ORIGINAL RESEARCH

Investigate the effect of different Forta Ferro fiber concentrations on the tensile strength of concrete, an experimental study employing the Barcelona and double punch tests

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Abstract:

Concrete is highly vulnerable to tensile stress, and the use of rebar is not always practical or cost-effective. Forta Ferro fibers offer an alternative solution for enhancing the tensile strength of concrete. In this study, 36 cylindrical and 36 cubic samples were tested using compressive strength, Barcelona, and double punch tests. The samples were aged for 28 days and contained 0, 1, 2, or 3 kg/m3 of Forta Ferro fibers.

The results showed that adding 1 to 3 kg/m3 of Forta Ferro fibers to the concrete increased the 28-day tensile strength (BCN test) by 8.40% to 9.04% in cylindrical samples and 8.71% to 8.93% in cubic samples. Similarly, the 28-day tensile strength (DPT) increased by 6.81% to 9.42% in cylindrical specimens and 3.92% to 6.69% in cubic specimens when Forta Ferro fibers were added.

The proposed Chen coefficient of 1.08 is suggested as the correction factor for the Forta Ferro fibers.

Keywords:
Concrete Tensile Strength, Forta Ferro Fiber, Barcelona test, Double Punch test

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1. Introduction

The low tensile strength of concrete is a significant disadvantage that limits its application. To address this issue, various investigations have been conducted with different approaches. In recent decades, the uniform dispersion of fibers throughout the concrete has been a way to create isotropic conditions, reduce fragility and brittleness, and increase ductility. Therefore, understanding the stress-strain behavior of fiber-containing concrete is essential for linear and nonlinear analysis and further design purposes. Forta Ferro fibers are one type of fiber that can improve tensile strength, ductility, and flexibility of concrete [30]. These fibers, made from various composite materials, consist of twisted bundle non-fibrillating monofilament and a filament fiber network that yields a high-performance concrete reinforcement system.

The tensile strength of concrete is typically measured by indirect tensile tests such as the Barcelona and Double Punch tests. The main difference between these tests is that the Barcelona test does not fail at the weakest points, while the Double Punch test fails at the weakest paths. In the Barcelona test, the sample under load breaks in the load path. Therefore, the resistances obtained from the Double Punch test, which are closer to reality, are lower than those obtained from the Barcelona test. Furthermore, the Double Punch test is easier to perform and requires a much lower final load for failure (20-30 kip compared to 40-60 kip in the Barcelona test), allowing for the use of smaller devices [32]; [31]; .

Kurtza and Balagurua investigated the use of different fibers, including polypropylene and nylon fiber-reinforced concrete (FRC), in controlling concrete cracking [17]. Applying these types of fibers decreased fracture and cracking by 0.1%. In another study, Yao found that in polypropylene fiber-reinforced concrete (PFRC) beams, tensile strength was reduced for 28 days, but it increased afterward due to the filling of micro-cracks by the fibers, which increased the structure of the concrete[34]. Song et al. conducted experiments by adding steel fibers to high-strength concrete, and impact tests on the samples confirmed that high-strength steel fiber-reinforced concrete (HSFRC) was significantly improved compared to high-strength concrete (HSC) with no fibers [28]. Nili and Afroughsabet investigated the effect of micro silica and steel fibers on the impact strength and mechanical properties of concrete [23]. Steel fibers were able to improve tensile and flexural strengths. Rodrigues et al. controlled the growth of cracks after fracturing to 0.2% using steel fibers in concrete, reducing crack width by 15% [26].

In this research, we compared the values obtained from Compressive, Barcelona, and Double Punch tests on cylindrical and cubic specimens with different percentages of Forta Ferro fibers. We also investigated the relationship between these tests.

2. Data and method

36 cylindrical and 36 cubic samples were prepared using Forta Ferro fibers at varying percentages of 0, 1, 2, and 3 kg/m3. After 28 days, the samples underwent compression, Barcelona, and Double Punch tests, and the results were analyzed. Portland Cement Type II and drinking water were used for concrete preparation, along with VM-MIX additive as a superplasticizer. This additive is a new combination of strong water-reducing resins that includes modified polycarboxylate ether, polymers, and special additives to preserve slump and adjust the viscosity of concrete. The four concrete mixing plans are presented in Table 1.

