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Study on Early Shrinkage Deformation and Crack Resistance of UFA High Performance Concrete in Highway Pavement Construction

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This paper mainly studies the early autogenous shrinkage characteristics of Ultra-Fine Fly Ash (UFA) and the influence of UFA on the early cracking sensitivity of concrete. Use UFA equivalent weight to replace the cement preparation of UFA road concrete, apply self-designed self-shrink testing device for concrete test the autogenous shrinkage deformation of the concrete at the early age (within 72 hours), and using the plate-limited shrinkage cracking test study the surface cracking resistance of the concrete within 26 hours, on the basis of the test, evaluate the early cracking sensitivity of UFA road concrete. With the incorporation of UFA, the early autogenous shrinkage deformation of the concrete is significantly reduced, while maintaining the same flow conditions, it significantly lower than the reference concrete, early crack resistance is better than the reference concrete, and with the increase of UFA content, the early cracking resistance is enhanced. The incorporation of appropriate amount of UFA can effectively reduce the early autogenous shrinkage of road concrete, thus reducing the sensitivity of early cracking and prolonging the service life of pavement structure. It also provides the theoretical and technical support for the application of UFA in practical engineering.

1. Introduction

With the continuous development of concrete technology, high-strength, high-performance concrete is the development trend of today's concrete (Mazloom), and reduce the water glue quality ratio, mixed with active mineral admixtures and admixtures is the preparation of high-strength high-performance concrete main Technical approach. However, the low water-binder ratio of concrete can provide less hydration of cement free water, the early strength of the rapid development of free water consumption is also faster (Mounanga et al., 2011), and thus no external water supply in the case of more prone to self-contraction, especially early Self-shrinkage increase (Nguyen, 2011), and lead to cracking, and then affect the strength and durability of concrete. The autogenous shrinkage of high strength concrete is a serious factor to increase cracking risk of concrete structure. The relationship between the strength development and autogenous shrinkage of fly ash concrete with different water-binder ratios in early hydration age was investigated. The results show that autogenous shrinkage and strength of concrete containing fly ash decrease with the increase of water-binder ratio, but quasi-linearly decrease with the increase of fly ash dosage. The autogenous shrinkage of concrete with various mix proportions consists of a rapidly increasing stage in the first hydrating day and a gently increasing stage in the later time. The shrinkage performance of concrete could be predicted through its mechanical property. Therefore, autogenous shrinkage is one of the main causes of cracking in high strength and high performance concrete (Rao). The proportion of total shrinkage has been increasing, and it is necessary to pay enough attention to it.

In highway concrete engineering, in order to pursue construction speed, sometimes in order to open the traffic as early as possible (such as in the road repair works), often emphasizing the early strength growth, usually low water glue mass ratio, and superplasticizer and active doping Such as material, resulting in increased early self-contraction of concrete, concrete pavement is caused by premature cracking of an important factor. Newer kinds of high-performance concrete show greater autogenous shrinkage than conventional concrete does, and cracks appear under certain circumstances. Many of these high-performance concretes have a

