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A Study on Compressive Fatigue Characteristic of Concrete in Mineral Oil Osaka City University

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Synopsis

The present paper describes the fatigue characteristic of concrete in compression in mineral oil through experimental test with focusing on loading cycle dependent hysteretic stress-strain relationship, residual strain increase and stiffness decrease.

KEYWORDS: Mineral Oil, Compressive Fatigue, Concrete, S-N Curve, Stiffness, Residual Strain

1. Introduction

In recent years, deterioration has been found in the concrete foundation for pressing machine of steel production factory[1]. The circumferential temperature reaches up to 40 to 50 ℃ around the concrete foundation. As the result, accelerated evaporation of entrained water provides negative pressure and leads absorption of mineral oil into concrete. In addition, repeated load is applied during normal operation. These facts suggest fatigue orient deterioration of concrete. Chemical attack by plant oil has been well known [2], but not by mineral oil. Rain water dependent deterioration of concrete slab subjected to repeated vehicle load is also well known.

In these backgrounds, compressive fatigue test has been conducted with concrete cylinders in the three different circumstances, i.e. in mineral oil, in water and in no liquid, normal condition. Focusing points are strength, load cycle dependent stiffness and hysteretic stress strain relationship in the present study.

2. Outline of Experimental Test

2.1 Test Cylinder and Curing Condition

Dimension of test cylinder is ϕ75mm×150mm in considering applied load capacity of the testing actuator. Ready mixed concrete is utilized with early aged Portland cement, crushed stone for coarse aggregate, river sand for fine aggregate and air entrained admixture as shown in Table.1. As for the curing, after four weeks water curing in the 20 ℃ temperature has been followed by two weeks dry curing. For less curing period dependence, after 24 hours evaporation in the drying apparatus, cylinders have been wrapped in drying

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condition until loading test. It is noted that specimens for mineral and water dependence were soaked into liquid respectively before load testing.

Age, soaked period, normal compressive strength, testing condition and so on are summarized in Table.2. In the table, date of casting is different among Group A and B. Group B is added not only for increase of number of specimens but for strain measurement. Eight specimens for stress ratio 10 to 80% in Group A is similar reason. Specimens for water dependence in Group B are soaked into water directly after two weeks dry curing. It is noted that no difference is found in compressive strength between mineral oil and normal conditions in the Group A, while 80% compressive strength water dependent specimen.

Table.1 Concrete Mixture

G_{max} (mm)	W/C (%)	s/a (%)	Unit (kg/m^3)			
			W	C	S	G
15	53	45.9	177	334	798	980

Table.2 Summary of Test Parameters

Group	One Week Strength	Environment	Age	Soaked Period	No. of Specimens		Strength	Elastic Modulus	Min.& Max
					Static	Fatigue			
A	19.7	Normal	52		3	5	22	20.8	10～80
		Water	66	14	3	5	16.9	18.2	
		Mineral Oil	92	40	3	8	21.6	20.5	
						5			10～70
						5			10～60
B	22.8	Normal	43		3	4	24.5	20.7	10～80
		Water	45	4	3	5	28	27.4	

2.2 Fatigue Test Procedure

Before the fatigue test, static loading compression test were conducted and obtained strength was utilized as a nominal strength for each case. In the fatigue, lower stress ratio was provide as 10% of nominal strength while upper stress one as 60, 70 and 80% of that for mineral oil case and only 80% of that for referential water and normal(with no liquid) cases. Five Hz cyclic sine wave load was applied with 250kN loading capacity actuator. Loading test was terminated when either compressive failure or decrease below lower stress ratio. Photo-1 shows test set up for mineral oil case where acryl storage tank with steel bottom pale was utilized for liquid case. For some test cases, dynamic strain was measured with strain gages in the middle height of specimen, which was coated with VM tape for liquid tightness.

