

# Use of Metal-mechanics Waste as an Addition in the Production of an Ecological Concrete

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**Abstract.** Currently, buildings are on the rise, which causes significant environmental pollution due to the lack of controlled landfills to deposit solid construction waste; an alternative solution is to recycle this waste produced by the construction and or demolition of concrete elements structural, and use them as coarse aggregate in the manufacture of concrete. On the other hand, the metalworking industry uses iron and steel as primary inputs, which are the main components of industrial waste, with its generation sources being industrial plants and manufacturing workshops for small and medium enterprises; a solution to this problem is to use your waste as a fine aggregate in the production of concrete due to its good properties. These solution alternatives preserve natural resources and promote their sustainability. The research work developed focuses on the use of structural concrete and steel waste to reduce its amount of waste and it is proposed to add it to the concrete. The results show that the addition of steel chips in concrete compared to standard concrete results in reduced slump, increased unit weight and contributes to the improvement of compressive strength, cylinder splitting tensile strength and flexural strength.

## 1. Introduction

The construction sector requires 40% of the total energy and 50% of the total natural resources for the development of its different activities [1]. Likewise, these activities in large cities have grown dramatically due to the increase in population, producing a greater demand for land and the need to have urban areas with large areas. This situation has generated an increase in the amount of solid construction waste, which leads to the existence of environmental problems that must be addressed by the municipalities and regional governments, through the control and distribution of land destined as landfills [2]. Due to the lack of these for construction, construction companies choose to dispose of their waste in nearby places to avoid higher expenses, which causes unpleasant impacts on the landscape, underground water and soil pollution, deforestation, erosion and a major food hazard to surrounding areas; As a solution, it is proposed to use recycled concrete aggregates from the demolition of structural elements in the manufacture of concrete to help preserve natural resources and promote their sustainability [3], as well as the development of sustainable construction. According to [2] that recycled

aggregates have a rougher texture than natural aggregates and this causes some changes in workability, even if recycled materials are pre-saturated, resulting in reduced workability due to the high rate of Form of recycled materials. The authors of [4] found that the content of hardened cement in the recycled aggregate is greater than in the natural aggregate, the water absorption of the recycled aggregate is greater, and its yield is lower. According to the studies of [5] a concrete with recycled aggregates has a minimum compressive strength of 76% compared to concrete with natural aggregates. The autor [6] indicates that the use of recycled aggregates produces a 25% reduction in compressive strength in a concrete with natural aggregates, while in the case of tensile strength the reduction value is 14%. The autor [7], replacing 20% of the natural coarse aggregate with recycled coarse aggregate, obtains that the flexural strength decreases by 13%.

It is known that steel is the main component of industrial solid waste and that steel chips are obtained from its waste, which are obtained mainly through the work of the lathe, molding accessories of varied geometries and the development of new elements. These are stored in bags for disposal or sale to companies dedicated to the smelting of

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this waste and can then be reused. A solution to this problem is to use them as a fine aggregate in the production of concrete because they have 0% absorption and a specific weight greater than the fine aggregate. In this sense, several authors propose steel chips, in our case called VA, as a replacement for the components of the concrete, after having studied the effect of the addition of VA on the properties of the concrete pattern. The autor [6] indicates that after 28 days of curing, there is an increase in tensile strength and compressive strength of 1.4 to 2.4 times and 1.1 to 1.3 times, respectively. The autor [8] comments that at the age of 28 days, compressive strength increases between 10-15% and tensile strength increases 10-18%. The autor [9] indicates that both compressive strength and flexural strength increase after 28 days by 18% and 9% respectively.

To have a broader view of the benefits of steel in concrete and having not found information on steel chips, we consider it important, for its similar behavior with steel chips, to describe the incidence of steel fibers in the properties of steel. concrete. Thus, we have that [10] explains that steel fibers have become very popular in the last two decades and are used in particular because they increase the self-healing capacity of cracks, covering these spaces where 1.5% is sufficient to perform this action. The autor [11] explains that the key to increasing the strength of a high-strength concrete is to increase its resistance to cracking; This increase is related to the number and size of the original cracks, and to the control of the beginning and extent of these cracks. On the other hand, [12] obtains that the cylinder splitting compressive strength at 28 days of concrete with steel fibers is twice as high as that of conventional concrete. This author evaluates the 3-point flexural strength with 100x100x500 mm samples tested at 28 days and obtains that the concrete with steel fibers is 43% higher than conventional concrete. Similarly, [13] studies different percentages of steel fiber addition: 0.5%, 1.0%, 1.5% and 2%, finding a maximum value of compressive strength at 28 days for 1.5% representing 15% more compared to conventional concrete; from there, the resistance decreases by 2% for 2.0% fiber. The autor [14] conducts the study for the addition of 1% steel fiber, finding that the compressive strength at 91 days increases by 18% compared to a concrete without fibers.

