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Application of Recycled Asphalt Pavement Aggregate in Rigid Pavement

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Abstract: In Mexico, heavy traffic with excessive loads is the main cause of pavement deterioration, which has influenced the consumption and exploitation of natural resources, thereby affecting road rehabilitation. The use of Reclaimed Asphalt Pavement (RAP) has been presented as a technique to reduce the aforementioned issues, which consists of milling the material of a flexible pavement during its rehabilitation. The objective of this work is to reuse RAP by using the Los Angeles Wearing Machine to recover fine aggregate, and use it in a rigid pavement. By means of compressive strength and diametral tension tests, different mixes were evaluated: RAP in washed recovered condition, LAV, and RAP in unwashed recovered condition, SL. A control mix, MC, and the RAP in original condition, CO, were also evaluated. The aggregates of the different mixes were sieved through the No. 8 sieve to later make concrete cylinders of 10 × 20 cm. By means of compressive strength and indirect tension tests, the performance of the materials as a whole was evaluated, not only giving the use of RAP aggregates, but also showing the work in a similar way to the virgin sand aggregates. The results indicate an increase of 3.97% in compression and 7.3% in indirect tension with the LAV material.

Key words: reclaimed asphalt pavement; resistance; compression; indirect tensile; hydraulic concrete

1. Introduction

According to data from the National Institute of Statistics and Geography in Mexico, in December 2019, the registration rate for freight trucks was 25.5%, for cars was 70.2%, and for passenger trucks was 4.2%. In December 2015, the asphalt pavement network of the national highway network was 98.5%, while the registration rate for hydraulic concrete was 1.5%. Although asphalt pavement is the main choice for road networks on land, Martinez et al. (2013) mentioned that Portland cement-based hydraulic concrete is the most commonly used building material in the world.

According to Gutierrez et al. (2017), the road surface consists of a set of relatively horizontal overlapping layers composed of different materials. There are generally two main types: rigid pavement and flexible pavement. According to Baamonde et al. (2017), a rigid pavement is defined as the composition of a hydraulic concrete slab that distributes loads over a larger area of the roadbed through the entire surface of the slab. While Huang et al. (2004) defined flexible pavement as an asphalt binder consisting of stone aggregates and asphalt binder, which is generally supported on two non-rigid layers, transmitting loads in a more concentrated manner and distributing the total load in fewer support areas. Gutiérrez et al. (2017) analyzed vehicles traveling on our roads in 360 stations, which are distributed throughout the national road network. Figure 1 shows the percentage of overloaded vehicles in different periods and the maximum overload recorded in relation to what is allowed by the standard on the maximum weight and dimensions with which vehicles may circulate (NOM-012-SCT).

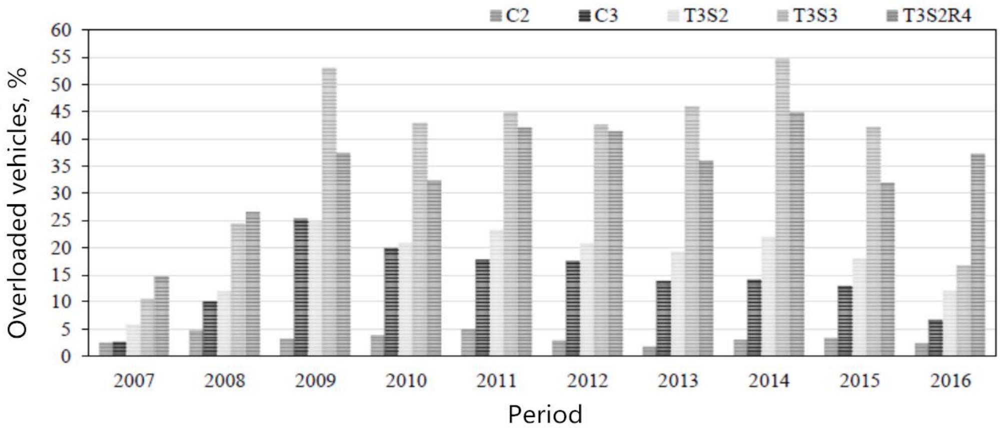

Figure 1. Heavy vehicle overload record. Source: Written by Gutierrez et al. (2017).

