A comparative Study of Basalt and Polypropylene Fibers Reinforced Concrete on Compressive and Tensile Behavior

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***Abstract*— Concrete made with Portland cement has certain characteristics: it is relatively strong in· compression but weak in tension and tends to be brittle. These two weaknesses have limited its use. Another fundamental weakness of concrete is that cracks start to form as soon as concrete is placed and before it has properly hardened. These cracks are major cause of weakness in concrete particularly in large onsite applications leading to subsequent fracture and failure and general lack of durability. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibres.**

This paper provides result data of the compressive strength, and split tensile strength of basalt and polypropylene fiber reinforced concrete containing fibres' of 0%, 0.3%, 0.6%, 0.9%, and 1.2% volume fraction by weight of cement (Vf) without admixture. For compression test,

A result data obtained has been analysed and compared with a control specimen (0% fiber). A relationship between Compressive strength vs. fiber volume fraction and tensile strength vs. fiber volume fraction of both basalt and polypropylene fiber are represented graphically. Result data clearly shows decrease in compressive strength for C30 Grade of concrete due to addition of basalt fiber and polypropylene fiber. Also, the result data shows that, the optimum dosage for the splitting tensile strength of basalt fiber is in the vicinity of 0.6%. While the optimum dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3%.

***Keywords*- Basalt fiber, Compressive strength, Control concrete, polypropylene fiber, Split tensile strength.**

I. INTRODUCTION

Compared to other building materials such as metal and polymers, concrete is significantly more brittle and exhibit a poor tensile strength. Based on fracture toughness values, steel is at least 100 times more resistance to crack growth than concrete. Concrete in service thus cracks easily, and this cracking creates easy access routes for deleterious agents resulting in early saturation, freeze than damage, scaling discoloration and steel corrosion.

As the structural use of concrete developed in the second half of the 1800's, interest was focused on reinforcements to enhance its low tensile capacity. The concern with the inferior fracture toughness of concrete are alleviated to a large extent by reinforcing it with fibers of various materials. The resulting material with a random distribution of short discontinuous fiber is referred as fiber reinforced concrete (FRC).

Research on fiber reinforced concrete has been conducted since the 1960's [1]. During the 1970's the commercial use of this material began to increase, particularly in Europe, japan and USA [2]. Common applications today are pavement, industrial floors, precast elements and various kinds of repairs [3].

Fiber reinforced concrete is the composite material containing fibers in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibers, which is largely dependent on the type of fiber, fiber geometry, fiber content, orientation and distribution of the fibers, mixing and compaction techniques of concrete, and size and shape of the aggregate. Fiber reinforced concretes (FRC) exhibit property improvement caused by the fibers [4].

It was reported that polypropylene fibers improves the plain concrete properties including splitting tensile strength, first crack strength and impact resistance [5]. Alhozaimy et al. [6] observed that an additional amount of 0.1% polypropylene fibers in the plan concrete had 44% increases in flexural toughness of the concrete. Some researchers also reported evidence of small but favorable effect of fiber addition on toughness [7], [8], [9], [10], [11]. Mindess *et al* (1988) [12] reported that compressive strength increased by about 25% at 0.5% volume fraction of PP fibers in the concrete mixture design. Hughes and Fattuhi [13] suggested that compressive strength decreases but flexural properties are improved with increasing fiber content.

The basalt fiber is a new inorganic fiber material with high tensile strength, good heat resistance, high dielectric property, corrosion resistance, high chemical stability and low cost. Since it is a typical ceramic fiber with a similar density (2.63 – 2.8g/cm3) as cement concrete and mortar, it has a unique advantage in terms of uniform distribution, thus becoming a new reinforcing material with a good development prospect. Hence this study explores the comprehensive experimental data and powerful statistical analyses regarding the effects of adding polypropylene fibers and basalt fiber with different volume fractions; aim is to do the comparative study between the two fibers on compressive strength and tensile strength study etc. with given grade of concrete, proportions and percentage of fibers.

II. MATERIAL USED AND MIX PROPORTION

In this experimental study, Cement, sand, coarse aggregate, water, polypropylene fiber and basalt fibers were used.

A. Cement

Cement is an important component of the concrete material which directly affects its strength grade. This test used 32.5slag cement, and its physical and mechanical properties are shown in Table 1.

TAB. 1
PHYSICAL AND MECHANICAL PROPERTIES OF SLAG CEMENT

Cement grade	Fineness (%)	Setting time (h:min)		Compressive strength (MPa)		Flexural strength (MPa)	
		Initial	Final	3d	28d	3d	28d
32.5A	7.0	3:11	4:26	18.9	44.3	4.4	9.3

B. Aggregate

This test is in accordance with current industries standard aggregate "Chinese National Standards (JGJ52-2006)" [14] requirements.

