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Mechanical characterization of concrete with additions of steel fiber and plastic fiber

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Abstract

Currently the disposable materials of metallurgical companies are not used in a beneficial way, but they can be reused and used to make different fibers, the application of fibers for concrete reinforcement is being carried out in the construction sector because it reduces the environmental pollution and also causes benefits in the mechanical properties of concrete. The objective of this research is to evaluate the mechanical properties of concrete with steel fibers (SF) and plastic fibers (PF). Mechanical tests were carried out on conventional concrete, concrete with SF in proportions of 0.44, 0.88, 1.32 and 1.76% of the volume of concrete and PF in proportions of 0.04, 0.07, 0.09 and 0.11% of the volume of concrete. According to the results, the improvement of 0.44% SF with 0.04% PF improves the compressive strength; the combination of 0.44% SF plus 0.11% PF increases the flexural strength and the combination of 0.44% SF plus 0.04% PF increases the tensile strength. It is concluded that the present study demonstrates that the combination of SF with PF improved the mechanical properties of concrete.

Keywords: Concrete, Steel fibers, Plastic fibers, Mechanical properties, Environmental pollution

1. Introduction

Concrete is an essential material in construction, but recently due to the decrease in natural resources and the increased demand for housing, research into new technologies and construction materials is required with the aim of making homes of good quality, useful and economic [1, 2]. Currently the disposable materials of the mineral and metal companies are not used in a beneficial way, but they can be reused and used to make different fibers or materials that improve the properties of concrete [3, 4]. Centuries ago steel bars were conventionally used in concrete casting; However, currently you can find different alternatives of SF and PF in the commercial market [5], which when added to concrete can enhance its mechanical and physical properties such as: plasticity, malleability and resistance of concrete [6, 7]. In recent years, research is being carried out on the benefits of using fibers in concrete due to the best results that were obtained [8]. On the other hand, it is necessary to mention that SF is one of the materials that is scarcely studied, however it is an adequate choice as structural reinforcement since its easy handling allows it to be used in different types of constructions [9].

Regarding the settlement (slump) of concrete Liu et al. [7] indicate that by adding 0.5% SF and 1.0% PF the settlement decreased by 5% compared to the control concrete; Strong Mohebi et al. [10] show that the improvement of 0.45% of PF reduces this property to 20%; On the other hand, in the study by Gallo Arciniegas et al. [9] indicate that slump decreases up to 50% when 0.74% SF is added. According to Badogiannis et al. [1] in his study it is shown that the addition of 1.0% of SF raises the unit weight of the concrete up to 2.22%. On the other hand, Almeshal et al. [11] in their research they indicate that concrete with 50% PF reduces its density up to 31.6% with respect to the standard concrete.

In the study by Grzymski et al. [12] shows that the compressive strength of concrete mixes is affected by the amount of SF used, because when recycled SF was used in dosages of 25 kg/m³, the resistance rises to 69.04 Mpa, which is equivalent to to an increase of 65.9%; on the other hand Thorneycroft et al. [13] express that in the compression tests of their research, the resistance was reduced up to 4.1% compared to the standard mixture when a dosage of 10% PF of 2 to 4 mm size was used instead of the fine aggregate. Regarding the flexural resistance in the study by Zhang and Gao [14] it is shown that the addition of 2.5% of industrial SF increases the resistance up to 8.8 Mpa, likewise Shirani et al. [2] presents similar results where the addition of 1.5% SF increases resistance up to 29.6%. On the other hand, the results obtained by Mohebi et al. [10] show that the addition of PF in dosages of 0.15, 0.30 and 0.45% on concrete reinforced with bars produce increases of up to 20% compared to control concrete. According to Anike et al. [15] express that the incorporation of SF in dosages of 0.125 to 1.5% increases the tensile strength up to 38% compared to the standard concrete. In this regard, Madandoust et al. [16] express in their study that the concrete (w/c ratio of 0.30) with the addition of PF in dosages of 0.1, 0.2 and 0.3%, the tensile strength increases by 15.9, 24.5 and 32.5% correspondingly.

