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Potential of Noncircular Fiber as Reinforcing Material
I. C-type carbon fiber

Hwan-Boh Shim, Bo-Sung Rhee
Department of Chemical Engineering, Chungnam National University

초 록 비슷한 역학적 특성을 갖는 단면의 형상이 C형인 탄소섬유와 전형적인 원형탄소섬유를 에폭시를 모재로 하여 상호의 단면 형상이 강화 효과에 미치는 영향을 실험하였다. 실험결과 C형 탄소섬유 강화 복합재가 굴곡강도(218%), 굴곡탄성률(223%), 층간전단강도(157%), 충격강도(227%), 횡굴곡강도(184%) 등의 모든 기계적 특성 부분에서 우수한 성능을 보였으며, 또한 재료의 피로수명, 마찰/마모계수와 같은 기계적 특성과도 많은 상관을 보이는 것으로 알려진 制振(damping)특성에 있어서도 약 185% 정도의 높은 값을 보였다. 본 연구팀은 이와같은 비원형 탄소섬유(C형)의 강화 효과및 가능성을 확인하여 제시하는 바 이다.

Abstract The reinforcing effect of C-shape carbon fiber was investigated as comparing to typical round-shape fiber with similar properties. The results show that C-shape fiber reinforced materials have better in almost all aspects of mechanical properties, or 218% in flexural strength, 223% flexural modulus, 157% interlamina shear strength, 227% impact strength, 184% transverse flexural strength and so on. Also in damping characteristics considerably concerned with fatigue life, friction/wear coefficient of a material, C-CF/EP had about 185% greater. In this research, we present the potential of non-circular fiber reinforcing materials by C-shape carbon fiber.

Key-words : C-shape carbon fiber, damping effect

1. INTRODUCTION

The cross-section of reinforcement fiber in fibrous composites is generally round-shape. In sturctural mechanics, as the optimization of the stress distribution of a material, some design engineers proved that hollow or noncircular-shape is better than round one in mechanical properties[1] and that they has applied in many structural materials, such as I-beam train road, construction support pipe/pile rod, etc. We applied in fiber the concepts like this and got better properties than the conventional round-shape carbon fiber. Especially C-shaped carbon fiber has a curved area in the surface contacting with matrices which would improve interfacial bonding force. The phenomina result would solve a delamination, playing a great part in the mechanical properties of these fiber reinforced composite materials. From the mid of 1980', the researches on non-circular carbon fibers have been proceeding as the moot forcus on microstructure, optimization of preparation process, and mechanical properies of them.[2~5] And in these studies, the potential of non-cirsular fibers has been proposed by research institutes, such as Karlsruhe University, Clemson University and Chungnam National University. But the realization of composites reinforced with these fiber is almost nil.[6]

So in this research, we studied on the reinforcing efforts of C-shape carbon filber among the noncircular shapes by using SEM, INSTRON and FFT-analyzer.

2. MATERIALS & METHODS

2－1 Materials

The resin used to this study was the general performance YD-128 epoxy resin with bifunctional group made in KUKDO Chem. Co. Ltd. The curing agent of this system was aromatic primary amine, 1,3 - phenylenediamine. And the reinforcing fibers were prepared from an isotropic pitch derived from Naptha Cracking Bottom oil, NCB oil which was treated under the condition of heat treatment of each 3hrs in 390 and 350℃, respectively.

2－2 CFRP preparation

Prepreg

Fibers were spun by monohole. Preparing the prepreg, we must pay much attention to it. It is difficult to adequeatly get the properties of composites reinforced with C-shape carbon fiber. For comparing to C-shape carbon fiber reinforced material with round shape one, each fiber was balanced by the same weight, and then a prepreg was fabricated by YD-128 epoxy resin as matrix and 1,3-phenylenediamine hardener.

Curing

To manufacture the composite samples, prepregs were cured according to the results of DSC and Rheometer(RFS-2). The first curing step was 60℃(1hr), exthotherm start point and second step was 150℃(1hr), enthotherm start pont. Also, the curing pressure($40Kg_f/cm^2$) was induced at 80℃, showing the minimum viscosity measured by RFS-2 Rheometer.

