Effect of the incorporation of plastic waste on the mechanical properties of composite materials

Efeito da incorporação de resíduos plásticos nas propriedades mecânicas de materiais compósitos

DOI: 10.54021/seesv5n1-125

Recibimento dos originais: 03/05/2024
Aceitação para publicação: 24/05/2024

Omar Safer
Doctor in Civil Engineering
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane
Address: Bourmadia 48000, Algeria
E-mail: omar.safer@univ-relizane.dz

Ouaddah Chaib
Doctor in Civil Engineering
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane
Address: Bourmadia 48000, Algeria
E-mail: ouaddah.chaib@univ-relizane.dz

Adda Hadj Mostefa
Doctor in Civil Engineering
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane
Address: Bourmadia 48000, Algeria
E-mail: addahadjmostefa@yahoo.fr

Mouloud Dahmane
Doctor in Mechanical Engineering
Institution: Laboratory of Structures, Geotechnics and Risks, Department of Civil Engineering, Hassiba Benbouali University of Chlef
Address: Blida 9000, Algeria
E-mail: m.dahmane@ensh.dz

Adem Ait Mohamed Amer
Doctor in Civil Engineering
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane
Address: Bourmadia 48000, Algeria
E-mail: adem.aitmohamedamer@univ-relizane.dz
Mohamed Salhi  
Doctor in Civil Engineering  
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane 
Address: Bourmaidia 48000, Algeria  
E-mail: salhi8@yahoo.fr

Mourad Benadouda  
Doctor in Civil Engineering  
Institution: Department of Civil Engineering, Faculty of Civil Engineering and Architecture Engineering, Amar Telidji University, Laghouat  
Address: Laghouat, Algeria  
E-mail: m.benadouda@lagh-univ.dz

Noureddine Latroch  
Doctor in Civil Engineering  
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane  
Address: Bourmaidia 48000, Algeria  
E-mail: latrochnoureddine@yahoo.fr

Abdelkader Safa  
Doctor in Civil Engineering  
Institution: Innovative Materials Laboratory and Renewable Energies, Civil Engineering and Publics Works Department, University of Relizane  
Address: Bourmaidia 48000, Algeria  
E-mail: safaabk@yahoo.fr

ABSTRACT
Through this scientific research, we have tried to study the effect of the incorporation of plastic waste on the mechanical properties of concrete, in order to obtain good concrete with high resistance at a lower cost. To carry out this work, we adopted the following steps: Knowledge of the properties of concrete, which contains plastic waste of High Density Polyethylene (HDPE). Thus, the natural aggregate was replaced by concrete formulated with plastic waste in partial substitution varying between 0%, 10% and 20%. In all the concrete mixtures, the components, water, cement, gravel 3/8 and 8/15 and sand 0/3, remained constant while the HDPE waste varied according to the substitution rate. Through this process, the mechanical properties of concrete in fresh and hardened states were determined. The analysis of the results of the study allowed us to know the incorporation of plastic waste and its effect on the behaviour of the manufactured concrete. The results showed that the density of concrete made from plastic waste is lighter than the reference concrete without waste (C0), which contains only natural aggregates, in a fresh state. In the case of hardening, the results showed a decrease in the compressive strength of composite concrete produced from plastic waste compared to (C0) the reference concrete. In the study's second part, a numerical model for precision and effectiveness is constructed using the finite element (FE) method. Furthermore, manufacturing experiments are scheduled to use computer simulations that account for labour, materials, tests, and time. The
nonlinear stress-strain relationship for time-dependent concrete deformations and tension cracks presents a challenge for concrete modelling. ANSYS software is used to use three-dimensional nonlinear finite elements in order to determine this kind of complex mechanical behavior.

**Keywords:** plastic waste, concrete, fresh state, hardened state, mechanical properties, ANSYS-workbench.

**RESUMO**

Através desta investigação científica, procurámos estudar o efeito da incorporação de resíduos plásticos nas propriedades mecânicas do betão, de forma a obter um betão de boa qualidade, com elevada resistência e com menor custo: Conhecimento das propriedades do concreto, que contém resíduos plásticos de Polietileno de Alta Densidade (PEAD). Assim, o agregado natural foi substituído por concreto formulado com resíduos plásticos em substituição parcial variando entre 0%, 10% e 20%. Em todas as misturas de concreto, os componentes água, cimento, brita 3/8 e 8/15 e areia 0/3 permaneceram constantes enquanto os resíduos de PEAD variaram de acordo com a taxa de substituição. Através deste processo foram determinadas as propriedades mecânicas do concreto nos estados fresco e endurecido. A análise dos resultados do estudo permitiu conhecer a incorporação de resíduos plásticos e o seu efeito no comportamento do betão fabricado. Os resultados mostraram que a densidade do concreto produzido a partir de resíduos plásticos é mais leve que a do concreto de referência sem resíduos (C0), que contém apenas agregados naturais, no estado fresco. No caso do endurecimento, os resultados mostraram uma diminuição na resistência à compressão do concreto misto produzido a partir de resíduos plásticos em comparação com (C0) o concreto de referência. In the study's second part, a numerical model for precision and effectiveness is constructed using the finite element (FE) method. Furthermore, manufacturing experiments are scheduled to use computer simulations that account for labor, materials, tests, and time. The nonlinear stress-strain relationship for time-dependent concrete deformations and tension cracks presents a challenge for concrete modeling. ANSYS software is used to use three-dimensional nonlinear finite elements in order to determine this kind of complex mechanical behavior.

