Influence of the Physical and Mechanical Properties of Concrete by Adding Rubber Powder and Silica Fume

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Abstract

The construction sector has been consuming raw materials that are becoming extinct over time; in order to contribute to the sustainability of these resources, the use of wastes that are produced on a large scale and often expelled into the environment without being well exploited, there we have the tire rubber and silica fume. This study seeks to evaluate the physical-mechanical properties of concrete, using rubber powder (RP) and silica fume (SF), as a partial substitute for fine aggregate and cement. Concrete samples were made using 5%, 7%, 11% and 14% of rubber powder plus 3%, 7%, 11% and 15% of silica fume. The physical properties were evaluated by slump, temperature and unit weight tests, while compression, tensile and flexural tests were developed at 7, 14 and 28 days of curing, to analyze the mechanical properties. The results showed that the physical properties maintain acceptable variations, since the deficiencies of the rubber powder are reduced by the silica fume; the properties of compression, flexion and traction revealed that even with 8% of rubber powder plus 7% or 11% of silica fume, the desired resistances can be reached, without presenting increases. It is concluded that partial substitution with rubber powder and silica fume does not contribute significantly to the properties of concrete, however, it can be a great alternative when high strength concrete is not required.

Keywords: concrete, rubber powder, silica fume, physical-mechanical properties.

Introduction

The progressive development of society has been demanding greater construction works, leading to a high production of cement and concrete, (Arun et al., 2020) points out that concrete is a fundamental element due to its multiple applications; however, during the process of extraction of raw materials that are used in its repair or production, a great pollution to the environment is originated.

At present, there are still factors that affect the stability in the construction industry, firstly, we have, the excessive use of natural resources that may be insufficient in later generations, and, secondly, the use of cement, as the main material in concrete, which generates many CO2 emissions, which are reflected in pollution and changes in climate (Venkata et al., 2019).

As for the environmental pollution, it is increasingly growing due to the waste accumulated daily. The recycling of these wastes is considered very necessary to lessen the deterioration of the environment, using them as raw materials in the production of concrete and other materials in the construction industry, in this perspective, many specialists in Turkey have focused their attention on tire rubber by testing its characteristics and performance when incorporated into concrete, with the expectation of being able to reuse this material (Habib et al., 2020).

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Tire rubber is a favorable option to be used as a replacement of concrete components, this is because it is available in large quantities, in disposable condition after having been used as tires respectively, in this regard (Chen et al., 2021),In this regard, it states that worldwide every year millions of tires are discarded and end their useful life, which causes a great environmental pollution, since there are no recycling programs or proposals at the level of cities or states and therefore more than 50% of the rubber is not recycled. With respect to this (Záleská et al., 2019).In this regard, he points out that the rubber from tires has shown its good performance when replacing the fine or coarse aggregate in the concrete mix, thus offering the reduction of the use of natural resources in the elaboration of concrete and enabling the development of an adequate management of discarded tires.

On the other hand, in the search for new alternatives in order to contribute to reduce the environmental pollution caused by the production of concrete, silica fume is presented as a complementary material to cement, according to (Landa et al., 2021)According to the company, this originates from silicon alloys such as iron-chromium, iron-manganese and calcium silicon, in the arc furnaces; during the production of these, considerable contamination is also generated. For this reason, extensive work has been carried out to develop systems that can capture silica fume and be used later (Balabanov & Putsenko, 2018).

Like rubber, silica fume is currently being employed in the production of concrete, but by adding it in certain percentages to the mix to partially replace cement. Such residue is an effective pozzolanic mineral that participates not only in improving the packaging system to reduce the number of voids, but also in binding the concrete matrices, where it acts by filling and modifying the structure of the concrete (Tkach, 2019).

Now, according to the circumstances mentioned in previous lines, studies can be found that demonstrate the possibility of producing concrete with these two materials obtaining results similar to those of conventional concrete.

The low-density levels of concrete that includes rubber fiber may be related to the reduced density of this material, the availability of air trapped in the rough areas, and above all by the increased replacement of the aggregate. However, when considering silica fume as a replacement for cement in the rubber concrete mix, the density is increased (Guptaa et al., 2016). In this same orientation, another investigation refers that when using substitution percentages of 7.5% of silica fume and 15% of rubber, the porosity is 27.84% lower than a concrete without rubber, unlike the mixture with 30% of rubber that presents an increase in the porosity of 28.39%, in this aspect the values of density are proportionally inverse to those of absorption and porosity. The increase of porosity is considerable in the concrete with rubber incorporations, for this reason the concrete concentrates more water, however, if silica fume is used as a partial substitute of cement to the mixture, it tends to be denser and less porous, resulting in a good adherence and decrease of its deficiencies, restoring a significant part of its resistance (Copetti et al., 2020).

Recycled aggregates tend to absorb more water by virtue of their rough surface, so that with their bond in concrete they tend to have high slump values (Mohd & Ahmad, 2020). Thus, when evaluating the slump with 20% rubber in a concrete mix with 5% percentages of silica fume does not exhibit significant variations, instead with 10% and 15%, the slump decreases, counteracting the effect of rubber (Youssf et al., 2016).

Likewise, it is found that from the compressive strength tests carried out on concrete with recycled aggregates with 10% silica fume and 5% rubber, replacing cement and fine aggregate respectively, an increase in strength is evidenced reaching 42.8 MPa with respect to concrete with natural aggregate, which obtained 40.7 MPa, showing better results than the addition of 3% silica fume, this due to the reduced size of the silica fume particles that being a higher percentage act with greater pozzolanic reactions (Xie et al., 2018). Another research, refers that when incorporating rubber to the concrete mixes, a substantial reduction of the resistance is produced, but with the silica fume, this is compensated (Copetti et al., 2020). Other results make reference that in the elaboration of the concrete mixture in replacement of 5% rubber and 10% silica dust, tested at 7 days, show an increase in its compressive strength of up to 29.66%, at 14 days did not reach 90% of the design strength, but increased by 3.15% and 16.47% with respect to the previous age. This behavior in substitutions of 10% and 15% of silica fume, at 28 days reached lower resistances than expected, they obtained 82.82% and 65.82% of their resistance (Giménez et al., 2016).

In the same way, it happens with the samples with percentages of rubber subjected to bending tests, where a reduced resistance is presented, although with 10% of rubber the highest resistance was obtained, even so, it is 2% below the control sample (Farfán & Leonardo, 2018). Therefore, it is said that the changes in the mechanical properties of concrete are due to the use of different types of rubber and the level of partial replacement of fine aggregate (Buši et al., 2018).

With respect to this, it is also had that, the decrease in tensile strength, is higher when the amount of substitution is higher , this because of the poor bonding of the rubber particles to the cement matrix, as is the case of mixtures with 5% rubber and 10% silica fume where the increases in strength range from 15% to 35%, despite their low tensile values such samples did not disintegrate completely due to the ductility and crack reduction capacity of the rubber particles (Onuaguluchi & Panesa, 2014). The analysis of concrete mixtures with percentages of 2% and 4% of rubber offer stable results, however, if this number of percentages is increased, the concrete will lose quality (Harahap et al., 2019). Referring to this, it is pointed out that the tensile strength and other mechanical strength can be improved with percentages of 5% and 10% of silica fume, but if these quantities are exceeded, the concrete tends to lose its physical-mechanical properties (Youssf et al., 2016).

The main objective of this research was to evaluate the physical-mechanical properties of concrete, using rubber powder and silica fume, as a partial substitute for cement and aggregates, focusing on the progress of resistance according to the curing ages.

Materials and Methods

Materials

In this research, materials that complied with the normalized standards in the American Society of Testing Materials (ASTM) were used, specifically Type I cement (MS), with density equal to 3.12, complied with the. (ASTM C1157, 2020). The natural aggregates were extracted from the Tres Tomas quarry, located in the district and province of Ferreñafe, region of Lambayeque - Peru; the fine aggregate and the coarse aggregate used went through a granulometric test according to the established in the norm (ASTM C136, 2019) where the particle size was obtained, from 0.15 to 4.75 mm and from 1.19 to 12.70 mm respectively, whose particle size distribution is shown in Fig. 1 and 2.