From the extensive literature review carried out, they have not found joint work on waste from recycled aggregates and VA as a replacement for the natural fine aggregate in the concrete production. What does exist are separate works of these wastes in the preparation of concrete. That is why, in the present investigation, the combination of the recycled coarse aggregate and the VA is used as a replacement for the natural fine aggregate in the preparation of concrete. For this, the physical, chemical and mechanical properties of the aggregates are studied: sieve analysis, moisture content, specific weight, absorption and unit weight; the properties of fresh concrete: slump and unit weight; and the properties of hardened concrete:

compressive strength, cylinder splitting tensile strength and flexural strength.

## 2. Materials and methods

### 2.1. Materials

The following materials were used for the development of the research: Cement Sol Portland Type I, its properties are validated in accordance with [15]; drinking water of the city of Lima; natural fine aggregate, modulus of fineness of 2.8; coarse recycled aggregate of structural elements with a maximum size of ¾”; Steel shavings with a maximum diameter of 0.3 cm, obtained from an automotive company. A sample of the steel chips used in the investigation can be seen in Figure 1.



Figure 1. Steel chips used in concrete.

### 2.2. Mix design

The elaborated mix designs were made based on the procedure developed by [16] for a resistance of 21 MPA with an a / c ratio of 0.50. A sample of standard concrete used as a reference was designed, 3 designs were made with additions of VA at 8%, 10% and 12% respectively, then a comparison of its physical properties with respect to the standard concrete was made. Table 1 shows a summary of the test pieces used for the different tests performed and Table 2 details the materials used in the dosing of concrete mixtures.

Table 1. Test tubes used in the tests.

Test type	Code	Age	Specimen	
			Quantity	Dimension (cm)
Compressive strength	VA-0	7, 14, 21 y 28	12	15 x 30
	VA-8	7, 14, 21 y 28	12	15 x 30
	VA-10	7, 14, 21 y 28	12	15 x 30
	VA-12	7, 14, 21 y 28	12	15 x 30
Cylinder splitting tensile strength	VA-0	7, 14, 21 y 28	4	10 x 20
	VA-8	7, 14, 21 y 28	4	10 x 20

	VA-10	7, 14, 21 y 28	4	10 x 20
	VA-12	7, 14, 21 y 28	4	10 x 20
Flexural strength	VA-0	7, 14, 21 y 28	4	15 x 15 x 50
	VA-8	7, 14, 21 y 28	4	15 x 15 x 50
	VA-10	7, 14, 21 y 28	4	15 x 15 x 50
	VA-12	7, 14, 21 y 28	4	15 x 15 x 50

Unit Weight	0, 8, 10, 12	NTP 339.046 [38] ASTM C-138 [39]
<b>Hardened Concrete Test</b>		
Compressive strength	0, 8, 10, 12	NTP 330.034 [40] ATM C-39 [41]
Cylinder splitting tensile strength	0, 8, 10, 12	NTP 339.084 [42] ASTM C-496 [43]
Flexural strength	0, 8, 10, 12	NTP 339.079 [44] ASTM C-78 [45]

**Table 2.** Materials by m<sup>3</sup> concrete mix

Materials	Sample Pattern	8% Chips	10% Chips	12% Chips
	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)
Air	0	0	0	0
Water	226.72	226.72	226.72	226.72
Cement	386.15	386.15	386.15	386.15
Recycled coarse ag.	972.78	972.78	972.78	972.78
Natural fine ag.	677.41	614.45	601.11	587.78
Chip	-	102.53	128.17	153.82
Total	2262.93	2302.48	2314.77	2327.06

### 2.3. Tests

The present work has been developed in the Laboratory of Concrete Technology of the UPC-Monterrico, the tests of characterization of aggregates are shown in Table 3 and the tests of the standard concrete and concrete with VA in fresh and hardened state are shown in the Table 4.