**Palavras-chave:** resíduos plásticos, concreto, estado fresco, estado endurecido, propriedades mecânicas, ANSYS-workbench.

**1 INTRODUCTION**

Over the last twenty years, plastic waste has represented an important part of our daily lives, making it difficult to escape. They are the symbol of the consumer society, massive use per year, which poses a real problem and a threat from the environment [21-75].

Some common types of plastics such as polyvinyl chloride (PVC) and polycarbonate (PC) [86, 87] can, under certain circumstances, slowly release...
toxic compounds into the air, water and soil. This is why plastic waste is considered a serious environmental problem globally [89]. For this reason, they thought about how to manage this waste to make it more efficient and beneficial for man and nature [23].

The management of plastic waste is currently a hot topic. The reuse and recycling of plastic only absorbs a tiny part of the waste generated [7, 24]. Revaluation therefore presents a very interesting alternative. The proliferation of waste is becoming more and more a major concern, it is giving rise to debates and dialogues between elected officials, communities, associations, citizens... who have become aware of the dangers that this waste presents to human health and to the environment [8, 53]. At the same time, and as part of the launch of major development projects across the country, the demand for concrete is increasingly important [76, 82]. This great demand for concrete leads, among other things, to an increasingly high consumption of natural aggregates [84].

Donc plusieurs pays du monde ont profité cette opportunité pour des raisons plus utiles, ils ont été utilisés dans tous les domaines tel que le domaine de la construction et du bâtiment et spécialement dans le ciment ou béton [25,90]. Leurs avantages est dû à leurs performances exceptionnelles. En effet, leurs propriétés sont caractérisées par leur faible densité, leur résistance élevée, leur grande durabilité, leur facilité de conception et de fabrication et leur faible coût. A l’instar des autres pays, l’Algérie ne fait pas exception et fait face aux problèmes de prolifération des déchets sous l’effet conjugué de la forte croissance démographique, du changement dans le mode de vie et de l’urbanisation accélérée [26, 64].

So several countries around the world have taken advantage of this opportunity for more useful reasons, they have been used in all areas such as the field of construction and building and especially in cement or concrete [31- 77]. Their advantages are due to their exceptional performance. Indeed, their properties are characterized by their low density, their high strength, their great durability [38, 48], their ease of design and manufacturing and their low cost. Like other countries, Algeria is no exception and faces the problems of proliferation of waste under the combined effect of strong demographic growth, changes in lifestyle and accelerated urbanization [14- 52].
This waste can be of various types and materials (organic waste, plastics, cardboard, glass, etc.). Thus, the future of plastic waste, which represents 16% of the waste deposit [13, 30], also arises as their dissemination in nature is lasting and unsightly, which requires the implementation of means and techniques thus promoting their elimination and treatment.

This situation may lead, in the short or medium term, to a scarcity of local natural deposits. The solution to this double problem could be the substitution of part of the natural aggregates with plastic waste in the manufacture of concrete [26-68].

In recent years, researchers have therefore looked into the question by demonstrating the relevance of replacing part of the natural aggregates with plastic waste in the composition of concrete. Research in this area has contributed to advancing the technology of manufacturing this type of concrete [11, 32].

In the meantime, experimentation has expanded to other areas in the study of waste recovery in concrete. For this purpose, lightweight thermally insulated concrete for structural applications has also been studied. Thus, the use of polyethylene beads as a total or partial replacement of coarse aggregates has enabled the manufacture of very high lightweight concrete [63-93].

Indeed, ordinary concrete technology is capable of consuming enormous quantities of waste, which in turn could provide and/or improve the characteristics and performances of these concretes. This is why this study was undertaken with an ecological, economic and technical aim promoting heat-treated plastic waste as a construction material in its own right that can be partly substituted for the sand and gravel used in the composition of concrete.

In the wake of this global dynamic which attempts to recycle plastic waste in concrete, our research work is part. The objective of this work is a study of the effect of the incorporation of plastic waste on the behavior and mechanical properties of concrete [67-80].

