surface of cement-Blaine method";

(2) Cement mortar strength test and abrasion test, as well as the concrete's mixture performance, mechanical properties test and durability test were according to JTG E30-2005 "Test Methods of Cement and Concrete for Highway Engineering";

(3) Cube compressive strength and splitting tensile strength test were used for size specimen 100 mm * 100 mm* 100 mm , Flexural strength of specimen size was used in 100 mm * 100 mm * 400 mm. Test results converted into standard strength values. Three specimens were tested to give each value.

PREPARATION OF THE HIGH PERFORMANCE ROAD CONCRETE

For low cement concrete, higher water-cement ratio and less sand amount, the fresh concrete mixture usually had poor cohesiveness, tend to bleed segregate and thus had poor performance. Hardened concrete also often had bad surface and poor durability, and the strength of concrete was low. In order to improve the workability, strength and durability, the conception of high-performance concrete was adopted. The test results are shown in Table 3.

Table 3. Test Results of High-Performance Pavement Concrete

Group	Cement (kg/m^3)	Water (kg/m^3)	CUFA (kg/m^3)	CUFA (%)	Sand (%)	Slump (mm)	Compressive strength (MPa)			Flexural strength (MPa)	
							3d	28d	56d	3d	28d
1	400	140	0	0	38	25	52.1	61.7	64.3	4.01	6.12
2	320	138	80	20	38	50	47.3	60.1	69.9	3.65	6.99
3	280	135	120	30	38	40	40.8	58.3	75.3	3.93	7.31
4	240	130	160	40	38	55	38.8	60.3	73.5	3.51	7.24
5	160	130	240	60	34	60	21.1	54.0	60.6	3.13	6.01
6	360	130	0	0	34	15	35.7	50.7	57.4	3.66	5.78
7	288	127	72	20	34	55	36.2	58.1	63.1	3.54	6.90
8	252	125	108	30	34	65	36.2	58.1	62.8	3.47	6.90
9	216	120	144	40	34	50	31.4	53.6	59.7	3.29	5.97
10	144	120	216	60	34	50	20.9	40.1	51.2	2.91	5.06

The test results in Table 3 indicated that, when the content of cementitious material was 400 kg/m^3, as the CUFA content increased, the workability of fresh concrete was improved significantly, and so did the slump. When the CUFA content ranged from 20% to 40 %, the 3d compressive strength of high-performance pavement concrete was higher than 35 MPa and the 3d flexural strength was higher than 3.5 MPa. According to the Portland cement concrete pavement specification JTJ 073.1-2002 "Technical Specifications of Cement Concrete Pavement Maintenance for Highway" in China, the flexural strength should be no less than 70% of designed strength when the road is open to traffic. In other words, the flexural strength should be higher than 3.5 MPa when the designed flexural strength was 5.0 MPa or 3.15 MPa (the designed flexural strength was 4.5 MPa). Therefore, the concrete containing 20%~40% CUFA was applicable and met the requirement of opening to traffic three days after the construction. In comparison with the control group whose 28d flexural strength was 5.0 MPa, the flexural strength of high performance pavement concrete containing 20~40% CUFA increased by 14.0%,

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19.4% and 18.3% respectively, and it met the requirement of opening to heavy traffic. When the dosage of CUFA reached to 60%, the 3 d compressive strength was low, but the 28d flexural strength was 6.01 MPa, and it was higher than that of the control group. Therefore, the content of CUFA could be higher when there is enough curing time.

When the content of cementitious materials was 360 kg/m^3 or 400 kg/m^3, the fresh concrete had good workability and consistency. In order to achieve 5.0 MPa design flexural strength and meet the requirement of 3 days traffic opening, the content of CUFA should not exceed 20%. When the content of CUFA was as high as 40%, the 3d flexural strength would be 4.5 MPa which was the design strength, and thus it would have sufficient strength to open to traffic after curing for three days.

Thus, adding 20 ~ 60% CUFA not only improved the workability of the high performance concrete, but also increased the strength significantly.