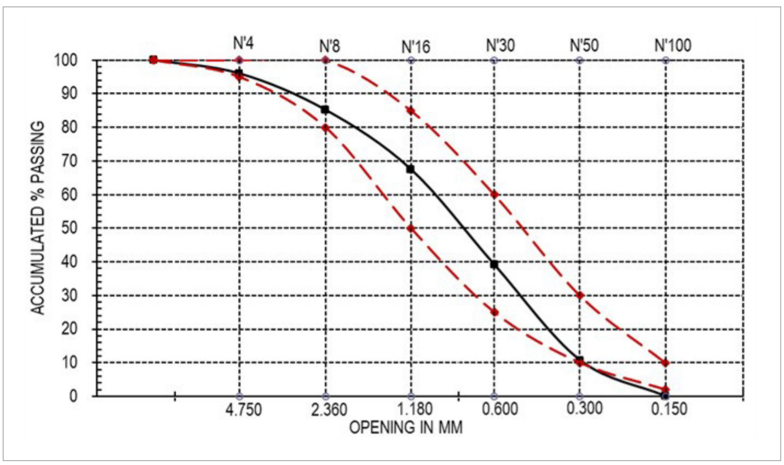


Fig. 1
Granulometric distribution of fine aggregate

In the case of the partial replacement material for the cement, silica fume was used, which complies with the standard (ASTM c1240, 2020). (ASTM C1240, 2020) no

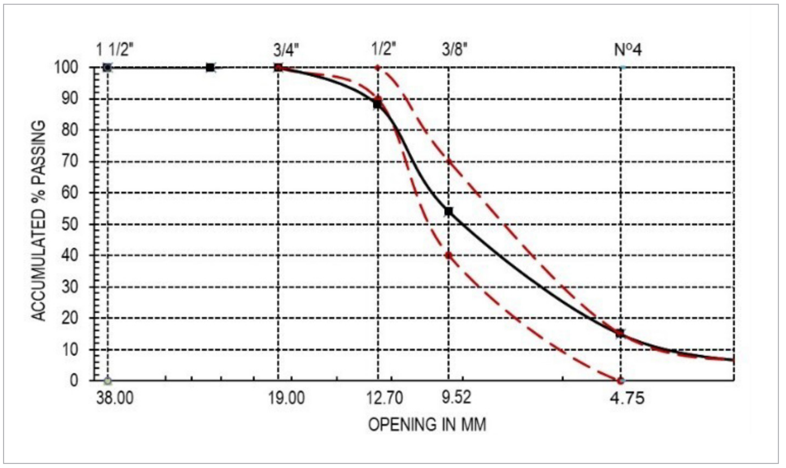
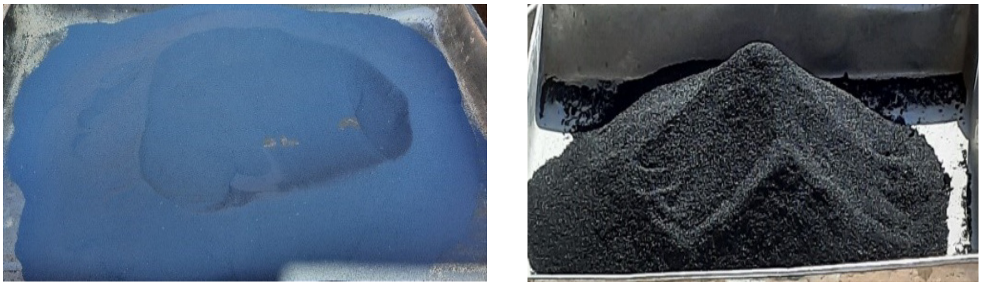


Fig. 2
Granulometric distribution of coarse aggregate

control tests were carried out on this additive, since the technical data sheet was provided by the supplier.

The rubber powder used in this evaluation was obtained by a shredding process of discarded tires, which had previously been dumped in landfills producing significant pollution in the environment. The rubber particle size was 0.50 mm in diameter and has been used as a partial replacement for fine aggregate. The materials in question are shown in Fig. 3.



(a) (b)

Fig. 3
Photographs of the test materials:
a) Silica fume,
b) Rubber powder

Mixing ratio and combinations

The mix designs were made, for a standard concrete, of the two concrete qualities, 21 MPa and 28 MPa, without additives and according to the ACI 211.1 (1991) committee method. Once the standard design was elaborated, the 16 mixtures were made with the partial substitution of the fine aggregate in 5%, 8%, 11% and 14% with rubber powder and of the cement in 3%, 7%, 11% and 15% with silica fume.

The substitution of the fine aggregate by the rubber powder was carried out estimating 5%, 8%, 11% and 14% of the total volume of the sand, for the case of silica fume, 3%, 7%, 11% and 15% of the volume of cement, these considerations were taken to verify if by replacing the same proportion of the material set aside, the concrete mix could reach the proposed strengths in its hardened state. The proportions of the 16 mixes iare shown in Table 1.

The concrete mix design was performed following ACI 211.1 (1991) procedure, the designs used in the concrete mix are given in Table 2 and Table 3.

Experimental trials

The test samples were elaborated, first weighing the replacement materials according to the replacement percentage and then mixing them, the mixture after showing the expected workability was poured into cylindrical molds of 30 cm high by 15 cm in diameter, in the case of the test specimens, This procedure was carried out in layers of approximately 15 cm, each layer received

25 blows with a metallic rod of 15 mm of diameter , to achieve its adequate compaction and to release the air bubbles retained in the mixture, 14 blows were given with a rubber hammer. For the beams, molds of 15 cm high by 15 cm wide and 60 cm long were used, and the same procedure was carried out in the same way, giving 75 blows with a metal rod of 15 mm diameter and 15 blows with a rubber hammer for each layer. After that, each one of the samples were letterheaded and stored to be demolded the next day and then undergo a curing process. The water for the preparation of the mixture and the curing of the samples came from the drinking water network.

Physical Properties

To obtain the physical properties of the concrete, slump, unit weight and temperature tests were carried out. The workability tests were carried out considering the norm (ASTM C143, 2020)For this purpose, an Abrams cone was used, a tool that is placed on a metal base, in which the concrete is poured in layers in its plastic state and at the same time it is compacted, after completing this process, the mold is removed, placing it inverted to the side of the settled mixture, to obtain its values, the distance between the steady mixture to the top of the mold is measured, see Fig. 4(a).

Cement	Silica Fume	Fine Aggregate	Rubber Powder	Coarse aggregate
100%	0%	100%	0%	100%
97%	3%	95%	5%	100%
93%	7%	95%	5%	100%
89%	11%	95%	5%	100%
85%	15%	95%	5%	100%
97%	3%	92%	8%	100%
93%	7%	92%	8%	100%
89%	11%	92%	8%	100%
85%	15%	92%	8%	100%
97%	3%	89%	11%	100%
93%	7%	89%	11%	100%
89%	11%	89%	11%	100%
85%	15%	89%	11%	100%
97%	3%	86%	14%	100%
93%	7%	86%	14%	100%
89%	11%	86%	14%	100%
85%	15%	86%	14%	100%

Table 1

Proportions carried out in the laboratory tests

Materials	Ratio by weight	Weights (kg/m^3)	Mixing ratio
Cement	1	408.31	17.88
Fine aggregate	1.56	637.99	27.94
Coarse aggregate	2.37	968.98	42.44
Water	27.9	267.93	11.74
Total, (kg/m^3)		2283.21	100.00

Table 2

Simple concrete mix design for the standard strength of 21 MPa with a w/c ratio of 0.56

Materials	Ratio by weight	Weights (kg/m^3)	Mixing ratio
Cement	1	495.22	21.64
Fine aggregate	1.13	559.41	24.45
Coarse aggregate	1.96	968.98	42.34
Water	22.7	264.71	11.57
Total, (kg/m^3)		2288.32	100.00

Table 3

Simple concrete mix design for the standard strength of 28 MPa at a w/c ratio of 0.47

(a) (b)

Fig. 4

Photographs of the fresh state tests:
a) Slump,
b) Temperature

In the case of density or unit weight, the standard was taken into account. (ASTM C138, 2017)The test for each combination was carried out by weighing a container completely filled to the level with concrete mix, the filling was done in layers and each of them was properly compacted. For the temperature, the tests followed what was established in the standard (ASTM C1064, 2017) for this, the concrete mix was placed on a container and then a thermometer was introduced at a certain depth, keeping it for two minutes until the reading was obtained, see Fig. 4(b).

Mechanical properties

For the hardened state, the cores were tested at different curing ages, at 7, 14 and 28 days, all the cores were subjected to a curing process according to the standard (ASTM C192, 2019) in order to analyze their mechanical properties, compression, tensile in cylinders and flexural in beams tests were carried out.

The concrete compression tests were carried out according to the standard (ASTM C39, 2021), in cylindrical specimens of 15 cm diameter by 30 cm height, a concrete electric press was used for the specimens in order to determine the highest compressive strength that each specimen supports at the age of 7, 14 and 28 days of curing, observing the increase of its resistances, see Fig. 5(a).

For bending, beams of 15 cm by 15 cm by 60 cm were made, according to the standard (ASTM C293, 2016) were performed on prismatic specimens for ages of 7, 14 and 28 days of curing, see Fig. 5(b), the procedure of the specimens was also given in an electric concrete press.

