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FATIGUE PERFORMANCE AND EQUATIONS OF ROLLER COMPACTED CONCRETE WITH FLY ASH

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ABSTRACT

In this paper, the influence of fly ash on the fatigue performance of roller compacted concrete was studied. The fatigue equations of roller compacted concrete without and with fly ash, which can be used for designing pavement, are proposed through the method of the regressive analysis, and compared with that of the same grade common concrete pavement. *© 1998 Elsevier Science Ltd*

Introduction

With the development of materials science and technology, concretes are currently developing into a kind of high performance composite material. roller compacted concrete (RCC) and fly ash RCC (FARCC) are two important ingredients used to produce high pavement materials. Much research has been done and good results have been obtained. However, there are still many problems to be resolved; examples include fatigue performance, fatigue damage process, fatigue equations for designing FARCC pavement, the effect of fly ash in FARCC, and so on. In this paper, we will introduce our study results on these aspects.

Materials and Test Methods

Materials

In this study, 425# ordinary Portland cement was used. The fine aggregate was a kind of river sand with the fineness modulus being 2.4, and the coarse aggregate was crushed dolomite stone with the maximum diameter being 20 mm. The chemical composition of fly ash is given in Table 1. The mix proportions of concrete specimens are shown in Table 2.

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TABLE 1
Chemical composition of fly ash (%).

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss on ignition
51.83	5.96	32.13	3.74	1.05	0.18	1.31

Test Methods and Fatigue Parameters (1,2)

The concrete specimen size was 100 × 100 × 400 mm. Specimens were cast with pressure about 50 g/cm^2 imposed on the upper surface of the mold while vibrating. The vibration time was 2 min. Specimens were cured in a room of 201 and 95% relative humidity after demolded until the prescribed test period.

The load cycle characteristic value ρ is defined as follows: $\rho = P_{min}/P_{max}$, where ρ is taken as 0.1, P_{min} refers to the minimum load of every cycle, and P_{max} is the maximum load of every cycle.

The stress ratio is defined as: $n = f^f{}_{fl}/f_{fl}$, where n is the stress ratio, $f^f{}_{fl}$ and f_{fl} are the flexural fatigue strength and the flexural strength, respectively. The loading frequency is 5∼8 Hz. A four-point bending test method was applied.

Experimental Results and Analysis

To demonstrate the effect of fly ash on fatigue properties of RCC, fatigue tests have been performed on specimens of four series, with the fly ash content being 0%, 15%, 30%, and 45%, respectively. For each series, the stress ratio changes from 0.85 to 0.55. After the number of cycle N reached 10^6, the test was continued to the failure of the specimen. The fatigue equations were established with the regression of test results, which were obtained by measuring more than 300 specimens under different stress ratios and corresponding fatigue number. The fatigue equations for four series of FARCC are shown in Table 3. For 99.7% assurance, three times of regression error was deducted from the stress ratio, and the corrected equations are given in the last column of Table 3.

The fatigue curves n-lgN of four series are shown in Figures 1 to 4. They indicate that the slopes of n-lgN curves are different in a certain degree with the increase of the content of fly ash on RCC from 0% to 45%, in other words, the degree of fatigue damage rises slightly with the increase of fly ash contents when the stress ratios are the same. However, the fatigue strength of FARCC increases with the addition of fly ash from 0% to 45%. The experimental

TABLE 2
The mix proportions of concrete specimens (kg/m^3).

Series	Cement	Fly ash	Admixture	Sand	Stone	Water
F0	300	0	1.500	802	1309	114
F15	270	45	1.575	752	1332	113
F30	240	90	1.650	699	1348	113
F45	210	135	1.725	650	1373	113
PCC	330	0	0.825	638	1344	142

TABLE 3
The fatigue equations of four series of FARCC.

Series	Fatigue equation before correction	Relative coefficient	Regression error	Corrected fatigue equation
F0	*n* = 0.986–0.06931gN	0.974	0.0165	*n* = 0.936–0.06931gN
F15	*n* = 0.988–0.07021gN	0.979	0.0165	*n* = 0.941–0.07021gN
F30	*n* = 0.991–0.07121gN	0.971	0.017	*n* = 0.940–0.07121gN
F45	*n* = 0.996–0.07201gN	0.972	0.018	*n* = 0.942–0.0721gN

results and the calculated results are shown in Table 4. When the fatigue strength number is equal to 10^6, the difference of stress ratios is very little, but the fatigue strength can be raised about 13.5% as the content of fly ash changes from 0% to 45%. The main reason for this is the regularity of the ultimate flexural strength's increase with the increase of the content of fly ash. Compared with common concrete in pavement (PCC), it can be raised by 58%. In this paper, the fatigue equation reflecting the relationship between stress ratio n, fatigue number N, and the contents of fly ash was obtained also by the regression analysis, and the equation is:

$$n = 0.94 - (0.0693 + 0.006Fa)1\text{gN}$$

where Fa refers to the content of fly ash in RCC(%). Comparing the calculated results from this equation with that of corrected equations, we can find that the calculated results are in good agreement. Therefore, this equation above can be used for both RCC and FARCC. The engineering application indicates that the results calculated from corrected fatigue equation for designing the pavement thickness are quite in agreement with the actual situation.

