ENGLISH VERSION...

Caucho reciclado en la resistencia a la compresión y flexión de concreto modificado con aditivo plastificante

Recycled rubber in the compressive strenght and bending of modified concrete with plasticizing admixtrue

M. Farfán [1]*, E. Leonardo *

* Universidad César Vallejo,Trujillo, PERÚ

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Abstract

The use of concrete made with recycled materials allows an alternative in the optimization and considerable reduction of resources during the manufacturing process of the components. The resistance to compression and bending in concrete of 210 Kg/cm2 modified with plastifying additive at ages 7, 14 and 28 days were evaluated using recycled rubber of 5, 10 and 15% in its composition. Three experimental groups were included, with plasticizing admixture and recycled rubber, and two control groups, with and without plastifying additive. The resistance to compression reached maximum values of 218.45 Kg/cm2 and 212.33 Kg/cm2 at 5% and 10% rubber, respectively. As for the flexural strength, a maximum value of 81.86 Kg/cm2 was achieved for 10% rubber. The recycled rubber proved to be an excellent addition to be used in concrete mixtures despite the losses of mechanical strength, but by adding plastifying additive, it significantly improves making it possible to be incorporated into concrete up to 10%. By means of variance analysis with significance of 5%, it is concluded that the percentage of recycled rubber has a significant effect on the resistance to compression and bending in the manufacture of modified concrete with plastifying additive.

Keywords: *Rubber, concrete, strength, compression, bending*

Resumen

La utilización de concreto elaborado con materiales reciclados permite tener una alternativa en la optimización y disminución considerable de recursos durante el proceso de fabricación de los componentes. Se evaluaron las resistencias a compresión y flexión en concreto de 210 Kg/cm2 modificado con aditivo plastificante a edades 7, 14 y 28 días, usando en su composición caucho reciclado de 5, 10 y 15%. Se incluyeron tres grupos experimentales, con aditivo plastificante y caucho reciclado, y dos grupos control, con aditivo plastificante y sin él. La resistencia a la compresión logró valores máximos de 218.45 Kg/cm2 y 212.33 Kg/cm2 a 5% y 10% de caucho, respectivamente. Para la resistencia a flexión se logró un valor máximo de 81.86 Kg/cm2 para 10% de caucho. El caucho reciclado demostró ser un excelente agregado a ser empleado en mezclas de concreto a pesar de las pérdidas de resistencia mecánica, pero agregándole aditivo plastificante mejora significativamente haciendo viable su incorporación en el concreto hasta en 10%. Mediante análisis de varianza con significancia de 5%, se concluye que el porcentaje de caucho reciclado tiene efecto significativo en la resistencia a compresión y flexión en la fabricación de concreto modificado con aditivo plastificante.

Palabras clave: Caucho, concreto, resistencia, compresión, flexión

1. Introduction

The disposal of tires after their lifespan indisputably affects the global environment. Since they are not biodegradable they are dumped in uncontrolled landfills or simply abandoned in public areas. In Peru, the environmental problem of tire waste is generated by the lack of knowledge of waste management matters both for cultural reasons and for the lack of policies and research on the reuse and final disposal of this type of waste. According to the Ministry of Transport and Communications (MTC, 2016), published in El Peruano official state gazette, during the period 2011 - 2014 the vehicle fleet increased at an average annual rate of 8.84%, moving from 2,523,441 vehicles in 2011 to 3,252,714 in 2014, and consequently the amount of discarded tires grew exponentially.

Under this scenario, the use of concrete made using recycled materials will allow for a considerable optimization and reduction of resources during the manufacturing process of the components. In this respect, the investigation evaluates the technical feasibility of incorporating tire waste as materials for the production of concrete.

Being rubber, as tire residue, a very popular material, many investigations have been carried out which account for the use of this material in the production of concrete, so we have Ghosh and Bera (2016) who conduct a comprehensive review and show that the waste tire rubber aggregates can be used in concrete as a partial replacement of fine and coarse aggregates, obtaining results that are within the acceptable limit. Thomas and Gupta (2015), analyzing the literature, also conclude that this waste material can be a partial substitute for aggregate in concrete. It has a high resistance to freeze-thawing, acid attack and chloride ion penetration. These authors also agree that the use of silica fume allows reaching high resistance to sulphates, acid and chloride.