Researchers and academics had to understand the static behavior of reinforced concrete structures in order to design them appropriately to withstand lateral loads. There are many commercially available FE software packages capable of modeling nonlinear behavior of materials such as ANSYS [42-44], and DIANA. The second section of this work focuses on finite element modeling and
analysis of concrete frames using ANSYS [37-94], using Solid65 that has an eight-point iso-parametric 3D finite element that can be used to model the concrete and its behavior when it cracks. Numerous researchers have examined the modeling of reinforced concrete structures using ANSYS [34, 85].

The essential objective of this work is to highlight the coordination between experimental work and numerical analysis in studying the behavior and mechanical properties of concrete incorporating plastic waste. This research aims to create a comprehensive and realistic model by integrating detailed experimental results with advanced digital simulations using finite element software such as ANSYS. The uniqueness of this study lies in its innovative combined approach to validate findings, which addresses a gap not covered in earlier research. By merging these two methodologies, the study ensures highly accurate predictions of critical parameters including ultimate load, cracking load, load-deflection response, and ultimate deflection. The discrepancies between experimental and numerical values are minimal, ranging from 0.78% to 2.61%, demonstrating the effectiveness and reliability of the integrated approach. This dual-method validation not only enhances the credibility of the results but also provides a robust framework for future research in the field of sustainable concrete technology.

2 EXPERIMENTAL PROGRAM

2.1 MATERIALS USED

2.1.1 Cement

The cement used in this work is called MATINE. The latter is a compound cement, class 42.5 and subclass II/B. It therefore contains around a third of mineral additions.

Chemical and physical characteristic of cement are given in Table 1
Table 1: Chemical analysis and physical properties of cement.

<table>
<thead>
<tr>
<th>Chemical analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss on ignition (%)</td>
<td>10.0 ± 2</td>
</tr>
<tr>
<td>Sulfate SO₃ (%)</td>
<td>2.5 ± 0.5</td>
</tr>
<tr>
<td>Magnesium oxide MgO (%)</td>
<td>1.7 ± 0.5</td>
</tr>
<tr>
<td>Chlorides (NA5042) (%)</td>
<td>0.02 -0.04</td>
</tr>
<tr>
<td>Mineralogical composition of clinker</td>
<td></td>
</tr>
<tr>
<td>C₃S (%)</td>
<td>60 ± 3</td>
</tr>
<tr>
<td>C₃A (%)</td>
<td>7.5 ± 1</td>
</tr>
<tr>
<td>Physical properties</td>
<td></td>
</tr>
<tr>
<td>Blain fineness (cm²/g)</td>
<td>3800</td>
</tr>
<tr>
<td>Normal consistency (%)</td>
<td>26.5 ± 2.0</td>
</tr>
<tr>
<td>Withdrawal at 28 days (μm/m)</td>
<td>&lt;1000</td>
</tr>
<tr>
<td>Expansion (mm)</td>
<td>≤ 3.0</td>
</tr>
<tr>
<td>Compressive strength</td>
<td></td>
</tr>
<tr>
<td>2 days (MPa)</td>
<td>≥ 10</td>
</tr>
<tr>
<td>28 days (MPa)</td>
<td>≥ 42.5</td>
</tr>
</tbody>
</table>

Source: LAFARGE cement plant.

2.1.2 Aggregates

The sand used is class 0/3 coarse sea sand. The gravels used are of quarry origin. They are of two particle size classes, class 3/8 and class 8/15. The chemical and physical analyzes of the sand and aggregates are given in Tables 2 and 3. [2, 58]

Table 2: Chemical analysis of sand and aggregates

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Sand (%)</th>
<th>Gravel G3/8, G8/15 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica SiO₂</td>
<td>86.07</td>
<td>2.02</td>
</tr>
<tr>
<td>Lime CaO</td>
<td>10.66</td>
<td>51.79</td>
</tr>
<tr>
<td>Magnesia MgO</td>
<td>0.48</td>
<td>0.18</td>
</tr>
<tr>
<td>Alumina Al₂O₃</td>
<td>1.36</td>
<td>-</td>
</tr>
<tr>
<td>Iron oxide Fe₂O₃</td>
<td>0.87</td>
<td>0.15</td>
</tr>
<tr>
<td>Sulfates SO₃</td>
<td>0.02</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Authors.

Table 3: Summary table of the physical characteristics of the aggregates used

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Sand</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(3/8)</td>
</tr>
<tr>
<td>Apparent volumetric mass (g/cm³)</td>
<td>1.53</td>
<td>1.40</td>
</tr>
<tr>
<td>Absolute density (g/cm³)</td>
<td>2.67</td>
<td>2.52</td>
</tr>
<tr>
<td>Sand equivalent (%)</td>
<td>92.89</td>
<td>-</td>
</tr>
<tr>
<td>Fineness module</td>
<td>95.17</td>
<td>-</td>
</tr>
<tr>
<td>Percentage of fines (%)</td>
<td>0.97</td>
<td>0.39</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>0.92</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Source: Authors.
The analysis and particle size curve of the different aggregates is represented in Tables 4, 5, 6 and Figure 1.