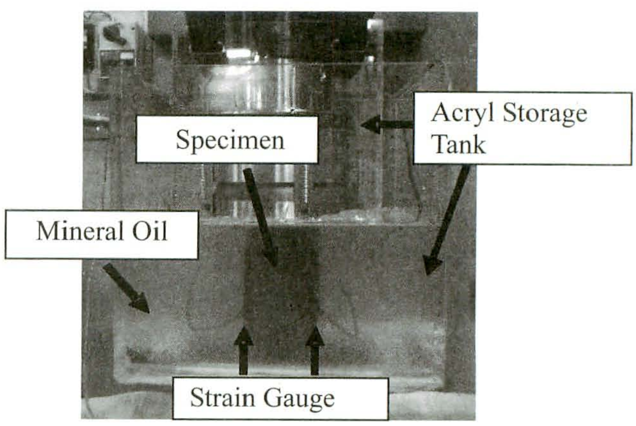

Photo.1 Test Specimen and Set Up

3 Test Results

3.1 Fatigue Life Cycle

Table-3 summarizes test results for all A and B group cases, where statistical analysis was carried out to evaluate fatigue life cycle value. Probable fatigue life cycle number p(Nr) is specified in the following equation, that is defined as lower r^{th} value in total n specimens.

$$p(N_r)=1-r/(n+1) \qquad (1)$$

Linear extrapolation for $p(N_r)$-logNr relationship with minimum square method [4] provides $p(N_{r50})$ as an averaged fatigue life cycle, where $p(N_{r50})= p(N_r)$ becomes 50%.

Fig.1 illustrates upper stress ratio-$\log N_{r50}$ relationship with defined value above, where water drained case provides significant reduction in fatigue life cycle compared with other cases. No reduction is found for mineral oil with 80% upper stress in comparison with water case. One of the reasons is no penetration of mineral oil into concrete core section. High cohesion of mineral oil as shown in Table-4 provides low penetration into potential micro cracks in addition to less inclusion in concrete core section before testing. Eye observation provides no penetration in the cut section of tested specimen.

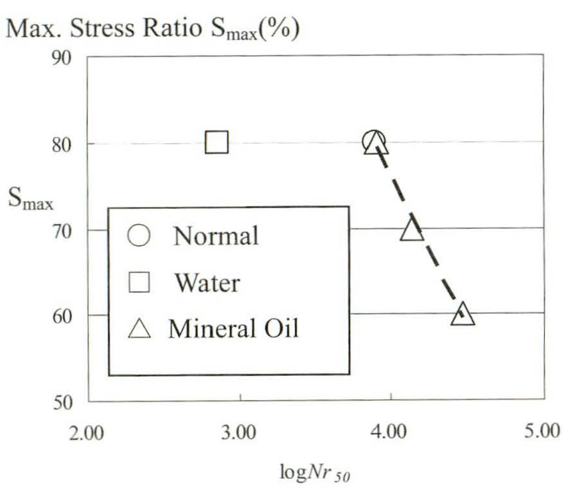

Fig.1 Loading Cycle Dependent Fatigue Strength

Table.3 Summary of Fatigue Test

Env. Condition	S (%)	r	Nr (回)	logNr	p (Nr) (%)
Normal	80	1	27	1.43	90.0
		2	799	2.90	80.0
		3	6825	3.83	70.0
		4	7032	3.85	60.0
		5	14505	4.16	50.0
		6	15282	4.18	40.0
		7	15648	4.19	30.0
		8	93346	4.97	20.0
		9	386900	5.59	10.0
Water	80	1	11	1.04	90.9
		2	131	2.12	81.8
		3	142	2.15	72.7
		4	200	2.30	63.6
		5	925	2.97	54.5
		6	1885	3.28	45.5
		7	3175	3.50	36.4
		8	3930	3.59	27.3
		9	4264	3.63	18.2
		10	9671	3.99	9.1
Mineral Oil	80	1	430	2.63	88.9
		2	466	2.67	77.8
		3	9354	3.97	66.7
		4	11169	4.05	55.6
		5	12395	4.09	44.4
		6	17374	4.24	33.3
		7	44743	4.65	22.2
		8	93993	4.97	11.1
	70	1	1570	3.20	83.3
		2	14620	4.16	66.7
		3	18059	4.26	50.0
		4	22956	4.36	33.3
		5	54233	4.73	16.7
	60	1	905	2.96	83.3
		2	8309	3.92	66.7
		3	71185	4.85	50.0
		4	200770	5.30	33.3
		5	217028	5.34	16.7

Table.4 Cohesion of Water and Mineral Oil

	Cohesion(mm^2/s)
Water	0.295 [5]
Mineral Oil	2～40 [6]