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lower water-to-binder ratio and an increased paste content, compared to conventional concrete. This article reports on a study in which the correlation between autogenous shrinkage and degree of hydration of fly ash was determined with the selective dissolution method. In addition, the relationship between the degree of hydration of fly ash and autogenous shrinkage was examined. The results showed that the degree of hydration of fly ash increased as its Blaine surface area increased. The degree of hydration of fly ash increased with time, and autogenous shrinkage increased corresponding to the increase in the degree of hydration of fly ash. The authors outline four stages of autogenous shrinkage and note that after day 56, autogenous shrinkage may depend mainly on the degree of hydration of fly ash. According to the pore theory of hardened cement paste, early self-desiccation effect of cement-based materials containing ultra-fine fly ash (UFA) was researched by the combination of theory and experience. And the improved testing device of autogenous shrinkage was used to test early autogenous shrinkage of UFA concrete. The results indicated that the inner self-desiccation degree of hardened cement paste containing UFA reduced more than that of ordinary hardened cement paste. On the other hand, the effective water/cement ratio of concrete increase in the course of early hydration, thus autogenous shrinkage reduced with the addition of UFA,and the more UFA was added, the less chemical shrinkage would be. From the above the truth, it was proved that the inner early self-desiccation effect of cement-based materials and early autogenous shrinkage of concrete had good correlation. The early autogenous shrinkage of highway concrete containing ultra-fine fly ash (UFA) was investigated, and the influence of UFA on early cracking sensitivity of concrete was analyzed.UFA highway concrete was produced with UFA replacing equivalent cement added into concrete, and by means of the autogenous shrinkage test device designed and improved, earlyage autogenous shrinkage of UFA concrete was tested.Furthermore,method of flat plate restricted shrinkage and cracking was used for testing crack resistance of UFA highway concrete in 26 hours, and based on the tests, the early cracking sensitivity of UFA highway concrete was appraised. The results indicated that early autogenous shrinkage of concrete reduced conspicuously with the addition of UFA,which was smaller than ordinary concrete under the condition of similar workability. On the other hand, early cracking resistance of UFA concrete was better than ordinary concrete, and the more UFA was added, the better the crack resistance would be. This demonstrates that adding proper amount of UFA can restrain effectively the early autogenous shrinkage of highway concrete, reduce early cracking sensitivity and extend service-life of pavement structure. Moreover, this investigation also provides the theoretical and technical support for the application of UFA in the practical engineering. In this paper, by adding appropriate amount of ultra-fine fly ash (UFA) preparation for highway road concrete, and through study the effect of UFA incorporation on the autogenous shrinkage of concrete, analyze early shrinkage effect and cracking sensitivity of UFA road concrete under condition of low water gum mass ratio, and provide some theoretical support for practical pavement concrete engineering.

2. Raw materials and test methods

2.1 Raw materials

(1) cement: 42.5# ordinaryportland cement; (2) ultra-fine fly ash (UFA): Chemical composition and physical properties shown intable 1; (3) sand: river sand, the fineness modulus is 2.75, Ⅱ district with qualified; (4) stone: river gravel, consistent with the 5 ~ 40mm continuous grading requirements, crushing index of 6.2%; (5) admixture: TQN naphthalene series superplasticizer.

2.2 Experiment methods

1) Self - shrinkage test method

The test method of autogenous shrinkage of concrete does not form a unified test standard. In this paper, the micro-displacement transducer (SeddikMeddah and Tagnit-Hamou, 2010) is used to measure the micro-displacement shrinkage of the concrete, which is transformed into the output frequency change of the electric quantity signal. The measurement range: 0~2000μm, measurement accuracy up to1μm, the signal acquisition and temperature test can be used as the instrument digital display, using the contact type displacement sensor designed by the author to measure the self-shrinkage deformation of concrete initial setting.

Table 1: Chemical composition and properties of ultra-fine fly ash

Material	Loss of ignition/%	Water content/%	SiO_2 /%	Fe_2O_3 /%	Al_2O_3/%	CaO/%	MgO/%	Na_2O /%	Specific surface area ($m^2 \cdot kg^{-1}$)
UFA	3.2	<1	51.8	5.0	26.4	4.1	1.0	1.0	603

The specific experimental steps and methods:

The test piece is molded into the stainless steel test-piece, and the sealing of the test-mold is shown in Fig.1. In order to make the test simple, the specimen is fixed at one end and relaxed at the other end.

Concrete specimens in two forming, first forming half the depth of the mold, vibrating, dense, and then into the temperature measurement components, then add the remaining concrete, and vibrating dense, smooth the surface, and then immediately sealed test mode.

When the concrete close to the initial setting (6h) remove the Teflon pads on the sides and the test leads, make the specimen separate from the test wall, and install the micro-displacement sensor, so that the probe and the test side probe are contact, and the self-shrinkage of concrete is measured by the instrument, the initial reading is recorded via the meter display, and converted into displacement.

Measurement of them at the same time to monitor the specimen internal temperature changes, and correct the measured value of autogenous shrinkage, the main measure of the early 72h (3d) of the autogenous shrinkage deformation during the test to ensure that the stability of the test system to avoid the displacement sensor or probe the collision, so as not to affect the test accuracy, the test conditions were as follows: temperature 25 °C, relative humidity 75%, in constant temperature and humidity chamber.

Data processing method: converts the frequency change into a displacement change value, the linear transformation scale formula is $Y = aX + b$, Y is the displacement, the unit is μm, X is the frequency, the unit is Hz; a, b is a constant.

