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Influence of the incorporation of recycled rubber in structural concrete and its hypothetical seismic response, Juliaca 2021

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Abstract

The present investigation was raised with the general objective of determining the influence of the incorporation of recycled rubber in structural concrete and its hypothetical seismic response, developing the investigation under a type of applied investigation, of pure experimental design with a non-probabilistic sample of DBCA method of 84 briquettes that include the standard concrete with a design of 210 kgf/cm2 and concrete with the incorporation of recycled rubber at 2%, 4% and 6%, which were evaluated at 7, 14 and 28 days of age under the technique From direct observation, parameters such as resistance to compression and indirect diametral traction where the results showed that the most optimal incorporation was 4% of both fine and granulated rubber at 28 days in all parameters, surpassing the resistance to compression by 3.76% and 4.14%, as well as the diametral indirect tensile strength by 8.98% and 16.05% with respect to the standard concrete and according to or with the analysis of the hypothetical seismic response with the optimal rubber percentages found, an improvement percentage was determined with the incorporation of 4% rubber, both fine and granulated, in the maximum drifts for the X-X direction 3.44% and 3.87%, as well same for the Y-Y direction of 3.47% and 3.96% respectively compared to the concrete pattern. Thus demonstrating that the use of 4% rubber, both fine and granulated, in concrete is acceptable.

Keywords: Concrete, recycled rubber, seismic response.

INTRODUCTION

Disused tires are among the largest and most problematic sources of waste in modern societies, due to their durability and the huge volumes of tires discarded each year. (Youssf, ElGawady, & Mills, 2015). According to the Ministry of Transport and Communications (MTC, 2016), in the period 2011 – 2014 the vehicle fleet grew annually at an average rate of 8.84%, from 2,523,441 vehicles in 2011 to 3,252,714 in 2014, which produced an exponential increase in disused tires. Likewise Farfán and Leonardo, (2018) mention that in Peru, the environmental problem of voting used tires is the product of little interest in waste management issues both for cultural reasons and for the lack of policies and inquiries about recycling and final disposal of this kind of waste. On the other hand according to Gibreil & Feng, (2017) Concrete due to its ability to acquire any shape is the most used component in the branch of construction worldwide, this results in an excessive expenditure of the raw materials that make it up. In that sense, the recycling of used tires conserves valuable natural resources and reduces the amount of rubber that enters the landfill. (Guo et al., 2014).

It is also noteworthy that seismic events generate the collapse of structures, in addition to economic losses and human lives (Pnevmatikos et al., 2020). Currently according to technical standard E.030, published by (Ministry of Housing, Construction and Sanitation, 2018) the city of Juliaca is located in a seismic zone 03, which indicates that there is a probability of suffering a telluric movement.

Under this scenario our objective is to determine the influence of the incorporation of recycled rubber in the structural concrete and analyze its hypothetical seismic response characterizing the components of the concrete and evaluating the mechanical properties of the concrete with incorporation of recycled rubber and likewise with the optimal results perform an analysis of its hypothetical seismic response.

Being rubber, a material investigated in the elaboration of concrete, so we have Ghosh and Bera, (2016) which show that rubber in waste can be used in concrete as a partial replacement of coarse and fine aggregates, obtaining results that are at the acceptable limit.

More recently the research of Farfán & Leonardo, (2018) They found that the optimal percentage of recycled rubber incorporated into concrete to achieve maximum compressive strength is 5% (218.45kgf/cm2) and to achieve maximum flexural strength is 10% (81.86kgf/cm2); They also mention that it is feasible to use recycled rubber in structures where there is little seismic intensity.

According to Novillo et al., (2017) They found that the 10% of recycled rubber incorporated in concrete presents better values in compressive strength and tensile strength, in addition they observed a decrease in its density. They also deduced that for the elaboration of a cubic meter of concrete density (2276kg / m3) 90kg of rubber would be needed, taking into account that the weight of a normal tire is 10kg would then need 9 tires for each cubic meter of concrete approximately.

Likewise Pelisser et al., (2011) They concluded that recycled tire rubber is an excellent aggregate that together with sodium hydroxide and silica smoke improves compressive strength and determined that this was reduced by only 14% at 28 days compared to conventional concrete, reaching 490 kgf / cm2 for the mixture of greater strength.

For its part Kara De Maeijer et al., (2021) They mention that recycled rubber can be applied as a replacement for natural aggregates and that it depends on the treatment of its surface and the optimization of the mixture design. They found that the optimal replacement range of recycled rubber based on mechanical, physical and durability properties could range from 10% to 20% for fine aggregate replacement and 5% for coarse aggregate replacement. Similarly Safan et al., (2017) They carried out a study of properties of rubber in concrete with substitution of 5, 10 and 15% by volume of sand, where the results showed a greater resistance to compression, bending, traction and modulus of elasticity, and that the use of rubber in construction could help reduce costs and solve the solid waste of these materials and thus be able to take care of the environment.

MATERIALS AND METHODS

Being the applied research which according to , consists of investigating to act, transform, modify or produce changes in a certain sector of reality, in this case the structural concrete. Carrasco Diaz, (2008)

On the other hand, research is classified into a pure experimental design that consists of the intentional manipulation of variables to determine their cause and effect (Hernández - Sampieri & Mendoza, 2018).

The research was conducted in the city of Juliaca, province of San Román in the Puno region, using the Geotechnical laboratory Puno E.I.R.L. located in Jr. Tiahuanaco. As a population of the present research we have the concrete used in the city of Juliaca for structural use, in this case we opted for a concrete of resistance f́ c = 210 kgf / cm2, using the parameters of minimum strength of structural concrete this should not be less than 173 kgf / cm2, as well as according to the National Building Regulation E.060 and the special provisions for the seismic design shown in section 21.3.1 suggests That the f́ c should not be less than 210 kgf/cm2.

For the determination of the sample, the non-probabilistic type was chosen under the randomized complete block design method shown in Table 1 and its nomenclature in Table 2.

Board 1 Number of samples at exploratory level.

Design	Proportion of recycled rubber	Compressive strength			Diametrical indirect tensile strength	Partial	Total
		7 days	14 days	28 days	28 days		
CP-S/C	0 %	3	3	3	3	12	84
C.- 2% C.F.	2 %	3	3	3	3	12	
C.- 4% C.F.	4 %	3	3	3	3	12	
C.- 6% C.F.	6 %	3	3	3	3	12	
C.- 2% C.G.	2 %	3	3	3	3	12	
C.- 4% C.G.	4 %	3	3	3	3	12	
C.- 6% C.G.	6 %	3	3	3	3	12	

Board 2 Nomenclature of briquettes.