3.2 Hysteretic Stress Strain Relationship

Fig.2 to Fig.6 represents hysteretic stress strain relationship with dynamic strain measured for 80% upper stress ratio for each liquid and normal (no liquid) case, where elastic line obtained in static load test is shown as a reference. The value in the legend of each figure right, is non-dimensional fatigue life, called loading cycle ratio which is defined as the hysteretic cycle number divided by the ultimate cycle one. As increase of loading cycle, hysteretic curve moves to the right because of residual strain increase. And the curve configuration appears from linear to parabolic shape as reported in the reference [7].

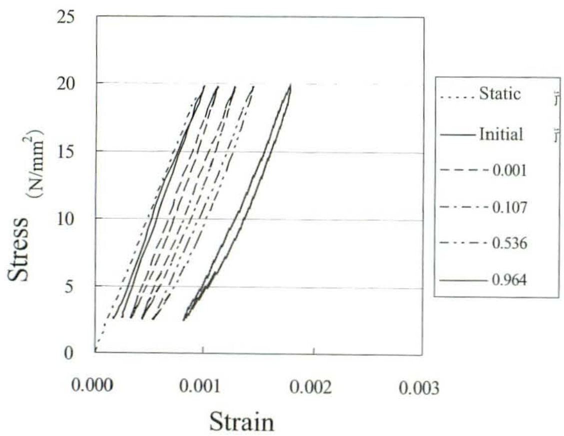

Fig.2 Hysteretic Stress Strain Relationship
(group B Normal, Nr=93346 times)

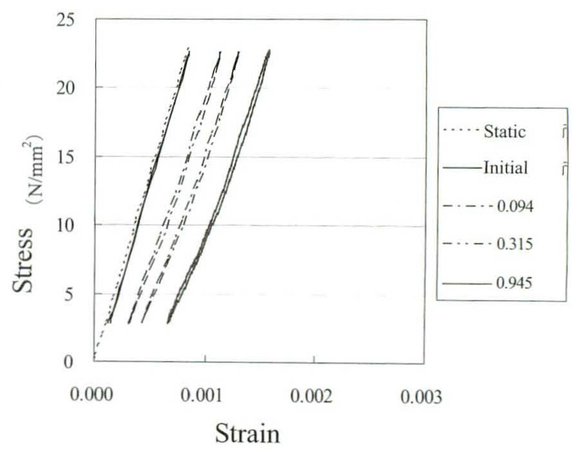

Fig.3 Hysteretic Stress Strain Relationship
(group B Water 1, Nr=3175 times)

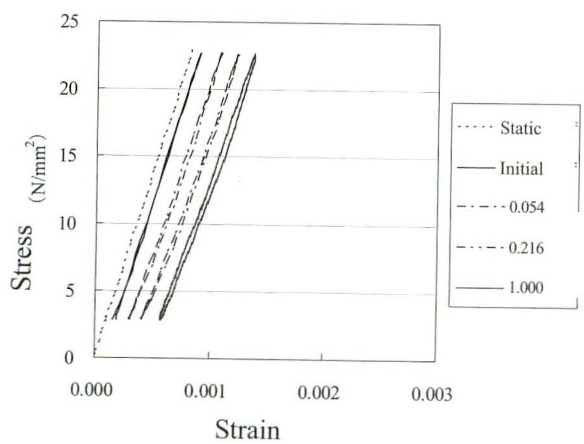

Fig.4 Hysteretic Stress Strain Relationship
(group B Water 2, Nr=925 times)

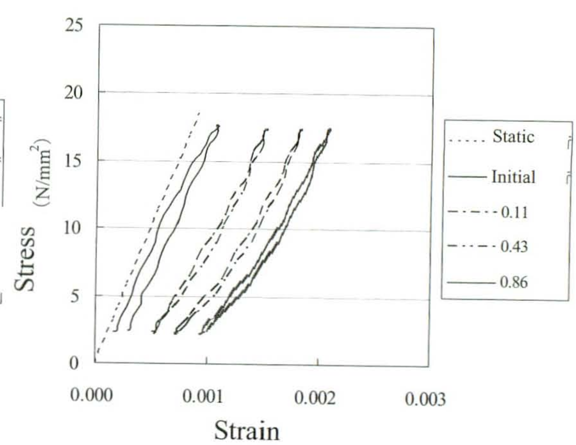

Fig.5 Hysteretic Stress Strain Relationship
(group A Mineral Oil 1, Nr=466 times)