THE MICROSTRUCTURE OF CEMENT PASTE

The microstructure of cement paste of high performance pavement concrete was observed by SEM technology. Figure 1 shows the SEM photo of cement paste at 3 d, and Figure 2 shows the SEM photo of cement paste at 28 d.

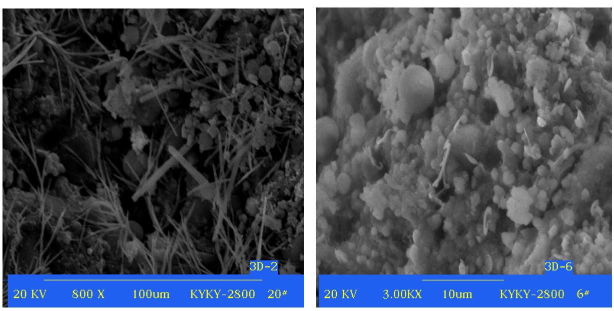

FIG. 1. The SEM photo of cement paste at 3 d

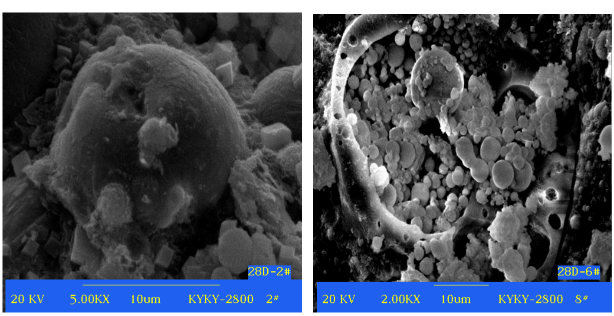

FIG. 2. The SEM photo of cement paste at 28 d

It can be seen from the Figures that, a large number of ettringite which were

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needle-like crystals overlapped reciprocally with hydrated calcium silicate gel and became net structure at 3 days. Fly ash particle of all sizes filled in the hydration products. There were Hydration products precipitate on the fly ash particle surface, which indicated the fly ash had started Hydration reactions. With the extension of age, the surface of fly ash was eroded obviously, and the reaction intensified. The net and fibriform structures of hydrated calcium silicate gel became more obvious. The ettringite crystals were sturdy more, and grew better. So the strength of cement paste increased significantly.

DURABILITY AND DRYING SHRINKAGE PROPERTIES OF THE HIGH PERFORMANCE PAVEMENT CONCRETE

Permeability and freezing resistance

Table 4 and 5 present the test results of the permeability resistance under certain hydraulic pressure and resistance to rapid freez-thaw test. C40 concrete containing CUFA was used for the tests. It can be seen from Table 4 and 5 that the concrete had good resistance to hydraulic pressure (greater than S30) and freeze-thaw (greater than or equal D200).

Table 4. Permeability Test Results of the High Performance Pavement Concrete

Item		1	2	3	4	5	6
Max hydraulic pressure（MPa）		3.0					
Permeate depth（mm）	Average	15.2	16.8	18.4	12.5	12.1	13.0
	Max.	16.2	18.1	21.3	15.2	16.2	14.1
	Min.	11.0	9.2	16.1	9.3	8.9	10.9
Remark		Load the hydraulic pressure to 3.0 MPa once and steady 8 hours， all specimens no seeping.					

Note: Group No. are the same with Table 2.

Table 5. Results of Rapid Freeze-Thaw Test of High Performance Pavement Concrete

Item	100 times freeze-thaw cycle	200 times freeze-thaw cycle
Standard curing strength (MPa)	51.5	55.2
Freeze-thaw strength (MPa)	48.1	45.7
Strength losing (%)	6.6	17.2
Weight losing (%)	0.0	0.0
Max. depth of permeability (mm)	35.0	46.0

Note: When the CUFA concrete is 30%; the slump was 40 mm.