Table 1 Characteristics of the four mixing schemes used in this study

Mixing number / Materials	1	2	3	4
W/C	0.376	0.376	0.376	0.376
Water (kg/m^3)	193.44	193.44	193.44	193.44
Cement (kg/m^3)	514.26	514.26	514.26	514.26
Gravel (kg/m^3)	953.78	953.78	953.78	953.78
Sand (kg/m^3)	662.69	662.69	662.69	662.69
Fiber (kg/m^3)	0	1 (0.11%)	2 (0.22%)	3 (0.33%)
Superplasticizer (kg/m^3)	2.579	2.816	3.342	4.106

2.1. FORTA-FERRO fibers

Made from 100% pure copolymer/polypropylene, Forta Ferro is a color blended fiber, composed of a twisted bundle non-fibrillating monofilament, and a filament fiber network that yields a high-performance concrete reinforcement system. These fibers reduce the shrinkage of fresh and hard concrete and increase the impact and fatigue resistance, and hardness of the concrete. The extra heavy-duty fiber offers long-lasting durability, increased structural properties, and the restriction of secondary or thermal cracks in the concrete through fusing a truly unique synergistic fiber system (forta-ferro.com). The appearance is intertwined fibers and single-strand and gray-colored fibers (Figure 1).

Figure1. Ferta Ferro fiber used in this research

These fibers are resistant to acid/alkali environments and have a tensile strength of 670-570 MPa, a specific gravity of 910 kg/m3, and a length of 54 mm.

2.2 Compressive strength test

This test is based on ASTM C39 standard and loading to the breakpoint. Although compressive and tensile strengths of concrete are closely related, there is no direct correlation between them. As the compressive strength of concrete increases, the tensile strength of concrete increases with a slower rate.

Figure 2. a) Compression in three layers b) Molded samples

Former studies have shown that the ratio of the direct tensile strength of concrete to compressive strength is 8 to 15 percent (MacGregor, James Grierson, et al. *Reinforced concrete: Mechanics and design*. Vol. 3. Upper Saddle River, NJ: Prentice Hall, 1997.). The following relationship is described in ACI 318, according to some studies, to estimate the average tensile strength (f_{ct}) by the splitting test:

$$f_{ct} = 0.56\sqrt{f_{cm}} \quad (1)$$

Where f_{cm} is the measured average compressive strength of concrete and it can be considered as $f_{c.}$ It is not easy to create pure tensile stresses in the range of 8% to 15% of its compressive strength directly in a concrete specimen in the lab, primarily because the specimen holders produce secondary stresses whose effects cannot be ignored. Direct tensile testing is difficult due to the complications of storing concrete in the clamps, which in turn, cause the early failure to not occur near the holding points since the load should not be off-axis. Therefore, direct tensile testing is not standard and is rarely used. ASTM C 78, ASTM C 496, and BS1881 standards recommend other methods for bending (fracture modulus) and indirect tensile (split off) to determine tensile strength. However, the results of the bending tensile test will be larger than the splitting tensile strength, and the splitting tensile test results will also be larger than the direct tensile test results.

2.3 Barcelona Test (BCN)

The Barcelona Splitting Test (ST) is performed according to the ASTM C496 standard, which is proposed below.

$$f_{ct} = \frac{2P}{\pi l D} \quad (2)$$

Where P is the maximum pressure (load applied at the moment of failure), d is the sample length, and L is the sample diameter.

