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Brief Analysis of Which Concrete Performance is Better under High-temperature Environments

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Abstract

With the deepening and development of research in the field of concrete both domestically and internationally, the performance of concrete in high temperature environments in China plays a leading role. In the past, people's understanding of the performance of concrete in high-temperature environments mostly focused on static mechanics, as static mechanics is the foundation of the entire concrete industry. In the current literature, there is a lot of important knowledge and information on how to improve the performance of concrete. This article reviews the relevant knowledge on improving concrete performance described in various literature, and analyzes what type of concrete performs better in high-temperature environments. They are interconnected, have their own uses, and promote and constrain each other, which is also why concrete is worth studying tirelessly by scholars both domestically and internationally.

Keywords

High Temperature; Concrete Performance; Water-cement Ratio; Silica Fume; Aggregate Size; Steel Fibre.

1. Introduction

(1) Concrete materials, due to their abundant raw materials, low prices, strong plasticity, and high mechanical properties, are widely used in various environments in various buildings, roads and bridges, and in the development of new industries. At the same time, they are gradually developing towards large-scale and high-rise buildings, and are applied in extreme special environments.

(2) Fires can cause high temperature damage to concrete structures at around 1000℃.Under the action of high temperature, a series of physical and chemical changes such as the expansion of coarse and fine aggregates and the dehydration and decomposition of colloids will occur inside the concrete, resulting in surface color changes, cracks, and even explosions. Moreover, due to the loss of water and the high-temperature decomposition of hydrated calcium silicate, the internal structure of the concrete has lost some of its adhesion, resulting in changes in the material and mechanical properties of the concrete.

1.1. Current Research Status at Home and Abroad

(1) In recent years, there has been more research on static mechanical properties compared to dynamic mechanical properties, and work has also focused on the dynamic compressive properties and strength of materials after high-temperature cooling. Previous researchers have studied steel fiber reinforced concrete materials, gradually leading to the development of high-performance and high adaptability in concrete. Through high-temperature dynamic compression performance tests of steel fiber reinforced concrete, it can be concluded that the high-temperature resistance of high-performance concrete has been improved significantly.

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There are many variation curves of concrete under different temperature environments in the literature, which can provide many references.

(2) Su,hongchao Li,chen and so on designed high-temperature dynamic loading equipment and explored the dynamic compression behavior of concrete materials under high temperature.

(3) Research deficiencies: At present, research in the field of ultra-high temperature is relatively scarce, and the ultra-high temperature environment that concrete is used in the vicinity of ultra-high temperature is extremely extreme. How to maintain the adhesion and various mechanical properties of concrete in ultra-high temperature environments is a very worthwhile aspect to study.

2. Factors Affecting the Performance of Concrete

2.1. Water Cement Ratio

At present, there are generally two methods for measuring the water cement ratio of concrete: one is to directly measure the ratio of cement to water; The second method is to establish a connection between water and a certain characteristic, and measure the water cement ratio by measuring this characteristic.

Zhao Muzi studied the influence of concrete water cement ratio on the creep of recycled concrete, and found that the water cement ratio (wor/cor) of matrix concrete has a greater impact on the creep of recycled coarse aggregate concrete[1], possibly even greater than the water cement ratio (w/c) of recycled concrete[1]. The impact data is shown in the following figure:

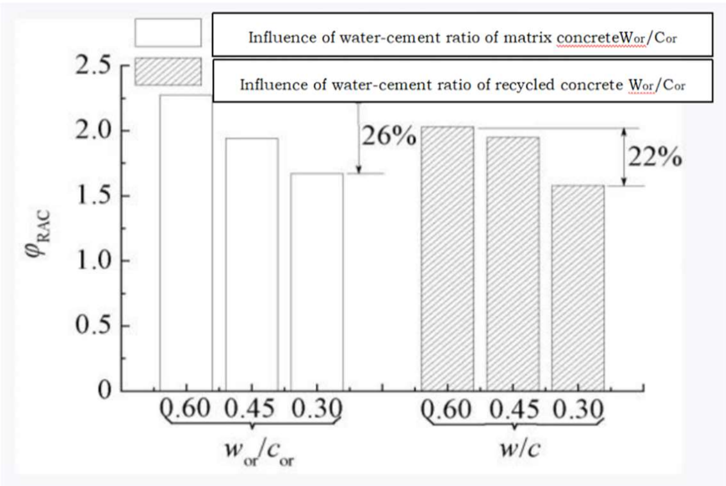

Figure 1. Water cement ratio

From the above figure, it can be seen that under the condition of wor/cor of 0.45, when w/c decreases from 0.6 to 0.3, the creep coefficient decreases by 22%; When w/c is 0.45, the creep coefficient decreases by 26% when wor/cor decreases from 0.6 to 0.3. From the above conclusion, it is important to consider the influence of the water cement ratio of the matrix concrete when predicting the creep deformation of recycled concrete.

2.2. Aggregate Particle Size

(1) Liu Jincheng studied the impact of aggregate properties on concrete performance , with less than 75% of concrete aggregates μ The fine particles of m have a significant impact on the performance of concrete[2] and have a significant impact on its slump resistance.

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(2) Li Yongwen mentioned in his study on the influence of aggregate particle size on the performance of ultra-high performance concrete : Four types of aggregates were used to prepare ultra-high performance concrete, and compressive strength, flexural tensile strength, elastic modulus, etc. were explored separately. And it is concluded that the highest elastic modulus and compressive strength are found in crushed stone concrete with a particle size less than 20mm, quartz sand concrete with a particle size less than 1.75mm, and river sand concrete with a particle size less than 4.75mm. The compressive strength and elastic modulus are relatively low. See the following three legends[3]:

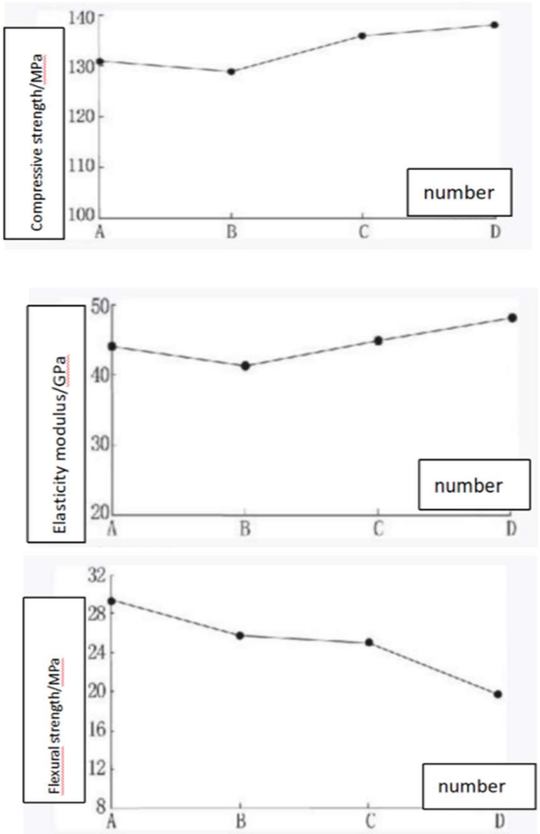

Figure 2. Aggregate particle size

A crushed stone concrete with particle size less than 20mm

B Small crushed stone concrete with particle size less than 10mm

C River sand concrete with particle size less than 4.75mm

D Quartz sand concrete with particle size less than 1.75mm

2.3. Steel Fibre

The effect of steel fibers on the specific heat of concrete can be ignored. The length of steel fibers is generally less than 50 mm, Mangat studied the effect of fibers below 30 mm on inhibiting creep[4]. It was found that the longer the fiber, the better the effect. This is related to the following:

(1) The longer the fiber, the greater the peak bonding force and energy consumption, and the better the bonding between the fiber and the matrix.

(2) The greater the probability of intersection between long fibers and microcracks, the more conducive it is to suppressing crack development. In addition, Bouziadi compared the differences in the inhibition of creep by fibers larger than 30mm [5] and found that 30mm was the best inhibitor of creep.

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In the post accident resolution experiment , by continuously and uniformly testing the specimen, the formula for making the specimen in a "quasi equal strain" state was obtained as follows[6]:

$$V\Delta W_{max}V_m \le 5 \quad (1)$$

After adding steel fibers, the toughness of concrete has been greatly improved. Compared to concrete without added steel fibers, it has better compressive strength in engineering applications and is a cement composite material composed of metal fiber reinforced materials. Compared to ordinary concrete, steel fiber reinforced concrete can increase its tensile strength by 25% -50% and significantly improve its durability.