Abrasion resistant ability

Table 6 showed that the abrasion per area of the high performance pavement

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concrete, which contained 15~40% CUFA, was less than ordinary concrete. Thus, the abrasion resistance ability of the high performance pavement concrete was better. On one hand, the bond property between cementitious materials and aggregates improved by adding CUFA; on the other hand, the high strength of the vitreous granule in fly ash reduced the abrasion of the high performance pavement concrete.

Table 6. Abrasion Resistance of the High Performance Road Concrete

Group	CUFA Replacement （%）	C （kg/m^3）	CUFA (kg/m^3)	28d Compressive strength (MPa)	Abrasion per area (kg/m^2)	Ratio （%）
1	0	360	0	50.0	2.048	100
2	15	306	54	52.7	1.888	92.2
3	25	270	90	56.9	1.124	54.9
4	40	216	144	56.7	1.756	85.7

Drying shrinkages

Based on the dry shrinkages test results showed in Table 7. The mixture proportion of group 1、2、3、4 and 5 concrete were shown in Table 3. The dry shrinkage value of the high performance pavement concrete increased with the increase of CUFA content. The dry shrinkage value of high performance concrete was less than the ordinary concrete as the CUFA content were less than 40%. The shrinkage values of the concrete containing 60% CUFA was much higher than those of the ordinary concrete. Thus, adding up to 40% CUFA reduced the dry shrinkage value of the high performance pavement concrete, and the crack resistance of the pavement concrete was improved.

Table 7. Dry Shrinkages Test Results of the High Performance Pavement Concrete

Group	Dry shrinkages ratio（*10^{-6}）							
	3d	7d	14d	28d	60d	120d	150d	360d
1	41	124	186	215	274	325		457
2	35	78	151	193	239	278	358	401
4	41	99	164	203	250	292	379	423
5	93	182	241	297	315	323	411	470

Mixture proportion of the high performance road concrete

Table 8. Mixture Design of the High Performance Pavement Concrete

Open traffic Time (day)	Cementitious materials (kg/m^3)	CUFA (%)	W/C ratio	Sand rate (%)	Remark
3	360 400	≯20 20～40	0.30～0.35	32～34 34～38	Crushed stone
28	360 400	20～40 20～40		32～34 34～38	

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Based on the results above and the properties of the high performance pavement concrete, the recommended proportion is shown in Table 8.

APPLICATION OF HIGH PERFORMANCE PAVEMENT CONCRETE

Project introduction

The Ji'an section of G105 highway in Jiangxi province is 110 kilometers long. The daily traffic volume was 20，000~30，000 with 50% over loading vehicles. Because of the heavy traffic load, 40~50% of the pavement surface had deteriorated, which highly reduced the traffic speed, comfort and safety and needed rehabilitation immediately. The highway department of Ji'an city Jiangxi province decided to use high performance pavement concrete on this repair, which must satisfy the requirement of opening to traffic in 3 to 5 days after paving.

Materials and mixture ratio

(1) Materials

Cement: 32.5R ordinary Portland cement , the compressive strength and flexural strength at 3d and 28d are 20.1 MPa, 3.7 MPa and 35.3 MPa, 5.6 MPa respectively.

Sand: River sand, produced in Ganjiang with the eligible aggregate grading, M_X=2.76.

Gravel: Crushed stone, produced in Ganjing with the continuous aggregate grading from 5 to 31.5 mm. Crushed index: 9.6%; Mud content: 0.5%.

CUFA: Offered by Central South University.

(2) Mixture ratio of the high performance pavement concrete

Basing on the lab test and considering the operation feasibility and the mechanics performance of the concrete, the mixture ratio was C: W: S: G: CUFA=300:135:610:1135:100 (kg/m^3). The designed slump was 20~30mm; the compress strength at 3 d was no less than 20 MPa and the flexural strength at 3 d was no less than 4.0 MPa.

Mechanics properties of designed high performance pavement concrete

(1) Concrete performance

There were three concrete boards (5.0 m*3.75 m*0.24 m*3, all board patched) repaired on the Ji'an section of G105 highway in Jiangxi province. The average slump of the concrete was 40 mm. The test results indicated that the operation of the high performance pavement concrete which with the excellent water conservation and cohesive property was fine.