2.4. Double punch test (DPT)

Chen describes a test to determine concrete tensile strength. In this test, the cylindrical or cubic concrete specimen is positioned vertically between the loading jack plates and compressed by two pieces of steel punch parallel to the upper and lower center of the specimen [10]. (Figure 3). The DPT method has been used in several studies (Chen and

Yuan, [12]; Marti, [19]; Molins et al., [21];; Kim et al., [16]

Figure 3. Compressive strength tests a) cylindrical sample b) cubic sample

The compressive loads transmitted through the steel punch to the specimen produce a stress distribution that is shown by the following formula to provide a roughly integrated average tensile strength across the crack diagonal plates:

$$f'_t = \frac{Q}{\pi(1.2bH - a^2)} \tag{3}$$

Where f'_t: tensile strength, Q: applied load, b: cylinder radius, H: cylinder height, a: punch radius, which must:

$$b/a \leq 5 \; or \; \frac{H}{2a} \leq 5 \tag{4}$$

And it has been emphasized that b = 5a or H = 10a should be used for any proportion outside this range. The ideal failure condition in the double punch test is to break the sample in several radial directions. Since the strength is an average value, the greater the number of radial failures, the more accurate the strength. When the top and bottom plates are very rough or parallel to each other, the specimen may be broken only in two directions and usually at a much lower applied load. Most samples break in three or four directions.

Figure 4. Cylindrical and cubic specimen broken in Barcelona test

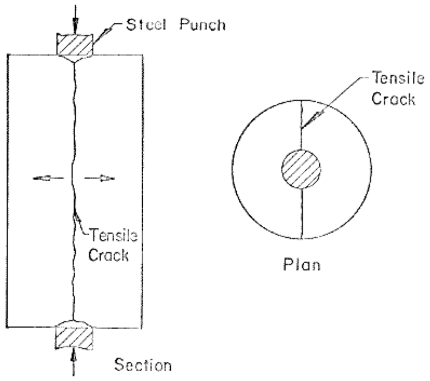

Figure 5. Double Punch Test [10]

Figure 6. Cylindrical and cubic specimens under double punch test

Figure 7. Cylindrical and cubic specimen is broken in double punch test

3. Results

Table 2 represents the results of the compressive strength, Barcelona, and double punch tests on cylindrical and cubic specimens. The results suggest that in cylindrical specimens, by adding 1, 2, and 3 kg/m3 fiber to the concrete, the compressive strength of the control specimen increased by 5.22%, 9.73%, and 15.53%, respectively. In cubic samples, the same values were 2.51%, 3.59%, and 7.63%, respectively. The Barcelona test shows that the tensile strength of cylindrical specimens increased by 7.93%, 11.61%, and 14.51%, respectively, compared to the control sample. In cubic samples, the tensile strength of cylindrical specimens increased by 2.07%, 3.07%, and 5.87%, respectively. The results of the Barcelona test reveal that in cylindrical specimens, by adding 1, 2, and 3 kg/m3 fiber to concrete, the tensile strength increased by 6.81%, 9.12%, and 9.42%, respectively. In cubic samples, the tensile strength increased by 3.92%, 5.32%, and 6.69%, respectively.

Table 2 Comparison of the results of compressive strength and double punch and Barcelona tests for cubic and cylindrical specimens

Fiber content ($^{kg}/_{cm^3}$)	Cylinder			Cube		
	Compressive ($^{kg}/_{cm^2}$)	Tensile ($^{kg}/_{cm^2}$)		Compressive ($^{kg}/_{cm^2}$)	Tensile ($^{kg}/_{cm^2}$)	
		Barcelona	Double punch		Barcelona	Double punch
0	362.49	30.43	30.21	445.79	39.82	33.9
1	373.03	32.85	32.27	456.92	40.65	35.23
2	379.3	33.97	32.97	471.2	41.05	35.7
3	**385.63**	**34.85**	33.06	**479.8**	**42.16**	36.17

A comparison between the results of cylindrical and cubic specimens in both double punch and Barcelona tests shows that this ratio is almost constant and is not significantly correlated with fiber content (Figure 8). The rate is between 20% and 30% in the Barcelona test and 8.2% and 12.2% in the double punch test.