For the tensile strength it was tested in cylindrical specimens, see Fig. 5(c), considering the standard (ASTM C496, 2017) analyzing the same ages of curing, the specimens were placed horizontally on the electric concrete press.

Fig. 5
Photographs of the hardened state tests:
a) Compression,
b) Flexure,
c) Tension

(a) (b) (c)

Results and discussion

Physical Properties

Workability

The results of the slump cone test show the workability obtained in the tested combinations, it is observed that the standard concrete with a design of 21 MPa and 28 MPa complies with the design slump of 10.26 cm, while, in the mixtures with partial substitution of silica fume and rubber powder some cases of slightly lower and/or higher slumps are presented, because it was reached slumps between 8.89 to 13.21 cm for a resistance of 20.49 MPa and 27.46 MPa, where slumps varying between 8.89 to 12.7 cm were obtained.89 to 13.21 cm for a strength of 20.49 MPa, the same happens for a strength of 27.46 MPa where slumps varying between 8.89 to 12.7 cm were obtained. However, in spite of this, they comply with the design values (see Fig. 6).

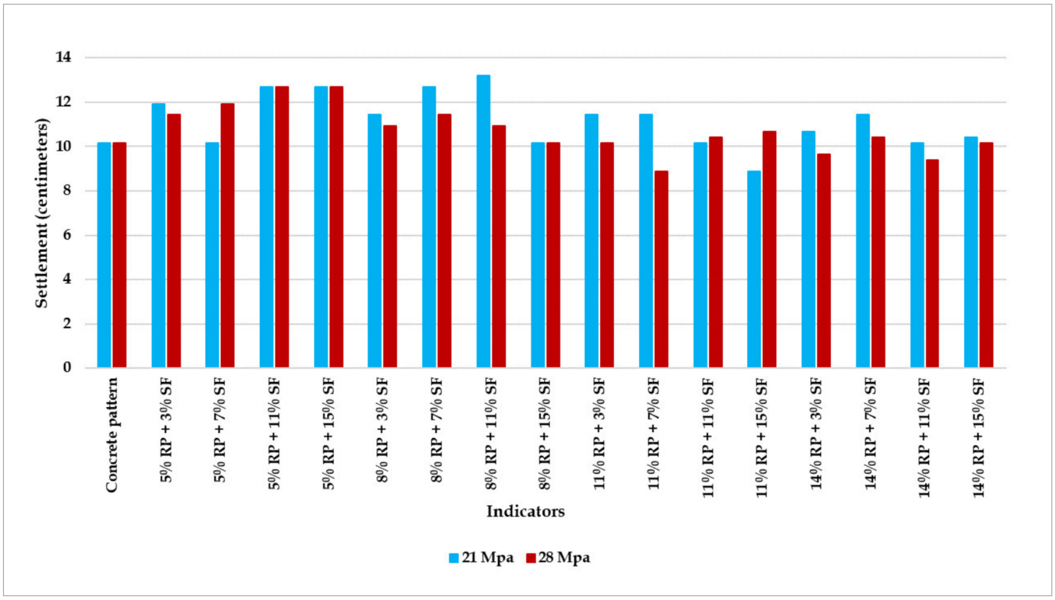


Fig. 6
Results of the slump test performed on the standard concrete and the experimental concrete, according to their design strengths

These variations are due to the replacement cementitious material that is silica fume, which provides the mixture with a fine part that allows it to act as a reducer of the water-cement ratio and even after incorporating the replacement of sand by rubber powder, achieving that the workability of the mixture remains constant. Therefore, it is considered that the influence of the presence of silica fume and rubber powder in the mixes is moderate, since the slumps do not vary significantly with respect to those of the standard mix.

It can be shown that the results achieved are identical and show agreement with the studies of (Mohd & Ahmad, 2020) which indicated that in recycled coarse aggregate concrete mixes with the addition of silica fume, slumps of 105 and 80 mm were obtained, slightly lower than the mix without addition of silica fume, due to the fact that the area of its surface is larger and so the level of water absorption is higher, reducing workability. Likewise, this was evidenced by (Youssf et al., 2016).The study was carried out by the study of the concrete mix, which found that the increase of silica fume up to 5%, in the conventional concrete and in the concrete with crushed rubber, did not significantly affect the slump, but with the addition of silica fume, in quantities of 10% and 15%, a decrease of 20% and 25% was observed in the slump of the concrete mix with crushed rubber.

Temperature

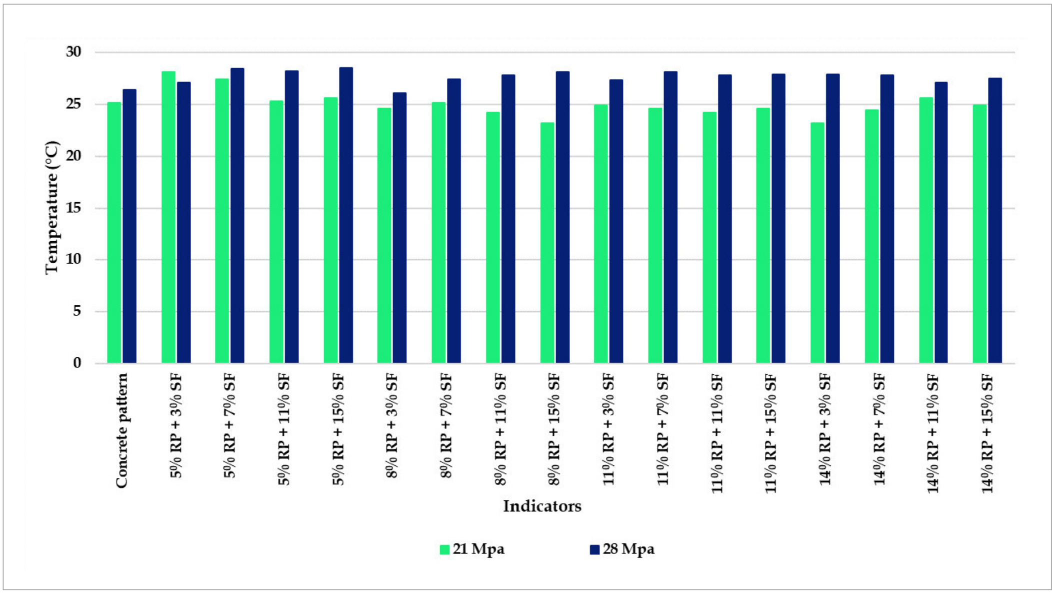
In the results we can observe that in the combinations tested in the laboratory the concrete temperatures are between 23.2°C and 28.1°C see **Fig. 7**, considering that the range of acceptance allowed is between 10°C to 32°C, according to the standard (ASTM C1064, 2017), the temperatures obtained are within the established range. In addition, to avoid curing problems, the temperature must necessarily be in the range of 5°C and 28°C, therefore the temperatures obtained are acceptable.

Unit Weight

A normal concrete has a unit weight between 2200 kg/m^3 and 2400 kg/m^3. In the different combinations tested, it is observed that the standard concrete with a design of 21 MPa and 28 MPa, have a density of 2478.3 kg/m^3 and 2433.59 kg/m^3 respectively. For the case of the unit weights obtained from the samples with silica fume and rubber powder replacement, these are between 2391.89 kg/m^3 to 2508.68kg/m^3 for a strength of 20.49 MPa and 2510.94 kg/m^3 to 2543.21 kg/m^3 for 27.46 MPa (see **Fig. 8**), which indicates that the values obtained correspond to a normal con-

Fig. 7

Results of the temperature test performed on the standard concrete and the experimental concrete, according to their design strengths



