FRACTURE PROPERTIES OF HIGH STRENGTH CONCRETE REINFORCED WITH VARIOUS FIBERS

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1. INTRODUCTION

Recently, the use of high strength concrete (HSC) as a construction material has been increasing. However, HSC possesses poor fracture properties such as high brittleness behavior. One of the methods to improve the fracture properties of HSC is the addition of fibers to its mixture as a fiber reinforced concrete (FRC).

Some examples of widely used fibers in FRC are steel fiber and polyvinyl alcohol (PVA) fiber. Another is a promising natural fiber called Sisal fiber. The hybrid FRC that gives additional performance more than just adding single type of fiber was also used [1]. The objective of this paper is to identify fracture properties of HSC with steel, PVA, sisal and hybrid fibers.

Fracture energy of FRC is calculated by using the load-displacement curve acquired from three point bending test of a notched beam by the following **Eq. (1)**.

$$G_F = \frac{0.75W_0 + W_1}{A_{lig}} \qquad (1)$$

$$W_1 = 0.75\left(\frac{S}{L}m_1 + 2m_2\right)g.LPDc \qquad (2)$$

where G_F is the fracture energy (Nmm/mm^2), W_0 is the area below the load – load point displacement (LPD) curve up to the rupture of a specimen (Nmm), W_1 is the work done by dead weight of a specimen and loading jig, and A_{lig} is the area of broken ligament (mm^2). S is loading span (mm), L is total length of a specimen (mm), m_1 is mass of a specimen (kg), m_2 is mass of equipment attached to a specimen (kg), g is gravitational acceleration (9.807 m/s^2) and $LPDc$ is load point displacement at the time of rupture (mm).

2. EXPERIMENTAL PROGRAM

The experimental program consisted of nine different types of mixtures with designed compressive strength of 80 N/mm^2. The mix proportion, specimen name and fiber content information are tabulated in **Table 1** and **Table 2**. SP80HU plasticizer was added to each mixture by weight ranged from 0.5% to 1.25% of cement weight for each mixture. Fiber was added in mixtures by volume ranged from 0.5% to 1% of full concrete volume. Five types of fiber were used in this research. Their properties are listed in **Table 3**.

For each type of mixture, five specimens were cast. Three point bending tests of notched beams were conducted according to JCI-S-001-2003 [2] and JCI-S-002-2003 [3] for the plain concrete mixture and FRC mixtures respectively. The specimen shape and dimension are shown in **Figure 1**.

Table 1 Mix proportion

G_{max} (mm)	W/C	s/a (%)	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)
20	0.3	51.2	165	550	847	190

Table 2 Specimen name and fiber content

Name	Fiber Type	Volume Fraction
NF	-	0%
SH62	SH62	1.0%
SH72	SH72	1.0%
SW	SFW	1.0%
SS	SS	1.0%
PVA	PVA	1.0%
SPV	SH62 & PVA	0.5 % + 0.5%
SH05	SH62	0.50%
PVA05	PVA	0.50%

Table 3 Properties of fibers

Name	Materials	End Type	Aspect Ratio	Length (mm)	Diameter (mm)	Tensile Strength (GPa)	Elastic Modulus (GPa)
SH62	Steel	Hooked	41.7	30	0.62	1.0	210
SH72			48	30	0.72	1.0	210
SW		Wave	50	30	0.6	1.0	210
PVA	PVA	Straight	45.5	30	0.6	0.86	23
SS	Sisal		151	25	0.165	0.58	*

* Data not available

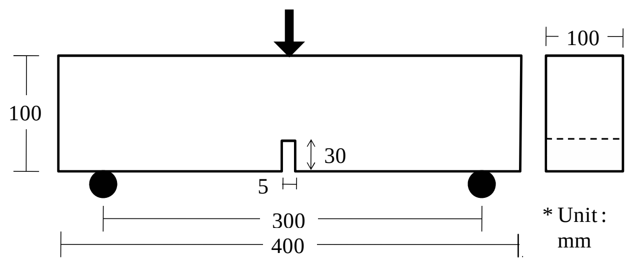

Figure 1 Detail of specimen size and dimension

Keywords: high strength concrete, fiber reinforced concrete, fracture properties, fracture energy, tension softening curve
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3. TEST RESULTS AND DISCUSSION

a) Compressive and tensile strength

Compressive and tensile splitting strength of specimens are shown in **Figure 2**. The average value of compressive test was 76.24 kN. Compressive strength of HSC with various fibers were changed depending on the type of fiber.

Tensile strength of SS was lower than plain concrete, while SH62 and SW were larger. SFH62 increased tensile strength larger than SFW. PVA increased the tensile strength larger and with lower fiber content had stronger tensile strength than SH72. SPV had the lowest tensile strength.

b) Fracture Energy

Load-LPD curve is shown in **Figure 3.** LPD was measured at the bottom of the beam at mid span. The fracture energies are shown in **Figure 4**. The fracture energy of SH62 and SW were the same. For the same fiber content, SPV had close value to SH62 and SW. Furthermore, it also gave higher fracture energy than SH72. SS fibers did not give significant effect to fracture energy. Fracture energy did not decrease to half when fiber content was reduced to half.

