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Mechanical properties of natural fiber-reinforced normal strength and high-fluidity concretes

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Abstract. An experimental investigation of mechanical properties of jute fiber-reinforced concrete (JFRC) has been reported for making a suitable construction material in terms of fiber reinforcement. Two jute fiber reinforced concretes, called jute fiber reinforced normal strength concrete (JFRNSC) and jute fiber-reinforced high-fluidity concrete (JFRHFC), were tested in compression, flexure and splitting tension. Compressive, flexural and splitting tensile strengths of specimens were investigated to four levels of jute fiber contents by volume fraction. From the test results, Jute fiber can be successfully used for normal strength concrete (NSC) and high-fluidity concrete (HFC). Particularly, HFC with jute fibers shows relatively higher improvement of strength property than that of normal strength concrete.

Keywords: jute fiber-reinforced concrete; mechanical property; splitting tensile strength; compressive strength; flexural strength

1. Introduction

One of the important properties of hardened concrete is its strength. Although the unreinforced concrete has adequate strength for many structural applications, it is relatively brittle material. In general, adding fibers to concrete has been used to overcome this problem and results in the increase of toughness, ductility and tensile strength. Factors affecting the characteristics of fiber reinforced concrete are fiber type, geometric configuration, forms, direction, surface condition, mixing proportion, curing method and etc. Also fiber reinforced concrete technology is in continuous growth and expansion around the world. There has been an interest in using natural fiber for making low cost and environment friendly construction materials in Korea. Jute is one of the most affordable natural fibers in recent years. Jute is a long, soft, shiny vegetable fiber that can be spun into coarse, strong threads. It is produced from plants such as the genus corchorus, which has been classified in the family tiliaceae, or more recently in malvaceae. Jute fibers are composed primarily of the plant materials cellulose and lignin (Aziz *et al*. 1981).

Some investigations have already been conducted on various mechanical properties of concrete using natural, steel, polypropylene, carbon and glass fibers. Aziz *et al*. (1981) investigated the optimum fiber length and volume fraction in normal strength concrete with jute fiber. The obtained

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optimum jute fiber length was approximately 25 mm and fiber volume fraction was 3% of concrete volume. Also the increases in compressive, tensile and flexural strengths up to 1% volume fraction were 7.15%, 13% and 33%, respectively.
Leung *et al*. (2004) reported the results of properties of wet-mixed fiber reinforced shotcrete and fiber reinforced concrete with steel (ST), polypropylene (PP) and polyvinylalchol (PVA) fibers. Test results showed that the compressive strength with 0.5% PP and 0.5% PVA fibers is lower than that of plain concrete. The compressive strength with 0.5% steel fiber, however, is higher than that of plain concrete as much as 30%. Yao *et al*. (2002) investigated the mechanical properties of concrete with carbon, steel and polypropylene fibers at low volume fraction (up to 0.5%). The results indicate that compressive, splitting and flexural increments with carbon are approximately 14.45%, 19.49% and 8.66%, respectively, with steel are approximately 7.9%, 10.09% and 24.54%, respectively and with PP are approximately 0.45%, -5.04% and 3.6%, respectively. Choi and Yuan (2005) reported the splitting and compressive strength results of glass fiber reinforced concrete (GFRC) and Polypropylene fiber reinforced concrete (PFRC). Test results shows that the additions of glass and polypropylene fibers up to 1.5% did not seem to increase compressive strength when compared to those of plain concrete. However, the splitting tensile strength was increased by approximately 20-50%. In this study, an investigation on the mechanical properties of jute fiber reinforced normal strength (JFRNSC) and jute fiber reinforced high-fluidity concrete (JFRHFC) is conducted for utilizing jute fiber in concrete pavement, construction, housing and other needs. Different fiber contents were used as reinforcements which were assumed randomly oriented and uniformly distributed in the matrix. Specimens with varying fiber contents were tested in compression, splitting tension and flexure. The results of this investigation have shown the feasibility of using jute fibers in developing a useful construction material when jute fibers are readily available.

2. Coupled finite element / reproducing kernel approximation

The experimental program was designed to evaluate mechanical properties of JFRNSC and JFRHFC. Although it is not possible to cover the entire actual conditions, laboratory tests may be used to predict or understand the behavior of the certain material in some desired respect.

2.1 Materials and specimens

Materials, type I/II Portland cement which meets the Korean standards KSL5201, 19 mm maximum size of crushed coarse aggregate with a specific gravity of 2.64, natural sand with a specific gravity of 2.56 and a fineness modulus of 2.42, a commercially produced jute fiber with a specific gravity of 1.03 and length of 9 mm as shown in Fig. 1, were used in this work.