2－3 Properties of sample

Flexural testing was performed in accord with ASTM 790. The sample was manufactured as the size of 60×10×2mm and measured by 3point-bending method with cross head speed of 2mm/min.

ILSS : ASTM D 2344, size(20×10×2mm), span length(10mm)

Impact strength : By TINUS OLSEN, size (60×10×2mm)

Damping effect was evaluated by ONO-SOKI CF-920 MINI FFT-analyzer. And the sample size was 150×50×2mm. The measuring frequency was in the range of 0 to 500Hz.

3. RESULTS & DISCUSSION

In the fiber reinforced plastic composites, the interfacial properties between fiber and matrix affect the transverse and shear properties as well as a load transfer. The interfaces of these systems are mainly composed of three types of bonds, such as ① chemical, ② electrical and/or ③ mechanical bonds. The interfacial bond like this is related to failure mode, modulus, interlamina shear and compressive strength of fibrous composites.

In this research, it is assumed that the bonds of ①, ② is equal in the same material, that is, where it was the epoxy resin and carbon fiber as matrix and reinforcement, respectively. So, we can consider only the case of ③ mechanical bond. In the case of the C-shape reinforcement, its fiber retain the interfacial bonding force with matrix resin greater than that of round-shape, because it has wider than that of round-shape in the contact area with matrix. Therefore the load applied can be effectively transfered.

Fig. 1 shows the schematic drawings of C-type and round-type for calculating the contact area. The theoretical contact area with matrix is calculated and the load transfer capacity can be expected as following.

(Assumptions)

(a) The average open degree of C-shape carbon fiber is 90°.,

(b) The cross-sectional area between C-shape and R-shape carbon fibers is equal.,

(c) The bonding between fiber and matrix is perfect.

The cross-sectional area of round-shape, A_R

$$A_R=\frac{\pi}{4}d^2 \quad (1)$$

The C-shape cross-sectional area, A_C

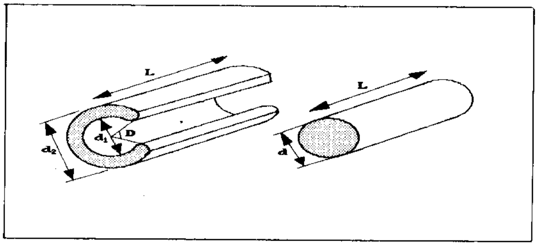

Fig. 1

$$A_C = \frac{360-D}{360} \times \frac{\pi}{4} \times (d_2^2 - d_1^2) \quad (2)$$

From the assumption (a), equation (2) is

$$A_C = \frac{3\pi}{16} \times (d_2^2 - d_1^2) \quad (3)$$

Also, from the assumption (b), equation (2) and (3) the relationship among diameters of the two models is summerized as.

$$d = \frac{\sqrt{3(d_2^2 - d_1^2)}}{2} \quad (4)$$

On the other hand, the contact area with matrix, CA

CA of round-shape,

$$CA_R = \pi dL = \frac{\pi L\sqrt{3(d_2^2 - d_1^2)}}{2} \quad (5)$$

CA of C-shape,

$$CA_C = \frac{3\pi L(d_2+d_1)}{4} + L(d_2 - d_1) \quad (6)$$

Therefore, the ratio of contact area, SA, between C-shape and round-shape from equation (5) and (6) is

$$SA = \frac{CA_C}{CA_R} = \frac{\frac{3\pi L(d_2+d_1)}{4} + L(d_2-d_1)}{\frac{\pi L\sqrt{3(d_2^2-d_1^2)}}{2}} \quad (7)$$

Where, if $d_2/d_1 = \xi$, equation (7) is

$$SA = \frac{3\pi(\xi+1)+4(\xi-1)}{2\pi\sqrt{3(\xi^2-1)}} \quad (8)$$

And if, ξ, the ratio of outside diameter for inside diameter, is 1.25, SA = 2.72.