From the expressed results, it can be concluded that, among other things, the most commonly used freight vehicles are T3S3 single body trucks and T3S2R4 double articulated trucksT3S3, especially the latter increasing over time. According to the data provided by this study, our road surface may experience significant excessive stress, which is one of the main reasons for its deterioration.

Baamonde et al. (2011) state that one of the main causes of deterioration of road pavements is repetitive traffic overloads. Currently, alternative technologies have been sought and proposed, which take into account materials to improve specific characteristics, such as flexural strength (modulus of rupture) in pavements, showing the parameter with which concrete is designed and evaluated, since it has a low flexural strength with respect to compression in the order of between 10% to 20%, according to Rivera (2000).

Recycling asphalt pavement is not new, and reducing the resources of flexible pavement on a global scale is achieved through RAP. Fabela et al. (1999) defined RAP as a new milling material for flexible pavement during repair and construction. For example, in Hong Kong, asphalt is imported from abroad, and nearly 200,000 tons of asphalt mixture are ground on roads every year, which can be used for road construction or repair (Isaks et al., 2015). Due to the high resource content generated by road reconstruction or restoration, it is necessary to reuse RAP, and one possible method to expand the use of RAP is to mix aggregates with Portland cement (Okafor, 2010).

The studies conducted by Delwar et al. (1997), Al-Oraimi et al. (2009), Okafor et al. (2010), and Hossiney and TIA (2010) unanimously concluded that adding asphalt aggregates to RAP reduces the strength of concrete. However, Hossiney and TIA (2010) analyzed different proportions of RAP aggregates in hydraulic concrete and evaluated their compressive and flexural strength. The results showed that as the water/cement content increased, the compressive strength decreased. It was found that the compressive strength is 25 MPa, and it has been proven that the use of RAP in concrete is feasible for medium to low strength. This is in agreement with Hossiney and Tia (2010) who investigated the contribution of tensile, compressive, flexural and elastic modulus strengths with different RAP contents at 0%, 20%, 40%, 70% and 100%. The results showed that as the RAP percentage increased, their resistance decreased. Similarly, they emphasized that the maximum stress in Portland cement concrete decreases with the increase of RAP content, indicating that the use of RAP can be used as an alternative to improve the performance of concrete pavement.

In contrast to those authors who unanimously believe that asphalt binders can reduce the strength of concrete, Okafor et al. (2010) analyzed two ratios of 1:2:4 and 1:3:6 for cement, sand, and RAP aggregates with water/cement ratios of 0.50, 0.60, and 0.70. These mixtures were examined during compression and bending. The results showed that with the increase of water/cement content, the compressive strength decreased by 4.2 MPa and 1.5 MPa at a water/cement ratio of 0.50 and 0.70, respectively. The conclusion drawn is that the decrease in strength compared to hydraulic concrete is due to the weak bonding between hydraulic concrete and the asphalt binder adhered to the aggregate.

Due to the reduced strength of the aforementioned concrete by asphalt binder, Sing et al. (2017) proposed an evaluation of RAP aggregates in hydraulic concrete and implemented a technique to improve the quality of RAP aggregates through wear. The mixture consists of dirty RAP (DRAP), washed RAP (WRAP), and natural aggregate concrete (NAC). After treatment, RAP (AB&AT) showed better performance, with compressive strength increased by 9.74% and 12.71%, tensile strength increased by 2.66% and 12.21%, and bending strength increased by 6.05% and 8.55%, respectively, compared to concrete containing DRAP and WRAP. The results of the 28-day evaluation are shown in Table 1.

Table 1. Resistance results. Source: Written by Sing et al. (2017).

Sample	Compression	Bending	Tension
	MPa	MPa	MPa
NAC	42.50	6.40	5.60
DRAP	33.00	4.60	3.45
WRAP	34.00	4.70	3.75
AB&AT	40.00	5.10	3.90

Hoyos et al. (2011), who used glass fibre to improve the utilization of RAP, presented the properties of concrete treated with glass fibre and RAP, where the compression results, as shown in Figure 2, increase with the percentage of dosage. Similarly, RAP and fiber RAP can be compared, and the results are similar. On the other hand, when evaluating the elastic modulus, people realize that fiber inclusions have a positive impact on cement-RAP by increasing its elastic modulus. The conclusion drawn is that it is generally feasible to use them in the base and sub-base layers.

