ANALYSIS OF THE PHYSICAL-MECHANICAL PROPERTIES OF CONCRETE USING RECYCLED PVC AND AGGREGATES

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Using recycled concrete has gained significant attention as a sustainable solution to reduce the environmental impact of construction waste. However, the mechanical properties of recycled concrete require thorough research to ensure its structural reliability. In this study, the objective was to determine the strength of concrete with PVC. A widely used material in most civil works is PVC, which is used in pipes and accessories for the project's hydro sanitary system. When the work is finished, a lot of PVC waste is discarded and is not recycled. In this research, the physical-mechanical properties of concrete are evaluated, using a dosage where the coarse aggregate is replaced by recycled and crushed PVC, in percentages ranging from 3% to 9%, mainly analyzing its behavior against compression and flexion at the age of 28 days, and obtaining its elastic modulus. The results obtained allow us to determine if the PVC added to the concrete mix gives us favorable results (greater compression and bending strength) or unfavorable results (higher costs, concrete slump, etc.)

Keywords: Construction, Cement, Compression, Bending, Standards.

1 INTRODUCTION

The field of construction is constantly growing and, evidently, the use of hydraulic concrete is a factor that plays a fundamental role in this area; but at the same time, it generates a significant impact on the environment when managing the waste that this material produces.

New technologies have been constantly studied that aim to reduce the environmental impact and, in turn, improve the physical-mechanical properties of conventional concrete. Therefore, we propose the addition of recycled and crushed PVC in different percentages as a replacement for the coarse aggregate, assuming the crushed PVC meets the technical specifications of our country so that it can be used as an aggregate for hydraulic concrete, and the final product has equal or better properties such as compressive strength, tensile strength, or elastic modulus.

2 MATERIALS AND TESTS

The aggregates used for this research were obtained from the “La Chimba” Mine located in Ecuador, in the province of Pichincha, where the process of obtaining this material is open pit, resulting in industrial, ornamental rocks and other materials used in construction. The cement used was from the "Selvalegre" brand, which is the most popular brand in Ecuador. PVC pipes were used, which were obtained mainly in drainage works and hydro sanitary systems of civil infrastructure works. After this, PVC pipes were crushed into pieces of approximately 2mm.
The aggregates, including the crushed PVC, were tested following the Ecuadorian Technical Standards: INEN (2011). Most of the tests were used to determine its granulometry, moisture content, specific gravity, degradation, and fine material.

The concrete design and the dosage of materials were determined using the Method 211 proposed by ACI Committee 211 (2002), considering the Füller-Thompson gradation principle for estimating the number of aggregates.

For the preparation of concrete samples, the recommendations of INEN (2015) in 1855 Standard were considered, obtaining for all this research the following number of samples (Table 1):

<table>
<thead>
<tr>
<th>Mixing Type</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Mix</td>
<td>6 cylinders - 4 beams</td>
</tr>
<tr>
<td>PVC Replacement 3%</td>
<td>6 cylinders - 4 beams</td>
</tr>
<tr>
<td>PVC Replacement 5%</td>
<td>6 cylinders - 4 beams</td>
</tr>
<tr>
<td>PVC Replacement 7%</td>
<td>6 cylinders - 4 beams</td>
</tr>
<tr>
<td>PVC Replacement 9%</td>
<td>6 cylinders - 4 beams</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>10 cylinders</td>
</tr>
</tbody>
</table>

The concrete samples were tested to determine its physical-mechanical properties, mainly compressive strength, flexural strength, and modulus of elasticity.

The compressive strength test allowed to measure the concrete's ability to resist loads that tend to compress it. This was determined following the process proposed by ASTM Committee C09 (2018a) in C39 Standard. It was obtained by applying a compressive axial load to the molded cylinders at a speed that is within a defined range until failure of the specimen occurs. The compressive strength of a specimen was calculated by dividing the maximum load achieved during the test by the cross-sectional area of the specimen.

The flexural strength test allowed us to measure the capacity of concrete to resist loads that tend to flex it, using combined compression and tensile stresses. This was determined following the process proposed by ASTM Committee C09 (2018b) in C78 standard. It was obtained by applying loads to a simply supported concrete beam, free at the ends, loaded in the middle thirds of the free span, until failure of the specimen occurred. The applied load was continuous, without impact at a constant speed. The flexural strength was obtained through the modulus of rupture.

