197.1

(3) Strength properties of ultra-high strength concrete in accordance with slump flow

The estimation results of the ultra-high strength concrete in accordance with the variations of the slump flows were shown in FIG.1. As shown, it was found that the compressive strength of more than 200MPa was obtained at the slump flows between 800mm and 900mm and the compressive strengths of less than 200MPa at the slump flows of less than 800mm.

(4) Strength properties of ultra-high strength concrete in accordance with air content

The estimation results of the ultra-high strength concrete in accordance with the variations of the air content were shown in FIG.1. As shown, it was found that the compressive strength was drastically decreased as the air content exceeded 2%.

(5) Strength properties of ultra-high strength concrete in accordance with casting method

The strength properties of the ultra-high strength concrete in accordance with the casting method were obtained as listed in Table 4. As listed, it was found that the compressive strength of the ultra-high strength concrete was more improved at the self-compacting casting when compared with the vibration compacting casting.

Table 4

Strength properties of ultra-high strength concrete in accordance with casting method

Division	Compressive strength (MPa)		
	7days of age	28days of age	91days of age
Vibration compacting	150.8	178.0	192.5
Self-compacting	153.2	187.2	201.7

(6) Strength properties of ultra-high strength concrete in accordance with curing method

The strength properties of the ultra-high strength concrete in accordance with the curing method were obtained as listed in Table 5. As listed, it was found that the compressive strength of the ultra-high strength concrete was remarkably improved when the water curing was conducted for 14 days.

Table 5

Strength properties of ultra-high strength concrete in accordance with curing method

Water curing period	Compressive strength (MPa) of 91 days of age
Air dried	179.6

Water curing for 3 days	191.4
Water curing for 7 days	202.5
Water curing for 14 days	212.0
Water curing for 28 days	211.9
Water curing for 91 days	189.2

【CLAIMS】**【Claim 1】**

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that dry-mixing of the gravels and the silica fume is first conducted for 20 to 40 seconds and the other mixing materials are put and mixed.

【Claim 2】

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that the water is finally put and mixed for 150 to 200 seconds, and after a stationing operation where the mixing operation stops for 200 to 400 seconds is conducted, the mixing operation is conducted for 150 to 200 seconds.

【Claim 3】

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that the mixture design of the ultra-high strength concrete is conducted with a slump flow of 850 ± 50 mm.

【Claim 4】

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that the mixture design of the ultra-high strength concrete is conducted with an air content between 1.0% and 2.0%.

【Claim 5】

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that self-compacting casting of the ultra-high strength concrete is conducted.

【Claim 6】

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that after the casting of the ultra-high strength concrete, wet curing of the ultra-high strength concrete is conducted for 14 to 28 days and air dry curing is then conducted.

【Claim 7】

A method for optimizing strength development of ultra-high strength concrete with mixture design in which mixing materials including water, cement, silica fume, blast furnace slag, gypsum, sand, and gravels are mixed with compressive

strength of 120MPa or more and a low water-binder ratio of 20% and less, the method characterized in that two or more steps are selected from the following steps of:

conducting the mixture design of the ultra-high strength concrete with a slump flow of $850\pm 50\text{mm}$;

conducting the mixture design of the ultra-high strength concrete with an air content between 1.0% and 2.0%;

conducting first dry-mixing of the gravels and the silica fume for 20 to 40 seconds and conducting the putting and mixing of the other mixing materials in the mixing process of the ultra-high strength concrete;

conducting final mixing of the water for 150 to 200 seconds and after conducting a stationing operation where the mixing operation stops for 200 to 400 seconds, conducting the mixing for 150 to 200 seconds in the mixing process of the ultra-high strength concrete;

conducting self-compacting casting of the ultra-high strength concrete; and

conducting wet curing for 14 to 28 days after the casting of the ultra-high strength concrete and conducting air dry curing.

【Claim 8】

The method for optimizing strength development of ultra-high strength concrete according to any one of claims 1 to 7, wherein the mixture design of the ultra-high strength concrete has the compressive strength of more than 200MPa.