1) *Fine Aggregate:* This test uses Jinzhou NVER river sand, its grading and performance indicators shown in Table 2.

TAB. 2
FINE ORTHOPEDIC INDICATORS

Apparent Density (kg/cm^3)	Bulk Density (kg/cm^3)	Fineness Modulus (μf)	Moisture (%)	Clay content (%)
2670	1554	2.46	3.1	3.0

2) *Course Aggregate:* This test uses particle size less than 20mm gravel, its findings and technical indicators shown in Table 3.

TAB. 3
THICK ORTHOPEDIC INDICATORS

Apparent Density (kg/cm^3)	Bulk Density (kg/cm^3)	Size grading (mm)	Clay content (%)	Flakiness content (%)
2665	1450	10~20	0.3	14

C. Water

Concrete mixing water used complies with "Chinese National Standards" (JGJ63-2006) [15]. This experiment uses Jinzhou City tap water.

D. Fiber

This test uses a continuous basalt and polypropylene fiber, as shown in Figure 1, and their performance as shown in Table 4 and Table 5 respectively.

Fig. 1 Basalt and polypropylene fiber morphology

TAB. 4
PERFORMANCE PROPERTIES OF BASALT FIBER

Densiy (g/cm^3)	Tensile strength (MPa)	Ultimate elongation (%)	Modulus (GPa)	Fiber Type	L(m)
2.65	3000~3500	3.2	90~110	Chopped	12

TAB. 5
PERFORMANCE PROPERTIES OF POLYPROPYLENE FIBER

Density (g/cm^3)	Tensile strength (MPa)	Ultimate elongation (%)	Modulus (GPa)	Mp (℃)	Fiber Type	L(m)
0.91	365~600	25~60	2.4~3.2	165~173	Bunchy	12

E. Test mix design

This test is based on "Chinese National Standards" (JGJ55-2011) [16], formulated on C30 ordinary concrete, such as shown in Table 6 below. Low elastic modulus polypropylene and high elastic modulus basalt of two kinds of fiber were used. 0.3%, 0.6%, 0.9%, and 1.2% were the percentage used of a mixing fiber.

TAB. 6
C30 CONCRETE MIX

CCement strength	Sand ratio	Sand species	Water-cement ratio	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Pebble (kg/m^3)
32.5	0.3	Medium sand	0.5	203.7	407	535	1245

III. EXPERIMENTAL METHODOLOGY

The mechanical tests used for the comparative study of polypropylene and basalt fiber were compressive strength and tensile strength.

This test is strictly in accordance with "Chinese National Standards" (GB / T 50081) [17]. The relevant compressive strength test specimens were produced using a non-standard specimen size 100mm × 100mm × 100mm cube and Splitting tensile test specimens using standard size 150mm × 150mm × 150mm cube. The production process of concrete has a direct impact on various performances. The test uses mixer to properly mix the coarse aggregate sand and gravel. In order to ensure uniformity of concrete mixture, the aggregate was dry mix in a blender for 30 seconds, then the dry mix cement was added, and finally the fiber.

The marinated fiber concrete was poured into the test mould, and placed on the vibration table. The specimens were removed from the mould after 24 hours and moved into the curing room; curing room temperature was 20 ± 2 ℃ and a relative humidity of 95% or more, the curing procedure was strictly in accordance with the "(GB / T 50081)". After 28d, the test was carried out for cubic compressive strength and splitting tensile strength.

The procedure for the test was in accordance with "Chinese National Standards "(GB / T 50081) [17]. The specimen was removed from the curing room to wipe clean; the size appearance of the specimen was checked immediately after the test.

A. Compressive strength test:

The specimen was placed at the lower platen center of the testing machine. In this experiment, the speed of 0.3 ~ 0.5MPa, continuous and uniform loading were used. The specimen damaged when the load reaches the maximum, the breaking load was recorded. Compressive strength was calculated according to formula (1)

$$f_{cu} = \frac{F_{c\max}}{Ac} \qquad (1)$$

Where;

f_{cu} is the cube compressive strength for the concrete, *(MPa)*

$F_{c\max}$ is the maximum load at failure of the concrete (N),

A_c is confined compression test specimen area (mm^2)