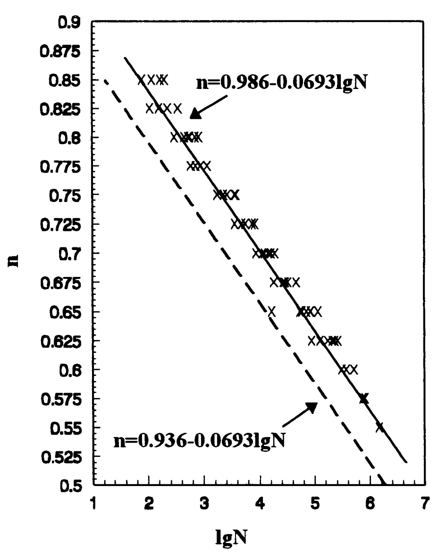

FIG. 1.
The fatigue curve of RCC without fly ash.

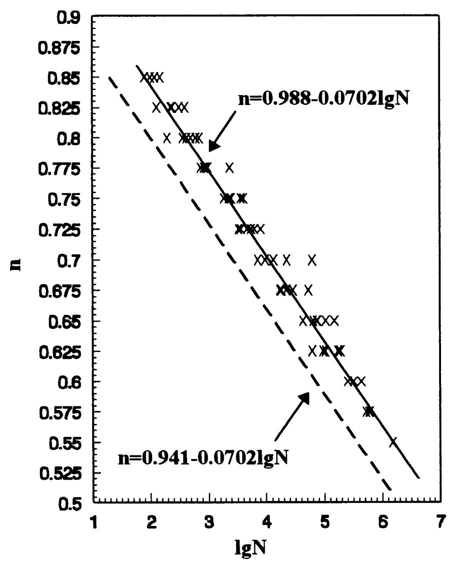

FIG. 2.
The fatigue curve of FARCC with 15% fly ash.

Analysis of Fatigue Mechanism on FARCC

The Role of Fly Ash

As is well known, fly ash has been widely used for decades due to its pozzolanic reactivity with cement hydrates. Fly ash can react with the cement hydration product calcium hydrox-

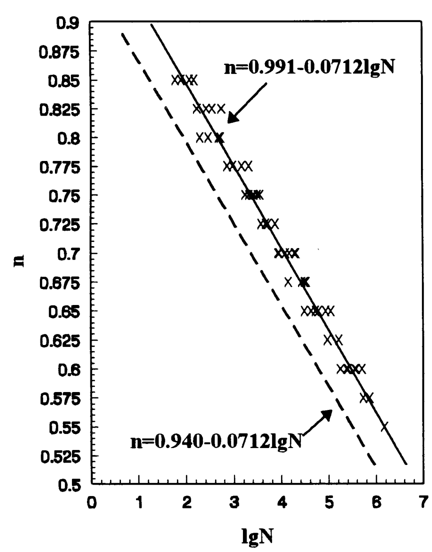

FIG. 3.
The fatigue curve of FARCC with 30% fly ash.

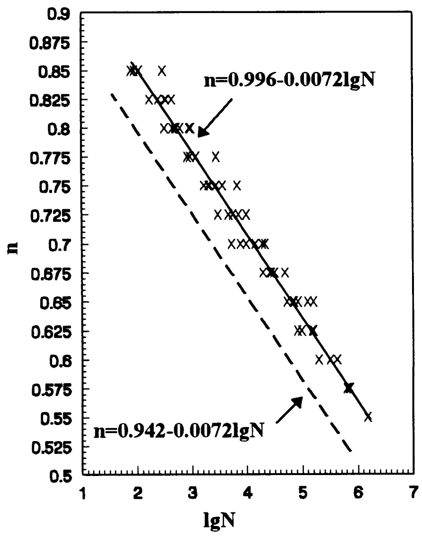

FIG. 4.
The fatigue curve of FARCC with 45% fly ash.

ide, reducing the content of calcium hydroxide and producing more CSH gel and AFt; as a result, the pore structure is improved and the matrix densified. Furthermore, the microaggregate of fly ash contributes to good performance, too. Evidently, fly ash plays a significant role in improving the fatigue performance of FARCC.