From the theoretical basis it can be evidenced the existence of extensive documents on the application of SF and PF in concrete; whose properties depend on the type of fiber used, its section (length/diameter ratio) because a high length/diameter ratio allows to obtain significant increases in the properties of concrete with a lower amount of fiber, the dosage to be used depends on the type of

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fiber and concrete requirements, but generally the amount of fibers added should not be extremely high because it affects the workability of concrete. The knowledge gap is that only SF-only or PF-only concretes have been made, whereas in the present study the combination of both materials was added to the concrete. The main objective of this research is to evaluate the manufacturing process of concrete with SF and PF; the physical and mechanical properties of concrete were studied. Parameters such as the optimum content of SF, and the optimum content of SF plus PF were established.

In the present investigation, it was carried out in two stages to study the mechanical properties of SF concrete with inclusion of PF. In the first stage, SF was added at 10, 20, 30 and 40 kg/m³ (0.44, 0.88, 1.32 and 1.76% by weight of the mix) determining the optimum percentage of SF. In the second stage, with the optimum percentage of SF, PF was introduced in 1.0, 1.5, 2.0 and 2.5 kg/m³ of concrete (0.04, 0.07, 0.09 and 0.11% of the weight of the mixture).

2. Materials and methods

2.1 Materials used for the manufacture of concrete

For the preparation of the mixtures, Type I Cement is used, which complies with the characteristics established in ASTM C150 [17], the properties of the cement used are shown in Table 1. The selection of the fine and coarse aggregate was carried out according to the ASTM C33/C33M [18] and ASTM C136-06 [19], the properties of the aggregate that is used is shown in Table 2, and Figure 1 and Figure 2 show the granulometry curve of the fine and coarse aggregate. As for the concrete mixtures with the incorporation of fibers, SF and PF were used as shown in Figure 3; the properties of these fibers are detailed in Table 3.

Table 1 Cement properties

Air Content (%)	Fineness (cm²/g)	Compression Strength (Mpa)			Setting time (min)	
		3 days	7 days	28 days	Initial	Final
8	4000	29.4	36.6	45.3	132	289

Table 2 Physical properties of fine and coarse aggregate

Aggregate	Natural humidity (%)	Absorption (%)	Mass Specific Weight (gr/cm³)	Fineness Module	Max size of the aggregate	Loose Unit Weight (kg/m³)	Compacted Unit Weight (kg/m³)
Fine	5.72	2.25	2.58	2.48	-	1556	1767
Coarse	0.47	0.85	2.68	-	3/4"	1385	1536