The mix design of NSC was prepared with the following: ordinary portland cement (type I/II) 410 kg/m^3, aggregate 1,629 kg/m^3, water-cement ratio of 0.50. The mix design of HFC was as follows: ordinary Portland cement (type I/II) 400 kg/m^3, aggregate 1,629 kg/m^3, superplasticizer 8 kg/m^3, viscosity modified admixture(VMA) 1 kg/m3, water-cement ratio of 0.50 and a 25% fly-ash replacement of the weight of the cement. The chemical composition and physical property of fly-ash, superplasticizer and viscosity modified admixture used in the present study are listed in Tables 1, 2 and 3, respectively.

Typical cylinder specimens of 100 mm in diameter and 200 mm in height were used

Fig. 1 Jute fibers

Table 1 Chemical composition and physical property of fly-ash

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Na_2O (%)	MgO (%)	SO_3 (%)	CaO (%)	Specific gravity	Fineness Modulus (mm^2/g)
20.59	4.96	3.40	62.04	3.47	2.47	0.34	2.19	317.2

Table 2 Physical property of superplasticizer

Type	Color	Major composition	P.H	Specific gravity
Liquid	Light-brown	Lignosulphonate	7~10	1.17

Table 3 Physical property of VMA

Type	Color	Major composition	P.H	Specific gravity
Liquid	Milky	Acrylic-ethyl acetate	6.0	1.17

forcompressive and splitting tensile tests. The size of beam specimen for flexural test was 100 × 100 × 400 mm. The fibers were uniformly dispersed in the mixer manually. Four different fiber contents by volume, 0, 0.25, 0.5 and 1.0%, were considered in the present work. In general, a relatively low content of fiber seems to have a small positive influence on the concrete. A relatively high content of fiber, however, may have a difficulty in mixing and the uniform distribution of fibers. Therefore the fiber contents used in this study seem to be reasonable for practical applications (Choi and Yuan 2005).

2.1 Materials and specimens

The casting and finishing of all specimens were made in a laboratory. The specimens were demolded approximately 24 hours after their casting and then cured in a water tank up to 27 days. Compression tests were conducted on a total of 30 cylinder specimens of JFRNSC, JFRHFC and plain concrete at 28 days in accordance with the Korean standards KSF 2405 (2009). The load was

Table 4 Slump and slump flow values

Type	Plain (0%)	0.25%	0.5%	1.0%
JFRNSC (height-mm)	180	120	70	30
JFRHFC (diameter-mm)	620	380	200	60

Table 5 Mechanical properties for JFRNSC and JFRHFC

Fiber volume (%)	JFRNSC			JFRHFC		
	f_{ck}(MPa)	f_{sp}(MPa)	f_{fs}(MPa)	f_{ck}(MPa)	f_{sp}(MPa)	f_{fs}(MPa)
0	30.85	3.02	6.13	26.36	3.30	5.87
0.25	32.05	3.16	7.00	40.22	4.34	6.78
0.5	32.45	3.25	7.35	41.51	4.33	7.07
1.0	32.65	3.28	7.23	39.88	4.42	7.40

applied at a rate of 0.02 mm/sec with a preload of about 200 N. The peak load and the load-axial displacement were recorded during the test by an acquisition system. Commonly, three test methods are used to measure tensile strength of concrete called the direct tension test, the modulus of rupture or flexural test and the splitting tensile test (Zain *et al*. 2002). The direct tension test (with typical dog-bone type specimen) can be attributed to the difficulty of insuring that the load is truly axial in direct tension when some eccentricities of the load may underestimate the tensile strength. The flexural (modulus of rupture) test is used to determine the tensile strength by using the maximum load obtained to cause failure. Although, the flexural tensile strength from a flexural test may show the true tensile strength of concrete, many researchers have indicated that the true tensile strength is approximately 65% - 70% of the flexural tensile strength (Zain *et al*. 2002, Rocco *et al*. 2001). The splitting tensile test is relatively simple and seems to provide reliable test results to calculate the tensile strength of concrete under uniform stresses at the top and bottom across the diameter of the tested cylinder specimens. Therefore, in this work the splitting tensile and flexural tests are used for investigation. Splitting tensile test was carried out according to the Korean standards KSF 2423 (2009). The load was applied at a rate of 0.01 mm/sec with a preload of about 50 N. The flexural test was carried out according to KSF 2408 standards (2009) at the same ages of concrete used for the compression tests. The applied load and central-deflection were recorded using an acquisition system. The load was applied at a rate of 0.005 mm/sec with a preload of about 25 N. The slump, compressive, splitting and flexural tests are shown in Fig. 2 ~ Fig. 5.