Also, Pelisser et al. (2011) determined that the recycled tire rubber proves to be an excellent aggregate that along with sodium hydroxide and silica fume enhances the compressive strength of concrete. In addition, Issa and Salem (2013)—who used ground rubber as a fine aggregate—were able to determine positive results of compressive strength when the rubber content is less than 25%. They also obtained improvements in ductility. Netravati (2017) also determined that the combination of tire rubber and fly ash gives good quality in compressive strength and concrete bending.

[1] *Corresponding author:*

Universidad César Vallejo,Trujillo, PERÚ
E-mail: mfarfan@ucv.edu.pe

Moreover, Chauhan and Sood (2017) conclude that adding tire rubber particles gives ductile properties to concrete and develops the load-bearing capacity even after cracking and maximum load is reached.

It is important to mention that the quality of the concrete depends on the quality of the paste and the aggregate and from their union. In a properly prepared concrete, each and every particle of aggregate is completely covered by the paste and all the spaces between the aggregate particles are completely filled (Kosmatka et al., 2004).

Apart from that, Tung-Chai (2011) used rubber content between 5% and 50% as a replacement of the sand volume to formulate linear and logarithmic equations to predict the density and the compressive strength of concrete blocks. It is important to mention that the type and size of the particles of recycled rubber aggregate is a conditioning factor to improve prediction

Another not less important component in the concrete mixture is the plasticizing or superplasticizing admixtures specifically used to reduce the amount of water in the mixture (Rivera, 2009), a component that helps to keep or to improve the compressive strength of the mixture (Mayta, 2014).

2. Discussion and development

2.1 Material and methods

In order to meet the stated objectives, a characterization of fine and coarse aggregates was made. With these materials, the design of concrete mixtures for compressive strength of 210 kg/cm² was carried out through the ACI 2010 method. Five types of mixtures were produced: plain concrete (PC), PC plus plasticizing admixture (PCPA), PCPA plus 5% volume of recycled rubber (PCPA5RR), PCPA plus 10% of recycled rubber (PCPA10RR), and PCPA plus 15% of recycled rubber (PCPA15RR). Each of the mixtures in a plastic state was subjected to settlement tests. The mixtures in a hardened state were measured for compressive strength in cylinders with a diameter of 150 mm and a height of 300 mm at ages 7, 14 and 28 days. Bending tests were conducted on beams measuring 150 mm x 150 mm x 500 mm at the age of 28 days. A total of 45 cylindrical specimens with a diameter of 150 mm and a height of 300 mm were produced.

The characterization of aggregates to produce the concrete used in the tests was selected by meeting the specification requirements for Peruvian technical standards, NTP 400.011 2013, NTP 400.037 2014, and ASTM C33 2016. Gravel and sand came from a supplier of DINO Arvesac materials. These were tested for granulometric analysis, specific weight and absorption, unit weight and moisture content in conformity with the ASTM C-136 2016, C-128 2016, C-29 2016 and C-566 2016 standards, respectively. The cement used was Pacasmayo Extraforte (Type 1), which complies with the NTP 334.090 2016 standard. The water used for mixing and curing the samples is the water that came from the network of water for human consumption in the city of Trujillo. In the case of the admixture, the SikaCem® water reducing superplasticizer was used, which complies with the ASTM C 494 2016 standard. No control tests were performed on this admixture, as certificates were issued by the supplier. Ground recycled rubber was obtained from waste tires from dumps and mechanics workshops and it was used without separating the textiles or steel from its composition. The size of the rubber particle was 0.5 cm of diameter.

The design of the concrete mixture was made by following the ACI 2010 procedure, setting as input data the compressive strength of 210 kg/cm², with 4″ settlement for plain concrete and 5.5″ settlement for concrete with plasticizing admixture. The ratios of recycled rubber for the production of the cylindrical specimens were set at 5%, 10% and 15% of volume in concrete with a plasticizer. In addition, control samples with and without plasticizer were made only to quantify variations in the properties under study. The same procedure was also conducted for the beams subjected to bending.

Tests in plastic and hardened concrete were conducted at different ages. Settlement tests were conducted in plastic state and compression tests in cylinders and bending tests in beams were conducted in hardened state. The settlement tests were conducted in conformity with the NTP 339.035 2016 and ASTM C 143 2016 standards, setting a comparison with the control sample. Compression tests in concrete cylinders were conducted in conformity with standard ASTM C39 2016.