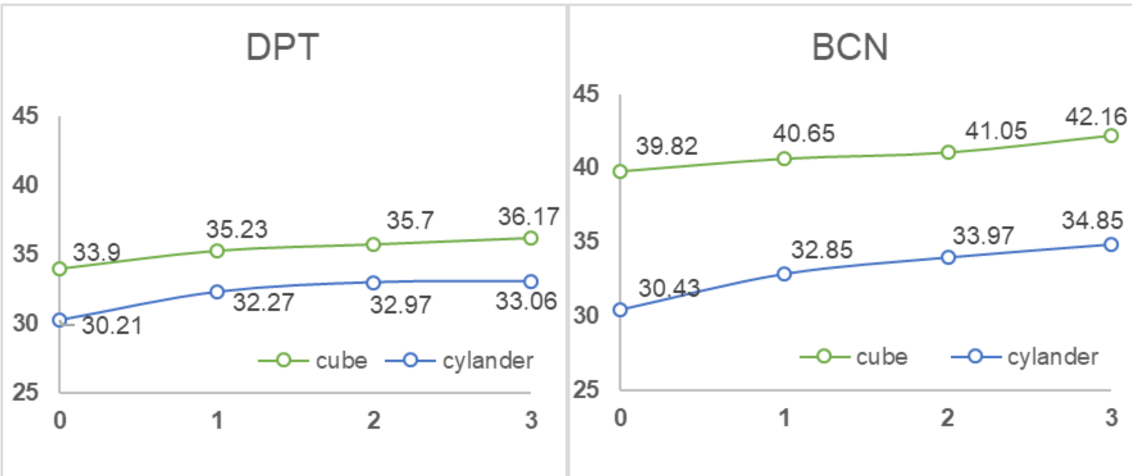

Fig. 8 Comparison of the strength of cylindrical specimens with cubic a) Barselona and b) double punch tests (kg/cm2)

The ratio of the cubic specimens in the Barcelona test is almost constant compared to the double punch, which will increase for cylindrical specimens with increasing fiber (Figure 9).

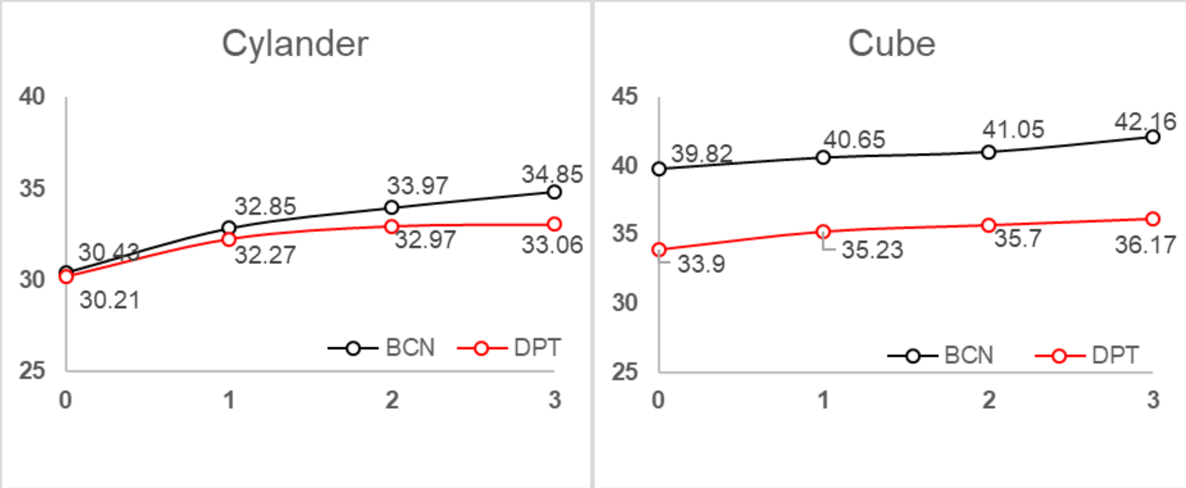

Fig. 9 Barcelona to Double Punch Test Ratio for samples of a) Cubic b) Cylindrical

The tensile strength values obtained from different proposed equations based on the compressive strengths compared to the Barcelona test values are shown in Table 3.