3. Results and discussion

The average slump and slump flow diameter of the JFRNSC and JFRHFC are given in Table 4, respectively. The fiber length was kept constant at 9 mm while the volume fraction was varied from 0 to 1.0%. The volume fraction is one of the important parametersthat affect the most mechanical properties of concrete.The slump value of JFRNSC is found to slightly decrease with the increase of fiber content. The slump flow value at JFRHFC is found to dramatically decrease with the increase of fiber content. The mix of HFC should have sufficient flowability to maintain

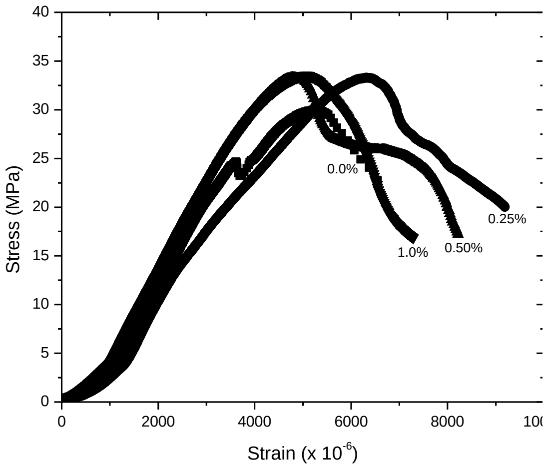


Fig. 6 Stress-strain curves of JFRNSC

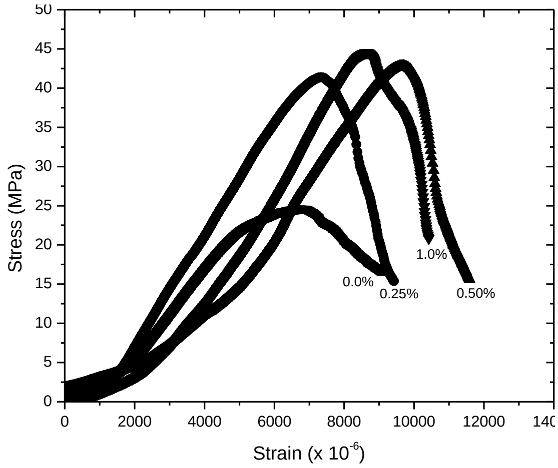


Fig. 7 Stress-strain curves of JFRHFC

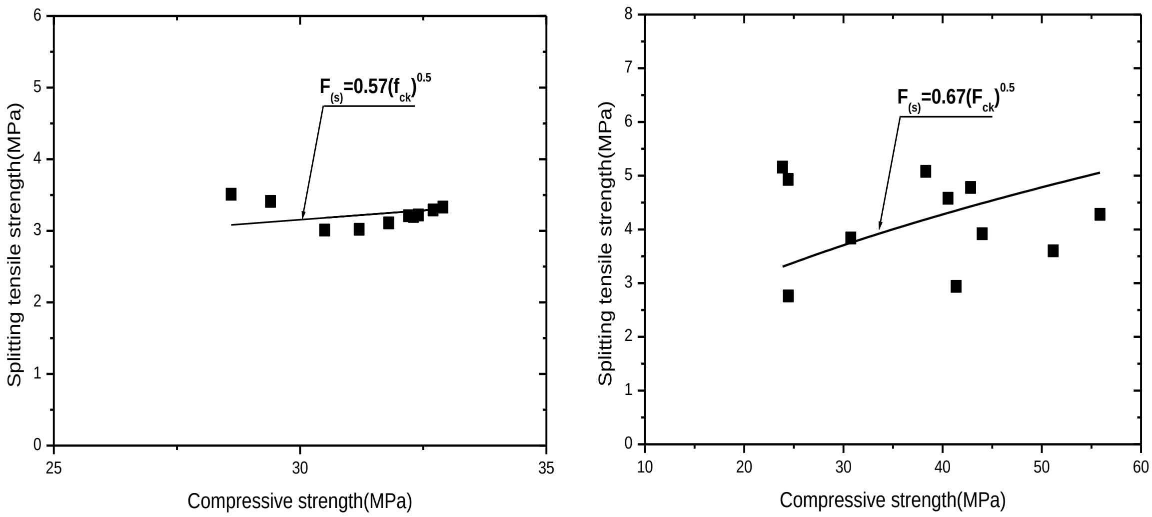
its own advantages. Therefore, the use of fiber in HFC must be carefully considered as reinforcement. In case of jute fiber, the expected reasonable volume fraction is considered by less than 0.25% to maintain HFC serviceability. The compressive (f_{ck}), splitting tensile (f_{sp}) and flexural strength (f_{fs}) at 28 days are shown in Table 5. Each of the results was the average of 3 test specimens.