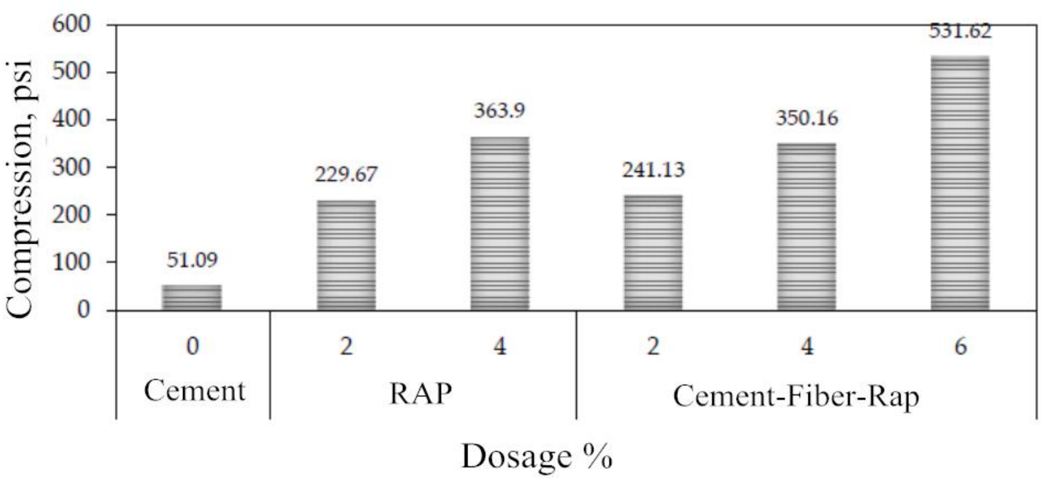

Figure 2. Performance of fibers in hydraulic concrete. Source: Written by Hoyos et al. (2011).

Monty et al. (2016) reported that adding fibers to hydraulic concrete containing RAP will restore or even improve the compressive and tensile strength of the concrete. Similarly, Hoyos et al. (2011) claimed that the use of cement fibers added to RAP has potential ecological and structural robustness for base and sub-base applications on road surfaces. Sing et al. (2017) allowed for the use of wear and tear methods to separate RAP and asphalt binders to improve compressive, tensile, and flexural strength, as the adhesion of asphalt binders to aggregates is a result of a decrease in concrete strength. For the above reasons, consistent with the issues reported by Monti et al. (2016) and the research route exposed by Hoyos et al. (2011), except for the limited use of RAP in hydraulic concrete, this study considers separating asphalt binders from RAP aggregates through wear and tear methods (Sing et al., 2017) to work together as fine aggregates and include them in hydraulic concrete to improve the tensile and compressive strength of rigid pavement.

2. Development

Methods and tests performed

2.1 Materials used

By consulting ASTM C131 (2014) and the technique of Sing et al. (2017), some process criteria were modified for the recovery of RAP fine aggregate after having been evaluated under different conditions in the Los Angeles Wearing Machine, MDA, times, aggregate content and abrasive load were modified (these modifications are presented below). Once the criteria and separation of the RAP fine aggregate were determined, the characteristics of the materials used for the preparation of the mixtures to be evaluated in compressive strength and radial tension in 10 × 20 cm hydraulic concrete cylinders were tested.

The materials used in this study were obtained from the Pavimentar S.A. plant in Medellin, Colombia, where the RAP stone aggregate was obtained. Table 2 shows the materials obtained.

Table 2. Material used for the elaboration of mixtures. Source: Own elaboration.

