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STUDIES OF THE LENGTH OF CONCRETE MICRO CRACK ZONE

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Abstract

Resistance wire strain gauges have been used to measure the length of the micro crack zone (MCZ) of concrete, mortar and pure cement paste. As the ligament height increases, the MCZ grows and the structure parameter Dc increases. The length of MCZ decreases with increasing strength. For a given water/cement ratio, the MCZ of concrete is the longest, of mortar the second, and of pure cement paste the shortest. The length of MCZ is not a constant and its structure can be described in fractal theory.

1 Introduction

The concept of micro crack defined by F.O. Slate et al (1968) has been employed in the paper, which regards 0.1 mm as the upper boundary of micro crack and the extreme tensile strain of concrete as the lower. When a crack is wider than the extreme tensile strain, the basic elements of material do not return to their original positions even after unloaded and micro cracks are expected to form at the position where the extreme tensile strain ε_u has been reached. Resistance wire strain gauges can be used to measure the strains at the main crack front of concrete materials.

2 Experiments

2.1 Main test equipments

1. Resistance wire strain gauge: model 5 × 80, resistance 120 ± 0.2 Ω (tested value 119.4~119.8 Ω), sensitivity factor 2.05 ± 0.07%, made in China.
2. Strain measurement: DATA LOGGAR UCAM-5B SERIES, made in Japan. It can print 10 strain values measured simutaneously with resistance wire strain gauge .

2.2 Mixing proportions of cement-based materials

28-day compressive strength, splitting tensile strength and extreme tensile strain ε_u of the specimens are given in Table 1. ε_u in the Table is calculated with the formula:

$$\varepsilon_u = f_1 / E \tag{1}$$

where f_1 is the splitting tensile strength and E the elastic modulus.

Table 1. Mixing proportions and mechanical properties of pure cement paste, mortar and concrete

No.	W/C	Materials (kg/m^3)						Mechanical properties			
		Enhancer	Cement	Water	Sand	Gravel	NF*	fc** (MPa)	f_1 (MPa)	E (10^{10}Pa)	ε_u ($\mu\varepsilon$)
1	0.30	55	495	165	542	1264	5.5	69.4	4.66	3.738	124.6
2	0.30	---	550	165	542	1264	5.5	58.9	4.22	3.622	116.5
3	0.40	---	450	180	575	1222	--	49.7	2.15	3.590	60.1
4	0.45	---	649	292	1297	---	--	53.2	3.01	1.196	252.0
5	0.33	---	1295	427	---	---	--	57.5	2.11	1.104	191.0

* NF--- a kind of superplasticizer. ** fc--- 28d compressive strength.

2.3 Geometry of specimens and positions for strain measurement

Wedge-splitting specimens recommended by RILEM were prepared. The initial crack length was fixed as a_0=3.95 cm for all specimens of pure cement paste, mortar or concrete, while the ligament height H was 14.5 cm,

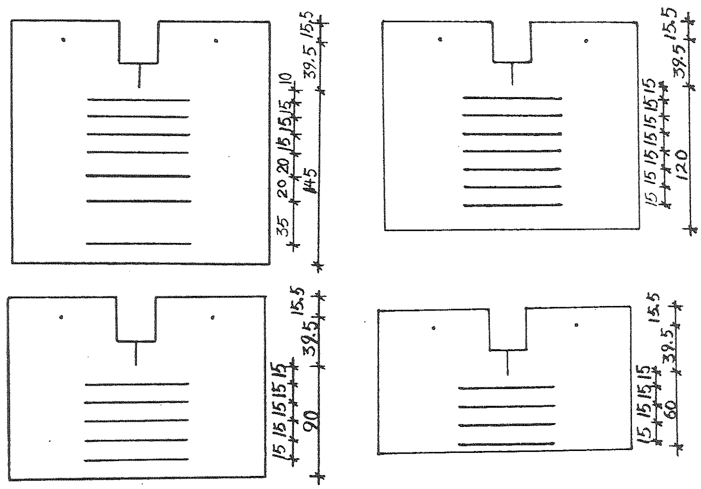

Fig. 1. Positions of the resistance wire strain gauges (represented with lines) on the surface of the specimens with various ligament heights

12 cm, 9 cm and 6 cm, respectively. The positions for strain gauges are shown in Fig. 1.

The strain readings on the electrical strain gauge were printed at a specific load step during tests. The step length was chosen short enough near the maximum load to trace the changes of strain values in the vicinity of peak value in detail .