The loss of stress transferred at the crack was by “pulled off” for steel fiber, and by “cut off” for both PVA and Sisal fiber. The hybrid (SPV) FRC showed both types that were pulled off in SH62 and cut off in PVA. These types seemed to be affected by the tensile strength of fibers.

c) Tension Softening Curve

Tension softening curves were calculated using “tension softening curve poly-linear approximation” software developed by JCI. Tension softening curve of specimens are shown in **Figure 5**. The curves showed that SH62, SW and SPV had a similar shape when crack opening displacement (COD) was in between 0 to 2 mm. Moreover, compared to other fiber, SPV Load-LPD curve also has close similarity with SH62 and SW.

SH62, SH72, SW, and SH05 had a similar tension softening curve shape. PVA05 and PVA also had a similar shape. PVA curves were rapidly decreased but then became gradually increase and at some point began to gradually decrease again. For SS, after rapidly decreased, the curve was still decreased but the slope became lower.

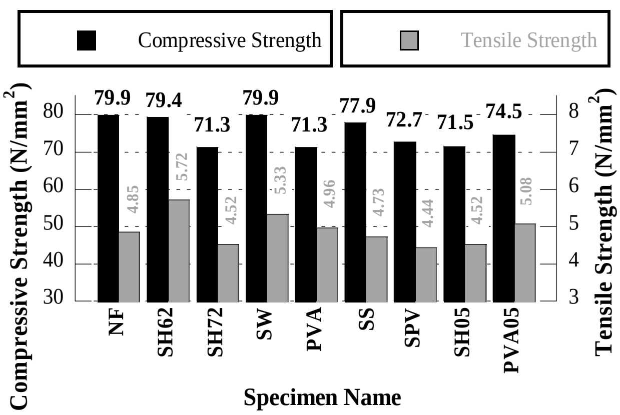

Figure 2 Compressive and tensile strength

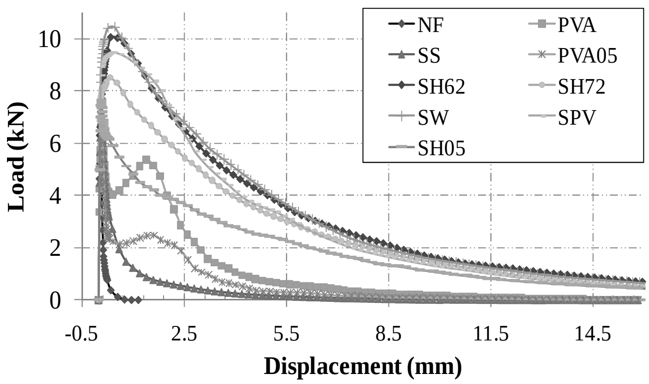

Figure 3 Load-LPD curves

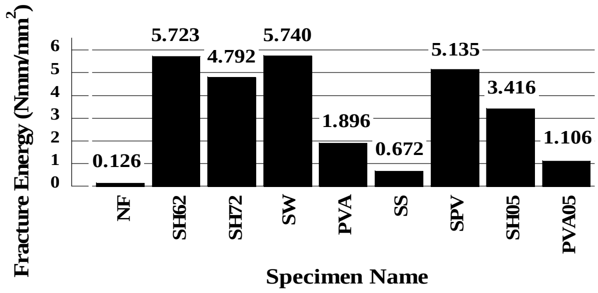

Figure 4 Fracture energy

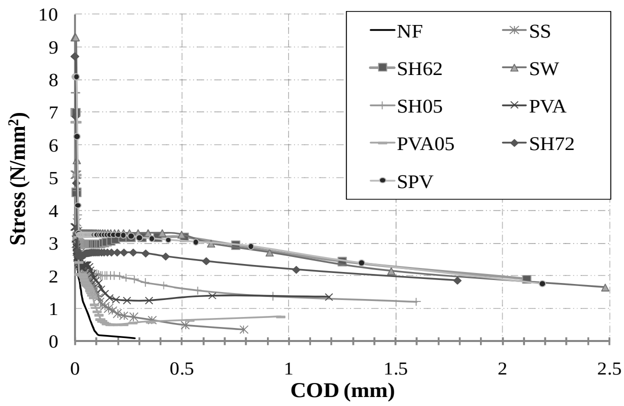

Figure 5 Tension softening curve of specimens

4. CONCLUSIONS

1. SH62 and SW showed similar fracture properties which indicated that hooked end type and wave end type of steel fibers did not strongly affect fracture properties of FRC.
2. Hybrid fiber composed of equal proportion of PVA and SH62 gain additional performance more than just adding single type of fiber.
3. The loss mechanism of stress transferred at the crack seemed to be different depending on the tensile strength of fiber.

REFERENCES

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[3] Japan Concrete Institute (JCI) (2003): *Method of test for load-displacement curve of fiber reinforced concrete by use of notched beam.*