DURABILITY AND FRACTURE PROPERTIES OF VARIOUS SHAPE CARBON FIBER REINFORCED LIGHT-WEIGHT CEMENT COMPOSITES

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Introduction

In the non-circular shape carbon fiber reinforcement, its fiber retains the interfacial bonding force with matrix greater than that of round-shape in the contact area between fibers and matrix. Reinforcing effect of C shape carbon fiber reinforced cement composites were increased than any other shapes.[1-2]

So in this study, durability and fracture properties of the carbon fiber reinforced light-weight cement composites were investigated by means of the reinforcing effect of various carbon fiber shapes from the dry shrinkage, freezing and thawing, single notched beam test. Crack propagation and microstructure on the fractured surface after CMOD test was observed by scanning electron microscope.

Theory

For given values of composite load P, and crack mouth opening displacement(CMOD), the corresponding crack length can be calculated can be calculated from linear elastic fracture mechanics(LEFM) formulation.[3-4] $CMOD=(6Psa/E_c d2t_c)V_1(a/d)$---(1), $V_1(a/d)=[0.76-28(a/d)+3.38(a/d)^2-2.04(a/d)^3+\{0.66/(1-a/d)^2\}]$, where t_c and E_c are thickness and young's modulus of the composite beam section, s and d are span and depth of the beam, a is the crack length. Because of fiber portion and the matrix portion of the beam have the same deformation and crack extension under the assumption of equal strains. The load resisted by the fiber portion P_f, can be estimated after knowing the values of CMOD and the corresponding crack length at different load levels, $P_f=E_f d^2 t_f CMOD/6saV_1(a/d)$---(2) where E_f is the modulus of the fiber, $t_f=\eta\, dV_f$ is the effective thickness of the fiber portion of the beam, and η is the fiber efficiency factor. Stress intensity factor, $K_{1C}=\sigma\sqrt{(\pi a)}F_1(a/d)$ ---(3), $F_1(a/d)=1.122-1.40(a/d)+7.33(a/d)-3.08(a/d)^3+14.0(a/d)^4$, where σ is the flexural stress. Crack tip opening displacement, $CTOD=CMODZ[\alpha(a),\beta(a)]$---(4), where $\alpha(a)=a/d$, $\beta(a)=a_0/a$ and $Z[\alpha(a),\beta(a)]=[(1-\beta(a))^2+(1.081-1.49\beta(a))(\beta(a)-\beta^2(a))]^{1/2}$, a_0 is initial crack (notch) length

Experimental

CFRC were mixed with ordinary Portland cement(OPC, Ssangyong cement), light-weight fine aggregate(Sirasu Balloon ; MSB301, micro cell ; SL150 , bulk density ; 0.35～0.4), silica fume(specific surface area 20㎡/g). admixtures were used superplasticizer (Mighty-150), methyl cellulose (BMC-324), and anti-forming agent (Agitan-803). Typical formulation of CFRC is shown in Table 1. Table 2 shows the properties of manufactured carbon fiber in the Lab from AR-20 mesophase pitch. Specimens of test of durability and fracture were prepared as a follow process : firstly, carbon fiber with dry materials were mixed for 5min and water added mixtures was mixed for 5minutes in an Omni mixer. Secondly, the wet mixtures were cast for a dry shrinkage, freezing and thawing, fracture specimen, 40×40×160 ㎜ by JIS R 5201 and A 1106. Finally, the cast samples were cured at 20℃ with 80% RH for 2days, and autoclave-cured at 180℃ with 10atm for 4hrs, and then dried at room temperature for 14 days. Dry shrinkage and freezing test applied KS F 2424, KS F 2456, CMOD is tested by ACI-SP155-2 and SP-155-5. Where the single edge(notch) length is 0.275d, and the load was applied at a displacement rate of 0.3mm/min cross head speed by the center point load method. CMOD is measured by gage(TML PI-2-50). And crack propagation and SEM observed microstructure of fracture surface after single notched beam test for CMOD.

Result and Discusion

Drying shrinkage and resistance to freezing and thawing were determined as durability tests. CFRC showed big shrinkage during the autoclave curing. It was, however, little after autoclave curing. Fig. 1 shows the length as a function of dry curing times for CFRC fiber length and volume of 6mm, 2% respectively. Less shrinkage was found in composite with C shape carbon fiber. As shown in fig. 2, Relative dynamic modulus of elasticty of CFRC was dramatically increased with increasing fiber length. Better resistance to freezing and thawing was noticed in composites with shorter fiber and large content. There was little shape effect.