Bending tests were conducted on 150 mm x 150 mm x 500 mm beams, in conformity with ASTM C293 2016 standard, both specimens underwent a water immersion curing process under controlled conditions in conformity with ASTM C 192M 2016. The number of beams produced was 15, from which 6 were control beams (with and without plasticizer) and 9 had percentages of recycled rubber at 5%, 10%, and 15% of volume.

The results of the compressive strength test were processed through an analysis of variance (ANOVA) in order to determine the differences in strength between the specimen groups. Then, the multiple comparison test, Tukey, was conducted in order to identify which of the group pairs are significantly different from each other, at a significance level of 5%.

2.2 Results

Each of the results obtained in the execution of the activities defined in the work methodology is presented below.

2.2.1 Physical-chemical characterization of materials and design of mixtures:

Figure 1 and figure 2 show the particle size distribution obtained in the tests conducted to the fine and coarse aggregates respectively.

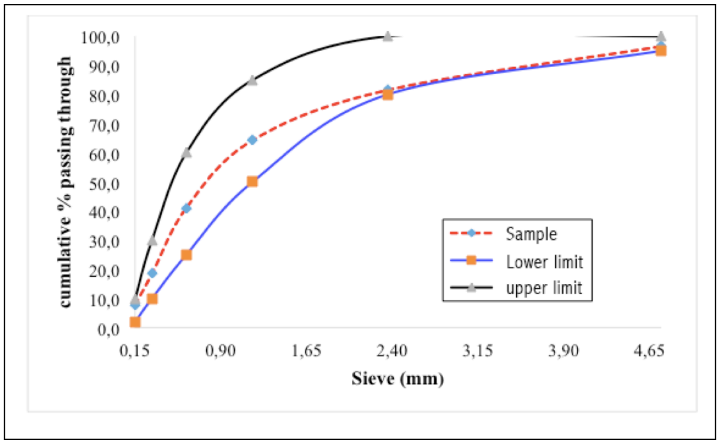

Figure 1. *Particle size distribution of fine aggregate – ASTM C33 2016 Specification Limits*

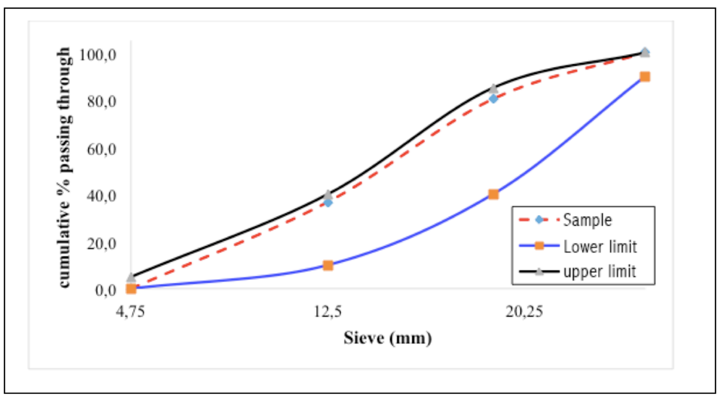

Figure 2. *Particle size distribution of coarse aggregate – ASTM C33 Specification Limits*

Table 1 shows the results on the physical-chemical and mechanical characteristics of the Pacasmayo Extraforte Cement (Type I) provided by the manufacturer. The design of the concrete mixture was made by following the ACI 2010 procedure and it was adjusted with the addition of water reducing superplasticizing admixture. The admixture was dosed according to the recommendation of the manufacturer. Table 2 and Table 3 show the proportions used in the concrete mixture.

Table 1. *Physical-chemical and mechanical characteristics of cement*

Chemical Properties	NTP 334.090 Requirement	Result	Check
MgO	6.0% maximum	1.3%	Meets the requirements
SO_3	4.0% maximum	1.99%	Meets the requirements
Physical and Mechanical Properties			
Air content	12% maximum	6%	Meets the requirements
Autoclave expansion	0.80% maximum	0.065%	Meets the requirements
Spherical surface	Not specified	5020 cm/g	Meets the requirements
Retained in sieve No. 325	Not specified	3.2%	Meets the requirements
Density	Not specified	3.00 g/mL	Meets the requirements
Initial set	45 min minimum	111 min	Meets the requirements
Final set	420 min minimum	260 min	Meets the requirements
Compressive strength after 3 days	133 kg/cm^2 minimum	245 kg/cm^2	Meets the requirements
Compressive strength after 7 days	204 kg/cm^2 minimum	288 kg/cm^2	Meets the requirements
Compressive strength after 28 days	255 kg/cm^2 minimum	330 kg/cm^2	Meets the requirements