C-shape reinforced materials will be have more effective load transfer capacity than round reinforced one for the same applied stress(based on stress = [load/area] from "load→matrix→fiber→total system"), because the contact area of C-type carbon fiber is 2.72 greater than that of round carbon fiber, which cross-sectional area is equal each other.

Table 1 shows the characteristics of C-type and round-type carbon fibers. The average cross-section area measured by image analyzer is almost the same as 379μm^2 and 358μm^2 for C-shape and round-shape, respectively. Tensile strength and modulus of these fibers are not much different, but in the case of torsional regidity property C-shape carbon fiber was about two times greater than that of round-shape. It is due to the shape factor of each fiber.

Table 1. Characteristics of monofilament carbon fiber used to composites

Carbon Fiber Shape	Properties(Average Values)				
	TS, kg/mm²	TM, ton/mm²	TR, GN/m²	D, μm	CAS, μm²
Round	95	5.5	4.8	22	379
C-shape	102	6.2	12.2	27(11)	358
Improve(%)	107	11.3	222	–	–

*TS : tensile strength, TM : tensile modulus, TR : torsional rigidity, D : diameter, CSA : cross-sectional area

And table 2 shows the steady properties of the composites. The mass fractions of the fibers were about 70%. Table 3 shows the mechanical properties of the composites. The flexural strength and modulus values revealed that C-shape carbon fiber reinforced materials were improved by 218% and 223%, respectively, comparing to round-shape carbon

Table 2. Steady-Properties of CF/EP system

Composites	Weight, g		Density, g/cm³	Fiber Mass
	Fiber	CF/EP	CF/EP	Fraction
R-CF/EP	15	22.283	1.438	0.673
C-CF/EP	15	21.565	1.486	0.693

Table 3. Mechanical properties of composites reinforced by C-shape and R-shape carbon fiber

Specimen	FS, MPa		FM, GPa		ILSS, MPa		IS, kg·cm/cm²		TFS, MPa	
No.	R	C	R	C	R	C	R	C	R	C
1	102	302	1.32	2.48	10.4	15.8	10.8	23.7	8.20	16.2
2	84.2	248	1.20	2.56	9.28	14.3	8.40	26.4	7.10	13.6
3	140	285	0.29	1.92	11.5	15.9	12.5	15.2	8.40	15.8
4	200	258	1.02	2.53	6.43	12.0	10.6	20.5	9.80	16.9
5	110	294	1.06	1.63	6.60	11.3	5.20	22.4	8.00	14.2
Mean	127	277	0.98	2.19	8.85	13.9	9.5	21.6	8.30	15.3
Std.D.	45.5	23.3	0.40	0.40	2.28	2.13	2.80	4.20	0.97	1.39

fiber reinforced one. This is due to the stiffness of C-shape carbon fiber, itself and the effective stress interaction between fiber and matrix as the matrix resin is impartially contributed to the hollow-out of C-shape carbon fiber. ILSS and transversal strength increased to 157%, 184%. Because it has the curved-area along the fiber axis and the contact area with matrix is wider and lead to the greater friction force, C-shape carbon fiber showed better properties than that of round-shape. The comparison values of impact strength also showed the 227% improving. This data were evaluated as the above results due to the effective load transfer. In all mechanical properties, C-shape reinforced materials show better reinforcing effect. Also in construction materials, damping capacity is an important propertiy to be taken into account together with other physicomechanical characteristics.[7] Fig. 2(a) and (b) show the transfer functions of the composite materials reinforced with round carbon fiber or C-shape carbon fiber, respectively. Based on these functions, the damping factors of both materials were calculated by 3dB decreasing method.[8] The results of damping factor, and various charateristic values calculated from fig. 2 are arranged in table 4. The result shows that C-shape reinforced materials were greater values than round carbon fiber reinforced materials by about 185%. We found out that C-shape carbon fiber plays more important role in damping of fiber reinforced plas-