2) Test methods for cracking performance of concrete at earlyage

The plate method used in this experiment is manufactured by Kraal [6-7] and other instruments developed by ourselves. Mold size: 600mm × 600mm × 80mm. Test surface cracking sensitivity in 26 hours after the concrete molding. Criteria for assessment of cracking level: 1) only very fine cracks; 2) average cracking area <10mm^2; 3) the number of cracks per unit area <10 / m^2, 4) total area per unit area ＜100mm^2/m^2. Cracking grade division: according to the above 4 criteria, the degree of cracking is divided into 5 grades: class Ⅰ - meet all 4 conditions, class Ⅱ - satisfying 3) and 4), class Ⅲ - satisfying 2) and 4), class Ⅳ - satisfying 1) and 4), class Ⅴ - none of them is satisfied.

3. Experimental results and analysis

3.1 Preparation of UFA road concrete

UFA 20%~40% replacement of the same amount of cement concrete, Mixing ratioas shown in table 2.

Table 2: Concrete mix ratio

Number	ρ(C)/(kg·m^3)	ρ (UFA)/(kg·m^3)	m(W):m(B)/%	ρ(S)/(kg·m^{-3})	ρ(G)/(kg·m^{-3})	Admixture/%
0	400	0	32	615	1250	0.75
1	320	80	29	615	1250	0.75
2	280	120	29	615	1250	0.75
3	240	160	28	615	1250	0.45

Note: 1) The concrete was prepared at an ambient temperature of 30°C and a relative humidity of 70%, which was different from the ambient conditions (temperature 25°C, relative humidity 75%) during the autogenous shrinkage test. 2) C-cement, W / B-hydro gel mass ratio, S-sand, G-stone. 3) The water mass ratio of concrete is determined by keeping the mixture at a similar flow rate (slump 3 to 5 cm).

3.2 Early autogenous shrinkage test and analysis

The reference concrete and UFA concrete were prepared under the condition of similar fluidity (see table 2), and the autogenous shrinkage deformation was measured at the early 72 h. The results are shown in figure 1.

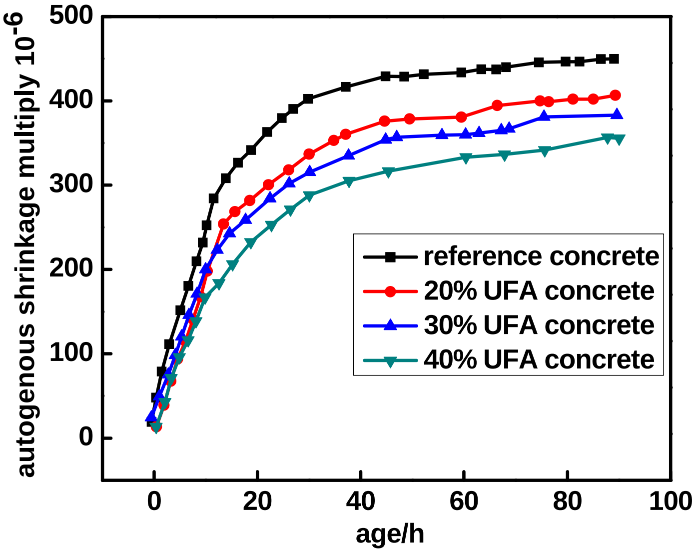

Figure 1: The early autogenous shrinkage deformation of reference concrete and UFA concrete

The experimental results show that the autogenous shrinkage deformation of UFA concrete has the following characteristics:

(1) With the incorporation of UFA, the concrete self-shrinkage deformation was significantly improved, compared with the reference concrete have different degrees of reduction. From the time of 6h (initial setting), the deformation value of concrete with 20% ~ 40% UFA is 301×10^{-6}, 284×10^{-6}, 261×10^{-6}, 82.5%, 77.8% and 71.5% of the reference concrete, respectively. And with the increase of the UFA content, the autogenous shrinkage deformation decreased.

(2) It can be seen from figure 1, from the 6h after the calculation, the self-shrinkage of concrete deformation in the 3 ~ 15h growth between the more rapid, from the hydration process to consider, this period should be after the formation of concrete hydration exothermic peak, so the hydration reaction to accelerate the internal water consumption to speed up, thus the degree of self-drying deepening, self-shrinkage increases, so it is essential to strengthen the concrete moisture at early stage.

