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Mechanical Properties of an *Eco-friendly Concrete* with partial replacement of POC and Rubber

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Abstract. Concrete plants consume 10 billion tons of natural aggregates annually from quarries and gravel plants for produce concrete, this demand requires exploiting natural resources from mountains and rivers producing an ecological imbalance. One solution is to use Palm Oil Clinker (POC), which is eliminated in large quantities in the dumps and rivers without taking advantage of its puzolanic, binding and resistance properties as an aggregate in the concrete; another alternative is to apply rubber from abandoned and discarded tires as waste in landfills or burned, without taking advantage of its performance of improvement in concrete, increasing its resistance to impact and fatigue. Unable to find joint POC and rubber information, this research studies its influence replacing 2.5% rubber (grained and crushed) with 10%, 12.5% and 15% POC in the fine aggregate on traditional concrete; results indicate that with 12.5% of POC as the ideal percentage, the compressive strength, tensile strength and flexural strength rise between 2.16 - 9.54%, so the concrete obtained has a cost of less than 4.09% and has 3.65% less CO_2 emission.

1. Introduction

The construction industry is the largest consumer of natural resources on the planet; where the most commonly used building material is the concrete [1]. Deforestation of green hills to obtain limestones to satisfy the demand for coarse aggregates leads to an ecological imbalance [2]. Counteracting the fast depletion of natural aggregates requires partially replacing sand with recycled aggregates or by-products from industries. The oil palm industry produces several by product and waste, one of them is POC, which is obtained after the oil extraction process, after the pressed layer and fibers are burned in the incinerator [3]. POC is used as an aggregate in the production of CT [4]. [3] with an addition of 12.5% POC finds a greater compressive strength of 3.5%, compared to CT. Tensile strength was studied with different additions of 12.5%, 25%, 37.5% and 50% obtaining values greater than CT [5]. Rubber in concrete provides greater durability and elasticity when is replaced as a fine aggregate. [6] studies ground rubber in 10% replacement of the fine aggregate obtaining a compressive strength of 53.13 MPa at 60 days, which represents 4% more than CT. With this same percentage of replacement in fine aggregate according to [7], compressive strength at 28 days is 1% lower than CT. From a wide bibliographic review, we show that we have not found joint work on POC and rubber in the elaboration of the concrete, what exists are separate works of this waste. This is why the combination of POC and rubber (granulated and screening) is used as a replacement for the natural fine aggregate, using 10%, 12.5% and 15% POC and 3%, 5% and 7% rubber to evaluate compressive strength, tensile strength, flexural strength , the cost per m^3 of concrete and the amount of CO_2 removal.

2. Materials and Method

2.1 Materials

The POC used has a fineness module of 3.79, the rubbers used are screening (0.15-19 mm) and granules (0.75-4.75 mm). The cement used is Portland type I, the natural aggregates are coarse sand and ¾" stone. The water was drinkable and a plasticizer additive was used with a dosage of 250 ml per cement bag.

2.2 Méthod

The mixing design was made according to the [8] for a concrete of f'_c 210 kg/cm^2 (called Traditional Concrete, CT). Table 1 shows the doses performed and table 2 shows the tests and number of specimens used. The specimens were cured in the laboratory up to 28 days according to [9], then demolded and tested.

Table 1. Dosage of concrete mixtures for a f'_c 210 kg/cm^2

<table>
<tr><th colspan="2">Code</th><th>POC (kg/m³)</th><th>Rubber (kg/m³)</th><th>Fine agregate (kg/m³)</th><th>Water (lt/m³)</th><th>SP (lt./m³)</th><th>Cement Port. Tipo I (kg/m³)</th><th>Coarse aggregate (kg/m³)</th><th>Air (%)</th></tr>
<tr><td>CT</td><td>0%</td><td>-</td><td>-</td><td>799.78</td><td rowspan="10">213.56</td><td rowspan="10">2.16</td><td rowspan="10">366.73</td><td rowspan="10">972.75</td><td rowspan="10">2</td></tr>
<tr><td>P-1</td><td>10%</td><td>79.98</td><td>-</td><td>719.80</td></tr>
<tr><td>P-2</td><td>12.50%</td><td>99.97</td><td>-</td><td>619.83</td></tr>
<tr><td>P-3</td><td>15%</td><td>119.97</td><td>-</td><td>499.86</td></tr>
<tr><td>C-1</td><td>3%</td><td>-</td><td>2.40</td><td>797.38</td></tr>
<tr><td>C-2</td><td>5%</td><td>-</td><td>39.99</td><td>759.79</td></tr>
<tr><td>C-3</td><td>7%</td><td>-</td><td>55.98</td><td>743.80</td></tr>
<tr><td>PC-1</td><td>10% - 2.5%</td><td>79.98</td><td>19.99</td><td>699.81</td></tr>
<tr><td>PC.2</td><td>12.5% - 2.5%</td><td>99.97</td><td>19.99</td><td>679.81</td></tr>
<tr><td>PC-3</td><td>15%-- 2.5%</td><td>119.97</td><td>19.99</td><td>659.82</td></tr>
</table>

