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DEVELOPMENT AND CHARACTERIZATION OF A COMPOSITE MATERIAL REINFORCED BY PLASTIC WASTE: APPLICATION IN THE CONSTRUCTION SECTOR

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ABSTRACT: Waste reuse is subject to an increasing amount of research aimed at reducing the negative impact of such material on the environment. This study explores the possibility of using plastic waste as reinforcement in composite materials. A family of materials was developed using an unsaturated polyester resin (UPR) organic matrix and various mineral fillers (marble powder, expanded perlite, sand, etc.), potentially allowing their use in wall and floor coverings and as raw materials in the manufacture of traditional ceramic tables. Selected mechanical properties of these materials were verified, including flexural strength, tensile strength, and density. The results demonstrate the role of reinforcement in oriented fibers or matt fabric in improving the mechanical properties of the materials. Flexural strength is improved via reinforcement in the form of random or woven plastic fibers (32.44 MPa). However, the use of expanded perlite as a filler results in a lower mechanical strength (31.16 MPa) than marble powder or sand because of its friability.

Keywords: Eco-materials, Composite materials, Plastic waste recovery, Expanded perlite

1. INTRODUCTION

According to the federation of plastic producers “Plastics Europe”, around 311 million tons of long-duration degradability (200 to 1000 years) plastic were produced worldwide in 2014, compared with 299 million tons in 2013, [1], with very little of this recycled and recovered (20 to 30%) [2]. Whereas the informal sector focuses on a basic form of recycling to produce simple items such as baskets or buckets, the formal sector produces garbage cans, sewage pipes and other items that are not designed to come into contact with food, such as lubricating oil cans. Similarly, much of the large quantities of marble powder that are generated during the process of block cutting are thrown back into nature. The grain sizes of these powders vary between 300 and 700 nm [3], which makes them a significant environmental hazard.

In this context, the present study was aimed at the development of composite materials comprising an organic matrix (unsaturated polyester resin or UPR) and the aforementioned two classes of waste, with plastic reused as reinforcement, and marble powder, expanded perlite or sand as filler [4].

Several tests were carried out on the prepared composite materials to check the following:

• The influence of the type of reinforcement and fiber texture on material mechanical properties (tensile strength and flexural strength).

• The influence of the charge mixture on material mechanical properties (tensile strength and flexural strength).

2. MATERIALS AND METHODS

A polymer material based on an unsaturated polyester resin matrix was synthesized using a PMEK (Peroxide Methyl Ethyl Ketone) catalyst (1%) and a cobalt octoate hardener (2-3%) [5]. The charge of the prepared composite was made using a range of materials, including marble powder, expanded perlite, calcium carbonate, kaolin, and synthetic sand. For the reinforcement of this composite material, crushed plastic waste of varying architecture (impregnated particulate reinforcement or very fine particles, unidirectional (UD) oriented fibrous reinforcement, woven reinforcement, and random fibrous reinforcement) were used as base materials [6].

In order to compare the mechanical performances of the composite materials, a variety of fiberglass architectures were used as reinforcement instead of plastic waste (fiberglass woven fabrics, canvas woven fabrics, glass woven mat) [7]. The preparation of the materials was carried out at ambient temperature, and proceeded as follows: The prepared dough was placed in an open mold to obtain the desired shape, with the mold then closed and the material compressed until complete hardening had been achieved. Figure 1 displays a flow chart of the manufacturing process.

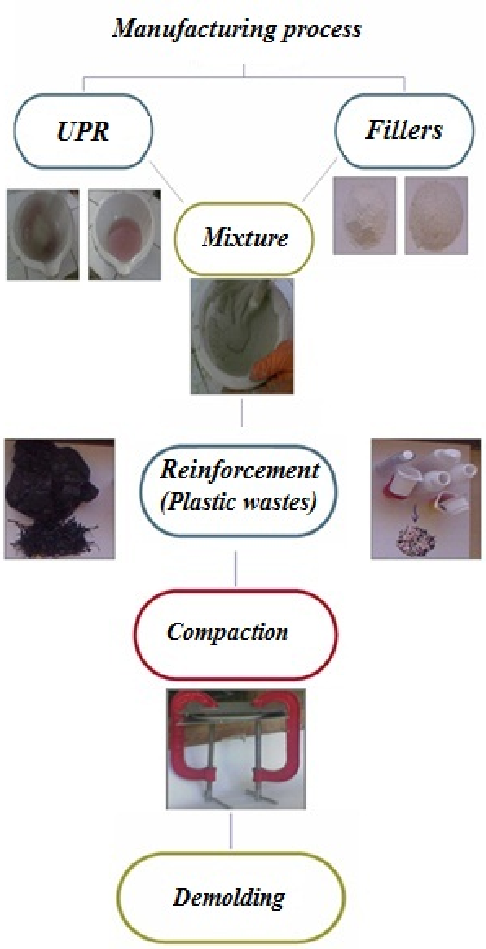

Fig. 1 Manufacturing process of composite materials

Rheological tests were then performed to determine the nature of the synthesized composite materials [8], including analysis of:

- resistance to bending and breaking force.
- water absorption.
- apparent relative density.