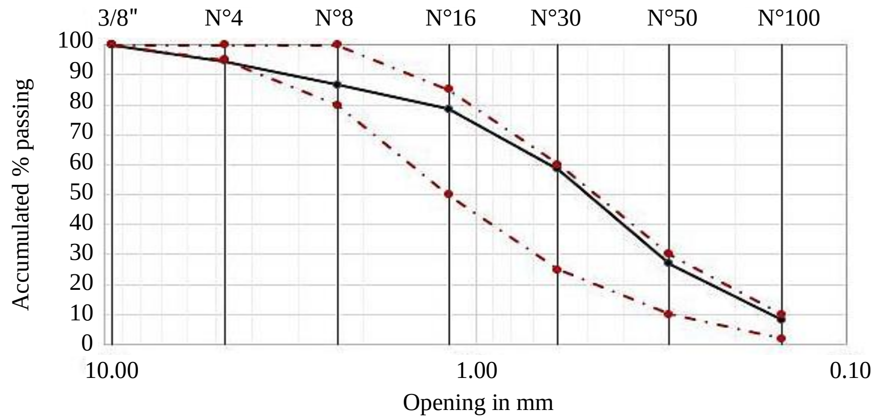


Figure 1 Fine aggregate granulometry

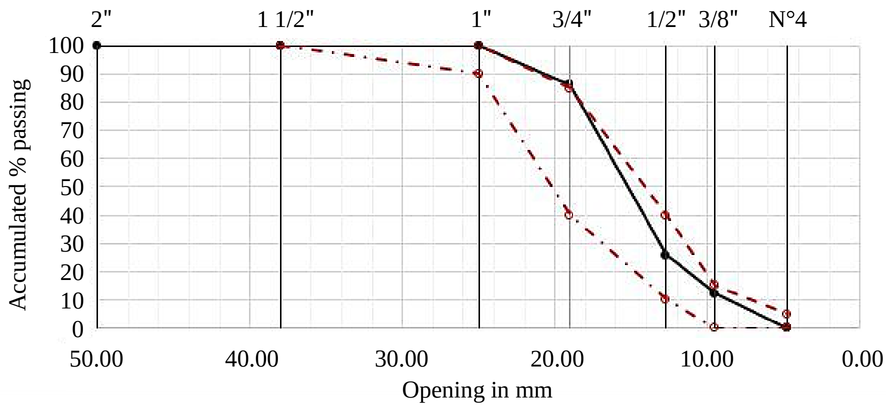


Figure 2 Coarse aggregate granulometry

Table 3 Fiber properties

Fibers	Length (L)	Diameter (D)	L/D Ratio	Resistance (Mpa)
Steel	60 mm	0.75mm	80	1200
Plastic	12.7-19mm	0.03-0.05mm	380	265

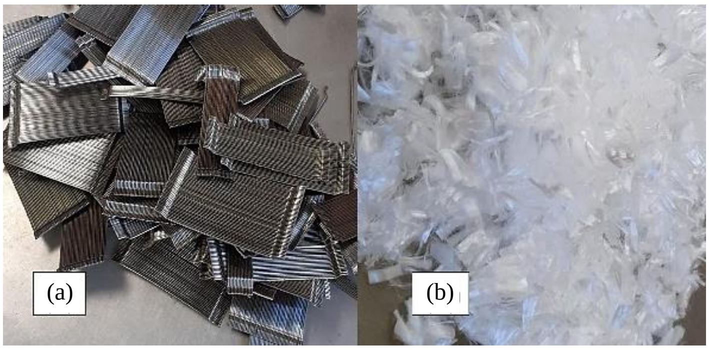


Figure 3 Fibers used in concrete mixes: (a) steel fibers, (b) plastic fibers.

2.2 Configuration of concrete specimens

The mix design was carried out using the ACI 211.1 [20] method; Likewise, it was sought to achieve mixtures of medium consistency to facilitate handling, placement and compaction, for which a w/c ratio of 0.6 was used for a resistance of f'c=210 kg/cm².

Regarding the concrete specimens that will be used in the compression (117 specimenes) and diametral traction tests (39 specimens), it was required to use a polyvinyl chloride (PVC) mold with a cylindrical configuration, the standard dimensions used are 15 cm diameters at the top and bottom and a total mold height of 30 cm. On the other hand, the manufacture of the specimens for the flexural test (39 specimens) was carried out through the use of prismatic moulds; said molds were 15 cm wide between the internal faces, a height of 15 cm from the base and a length of 50 cm.

2.3 Concrete mixes incorporating the fibers

A standard mix design was made (mixture C) and later SF was added in dosages of 10, 20, 30 and 40 kg/m³, mixtures were obtained with the addition of PF in dosages of 1.0, 1.5, 2.0 and 2.5 kg/m³. Regarding the mixtures with the addition of SF plus PF, 10 kg/m³ of SF (0.44% of SF) were obtained because it is the optimal amount of SF in the compression test and additionally PF was incorporated in dosages of 1.0, 1.5, 2.0 and 2.5 kg/m³ of concrete (0.04, 0.07, 0.09 and 0.11% of PF). Table 4 details the compositions of the mixtures with SF and PF.