Code	Designation
CP-S/C	Concrete pattern without rubber.
C. - 2% C.F.	Concrete with 2% of the weight of the sand replaced by fine rubber.
C.- 4% C.F.	Concrete with 4% of the weight of the sand replaced by fine rubber.
C. - 6% C.F.	Concrete with 6% of the weight of the sand replaced by fine rubber.
C. - 2% C.G.	Concrete with 2% of the weight of the sand replaced by granulated rubber.
C. - 4% C.G.	Concrete with 4% of the weight of the sand replaced by granulated rubber.
C. - 6% C.G.	Concrete with 6% of the weight of the sand replaced by granulated rubber.

To meet the objectives set, the characterization of the fine and coarse aggregates was carried out; and with these materials the mixture design was carried out by the ACI 211 method, for the tests of compressive strength and diametrical indirect tensile strength, briquettes of 150mm in diameter and 300mm high were made.

For the characterization of the aggregates, the ASTM C33 standard was used. The gravels and sands come from the Cabanillas quarry, they were tested for granulometric analysis, specific gravity and absorption, unit weights and abrasion, according to ASTM D-422, ASTM C-128, and ASTM C-131 respectively. The cement used was RUMI (Type IP) and the water used for mixing and curing the briquettes was used from the water network for human consumption in the city of Juliaca. The recycled rubber was obtained from tires in waste from dumps and retreading workshops, the material retained in sieve No. 50 was used as fine rubber and the material retained in sieve No. 8 Figure 1 was used as granulated rubber.

Likewise, for the tests of density, absorption and porosity, compressive strength and diametrical indirect tensile strength, the standards ASTM C-642, ASTM D-422 and ASTM C 496 – 96 respectively were used, as for the static modulus of elasticity it was determined considering the formula 8.3 of the R.N.E. E.60 which is a function of the compressive strength achieved.

Figure 1: Fine and granulated rubber particles.

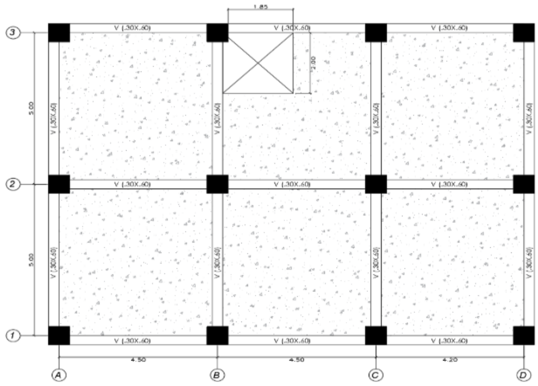
The data collection technique was direct observation. This is how the necessary data were obtained to process them through spreadsheets (formats) for each type of trial, and achieve the results sought in this research.

Similarly, for data processing, the ANOVA analysis of variance technique was used with the MINITAB 18 software, which, according to Amat Rodrigo, (2016) is the statistical test to be used when comparing the means of two or more groups. Likewise, Tukey's test was used which, According to Garcia et al., (2001) creates confidence intervals for all differences in pairs between the means of factor levels while controlling for the error rate per family at a specified level.

Finally, for the analysis of the hypothetical seismic response of the building with the optimal results was determined by means of a manual calculation following the method of concentrated masses and a static seismic analysis, for which a regular structure of housing use was established, which consists of 4 levels.

It was considered for the first level a height of 3.20m and 3m for the upper levels, it consists of a system of porticoes, its columns are of section 0.60 x 0.60 m2, the beams are of section 0.30 x 0.60 m2 in both directions X and Y, likewise a solid slab of 0.15m. Finally, the configuration and distribution of the structural elements is shown in Figure 2. Table 3 also shows the loading patterns.

Figure 2: Configuration and distribution of structural elements.



Board 3 Load patterns and values.

Type of cargo	Symbol	Value
Finishes	CM	100 kg/m2
Partition	CM	100 kg/m2
Overload	CV	200 kg/m2
Roof overload	CV	150 kg/m2

For static seismic analysis, the data are shown in Table 4. Likewise, for the estimation of the weight of the building was carried out with the provisions of article 26 of the RNE E.030, which corresponds to a building of category (C), the weight is calculated by adding to the permanent and total load of the building a percentage of live load of 25%.

Board 4 Data for static seismic analysis.

Data	Parameters	Values
Zone	Z	0.35
Use	Or	1.0
Soil	S	1.15
Seismic amplification factor	C	2.5
Structural system	R	8

RESULTS AND DISCUSSION

Characterization of concrete components.

Laboratory tests Table 5 shows the density of

Materials, in the same way Table 6 shows the characteristics obtained from the aggregates.

Board 5 Density of materials

Material	Density (gr/cm3)
Cement	2.90
Water	1.00
Rubber	1.02

Board 6 Summary of aggregate characteristics.

Property	Unit	Fine aggregate	Coarse aggregate
Compacted dry unit weight	(kg/m3)	1.713	1.359
Loose dry unit weight	(kg/m3)	1.613	1.228
Specific weight of the mass	(gr/cm3)	2.623	2.626
Moisture content	(%)	1.600	1.620
Percentage of absorption	(%)	3.520	2.430
Fineness module		3.241	7.987
Nominal maximum size	In.	----	3/4"

Having the characteristics of the aggregates, the mixture design was carried out for a f'c = 210 kgf / cm2 following the ACI 211 method, obtaining the dosage per cubic meter shown in table 7.

Board 7 Dosage of concrete mixture f'c = 210 kgf/cm2 with an a/c ratio of 0.497.

Material	Value	Unit
Cement	369.90	kg/m3
Coarse aggregate	1044.77	kg/m3
Fine aggregate	687.84	kg/m3
Water	206	lt/m3

Therefore, Table 8 shows the types of dosages of concrete with incorporation of rubber.

Board 8 Dosing of concrete with recycled rubber.

Types of concrete	Cement (kg/m3)	Stone (kg/m3)	Sand (kg/m3)	Rubber (kg/m3)
CP-S/C	369.9	1044.77	687.84	0
C. - 2% C.F.	369.9	1044.77	674.08	5.35
C. - 4% C.F.	369.9	1044.77	660.33	10.70
C. - 6% C.F.	369.9	1044.77	646.57	16.05
C. - 2% C.G.	369.9	1044.77	674.08	5.35
C. - 4% C.G.	369.9	1044.77	660.33	10.70
C. - 6% C.G.	369.9	1044.77	646.57	16.05

Compressive strength

According to Pasquel, (1998), it is the ability to withstand loads and efforts, through the adherent properties of cement paste. It is primarily linked to the concentration of cement paste, which is often expressed in relation to water / cement. Figure 3 shows the summary of the compression tests of the specimens.