(2) Mechanics performance

Eight groups of specimens were fabricated by using insert vibrating method, 150 mm * 150 mm * 150 mm cube specimens were used for compressive strength test and 150 mm * 150 mm * 550 mm beam specimens were used for the flexural strength test. Four groups of specimens were cured in water while the other four groups were cured in the standard curing room at the job sites. As shown in Table 9, the test results indicated that

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flexural strength and compressive strength at 3 d were 4.7 MPa and 30.2 MPa respectively; the 28 d strength were 7.6 MPa and 55.8 MPa respectively. The effect of the CUFA on increasing the strength of the concrete was prominent, and the high performance pavement concrete prepared with CUFA and 32.5R Portland cement met the requirement of opening traffics 3 days. No cracking or severe abrasion were found on the pavement two years after the construction.

Table 9. Mechanical Properties of the Designed Pavement Concrete on site

Group	Flexural strength (MPa)		Compressive strength (MPa)	
	3d	28d	3d	28d
Standard conserving	4.5	7.5	29.4	56.3
Conserved in the same condition	4.7	7.6	30.2	55.8

Application and economic benefit of the high performance pavement concrete

Based on the successful application of the high performance pavement concrete on the test road, the concrete had been widely used on other three sections of highway in Ji'an city of Jiangxi province. Compared with the ordinary concrete, which incorporated hardening accelerator admixture, the new technology of high performance pavement concrete saved ￥1 , 000 , 000. Besides, the society and environment benefits were obvious for opening to traffic earlier, alleviating traffic jam, reducing bypass expenditure and extending the application of fly ash.

CONCLUSIONS

Based on the test results above and the site application experience, some conclusions were summarized as follows:

1. With cementitious material amount of 360~400 kg/m^3 and CUFA content of 20% ~ 40%, the incorporation of CUFA could significantly improve the workability of concrete properties. In the meantime, it could obtain the high performance pavement concrete with a compressive strength as high as 50MPa, and the later strength of concrete continued to grow. This would meet the requirements of opening of traffic in 3 days after paving and to heavy traffic in 28 days.
2. The high performance pavement concrete containing 30% CUFA had good resistance to permeation, freeze-thaw and abrasion; dry shrinkages of the high performance pavement concrete mixed containing 20% to 40% CUFA decreased largely, which improved the crack resistance of the concrete.
3. Mixture proportion of the high performance pavement concrete used in this paper were suggested.
4. The site application showed that the 3 d flexural compressive strength of the high performance pavement concrete were 4.7 MPa and 30.2 MPa, and the 28 d flexural and compressive strength were 7.6 MPa and 55.8 MPa, which satisfied the requirement of opening to traffics in 3 days. No cracking or severe abrasion were found on the pavement two years after construction.

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REFERENCES

Nehdi, M., Mindess, S., Aitcin, P.C. (1998). "Rheology of high performance concrete Effect of ultrafine particles." *Cement and Concrete Research*, Vol.28 (5):687~697.

Sharma, R. L. and Pandey, S. P. (1999). "Influence of mineral additives on the hydration characteristics of ordinary Portland cement." *Cement and Concrete Research*, Vol. 29(9): 1525~1529.

Ferraris, C.F., Obla, K.H. and Hill, R. (2001). "The influence of mineral admixtures on the theology of cement paste and concrete." *Cement and Concrete Research*, Vol. (31): 201~206.

Grzeszczyk, S. (2000). "Effect of superplasticizers on the rheological properties of fly ash suspensions containing activators of the pozzolanic reaction." *Cement and Concrete Research*, Vol. (30): 1263~1266.

Feng, N. (1996). "High Performance Concrete." Beijin: *China Construction Industry Press*.

Wu, Z. (1999). "High performance concrete and its fine mineral admixtures." *Architecture Technology*, Vol. 30 (3): 160-163.