2.4. Admixtures

(1)Slag. Master Lu Weihua used concrete specimens with density of 2430kg/m ^ 3, gel material amount of 450kg/m ^ 3 and sand ratio of 38% to test the influence of large amount of mineral admixtures on the carbonation resistance of concrete .In order to analyze the impact of mineral admixtures replacing cement, three types of experiments were set up for the total dosage of double mixed fly ash and slag: 40%, 60%, and 80%, respectively[7]. Then, the bending strength and compressive strength formulas were used for calculation, with an accuracy of 0.1 MPa (this experiment used cross design method).

In Liu Qian et al. [8]'s research on the mechanical properties of slag concrete after high temperature, Zhang Xuesong et al. showed that, under the same slag content, the residual compressive strength of slag concrete gradually decreases with increasing temperature, with a relatively small decrease in the early stage and a relatively large decrease in the later stage.For high content slag, at temperatures of 200℃, 400℃ and 600℃, its residual compressive strength is greater than the residual compressive strength of the reference concrete; At a temperature of 800℃, the residual compressive strength rate of the specimen is slightly lower than that of the concrete, and the residual tensile strength of the specimen is 30% of the room temperature.Overall, replacing cement with equal amounts of slag is beneficial for improving the mechanical properties of concrete in high-temperature environments[9]. The residual mechanical properties of alkali slag gel material after high temperature are shown in the figure below:

Table 1. The Influence of Different Dosages of Double Mixed Mineral Admixtures(unit:kg/m^3)

number	Water binderratio	p. II Cement	S95 slag	Grade I fly ash	water consumption	sand	stone	Water reducing agent
A	0.35	450	0	0	157.5	710.8	1111.7	0.25%
G	0.35	180	135	135	157.5	710.8	1111.7	0.25%
H	0.35	90	180	180	157.5	710.8	1111.7	0.25%
I	0.35	270	90	90	157.5	710.8	1111.7	0.25%

(2) Silica fume. Silica fume is a valuable inorganic non-metallic material. In the study on the effect of carbon dioxide on the compressive strength of silica fume concrete, Wang Wenzhuo et al. conducted experiments on three types of concrete: C40, C60, and C80. The compressive strength of concrete mixed with silica fume was roughly positively correlated with the returned carbon dioxide content. As the carbon dioxide content of silica fume increased, the compressive

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strength also increased, and the change curves of the three types of concrete were almost the same.

3. The Impact of High Temperature on Various Materials

3.1. What Substances are Present in Concrete at High Temperatures

Guo Qiang conducted special experiments on the microstructure and composition of high-temperature concrete at 200℃, 400℃, 600℃ and 800℃. Among them:

At 200℃, there is no significant change in concrete compared to room temperature, and the aggregate is tightly bound.At 400℃, some cracks appeared on the interface between aggregates and mortar in concrete; Hydrated calcium silicate (C3S2H4) begins to dehydrate at 100℃ and continues until 850℃.

At 600℃, cement mortar generates a large number of penetrating cracks and large pores; When the temperature exceeds 400℃, calcium hydroxide (CH) begins to decompose; When the temperature reaches 550℃, hydrated calcium silicate (C3S2H4) also decomposes. When reaching around 570℃, the strength of the coarse aggregate decreases. Because at this time, the coarse aggregate α Type quartz transforms into β Type quartz will generate expansion stress due to its accompanying large volume expansion.

At 800℃, a large number of small pores appear in the cement mortar, and the aggregates are almost separated from the cement mortar. The surface cracks of the mortar are intertwined, causing the concrete surface to appear in a cracked state[10]. As far as the overall structure is concerned, the concrete has become very loose, the cement mortar is in powder form, and the calcium hydroxide (CH) has been completely decomposed, leaving only a small amount of calcium silicate gel residue, which is completely decomposed.In addition, the decomposition of calcite and dolomite in coarse aggregate also occurs, which together leads to a sharp decrease in the compressive strength of concrete.