3 Results

Typical relations between the load P and the strain are shown in Fig. 2. The load-strain curves of concrete, mortar and pure cement paste specimens of different mixing proportions have been converted to curves which reflect the strains of different positions at the main crack front under various load levels.

Figs. 3~6 show the relation between the strain and the distance from the main crack tip for specimens No. 1 (W/C=0.30) which contain enhancement agent; Figs. 7~10 show that of specimens No. 2 (W/C=0.30) which contain no enhancement; Figs. 11~14 of concrete specimens No. 3 (W/C=0.40); Figs. 15~17 of mortar specimens No. 4 (W/C =0.45), and Fig. 18 of pure cement paste specimens No. 5 (W/C=0.33), respectively.

The strains at the crack tip front increase with increasing load level(Figs. 3~6), and the strains change nonlinearly with varying distance D from the main crack tip: strains are very large near the the tip and *vice versa*. Besides, by examing the strain-D relationship, it can be seen that compression zones are present in all specimens. The zero strain point (i.e.

the neutral axis) moves downward to the bottom of the specimen gradually with the increase of load level or the initiation of cracking. A horizontal line representing the strain of ε_u can be drawn on each of these strain-D diagrams, and intersect the strain-D curve at the maximum load. The horizontal abscissa of the intersection represents the length of MCZ. As shown in Figs. 3~6, for specimens with ligament height H of 14.5 cm, 12 cm, 9 cm, 6 cm, the length of MCZ (lp) is 5.92 cm, 3.40 cm, 3.32 cm, 1.94 cm, respectively. The measured lp of concrete, mortar and pure cement paste specimens are listed in Table 2.

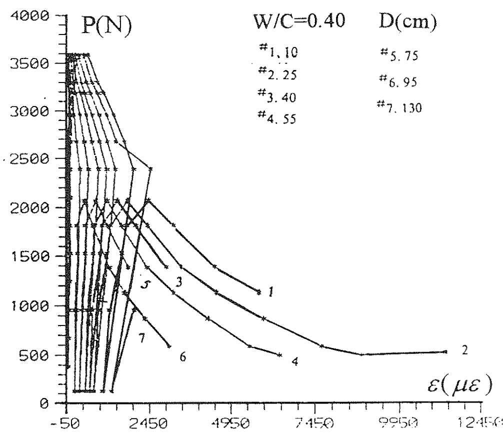

Fig.2. Typical experimental load - strain curves

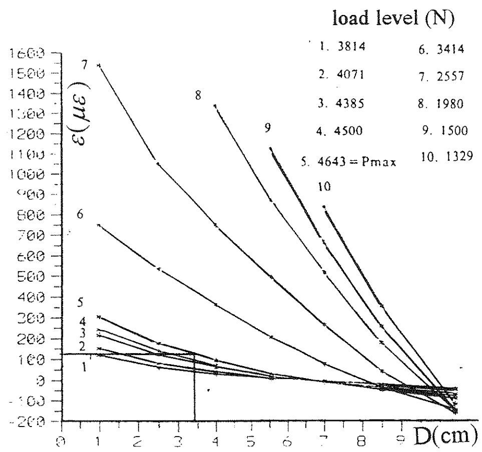

Fig.4. ε versus D of concrete with enhancement agent (H=12cm)

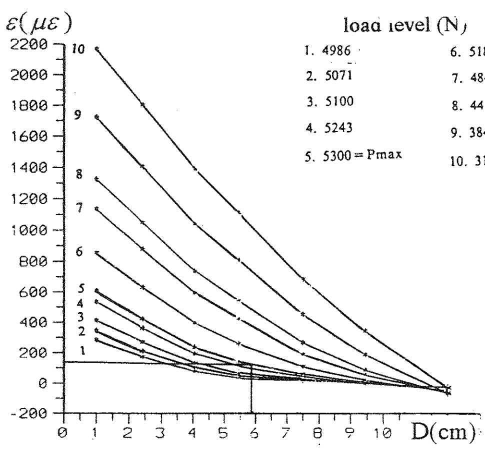

Fig.3. ε (strain) versus D (corresponding distance from the main crack tip) of concrete with enhancement agent (H=14.5cm)