**Table 3.** Aggregate tests.

Test type	Methods
Sieve analysis of fine and coarse aggregate	NTP 400.012 [26] ASTM C-136 [27]
Total evaporable moisture content of aggregates by drying	NTP 339.185 [42] ASTM C-566 [29]
Specific gravity and absorption of fine aggregate	NTP 400.022 [30] ASTM C-128 [31]
Specific gravity and absorption of coarse aggregate	NTP 400.021 [32] ASTM C-127 [33]
Unit Weight	NTP 400.017 [34] ASTM C-29 [35]

**Table 4.** Concrete tests.

Concrete Tests	Steel chip (%)	Methods
<b>Fresh Concrete Test</b>		
Slump	0, 8, 10, 12	NTP 339.035 [36] ASTM C-143 [37]

## 3. Results

### 3.1. Aggregate tests

Table 5 shows the results for the tests of the aggregates used. The recycled coarse aggregate has its unit weights and specific gravity lower than the conventional aggregate, and the moisture and absorption content have values greater than a conventional aggregate. In the case of the natural fine aggregate, the values are within those established in [18]. In the case of steel chips, their specific weight is much higher than the conventional aggregate.

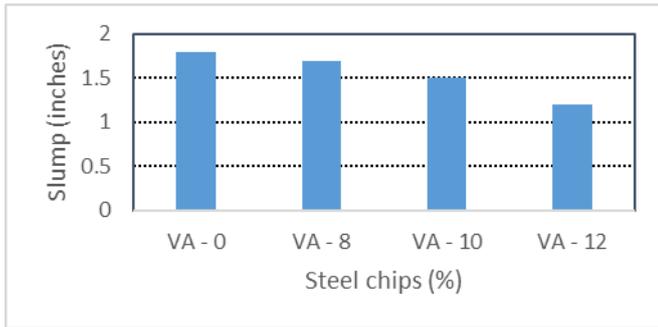
### 3.2. Test in fresh concrete

#### 3.2.1 Slump

Figure 2 shows the influence of the percentage of steel chips on the slump, it shows that the slump decreases as the addition of steel chips is increased, obtaining 1.7 inches of slump for 8% VA for an addition of 12% the value of 1.2 inches being the decrease of 29.41%.

**Table 5.** Aggregate tests.

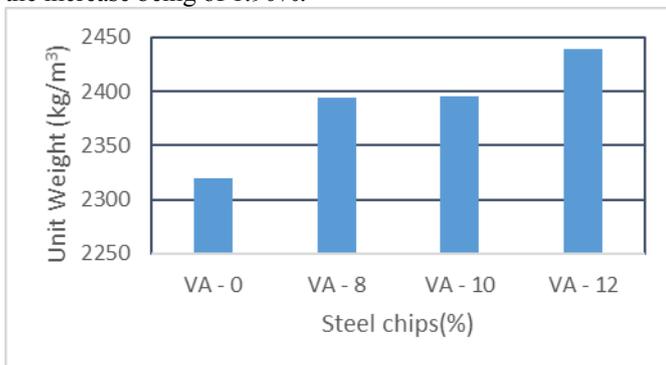
Properties	Recycled coarse aggregate	Natural fine aggregate	Steel chips
TMN (inches)	1	-	-
Fineness module	-	2.8	-
Moisture content (%)	2.23	1.58	-
Specific weight (kg/ m <sup>3</sup> )	2329	2622	5040
Absorption (%)	5.736	1.638	-
Compacted unit weight (kg/m <sup>3</sup> )	1420	1800	-



**Figure 2.** Influence of the percentage of VA on Slump.

### 3.2.1. Unit weight

Figure 3 shows the incidence of the percentage of steel chips on the unit weight of the concrete. The results indicate that the unit weight increases when the percentage of VA is increased, obtaining a value of 2394.08 kg/m<sup>3</sup> for 8% of VA and for the addition of 12% of VA a value of 2439.60 kg/m<sup>3</sup>, the increase being of 1.90%.