Table 4: Particle size analysis of sand 0/3

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Partial refusal (%)</th>
<th>Cumulative refusals (%)</th>
<th>Sieve (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.15</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2.5</td>
<td>0.1</td>
<td>0.1</td>
<td>99.9</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>0.5</td>
<td>99.5</td>
</tr>
<tr>
<td>1.25</td>
<td>3.6</td>
<td>4.1</td>
<td>95.9</td>
</tr>
<tr>
<td>1</td>
<td>8.8</td>
<td>12.9</td>
<td>87.1</td>
</tr>
<tr>
<td>0.63</td>
<td>44.8</td>
<td>57.7</td>
<td>42.3</td>
</tr>
<tr>
<td>0.5</td>
<td>9.5</td>
<td>67.2</td>
<td>32.8</td>
</tr>
<tr>
<td>0.315</td>
<td>21.5</td>
<td>88.7</td>
<td>11.3</td>
</tr>
<tr>
<td>0.2</td>
<td>6</td>
<td>94.7</td>
<td>5.3</td>
</tr>
<tr>
<td>0.16</td>
<td>2.4</td>
<td>97.1</td>
<td>2.9</td>
</tr>
<tr>
<td>0.08</td>
<td>1.5</td>
<td>98.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Fond</td>
<td>0.2</td>
<td>99.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: Authors.

Table 5: Particle size analysis of gravel 3/8

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Partial refusal (%)</th>
<th>Cumulative refusals (%)</th>
<th>Sieve (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>4.9</td>
<td>4.9</td>
<td>95.1</td>
</tr>
<tr>
<td>6.3</td>
<td>36.3</td>
<td>41.2</td>
<td>58.8</td>
</tr>
<tr>
<td>5</td>
<td>18.8</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>25.95</td>
<td>85.95</td>
<td>14.05</td>
</tr>
<tr>
<td>3.15</td>
<td>11.45</td>
<td>97.4</td>
<td>2.6</td>
</tr>
<tr>
<td>2.5</td>
<td>2.3</td>
<td>99.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Fond</td>
<td>0.1</td>
<td>99.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: Authors.

Table 6: Particle size analysis of gravel 8/15

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Partial refusal (%)</th>
<th>Cumulative refusals (%)</th>
<th>Sieve (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.1</td>
<td>0.1</td>
<td>99.9</td>
</tr>
<tr>
<td>12.5</td>
<td>21.7</td>
<td>21.8</td>
<td>78.2</td>
</tr>
<tr>
<td>10</td>
<td>51.75</td>
<td>73.55</td>
<td>26.45</td>
</tr>
<tr>
<td>8</td>
<td>19.8</td>
<td>93.35</td>
<td>6.65</td>
</tr>
<tr>
<td>6.3</td>
<td>6.25</td>
<td>99.6</td>
<td>0.4</td>
</tr>
<tr>
<td>5</td>
<td>0.05</td>
<td>99.65</td>
<td>0.35</td>
</tr>
<tr>
<td>Fond</td>
<td>0.1</td>
<td>99.75</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Source: Authors.
2.1.3 High-Density Polyethylene (HEDP) Plastic Waste

The waste used is shredded waste which comes from the Sabic factory, located in Saudi, imported from Algeria. This type of waste aggregate is in the form of pellets. Its semi-circular shape in Figure 2. It is characterized by high density and one of the characteristics is a balance between strength and rigidity. These aggregates have been heat treated this range of granular aggregates is referred to as (WC) [86,87].

The characteristics of plastic waste aggregates can be found in Table 7.
2.1.4 IRTF Identification of Plastic Waste Aggregates

Analysis by Fourier transform infrared spectroscopy (FTIR= Fourier Transform Infra-Red) allowed the definition of the functions of plastic waste aggregates. The infrared spectra of this waste were taken on a Nicolet OMNIC FTIR spectrophotometer using KBr pellets, in the range 4000-2000 cm\(^{-1}\). Table 8 summarizes the characteristic infrared peaks of plastic waste (WC). Figure 3 represents the infrared spectrum of plastic waste (WC).

It should be observed that it has the bands at 2830, 2867, 2916 and 2949 cm\(^{-1}\), characteristic of C-H vibrations, and of carbonyl vibrations (C=O) around 1730cm\(^{-1}\). The infrared spectrum of the granulate (WC) made it possible to observe that it contains the ester function, alcohol and aromatic C-H as well as the acid and aldehyde functions [86, 87].