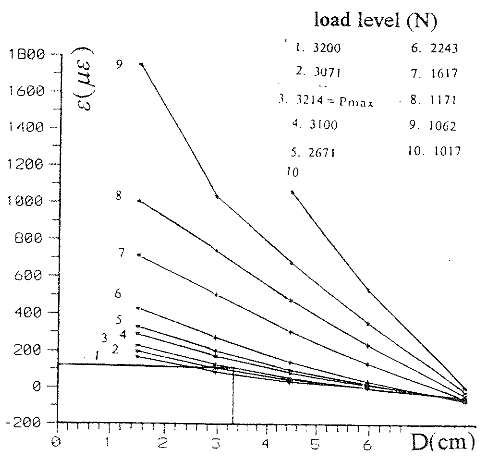

Fig.5 ε versus D of concrete with enhancement agent (H=9cm)

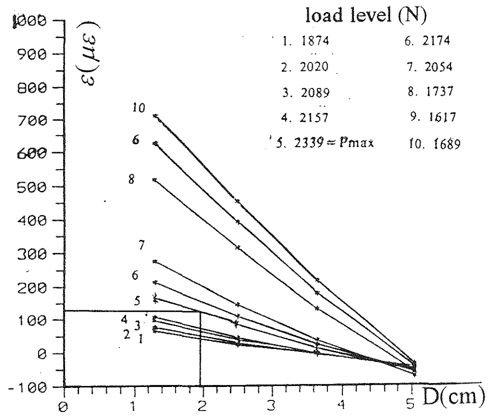

Fig.6 ε versus D of concrete with enhancement agent (H=6cm)

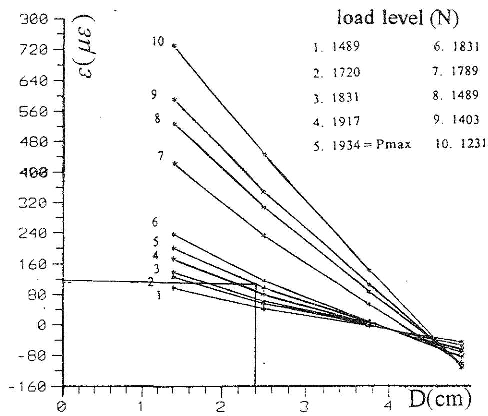

Fig.9 ε versus D of concrete without enhancement agent (H=9cm)

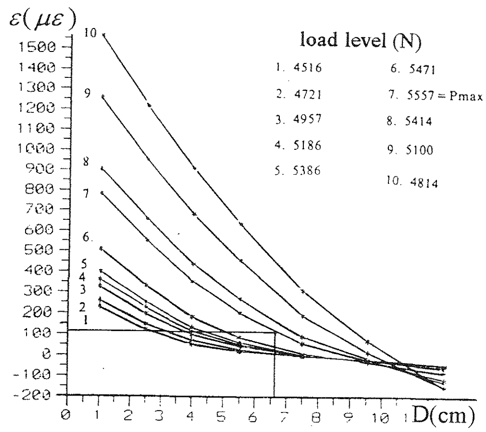

Fig.7 ε versus D of concrete without enhancement agent (H=14.5cm)

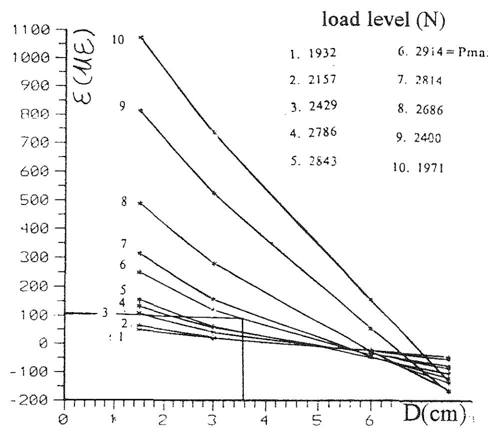

Fig.10 ε versus D of concrete without enhancement agent (H=6cm)

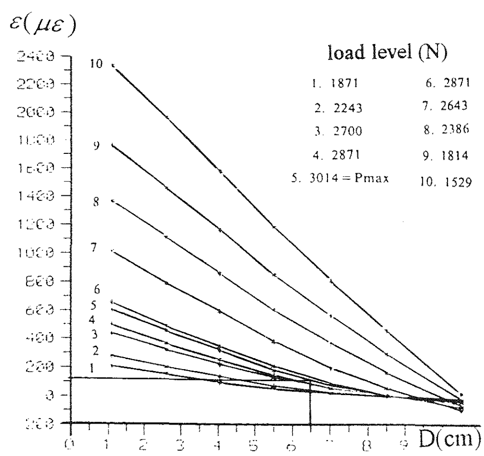

Fig.8 ε versus D of concrete without enhancement agent (H=12cm)