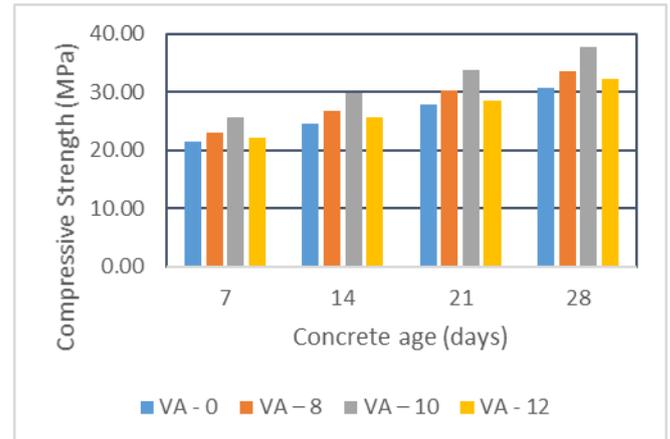


**Figure 3.** Influence of the percentage of VA on the unit weight.

## 3.3. Tests in hardened concrete

### 3.3.1. Compressive strength

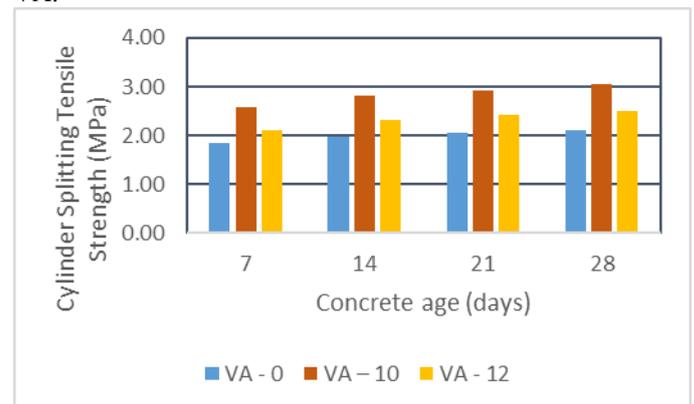
The influence of the test age on the compressive strength for different percentages of VA is shown in Figure 4. In view of the results, it can be indicated that the compressive strength increases as the percentage of VA increases from 0% to 10% and from there decreases to the value of 12%. The maximum resistance value reached at 28 days is 37.74 MPA and represents a 22.37% increase with respect to the standard concrete and the minimum value of 32.21 MPA representing a percentage of 4.45% increase with respect to the standard concrete.



**Figure 4.** Influence of the test age on the compressive strength.

### 3.3.2. Cylinder splitting tensile strength

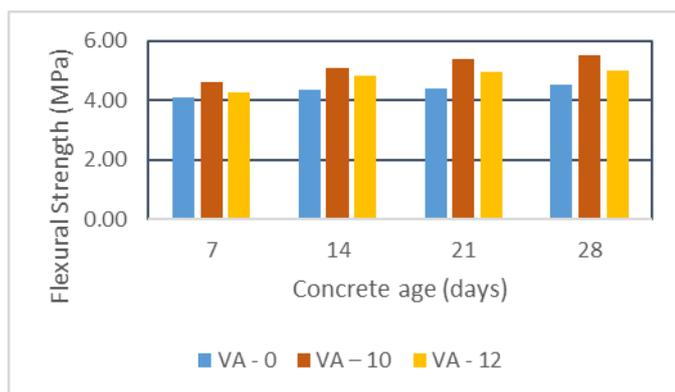
The influence of the test age on cylinder splitting tensile strength for different percentages of VA is shown in Figure 5. According to the results, it can be indicated that the tensile strength increases with the test age, obtaining a maximum resistance value at 28 days of 3.04 MPA for 10% VA, representing 43.39%; from this value there is a decrease of 18.09% corresponding to the value of 2.49 MPA for 12% of VA.



**Figure 5.** Influence of the test age on cylinder splitting tensile strength.

### 3.3.3. Flexural strength

The influence of the test age on the flexural strength with load in the center of the section for different percentages of VA is shown in Figure 6 from the results, it can be indicated that the flexural strength increases with the test age, reaching a maximum resistance value at 28 days of 5.51 MPA for a 10% VA representing a value of 21.63%; from this value there is a decrease of 8.89% corresponding to the value of 5.02 MPA for 12% of VA.



**Figure 6.** Influence of the test age on the flexural strength with load in the center of the concrete section.

## 4. Analysis

### 4.1. Aggregate tests

In work [19] conducts studies with the recycled coarse aggregate used in the preparation of a concrete and obtains values like section III.A. In the case of the specific weight it finds the value of 2280 kg / m<sup>3</sup>, for the apparent density it obtains 1310 kg / m<sup>3</sup> and 5.8% for the Absorption.