Condition	Identification	Particularity
Stone Aggregates	MC	Aggregates, obtained from the Pavimentar S. A. Plant
RAP Original	CO	RAP, obtained from the hollow of the Pavimentar S. A. Plant
Unwashed Recovered RAP	SL	Recovered RAP, obtained from the incorporation of CO in the Unwashed MDA
Washed Recovered RAP	LAV	Recovered RAP, obtained from the incorporation of CO in the washed MDA

3. Material Selection

3.1 Quartering and screening

The material selection for MC, CO, SL and LAV aggregates was carried out by quartering the materials according to ASTM C702 (2018). This standard allows reducing large aggregate samples to the appropriate size for the test to be evaluated, with the following steps: divide the sample into four parts (Figure 3a), with a brush to separate the quarters (Figure 3b) and take two quarters diagonally (Figure 3c). For sieving, the materials were sieved according to ASTM C136 (2014). The MC and CO aggregates were sieved through the No. 8 sieve, likewise, CO aggregates were taken to be processed in the MDA, which was sieved in two parts: coarse RAP (> 4.75 mm) and fine RAP (< 4.75 mm).

a) b) c)

Figure 3. Quartering of stone aggregates. Source: Own elaboration.

3.2 Recovery of fine aggregate RAP

The RAP fine aggregate recovery process was done by implementing the MDA to obtain LAV and SL sand (Figure 4). According to standard modifications applied in the process described in ASTM C131 (2014), in order to obtain the separation of the binder from the stone aggregate, the modifications were based on different time trials, thus obtaining the highest possible fine aggregate recovered rate. Table 3 shows a breakdown of the process to be followed as indicated in the standard and the standard that were modified.

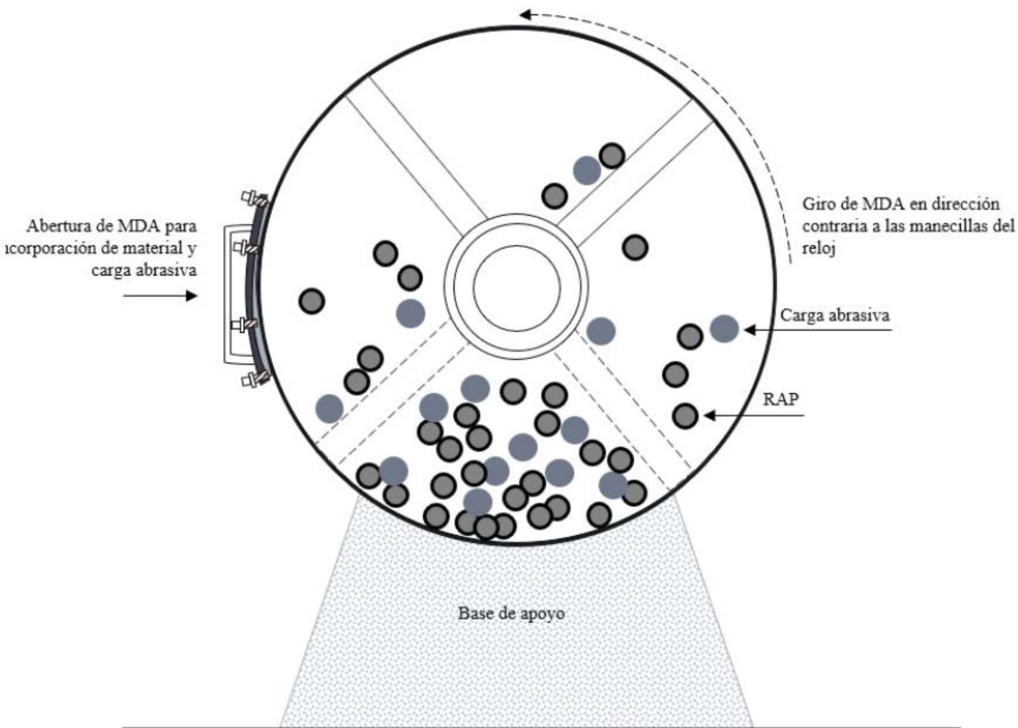

Figure 4. View of Los Angeles Wearing Machine with incorporation of RAP and abrasive load. Source: Own elaboration.

Table 3. Obtaining the RAP fine aggregate in LAV and SL conditions.