Table 4 Composition of concrete mixes

Mix reference	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Steel fibers		Plastic fibers	
					SF (kg/m³)	SF (%)	PF (kg/m³)	PF (%)
C	333	818	1003	177	-	-	-	-
S-D1	333	818	1003	177	10	0.44	-	-
S-D2	333	818	1003	177	20	0.88	-	-
S-D3	333	818	1003	177	30	1.32	-	-
S-D4	333	818	1003	177	40	1.76	-	-
P-D1	333	818	1003	177	-	-	1.0	0.04
P-D2	333	818	1003	177	-	-	1.5	0.07
P-D3	333	818	1003	177	-	-	2.0	0.09
P-D4	333	818	1003	177	-	-	2.5	0.11
SP-D1	333	818	1003	177	10	0.44	1.0	0.04
SP-D2	333	818	1003	177	10	0.44	1.5	0.07
SP-D3	333	818	1003	177	10	0.44	2.0	0.09
SP-D4	333	818	1003	177	10	0.44	2.5	0.11

2.4 Test methods

Regarding the test methods applied to fresh concrete, the settlement is measured using the Abrams cone according to the parameters established in the ASTM C143 [21] standard and also the unit weight of the concrete according to the ASTM C138 [22] standard. On the other hand, to determine the mechanical properties of the hardened concrete, the compression resistance tests were carried out using the ASTM C39 [23] norm, flexural resistance using the ASTM C293 [24] norm and finally the diametral tensile strength according to the norm ASTM C496-96 [25]. The compression, flexural and traction test that was carried out on said specimens is shown in Figure 4.

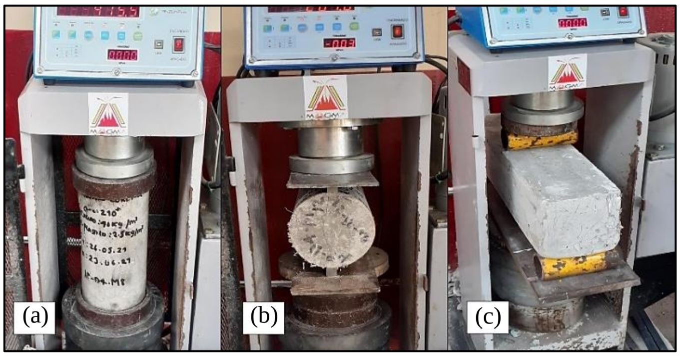


Figure 4 Test of: (a) Compressive strength, (b) Flexural strength, (c) Diametral tensile strength

3. Results and discussion

3.1 Settlement of concrete mixes

According to Figure 5, it is shown that adding SF progressively reduces the settling of the mix [9, 26]. On this Pinedo Díaz et al. [8] in his research, he was able to obtain results in the 3 ½" (88.9 mm) slump for the control concrete, but by incorporating SF in dosages of 25 and 30 kg/m³, the slump reduces 28.6 and 36.3%. On the other hand, in concrete mixes with the incorporation of PF in dosages of 1, 1.5, 2, 2.5 kg/m³ (P-D1 to P-D4) the slump obtained is 94, 92, 91 and 89 mm respectively, in the case of Almeshal et al. [11] and Belmokaddem et al. [27] a similar effect was manifested in the concrete mixtures; which shows that the increase in the amount of PF significantly reduces the workability of the concrete. Regarding the concrete mixtures with the combination of SF plus PF in the study by Liu et al. [7] it is shown that the combination of 0.5% SF with 1.0% PF reduces slump up to 5%. This research agrees because the results indicate that the SP-D4 mix reduces concrete settlement up to 24.0%.