Figure 3 shows that the strength of concrete with incorporation of 2% and 4% recycled rubber, both fine and granulated, have the highest values with respect to standard concrete, as also confirmed by Novillo et al., (2017), who found that 10% recycled rubber incorporated into concrete outperforms the resistance under study at 28 days. Likewise Farfán & Leonardo, (2018) They obtained maximum compressive strength with the incorporation of 5% recycled rubber.

On the other hand Pelisser et al., (2011) They found that recycled rubber along with sodium hydroxide and silica fume improves compressive strength.

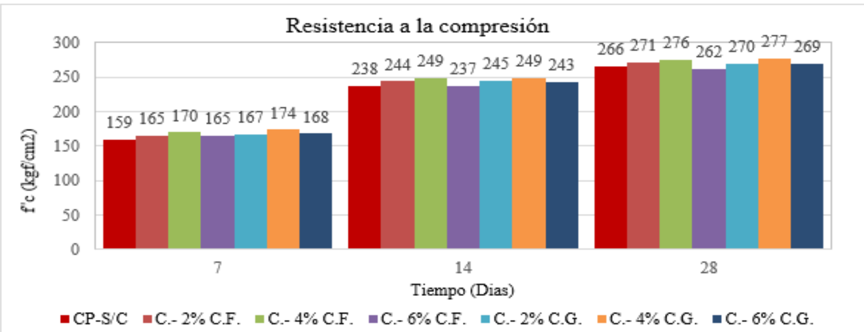
Statistical analysis of compressive strength

When carrying out the research, two hypotheses are proposed, the alternate shows that, when adding fine or granulated rubber, the compressive strength improves significantly and the null hypothesis mentions that, no matter how much the amount of fine or granulated rubber is added, the resistance will always be the same; when having these hypotheses, the analysis of results is executed with the Tukey test of analysis of variance.

Statistical analysis of compressive strength with incorporation of fine rubber.

When processing the 36 treatments in relation to the standard concrete, we present the analysis of variance whose P value is 0.000 less than 0.05; Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Likewise, according to Table 9, a calculated F value of 777.30 is shown, which is greater than the critical F value of 2.22.

Figure 3: Results of the compressive strength test.



Board 9 Analysis of variance

From the analysis in Table 9 it can be deduced that the incorporation of 2% 4% and 6% of fine rubber improves the compressive strength based on the increase of this aggregate with respect to the standard concrete of 210 kgf/cm2. What states that there is a difference between the means of the treatments of the research, so is also shown by the Tukey method the grouping of means in Table 10.

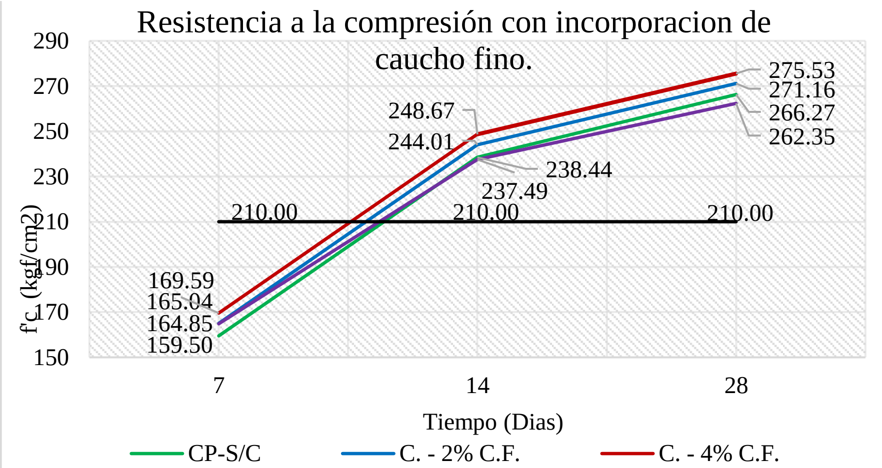
Board 10 Comparative analysis using Tukey's method and 95% confidence

Treatments	N	Stocking	Grouping					
C.- 4% C.F. (28 days)	3	275.53	To					
C.- 2% C.F. (28 days)	3	271.16	To	B				
CP-S/C (28 days)	3	266.27		B				
C.- 6% C.F. (28 days)	3	262.35		B				
C.- 4% C.F. (14 days)	3	248.67			C			
C.- 2% C.F. (14 days)	3	244.01			C	D		
CP-S/C (14 days)	3	238.44				D		
C.- 6% C.F. (14 days)	3	237.49				D		
C.- 4% C.F. (7 days)	3	169.59					And	
C.- 6% C.F. (7 days)	3	164.85					And	F
C.- 2% C.F. (7 days)	3	165.04					And	F
CP-S/C (7 days)	3	159.50						F

Stockings that do not share a letter are significantly different.

Table 10 shows that the most optimal resistance is 4% and 2% fine rubber in 28 days, whose means are in group "A" with a compressive strength of 275.53 and 271.16 kgf/cm2 respectively. For more details, the behavior of compressive strengths at 7, 14 and 28 days of age is shown in Figure 4.

Figure 4: Compressive strength with incorporation of fine rubber.



The behavior of the resistances with the incorporation of rubber at 2%, 4% and 6% had an accelerated increase in resistance from 7 to 14 days and a decrease from 14 to 28 days of age, having between them a homogeneous behavior Figure 4. Table 11 presents the statistical probabilities of maximum and minimum resistances that could be reached according to the conditions in the work field; Therefore, it shows that the incorporation of 4% rubber in 28 days is the most optimal, with an average of 275.53 kgf / cm2, which has the possibility of reaching a maximum resistance of 279.10 kgf / cm2, as well as can remain only at 272.23 kgf / cm2.

Board 11 Statistical probabilities of maximums and minimums.