Table 2. Table of tests and specifications

<table>
<tr><th>Estate</th><th>Test type</th><th>Specimens number</th><th>Time/ Age</th><th>Method</th></tr>
<tr><td rowspan="3">Hardened Concrete</td><td>Compressive Strength</td><td>30</td><td>28 d</td><td>[10], [13]</td></tr>
<tr><td>Tensile Strength</td><td>30</td><td>28 d</td><td>[11], [14]</td></tr>
<tr><td>Flexural Strength</td><td>20</td><td>28 d</td><td>[12], [15]</td></tr>
</table>

3. Results y Analysis

3.1 Compressive Strength

Figure 3 shows the incidence of the percentage of PC on compressive strength. The results indicate that the resistance increases when the PC percentage is increased, with the maximum value being 356.75 Kg/cm^2 for PC2 blending with 12.5% and a variation on CT of 9.54%; from this value the resistance decreases. [3] replaces 12.5% POC and gets the resistance of 80 MPa at 28 days, being 3% more than CT. [16] replaces 10% of PC and obtains a resistance of 55 MPa at 28 days, which represents 17% more than CT. This increase is related to the expansión of the POC as a fine aggregate since it allows the the concrete to achieve máximum compaction by filling its pores, as well as becoming active as a pozzolanic material and improving compressive strength. On the other hand, [17] performs the replacement of 5% rubber as a fine aggregate obtaining a resistance of 27 Mpa at 28 days, which is 20% less than CT. [18] with a 5% replacement of granulated and screening rubber, obtains a resistance of 48.8 MPa at 28 days, which is equal to CT. Also, [19] replaces 10% rubber as a fine aggregate and achieves a resistance of 22.4 MPa at 28 days, which is 7.91% less than CT. This behavior is explained by the SEM (Scanning Electron Microscope) analysis that characterizes the morphology and porosity of the interface between the rubber particle and the cement matrix, observing the presence of a particle space and the matrix of cement and the rubber content leading to the reduction of resistance [19].

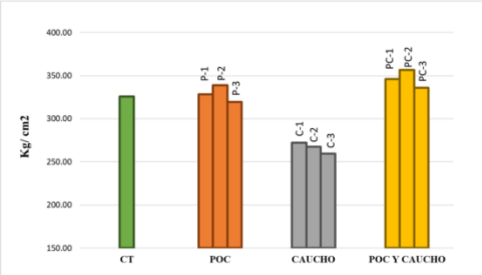

Figure 1. PC Compressive strength respect to CT

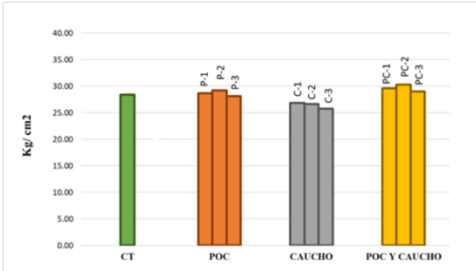

Figure 2. PC Tensile strength respect to CT

3.2 Tensile Strength

Figure 4 shows the influence of the PC percentage on tensile strength. The results show that the resistance is increased with the increase in the percentage of PC, reaching the maximum value of 30.28 Kg/cm2 for PC2 mixture with 12.5% and a variation with respect to CT of 6.6%; from this value the resistance decreases. [7] replaces 50% POC and obtains a resistance of 2.17 MPa at 28 days, reaching a resistance of 23% less than CT. This behavior attributes it to the presence of porous characteristics in the matrix produce microcracks in time that decrease resistance with increased POC, reason also reported by [4]. [5] replaces 10% granulated rubber and achieves a resistance of 3.6 MPa at 28 days, which represents 34.60% less than CT. So is [17] with a 5% rubber replacement achieves a resistance of 2.5 MPa at 28 days, which represents 17% less than CT. This decrease is related to the low density and softness of rubber particles, which form a non-uniform mixture that leads to lower resistance of the rubber parts of the concrete; this reduction in strength increases with the increase in the percentage of rubber. [17].