Table 2. *Design of plain concrete mixture for 210 kg/cm^2 and a w/c ratio of 0.6*

Material	Weight ratio	Weight (kg)	Mixture %
Cement	1.00	386	15.72
Water	0.60	232	9.45
Gravel	2.25	869	35.38
Sand	2.51	969	39.45
Total for 1m^3		2456	100.0

Table 3. *Design of mixture for 210 kg/cm^2 with plasticizing admixture and a w/c ratio of 0.48*

Material	Weight ratio	Weight (kg)	Mixture %
Cement	1.00	386	15.98
Water	0.48	186	7.70
Gravel	2.25	869	35.98
Sand	2.51	969	40.12
Plasticizer	0.014	5.44	0.225
Total for 1m^3		2415.44	100.0

2.2.2 Plastic state tests and mechanical tests in hardened state

Table 4 shows the tests of the samples in fresh state.

Table 4. *Concrete settlement in fresh state*

Mixtures	w/c Ratio	Maximum Slump (inches)	% of Variation
PC*	0.60	4	0%
PCPA**	0.48	5.5	38%
PCPA5RR**	0.48	5.5	38%
PCPA10RR**	0.48	5.7	43%
PCPA15RR**	0.48	5.8	45%

**w/c ratio = 0.60*
***w/c ratio = 0.48*

Table 5 shows the tests of the samples in hardened state. Figure 3, figure 4 and figure 5 show the tests of the cylindrical samples of 150 mm diameter and 300 mm height and Table 6 and Figure 6 show the tests for 150 mm x 150 mm x 500 mm beams.

Table 5. *Compressive strength of concrete in hardened state*

Mixture	Compressive strength (kg/cm²)						Maximum deflection (mm/1000)
	7 days	alc. %	14 days	alc. %	28 days	alc.%	
CP*	164.3	78%	197.95	94%	219.06	104%	4571.72
PCPA**	209.96	100%	251.37	120%	295.73	141%	6395.50
PCPA5RR**	152.916	73%	176.946	84%	218.452	104%	6808.53
PCPA10RR**	152.882	73%	180.486	86%	212.337	101%	6934.77
PCPA15RR**	149.156	71%	169.043	81%	198.875	95%	7451.99

**w/c ratio = 0.60*
***w/c ratio = 0.48*

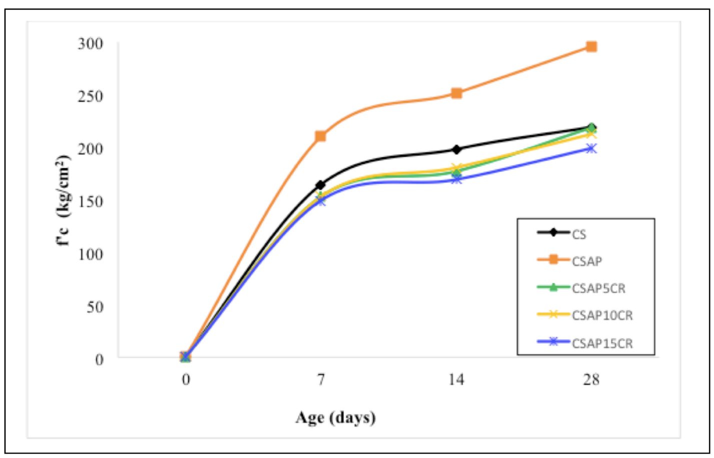

Figure 3. *Compressive strength of concrete in hardened state according to curing time*