At room temperature, the concrete phase is mainly composed of CaCO3, SiO2, Ca (OH) 2, and Ca2SiO4. As shown in the figure below, the diffraction peaks of CaCO3 and SiO2 are very high, indicating a higher content of these two substances, while the content of Ca (OH) 2 and Ca2SiO4 is relatively low.

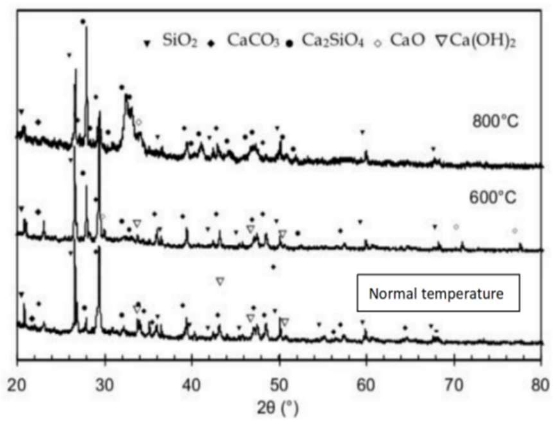

Figure 3. X-ray diffraction analysis

After analyzing the curve after high-temperature treatment at 800℃, it can be found that a large amount of Ca2SiO4 can be detected, and the content of SiO2 and CaCO3 is significantly reduced. CaO basically disappears after high-temperature environment.Nobuaki et al. (2015) confirmed:

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When the reaction temperature is above 650℃, CaO and SiO2 will react to form Ca2SiO4. It can also be concluded that the consumption of Ca (OH) 2 and CaCO3 leads to the formation of Ca2SiO4 at high temperatures; The decomposition of Ca (OH) 2 and CaCO3 produces gas, leading to the formation of numerous small pores inside the cement slurry and making the slurry appear in powder form.

3.2. The Effect of High Temperature on Compressive Strength

In Shang geng's research on the influence of temperature on the compressive strength of high-performance concrete and ultra-high performance concrete, he found that moisture content has a certain weakening effect on compressive strength through analysis by Deng Yousheng, and conducted relevant comparative experiments [11].At room temperature, the compressive strength of two types of concrete under different storage conditions is the lowest compared to underwater storage. Underwater storage leads to high saturation of the specimens. Under the same effect of storage conditions and temperature, it can be concluded that the compressive strength not only increases with the increase of concrete moisture, but also increases with the decrease of temperature. At the same time, as the temperature increases, the strength of the specimens stored underwater and in the climate chamber decreases significantly.

3.3. Dynamic Strength of Steel Fiber Reinforced Concrete under High Temperature Conditions

Peng Shuai et al. conducted research and experiments on the dynamic strength growth factor (DIF) of steel fiber reinforced concrete at temperatures of 200℃, 400℃, 600℃and 800℃, which is the ratio of dynamic strength to static strength of concrete materials. At 800℃, the DIF value of steel fiber reinforced concrete is significantly higher than that under normal temperature conditions[12]. This indicates that under high temperature conditions, the strain rate effect of steel fiber reinforced concrete is more significant.

4. Conclusion

(1) The concrete after high temperature is not treated in any way, and the elastic modulus of the concrete after cooling is greatly affected.

(2) Ca2SiO4 is relatively less affected under high temperature conditions and can not be decomposed under high temperature conditions. However, both SiO2 and CaCO3, which make up concrete, are greatly affected by temperature.

(3) The compressive performance and elastic modulus of crushed stone concrete with aggregate particle size less than 20mm are relatively excellent. But in high-temperature environments, cement mortar will continue to contract, while aggregates will continue to expand, leading to cracks in the concrete. Aggregates are severely damaged by heat. Previous studies have found that coarse aggregates undergo reactions such as quartz transformation and decarburization of limestone at high temperatures.

(4) In high-temperature environments, slag concrete can more effectively resist high temperatures because its residual compressive strength is relatively high.

(5) Through the high-temperature dynamic compression performance test of steel fiber reinforced concrete, it can be concluded that the high-temperature resistance of high-performance concrete has been significantly improved.

(6) As the temperature increases, the dynamic compressive strength of steel fiber reinforced concrete gradually decreases, and the dynamic peak strain also gradually increases. Steel fiber reinforced concrete has a significant temperature damage effect, and as the temperature increases, its dynamic mechanical properties gradually deteriorate, which is more severely affected by high temperatures.

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