Zhou, S., Liu, B., Xie, Y., Yin, J. and Yuan, Q. (1999). "Ultra pulverized Fuel Ash composite Powder used for HPC.", *Construction Technology*, Vol. 28(5):13-14.

Yin, J., Zhou, S. and Xie Y (2002). "Investigation on Preparation and Application of High Strength Performance Concrete.", *Journal of Changsha Railway University*, Vol. 20(2):17-22.

Yin, J. and Zhou, S. (2005). "Study and Application on High-performance Rapid Repair Concrete.", China Railway Science, Vol. 26(3):136-138.

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Influence of the Micro-gradation of Fly ash and Slag on the Properties of Cement Mortar

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ABSTRACT: The particle size distributions of the mixture of fly ash, slag and cement were studied. The micro gradation of the mixture of fly ash and slag, also named as Ultra Fly ash and Slag (UFS), was analyzed and optimized. The properties of cement mortar containing fly ash, slag and UFS were studied through laboratory tests. The hydration of UFS when adding the activator was also analyzed. Test results indicated that best ratio of fly ash to slag was 4:1, which would achieve the best filling effect, much better micro gradation and the highest density for UFS, and thus improve the early strength. Both the early and late stage strength of cement mortar containing fly ash was lower than those of the cement mortar containing slag or UFS. At the environment provided by the activator, the strength performance of cement mortar would be highly improved because of the secondary hydration of the cementitious material due to the water reducing and densifying effect of the UFS.

INTRODUCTION

As the development of cement concrete pavement technology, the mineral additives have already been an important component in the concrete for rigid pavement. The mineral additives have lots of advantages including improve the micro structure of concrete, the mechanical properties and the durability. However, there are still some deficiencies of those additives. For example, the early strength of the concrete incorporating fly ash was low and the concrete strength decreases as the fly ash content increases. Yang et. al. (2005) found that although the early strength of concrete can be improved by adding slag, slag also tends to excrete water and generate more harmful air voids in the concrete, which reduced the mechanical properties and the durability. A potential promising method to utilize the advantages of the two mineral additives is to add both fly ash and slag into concrete simultaneously. Research results indicated that adding both fly ash and slag would reduce the amount of the harmful voids and the size of the voids and improve the water-retaining property, the compatibility with other additives, the density of the cement paste and the strength at both early and late stage (Liu et. al., 1995; Sun et. al., 2004; Long et. al., 2002).

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This paper investigated the particle size distributions and micro gradations of the mixture of fly ash, slag and cement. The mechanical properties of cement mortar incorporating fly ash, slag, and mixed additives were evaluated through laboratory tests. The hydration of UFS at the existence of activator was also investigated.

MATERIAL PROPERTIES AND TEST METHOD

42.5 grade regular Portland cement was used in this study. The 3d and 28d compressive strength of the cement mortar are 27.7 MPa and 52.2, respectively. The 3d and 28d flexural strength of that are 5.03 MPa and 8.10 MPa, respectively. The physical and chemical properties of the cement all met the requirement of the current Chinese specification. Natural sand was used as fine aggregate. The gradation of the natural sand met the requirement of region II of the Chinese specification and the fines modulus was 2.61. An ultra fine fly ash was used, the specific surface of which was 5500 cm^2/g. The density of slag was 2.87g/cm^3, the specific surface was 3500 cm^2/g. A polycarboxylate type super plasticizer and a naphthalene type super plasticizer (SP) were used. Table 1 presents the different components of cement, fly ash and slag. 40mm*40mm*160mm beam specimens were prepared and cured in the standard curing room. The strength and fluidity of the cement mortar were tested according to the Chinese specification.