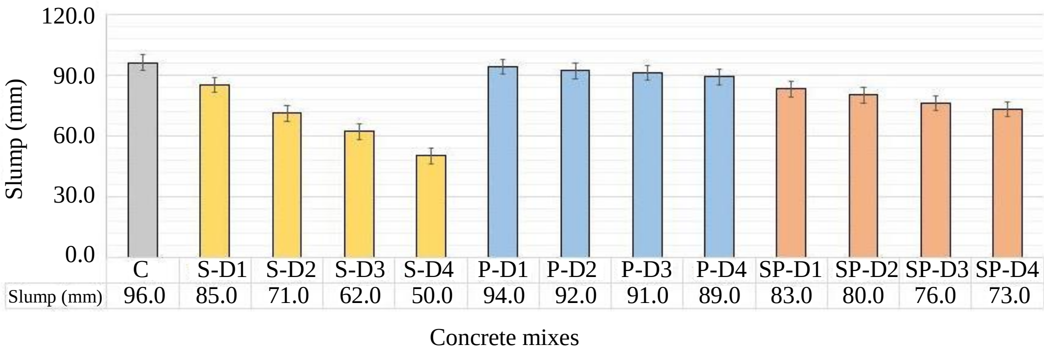


Figure 5 Settlement of standard concrete and concrete with fibers

3.2 Unit weight of concrete

The results shown in Figure 6 show that the concrete mix with the addition of SF has a higher unit weight than the standard concrete with an upward trend as the dosage of said fiber increases, as Zhang et al. [26] demonstrates it in his study where with the addition of 50 kg/m³ of SF, a unit weight greater than 2510 kg/m³ was obtained; which agrees with this study in view of the fact that the unit weight increases progressively in each of the mixtures with SF, but in a depreciable way. In reference to the unit weight of concrete with PF, in the present study it was possible to show that the incorporation of PF in dosages of 1, 1.5, 2 and 2.5 kg/m³ generates a slight decrease of up to 0.2% compared to the standard concrete, taking a result similar to the investigation by Almeshal et al. [11] where the replacement of the aggregate by 50% of PF reduces the density up to 36%.

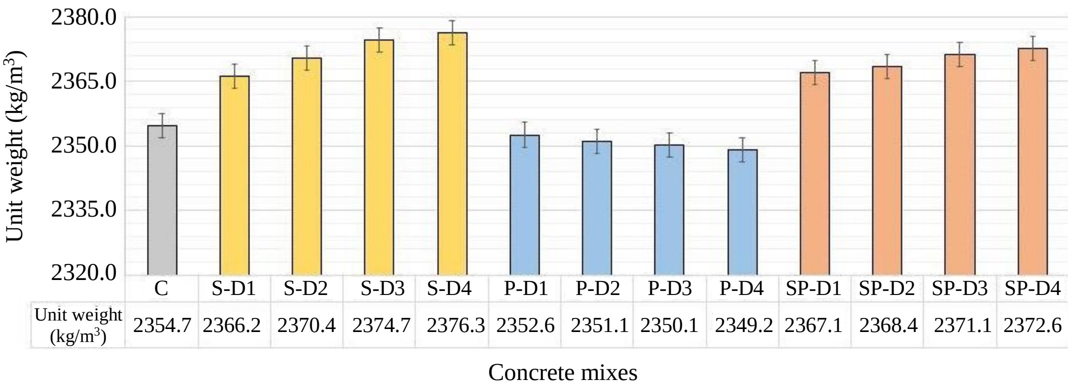
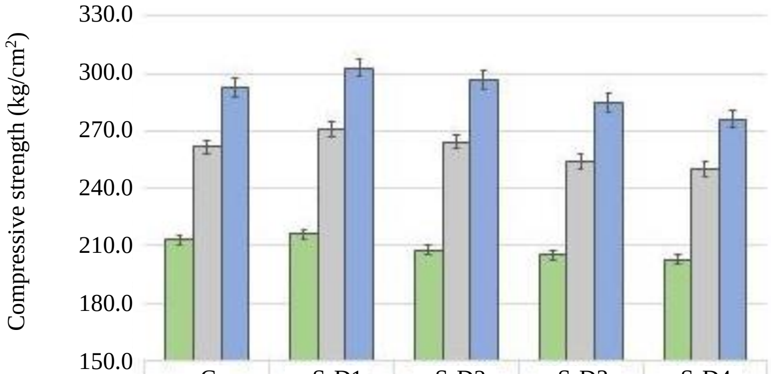