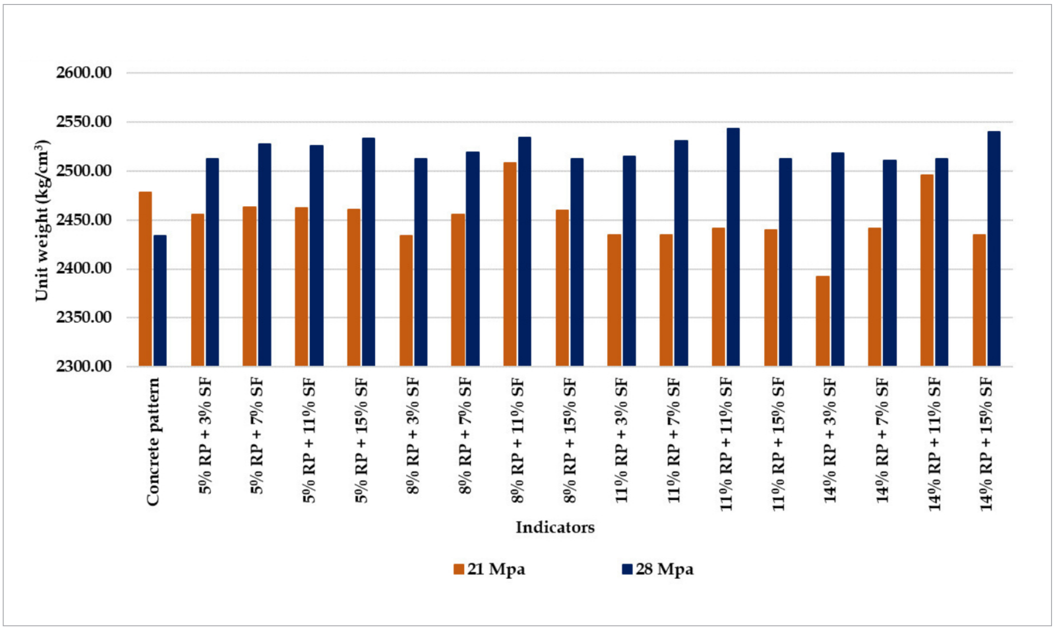
crete, for all combinations. It is observed that the unit weights obtained do not show a significant variation with respect to the standard concrete. The concrete, due to the incorporation of rubber, obtains a high number of voids and therefore a higher air content, which makes the mixture less dense; however, by adding silica fume in partial replacement of cement, it makes the concrete structure more compact, since it acts by filling the voids generated by the rubber, increasing its unit weight.

So it can be deduced that the strength of concrete with incorporation of silica fume and rubber powder depend on hydration rather than unit weight property, due to the presence of silica fume that generates better hydration.

Such a development is also observed in tests conducted by. (Guptaa et al., 2016), that by replacing cement with silica fume, the density increases for both standard concrete and rubber fiber concrete with a 10% substitution of cement by silica fume, opposite case happens when replacing

Fig. 8

Results of the unit weight test performed on the standard concrete and the experimental concrete, according to their design strengths



25% of sand by rubber fiber, where the density decreases, this due to the low density of rubber compared to conventional aggregate. In the same perspective, (Copetti et al., 2020)points out that with additions of 7.5% and 10% of silica fume, the amount of pores of the mixture, with 15% of rubber, intensified in 18.32%, with respect to the concrete without silica fume, in the same way it is possible to relate the decrease of the density of the concrete with the increase of the amount of rubber.

Mechanical properties

Compressive strength

The compressive strength of concrete with the different combinations of rubber powder and silica fume as partial replacement of fine aggregate and cement, for a design of 27.46 MPa shows that, at 7 days of curing, see Fig. 9, the standard concrete reached a strength of 16.94 MPa. The experimental concrete with 5% rubber powder plus 11 % silica fume obtained the highest strength of 16.53 MPa followed by the concrete with 5% rubber powder plus 7 % silica fume with a strength of 16.24 MPa, i.e., both combinations reached a percentage of 80.24 % and 74.56 % correspondingly, of their required strength with respect to that age of curing. Also at 14 days, see Fig. 10, a significant increase is shown in the concrete with 11% of rubber powder plus 11% of silica fume reaching a resistance of 18.21 MPa unlike the aforementioned combinations, which are below with 1.55%.

On the other hand, it is evident that the increase in the compressive strength of the concrete is due to the influence of the curing time, observing that, at 28 days, see Fig. 11, the most favorable percentage is 5% of rubber powder plus 11% of silica fume that obtains a strength of 20.61 MPa which means that it meets the design strength, but still does not exceed the values of the standard concrete which is above reaching a strength of 23.79 MPa . In the same way, it can be evidenced that the combination of 5% rubber powder plus 7% silica fume is also close to the required strength, specifically it is located below with 0.18% according to the combination mentioned in previous lines.

The other results show relatively low resistances which can be attributed to the greater presence of rubber powder, obtaining as the lowest value of compressive strength 14.91 MPa .

In the same way it is presented in the Fig. 12, the compressive strength for a design of 27.46 MPa , showing unfavorable results in the combinations unlike the standard concrete, which reaches a resistance of 27.79 MPa so it is the highest, the combination that presented higher resistance was the 5% rubber powder and 11% of silica fume reaching 22.69 MPa, then it shows a significant difference in the other combination with respect to the standard concrete.

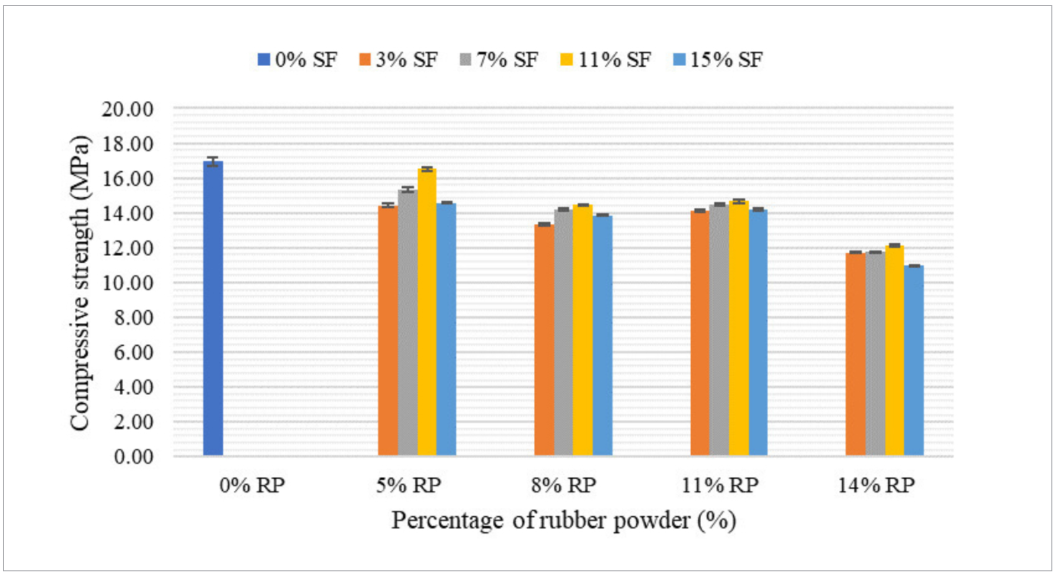


Fig. 9
Compressive strength at 7 days of standard concrete and experimental concrete for 21 MPa

Fig. 10

Compressive strength at 14 days of standard concrete and experimental concrete for 21 MPa

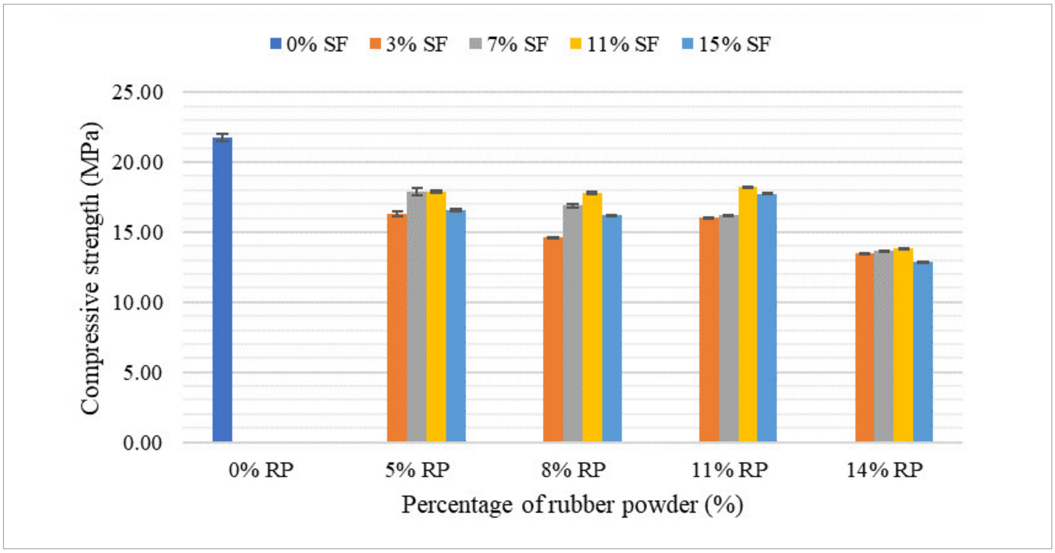


Fig. 11

Compressive strength at 28 days of standard concrete and experimental concrete for 21 MPa