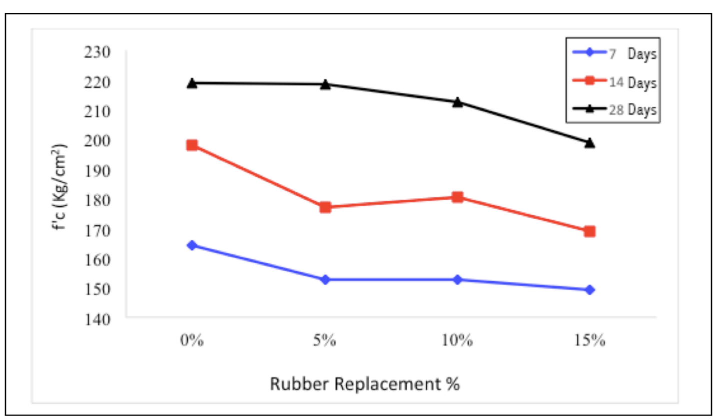

Figure 4. *Compressive strength according to the percentage of recycled rubber*

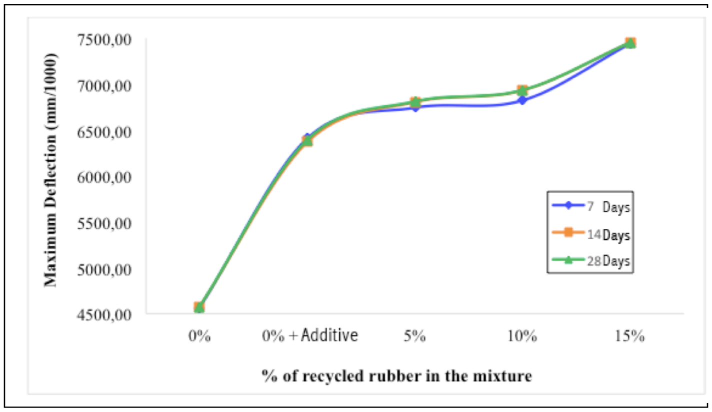

Figure 5. *Maximum deflection according to the percentage of recycled rubber*

Table 6. *Flexural strength of concrete in hardened state*

Mixture	Flexural strength (kg/cm²)	Maximum deflection (mm/1000)
	28 days	
CP*	83,580	3577.94
PCPA**	102,092	3318.09
PCPA5RR**	71,219	2454.95
PCPA10RR**	81,861	3578.18
PCPA15RR**	77,768	3814.69

**w/c ratio = 0.60*
**w/c ratio = 0.48

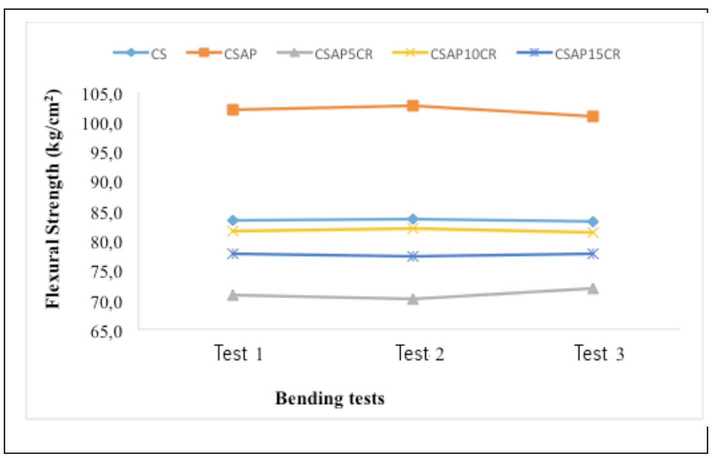

Figure 6. *Flexural strength in 28-day cured concrete at different proportions of recycled rubber*

2.2.3 Statistical analysis of results

All samples met the normality test (p>0.05) according to the age of the concrete cylinders. Tables 7, 8, 9 and 10 show the analysis of variance and the multiple comparison test, Tukey, and the tests of compressive and flexural strength of the five independent treatments.

Table 7. *Analysis of variance (ANOVA) for compressive strength data according to the age of the concrete cylinders*

Cylinder Age	Mean	Standard Deviation	F	Significance (p)*
7 days	165.84	23.44	3040.869	0.000
14 days	195.16	30.71	2784.031	0.000
28 days	228.89	35.40	59034.331	0.000

**The difference of means is highly significant at the 0.01 (p<0.01) level*

About the effect of the percentage of recycled rubber, according to the curing days, Table 7 shows that there are very significant differences ($p<0.01$) in concrete cylinders for 7, 14, and 28 curing days. Table 9 shows that at 28 curing days there are no significant differences ($p>0.05$) between the strengths of the PCPA5RR and PC samples. In all the remaining cases there are very significant differences ($p<0.01$). For the bending analysis, Table 8 shows that beam samples present very significant differences ($p<0.01$) in their mean differences. In addition, in the case of multiple comparisons, Table 10 only shows in PC and PCPA10RR samples that the difference in means is not significant ($p>0.05$).

