FLEXURAL BEHAVIOR OF THE STRUCTURAL CONCRETE REINFORCED WITH STEEL AND POLYPROPYLENE FIBERS

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ABSTRACT

In this investigation, the effect of steel and polypropylene fibers on the flexural strength of structural concrete was evaluated. The granulometric properties of the aggregates were analyzed under the norms ASTM C136 and NTP 400.012, with the results obtained, the mixture design was made with a characteristic resistance to the compression of 210 Kg/cm², to which proportions of 10%, 15% and 20% of steel and polypropylene fibers were added. Fine and coarse aggregate (1/2" stone), Portland cement Type ICo, steel fibers (Sika Fiber CHO 65/35 NB) and polypropylene fibers (Sika Fiber PE) were used. Forty-eight 150x150x600 mm concrete beams were produced in three experimental groups and a control group, which were tested for flexural strength according to ASTM C78 and NTP 339.078, after 14 and 28 days of curing. Maximum values were achieved after 28 days with 30.1 kg/cm² for standard concrete and 32.5 kg/cm² for concrete with 20% steel fiber and polypropylene. The fibers proved to be an excellent aggregate to be used in concrete mixtures because they significantly improve its physical and mechanical characteristics. Fiber-reinforced concrete with a 20% proportion achieved a 7.7% increase in strength over standard concrete, concluding that a concrete with added steel fibers and polypropylene has a better performance compared to conventional concrete.

Keywords: Steel fibers, polypropylene fibers, flexural strength, structural concrete.

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1. INTRODUCTION

Concrete is one of the most used elements in the construction industry, due to the contributions of its physical and mechanical properties such as its versatility, workability, durability and resistance [1] [2].

Adding fibers to concrete to decrease the expansion of failures, due to weakness in tension and drying contraction [3], not only develops compressive, tensile and flexural strength, but

also provides adequate response before and after cracking. Since 1967, various types of filaments have been successfully used in concrete to limit crack propagation and improve ductility and strength [4]. Experimental studies have shown the ability of the fibers to provide better response to seismic stresses.

2. METHODS AND MATERIALS

An experimental research design with post-test only and control group was used [5]. Initially, the granulometric analysis of the materials was performed following the procedures described in ASTM C136 [6] and NTP 400.012 [7]. A sample of 48 prismatic rectangular specimens of 150x150x600 mm was worked with according to the ASTM C192 standard [8], distributed evenly for the experimental and control groups, according to 14 and 28 days of curing.

The experimental samples were increased 10%, 15% and 20% of steel and polypropylene fibers. High-quality drawn steel fibers of Sika Fiber CHO 65/35 NB [9] were used to facilitate the homogenization of the concrete by preventing the agglomeration of the individual fibers. Sika Fiber PE polypropylene fibers were also used. This is a high-tenacity synthetic reinforcement that prevents cracking in concrete and mortar, and is composed of a mixture of crosslinked and rolled monofilaments.

During mixing, Sika Fiber PE is randomly distributed within the concrete or mortar mass, forming a very uniform three-dimensional network. A mix design was developed for a compressive strength of $f'_c = 210 \text{ Kg/cm}^2$ in which both fine and coarse aggregate (1/2" stone), Portland cement Type ICo and subsequently steel fibers (Sika Fiber CHO 65/35 NB) and polypropylene fibers (Sika Fiber PE) were used for the experimental samples.

The technical standards NTP 339.035 [10], NTP 339.078 [11] and ASTM C78 [12] were used to perform the corresponding tests. The 150x150x600 mm test beam was symmetrically supported by two parallel steel rollers with a separation distance of 45 cm.

The load was applied through two rollers mounted on a metal plate which in turn was loaded at the central point (Method of testing on beams simply supported with loads to the third of the section). The flexural strength was measured through the modulus of rupture $R = \frac{pl}{bd^2}$, where p: maximum applied load, l: free length between supports (mm), b: average width of the sample (mm), d: average height of the sample (mm). See figure 1.

Figure 1 Curing and testing of concrete samples

3. RESULTS

3.1. Characterization of Materials and Design of Mixtures

Figures 2 and 3 show the granulometry of the fine and coarse aggregates obtained from the tests carried out, according to ASTM C136 [6] and NTP 400.012 [7].