An example of a prepared sample is shown in Figure 2.

Fig. 2 A prepared sample

2.1 Family composition

All the composite material families synthesized using the various reinforcement and charge types are displayed in Tables 1 to 4.

2.1.1 Influence of reinforcement texture on composite materials (plastic wastes)

Families of composite materials synthesized using different textures of plastic waste as reinforcement are shown in Table 1.

The range of plastic reinforcement types was selected in order to evaluate the influence of texture on the mechanical properties of the final material. For all families of materials (1,2,3,4) listed in Table 1, unsaturated polyester resin (UPR) was used as the matrix, with a hardener percentage of 3% and catalyst percentage of 1%.

Table 1 Formulation of composite materials with different types of plastic reinforcement texture

Family	Matrix	Reinforcement	Charge
1	UPR	Plastic bags (Impregnated particulate)	Marble powder
2	UPR	Plastic bags (Oriented fibrous reinforcement UD)	Marble powder
3	UPR	Plastic bags (Woven reinforcement)	Marble powder
4	UPR	Plastic bags (Random fibrous reinforcement)	Marble powder

2.1.2 Influence of reinforcement rate on composite materials

In order to evaluate the influence of the reinforcement rate on the mechanical properties of the final composite materials, the texture type was fixed (unidirectional oriented fibrous reinforcement) and the percentage varied (10, 15, 20 and 25%). The mixture was then completed using the required percentage of marble powder [9], as shown in Table 2.

Table 2 Formulation of composite materials with different reinforcement rates

Family	Matrix	Reinforcement	Charge
2	UPR 25%	Plastic bags (UD oriented fibrous reinforcement) 25%	Marble powder 46%
2’	UPR 25%	Plastic bags (UD oriented fibrous reinforcement) 20%	Marble powder 51%
2’’	UPR 27%	Plastic bags (UD oriented fibrous reinforcement) 15%	Marble powder 54%
2’’’	UPR 30%	Plastic bags (UD oriented fibrous reinforcement) 10%	Marble powder 56%

2.1.3 Influence of reinforcement texture on composite materials (glass fibers)

Families 5, 6 and 7 listed in Table 3 were synthesized using glass fiber reinforcement instead of plastic waste. The texture of this reinforcement was also varied to evaluate its influence on the mechanical properties of the material.

Table 3 Formulation of composite materials with different types of woven reinforcement texture

Family	Matrix	Reinforcement	Charge
5	UPR	Glass woven fabrics (UD)	Marble powder
6	UPR	Canvas woven fabrics	Marble powder
7	UPR	Glass woven mat	Marble powder

2.1.4 Composite materials with different fillers

To evaluate the influence of the filler on the mechanical properties of the final composite materials, both the type of reinforcement (plastic waste) and reinforcement texture (unidirectional oriented fiber reinforcement) were fixed and the type of filler varied. These families contained primarily marble powder as their main element, together with other constituents such as expanded perlite, calcium carbonate, synthetic sand, and kaolin. The formulation of these materials is given in Table 4.

Table 4 Formulation of composite materials with different fillers

Family	Matrix	Reinforcement	Charge
8	UPR	Plastic wastes UD oriented fibrous reinforcement	Marble powder 36% + Kaolin 10%
9	UPR	Plastic wastes UD oriented fibrous reinforcement	Marble powder 36% + Perlite 10%
10	UPR	Plastic wastes UD oriented fibrous reinforcement	Marble powder 36% + Synthetic sand 10%
11	UPR	Plastic wastes UD oriented fibrous reinforcement	Marble powder 36% + Calcium carbonate 10%

3. RESULTS AND DISCUSSION

3.1 Determination of flexural strength and tensile strength

As shown in Table 5, the mechanical properties of the synthesized composite materials were highly influenced by the texture of the plastic fiber reinforcement. The woven fabric texture achieved the highest tensile strength, with the surface properties of the resulting composite material providing resistance in two dimensions [10].