B. Splitting tensile test:

The specimen was placed at the splitting tensile device center, the testing machine was started at the speed of 0.3 ~ 0.8MPa and uniformly loaded. When the destruction of the specimen was approached, the load reaches maximum, the breaking load was recorded. Splitting tensile strength was calculated according to equation (2)

$$f_{ts} = 0.637\frac{F_{ts\max}}{A_{ts}} \qquad (2)$$

Where;

f_{ts} is the splitting tensile strength of concrete (MPa) ;

$F_{ts\max}$ is the maximum load of concrete splitting failure (N)

A_{ts} is the splitting test specimen area, mm^2 ;

IV. EXPERIMENTAL RESULTS AND ANALYSIS

Results of Compressive and tensile strength for C30 grade of concrete on cube specimen with 0%, 0.3%, 0.6%, 0.9% and 1.2% of Basalt and Polypropylene Fibers are shown in table3.1

TAB. 7
TESTRESULTS

Test Packet	Test Number	Dosage (%)	compressive strength (MPa)	Splitting strength (MPa)
Ordinary	OC	0	36.09	2.95
basalt fiber	BC1	0.3	32.78	3.03
	BC2	0.6	29.13	3.62
	BC3	0.9	35.87	2.62
	BC4	1.2	29.5	2.37
polypropylene fibers	PC1	0.3	33.25	3.40
	PC2	0.6	33.65	3.18
	PC3	0.9	29.86	3.11
	PC4	1.2	27.49	2.65

A. Analysis of Compressive strength test results

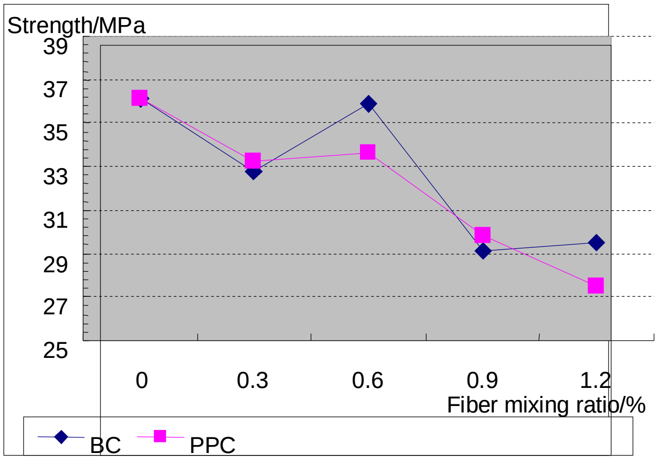


Fig. 2 Compressive strength of basalt and polypropylene fiber

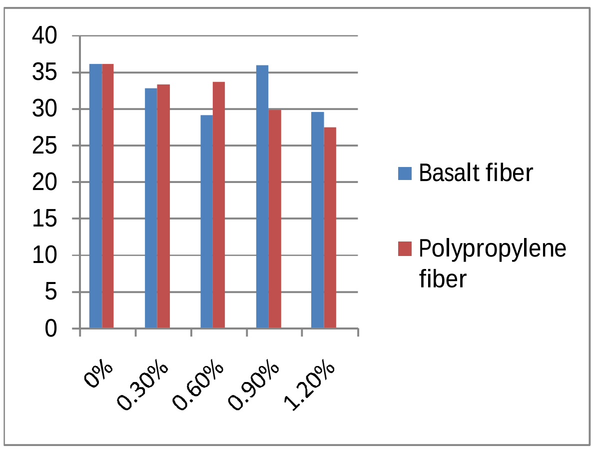


Fig. 3 comparison between Compressive strength of basalt and polypropylene fiber.

As seen in Figure 3, addition of 0.3%, 0.6%, 0.9% and 1.2% resulted in a decrease of compressive strength relative to plain concrete by 9%, 19%, 1%, and 18% respectively. Similarly, addition of 0.3%, 0.6%, 0.9%, and 1.2% volume of polypropylene resulted in a decrease of strength relative to plain concrete by 8%, 7%, 17% and 24% respectively.

The incorporation of polypropylene and basalt fibers in the concrete mixture has different degrees of reduction on the compressive strength. Because many factors affect the strength of concrete, such as cement strength, water-cement ratio, and the size of the aggregates [14]. Incorporation of the fibers within the concrete matrix changes the phase of each component. As seen from the test results analysis, with the same series of fiber concrete, the strength decreases with the increase of fiber mixing ratio increases. Also, with the same volume of fiber, the addition of different series of fiber results in different compressive strength of concrete.