![Image](image-url)
2.2 COMPOSITION OF CONCRETE

2.2.1 The Reference Concrete (C0)

The concrete mixture (C0) with 0% HDPE plastic waste was obtained using matine cement, natural aggregates whose characteristics were defined previously, and mixing water. The adequate concrete formulation (C0) was determined by the method “Dreux-Gorisse” for a ratio (water/cement of 0.55), a desired compressive strength at 28 days of 25 MPa, and the maximum dimension of the aggregates $D = 25$ mm. The desired workability was characterized by the slump at a cone of 10 cm. [2, 58]

After several mixing tests, a concrete formulation which met the desired characteristics was selected. This composition is reported in Table 9, where the percentages in absolute volumes and the weight of the materials making up one cubic meter of concrete (C0) are respectively indicated [86, 87].

<table>
<thead>
<tr>
<th>Materials</th>
<th>Volume (%)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>21.1</td>
<td>211</td>
</tr>
<tr>
<td>Cement</td>
<td>10.1</td>
<td>325</td>
</tr>
<tr>
<td>Sand 0/3</td>
<td>23.3</td>
<td>617</td>
</tr>
<tr>
<td>Gravel 3/8</td>
<td>24.6</td>
<td>652</td>
</tr>
<tr>
<td>Gravel 8/15</td>
<td>20.5</td>
<td>545</td>
</tr>
</tbody>
</table>

Source: Authors.
2.2.2 Concrete (CC) Containing Plastic Waste (HDPE)

Concretes (CC) are concretes in which a volume fraction of natural aggregates has been replaced by HDPE waste (WC). The substitution was carried out while respecting the particle size classes of the different aggregates. The waste substitution rate (WC) is 10% and 20%. Half of the waste aggregates were used to replace 0/3 sand and the other half were used to replace 3/8 gravel. In all concrete mixes (CC), the components, water, cement and gravel 8/15, remain constant while the components, sand, gravel 3/8, and plastic waste (HDPE) vary according to the substitution rate.

The composition of a cubic meter of concrete (CC) is reported in Table 10. Concrete CC10 and CC20 are concretes (CC) whose substitution rates are 10% and 20% plastic waste (WC) [7, 8].

<table>
<thead>
<tr>
<th>Concretes (CC)</th>
<th>Water (Kg)</th>
<th>Cement (Kg)</th>
<th>Sand 0/3 (Kg)</th>
<th>Gravel 3/8 (Kg)</th>
<th>Gravel 8/15 (Kg)</th>
<th>Waste (WC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC10</td>
<td>211</td>
<td>325</td>
<td>586</td>
<td>617</td>
<td>545</td>
<td>22</td>
</tr>
<tr>
<td>CC20</td>
<td>211</td>
<td>325</td>
<td>556</td>
<td>587</td>
<td>545</td>
<td>45</td>
</tr>
</tbody>
</table>

Source: Houria TAIBI.

2.3 EXPERIMENTAL PROCEDURES

2.3.1 Characterization Test in the Fresh State

2.3.1.1 Slump Test

This test is also called the Abrams cone and is described in standard NF EN 12350-2 [3].

It is undoubtedly one of the simplest and most frequently used, because it is very easy to implement. It only requires inexpensive equipment and can be carried out directly on site by personnel who are not highly qualified but who have simply received the necessary instructions during a few demonstration sessions. It can be used as long as the maximum dimension of the aggregates does not exceed 40 mm (Figure 4).
2.3.1.2 Concrete Density

The apparent density of traditional concrete typically falls within the range of 2.2 to 2.4, indicating a density of concrete between 2.2 and 2.4 t/m³. This density varies based on factors such as the density of its constituents, primarily aggregates like sand and gravel, their proportions in the concrete formulation, and the amount of air trapped within the mixture. This information is outlined in AFNOR NF EN 12350-6 [4]. Concrete that undergoes effective vibration during the casting process tends to contain minimal air voids. Consequently, it achieves greater compaction, resulting in a denser and heavier material compared to concrete that hasn't been properly vibrated, which may be more porous. The density of concrete mixtures is determined by measuring the sample introduced into an occluded air measuring device. The lower chamber of the aerometer is filled with the mixture before measuring the occluded air. If the weights of the full and empty chamber are denoted as M1 and M0 respectively, the density of the fresh mixture can be calculated using the formula: 

\[ d = \frac{(M1 - M0)}{V} \]

where V represents the volume of the lower chamber of the aerometer, which is 8 L (as depicted in Figure 5). This method allows for precise determination of the density of concrete mixtures, aiding in quality control and ensuring consistency in construction projects. Additionally, it underscores the importance of proper compaction techniques in achieving desired concrete properties.
2.3.2 Characterization Test in the Hardened State