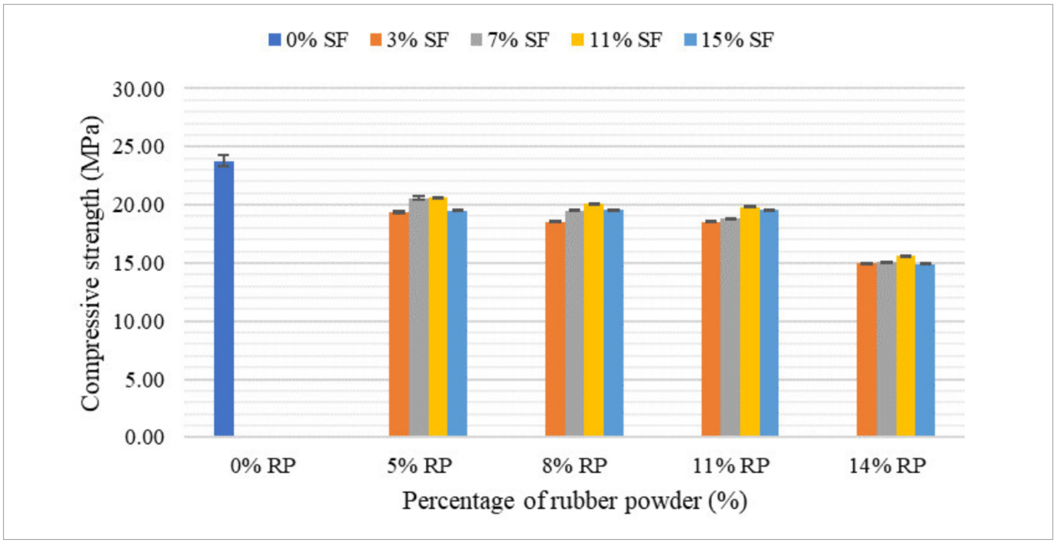
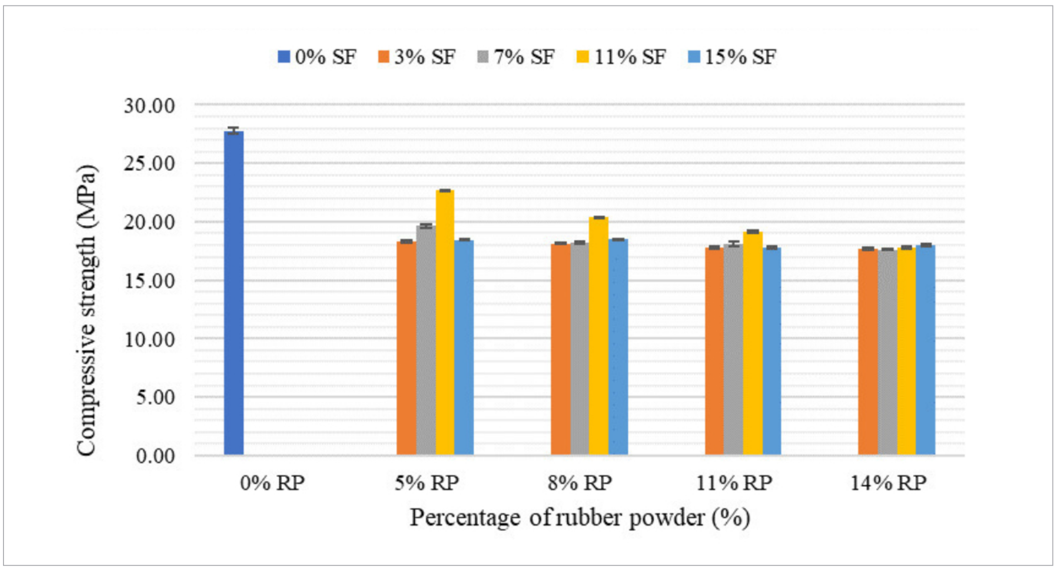


Fig. 12

Compressive strength at 7 days of standard concrete and experimental concrete for 28 MPa



Considering the results of **Fig. 13 (a)** compressive strength (MPa) per 21, the p-value of significance of the Kruskall-Wallis test, presented a value lower than 0.05 (p=5.05e-08<0.05), showing that there is a significant difference in at least two treatments regarding the variable compressive strength, which with the Dunn's multiple comparisons test, allows us to know that it was the treatment T1 (Standard concrete), who presented the significantly higher average compressive strength among all the treatments, presenting an average sample strength of 23.79 MPa, also, no significant differences were evidenced between treatments T4 (5% RP + 11% SF) and T3 (5% RP + 7% SF), highlighting that treatment T4 (5% RP + 11% SF), who presented the highest average resistance to sample compression, with a value of 20.61 MPa, in **Fig. 13 (b)** resistance to compression (MPa) per 28, the unifactorial ANOVA test presented a p-value lower than 0.05 (p=2e-16<0.05), that is to say, there is a significant difference between at least two treatments with respect to the variable compressive strength, where the post hoc test of multiple comparisons of Tukey, showed that it was the treatment T1 (Standard concrete) who reached a significantly higher compressive strength with a sample mean of 27.80 MPa, followed by the treatment T4 (5% RP + 11% SF) who reached a sample mean of 22.69 MPa.

The results obtained are in agreement with the research conducted by. (Xie et al., 2018), in which he points out that with the increase of rubber the compressive strength decreases significantly, but with the addition of silica fume this problem can be reversed and it is possible that the bonding properties improve, if the amount of rubber fiber is less than 20% of silica fume. This behavior was corroborated by (Copetti et al., 2020) who discovered that, when substituting the fine aggregate by rubber, residues of automobile tires, a reduction of the mechanical and physical characteristics of the concretes is generated with lower densities, 10.5%, with higher porosities, 18%, and with a percentage of water absorption between 2% and 4% than the standard concretes. For this reason, the silica fume covers the voids generated by the rubber particles, the structure of the concrete observes pores in smaller quantity, being denser, improving the characteristics of the concrete.

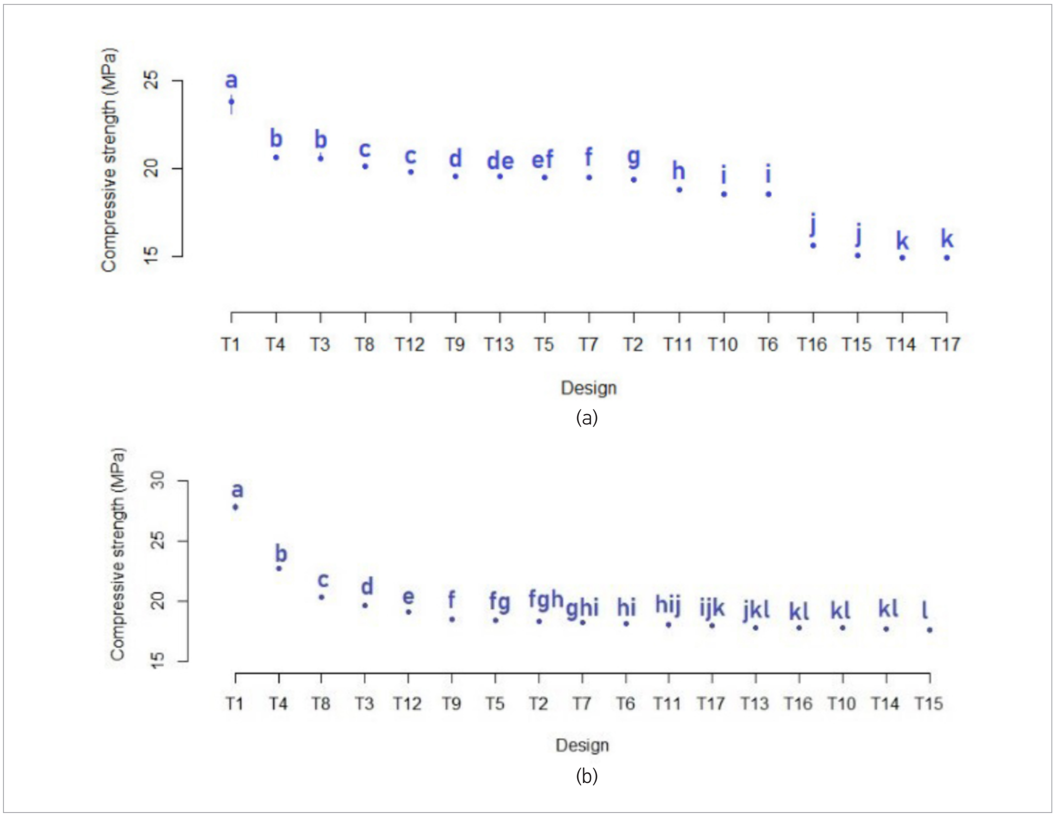


Fig. 13

Comparison of means of compressive strength based on the test of, (a) (Kruskal Wallis, p=5.05e-08<0.05; Kolmogorov Srminov; p=1.061e-06<0.05) for 21 MPa and (b) (Unifactorial Anova, p=2.0e-16<0.05; Kolmogorov Srminov, p=0.2111>0.05) for 28 MPa

According to Giménez and his collaborators, when substituting the mixtures with 10% silica and 5% rubber, they achieved the design strength at 90 days, showing that silica reacts at longer times and the too high percentages of these materials do not favor the concrete. (Guptaa et al., 2016).