Figure 2 Granulometric curve of fine aggregate - specification limits ASTM C33 [13].

Figure 3 Granulometric curve of coarse aggregate - specification limits ASTM C33 [13].

Table 1 shows the physical-chemical characteristics of Pacasmayo Extraforte Cement (Type ICo), provided by the manufacturer [14]. The mixture design was made using the 211 ACI Committee Method [15], being the proportions used as indicated in table 2.

Table 1 Physical-chemical and mechanical characteristics of cement.

Chemical Properties	Requirement NTP 334.090 [16]	Result
MgO	Maximum 6%	2.3%
SO ₃	Maximum 4%	2.4%
Physical and mechanical properties		
Air content	Maximum 12%	5%
Specific surface	It does not specify	5440 cm ² /gr
Density	It does not specify	2.96 gr/ml
Compression resistance at 3 days	Mínimum 133 kg/cm ²	206 kg/cm ²
Compression resistance at 7 days	Mínimum 204 kg/cm ²	264 kg/cm ²
Compression resistance at 28 days	Mínimum 255 kg/cm ²	335 kg/cm ²
Initial curing	Mínimum 45 (min)	124 min
Final curing	Maximum 420 (min)	254 min

Table 2 Design of concrete mixtures for $f'_c=210$ kg/cm² with a/c ratio of 0.60

Material	Weight Ratio	Weight in Kg	% of mixture
Cement	1,00	345,6	14,9
Sand	1,96	678,2	29,3
Gravel	3,14	1086,6	46,9
Water	0,60	208,1	9,0
Total for 1 m ³		2318,5	100,0

3.2. Testing of Concrete in a Fresh and Hardened State

The slump test was conducted in accordance with NTP 339.035 [10] and ASTM C143 [17], which serves to determine the consistency or fluidity of the mixture. The results of this test are shown in Table 3.

Table 3 Maximum fresh concrete slump

Group	SLUMP (inches)	% Variation
SC	3.75	0%
SC10SPF	3.60	-4.0%
SC15SPF	3.55	-5.3%
SC20SPF	3.50	-6.7%

Flexural strength tests, on samples of hardened concrete, were performed according to ASTM C78 [12] and NTP 339.078 [11], whose results are shown in Table 5 and Figures 4 and 5.

Table 4 Flexural strength in concrete beams in a hardened state at different curing ages.

Mixture	Resistance to flexion (Kg/cm ²)					
	14 days	% scope	Maximum deformation (mm)	28 days	% scope	Maximum deformation (mm)
SC	29.8*	80.0	1.7	30.1	100.0*	1.8
SC10SPF	28.6	76.9	1.7	30.9	102.4	1.8
SC15SPF	25.9	69.8	1.5	30.1	99.9	1.8
SC20SPF	27.8	74.7	1.6	32.5	107.7	1.9

Note: *Strength tolerance according to the age of curing of the concrete. NTP 339,034 [18]

Figure 4 Flexural strength of concrete according to curing age.

Figure 5 Flexural strength of concrete according to different proportions of SF and PF fibers.

Figure 6 Maximum deformation according to proportion of SF and PF fibers.

3.3. Statistical Analysis of Results

The samples tested at 28 days of age met the normality test ($p > 0.05$) with the exception of the CS mixture ($p < 0.05$), and therefore the Kruskal-Wallis statistical test was used as detailed in Table 5.

Table 5 Kruskal - Wallis for flexural strength values of concrete specimens tested at 28 days of age

Test statistic	Values
H of Kruskal-Wallis	4.451
gl.	3
Asymptotic significance	0.217

The non-parametric Kruskal Wallis test determined that $p = 0.217 > 0.05$, therefore, the averages of the modified mixtures (SC10SPF, SC15SPF and SC20SPF) do not show a significant difference from the SC mixture (Table 5 and Figure 4).

4. DISCUSSION OF RESULTS

4.1. Slump

It was observed that slump decreases as the proportion of steel and polypropylene fibers in the concrete mix increases (decrease up to 6.7%, table 3); this situation is due to the need for mortar due to the formation of a very uniform three-dimensional network with both fibers. The differences can be seen in table 3. These variations in slump are also found by [19], [20], [21], [22], [23], in some cases they came to use and/or recommend the use of plasticizing additives to improve the workability of the concrete. Patil and Shinde (2016) [24] also determined that increasing the steel fiber in the concrete decreases its workability.