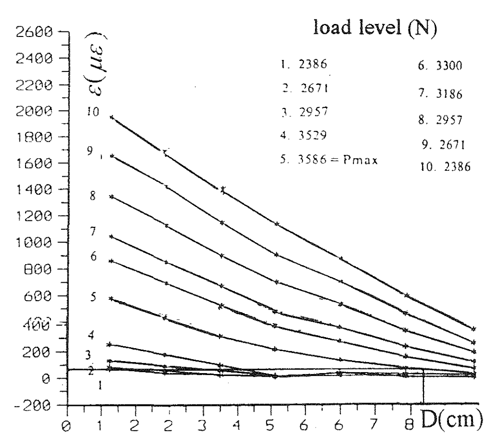

Fig.11 ε versus D of concrete of W/C=0.40 (H=14.5cm)

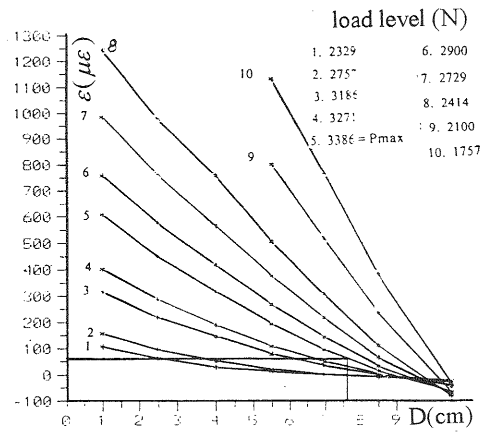

Fig.12 ε versus D of concrete with W/C=0.40 (H=12cm)

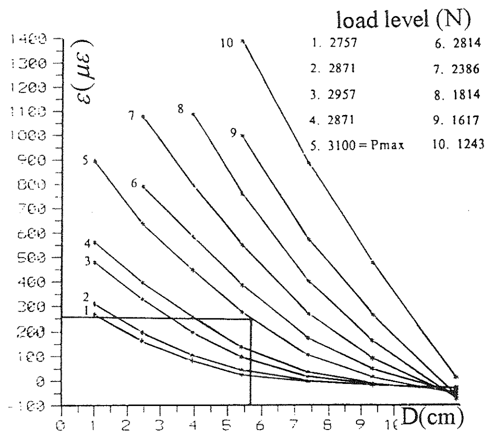

Fig.15 ε versus D of mortar (H=14.5cm)

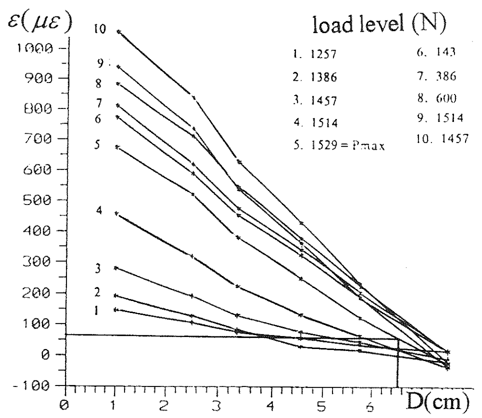

Fig.13 ε versus D of concrete with W/C=0.40 (H=9cm)

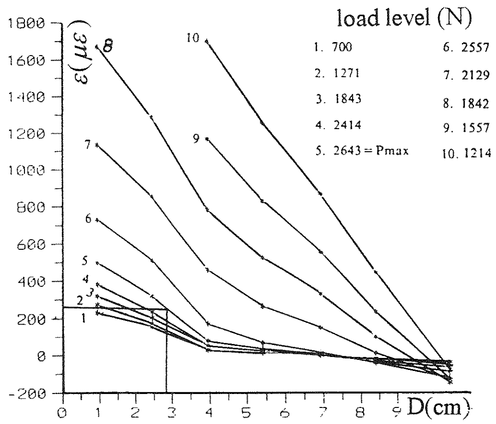

Fig.16 ε versus D of mortar (H=12cm)