Figure 6 Unit weight of standard concrete and concrete with fibers

3.3 Compressive strength

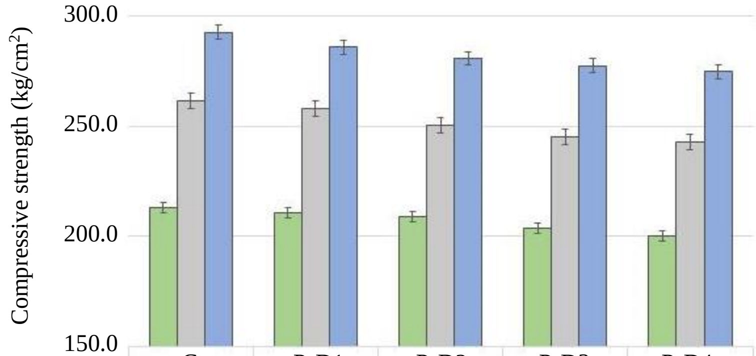
Figure 7 shows that the resistances of concrete specimens that were manufactured with the addition of SF; Likewise, the compression test carried out at 28 days showed that mixture C has an average resistance of 292.7 kg/cm². When incorporating the SF it was possible to observe that initially the resistance tends to increase, however when increasing the dose of the fibers, the resistance of the concrete decreases; This same behavior is observed in the investigations of Anike et al. [15], Li et al. [28] and Abbass et al. [29]; In the present study, the S-D4 mixture reduces its resistance by up to 5.64% with respect to the C mixture, but instead with the proportion of fibers of 0.44% (S-D1) the concrete increases its resistance up to 3.48%; the present study agrees because similar results were obtained, with the S-D1 mixture obtaining the highest values.



	C	S-D1	S-D2	S-D3	S-D4
Fc-7 days (kg/cm²)	213.3	215.9	207.6	205.3	202.7
Fc-14 days (kg/cm²)	261.5	270.8	264.3	254.0	250.2
Fc-28 days (kg/cm²)	292.7	302.9	296.5	284.7	276.2

Figure 7 Compressive strength of concrete with SF

According to Figure 8, it is shown that all the mixtures with PF generate a slight decrease in the resistance in the specimens, it is also evident that when the amount of PF in the concrete is increased, the resistance progressively decreases, being P-D4 the mixture with the most unfavorable values since the resistance reduces up to 274.9 kg/cm², this behavior of concrete with PF occurs in a similar way in the investigation of Almeshal et al. [11] where the mixtures with 20% PF slightly reduced the resistance and the mixtures with 50% PF decreased up to 60% the resistance in the specimens tested at 28 days. Likewise Thorneycroft et al. [13] express that in the compression tests of their research the resistance was reduced up to 4.1% compared to the standard mixture when PF of 2 to 4mm in size were used; also Cotto-Ramos et al. [30] and Faraj et al. [31] indicate in their studies that the replacement of the aggregate by PF considerably reduces resistance.



	C	P-D1	P-D2	P-D3	P-D4
F′c-7 days (kg/cm²)	213.3	210.8	209.3	203.7	200.5
F′c-14 days (kg/cm²)	261.5	257.9	250.4	245.2	243.1
F′c-28 days (kg/cm²)	292.7	285.8	280.8	277.5	274.9

Figure 8 Compressive strength of concrete with PF

As shown in Figure 9, with the combination of SF and PF it was possible to obtain higher values in the resistance of the concrete in such a way that the mixture SP-D1 (0.44% of SF and 0.04% of PF) increased up to 10.86% the endurance; likewise in the study by Liu et al. [7] it is shown that the combination of 0.5 SF and 0.5% PF increases the resistance up to 15.1%, however, by increasing the amount of PF the resistance reduced up to -1.0% compared to the standard concrete.