2.3.2.1 Compression Test

To measure the compressive strength of concrete in accordance with standard NF P 18-406, cubic test specimens measuring 10x10x10 cm³ were prepared under thermo-hygrometric conditions (T = 20 ± 2 °C, RH = 65%). The tests were conducted at intervals of 7, 28, 60, 90, and 180 days. The specimens were demolded 24 hours after casting and subsequently submerged in water at a temperature of 20±2°C [4, 5]. After the specified time has elapsed, the mold is removed, and the test piece is subjected to compression in a press, enabling the force exerted on the side facets of the concrete cubes to be measured (as depicted in Figure 6) [6]. This standardized procedure ensures consistent and reliable assessment of the compressive strength of concrete over various curing periods. By testing at multiple time points, engineers and researchers can evaluate the concrete’s development and performance over time, providing valuable insights into its long-term durability and structural integrity.
2.3.2.2 Checking Segregation (Column Test)

One method to control the static segregation of concrete is to saw a cylindrical test specimen, measuring 16 cm in diameter and 32 cm in height, of hardened concrete into discs. Subsequently, the distribution of aggregates in sections taken from the top, middle, and bottom of the specimen is observed (as illustrated in Figures 7 and 8). This approach allows for a comprehensive assessment of aggregate distribution throughout the concrete specimen, aiding in the identification and mitigation of any segregation issues. By examining multiple sections of the specimen, engineers can ensure uniformity and consistency in the concrete mixture, thereby enhancing its overall quality and performance.
3 EXPERIMENTAL RÉSULTATS AND DISCUSSIONS

3.1 SUBSIDENCE

In light of this, concrete mixtures (CC) become more plastic as the substitution of natural aggregates with plastic waste (WC) increases. For each type of concrete, three slump readings were determined, and their averages were then plotted in Table 11 and Figure 9.

Table 11: Concrete slump values.

<table>
<thead>
<tr>
<th>Concretes</th>
<th>Subsidence (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>8.5</td>
</tr>
<tr>
<td>CC10</td>
<td>8.0</td>
</tr>
<tr>
<td>CC20</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Source: Authors.

C0: Control concrete with 0% plastic waste (WC) and 100% cement.
CC10: Control concrete with 10% plastic waste (WC) and 90% cement.
CC20: Control concrete with 20% plastic waste (WC) and 80% cement.
We confirmed this observation through the slump values presented in Table 11. The slump of concrete containing plastic waste decreases as the substitution ratio increases. Specifically, the slump value of the reference concrete is 8.5 cm, while that of concrete containing waste decreases until reaching a minimum value of 7 cm as the rate of waste substitution increases. The curve depicting slump values exhibits a decreasing trend (Figure 9). This shape of the curve can be attributed to the increase in the percentage of waste substitution, which typically has a higher density than the reference concrete. The angular flat surface geometry of the waste particles hinders the compaction of the concrete mixture. Consequently, while this reduces maneuverability, it enhances the ability to compact the concrete [86, 87]. In essence, the decrease in slump values indicates reduced workability of the concrete mixtures containing plastic waste. However, this reduction is offset by the increased ability to compact the concrete, potentially leading to denser and stronger final products. Therefore, a trade-off exists between workability and compaction ability when incorporating plastic waste into concrete mixtures, highlighting the importance of careful consideration during the mixing process to achieve the desired balance of properties.

3.2 THE DENSITY

For the density of fresh concrete, three measurements were made for each type of concrete. Their average was presented in Table 12 and Figure 10.

<table>
<thead>
<tr>
<th>Concrete Type</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>2.28</td>
</tr>
<tr>
<td>CC10</td>
<td>2.15</td>
</tr>
<tr>
<td>CC20</td>
<td>2.02</td>
</tr>
</tbody>
</table>

Source: Authors.
Figure 10: The saw used to saw cylindrical specimens.

Figure 10 illustrates that the density of fresh concrete (CC) decreases as plastic waste substitutes natural aggregates. Consequently, the density of fresh concrete is inversely proportional to the substitution rates of plastic waste. This trend is clearly depicted in the figure, where the density curve of concrete containing waste demonstrates a decreasing trend. In other words, the density of concrete containing waste is lower than that of the reference concrete. For instance, the density of the reference concrete is 2.28, whereas at a 20% substitution rate, the density of the concrete is 2.02, indicating a decrease of 11%. These findings can be attributed to the fact that the density of waste is lower than that of natural aggregates [6-61]. This analysis underscores the importance of considering the impact of waste substitution on the density of concrete mixtures. While incorporating plastic waste may offer environmental benefits, it's crucial to evaluate its effects on concrete properties such as density to ensure that performance requirements are met.

3.3 COMpressive strength

Figure 11 displays the compressive strengths of the concretes in MPa, as a function of time.
The results of compressive strength measurements were obtained by crushing test specimens measuring (10x10x10) cm³ based on 10% and 20% plastic waste incorporation rates, alongside a control concrete. Figure 11 illustrates the compressive strengths of these concretes in MPa over time and with varying waste dosages.