Process		Standard	Modification
1. Preparation of MDA		Verify that the machine is free of any other material.	-
2. Incorporation of RAP CO material into MDA		Incorporate 5 kg based on the nominal size of the aggregate.	Introduce 10 to 12 kg of aggregate regardless of its nominal size.
3. Incorporation of abrasive load into the MDA		Choose how much abrasive to add based on the nominal size of the aggregate, with a diameter of 46 - 48 mm and a mass of 390 - 445 g.	Incorporate 14 spheres with the same diameter and mass specifications as indicated in the standard.
4. Material wear		Rotate the MDA at a speed of 30 to 33 rpm for 15 min.	Rotate the MDA for 20 min at the same speed as indicated in the standard.
5. Material recovery		Remove abrasive load and material from MDA.	-
6. Washing		Wash the material through sieve No. 12.	Washing of LAV material through 3/4" and No. 200 sieve to remove dust.
7. Screening		Screen the material through the No. 12 sieve and discard everything that passes through the sieve.	Sieve LAV material and Sieve SL material through the No. 8 sieve, discarding what passes the No. 200 sieve.
8. Drying		Dry the material in the oven at a temperature of 100°C for 24 ± 4 hours.	-

3.3 Characteristics of materials

The characterization of the stone aggregates to manufacture hydraulic concrete obtained from the production center of the company Pavimentar, in Medellin, Colombia, was carried out in accordance with SCT regulations:

- M.MMP.2.02.020/18 Granulometry of the stone aggregates.
- M.MMP.2.02.023/18 Volumetric mass of stone aggregates.

3.4 Specimen processing

ACI 211. 1-91 (2009) is a standard practice for selecting the proportions of ordinary, heavy, and mass concrete. In 2009, a mixture with compressive strength f'c = 250 kg/cm^2 was designed with a minimum diagonal stress strength of 12.5 kg/cm^2, in order to evaluate its compressive and tensile strength in the absence of RAP aggregate, and subsequently compare the results with the addition of RAP fine aggregate. For both cases, the same mixture design was used. For the three mixtures to be compared, three RAP materials were used to replace the original sand under different CO, SL, and LAV conditions.

From the mix design, the proportion of cement, sand, gravel and water was obtained for the calculated volume of concrete for each sample. According to the experimental design, 7 samples of hydraulic concrete cylinders were made according to the Mexican standard NMX-C-159-ONNCE-2016 for compressive strength and diagonal tension tests at 7, 14 and 28 days respectively. The first sample was made with virgin stone aggregates, while the other 6 samples consisted of virgin coarse aggregate and RAP fine aggregate in their different conditions, CO, SL and LAV. The mix consisted of 5.1 kg of Portland cement with 3.1 liters of water to maintain a water/cement ratio of 0.62. Since the samples were processed on different days, aggregate moisture correction for the amount of water was carried out for both sand and gravel (Equation 1).

a = (w - abs) kg/100a= w-abs kg/100 (1)

Where:

a = amount of water to be added or removed to the mix design, kg

w = moisture content of the aggregate, % w

abs = aggregate absorption, %

kg = calculated quantity of aggregate in the mix design, kg

Finally:

$a_{final} = a_{initial} - (a_{aggravate} + a_{sand})$

a_{final}: amount of water to be added or removed to the original design, kg

For each sample, the slump test was performed in according with the Method of Sampling and Testing of Materials (M.MMP.2.02.056-2006), obtaining favorable results in all tests based on the mix design. Each specimen was cured according to the standard for preparation and curing of concrete specimens (NMX-C-159-ONNCCE-2016), (Figure 5).

Figure 5. Specimen fabrication. Source: Own elaboration.

3.5 Compressive strength test

According to the "Standard for Determining Compressive Strength" (NMX-C-083-ONNCE-2014), tests were conducted within 7, 14, and 28 days to determine the strength of concrete cylinders. Equation 2 provides a formula for determining compressive strength based on standards.

f'c = P max/S (2)

Where:

f'c = compressive strength, kg/cm^2

P = maximum applied load, kg

S = cross sectional area of specimen, cm^2

3.6 Tensile strength tests

In accordance with the standard for the tensile strength of concrete cylinders (M-MMP-2-02-059-2004), tests were performed at 7, 14 and 28 days to determine the diagonal tensile strength of concrete cylinders. This standard allows determining the strength of hydraulic concrete by diametral compression in molded cylindrical specimens. The strength calculation was determined according to Equation 3 presented in the standard (Figure 6).

$$T = 2\,P/\pi\, l\, d \qquad (3)$$

Where:

T = Diametral compressive tensile strength, kg/cm^2

P = Maximum applied load, kg

l = Average specimen length, cm

d = Average specimen diameter, cm

Figure 6. Tensile and compressive strength tests. Source: Own elaboration.