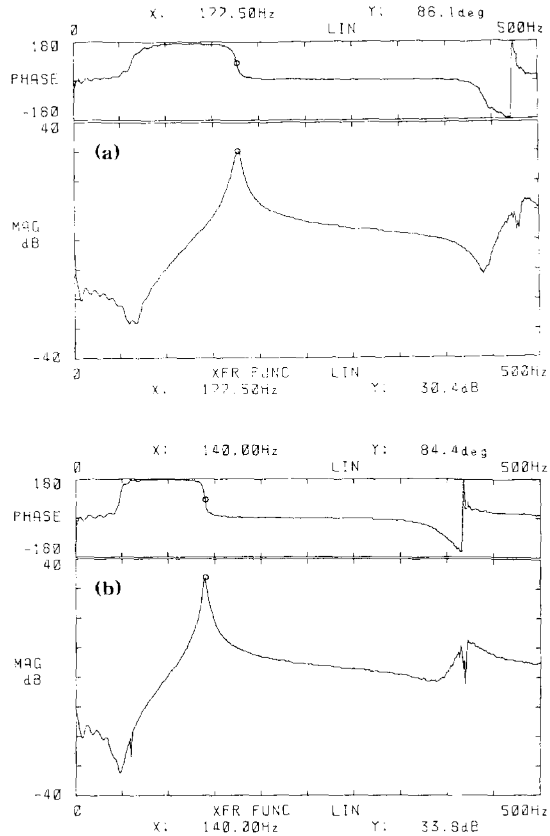

Fig 2

Table 4. Vibration properties of two CF/EP system

Composites	Natural Frequency, Hz	Magnitude, dB	Phase, deg.	Damping Factor
R-CF/EP	177	30.4	86.1	0.026
C-CF/EP	140	33.6	84.4	0.048

tics than round fiber. Bsed on the path of the applied stress "① load⇒② matrix⇒③ fiber⇒④ composite system" the effective interaction between ② and ③ step can easily transfer the load applied.

Conclusively, the reinforcing effect of non-circular(C-shape) fiber is due to wider contact area, and we proved out having the advantages of preparing the high strength composites. We made sure of the superiority of the mechanical and vibrational properties for C-shape carbon fiber. Also, we can viewly certify it as observing the failure mode by using SEM. Fig. 3(a) is SEM photo of the bundle of C-shape carbon fiber, which has long hollowed - out along the fiber axis, making