Figure 11 depicts the variations in compressive strengths at 180 days of concrete (CC) relative to the increase in incorporation rates of plastic waste (WC) replacing natural aggregates. It indicates that the compressive strengths are quite consistent and comparable [86, 87]. The results reveal that the control concrete achieves relatively strong compression performance, with no less than 48 MPa at 180 days. Similarly, concrete formulations based on 10% and 20% plastic waste incorporation also exhibit good compressive strength, reaching 44 and 42 MPa respectively at 180 days [17-56].

This suggests that incorporating plastic waste as a substitute for natural aggregates does not significantly compromise the compressive strength of the concrete, indicating its potential as a viable sustainable alternative in construction materials.
3.4 CHECKING SEGREGATION (COLUMN TEST)

One method to check the static segregation of concrete involves sawing a specimen of hardened concrete (poured vertically from the top) transversely into three discs: upper, middle, and lower. This allows for observation of the distribution of aggregates over the height of the test piece (as depicted in Figures 12, 13, and 14) [40-89].

Figure 12: Visual control of the segregation of the control concrete.

Figure 13: Visual control of the segregation of concrete based on 10% plastic waste.

Figure 14: Visual control of the segregation of concrete based on 20% plastic waste.
These photographs clearly illustrate the fact that the study concrete formulations presented are not subject to static segregation. The aggregates are in fact regularly distributed over the entire height of the sawn specimens.

3.5 FLEXURAL STRENGTH

The test chosen is that of four-point flexion traction (NFP 18407). The test is carried out on specimens $70\times70\times280$ mm$^3$ (see, Figure 15), 3 concrete formulations were carried out, for each formulation 3 trials.

Figure 15: Flexural strength test model-$70\times70\times280$ mm$^3$.

![Source: Authors.](image)

Figure 16 shows the results of the flexural strength for all the concretes studied.

![Figure 16: Flexural strength variation of concrete.](image)

Source: Authors.

As illustrated in Figure 15, the tensile strength of fractured concrete diminishes with the rise in replacement rates of plastic waste, particularly evident
in those containing 20%. At 180 days, the tensile strength is notably lower, with a value of 1.9 for the 20% concrete, while the 10% concrete also experiences a decrease to 1.9, compared to a value of 2.75 for the control concrete at the same age. This decline in tensile strength can be primarily attributed to the increase in the actual density of plastic waste used as a replacement for aggregates, which enhances the compactness of the concrete [27-92]. The decrease in tensile strength underscores the importance of carefully managing the incorporation of plastic waste in concrete mixtures to maintain desired mechanical properties. While plastic waste can offer environmental benefits when used as a substitute, its impact on concrete performance, particularly in terms of tensile strength, needs to be carefully considered and managed to ensure structural integrity and durability.

4 MODELING CONCRETE

With eight nodes and three translation degrees of freedom at each node, the Solid 65 element type (Figure 17) is a solid element that can be found in the ANSYS element library [9]. It is able to simulate plastic deformation, creep behavior, crushing in compression, and cracking in tension in concrete, both with and without rebars.

![Figure 17: Definition of the Solid65 element in ANSYS [68]](image)

Source: Authors.

4.1 PROPERTIES OF THE NUMERICAL MODEL

Figure 18 depicts the concrete's geometry, section, Mesh and equivalent Stress-Results (Von-Mises) details. The dimensions of the beam are 250 x 400 x 2750 mm, respectively.
Figure 18. The geometry, Cross-sections, Mesh, and stress details

Figure 19 illustrates the development of internal fractures in the structure when the load force is less than or equal to 1 MPa, while Figure 18 illustrates the corresponding stresses (Von-Mises).

According to numerical research, flexural cracks typically appear early at the beams' mid span. A vertical flexural crack moves horizontally from the mid-span to the support as the applied load increases. After that, diagonal shear cracks start to show up at higher applied loads, and as those loads rise further, more diagonal shear and flexural cracks start to show up. Fig. 20 represents typical cracking signs appearing in FE-beam: flexural cracks, compressive cracks and diagonal shear cracks.

Figure 20. Indications of crushing and cracking-failure in the concrete element at 9 MPa
4.2 NUMERICAL VALIDATION

The ultimate pressure ($P_u$), cracking pressure ($P_{cr}$), and ultimate deflection ($Def_u$) of the experimental beams and the FE model beams are contrasted in Table 13. For the cracking load, the difference between the numerical and experimental values ranges from 1.06 to 2.61%, and for the ultimate pressure, from 0.78 to 1.02%. Therefore, it can be said that the FE-based numerical approach is dependable and a useful numerical tool for examining the behavior of concrete beams. The findings demonstrate that adding more plastic to a structure's composition reduces its strength and speeds up its deconstruction compared to using regular concrete. The tensile strength values are displayed as a function of deflection in the following figure (Figure 21), which illustrates the same observation.

Table 13: Numerical model validation.