In [20], states that when old concrete is crushed, a certain amount of mortar from the original concrete remains attached to the stone particles in the recycled aggregates. This bonded mortar makes recycled aggregates present different properties than natural ones that are reflected in an increase in water absorption, lower density, lower resistance, lower hardness and fragmentation resistance.

### 4.2. Fresh concrete tests

#### 4.2.1. Slump

In work [21] conducted tests with a concrete with natural aggregates and steel chip additions. Their results show a trend like that indicated in section 3.2.1, so we have that the percentage of slump decrease is 8% when going from 10% to 20% of VA.

In work [7] explains that the reduction in slump is because the absorption of crushed concrete is greater than that of coarse aggregates. Therefore, the higher the percentage of aggregate of recycled concrete, the higher the percentage of absorption, the lower the fall. In [21] explains that this trend could be due to the heterogeneity and angular shapes of the steel chip particles, which lead to a lower fluidity of the mixtures.

#### 4.2.2. Unit weight

In work [21] studies the unit weight of concrete mixtures with 10%, 15% and 20% steel chips and finds an increase of

0.81%, 1.24% and 2.04%, with respect to the unit weight of the standard sample.

In [9], indicates that this trend can be attributed to the fact that the specific gravity of steel chips is approximately 42.8% greater than the specific gravity of the fine aggregate and that the greater the addition of chips the greater the weight is concrete unit.

### 4.3. Hardened concrete tests

#### 4.3.1. Compressive strength

In work [21] conducts a study with 10%, 15% and 20% addition of VA in the concrete and obtains a behavior like that indicated in section 3.3.1. their results indicate that after 28 days of curing their concrete samples with 20% steel chips reach a compression resistance of 51.64 MPA which represents a 17.4% increase in reference to their standard sample. However, after 14 days of curing, a slight delay in the hydration of the cement was observed in comparison with the reference mixture, which resulted in a slight decrease in compressive strength of the mixtures with additions of steel chips.

In [22] explains that this trend may be due to the high density and strength of steel chips. On the other hand, [9] pointed out that at high VA contents, the reduction of concrete compactness causes a reduction in its compressive strength, however, it also observes a decrease in resistance. In this regard, [23] explains that this may be because the accumulation of iron residues in the cement particles forms a low penetration pseudomorph layer which causes a decrease in resistance.

#### 4.3.2. Cylinder splitting tensile strength

In work [24] conducted different concrete tests at the ages of 7, 14 and 28 days using natural aggregates and steel chips with additions of 15%, 30% and 60% and obtained a similar trend to section 3.3.2. The author indicates that the cylinder splitting tensile strength of concrete specimens with VA increases with the increase in the percentage of chips in all curing periods. After 28 days of curing it obtains a maximum strength of 3.11 MPA with an addition of 60% steel chips, which represents 43.98% with respect to the standard sample.

In [9] explains that at small percentages, the chips increase the strength of the reinforced concrete by introducing some ductility in the post-fault behavior, and the fibers continue to support traction through the macro cracks; for high contents, the reduction of concrete compactness causes a reduction in its cylinder splitting tensile strength.

#### 4.3.3. Flexural strength

In work [21] conducted concrete trials at ages 3, 7, 14 and 28 days using natural aggregates and additions of 10%, 15%

and 20% steel chips, obtaining a trend similar to section 3.3.3. The results indicate that after 28 days the concrete samples with 20% steel chips reach a resistance of 7.54 MPA which represents a 27.68% increase in reference to the standard sample. However, at 14 days a slight decrease in resistance is observed.

In [25] explains that this trend of increase occurs because metal chips are granulated in small sizes, which contributes to the VA being compatible in the concrete mix and improving their properties, however, it also observes a decrease in the resistance. In work [13] can attribute this to the accumulation of iron particles that prevent water penetration, with the consequent delay in cement hydration.

## 5. Conclusions

- The reuse of construction waste and VA help reduce the environmental impact that these wastes produce and contribute to sustainable construction.
- The coarse aggregate recycled because of its stone composition with mortar has a higher absorption percentage than a natural aggregate.
- The use of VA reduces the consistency of the concrete mixture, which is reflected in the lower slump values by increasing the percentage of VA.
- The use of VA in concrete with recycled coarse aggregate produces an increase in compressive strength, cylinder splitting tensile strength, and flexural strength.
- The addition of an optimal percentage of VA as a replacement for the fine aggregate in the mix design allows a greater resistance of the standard design.

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