Bending strength

The results of the flexural strength for a F'c of 21 MPa, at the age of 7 days show in **Fig. 14** that the highest value is obtained with 5% rubber powder with 7% silica fume, which is 3.59 MPa, followed by the concrete with replacement of 5% rubber powder with 11% silica fume that acquired a flexural strength of 3.37 MPa. However, these strengths do not exceed the standard concrete which ranks above them with 4.57 MPa representing 4.77% more.

The flexural strength for 28 days, in **Fig. 15**, shows that the standard concrete still acquires a higher strength with, 5.87 MPa being superior to the strength of the experimental concrete groups. Within these groups the highest strengths are with 5% rubber powder with 7% silica fume and 8% rubber powder with 11% silica fume which were 4.96 MPa and 4.86 MPa respectively.

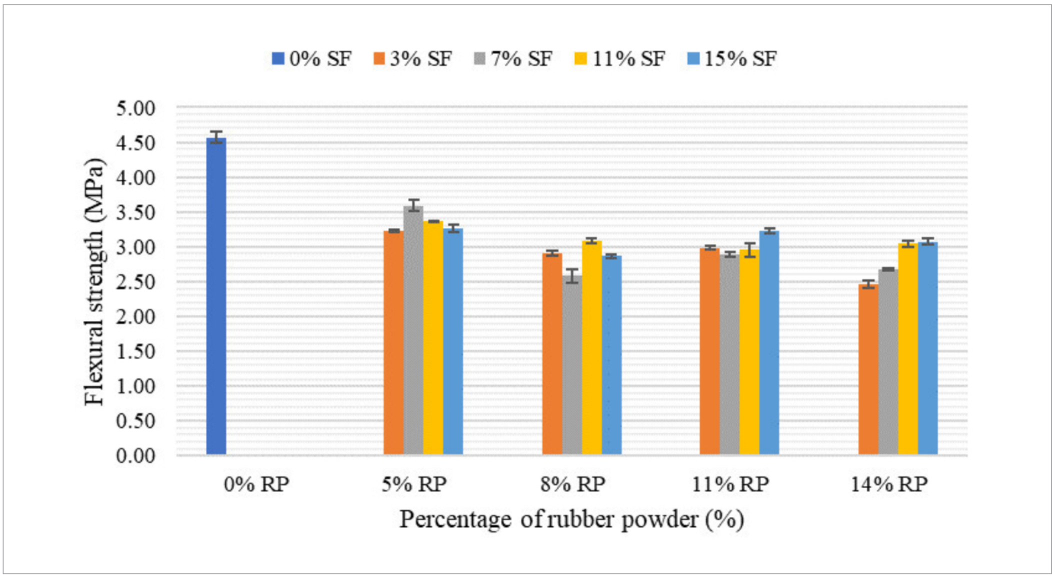


Fig. 14
Flexural strength at 7 days of standard concrete and experimental concrete for 21 MPa

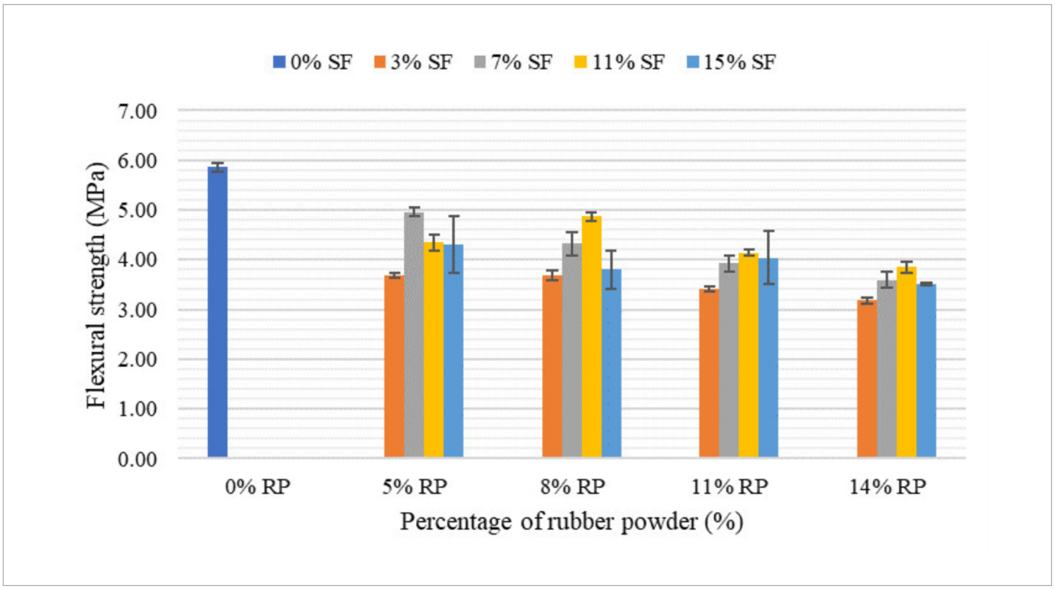


Fig. 15
Flexural strength at 28 days of standard concrete and experimental concrete for 21 MPa

Like the samples for a 21 MPa design, the results of the flexural strength in a 28 MPa concrete, the samples of the experimental concretes did not achieve an increase over the standard concrete which had 5.03 MPa. **Fig. 16** shows that the highest strengths are given by 8% rubber powder with 11% silica fume, with a value of 4.67 MPa, followed by 5% rubber powder with 7% silica fume, which was 4.57 MPa, followed by 11% rubber powder with 11% silica fume, giving a value of 4.57 MPa.

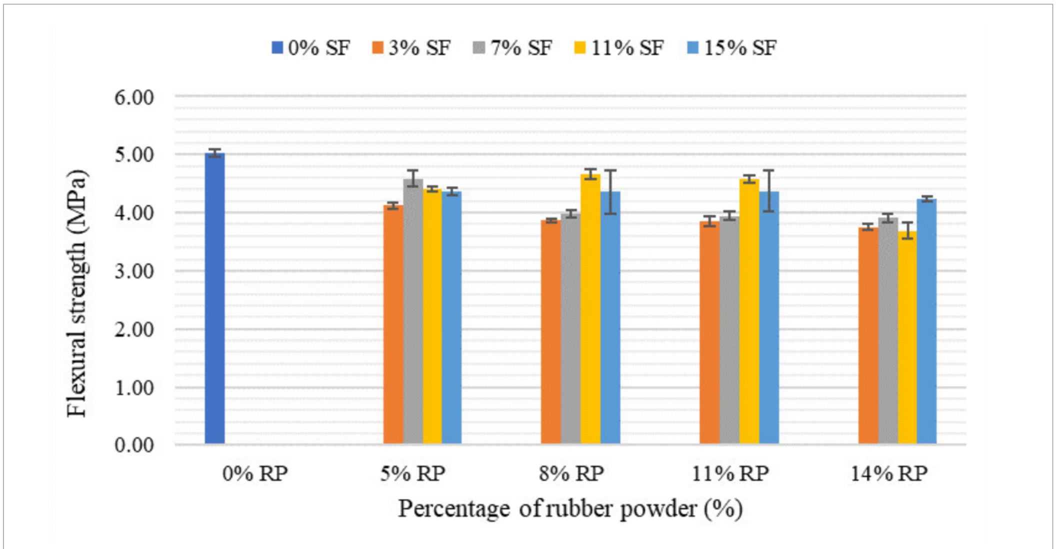


Fig. 16

Flexural strength at 28 days of standard concrete and experimental concrete for 28 MPa

At a statistical level in **Fig. 17(a)**, flexural strength (MPa) per 21, the Kruskal Wallis test with a p-value of significance less than 0.05 ($p=1.67e-06<0.05$), and the Dunn's multiple comparisons test, allowed to know that treatments T1 (Standard concrete), T3 (5% RP + 7% SF) and T8 (8% RP + 11% SF), did not present significant differences, whose average sample flexural strengths found were of 5.87 MPa, 4.96 MPa and 4.86 MPa respectively, that is to say, it was treatment T3 who presented the highest sample strength after treatment T1, considering **Fig. 17(b)**, flexural strength (MPa) per 28, the p-value of significance of the Kruskal Wallis test was less than 0.05 ($p=3.69e-07<0.05$), that is, the existence of significant difference in at least two treatments in the flexural strength variable is evidenced, where the Dunn's post hoc test of multiple comparisons, allowed identifying that there was a significant difference between treatments T1 (Standard concrete) and T8 (8% RP + 11% SF), likewise, they were the treatments that allowed maximizing the flexural strength variable, whose sample means were 5.03 MPa and 4.67 MPa respectively.