Table 3. Comparison of tensile strengths obtained with others' researchs

Fiber content (kg/m^3)	Compressive (N/mm^2)	Tensile strength from compressive strength (N/mm2)							
		BCN test	**ACI Committee 318 (2014)**	**CEB-FIB (1991)**	**Carino and Lew (1982)**	**Oluokun et al. (1991)**	**Arıoglu et al. (2006)**	**Lavanya and Jegan (2015)**	**Gardner (1990)**
	Measured value	**Measured value**	$0.56f'c^{0.5}$	$0.3f'c^{0.66}$	$0.272f'c^{0.71}$	$0.294f'c^{0.69}$	$0.387f'c^{0.63}$	$0.249f'c^{0.772}$	$0.33f'c^{0.667}$
0	36.95	3.10	3.40	3.25	3.38	3.50	3.76	4.04	3.67
1	38.03	3.35	3.45	3.31	3.45	3.57	3.83	4.13	3.74
2	38.66	3.46	3.48	3.35	3.49	3.61	3.87	4.18	3.78
3	39.31	3.55	3.51	3.38	3.53	3.65	3.91	4.24	3.82

Using a power trend line, we can find the relationship between the compressive strength and tensile strength obtained from the tests, which can be estimated with an appropriate confidence coefficient, having concrete compressive strength, tensile strength. However, these relationships are true for the consumption range of 0 to 3 kg/m3 of the Forta Ferro fiber in concrete. The following formulas illustrate the relationship between compressive strength and tensile strength in cubic specimens.

$$F_t=0.55F_c^{0.71}\ ,\quad R^2=0.94 \quad \text{for BCN} \tag{5}$$

$$F_t=0.22F_c^{0.83}\ ,\quad R^2=0.92 \quad \text{for DPT} \tag{6}$$

4. Conclusion

The effect of Forta Ferro fiber fibers on the compressive and tensile strength of concrete was investigated by the compressive strength, Barcelona, and Double Punch tests. Values of 1 to 3 kg/m3 were added to the concrete, and the following results were obtained.

1. The ratio of 28-day compressive strength values obtained from tests on cubic specimens in samples containing 0, 1, 2, and 3 kg/m3 of Forta Ferro fibers was 22.98%, 22.49%, 24.23%, and 24.42% higher than results of tests on cylindrical specimens.

2. By adding 1, 2, and 3 kg/m3 Forta Ferro fibers to concrete, the 28-day compressive strength was increased 2.91%, 4.64%, and 6.38% in cylindrical specimens, and 2.50%, 5.70%, and 7.63%, in cubic specimens, respectively.

3. The 28-day tensile strength (BCN test) values obtained from tests on concrete samples containing 0, 1, 2 and 3 kg/m3 of

Forta Ferro fibers concerning the compressive strength of the same sample were 8.40%, 8.81%, 8.96%, and 9.04% in cylindrical samples, and 8.93%, 8.90%, 8.71%, and 8.79% in cubic samples, respectively.

4. The 28-day tensile strength (DPT) values of concrete samples containing 0, 1, 2 and 3 kg/m3 of Forta Ferro fibers for the compressive strength of the same sample were 8.33%, 8.65%, 8.69%, and 8.57 in cylindrical samples and 7.60%, 7.71%, 7.58%, and 7.54% in cubic samples, respectively.

5. By adding 1, 2 and 3 kg/m3 of Forta Ferro fibers to concrete, the 28-day tensile strength (BCN test) were increased 7.93%, 11.61%, and 14.51% in cylindrical specimens, and 2.07%, 3.07%, and 5.87% in the cubic samples compared to the control sample.

6. By adding 1, 2 and 3 kg/m3 of Forta Ferro fibers to concrete, the 28-day tensile strength (DPT) were increased 6.81%, 9.12%, and 9.42% in cylindrical specimens, and 3.92%, 5.32%, and 6.69% in the cubic samples compared to the control sample.

7. By using more fiber, as expected, cracks were minimized, and the cracks created were smaller than the control sample crack. The integrity of the concrete was maintained.

8. It is suggested that in the proposed equation of Chen [10]& [11], a coefficient of increase of 1.08 can be used as a correction factor in the case of Forta Ferro fibers.

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