3.1 Compressive strength

It is interesting how the jute fiber affects the compressive strength of normal strength and high-fluidity concrete because compressive strength is widely considered to be the most important property. The typical stress-strain curves of JFRNSC and JFRHFC depend on the fiber content are given in Fig. 6 and Fig. 7, respectively. A somewhat significant difference between JFRNSC and JFRHFC was observed.The addition of jute fiber up to 1% by volume in normal strength concrete showed the slight compressive strength improvement by approximately 5% which is very similar with many findings before. This slight increasemay come from the fibers interacting with the advancing cracks. The compressive strength of JFRHFC with jute fiber up to 1% by volume, however, shows a significant increase by approximately 55% when compared to the plain concrete. A thinkable scenario is that the mixing of jute fibers into the HFC makes more compaction and less entrapped air or void due to the jute fibers distributed more thoroughly throughout the HFC (Song *et al*. 2005). Also the strains corresponding to peak load mostly increased and the toughness also increased considerably. Furthermore, both the ascending and descending portions of the stress-strain curves were affected by the fibers.

3.2 Splitting tensile strength

The splitting tensile strength for JFRNSC and JFRHFC is higher than that of plain concrete by approximately 6% and 30%, respectively. The improvement of splitting tensile strength of JFRHFC is higher than that of JFRNSC. As observed in compressive strength, this result may have come partially from the reinforcing fiber's role to resist cracking and spalling of specimen across



(a) JFRNSC (b) JFRHFC

Fig. 8 Suggested equations with experimental results: (a) JFRNSC, (b) JFRHFC

the failure planes due to number of fibers intersecting the fracture surfaces (Song *et al*. 2005). Also the addition of jute fiber significantly increased the concrete ductility which is defined as the amount of strain exceeding the proportional limit up to the point of failure. The average splitting tensile strength obtained from tests increased from 9% to 12% for JFRNSC and from 10.5% to11% for JFRHFC of their compressive strength with the increase of fiber content. These ranges are relatively similar to those found for SFRC, GFRC and PFRC (Choi and Yuan 2005, Yao *et al*. 2003).

In order to estimate the effect of jute fiber on the splitting tensile strength, a regression analysis (curve fitting technique) was performed. From a large number of tests on concrete, a simple 0.5 power law model has become one of the most widely used analytical models for describing the relationship between the splitting tensile strength and compressive strength of concrete. In this investigation, the tensile strength of concrete containing jute fiber is assumed proportional to the square root of their compressive strengths. The general form of the 0.5 power law equation is given as

$$F_{(sp)_i} = a\sqrt{(f_{ck})_i} \tag{1}$$

where, $F_{(sp)I}$ and $(f_{ck})_i$ are the splitting tensile and compressive strengths at the i^{th} day, respectively. The intercept αrepresents the value of the constant at each age from the regression analysis.

