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Comparative Study of the Adhesion of Reinforcements in Polymer Concrete and Cementitious Concrete

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Abstract

This study is part of a sustainable innovation initiative, proposing the use of plastic waste as a binder, combined with flint, for the formulation of environmentally friendly polymer concrete. The aim is to demonstrate the technical feasibility of replacing traditional cementitious binders while ensuring reliable adhesion between metal reinforcements and the polymer matrix. A comparative study was conducted between conventional cement concrete and several formulations based on melted plastics. The results showed that PET + flint concrete offers remarkable adhesion (8.06 MPa), superior to cement concrete (6.59 MPa), for which the values set by the BAEL 91 and Eurocode 2 standard are between 2.8 and 3.2 MPa. Although HDPE and PP-based concretes have slightly lower adhesion, they exceed the usual reference values while displaying improved compressive strength, in line with previous studies. These results confirm the feasibility of polymer concretes reinforced with reinforcement for specific uses such as the prefabrication of components for use in roads, networks and various other applications, as well as in wet areas.

Keywords

Plastic Concrete, Cement Concrete, Adhesion, Plastic Waste, Innovation

1. Introduction

Plastic waste management is now a major environmental issue. According to the UN, more than 430 million tonnes of plastic are produced each year, two-thirds of which quickly become unrecycled waste ending up in landfills or the marine environment, illustrating the urgent need for innovative recycling solutions [1].

At the same time, the construction sector, a major consumer of resources, is responsible for 6% to 8% of global CO_2 emissions, mainly due to cement manufacturing [2]. These findings have stimulated the search for sustainable solutions, such as the use of recycled plastic-based components as composite materials in the construction sector. This work explores the possibility of completely replacing cementitious binders with plastic binders, while ensuring reliable adhesion between the reinforcement and the matrix. This mechanical bond is essential to the strength of reinforced structures and determines their overall performance, durability and compliance with current technical standards.

The analysis focuses on comparing the adhesion of standard concrete and concrete made from recycled plastics. This study aims to complement the very interesting mechanical properties obtained in particular in compression and tension [3] [4].

This approach is part of a circular economy approach, aiming to limit greenhouse gas emissions while recycling plastic waste for constructive use.

The methodology is based mainly on pull-off tests on cylindrical specimens, in accordance with standards [5]. These tests make it possible to quantify the bond stress and identify the modes of failure in order to evaluate the quality of the steel-polymer matrix bond in each of the formulations studied.

2. Materials and Methods

2.1. Materials

Raw Materials

1) Flint

Flint is the main component of our material. It is a by-product of the phosphate beneficiation process. It is obtained from the pre-treatment plant landfill, with a roughly known particle size distribution. Flint is a siliceous sedimentary rock corresponding to a continuous bed of flint. It is composed mainly of quartz, hematite and alkali feldspars, and occurs as blocks with dark cores and white cortexes. The cortex has been eliminated or reduced by dynamic fragmentation of the blocks during the settling process. These flints are extracted to produce 0/3; 3/8 and 8/16 aggregates [3]. **Figure 1** shows a sample of 0/3 aggregates used in this study.

Figure 1. Taïba flint sample.

2) Plastic waste

Plastic waste generally breaks down into two basic material categories with a number of sub-categories: Thermoplastics and Thermosets, These families are differentiated by their chemical, thermal and mechanical properties, their processing methods and the properties obtained in composites [3].

Within the framework of this study, we will use the family of thermoplastics, namely high-density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP) and polyethylene terephthalate (PET) (**Figure 2**).

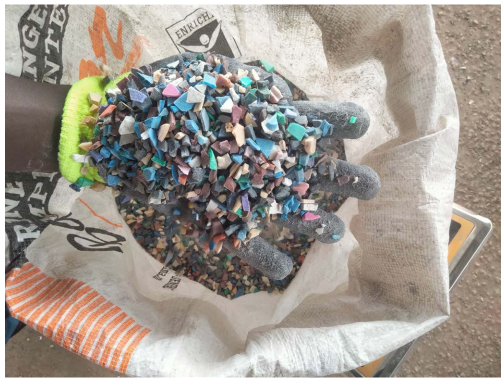

Figure 2. Crushed HDPE plastic.

To produce the samples, the plastic is melted. This method was chosen to exploit the thermoplastic binding properties of polymers. The general methodology adopted in this study is detailed in **Figure 3**.