The modulus of elasticity of the concrete was determined following the process proposed by ASTM Committee C09 (2002) in C469 standard, which relates the normal stress applied to the concrete specimen and the unit deformation that it causes, data obtained from the stress-deformation graph from the laboratory test. In summary, what is done in this test is to determine the slope of the line within the linear range of deformation suffered by the concrete specimen. The strains can be taken continuously or to simplify this process, this standard proposes taking the readings when the unit strain is 0.00005 and the second reading is the one corresponding to applying 40% of the ultimate strength of the concrete.

3 RESULTS AND DISCUSSION

The crushed PVC used in concrete greatly influences the behavior of the concrete against compression and bending strength. By adding crushed PVC to the mixture in small percentages,
the physical-mechanical properties of both fresh concrete and set concrete can be improved in the following ways:

- The use of crushed PVC in concrete improves compressive and bending strength when we use from 3% to 9% replacement percentage, as can be seen in the Figure 1 and 2. However, the higher the percentage of PVC, the less compressive and tensile strength the concrete has.

![Figure 1](image1.png)  
**Figure 1.** Results: Average f′c with different percentages of PVC.

![Figure 2](image2.png)  
**Figure 2.** Results: Average MOR with different percentages of PVC.

- The use of crushed PVC in concrete allows for a higher elastic modulus when we use from 3% to 9% replacement percentage, as can be seen in the Figure 3. However, the higher the percentage of PVC, the lower the modulus of elasticity.
• PVC has a relatively lower density than commonly used aggregates, therefore, lightweight concrete could be produced while maintaining its mechanical performance.
• Concretes with less volumetric instability are obtained because PVC accommodates better with other materials, considering the granulometry of PVC presented in this work.
• PVC, due to its structure, contributes to the reduction of cracking that may be generated in the setting and drying process; likewise in the process of applying forces.

![Figure 3. Results: Average Elastic Modulus with different percentages of PVC.](image)

However, the use of PVC in concrete can also harm the properties of the concrete in the following ways:
• Concrete made with crushed PVC generate less slump, due to the hydrophobic effect that this material has, causing less workability and manageability in the mixture.

4 CONCLUSIONS
• The aggregates obtained from Cayambe – Ecuador and “Selvalegre” Cement satisfactorily meets all the requirements requested by standards used in this research.
• Cylindrical samples made of conventional concrete meet the expected compressive strength f'c= 240 kgf/cm², obtaining a higher characteristic strength f'c= 250 kgf/cm² and a final slump of 12.5 cm, which means that it also has good workability. Maximum performance is obtained with 3% PVC replacement, giving a compressive strength f'c= 336 kgf/cm², that is, a 34% increase in strength compared to the strength obtained with conventional concrete. The compressive strength values tend to decrease when the percentage of crushed PVC increases. This concrete with PVC could have better performance in masonry elements or small structures that are not supporting high loads.
• Prismatic samples (beams) made of conventional concrete obtained a characteristic modulus of rupture MOR= 40 kgf/cm². Only samples made with 3% and 5% PVC replacement, equal or exceed the modulus of rupture value obtained with conventional concrete. Modified concrete with PVC could be used in small slabs or sidewalks.
• The elastic modulus obtained with conventional concrete is 229731 kgf/cm² and the maximum value obtained is 264948 kgf/cm², in concrete with 3% PVC replacement. In all cases in which the concrete is modified with PVC, it presents an increase in the modulus of elasticity compared to conventional concrete; however, a decreasing trend in this value is observed as the percentage of replacement PVC increases. A value of $\alpha$ (alpha) of 14035 is obtained for conventional concrete, compared to the value suggested by ACI 318 (ACI Committee 318 2014), which is 15100, we determine that it is an acceptable value and better adapted to our country, because the properties of Ecuadorian components.
• More tests with a better level of detail are necessary to define the interaction and behavior that exists between PVC and cement, using the same characteristics as used in this research.
• It is important to continue the study of the use of PVC with concrete, it could be preparing concrete mixtures with aggregates from another cities or countries, maintaining the same PVC granulometry.

References
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