Treatments	N	Stocking	Standard deviation	95% confidence interval
C.- 2% C.F. (14 days)	3	244.01	1.73	(240.57; 247.43)
C.- 2% C.F. (28 days)	3	271.16	3.46	(267.57; 274.43)
C.- 2% C.F. (7 days)	3	165.04	2.00	(161.57; 168.43)
C.- 4% C.F. (14 days)	3	248.67	3.21	(245.23; 252.10)
C.- 4% C.F. (28 days)	3	275.53	3.06	(272.23; 279.10)
C.- 4% C.F. (7 days)	3	169.59	3.06	(165.90; 172.77)
C.- 6% C.F. (14 days)	3	237.49	3.79	(233.90; 240.77)
C.- 6% C.F. (28 days)	3	262.35	4.93	(259.23; 266.10)
C.- 6% C.F. (7 days)	3	164.85	1.73	(161.57; 168.43)
CP-S/C (14 days)	3	238.44	1.53	(234.899; 241.767)
CP-S/C (28 days)	3	266.27	1.16	(262.899; 269.767)
CP-S/C (7 days)	3	159.50	2.52	(155.90; 162.77)

Pooled standard deviation = 2.88

Statistical analysis of compressive strength incorporating granulated rubber

When processing the 36 treatments in relation to the standard concrete, we present the analysis of variance whose P value is 0.000 less than 0.05; Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Table 12 also shows a calculated F-value of 878.64 that is greater than the critical F-value of 2.22.

Board 12 Analysis of variance.

Fountain	Degrees of freedom	Fitted sum of squares	Adjusted mean squares	F-value	P-value
Treatments	11	70387.9	6398.9	878.64	0.000
Error	24	174.8	7.28		
Total	35	70562.7			

From the analysis in Table 12 it can be deduced that the incorporation of 2% 4% and 6% of granulated rubber improves the compressive strength based on the increase of this aggregate with respect to the standard concrete of 210 kgf / cm2. What it states that there is a difference between the means of the treatments of the research, as well as the grouping of means in Table 13 is shown by the Tukey method.

Board 13 Information groups using Tukey's method at 95% confidence

Treatments	N	Stocking	Grouping					
C.- 4% C.G. (28 days)	3	276.68	To					
C.- 2% C.G. (28 days)	3	270.28	To	B				
C.- 6% C.G. (28 days)	3	269.31	To	B				
CP-S/C (28 days)	3	266.27		B				
C.- 4% C.G. (14 days)	3	249.25			C			
C.- 2% C.G. (14 days)	3	244.77			C	D		
C.- 6% C.G. (14 days)	3	243.03			C	D		
CP-S/C (14 days)	3	238.44				D		
C.- 4% C.G. (7 days)	3	173.84					And	
C.- 6% C.G. (7 days)	3	167.56					And	
C.- 2% C.G. (7 days)	3	166.58					And	F
CP-S/C (7 days)	3	159.50						F

Stockings that do not share a letter are significantly different.

Figure 5: Compressive strength with incorporation of granulated rubber.

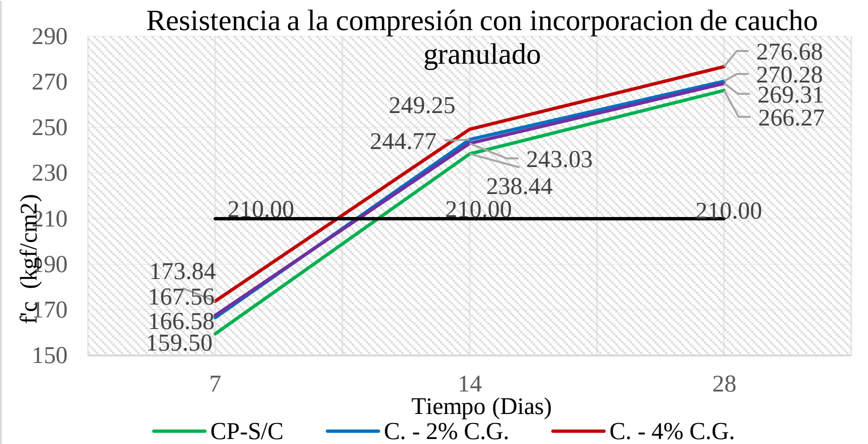


Table 13 shows that the most optimal resistance is 4%, 2% and 6% granulated rubber at 28 days, whose means are in group "A" which show a compressive strength of 276.68 kgf / cm2, 270.28 kgf / cm2 and 269.31 kgf / cm2 respectively. For more details, Figure 5 shows the behavior of compressive strengths at 7, 14 and 28 days of age.

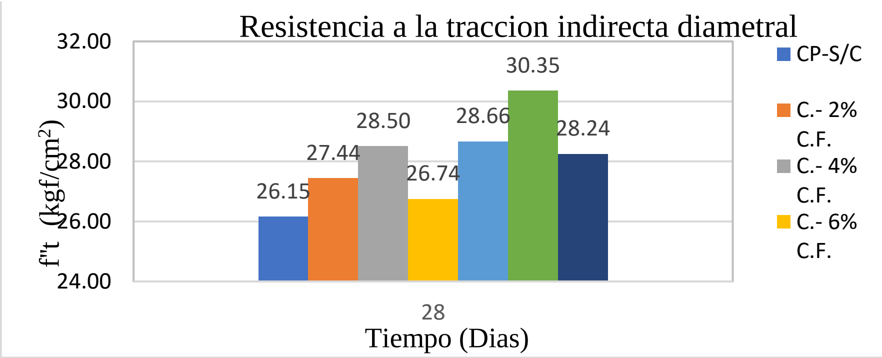
As shown in Figure 5, the behavior of resistances with incorporation of rubber at 2%, 4% and 6% had a significant increase rate between days 7 and 14 days and this was reduced between 14 and 28 days having among themselves a homogeneous behavior Figure 5. Also in table 14, the statistical probabilities of maximum and minimum resistances that could be reached according to the conditions in the field of work are presented; Therefore, it shows that the incorporation of 4% rubber in 28 days is the most optimal with an average of 276.68 kgf / cm2, which has the possibility of reach a maximum resistance of 279.90 kgf/cm2, as well as stay only at 273.47 kgf/cm2.

Board 14 Statistical probabilities of maximums and minimums.

Treatments	N	Stocking	Standard deviation	95% confidence interval
C.- 2% C.G. (14 days)	3	244.77	2.58	(241.55; 247.98)
C.- 2% C.G. (28 days)	3	270.28	3.14	(267.06; 273.49)
C.- 2% C.G. (7 days)	3	166.58	0.974	(163.37; 169.80)
C.- 4% C.G. (14 days)	3	249.25	3.98	(246.04; 252.47)
C.- 4% C.G. (28 days)	3	276.68	4.72	(273.47; 279.90)
C.- 4% C.G. (7 days)	3	173.84	0.541	(170.63; 177.06)
C.- 6% C.G. (14 days)	3	243.03	3.1	(239.81; 246.25)
C.- 6% C.G. (28 days)	3	269.31	3.3	(266.09; 272.52)
C.- 6% C.G. (7 days)	3	167.56	1.013	(164.34; 170.77)
CP-S/C (14 days)	3	238.44	1.528	(235.12; 241.55)
CP-S/C (28 days)	3	266.27	1.155	(263.12; 269.55)
CP-S/C (7 days)	3	159.50	2.52	(156.12; 162.55)

Pooled standard deviation = 2.70

Figure 6: Results of the diametrical indirect tensile strength test.