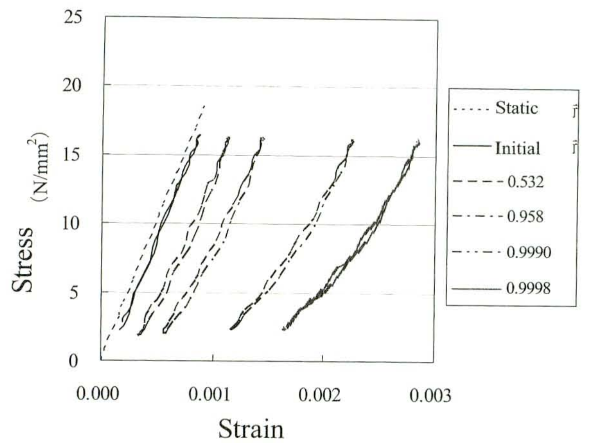

Fig.6 Hysteretic Stress Strain Relationship

(group A Mineral Oil 2, Nr=93993 times)

3.3 Hysteretic Residual Strain

Fig.7 represents loading cycle ratio dependent residual strain for the specimens with 80% upper stress ratio, where the residual strain is defined as that at lowest stress loaded, 10% of normal compressive strength. In the ultimate stage close to 1 for loading cycle ratio, rapid increase of residual strain appears for all the specimens and stable increase appears from initial stage for the normal and water cases, where steeper ascendance appears for the water case rather than normal. The residual strain just before ultimate for water case is larger in comparison with another two cases.

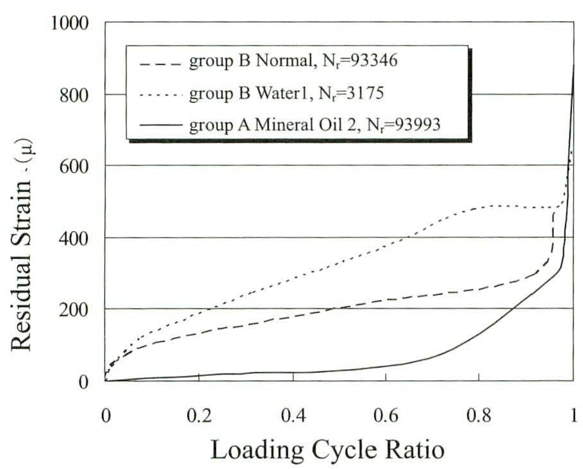

Fig.7 Residual Strain - Loading Cycle Ratio Relationship

3.4 Hysteretic Stiffness

Fig.8 represents loading cycle ratio dependent stiffness ratio for the specimens with 80% upper stress, where the stiffness ratio is defined as initial secant modulus of stress strain relationship divided by that for the first loading cycle. The stiffness ratio for normal case increases down to 0.3 loading cycle ratio followed by constant stage. For the water case, it continuously decreases followed by less inclination after 0.3 loading cycle ratio. For the mineral oil case, it decreases more rapidly in the initial stage followed by stable inclination. In general, the stiffness in the ultimate stage appears around 70% of the initial one. This result agrees with the reference reported 7).

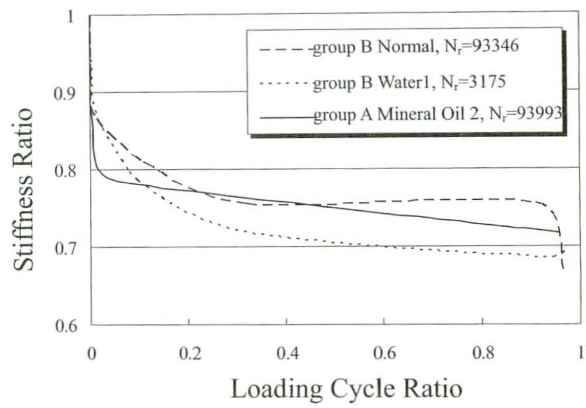

Fig.8 Stiffness Ratio - Loading Cycle Ratio Relationship

3.5 Shape of Stress Strain Relationship

As described in the section 3.2, the stress strain curve appears from linear to parabolic shape. Fig.9 to 11 illustrates shape of these curves for normal, water and mineral oil case respectively, where all the curves are fitted with origin at minimum stress, i.e. 10% stress ratio, each loading cycle. In general, loading and unloading strain increases more up to ultimate stage with loading cycle ratio of 1. No significant difference is found in amount of strain increase between three cases.