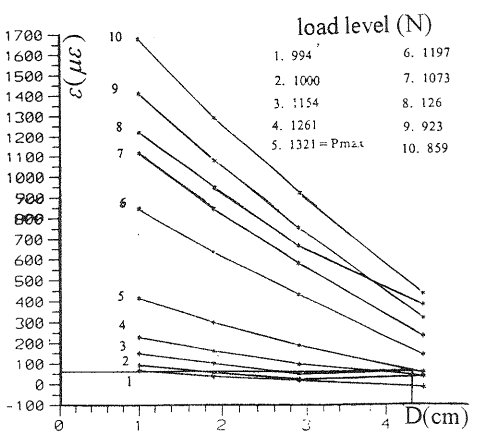

Fig.14 ε versus D of concrete with W/C=0.40 (H=6cm)

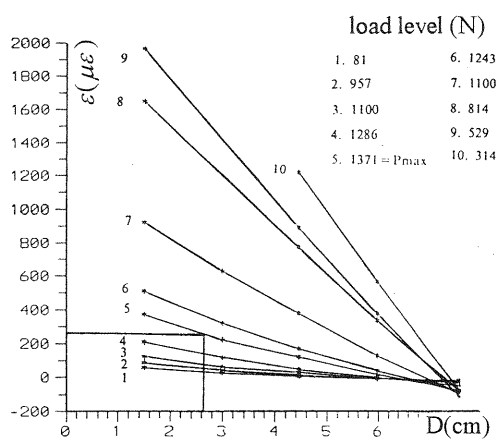

Fig.17 ε versus D of mortar(H=9 cm)

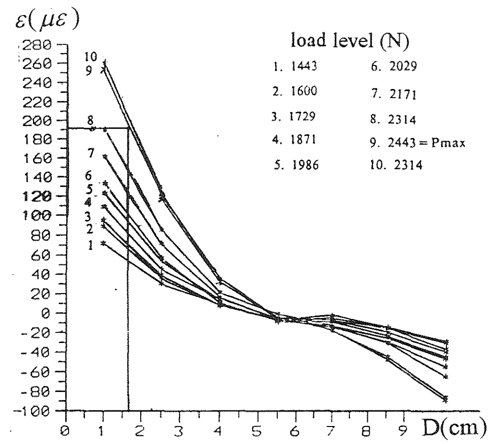

Fig. 18 ε versus D of pure cement paste (H=12cm)

Table 2. Length of MCZ of pure cement paste, mortar and concrete

No.	Material	H (cm)			
		14.5	12	9	6
		lp (cm)			
1	concrete*(W/C=0.3)	5.92	3.40	3.32	1.94
2	concrete(W/C=0.3)	6.60	6.50	3.56	2.40
3	concrete(W/C=0.4)	8.32	7.52	6.56	4.37
4	mortar		2.80	2.64	
5	cement paste		1.70		

* Concrete contains enhancement agent.

It is apparent from Table 2 that:

1. lp increases with H;
2. lp decreases with increasing strength for the concrete with enhancement;
3. The length of the MCZ of pure cement paste is the shortest, mortar the second, concrete the longest. The less obvious size effect of pure cement paste and mortar specimens compared to concrete is considered to be due to their smaller MCZ.

Corresponding to measurement of the length of the MCZ, fracture energy Gf, fracture toughness relating to H of concrete, mortar as well as pure cement paste are shown in Fig. 19~22. The relationship between fracture energy and ligament height conforms to the formula:

$$G_f = 2\gamma_s C'' H^{D_c - 1}, \quad (2)$$

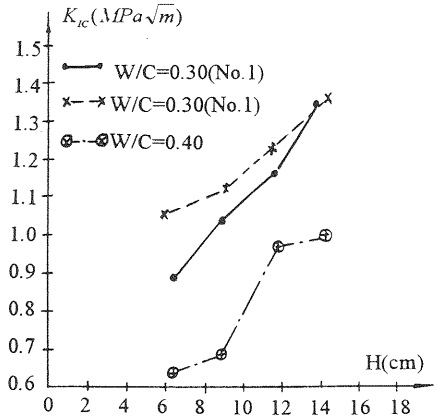

Fig.19 K_{IC} versus H of concrete with different W/C

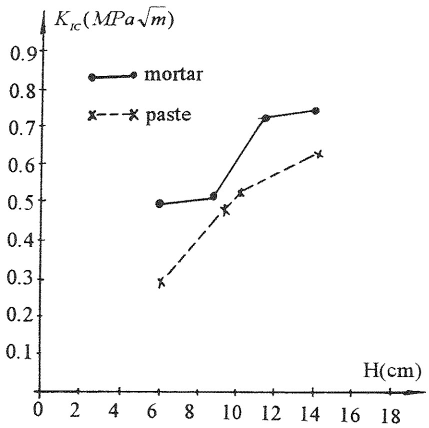

Fig.20 K_{IC} versus H of mortar and cement paste

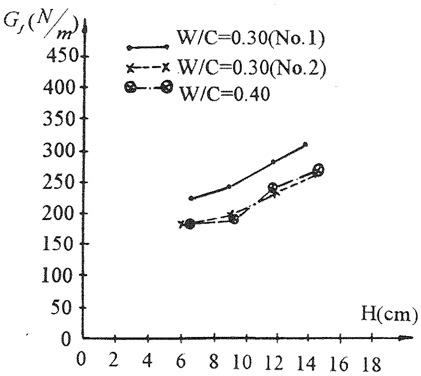

Fig.21 G_f versus H of concrete

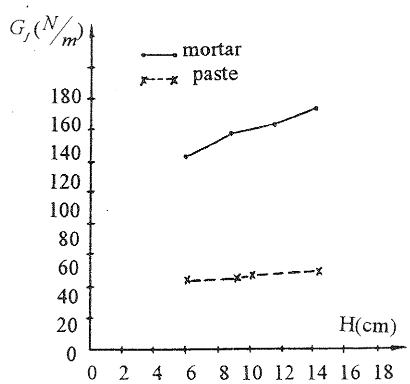

Fig.22 G_f versus H of mortar and cement paste

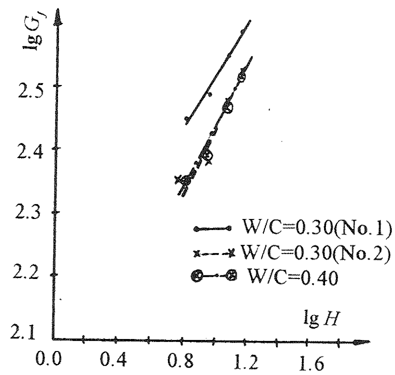

Fig.23 lg(G_f) versus lg(H) of concrete

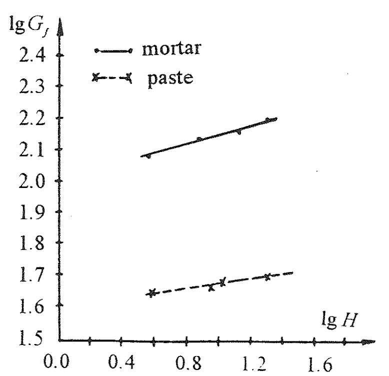

Fig.24 lg(G_f) versus lg(H) of mortar and cement paste where γ_s is the surface energy of concrete, D_c the fractal dimension of the crack structure, and C" a coefficient. Straight lines regressed in $lg(G_f)$-$lg(H)$ coordinate are shown in Figs. 23~24. Regression results are in Table 3.

Table 3. Regression results in $lg(G_f)$-$lg(H)$ coordinate

Material	K(slope)	Dc(fractal dimension)	S(intercept)	r(correlation coefficient)
concrete*(W/C=0.3)	0.4435	1.4435	1.9814	0.989
concrete (W/C=0.3)	0.4646	1.4646	1.8793	0.946
concrete (W/C=0.4)	0.4949	1.4949	1.8442	0.985
mortar	0.2612	1.2612	1.8849	0.991
pure cement paste	0.1384	1.1384	1.534	0.964

* Contains enhancement agent

From Table 3, the fractal dimension D_c in descending order is: concrete with W/C=0.40, 0.30, and 0.30 with enhancement, and mortar, pure cement paste. It is apparent that D_c is greater with increasing length of MCZ. Consequently, D_c can be regarded as a parameter representing the microscopic crack structure of the micro crack zone. So fractal dimension theory can be used to describe the micro crack structure.

4 Conclusions

Measurement results of the length of the MCZ of concrete, mortar and pure cement paste show that:

1. The length of MCZ increases with increasing ligament height H and decreases with increasing concrete strength.
2. For a given water/cement ratio, the MCZ of concrete is the largest, mortar the second, pure cement paste the shortest.
3. Fractal dimension D_c as a structural parameter increases with the increase of the length of MCZ, so the structure of MCZ can be described in fractal dimension theory.

5 References

Slate, F.O. et al. (1968) Deformation of plain concrete, in **Proceedings of 5th International Symposium on the Chemistry of Cement**, Tokyo, Japan