4. Discussion and Result Analysis

Material Properties

4.1 Aggregate size

Based on the particle size distribution results of MC material in coarse and fine aggregates (Figure 7 and Figure 8), it can be observed that it has sufficient distribution for mixture control design and can be used for experimental design.

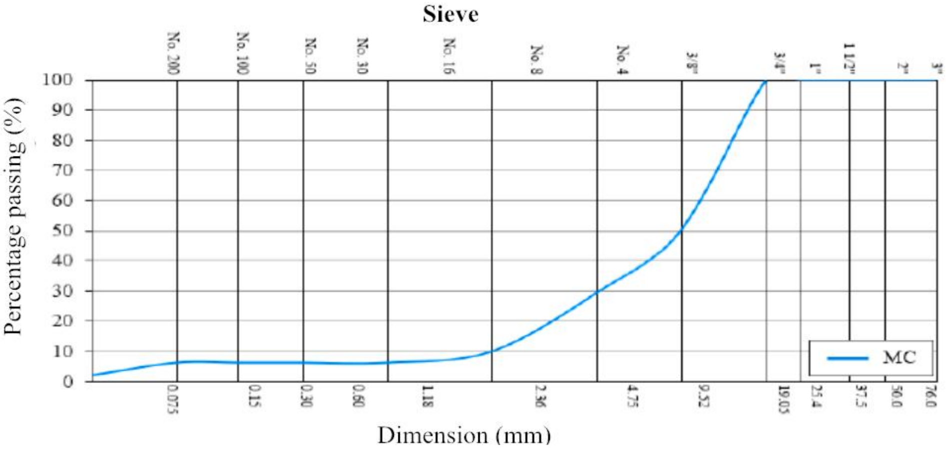

Figure 7. Particle size distribution of MC coarse aggregate. Source: Own elaboration.

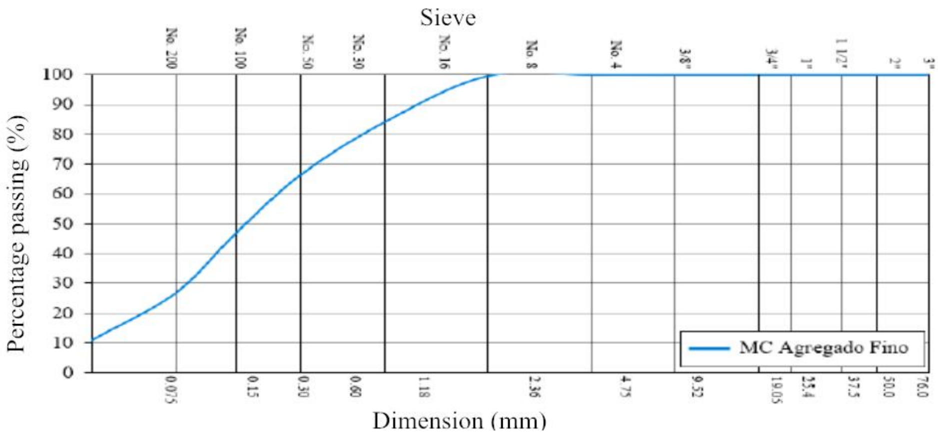

Figure 8. Particle size distribution of MC fine aggregate. Source: Own elaboration.

According to the accumulated percentages (Figure 9), it was observed that the CO aggregate showed a lack of sizes in the distribution, caused by the milling that is available for asphalt pavements. On the one hand, the SL and LAV aggregates present a better distribution and, on the other hand, the aggregates meet the criteria for sizes of 16 mm or smaller, according to IS: 383 (1970).