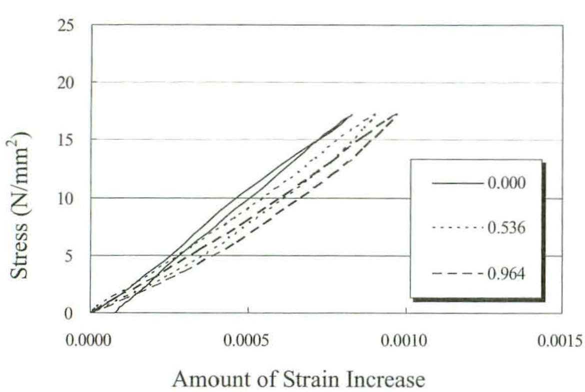

Fig.9 Stress – Strain Increase Relationship
(group B Normal, Nr=93346 times)

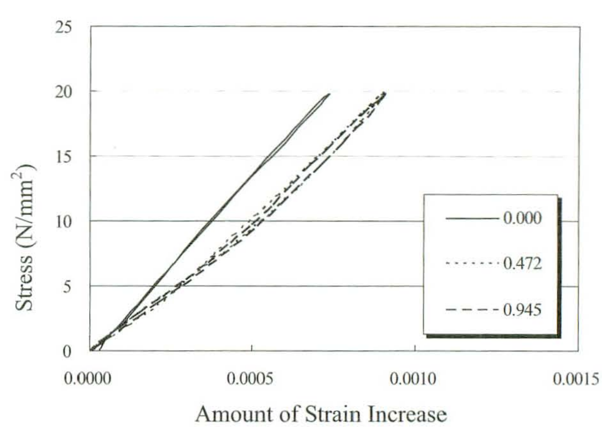

Fig.10 Stress – Strain Increase Relationship
(group B Water 1, Nr=3175 times)

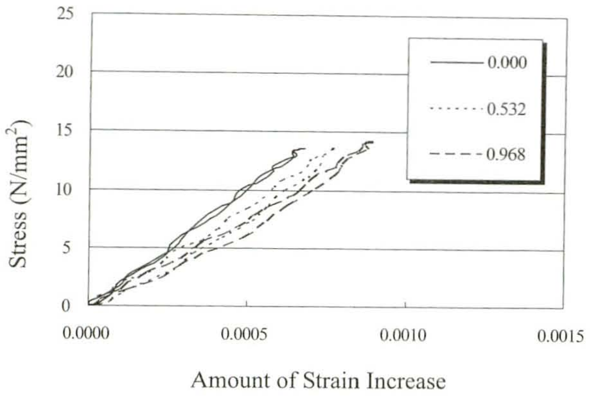

Fig.11 Stress – Strain Increase Relationship
(group A Mineral Oil 2, Nr=93993 times)

4. Concluding Remark

Followings are concluded in the present study.

1) Static compressive strength of concrete soaked in mineral oil is as same as that in normal condition.

2) Fatigue life cycle in mineral oil is as same as that in normal condition and longer than that soaked in water.

3) Stable increase of residual strain during cyclic loading is similar between normal and water soaked cases, while more rapid increase at final stage for mineral oil case.

4) Stiffness just before ultimate is around 70% of initial that for all cases.

5) As the loading cycle increases, stress strain curve configuration appears from linear to downward parabolic shape.

The experimental test provided no significant reduction in mineral oil soaked fatigue strength compared with normal case. In water soaked case, fatigue strength reduction is possible with water pressure wedge action, however some difference in cohesion is considered between water and mineral oil. In addition, the period soaked in mineral oil was 40 days limited. To obtain general conclusions further study is needed including reproduction of mineral oil environmental condition.

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