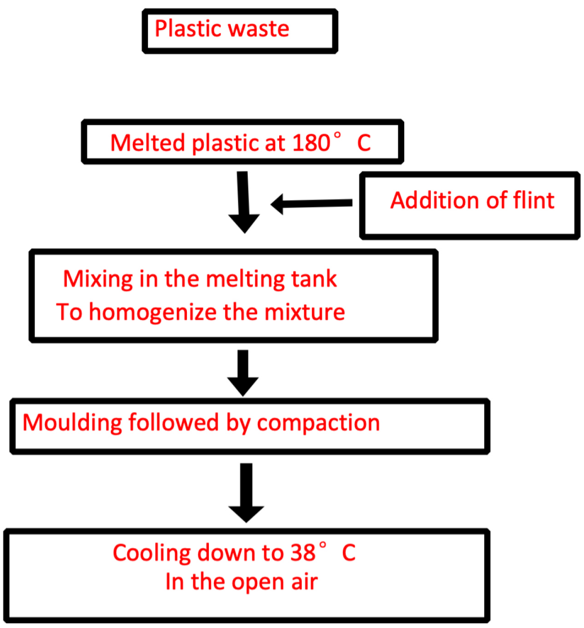

Figure 3. Sample preparation methodology

The various stages of the polymer concrete sample formulation process, as well as the density of the material, have been described in detail in previous studies [3], [6].

After manufacturing the cylindrical components using traditional methods, pull-out tests were carried out using a 1000 kN automatic servo-hydraulic universal testing machine capable of performing tensile, compression and bending tests. This machine is equipped with a digital control system with a touch screen and computerised management, allowing precise control of load, displacement and deformation parameters in accordance with standard NF EN ISO 6892-1 [7]. **Figure 4** shows the experimental device.

Figure 4. Experimental setup for the pull-out test.

A support was designed using two steel plates connected by four equidistant rods. Bolt fastenings ensure the rigidity of the assembly and enable the forces applied during the test to be transmitted efficiently.

The pull-out test aims to evaluate the resistance to extraction of a reinforcement inserted into a cementitious or polymer matrix. It allows analysis of the adhesion between the reinforcement and the surrounding material, as well as the mechanical behaviour of the system under direct tensile stress.

2.2. Methods

The test piece is positioned vertically on the test machine's support plate. The lower jaw of the machine firmly holds the steel rod embedded in the polymer concrete, while the upper jaw grips the stud on the platform attached to the sample. The latter moves gradually downwards, generating an increasing tensile force on the reinforcing bar.

The universal servo-hydraulic machine continuously records:

- The intensity of the applied load (in kN)
- The application speed (MPa/second)

The test continues until the system fails, which can manifest itself as:

- A break in the reinforcement/matrix interface
- Excessive slippage of the reinforcement
- A cohesive failure of the surrounding material

The data collected is used to identify the failure mode and calculate the maximum pull-out stress. These results are essential for evaluating the adhesion performance of the formulations tested, particularly those incorporating recycled polymers and silexite. Figure 5 shows the preparation of steel rods and cementitious concrete and polymer concrete samples for the pull-off test.

Figure 5. Preparation of steel rods and components obtained.

Figure 6 shows the configuration of the test specimen for the pull-out test.

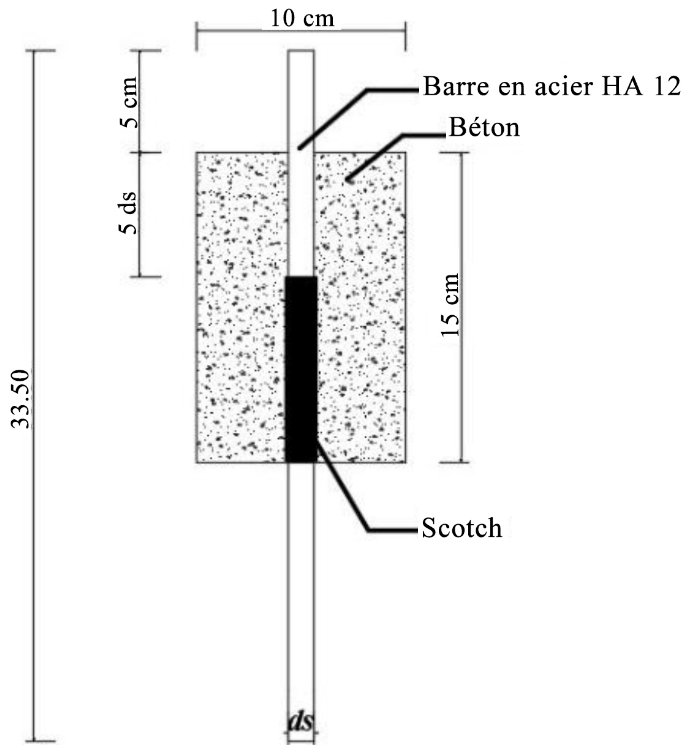

Figure 6. Test piece configuration for pull-out testing.

3. Results and Discussions

Figure 7 shows the average results obtained for each type of concrete.

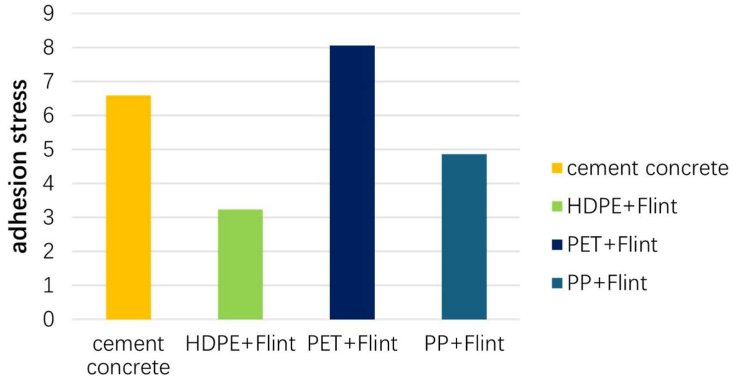

Figure 7. Average adhesion stress depends on the type.