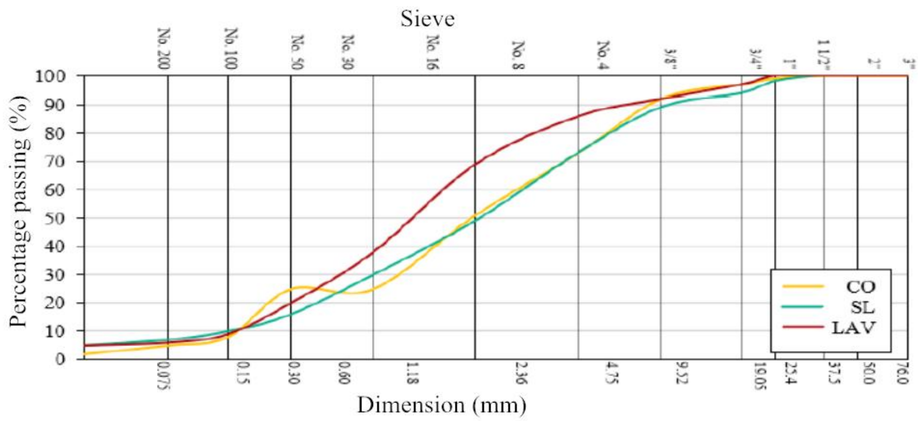

Figure 9. Granulometric distribution of fine aggregates RAP. Source: Own elaboration.

4.2 Specimen processing

For the manufacturing of the mixture, this work is based on the design of MC, therefore the quantity was obtained according to the design of ACI 211.1-91 (2009). Table 4 shows the design data for a strength of 250 kg/cm^2, with variations in the fine aggregate of CO, SL, and LAV mixtures.

Table 4. Mixed design. Source: Own elaboration.

Data	Considerations
Thickening TMN	8 cm 20
No air included	
f'c Fineness modulus Gravel density Density of sand Density of cement Gravel volumetric mass Volumetric mass of sand	250 kg/cm^3 2.5 2.813 2.75 3.15 1777 kg/cm^3 1731 kg/cm^3

Material	Quantities per 1 m^3
Cement Water Sand Gravel	322.58 kg 200.00 kg 789.20 kg 1155.05 kg

In the final 28-day RAP fine aggregate compressive strength test, it was observed that the LAV sample showed an improvement in strength compared to the control sample MC. Table 5 shows a summary of the compressive strength of the mixture, indicating that the LAV material exhibits good behavior in terms of strength.

Table 5. Summary of compressive strength of mixtures. Source: Own elaboration.

Age days	MC kg/cm^2	CO kg/cm^2	SL kg/cm^2	LAV kg/cm^2
7	198.02	175.25	192.53	205.15
14	238.26	201.46	231.31	236.15
28	259.48	202.032	244.64	259.79

Table 6 shows the percentage behavior of decreased or increased resistance in each sample at 28 days compared to the control sample MC, with LAV materials observed to exhibit behavior similar to MC.

Table 6. Percentage increase or decrease in resistance. Source: Own elaboration.

MC kg/cm^2	CO kg/cm^2	SL kg/cm^2	LAV kg/cm^2
--	- 22.13%	- 5.72%	+ 3.97%

Figure 10 summarizes the compressive strength of all samples, including the control sample MC and samples evaluated using RAP under different conditions. It was observed that the decrease in CO and SL materials was smaller than the evolution of the MC sample, and it was also found that the LAV sample was well-known for its increase in its evolution at the first experimental age (7 days). Considering this, its compressive strength has increased by 3.97%, which is sufficient to be considered a concrete with good strength.

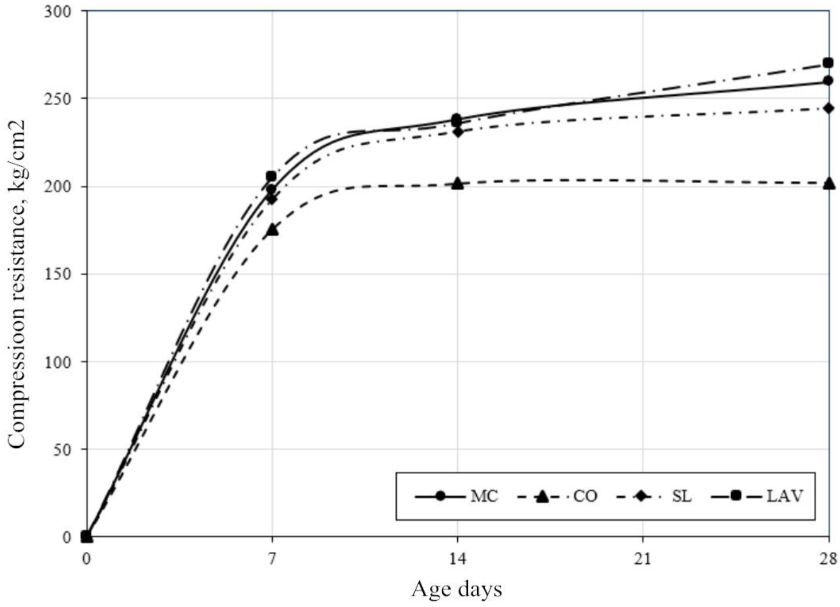

Figure 10. Evolution of the compressive strength of hydraulic concrete. Source: Own elaboration