Table 8. *Analysis of variance (ANOVA) for flexural strength data according to 28-day concrete beam samples*

Samples	Mean	Standard Deviation	F	Significance (p)*
PC	83.57	0.208	896.995	0.000
PCPA	102.10	0.954		
PCPA5RR	71.13	1.050		
PCPA10RR	81.87	0.3511		
PCPA15RR	77.77	0.231		

**The difference in means is very significant at the 0.01 level ($p<0.01$)*

Table 9. *Multiple comparisons between the concrete cylinder samples according to their age*

Samples	PC	PCPA	PCPA5RR	PCPA10RR	PCPA15RR
7 days					
PC	-------	0.000**	0.000**	0.000**	0.000**
PCPA	0.000**	-------	0.000**	0.000**	0.000**
PCPA5RR	0.000**	0.000**	--------	1.000	0.000**
PCPA10RR	0.000**	0.000**	1.000	--------	0.000**
PCPA15RR	0.000**	0.000**	0.000**	0.000**	--------
14 days					
PC	--------	0.000**	0.000**	0.000**	0.000**
PCPA	0.000**	--------	0.000**	0.000**	0.000**
PCPA5RR	0.000**	0.000**	--------	0.017*	0.000**
PCPA10RR	0.000**	0.000**	0.017*	--------	0.000**
PCPA15RR	0.000**	0.000**	0.000**	0.000**	--------
28 days					
PC	--------	0.000**	0.123	0.000**	0.000**
PCPA	0.000**	--------	0.000**	0.000**	0.000**
PCPA5RR	0.123	0.000**	--------	0.000**	0.000**
PCPA10RR	0.000**	0.000**	0.000**	--------	0.000**
PCPA15RR	0.000**	0.000**	0.000**	0.000**	--------

**The difference in means is significant at the 0.05 level ($p<0.05$)*
*** The difference in means is very significant at the 0.01 level ($p<0.01$)*

Table 10. *Multiple comparisons between the concrete beam samples according to mixture composition*

Muestras	CS	CSAP	CSAP5CR	CSAP10CR	CSAP15CR
CS	-------	0,000**	0,000**	0,066	0,000**
CSAP	0,000**	-------	0,000**	0,000**	0,000**
CSAP5CR	0,000**	0,000**	--------	0,000**	0,000**
CSAP10CR	0,066	0,000**	0,000**	--------	0,000**
CSAP15CR	0,000**	0,000**	0,000**	0,000**	--------

2.3 Discussion of results:

2.3.1 Settlement of fresh concrete

From Table 4, we could observe that the settlement in the concrete samples had an increase from 38% to 45% in comparison with the plain concrete: in concretes with rubber plus plasticizing admixture, there was an increase from 5% to 15%. However, Maldonado et al. (2016), only reported increases in settlement between 1% and 3% when using recycled rubber. Apart from that, Bravo and Brito (2012) also determined increases in settlement from 11% to 25% and from 14% to 16% in concretes with 10% and 15% of recycled rubber, respectively, as a replacement for fine and coarse aggregates. In addition, when using plasticizers at different doses, Mayta (2014) obtained minimum average increases of 47.9% and maximum average increases of 139.6%. It is clearly observed that this substantial difference is mainly due to the plasticizer admixture used in the concrete mixture as it ensures a limited fluidity so that the concrete can be easily accommodated.

2.3.2 Compressive strength

Compressive strength measurements from Table 5 show that only the mixture of concrete and plasticizing admixture reached the expected strength at the three ages under study. This was also confirmed by Reina et al. (2010) who found out that the strength reached after 28 days exceeded the strength under study. Apart from that, Mayta (2014) could also determine that using a superplasticizing admixture exceeds the strength under study from 3 to 28 curing days. We can say that this increase in strength was caused by the properties of the plasticizing admixtures, also known as water reducers. This was evidenced in the decrease in the w/c ratio from 0.6 to 0.48, which resulted in such an increase in strength.