Analysis of Figure 7 highlights significant differences in adhesion between the reinforcement and the matrix depending on the type of binder used.

Cementitious concrete performs well with an average pull-off stress of 6.59 MPa, accompanied by concrete failure illustrated in Figure 8(a), indicating excellent adhesion between the steel and the cementitious matrix.

(a) rupture by bursting

(b) rupture by sliding

Figure 8. Fracture behaviour of different concretes used in the pull-out test type of matrix.

For plastic concrete, the PET + flint formulation offers the highest strength (8.06 MPa). This demonstrates PET's strong ability to develop an effective bond with the reinforcement, to the point of causing the concrete to break. The pull-out strength of HDPE-based plastic concrete remains good (3.23 MPa) as it is higher than the usual reference values, despite being lower than other plastic concrete formulations. The slip failure mode shows in **Figure 8(b)** [8], and indicates a less effective interface, with no deterioration of the matrix. PP + silex has an intermediate performance (5.45 MPa) exceeding the standards for conventional concrete. Although the mode of failure is also related to slippage, the presence of an effective mechanical bond gives it a balanced profile, potentially viable for moderate or semi-load-bearing structural applications.

The pull-out test results indicate that certain specimens, notably cementitious concrete (2), HDPE + flint (3) and PET + flint (3), have significantly lower pull-out resistance values than the other samples in their category. This behaviour can be explained by poor centring of the reinforcing bar in the matrix, as illustrated in **Figure 9**, which promotes an asymmetrical distribution of adhesion stresses, reducing the efficiency of load transfer and leading to early slip initiation or localised failure without complete mobilisation of the matrix.

Figure 9. Off-centre bars in the matrix.

3.1. Comparative Analysis of the Results of the Pull-Out Test

To evaluate the performance of plastic concretes formulated with recycled polymers (HDPE, PET, PP) and flint, it is essential to compare them with the reference values for steel-cement concrete adhesion. These different values are recorded in **Table 1**. According to BAEL standards and experimental observations, the typical bond stress for medium-strength cementitious concrete (≈25 MPa) is between 2.8 and 3.2 MPa [9].

Table 1. Comparative table of pull-off test results for the two types of concrete.

Formulation	τmax average (MPa)	Deviation from the reference (≈3 MPa)	Dominant failure mode	Interpretation
Cementitious concrete	6.59	3.59	Concrete breakage	Excellent adhesion, exceeding standards
HDPE + Fint	3.23	0.23	Sliding	Adhesion just above the reference threshold
PET + Fint	8.06	5.06	Concrete breakage	Excellent adhesion, far superior to cementitious materials
PP + Fint	4.86	1.86	Sliding	Moderate adhesion, viable for secondary structures

3.2. Influence of Plastic Type on Fracture Mode

Figure 10 shows the fracture patterns of the different types of concrete used in the pull-out test.

Figure 10. Facies after rupture for cementitious concrete (a) and PET (b).

Figure 10 shows crack-induced failure behaviour for cementitious concrete in Figure 6(a) and PET-based plastic concrete in Figure 6(b), confirming their similar behaviour in failure mode.

This illustrates that PET can partially replace cement in demanding applications.

For HDPE and PP polymer-based concretes, a bar slip failure mode is observed, exhibiting brittle behaviour under tear loading.

Nevertheless, the results show that they provide adequate adhesion, sufficient for their use in secondary or optimised structures.

4. Conclusions

Plastic pollution is now one of the most pressing environmental challenges worldwide, particularly due to the slow degradation of polymers and their accumulation in natural environments. With this in mind, our study is part of a drive for innovation and sustainable development in the construction sector, exploring the use of recycled plastics as an alternative binder to cement in reinforced concrete. Through a rigorous experimental approach, it was possible to compare the adhesion performance between reinforcement and matrix in two types of concrete: one conventional, cement-based, and the other melted plastic-based.

The comparative study of adhesion between reinforcement and matrix revealed good adhesion in plastic concrete, although slightly lower than that observed in cement-based concrete. However, this difference remains within a tolerable margin for certain non-structural applications, and even structural applications under controlled conditions. This solution could therefore be a reliable alternative to traditional concrete, particularly in contexts where sustainability is sought.

Nevertheless, the introduction of these plastic concretes into the construction industry represents a promising prospect. It offers a concrete response to the challenges of plastic pollution while paving the way for lighter, more resistant building materials that are adapted to local resources.

Looking ahead, studies on ageing and fire behaviour will be required to ensure its applicability on a large scale.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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