Diametrical indirect tensile strength

According to Vargas, (2016) this test consists of subjecting a cylindrical specimen to diametrical compression, applying a load uniformly during two lines or opposite generators until the breakage is found. This shows the summary of the tests to diametrical indirect tensile strength of the specimens in Figure 6.

Figure 6 shows that resistance

to the diametrical indirect traction of concrete with incorporation of 2% and 4% of recycled rubber both fine and granulated have the highest values with respect to the standard concrete, as also confirmed by Verzegnassi et al., (2011) who found that 1% and 3% of recycled rubber in concrete at 7 days of age presents an improvement in the resistance to diametrical indirect tensile in relation to standard concrete. Likewise Novillo et al., (2017), found that 10% and 30% rubber

Recycled embodied in concrete outperforms indirect tensile strength compared to standard concrete.

On the other hand, Rodríguez et al., (2019) found that the resistance to diametrical indireca traction with incorporation of 5% recycled rubber presents the highest value 44.46 kgf / cm2.

Statistical analysis of diametrical indirect tensile strength

When carrying out the research, two research hypotheses are proposed which, the alternate shows that, by adding the fine or granulated rubber, the resistance of the diametrical indirect traction improves significantly and the null hypothesis mentions that, no matter how much the amount of fine or granulated rubber is added, the diametrical indirect tensile strength will always be the same; when having these hypotheses, the analysis of results is executed with the Tukey test of analysis of variance.

Statistical analysis of diametrical indirect tensile strength incorporating fine rubber

When processing the 12 treatments in relation to the standard concrete, we present the analysis of variance whose P value is 0.005 less than 0.05; Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Table 15 shows a calculated F-value of 9.36 that is greater than the critical F-value 4.07.

Board 15 Analysis of variance

Fountain	Degrees of freedom	Fitted sum of squares	Adjusted mean squares	F-value	P-value
Treatment	3	9.165	3.0552	9.36	0.005
Error	8	2.612	0.3265		
Total	11	11.777			

The analysis of Table 15 shows that the incorporation of 2% 4% and 6% fine rubber improves the resistance to diametrical indirect traction based on the increase of this aggregate with respect to the standard concrete of 210 kgf / cm2. What states that there is a difference between the means of the treatments of the research, so also by Tukey's method we show the grouping of means in Table 16.

Board 16 Information groups using Tukey's method and 95% confidence

Treatment	N	Stocking	Grouping	
C.- 4% C.F. (28 days)	3	28.50	To	
C.- 2% C.F. (28 days)	3	27.44	To	B
C.- 6% C.F. (28 days)	3	26.74		B
CP-S/C (28 days)	3	26.15		B

Stockings that do not share a letter are significantly different.

From Table 16, it is observed that the most optimal resistance is 4% and 2% fine rubber at 28 days, whose means are in group "A" with a compressive strength of 28.50 kgf/cm2 and 27.44 kgf/cm2 respectively. For more detail, the behavior of the diametrical indirect tensile strengths at 28 days of age is shown in Figure 7.

Figure 7: Diametrical indirect tensile strength vs % fine rubber.

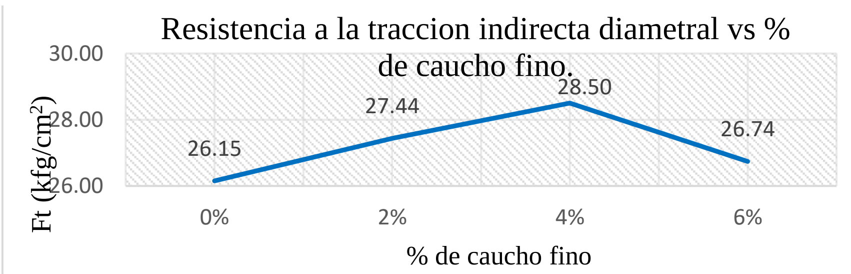


Table 17 presents the statistical probabilities of maximum and minimum resistances that could be reached according to the conditions in the work field; It therefore shows that the Incorporation of 4% rubber in 28 days is the most optimal with an average of 28.50 kgf/cm2, which has the possibility of reaching a maximum resistance of 29.26 kgf/cm2, as well as being left alone at 27.74 kgf/cm2.

Board 17 Statistical probabilities of maximums and minimums.

Treatment	N	Stocking	Standard deviation	95% confidence interval
C.- 2% C.F.	3	27.44	0.605	(26.68; 28.20)
C.- 4% C.F.	3	28.50	0.276	(27.74; 29.26)
C.- 6% C.F.	3	26.74	0.621	(25.98; 27.50)
CP-S/C	3	26.15	0.691	(25.39; 26.92)

Pooled standard deviation = 0.57

Statistical analysis of diametrical indirect tensile strength incorporating granulated rubber

When processing the 12 treatments in relation to the concrete pattern, we present the analysis of variance whose P value is 0.0000 less than 0.05; Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Table 18 also shows a calculated F-value of 24.56 that is greater than the critical F-value 4.066.

Board 18 Analysis of variance

Fountain	Degrees of freedom	Sum of square Adjusted	Square Half Adjusted	F-value	P-value
Treatment	3	26.816	8.9385	24.56	0.0000
Error	8	2.912	0.364		
Total	11	29.727			

The statistical tests shown in Table 18 determine that the incorporation of 2% 4% and 6% granulated rubber improves the diametrical indirect tensile strength based on the increase of said aggregate with respect to the standard concrete 210 kgf / cm2. What states that it differentiates between the means of the treatments of the investigation, as well as by Tukey's method the grouping of means is shown in Table 19.

Board 19 Information groups using Tukey's method and 95% confidence

Treatment	N	Stocking	Grouping		
C.- 4% C.G.	3	30.35	To		
C.- 2% C.G.	3	28.66		B	
C.- 6% C.G.	3	28.24		B	
CP-S/C	3	26.15			C

Stockings that do not share a letter are significantly different.

Table 19 shows that the most optimal diametrical indirect tensile strength is 4% granulated rubber in 28 days, whose average is in group "A" which shows a tensile strength of 30.35 kgf / cm2. For more details, the behavior of tensile strengths at 28 days is shown in Figure 8.

Figure 8: Diametrical indirect tensile strength vs % granulated rubber.