$$F_{(sp)_{28}} = 0.57\sqrt{(f_{ck})_{28}} \tag{2}$$

$$F_{(sp)_{28}} = 0.67\sqrt{(f_{ck})_{28}} \tag{3}$$

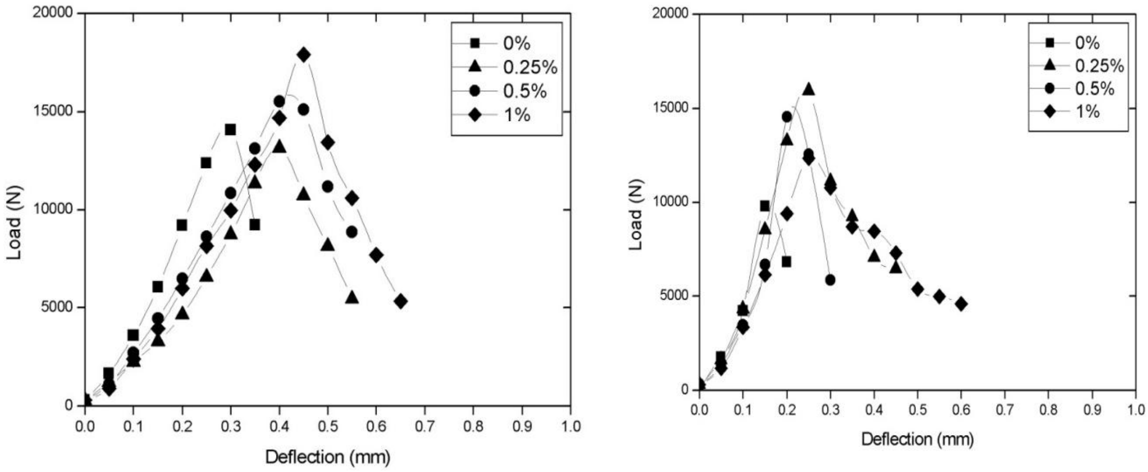


Fig. 10 Load-Deflection curves of JFRHFC

Eqs. (2) and (3) have been proposed for the normal strength concrete and high-fluidity concrete containing jute fiber, respectively: The obtained equations are similar to those found for GFRC, PFRC and SFRC by Choi and Yuan (2005) and Nataraja *et al*. (2001).

These proposed equations are plotted in Fig. 8 with the experimental results. It can be seen that the regression lines of equations showed a relatively good relation for the splittingand compressive strength with R^2=0.92 and 0.78, respectively. Most statisticians consider a R^2=0.70 or higher for a reasonable regression (Ostle *et al*. 1999). Actually, it is noted that tensile strength of fiber reinforced concrete could be affected by the many other factors such as the types of fiber, fiber content, length of fiber, directions of embedded fibers, aspect ratios of fiber. Furthermore, the number of tested specimens is important because more test data may provide better statistical validation for various factors (Nataraja *et al*. 2001).

The proposed equations, however, were given only as a function of their compressive strength from a relatively small number of experiments. Therefore, further research is needed to verify the proportional relationship and to determine the effects of fiber types, the number of specimens, curing time and other factors.

3.3 Flexural strength

It can be observed that the addition of jute fiber in the normal strength concrete and HFC increased the flexural strength by approximately 17% and 20% when compared to the plain concrete, respectively. This result may come from the fibers intersecting the cracks in tension of the specimen. Also the average flexural strength from tests ranged from 21% to 24% for JFRNSC and from 16% to18% for JFRHFC of its compressive strength, respectively. Unlike compressive and splitting strengths, the increase in flexural strength was not significantly different for JFRNSC and JFRHFC. The most common method to measure toughness is to use the load-deflection curve obtained using a simply supported beam loaded at the third points (Nataraja *et al*. 2000). Fig. 9 and Fig. 10 show the load-deflection curves for flexural test of JFRNSC and JFRHFC up to the point of failure, respectively.

In general, the ASTM C 1018 and the JSCE SF-4 methods are the most widely used for measuring toughness of fiber-reinforced concretes. In this work, the average flexural toughness value was determined using the JSCE SF-4 method. As shown in Fig. 9 and Fig. 10, the central deflection of beam specimen could not reach the value of L/150 (approximately 2.0 mm in this work) which is specified in JSCE SF-4. However, Nataraja *et al*. (2000) pointed out that a deflection of L/150 is considered excessive for many applications and is purely arbitrary and not based on serviceability considerations. Therefore, the flexural toughness in this study is determined as the area under the deflection up to 0.6 mm as shown in Fig. 9 and Fig. 10, respectively. With increasing of flexural strength, the addition of jute fiber also significantly increased toughness. The calculated flexural toughness values of JFRNSC and JFRHFC were improved about 400% and 200% when compared to its plain concrete, respectively.

4. Conclusions

This paper describes the influence of fiber volume fraction on the compressive, flexural and splitting strength of jute fiber reinforced normal strength concrete and high-fluidity concrete. Based on the experimental and analytical results, the following conclusions are obtained

(1) The compressive strength of the JFRHFC improved by 55% when compared to without fiber, but the JFRNSC showed slight improvement by approximately 5% which is very similar with many findings before. Also addition of jute fibers in NSC and HFC increased the splitting tensile strength by approximately 6 and 30% that of plain concrete, respectively. The splitting tensile strengths approximately ranged from 9% to 12% of their compressive strength.

(2) The addition of jute fiber in the NSC and HFC increased the flexural strength by approximately 17% and 20% when compared to that without fiber, respectively. Also, the average flexural strength ranged from 21% to 24% for JFRNSC and 16% to18% for JFRHFC of its compressive strength, respectively.

(3) Using a relatively small amount of experimental data, a simple 0.5 power law relationship between the tensile strength and the compressive strength of JFRC can be successfully used to estimate their splitting tensile strength, which result is very similar to other fibers.

(4) From the test results, jute fiber can be successfully used in normal strength concrete and high-fluidity concrete. Particularly, HFC with jute fibers shows relatively higher improvement of strength property than that of normal strength concrete. Also, further research is needed to verify this result.

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