Table 5 Influence of plastic reinforcement texture

Sample	Reinforcement architecture	Tensile strength (MPa)	Stress (MPa)
1	Impregnated particulate reinforcement (very fine particles)	23.10	29.75
2	UD oriented fibrous reinforcement	23.80	30.64
3	Woven reinforcement	25.20	32.44
4	Random fibrous reinforcement	24.90	31.93

Composite material stress was also highly dependent on the texture of the introduced fibers (Figure 3) [11]. When the reinforcement was distributed randomly, the obtained material exhibited an average performance [12]; in contrast, when the fibers were oriented in a specific direction, the produced material exhibited resistance, which typically depends on the direction of the applied load.

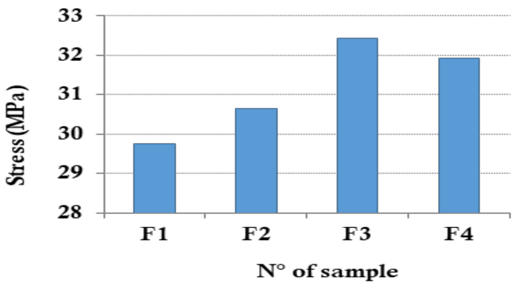

Fig. 3 Measurement of stress in composites with different types of reinforcement (samples 1, 2, 3, 4)

Table 6 shows the influence of the rate of reinforcement on the tensile strength and stress of the tested samples.

Table 6 Influence of rate of plastics reinforcement

Sample	Reinforcement rate	Tensile strength (MPa)	Stress (MPa)
2	25%	23.80	30.64
2’	20%	23.45	30.19
2’’	15%	22.90	29.5
2’’’	10%	22.75	29.3

As illustrated in Figure 4, sample 2 (reinforcement rate of 25%) achieved the highest flexural strength, while sample 2''', which was synthesized using the lowest (10%) rate of reinforcement, exhibited the lowest flexural strength. Thus, the composite material flexural strength increases with increasing plastic fiber percentage [13]. This is due mainly to matrix - fiber adhesion and the latter’s ability to stop the propagation of cracks.

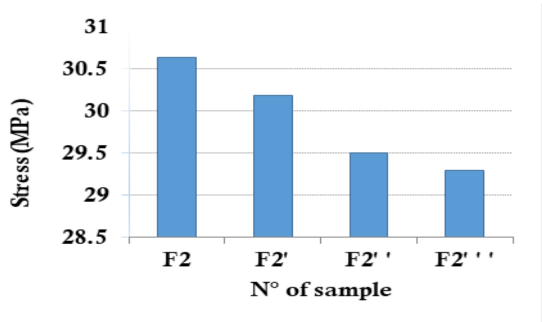

Fig. 4 Measurement of stress in samples with different rates of reinforcement (samples 2, 2’, 2”, 2”’)

Figure 5 shows the stress results recorded for the samples reinforced with different textures of glass fiber in comparison to that reinforced with woven plastic (sample 3). Analysis of this graph reveals that samples 3 and 6 exhibited similar stress values, reflecting the fact that these samples possessed the same fiber texture. In contrast, a change in the fiber texture resulted in an increase in material flexural strength (Table 7), likely associated with the random dispersion of fibers in the plane of the reinforcement (samples 5 and 7) [14].

Table 7 Influence of glass reinforcement texture on material properties compared to sample 3 (woven plastic)

Sample	Type of reinforcement	Tensile strength (MPa)	Stress (MPa)
3	Plastic bags as tissue	25.20	32.44
5	Glass woven fabrics (UD)	26.23	33.77
6	Canvas woven fabrics	25.00	32.19
7	Glass woven mat	25.83	33.26

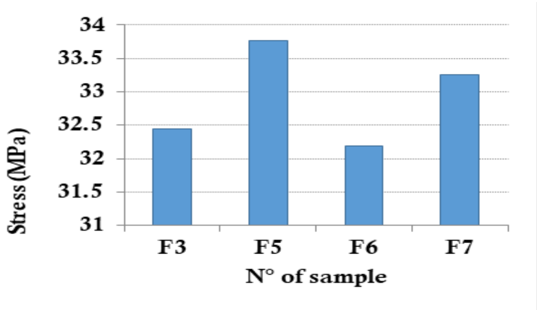

Fig. 5 Measurement of stress in samples with different textures of glass reinforcement (samples 3,5,6,7)

Figure 6 shows the stress values recorded for samples with the same type of reinforcement (plastic waste) and varying filler/charge compositions. Analysis of this figure reveals that the components of the filler have a considerable influence on the final mechanical properties of the synthesized composite material, with sample 9 (filler mixture of marble powder and expanded perlite) recording the lowest stress value (31.16 MPa).

This result can be explained by the fragile and porous structure of the expanded perlite, with the final composite compressive strength determined largely by the partial filling of these voids by the other components. Nevertheless, expanded perlite is a very good building insulation material whose porous structure provides the synthesized composite with significant thermal properties [15].

Table 8 Influence of filler composition on composite material properties

Sample	Rate of charges	Tensile strength(MPa)	Stress (MPa)
Marble powder + Kaolin	36 % + 10 %	26.05	33.55
Marble powder + Perlite	36% + 10 %	24.20	31.16
Marble powder + Synthetic sand	36 % + 10 %	25.52	32.86
Marble powder + Calcium Carbonate	36 % + 10 %	26.15	33.67

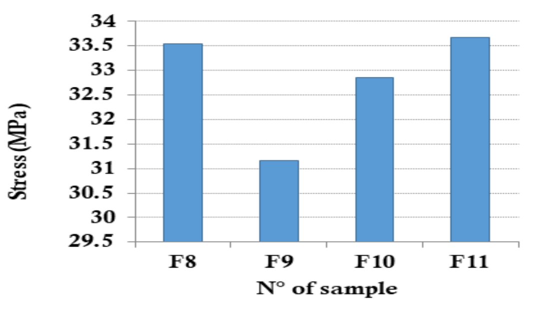

Fig. 6 Measurement of stress in samples with different filler compositions (samples 8,9,10,11)

3.2 Determination of water absorption in composite materials with different textures of plastic reinforcement

The results of the water absorption tests for the synthesized composite materials are shown in Table 9.

These data exhibit a similar pattern to the water absorption results obtained by Loos and Springer [16]. Thus, the main diffusion parameters of the synthesized composite material depend very strongly on the texture of the reinforcing fibers.

Table 9 Water absorption of composite materials with different textures of plastic reinforcement [17]

Reinforcement texture	Absorption %
Impregnated particulate reinforcement (very fine particles)	1.0
Oriented (unidirectional) fibrous reinforcement (long fibers)	1.4
Woven reinforcement	1.9
Random fibrous reinforcement (long fibers)	1.8

3.3 Determination of apparent relative density in composite materials with different textures of plastic reinforcement

Table 10 displays the relative density results obtained for samples synthesized using the same filler (marble powder) and varying reinforcement textures. Analysis of these data reveals that the reinforcement texture does not greatly influence the density of the synthesized composite material [18]. The use of composite materials is increasingly common as they allow the construction of structures with a lower weight than those built of metallic materials, whilst maintaining rigidity and resistance at acceptable levels.

Table 10 Apparent relative density of composite materials with different textures of reinforcement

Reinforcement architecture	Density(g/cm^3)
Impregnated particulate reinforcement (very fine particles)	2
Oriented (unidirectional) fibrous reinforcement (long fibers)	2.1
Woven mat reinforcement	2.05
Random fibrous reinforcement (long fibers)	2.03

4. CONCLUSION

In view of the results obtained for the composite materials synthesized using an organic matrix and mineral filler, the following conclusions can be drawn:

- The mechanical properties of the composite materials are influenced by the fiber architecture of the reinforcement.
- A texture comprising woven or randomly oriented fibers provides better resistance than other fiber textures.
- Reinforcement with plastic waste fibers is similar to that obtained using glass fibers with the same texture.
- The weight of the final composite material produced is decreased when expanded perlite is introduced in the filler.

Composite materials containing a mixture of UPR reinforced with short fibers derived from plastic wastes, and mineral fillers such as expanded perlite and marble powder, are environmentally friendly and are suitable for use in sustainable development projects. In fact, these eco-materials can have various applications in building construction, wall and floor covering, and as a raw material in the manufacture of traditional ceramic tables. The physical, mechanical and chemical properties of these eco-materials compared to those of traditional concrete materials are interesting and do not allow the absorption of moisture.

5. ACKNOWLEDGMENTS

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6. AUTHOR CONTRIBUTIONS

Halimi Youssef performed the experiments, drafted the article and interpreted the results as part of his PhD research project, under the supervision of Prof. Zyade Souad. Inchaouh Manal performed the experiments and interpreted the results. Prof. Tahiri Mohamed conducted and oriented the experiments, and assisted in data interpretation and in developing partnerships with businesses.

7. ETHICS

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript, and that there are no ethical issues involved. This article is an original work and is not currently under consideration for publication in any other journal. There are no conflicts of interest associated with this paper.

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