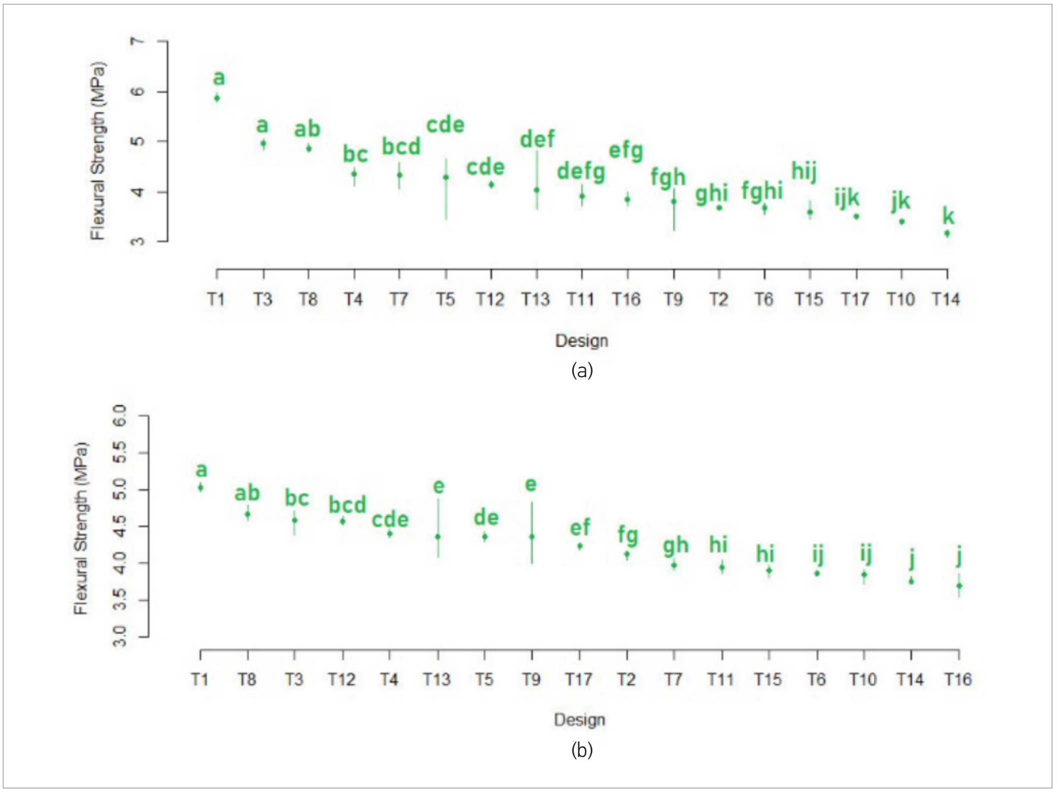
By replacing sand with tire rubber, the flexural strength of the concrete mixes was reduced, however, the ductility of the concrete was improved. (Othman et al., 2021).

The flexural strength tends to decrease in mixtures with different percentages of rubber, but it could be observed that the mixture with 10% rubber improved its behavior, obtaining 2% less than the standard sample. Likewise, it was observed that with the addition of rubber its flexural strength decreases up to 8%, showing that the addition of rubber in the concrete sample did not favor the concrete to break and achieve a higher resistance. (Farfán & Leonardo, 2018).

By adding tire rubber as a replacement of natural aggregate material, fine or coarse, in the concrete mix, and for the same degree of rubber substitution, a similar reduction in reduction of flexural strength was obtained, not being relevant the size of the rubber particles, the reason being the same exposed. The air trapped between the rubber and the cement paste, which could be due to the roughness of the rubber surface, negatively affects the flexural strength, as well as the compressive strength. But some samples, with the addition of rubber, did not collapse quickly during the test, this is attributed to the elasticity of the rubber particles. (Buši et al., 2018).

Fig. 17

Comparison of means of flexural strength based on the test of, (a) (Kruskal Wallis, p=1.67e-6<0.05; Kolmogorov Srminov; p=0.00195<0.05) for 21 MPa and (b) (Kruskal Wallis, p=3.69e-07<0.05; Kolmogorov Srminov; p=0.001031<0.05) for 28 MPa

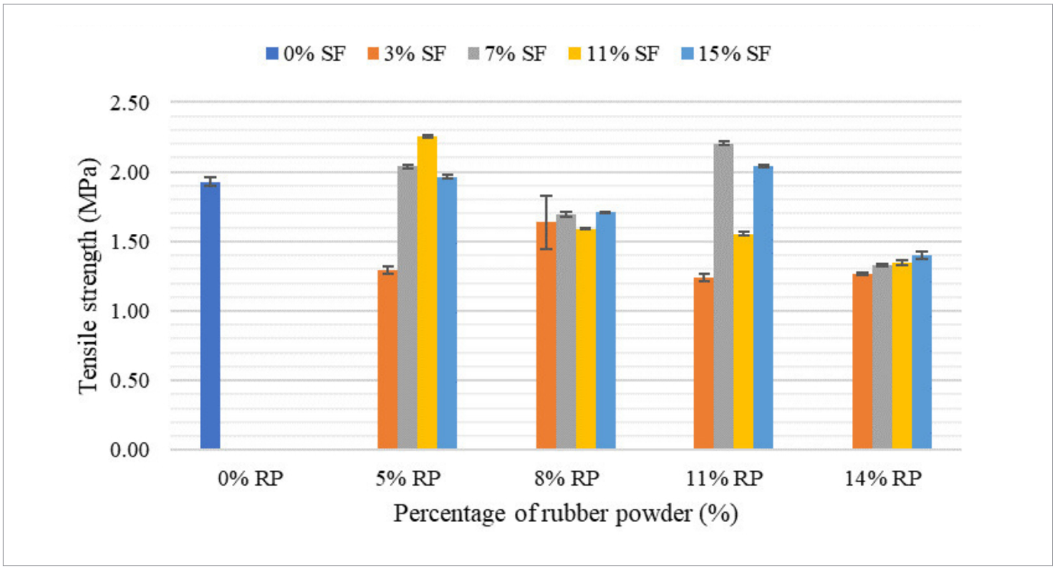


Tensile strength

The tensile strength in a design of 21 MPa can be seen in Fig. 18 that at 7 days the combinations of the experimental concrete has high strengths as in the case of 5% rubber powder with 11% silica fume obtaining a strength of 2.26 MPa, followed by 5% rubber powder with 7% silica fume, which has a value of 2.04 MPa, then 11% rubber powder with 7% silica fume and 15% silica fume showing values of 2.20 MPa and 2.04 MPa respectively, thus being higher than the standard concrete that obtained a value of 1.93 MPa. On the other hand, it is highlighted that, at 28

Fig. 18

Tensile strength at 7 days of standard concrete and experimental concrete for 21 MPa



days, in Fig. 19, the mentioned combinations lost resistance with respect to the standard concrete that reached a value of 4.17 MPa, leaving below the 5% rubber powder with 7% silica fume and 11% silica fume that reached a value of 3.44 MPa and 3.71 MPa respectively.

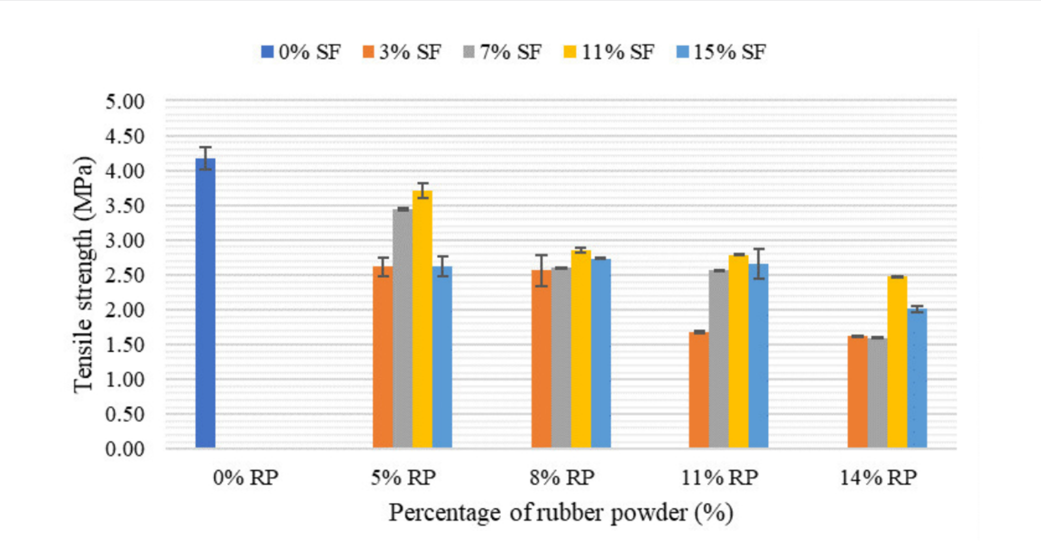


Fig. 19
Tensile strength at 28 days of standard concrete and experimental concrete for 21 MPa

The results of the experimental concrete designed for a strength of 28 MPa, indicate in Fig. 20 that the highest tensile strengths in the experimental concrete were 5% rubber powder with 7% silica fume which was 3.73 MPa, followed by 8% rubber powder with 11% silica fume which obtained a value of 3.71 MPa, despite having the highest values are still below the standard concrete that reached 4.18 MPa.