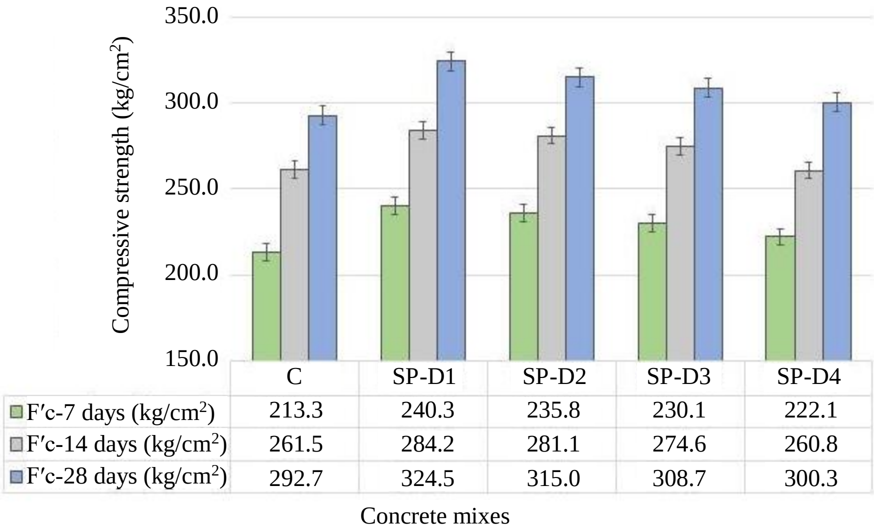


Figure 9 Compressive strength of concrete with SF plus PF

3.4 Flexural strength of concrete

From Figure 10 it is evident that the resistance in the flexion tests the specimens made with the mixture C had an average resistance of 50.94 kg/cm², also as in the study by Zhang and Gao [14] it was possible to observe that at the moment of increasing the dose of SF, its resistance to flexion rises considerably, in the present study said resistance increases up to 22.56% (Resistance of 62.43 kg/cm²) when 1.76% of SF is added (S-D4) in the concrete pattern. In the same way, by increasing the incorporation of PF, the resistance is greater [1, 10]. With the addition of 0.11% PF (Mixture P-D4) the greatest increase is 10.13% (resistance of 56.10 kg/cm²) with respect to the standard design that was carried out; Also, the combination of SF and PF equally present higher values than the specific standard, as demonstrated in their study by Liu et al. [7] and Caetano et al. [32], in the present study the resistance increases up to 16.18% (59.18 kg/cm²) when using a dose of 0.44% SF and 0.11% PF.

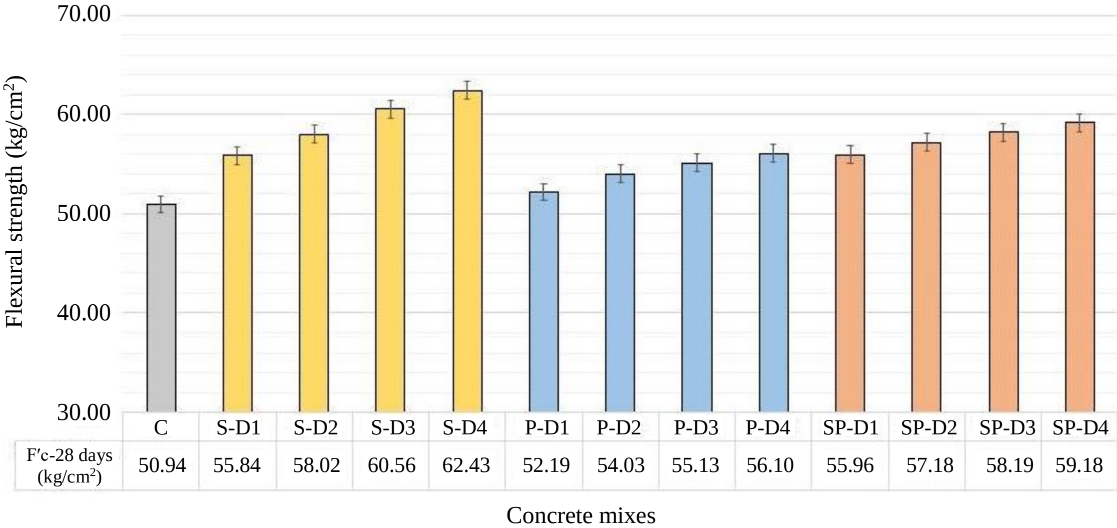


Figure 10 Flexural strength standard concrete and concrete with fibers

3.5 Diametrical tensile strength of concrete

Likewise, in Figure 11 it can be seen that SF produces an increase in resistance; In addition, when the amount of fibers in the concrete is increased, its resistance is also increased. On the other hand, in the case of the mixtures with PF in the study by Madandoust et al. [16] indicate that when the dose of the fibers is increased, the resistance of the concrete increases to a certain point; However, at high doses of fiber, the resistance then tends to decrease. This agrees with the present study because initially with the dose of 0.04% PF (Mixture P-D1) the concrete increases its resistance up to 4.62% but with a greater amount of fiber the resistance reduces. Regarding the mixtures of SF and PF in the study by Liu et al. [7] it is shown that the combination of 0.5% SF with 0.75% PF increases the tensile strength up to 80%; the present investigation agrees because the combination of SF with PF show an increase in values compared to the standard concrete, increasing up to 10.78% tensile strength when using a dose of 0.44% SF and 0.04% of PF; In addition, the behavior of the concrete when adding more PF is similar since the resistance reduces slightly.