After testing the tensile strength, at the final age of 28 days, an increase in the LAV sample was observed, improving its strength with respect to the control sample, MC. Figure 11 shows the tensile strength results evaluated at 7, 14 and 28 days for the different mixtures. It was observed that the strengths were reduced by 9.2 %, 6.0 % for CO and SL, respectively, according to the MC mix. From the results, it can be determined that benefiting RAP with Washed Sand Aggregate Recovery (LAV) could be a way to increase the performance of concrete with RAP aggregates.

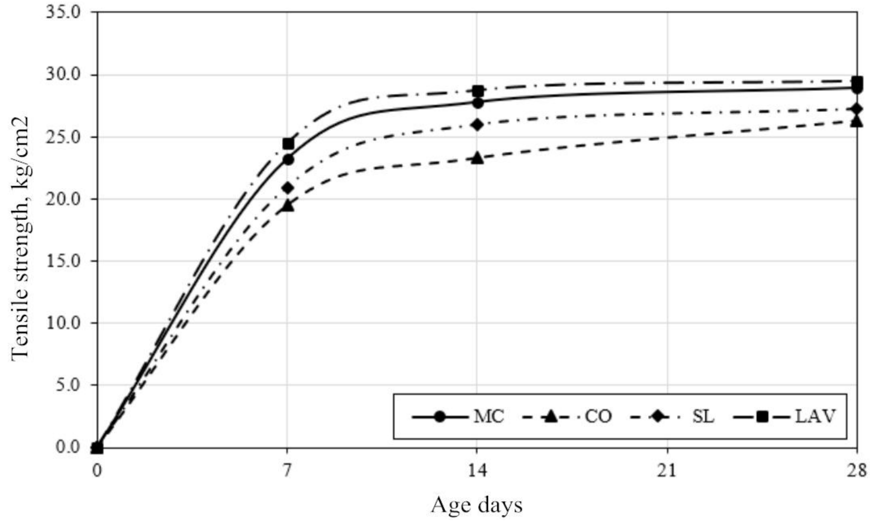

Figure 11. Tensile strength evolution of hydraulic concrete. Source: Own elaboration.

5. Conclusions

When testing the performance of the four different concrete mixes, a good distribution of the aggregates was observed, due to the longitudinal failures in the specimens.

On the one hand, the results of the control sample in terms of compressive strength showed that compared with the control sample, f'c was 253 kg/cm^2, while the compressive strength of the RAP mixture under original conditions and the RAP mixture under unwashed recycling conditions decreased by 22.14% and 5.72%, respectively. On the other hand, under recycled washing conditions, RAP increased by 3.98%.

Regarding the results obtained for the tensile strength of the washed reclaimed mix (LAV), it is worth noting that, when added to the concrete, it improves the strength at 28 days of age, compared to the other mixes that gave 25.4 kg/cm^2 and 27.8 kg/cm^2, RAP in original condition and RAP in unwashed reclaimed condition, respectively.

It was observed that the RAP sample in washed recovered condition improves the resistance in its two evaluations: resistance to tension and compression, according to the RAP samples in unwashed recovered condition, and RAP in washed recovered condition. Likewise, it can be noted that RAP material in washed condition could be an aggregate application as a replacement for hydraulic concrete.

By reusing, reducing, and recycling construction materials, RAP has created new products with different treatments and characteristics that are feasible for road use and construction, avoiding the use of natural resources. In the recycling process, the resources used to manufacture materials are usually less than those extracted from natural resources, which will reduce the filling of road debris caused by new construction to repair roads. However, due to the high demand, the appropriate locations of these materials are usually filled quickly or simply discarded in unsuitable locations.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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