Table 1. Chemical Components of Cement, Fly Ash, and Slag (%)

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Loss on ignition
Cement	22.05	4.34	4.42	62.68	4.58	—	—	2.21	2.84
Fly ash	50.15	30.51	2.08	12.50	0.088	1.08	0.53	0.40	3.43
Slag	28.99	14.22	1.49	49.83	0.35	0.34	0.22	3.25	1.99

DISCUSSION OF TEST RESULTS

Optimizing the Ratio of Fly Ash to Slag

The strength and durability of concrete is mainly determined by the properties of cement paste, aggregate and the bonding between cement paste and aggregate. The cement paste is composed of cement, water, mineral additives and other chemical additives. Recent research indicated that the bulk density of the dry mixture of cement, fly ash and slag could be maximized by optimizing the gradation of cement and mineral additives, which would improve the density of cement paste and thus the strength, density and durability of the cement paste and the concrete could also be improved. 5 groups of fly ash and slag mixture were prepared. The ratios of fly ash to slag for the 5 groups were 1:1, 1:2, 1:3, 1:4 and 1:5, respectively. Table 2 and Figures 1 and 2 present the air voids and particle size distribution of the 5 groups of mixture as well as the cement.

It can be seen from Figure 1 that, the volume fraction of all the 6 groups reached peak values around 0.23 μm and dropped to low values around 0.42 μm, indicating that the gradations were discrete around 0.42 μm. Actually, the ideal gradation, which would achieved the highest bulk density, should be continuous and less discrete. With the increase of the fly ash content, the gradations tended to be more continuous. By adding

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more fly ash, the volume fraction around 0.23 μm was increased, the discrete gradation around 0.42 μm was improved and thus the density of the mixture was highly improved. When the ratios of fly ash to slag was 4:1 or 5:1, the fraction between within 0-30 μm were between 89.55% to 89.89%, which is consistent with the results in Table 2. Besides, the fraction smaller than 1 μm increased as the content of fly ash increased, which would also improve the density of the cement paste and thus the early strength of the concrete would be improved.

Figure 2 presents the particle size distributions of the mixed fly ash, slag and cement. The new compound mixture was made of the 5 groups of fly ash and slag mixture mixed with cement at the ratio of 3:7. Test results indicated that the fraction around 0.42 μm of the compound mixture was higher than that of cement. Some discrete gradations were improved. Thus, the micro gradation of the compound mixture was more continuous. The fine particles filled the voids and the densities of the cementitious materials mixture were improved.

In general, high densities were achieved by mixing fly ash and slag at the ratio of 4:1 or 5:1. However, considering the fact that more slag would improve the early strength of concrete, the ratio of fly ash to slag was selected as 4:1. At this ratio, both density and early strength would be satisfied. This mineral additive mixture was named as Ultra Fly ash and Slag (UFS).

Table 2. Air Voids and Volume Fraction of the Mixture of Fly ash and Slag

Items		**Ratios of fly ash to slag**				
		1：1	**2：1**	**3：1**	**4：1**	**5：1**
Percent of total volume (%)	0-3μm	30.61	34.27	36.10	37.19	37.92
	3-30μm	55.90	53.93	52.95	52.36	51.97
Apparent density (g/cm^3)		2.56	2.47	2.45	2.39	2.21
Bulk apparent density (g/cm^3)		0.780	0.759	0.754	0.746	0.777
Air voids (%)		70.00	69.27	69.22	68.92	64.84

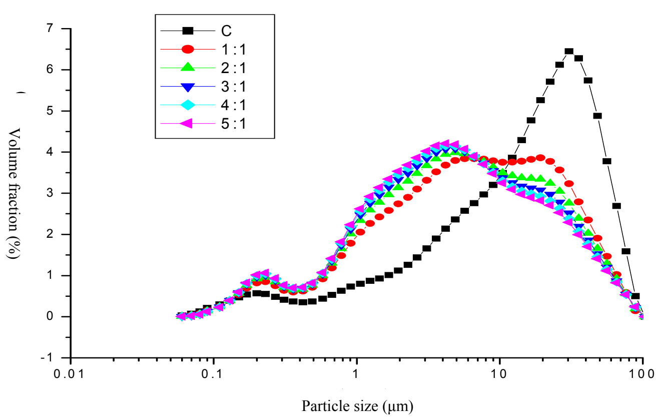

FIG. 1. Volume fractions of the fly ash and slag mixtures and cement

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