The Pore Structure

As was mentioned above, the fatigue performance of FARCC is much better than that of RCC and PCC for the same grade pavement. This result comes from not only the addition of fly ash to the concrete but also the roller compact technology. First of all, the ability to arrest cracks is of great importance in the process of fatigue. The damage degree and the sustaining

TABLE 4
The comparison of the fatigue performance of RCC, FARCC, and PCC.

Series	Flexural strength (MPa)		Stress ratio (n)	Fatigue number (N)	Fatigue flexural strength (MPa)		Fatigue damage extent (%)
	28 days	90 days			28 days	90 days	
F0	6.62	6.70	0.570/0.520	10^6	3.77/3.44	3.82/2.48	43.0
F15	6.63	7.08	0.567/0.520	10^6	3.76/3.45	4.01/3.68	43.3
F30	7.29	7.68	0.564/0.513	10^6	4.11/2.74	4.33/3.94	43.6
F45	7.18	7.62	0.564/0.510	10^6	4.05/2.66	4.03/2.89	43.6
PCC	—	5.29	0.482	10^6	—	/2.55	51.8

Note: The values above "/" are calculated by using uncorrected equations; the values under "/" are calculated from corrected equations. The equation for calculating series PCC is $n = 0.944-0.771gN$.

TABLE 5
The effect of addition of fly ash on the pore structure.

Series	Pore diameter (nm)				Total pore volume (cm^3/g)
	100 ~ 200	200 ~ 100	100 ~ 20	<20	
PCC	0.0182	0.0056	0.0178	0.0209	0.0670
	27.2	8.30	26.61	31.2	
F0	0.0105	0.0033	0.0148	0.0209	0.0518
	20.27	6.37	27.11	40.35	
F15	0.0086	0.0026	0.0018	0.0211	0.0427
	20.05	6.16	20.80	49.50	
F30	0.0053	0.0025	0.0109	0.0211	0.0413
	12.90	6.00	26.48	50.97	
F45	0.0041	0.0020	0.0068	0.0197	0.0354
	11.64	5.78	19.13	55.78	

Note: For each series, the values in the first row stand for the pore volume (cm^3/g), and the values in the second row stand for the porosity (%).

time in the fatigue process depends on the character and structure of material, especially the dimension and amount of the original crack and the capacity of resistance to crack propagation under repeated load (3,4). Improvement of pore structure is an important factor in the materials' resistance to fatigue damage. We examined the pore structure of mortars made from concrete specimens after the coarse aggregates were rejected. A mercury intrusion porosimetry was applied for this purpose. The results are listed in Table 5.

Table 5 indicates that the micropore structure of RCC and FARCC is improved remarkably because of the addition of fly ash into RCC. The total pore volume of the PCC is 0.067 cm^3/g, that of roller cement mortar with or without fly ash is 0.0354~0.0518 cm^3/g. The ratio of pore volume of pores larger than 100 nm to the total pore volume of RCC is 20~30% in RCC and FARCC; however, it is 42.6% in PCC. Compared with PCC, RCC and FARCC possess not only a smaller porosity, but also very few harmful pores (>100 nm). Compared with RCC, the total pore volume of FARCC is 0.0427 cm^3/g, 0.0413 cm^3/g, and 0.0354 cm^3/g, respectively, with the addition of 15~45% fly ash into RCC. Experimental results indicate also that the number of harmful pores with diameter larger than 200 nm are reduced successively with the increase of fly ash content, and that of harmless pores with diameter less than 200 nm raised, obviously.

Conclusions

1) Compared with PCC, both FARCC and RCC possess excellent fatigue performance if fatigue numbers are the same; i.e., the fatigue strength of FARCC and RCC may raise by 40~50%.
2) The fatigue equations of RCC and FARCC are in good agreement with practically measured results. These fatigue equations can be used for designing the pavement thickness of RCC and FARCC if the content of fly ash is varied from 0~45%.
3. The mechanism by which fly ash improves the fatigue performance of RCC lies mainly

in the composite effect of the densification produced by the roller compacted technology and the pozzolanic reactivity and microaggregate effect of fly ash.

4. The composite effect of roller compact technology and the addition of different amounts of fly ash into RCC may improve the pore structure of RCC and FARCC, which is a key factor in increasing the fatigue service life and the capacity of bearing fatigue load.

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