4.2. Flexural Strength

Table 4 details the average values of the flexural strength of the specimens in the studied proportions. It is observed that the resistance has a maximum decrease of 10.2% (SC15SPF) in the fiber-reinforced specimens at 14 days of cure, considering that the SC reaches 80% of its resistance. Unlike the previous specimens, at 28 days all the fibre-reinforced mixtures were equal to or higher than SC, with the SC20SPF obtaining an increase of 7.7% in the modulus of rupture having a control function against the propagation of micro-flaws. Badogiannis, Christidis and Tzanetatos (2019) [25] report that the combination of SF and PF increases the flexural strength from 47% to 110%, referring that this is due to the type and shape of the steel fiber [26] that allowed to control the development of cracks increasing its strength and toughness even after cracking had started. This control of structural cracks is also confirmed by [19], [27] and [28].

On the other hand, Mastali, Dalvand, Sattarifard, Abdollahnejad and Ilikainen (2018) [29] detail that the type of fiber (SF and PF), the combination or the proportion can improve the ability of the mixtures to stop the propagation of cracks, mainly fibers of industrial origin. The incorporation of FP alone into concrete also helps to improve strength, as confirmed by Mashrei, Sultan and Mahdi (2018) [30] who found an increase of up to 104% over standard concrete, when used up to a certain ratio, helping to reduce the width of cracks. For their part, Al-Katib, Alkhudery and Al-Tameemi (2018) [31] found that flexural strength increases considerably when the PF ratio is increased, with increases ranging from 72% to 277% when PF ranged from 0.5 to 3.5%, which is favorable for counteracting additional load cycles; they also claim that flexural strength can be further increased when combined with improved cement.

Chapoñan and Quispe (2017) [32], Sarta and Silva (2017) [20], Armas (2016) [21], Condori (2015) [33] and Ortiz (2015) [22], also found that the addition of fibers generates an increase in the flexural strength of the concrete, and when using plasticizing additive in the mix, a higher value is achieved in the modulus of rupture, since it has the property of increasing the mechanical strength and improving the workability of the mix. It should be highlighted that the increases in flexural strength can be attributed to the action of the fibers in their purpose of preventing the propagation of micro-cracks in the concrete when it is subjected to solicitations, restricting their extension or elongation.

On the other hand, during the tests in both ages of curing, it was observed that the SC specimens presented fragile faults reaching total collapse, unlike the specimens with added fibers in proportions of 10%, 15% and 20% that presented ductile faults, that is to say that when applying the loads in the element, cracking was present in its central third, but the beam remained firm due to the presence of fibers. Sarta and Silva (2017) [20], Condori (2015) [33], Ortiz (2015) [22] and Millán (2013) [34] state that the presence of fibers changes the behavior from a fragile break to a ductile one.

With regard to the maximum deformation reached after 28 days of curing, Figure 5 shows that the highest value reached in the SC20SPF sample was 1.9 mm, which is 5.6% higher than the simple concrete (SC) design without fibers.

4.3. Statistical Analysis

With regard to the effect of the dosage of SF and PF on the flexural strength of the concrete, table 5 shows that there is no differentiated behavior, but the sample that reached a better development at 28 days of curing, above SC, was SC20SPF (Figure 5). Although these values are not statistically significant, it was evident that the addition of steel and polypropylene fibers generate an increase in the flexural strength of the concrete.

5. CONCLUSIONS

- SF and PF fibers proved to be an excellent aggregate to be used in concrete mixtures because they significantly improve its physical and mechanical characteristics.
- Fiber-reinforced concrete with a proportion of 20% of SF and PF achieved an increase of the modulus of rupture of 7.7% with respect to the simple concrete, letting us affirm that this concrete has a better behavior compared to a conventional concrete.
- The maximum deformation reached was 1.9 mm in the SC20SPF sample at 28 days of cure, representing 5.6% higher than simple concrete (SC) without fibers.
- Fiber-reinforced mixtures do not present a significant statistical difference despite having exceeded the bending performance of conventional concrete (SC) by up to 7.7% at 28 days of cure.
- Concrete specimens that included the combination of SF and PF reduce the presence of cracks and can withstand additional load cycles after failure loading is released.

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