Fracture toughness and resistance to crack propagation was better in composite with C shape carbon fiber, which were resulted from the more absorption of fracture energy at the larger interface by table 3-4.

There were superior in the order of composites with C shape, Round, and Hollow shape carbon fiber. The inside space of C-shape was compacted by the matrix and the fiber acted as a mechanical anchor. Fracture behavior at the crack tips was analyzed with stress intensity factor and crack mouth opening displacement at the stage of crack initiation in carbon fiber reinforced cement composite. And, Fig. 3 shows the length effect of C-shape, load and deflection curve is shifted with increasing fiber length by means of bridging effect.

Reference

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Table 1. Mixing ratios of cement matrix for CFRC(wt%)

Fine aggregates			Admixtures (C x wt.%)			Ordinary Portland Cement	W/C
Sirsu Balloon	Micro cell	Silica Fume	BMC	A-803	M150		
15	5	16	0.25	0.5	3.0	100	0.465
31	5	-					

* Carbon fiber : 1~3 V_f%, 3~25 mm, C,H,R shape respectively
**C : C shape CF, H : Hollow shape CF, R : Round shape CF

Table 2. properties of AR 20-mesophase pitch based carbon fiber(from JIS R 7601)

Fiber Shape	Tensile Strength (Kg_f/cm^2)	Tensile Modulus (Kg_f/cm^2)	Diameter (μm)	Cross Sectional Area (μm²)
C open=120°	9,200	794,000	Do 40.2 Di 22.8	574.0
Hollow	8,300	943,000	Do 36.1 Di 23.8	589.8
Round	8,600	1,130,000	26.8	564.1

Table 3. Calculated and tested result from notched beams

Condition	Fiber Shape	t_f(mm)	η	CMOD(mm)	E_f (Kgf/mm²)	P_f (Kgf/cm²)
6mm-2% with SF	C	0.291	0.364	0.08	10,244	3.609
	Hollow	0.281	0.352	0.09	11,857	4,538
	Round	0.275	0.344	0.10	7,158	2,979
6mm-2% without SF	C	0.219	0.274	0.07	10,244	2,376
	Hollow	0.204	0.255	0.04	11,857	1,464
	Round	0.198	0.247	0.06	7,158	1,287

Table 4. Critical stress intensity factor of various CFRC

Shapes	C	Hollow	Round	Remark
K_{IC}(Kgf/mm$^{3/2}$)	595.8	536.3	555.0	By Eq. 3

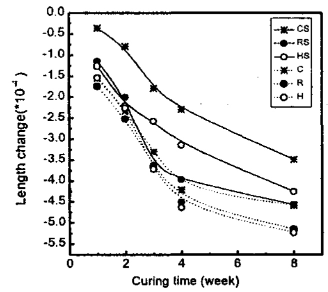

Fig. 1 Relationship between length change and curing time of CFRC added with or without silica fume according to fiber shapes. Fiber length = 6mm, V_f=2%

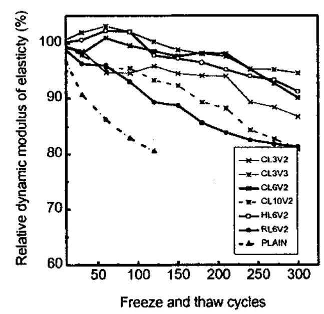

Fig. 2 Relationship between relative dynamic modulus of elasticity and freeze/thaw cycles of CFRC using silica fume according to fiber shapes, fiber length and fiber volume.(CL3V2; C shape, length 3mm, volume 2%)

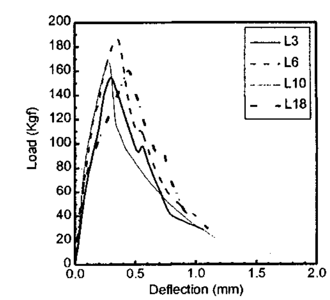

Fig. 3 Effect of carbon fiber length : flexural load versus deflection from flexural test in C shape CFRC using silica fume.(V_f=2%, S=2.5d, a_0=0.275d, L3:length 3mm)