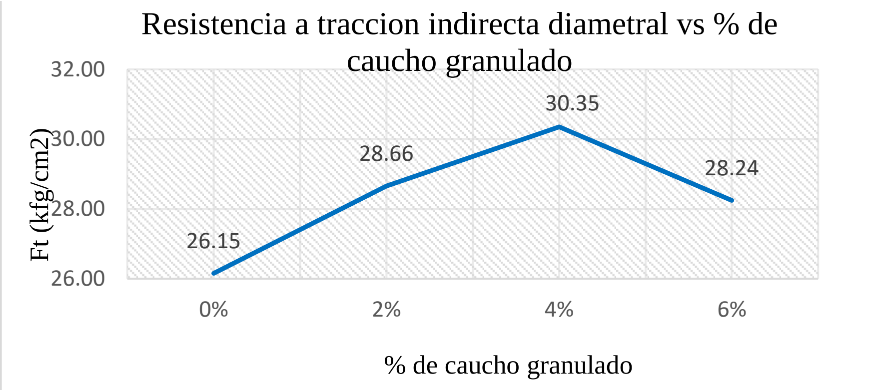


Table 20 presents the statistical probabilities of maximum and minimum resistances that could be reached according to the conditions in the work field; Therefore, it shows that the incorporation of rubber at 4% in 28 days It is the most optimal with an average of 30.35 kgf / cm2, which has the possibility of reaching a maximum resistance of 31.16 kgf / cm2, as well as can be left only at 29.55 kgf / cm2.

Board 20 Statistical probabilities of maximums and minimums.

Treatment	N	Stocking	Standard deviation	95% confidence interval
C.- 2% C.G.	3	28.66	0.606	(27.86; 29.46)
C.- 4% C.G.	3	30.35	0.624	(29.55; 31.16)
C.- 6% C.G.	3	28.24	0.47	(27.44; 29.04)
CP-S/C	3	26.15	0.691	(25.35; 26.96)

Pooled standard deviation = 0.60

Static modulus of elasticity

According to Serrano and Pérez, (2010) this module describes the relative stiffness of a material, which is a parameter related to its compressive strength. In this way it was considered to determine the modulus of static elasticity with the formula 8.3 of the R.N.E E.060 which is a function of the compressive strength achieved, in figure 9 shows the summary of the results obtained from the modulus of static elasticity.

Figure 9: Results of the static modulus of elasticity test

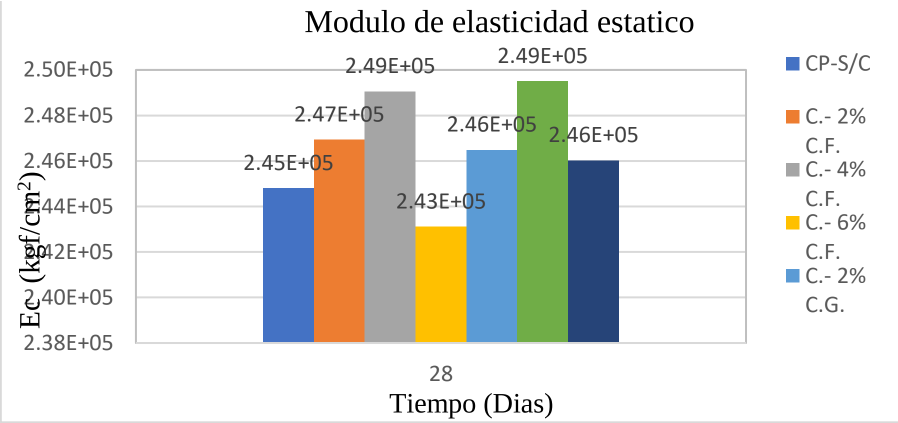


Figure 9 shows that the Static elasticity with incorporation of 2% and 4% recycled rubber, both fine and granulated, have the highest values with respect to standard concrete, as well as confirmed Verzegnassi et al., (2011) who found an increase in the modulus of elasticity with the incorporation of 1% recycled rubber in the concrete. For its part Safan et al., (2017) They found an increase in modulus of elasticity with the incorporation of recycled rubber treated with sodium hydroxide.

Statistical analysis of the static modulus of elasticity

When conducting the research, two research hypotheses are proposed which, the alternate shows that, by adding the fine or granulated rubber, the static modulus of elasticity improves significantly and the null hypothesis mentions that, no matter how much the amount of fine rubber or granules is added, the static modulus of elasticity will always be the same; when having these hypotheses, the analysis of results is executed with the Tukey test of analysis of variance.

Statistical analysis of the static modulus of elasticity with incorporation of fine rubber.

When processing the 12 treatments in relation to the concrete pattern, we present the analysis of variance whose P-value is 0.008 less than 0.05; therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Table 21 shows a calculated F-value of 8.07 that is greater than the critical F-value of 4.066.

Board 21 Analysis of variance

Fountain	Degrees of freedom	Fitted sum of squares	Adjusted square halfs	F-value	P-value
Treatment	3	6.00E+07	2.00E+07	8.07	0.008
Error	8	1.98E+07	2.48E+06		
Total	11	7.99E+07			

The statistical tests shown in Table 21 determine that the incorporation of 2% 4% and 6% of fine rubber increases the modulus of static elasticity based on the increase of said aggregate with respect to the standard concrete of 210 kgf/cm2. Which states that there is a difference between the averages of the research treatments. Also by Tukey's method we show the grouping of means in Table 22.

Board 22 Information groups using Tukey's method and 95% confidence

Treatment	N	Stocking	Grouping	
C.- 4% C.F.	3	2.49E+05	To	
C.- 2% C.F.	3	2.47E+05	To	B
CP-S/C	3	2.45E+05		B
C.- 6% C.F.	3	2.43E+05		B

Table 22 shows that the most optimal static modulus of elasticity is 4% and 2% fine rubber in 28 days, whose means are in grouping "A" with a static modulus of elasticity of 2.49E+05 kgf/cm2 and 2.47E+05 kgf/cm2 respectively. For more details, the behavior of the static modulus of elasticity at 28 days is shown in Figure 10.

Figure 10: Modulus of static elasticity vs % fine rubber.