3.3 Flexural Strength

Figure 5 shows the influence of the PC percentage on flexural strength. It sees that the strength increases when the PC percentage is increased, being the maximum value of 71.09 Kg/cm2 for PC2 mixture with 12.5% and a variation from CT of 5.21%; from this value the resistance decreases. [3] replaces 12.5% POC for a resistance of 13.5 MPa at 28 days, reaching a resistance of 4% more than CT. This increase is related to the existence of a good interlock rate between the POC and the cement matrix. That is, the irregular shape of the POC with its scatable structure increases the interaction or joining of the interface, producing a higher load support capacity per bending [3]. [5] with a replacement of 10% granulated rubber obtains a resistance of 2.5 MPa at 28 days, which represents 20% less than CT; this behaviour is due to the performance of small rubber particles in the isolation of the aggregates with each other and also to the binder paste that leads to weak adhesion between the particles in the mixture [5]. There are other studies [11] that with a replacement of 5% rubber as a fine aggregate obtains a resistance of 5.97 MPa at 28 days, which is 25% more than CT.

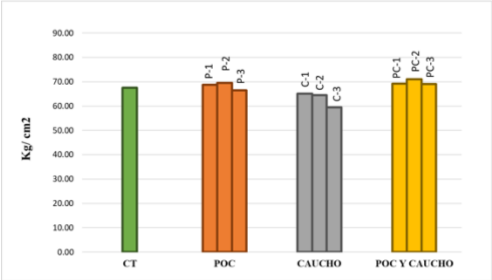

Figure 3. PC flexural strength respect to CT

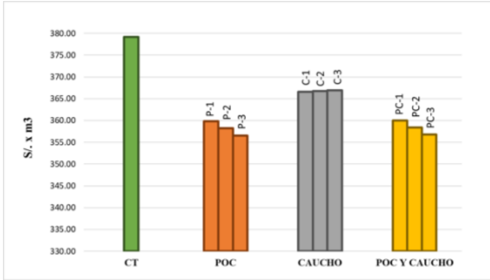

Figure 4. PC cost respect to CT

3.4 Cost and Sustainability

3.4.1 Cost evaluation

Figure 6 shows the influence of the percentage of PC related to the specific cost/m3. It sees that the cost decreases with the increase in the percentage of PC, reaching the value of S/. 356.76 for 15% PC and representing a 3.9% decrease over CT. [3] develops concrete with 12.5% POC replacement, resulting in a 3% decrease from CT. This is because the sand being replaced in a certain percentage by a much lower or non-existent price material, the cost of mixing decreases relative to conventional aggregates. [3]

3.4.2 CO_2 emission

Figure 7 shows the influence of the percentage of PCs related to CO2 emission. The results indicate that CO_2 emission decreases by increasing the percentage of PCs, obtaining the value of 547.95 for 15% of PC and representing a decrease of 3.8% compared to CT. [3] with a 12.5% POC replacement reduces concrete CO_2 emissions by 4% over CT. From an environmental point of view, the use of waste materials generally reduce the carbon footprint, in the case of POC its processing stages do not involve the production of significant carbon emissions. [3]. [19] with a 5% rubber replacement reduces concrete CO_2 emissions by 1% over CT. The same author, with a replacement of 5% rubber as a fine aggregate gets 6,626 kg of concrete CO_2/m3, which is 0.73% higher than CT. This CO_2 footprint increase behavior is due to the need for increased energy to crush rubber compared to natural aggregate sieving [19].

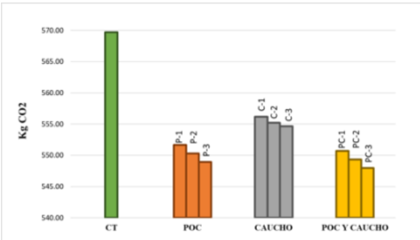

Figure 5. CO_2 emission respect to CT

4. Conclusion

- The main contribution of using POC + rubber in concrete is to reduce the CO_2/m3 emission of concrete by 4% and obtain an improved concrete by 6% in its strength.
- The mix design that shows a better mechanical performance compared to the CT is achieved with 2.5% rubber and 12.5% POC as a replacement for fine aggregate in concrete.
- The use of POC + rubber represents a lower cost per m3 of concrete compared to a CT, being an interesting alternative for the recycling and reuse of these highly polluting waste and a great opportunity for use in sustainable housing construction.

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