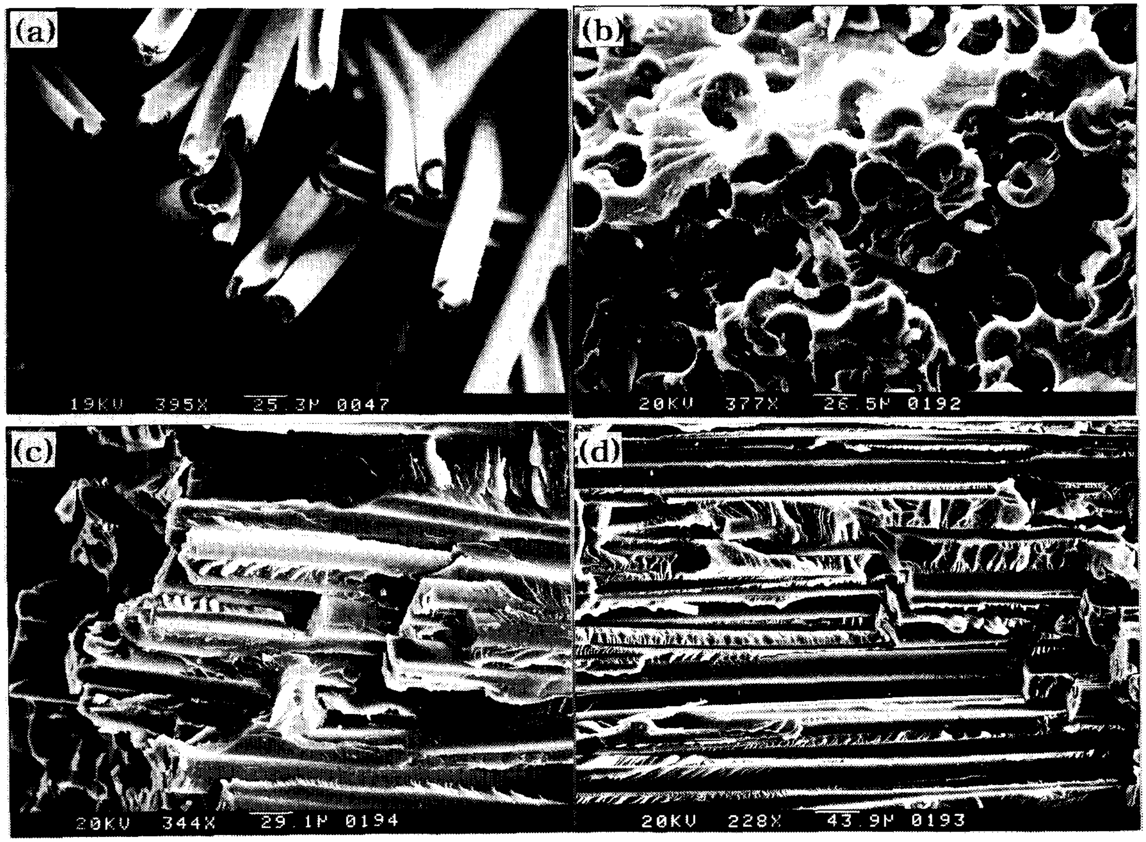

Fig 3

it expected to greater interface. Photo (b) shows the failure surface of the sample after flexural test. Up to the curved area of the fibers, matrix was impratially contributed and had a good wettability. These results can also make sure from the SEM photos of fig. 3(c) and (d) which show the failure modes of the fiber side, matrix side, respectively after breaking the sample along the fibers. The matrices engulfed by the hollowed-out area of the C-shape fiber keep still intact. This allows the matrix to secure more bonds. Also, in the case of the matrix side the failure modes like scale (Fig. 3(d)) intimate the better adhesive force between two phases, which can effectively transfer the load applied to the fiber reinforced composite system.

4. CONCLUSIONS

A curved area of C-shaped carbon fiber regared as a parallel solution to the surface treatment of the smooth round carbon fiber lead to increase the surface area of the fiber to permit better wetting and make available more area to adhere to.

As a result, C-shape fiber reinforced materials showed improved mechanical properties and damping effect.

The experimental results of C-CF/EP are summerized as follows:

Mechanical properties improvement(%)					Damping effect improvement(%)
FS	FM	ILSS	IS	TFS	185
218	223	157	227	184	

5. REFERENCES

1. R. Meredith, "Physical properties of textiles", Part I, p 13-19(1950).
2. S.S. Kim, "Property of Pitch-based C-shape Carbon Fiber", M.S thesis, CNU(1990).
3. B.S. Rhee, "Mechanical Property of C and Hollow Carbon Fiber according to the Fiber Thickness", Proc. of Twentieth Bienial Conf. on Carbon, SANTA BABARA, 306-307(1991).
4. H.B. Shim, "Preparation and characteristics of epoxy composite reinforced with hollow and C-type carbon fiber", MS paper, CNU, (1993).
5. E.G Stoner, "Mechanical Property of non-circular pitch-based carbon fiber", High-Temperature High-Pressure, 22, 299-308 (1990).
6. H.B. Shim, J.I. Lee, B.S. Rhee, "'93 Advanced Composite Materials", Edited by T. Chandra and A.K. Dhingra, TMS, 721-727(1993).
7. Michael B. Bever, "Encyclopedia of materials science and engineering", vol. 3, The MIT press, 2127(1986).
8. J.T. Kim, "구조물의 진동의 이해와 실험적 접근 방법", 한국항공우주학회지, 제19권, 제1호, p 84(1991).