In the case of samples with different contents of recycled rubber, the strengths found were up to 29% below the design strength for ages 3 and 14 curing days. Only at the age of 28 days, the design strength was exceeded in samples with 5% and 10% of rubber and plasticizer admixture. It is demonstrated that the increase in the compressive strength of concrete is a result of the influence of curing time, noticing (Table 5) that at 7 days the average strength achieved by the mixtures under study is approximately 79%, at 14 days is 93% and at 28 days it reached 109% in comparison with the design strength (210 kg/cm^2 at 28 days).

Also, Bravo and De Brito (2012) determined that when a fine aggregate is replaced by rubber, the decrease in compressive strength at 28 days reaches 50%. Apart from that, Torres (2014) just used Grass-type recycled rubber from discarded tires and could exceed the design strength (21 MPa) only at 90 days for rubber ratios of 10% and 20%. As observed in Table 3, this property improves with long-term tests, although it is also true that as the percentage of rubber increases, the strength tends to decrease, as observed in Figure 4. In this regard, Valadares et al. (2012) state that compressive strength is affected and reduced by the addition of ground rubber. However, this issue could be compensated with the incorporation of sodium hydroxide and silica fume (in our case, plasticizer admixture) as stated by Pelsser et al. (2011).

With regard to the maximum deflection reached, Figure 5 shows that deflections tend to increase as rubber additions increase. The highest value achieved was 7451.99 mm/1000 for the mixture with rubber at 15%, which represents 63% higher than the design of plain concrete without admixture (PC).

2.3.3 Flexural Strengt:

Table 6 shows the average values of flexural strength at 28 curing days in 150 mm x 150 mm x 500 mm beams, with the plain concrete mixture with plasticizer admixture (PCPA) being 22% higher than the flexural strength of the control sample. (PC). The mixtures with different percentages of rubber tend to decrease the strength, although the mixture that obtained the best performance was the mixture that incorporated 10% of rubber, which was 2% less than the control sample, as shown in Figure 6. Maldonado et al. (2016) also determined that the concrete with rubber decreases flexural strength by up to 8%. The authors claim that rubber incrustations in the structure of the concrete cylinder did not allow it to be destroyed and obtained greater strength capacity. Similar rubber performance was seen in compressive and tensile strength tests as reported by Albano et al. (2007). Estrada (2016) also reports a decrease in strength when using rubber in concrete, showing decreases between 22% and 44% at different ages and proportions of coarse rubber as a substitute for the fine aggregate.

2.3.4 Statistical analysis

Regarding the effect of rubber dosing on the compressive strength of concrete, Table 7 shows that there are very significant variations ($p<0.01$) between the strengths *of the samples for each age group. This would reaffirm that concrete components play a fundamental role in this mechanical property. The same happens for the flexural strength in table 8, where the strengths show a differentiated performance and the PCPA10RR sample reaches a better development of this property. Table 9 presents the multiple comparisons between the samples and shows that after 7 days of curing, the samples with rubber proportions already tend to differ from the standard sample (PC), but PCPA5RR and PCPA10RR samples have similar performance (p>0.05). At 14 days, these differences persist, although they are below the design differences. At 28 days, the PCPA5RR sample has a performance similar to PC, showing no significant differences (p>0.05). This is not the case in other situations where there are very significant differences (p<0.01) between PCPA10RR and PCPA15CR, and compared to the standard sample (PC and PCPA). Therefore, it is demonstrated that the presence of rubber as a structural component of concrete influences its mechanical properties, especially its compressive strength.*

From table 10 it can be inferred that the PCPA10RR sample has better performance and is similar to the control sample (PC), developing a better flexural strength than samples with 5% and 15% of rubber.

3. Conclusions

The optimum percentage of recycled rubber to obtain the maximum compressive strength of concrete (218,452 kg/cm²) is 5%, after 28 days.
The optimum percentage of recycled rubber to obtain the maximum flexural strength of concrete (81,861 kg/cm²) is 10%.

It is possible to use recycled rubber in combination with plasticizing admixture in order to significantly recover mechanical strength by up to 10%. This also decreases the negative effects of rubber waste on the environment.

Compressive strength is affected by the replacement of natural aggregate with disused tire rubber aggregate, with a reduction of approximately 12% for a 15% replacement ratio.

Waste tire rubber is an excellent aggregate alternative in concrete preparation and can be used in structures with low seismic intensity.

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