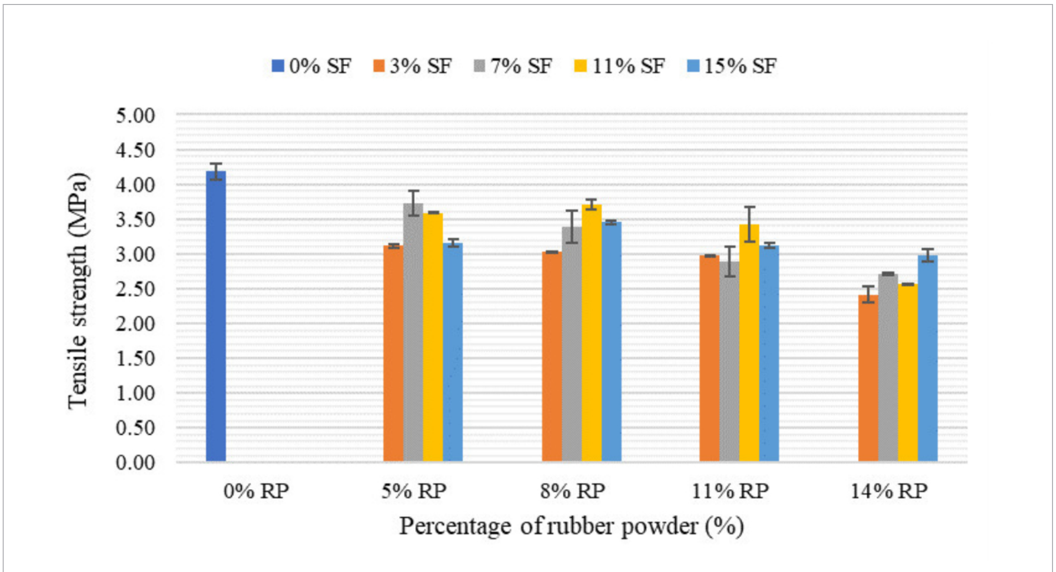


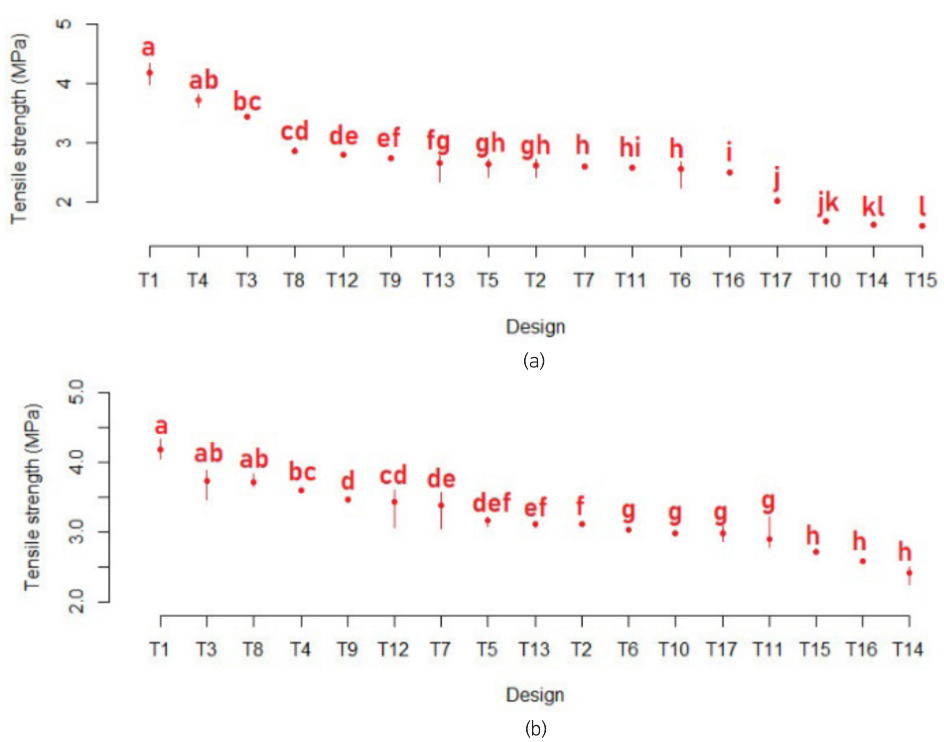
Fig. 20
Tensile strength at 28 days of standard concrete and experimental concrete for 28 MPa

At statistical level, in Fig. 21 (a) tensile strength (MPa) by 21, the Kruskal Wallis test, exhibited a p-value of significance less than 0.05 ($p=1.51e-07<0.05$), that is to say, there was a significant difference in at least two treatments in the tensile strength variable, also the post hoc test of multiple comparisons of Dunn, showed that there were no significant differences between treatments T1

(Standard concrete) and T4 (5% RP + 11% SF), being also the treatments that allowed maximizing the tensile strength variable, whose sample means were 4.17 MPa and 3.71 MPa respectively, and finally in **Fig. 21 (b)** tensile strength (MPa) per 28, the Kruskal Wallis test, which presented a p-value of significance less than 0.05 (p=2.35e-07<0.05), together with Dunn's post hoc test, made it possible to identify that treatments T1 (Standard concrete), T3 (5% RP + 7% SF) and T8 (8% RP + 11% SF), were the treatments that allowed maximizing the tensile strength variable, whose sample means found were 4.18 MPa, 3.73 MPa and 3.71 MPa respectively, being therefore treatment T3 (5% RP + 7% SF) who presented the highest sample tensile strength followed by treatment T1 (Standard concrete).

Fig. 21

Comparison of means of flexural strength based on the test of, (a) (Kruskal Wallis, p=1.51e-07<0.05; Kolmogorov Srminov, p=6.317e-13<0.05) for 21 MPa and (b) (Kruskal Wallis, p=2.35e-07<0.05; Kolmogorov Srminov; p=9.666e-07<0.05) for 28 MPa



Similar results were stated by Onuaguluchi and Panesar who determined that the tensile strength is reduced due to the same causes that reduce the compressive strength, including in one of them, the porosity which increases with the amount of incorporated rubber, and in the other, the bond of the rubber with the cement paste is weak resulting in cracking of the concrete when loads are applied (Onuaguluchi & Panesa, 2014). Similarly, it was observed that with the addition of 4% of latex waste, the split tensile strength increases, however, by adding larger amounts decreases, which means that by adding excessively can be generated in the concrete structure, clots, and these would reduce the bond between the aggregate and cement, as well as between the aggregates themselves. (Harahap et al., 2019).

On the other hand, (Youssf et al., 2016)., points out that the use of 5% of silica fume attributes improvements in the tensile strength property of a conventional concrete and in a concrete with rubber waste, but by increasing the substitution the results are inverse as a result of the soft texture of the rubber particles that presents problems of adhesion with the cement paste, the stiffness of the rubber generates higher tensile stresses, causing early failures, decreased resistance in the tensile property of the concrete.

Conclusions

The substitution of fine aggregate and cement by rubber powder and silica fume, respectively, decreased the physical-mechanical properties of the concrete for both strengths of 21 MPa and 28 MPa.

The use of silica fume as a partial substitute for cement was beneficial because it balanced the low density or unit weight that the rubber powder contributed to the concrete mix, since this material tends to lighten the weight of the concrete, which resulted in obtaining an acceptable density and workability, without significant changes.

The compressive strength and other mechanical properties for a mix design of 21 MPa and 28 MPa are affected by the presence of rubber that due to its poor adhesion with the cement matrix made it lose much of the same as the dosage of rubber powder was increased, however, such resistance reached improvement rates with the addition of silica fume due to its cementitious and pozzolanic characteristic that helps to fill voids left by the rubber powder.

The statistical results allow determining that for the compressive, tensile and flexural strengths of concrete with 5% rubber powder and 11% silica fume, 5% rubber powder and 7% silica fume, 8% rubber powder and 11% silica fume as partial replacement of fine aggregate and cement respectively, having longer curing times are a great alternative to reduce the excessive requirement of raw materials and environmental pollution, as long as it is applied in concrete with normal strength.

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