B. Analysis of splitting tensile test results

Table 7 records the splitting tensile test results as plotted in a scatter line chart shown in Figure 4

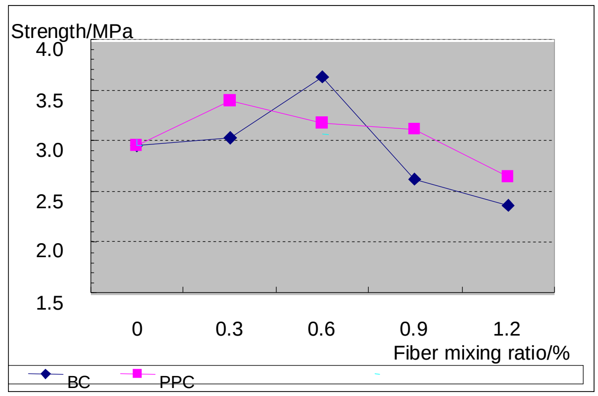


Fig. 4 Splitting tensile strength of basalt and polypropylene fiber

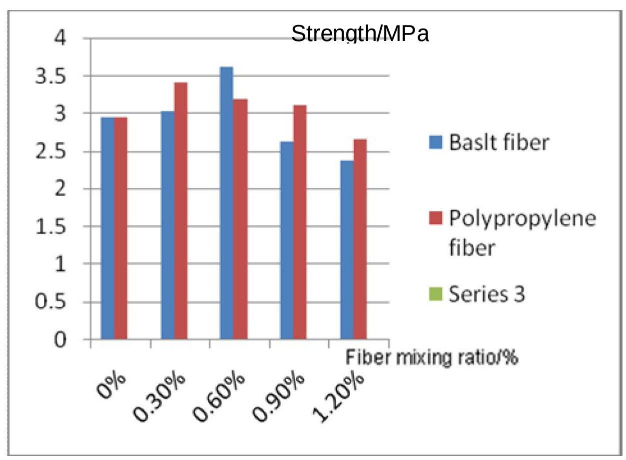


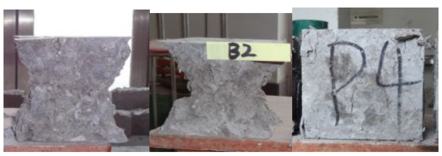
Fig. 5 comparison between splitting tensile strength of basalt and polypropylene fiber.

As can be seen from Figure 4, the incorporation of fibers in the concrete matrix greatly increases splitting tensile strength. Addition of 0.3% and 0.6% volume of basalt fiber increase the splitting tensile strength of concrete by 2.6% and 22.9% respectively; while for 9% and 1.2% volume, the splitting tensile strength of concrete decreased by 11.3% and 19.8% respectively; therefore, the optimum dosage for the splitting tensile strength of basalt fiber is in the vicinity of 0.6%. Also, addition of 0.3%, 0.6%, and 0.9%, volume of polypropylene fiber increase the splitting tensile strength of concrete by 15.1%, 7.8%, and 5.6% respectively; the optimum dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3%.

V. FAILURE MODE ANALYSIS

A. Compressive strength failure mode analysis

The plain concrete specimens and basalt fiber specimens destructed after the maximum load reached and started decreasing, the surface of the concrete specimen showed serious damage after been tapered to a shape as shown in fig. 6 (a), (b). While for the polypropylene fiber, destruction occurred at maximum load that is immediately after reaching the maximum load at failure.

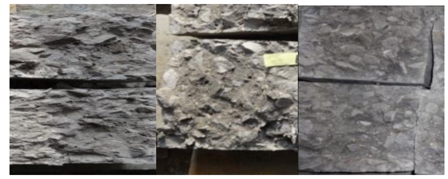


(a) (b) (c)

Fig. 6 Compressive strength failure mode analysis of basalt and polypropylene fiber.

B. Splitting tensile test failure mode analysis

As seen from the test result: Addition of low content of fiber has improved the splitting tensile strength of the reinforced concrete matrix to a varying degrees, while the splitting tensile strength decreases with the addition of high content of fiber to a concrete matrix. The role of each phase had dramatically changed, due to the high amount of fibers inside the concrete matrix. Figure 7 (a), (b), and (c) represents the failure mode of the specimen for plain and 0.3% fiber content, due to the low content of fiber, the change in the inner part was very small, therefore, plain concrete failure modes and low fiber content failure mode were basically the same, where by all the specimens were broken in half. For high content of fiber, the failure mode can be represented in Figure 7 (d), (e), (f), in which the specimen is not completely broken in half, but fibers linked the two half where you can clearly see the fibers in the specimens between the two cleavage planes, which showed fiber effect on crack resistance of concrete, the fundamental effect caused by high fiber content did not improved splitting tensile strength of concrete.