(3) From the mix of concrete to consider, the early autogenous shrinkage deformation is mainly determined by the effective water-cement mass ratio (W / C, i.e. the ratio of the actual water content to the cement content) of the concrete. With the incorporation of UFA, because of early UFA does not participate in hydration, the effective water-cement mass ratio of the early reaction of concrete increases with the increase of UFA-substituted cement, so that concrete free water increased, while under the condition of no material exchange with the outside environment, the increase of free moisture causes the concrete self-desiccation phenomenon to weaken, and the autogenous shrinkage deformation decrease. In addition, it is found that using the modified self-shrinkage testing device has the advantages of high test precision and continuous measurement, especially for the early low water gel mass ratio concrete with good self-contraction.

3.3 Experiment and analysis of early crack resistance

Concrete early cracking resistance test shown in table 3. The test results were recorded according to the above-described test method, as shown in Table 3, and their cracking performance level is divided, as shown in Table 4.

Table 3: Concrete surface shrinkage cracking test records

number	8h	10h	12h	23h	25h	26h
0	no cracks	Micro-crack (one)	Micro-crack (one)	Crack propagation (three)	Crack propagation (three)	Crack propagation (three)
1	no crack	no crack	no crack	Micro-crack (two)	Micro-crack (two)	Micro-crack (two)
2	no crack	no crack	no crack	Micro-crack (one)	Micro-crack (one)	Micro-crack (two)
3	no crack	no crack	no crack	no crack	no crack	no crack

Table 4: Concrete surface shrinkage cracking test results evaluation

Number	The first crack time/h	Number of cracks per unit area/(strip·m^{-2})	Total area per unit area/($mm^2 \cdot m^{-2}$)	Cracking level
0	10h	8.33	88.13	Ⅱ
1	23h	5.56	27.8	Ⅰ
2	23h	2.78	5.56	Ⅰ
3	none	0	0	Ⅰ

According to the test results, the reference concrete cracks at 10h, and with the extension of age, the number of cracks and width, length, etc. has different degrees of growth, until to 23 hours, there are three visible cracks, one of the maximum width of 0.5mm crack, the length of 85mm. While UFA-containing concrete showed good crack resistance, with the increase of UFA content, the anti - cracking performance of concrete is increasing. When the continuous blowing to 23h, the number of cracks in the concrete with UFA 20% and 30% were only two and one, respectively, the maximum crack width is only 0.15mm; the UFA content of 40% of the group until the end of the blowing (26h) has no visible cracks, the grades of early shrinkage cracking of UFA road concrete are “ Ⅰ grade”. This shows that the incorporation of UFA can effectively inhibit the cracking of concrete; the cracking sensitivity is greatly reduced, and improves the resistance to surface shrinkage cracking ability. There is much controversy about whether the incorporation of mineral ultra-fine powder increases the possibility of early cracking of concrete [8-9], in this paper, we found that the incorporation of UFA can effectively reduce the early cracking sensitivity of concrete, for its mechanism can be analyzed from the following aspects.

(1) The incorporation of UFA replaces a certain amount of cement, the effective mass ratio of water cement was increased at the early stage of hydration, Making the participation of cement hydration of water reduced, and free water increased, this part of the free water is also conducive to alleviate the surface capillary pressure, thereby reducing the plastic shrinkage stress caused by surface cracking.

(2) UFA particles are good quality fly ash particles, the water demand is small, and while the formation of the micro-skeleton can effectively lock the water to keep the whole structure of the water is not easy to be evaporated, reducing the surface evaporation rate of water.

4. Conclusion

(1) With the incorporation of UFA, the autogenous shrinkage deformation of UFA concrete is obviously improved, and with the increase of UFA content, the autogenous shrinkage deformation decreases. The early autogenous shrinkage deformation of concrete mainly depends on the effective water-cement mass ratio (m (w) / m (c)) of the concrete, that is, the ratio of the actual water content to the cement content.

(2) Compared with the reference concrete, the cracking resistance of the UFA concrete is much better than that of the reference concrete, and the crack resistance is greatly improved with the increase of the UFA content.

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