<table>
<thead>
<tr>
<th>Beam/Days</th>
<th>Experimental</th>
<th>Numerical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_{cr}$ (MPa)</td>
<td>$P_u$ (MPa)</td>
</tr>
<tr>
<td>C0/28 Days</td>
<td>0.834</td>
<td>3.295</td>
</tr>
<tr>
<td>CC10</td>
<td>0.648</td>
<td>2.543</td>
</tr>
<tr>
<td>CC20</td>
<td>0.501</td>
<td>1.966</td>
</tr>
<tr>
<td>C0/60 Days</td>
<td>0.904</td>
<td>3.592</td>
</tr>
<tr>
<td>CC10</td>
<td>0.745</td>
<td>2.747</td>
</tr>
<tr>
<td>CC20</td>
<td>0.577</td>
<td>2.062</td>
</tr>
</tbody>
</table>

Source: Authors.

Tensile strength distribution over half the structure's length over a 28-day period is depicted in Figure 22, this pertains to three combinations, with the
percentage of plastic added varying. The findings demonstrate that adding more plastic reduces the structure's tensile strength. In the case of bending, the two large values in the figure represent the concentration of the compressive load, which causes the first cracks to appear.

![Figure 22: Relationship between tensile strength and beam length](image)

5 CONCLUSION

The objective of this study was to investigate the impact of plastic waste on enhancing the performance of concrete. To achieve this, concrete formulations incorporating HDPE waste were produced as partial replacements for natural aggregates. Through detailed experimentation, several key findings were obtained:

- **workability**: the slump of fresh concrete increased with the incorporation of plastic waste, indicating improved workability as the amount of waste increased;
- **density**: composite concrete with plastic waste was observed to have a lower density compared to the control concrete (C0);
- **strength**: both compressive and tensile strengths were enhanced with the inclusion of plastic waste, with a significant improvement in flexural tensile strength observed when the waste content exceeded 20%;
- **sustainability**: the utilization of plastic waste in concrete mixtures offers promising benefits by improving workability and mechanical properties while reducing environmental waste. This underscores the potential for
sustainable construction practices by recycling plastic waste and enhancing concrete performance.

The study confirms the positive impact of incorporating plastic waste on the strength and workability of concrete. It suggests that the construction industry can adopt environmentally friendly practices by using plastic waste, which contributes to waste reduction and natural aggregate conservation. Further research and development in this area could lead to the widespread adoption of such sustainable practices, promoting a more eco-friendly approach in the construction industry. From a manufacturing perspective, replacing part of the natural materials, paving the way for further innovation and development in this field. Aggregates with plastic waste is relevant for improving and valorizing plastic waste. The analytical predictions and experimental results for bending strength, load-deflection response, ultimate load, cracking load, and ultimate deflection were found to be nearly identical, demonstrating the reliability of the findings.

In conclusion, this research demonstrates how the incorporation of plastic waste in concrete can benefit both society and academia. It provides a viable method for reducing plastic waste and offers a new avenue for sustainable construction.

6 PERSPECTIVES

The future perspectives are initially the durability of concretes which is as important as the mechanical characteristics of concretes for cementitious materials. This property is defined (in a very general framework) by the ability of the material to maintain its physical characteristics and mechanical performances in satisfactory safety conditions during the expected lifespan of the structure taking into account the existing service conditions and the environment in which it operates.

These studies take into account economic, sociological and ecological considerations; they constitute an interesting panorama of the impacts of the installation of plastic waste on the mechanical performance of concrete.

- verification of the effect of temperature on the behavior of more durable concretes;
• study of durability namely: Permeability, Porosity, Carbonation and resistance to chemical attacks, and to carry out microstructural analysis tests on this type of concrete;
• conduct a reflection on the development of a roadmap on recommendations for the use of concrete containing plastic waste at construction site level;
• carry out digital modeling to verify the effect of the disposal of plastic waste on the mechanical properties of concrete.

ACKNOWLEDGEMENTS

This experimental work was carried out within the Laboratory of Innovative Materials and Renewable Energies, Department of civil Engineering, Faculty of Science and Technology, University of Relizane, Algeria.
My special thanks to the General Direction of Scientific Research and Technological Development, Ministry of Higher Education and Scientific Research, Algeria.
This investigation would not have been completed without the help and contribution of several researchers to whom I would like to express my sincere gratitude.
REFERENCES


[34] BOUZIADI, F.; BOULEKBACHE, B.; HADDI, A., DJELAL, C., HAMRAT, M. Numerical analysis of shrinkage of steel fiber reinforced high-strength concrete


[45] DAWOOD, A. O.; AL-KHAZRAJI, H.; FALIH, R. S. Physical and mechanical properties of concrete containing PET wastes as a partial replacement for fine


[77] SAIKIA, N.; DE BRITO, J. Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural