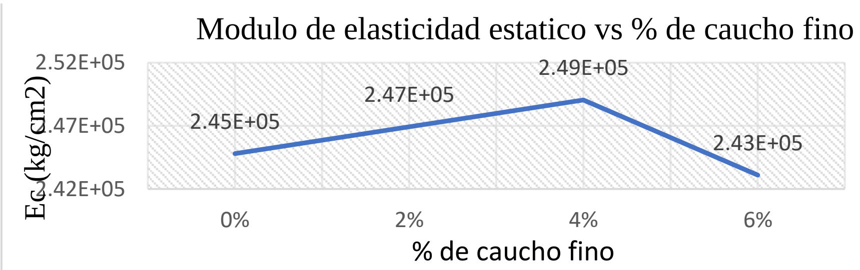


Table 23 presents the statistical probabilities of maximums and minimums of the value of the static modulus of elasticity that could be reached according to the conditions in the work field; therefore, it shows that the incorporation of 4% rubber in 28 days is the most optimal with an average of 2.49E + 05 kgf / cm2, which has the possibility of reaching a static modulus of elasticity of 2.51E + 05 kgf / cm2, as it can also be left alone in 2.47E+05 kgf/cm2.

Board 23 Statistical probabilities of maximums and minimums.

Treatment	N	Stocking	Standard deviation	95% confidence interval
C.- 2% C.F.	3	2.47E+05	1581	(2.45E+05; 2.49E+05)
C.- 4% C.F.	3	2.49E+05	1379	(2.47E+05; 2.51E+05)
C.- 6% C.F.	3	2.43E+05	2289	(2.41E+05; 2.45E+05)
CP-S/C	3	2.45E+05	531	(2.43E+05; 2.47E+05)

Pooled standard deviation = 1574.94

Statistical analysis of the static modulus of elasticity with incorporation of granulated rubber.

When processing the 12 treatments in relation to the concrete pattern, we present the analysis of variance whose P value is 0.032 less than 0.05; Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Table 25 shows a calculated F-value of 4.88 that is greater than the critical F-value of 4.066.

Board 24 Analysis of variance

Fountain	Degrees of freedom	Fitted sum of squares	Adjusted square halfs	F-value	P-value
Treatment	3	3.59E+07	1.20E+07	4.88	0.032
Error	8	1.95E+07	2.45E+06		
Total	11	5.54E+07			

The statistical tests shown in Table 24 determine that the incorporation of 2% 4% and 6% of granulated rubber improves the value of the modulus of elasticity based on the increase of said aggregate with respect to the concrete standard of 210 kgf / cm2. Which states that there is a difference between the averages of the research treatments. Likewise, by Tukey's method, we show the grouping of means in Table 25.

Board 25 Information groups using Tukey's method and 95% confidence

Treatment	N	Stocking	Grouping	
C.- 4% C.G.	3	2.49E+05	To	
C.- 2% C.G.	3	2.46E+05	To	B
C.- 6% C.G.	3	2.46E+05	To	B
CP-S/C	3	2.45E+05		B

Table 25 shows that the most optimal static modulus of elasticity is 4%, 2% and 6% granulated rubber in 28 days, whose means are in group "A" with a modulus of elasticity of 2.49E + 05 kgf / cm2 and 2.46E + 05 kgf / cm2 respectively. For more details, the behavior of the static modulus of elasticity at 28 days is shown in Figure 11.

Figure 11: Modulus of static elasticity vs % granulated rubber.

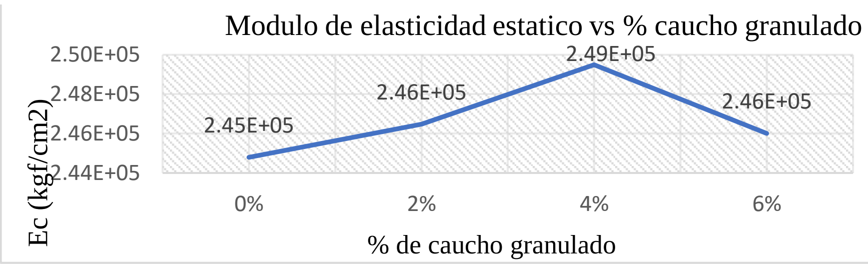


Table 26 presents the statistical probabilities of maximums and minimums of the value of the static modulus of elasticity that could be reached according to the conditions in the work field; It therefore shows that the incorporation of 4% granulated rubber in 28 days it is the most optimal with an average of 2.49E + 05 kgf / cm2, which has the possibility of reaching a static modulus of elasticity of 2.52E + 05 kgf / cm2, as well as can be left alone in 2.47E + 05 kgf / cm2.

Board 26 Statistical probabilities of maximums and minimums.

Treatment	N	Stocking	Standard deviation	95% confidence interval
C.- 2% C.G.	3	2.46E+05	1578	(2.44E+05; 2.49E+05)
C.- 4% C.G.	3	2.49E+05	2127	(2.47E+05; 2.52E+05)
C.- 6% C.G.	3	2.46E+05	1581	(2.44E+05; 2.48E+05)
CP-S/C	3	2.45E+05	531	(2.43E+05; 2.47E+05)

Analysis of the hypothetical seismic response of the building with the optimal results.

Table 27 shows the summary of optimal results obtained from concrete with incorporation with recycled rubber with respect to the pattern concrete, in which It observed that the value of the modulus of elasticity did not vary significantly, but there was a reduction in specific weight and an improvement in the compressive strength of the samples.

Board 27 Summary of optimal results obtained.

Types of concrete	Compressive strength (kg/cm2)	Specific gravity (kg/m3)	Modulus of elasticity (kg/cm2)
C.P- S/C	266	2376	2.45E+05
C.- 2% of C.F.	271	2365	2.47E+05
C.- 4% of C.F.	276	2327	2.49E+05
C.- 2% of C.G.	270	2362	2.46E+05
C.- 4% of C.G.	277	2316	2.49E+05

Figure 12 and 13 show the results of the buildings evaluated with the data in table 27 from which It deduces that the incorporation of granulated and fine rubber at 2% and 4% positively improves the elastic characteristics of the building with respect to the building evaluated with the standard concrete. They also showed a reduction in the displacements of mezzanines, because their static modulus of elasticity did not vary significantly, but there was a reduction in specific weight which made the structure have a more ductile and elastic behavior against seismic stresses.

Figure 12: Inelastic drifts x-x earthquake with incorporation of recycled rubber.