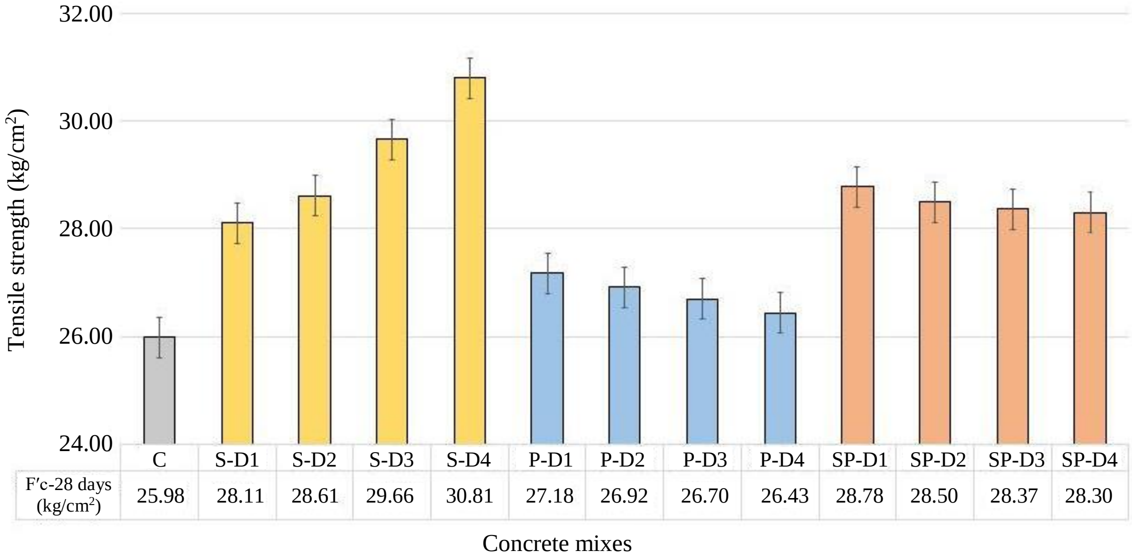


Figure 11 Diametrical tensile strength standard concrete and concrete with fibers

According to the tests of the mechanical properties of concrete with the incorporation of SF plus PF, it was observed that the mixtures produced an increase in compressive and tensile strength, with a slight decreasing trend in strength as the amount of PF increased; on the other hand, the flexural strength was higher than the standard concrete with an increasing trend as the amount of these fibers increased.

4. Conclusions

When comparing the values obtained in the compression tests, it is concluded that when SF is added to the concrete in a proportion of 0.44% of SF, the resistance increases up to 3.48%, but then there is a decreasing tendency towards a greater quantity of SF since with the proportion of 1.76% of SF, the resistance is lower by 5.64% in relation to the standard concrete; On the other hand, the incorporation of PF in the proportions used in the present investigation of 0.04, 0.07, 0.09 and 0.11% of PF have a decreasing tendency in the resistance and the combination of SF plus PF with the dosage of the mixture SP-D1 (0.44% of SF plus 0.04% of PF) an increase in resistance of 10.86% was obtained and with the combinations of the dosages of the mixtures SP-D2 to S-D4 the tendency of resistance is decreasing; however, they are superior to the resistance of standard concrete. From the comparison of the results of the bending and tensile tests, it is concluded that the resistance of the mixtures that add SF are greater than the standard concrete and even that the mixtures that incorporate PF; Likewise, it is shown that the combination of both fibers increases the resistance to flexion and traction up to 16.18 and 10.78%, respectively, compared to the standard concrete.

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