(a) (b) (c)

(d) (e) (f)

Fig. 7 Splitting tensile failure modes analysis of basalt and polypropylene fiber

VI. CONCLUSION

The study on the effect of Basalt and Polypropylene Fibers with different volume can still be a promising work as there is always a need to overcome the problem of brittleness of concrete.

The following conclusions could be drawn from the present investigation-

1 It is observed that the compressive strength for C30 grade of concrete from two different type of fiber at different volume fraction shows different degree of reduction.

2 Addition of 0.3%, 0.6%, 0.9% and 1.2% resulted in a decrease of compressive strength relative to plain concrete by 9%, 19%, 1%, and 18% respectively. Similarly, addition of 0.3%, 0.6%, 0.9%, and 1.2% volume of polypropylene resulted in a decrease of strength relative to plain concrete by 8%, 7%, 17% and 24% respectively.

3 It was observed that the incorporation of fibers in the concrete matrix greatly increases splitting tensile strength. Addition of 0.3% and 0.6% volume of basalt fiber increase the splitting tensile strength of concrete by 2.6% and 22.9% respectively; while for 9% and 1.2% volume, the splitting tensile strength of concrete decreased by 11.3% and 19.8% respectively; therefore, the optimum dosage for the splitting tensile strength of basalt fiber is in the vicinity of 0.6%. Also, addition of 0.3%, 0.6%, and 0.9%, volume of polypropylene fiber increase the splitting tensile strength of concrete by 15.1%, 7.8%, and 5.6% respectively; therefore, the optimum

dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3%.

REFERENCES

[1] Shah, S, P.; Skarendahl, A. "Steel fiber concrete", preface. US-Sweden, Join seminar (NSF-STU, Stockholm Sweden, 1985.

[2] Clarke, J. L, Vollum, R. L., Swwannell, N. et al. "Guidance for the Design of Steel-Fiber-Reinfored Concrete". Technical Report No. 63, Report of a Concrete Society Working Group.UK , 2007.

[3] Carlsward, J. "Shrinkage cracking of steel fiber reinforced self compacting concrete overlays", test methods and theoretical modeling. Doctoral thesis, lulea university of technology Sweden, 2006.

[4] Bentur A, Mindess S., "Fibre Reinforced Cementitious Composites", Elsevier *Applied Science, London, UK. 1990*

[5] Song P. S., Hwang S., and Sheu B. C. "Strength properties of nylon- and polypropylene-fiber reinforced concretes", *Cement And Concrete Research,35: 1546-1550, 2005.*

[6] Alhozaimy A. M., Soroushian P., and Mirza F., "Mechanical properties of polypropylene fiber reinforced concrete and the effects of pozzolanic materials", *Cement and Concrete Composites, 18: 85-92, 1996.*

[7] Tanyildizi H., "Statistical analysis for mechanical properties of polypropylene fiber reinforced lightweight concrete containing silica fume exposed to high temperature", *Materials and Design, 30: 3252–3258, 2009.*

[8] Soroushian P, Nagi M, and Hsu J., "Optimization of the use of lightweight aggregate in carbon fiber reinforced cement". *ACI Mater J,* 89(3):267–76, 1992

[9] Balendran R.V., Zhou F.P., Nadeem A., and Leung A.Y.T., "Influence of steel fibres on strength and ductility of normal and lightweight high strength concrete", *Build. Environ. 37: 1361 1367, 2002.*

[10] Malisch, W. R., "Polypropylene Fibers in Concrete, What do the test tell us*?" Concrete Construction, 31: 363-8, 1986.*

[11] Kraii, P. P., "A Proposed test to determine the cracking potential due to drying shrinkage of concrete". *Concrete construction, 30: 775-778, 1985.*

[12] Mindess, S. & Vondran, G., "Properties of concrete reinforced with fibrillated polypropylene fibers under impact loading". *Cement and Concrete Research, 18: 109-15, 1988.*

[13] Hughes, B. P., Fattuhi, N. I., "Improving the toughness of high strength cement paste with fiber reinforcement", *Composite, 7 (4): 185-8, 1976.*

[14] Chinese National Standards, for technical requirements and test method of sand and crushed stone for ordinary concrete.(JGJ52-2006).

[15] Chinese National Standards of water for concrete.(JGJ63-2006).

[16] Chinese National Standards. Specification for mix proportion design of Ordinary concrete. JGJ55, 2011.

[17] Chinese National Standards, for test method of mechanical properties on ordinary concrete.（GB/T 50081)

[18] Shen Rong-Xi." Fiber Reinforced Concrete" [M]. Beijing, China Building Industry Press,880 ~ 920, 1995.