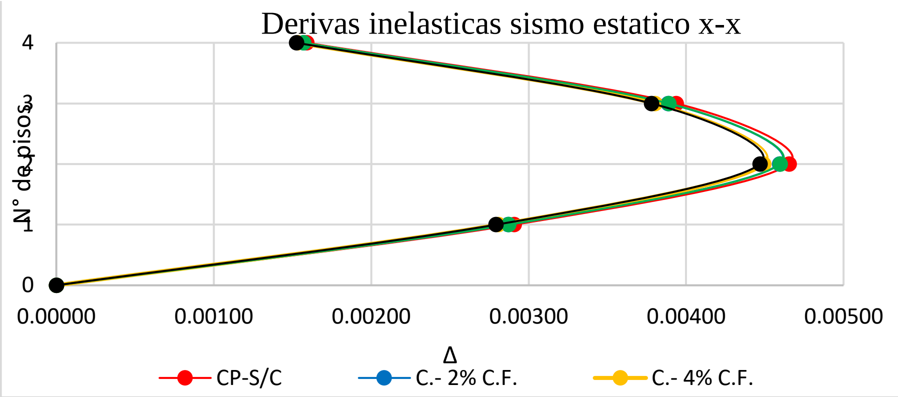
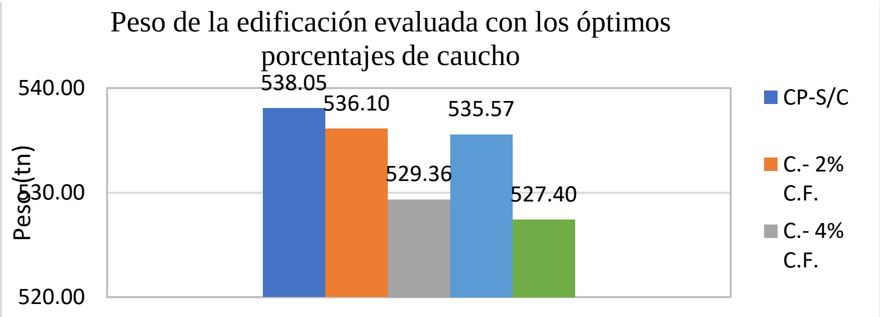


Figure 13: Inelastic drifts earthquake and-y with incorporation of recycled rubber.

As previously visualized the specific weight of concrete notoriously influences the seismic behavior of the structures, figure 14 shows the alteration of the weight of the building analyzed with the optimal percentages of rubber found, so the weight of the building was reduced as recycled rubber was increased, thanks to the fact that rubber has the property of being lighter than aggregates.

Figure 14: Weight of the building evaluated with the optimal percentages of rubber.



Percentage of improvement of the hypothetical seismic response of the building with the optimal results.

Table 28 shows the maximum drifts for the X-X earthquake of the evaluated building with the optimal percentages of rubber, as well as the percentage of improvement of the seismic response with respect to the building evaluated with the standard concrete. So it is observed that both fine and granulated rubber at 4% has the highest percentage of improvement with 3.44% and 3.87% respectively.

Board 28 Maximum drifts (Earthquake X-X) and % improvement.

Structure	Maximum drift x-x	%	% improvement
Concrete Pattern	0.00465	100	0.00
C. E. with 2% of C.F.	0.00459	101.29	1.29
C. E. with 4% of C.F.	0.00449	103.44	3.44
C. E. with 2% of C.G.	0.00460	101.08	1.08
C. E. with 4% of C.G.	0.00447	103.87	3.87

Table 29 also shows the maximum drifts for the Y-Y earthquake of the building evaluated with the optimal percentages of rubber, as well as the percentage of improvement of the seismic response with respect to the building evaluated with the standard concrete. So it is observed that both fine and granulated rubber at 4% has the highest percentage of improvement with 3.47% and 3.96% respectively.

Board 29 Maximum drifts (Earthquake and-y) and % improvement.

Structure	Maximum drift y-y	%	% Improvement
Concrete Pattern	0.00547	100.00	0.00
C. E. with 2% of C.F.	0.00540	101.28	1.28
C. E. with 4% of C.F.	0.00528	103.47	3.47
C. E. with 2% of C.G.	0.00540	101.28	1.28
C. E. with 4% of C.G.	0.00525	103.96	3.96

CONCLUSIONS

The incorporation of recycled rubber both fine and granulated to 4% evidences an improvement of some mechanical properties of the concrete, and this is also observed in the analysis of the hypothetical seismic response of the building, which showed an acceptable elastic behavior, so it is verified that the recycled rubber positively influences the structural concrete and therefore the use of this percentage of rubber in the concrete is suggested. On the other hand, a decrease in properties was observed with the incorporation of both granulated and fine rubber at 6%.

In relation to the tests completed to the aggregates of the concrete to obtain the standard mixture in accordance with the ASTM, which show that the aggregates are within the parameters and limits established by the standard already named, thus having aggregates suitable for making the mixture designs raised in the investigation.

The compressive strength with the incorporation of both fine and granulated rubber at 4% exceeded the compressive strength by 3.76% (276 kgf / cm2) and 4.14% (277 kgf / cm2) with respect to the standard concrete (266 kgf / cm2), this being the most optimal, on the other hand, the incorporation to 6% of both fine and granulated rubber already presents a decrease in its resistance 262 kgf / cm2 and 269 kgf / cm2, That is to say that the greater the amount of rubber, the compressive strength decreases.

From the test of the diametrical indirect tensile strength, for concrete with incorporation of 4% rubber both fine and granulated increases by 8.98% (28.50 kgf / cm2) and 16.05% (30.35 kgf / cm2) with respect to the standard concrete (26.15 kgf / cm2), which shows that the specimens with rubber detail a high aptitude to absorb plastic energy, Therefore, rubber has the ability to withstand large deformations before failure.

The static modulus of elasticity does not vary greatly for concrete with incorporation of 4% both fine and granulated, but if a decrease is observed for concrete with incorporation of rubber to 6% both fine and granulated, that is, the higher the percentage of rubber, the modulus of elasticity tends to fall with respect to the standard concrete, In this way it is evident that rubber has the simplicity to deform in the presence of compression loads.

From the analysis of the hypothetical seismic response of the building evaluated with the optimal results, it was concluded that the concrete with the incorporation of 4% recycled rubber, both fine and granulated, improved the elastic characteristics of the building with respect to the standard concrete, in addition to its displacements were reduced, with a superior compressive strength, maintaining a static modulus of elasticity similar to that of standard concrete and at the same time the weight of the structure was reduced due to the lower specific weight of concrete with recycled rubber.

According to analysis of the hypothetical seismic response of the building evaluated with the optimal results, a percentage of improvement was determined with the incorporation of rubber at 4% of the maximum drifts in direction X of 3.44% for concrete with fine rubber and 3.87% for concrete with granulated rubber, likewise for direction Y of 3.47% for concrete with fine rubber and 3.96% for concrete with fine rubber Granulated rubber with respect to the standard concrete. Thus demonstrating that the use of 4% rubber is acceptable, both fine and granulated, in concrete.

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