THERMAL AND FIRE BEHAVIOUR OF CEMENT BLOCKS WITH RECYCLED ROOF WASTES

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ABSTRACT

In accordance with the European politics of reducing the amount of plastics and polymers sited in landfills, the inclusion of compounds such as roof wastes as recycled and reusable materials to replace variable amounts of aggregates is interesting in the production of new construction materials due to their physical and chemical behaviour. Mortars made with Portland cement, sand, water and grinded roof wastes from the automobile industry that replace in different amounts part or all of the aggregates are examined in this study. To try to avoid the mechanical resistance limitation due to the use of roof wastes, the chemical properties of the binders have been modified with non-ionic surfactants that changed the effect on the hydration of the clinker. This variation produces an important change in the mechanical resistance to achieve recycled structural materials with a low density compared to conventional light mortars. In addition, these additives improve other properties including workability, compaction of the matrix, prevent the disintegration of the particles and help to improve the mechanical properties, ductility, thermal resistance and durability against fire to reinforce the materials. These eco-mortars have a lower thermal conductivity as more quantity of roof wastes are incorporated, which greatly favours the thermal insulation of the final envelope, as well as a good behaviour against temperature, measured in terms of thermogravimetry and non-combustibility test. With these results, we can consider the use of roof wastes as a sustainable alternative to the materials currently used and then with them we can be able to contribute to a more ecological business model in the building sector.
Keywords: recycled ceilings, lightweight prefabricated, fire resistance, polyurethane.

1 INTRODUCTION

In an effort to reduce the dependence on raw materials and reuse waste, we are working on numerous awareness, reuse and recycling actions in European, national and regional programs, which leads to the development of new techniques for recycling wastes for the construction materials, moving from waste to new raw materials, in order to close production cycles towards continuous reuse.

The polyurethane sector involves only in Europe 18,000 people and moves a turnover of about 4,000 million euros. Worldwide, it involves 240,000 companies, with one million jobs and generates an economy worth of about 207 billion euros. Trials are underway to introduce recovery systems for construction waste in order to divert it from landfills and treat it according to the other options at the end of its life. The main technologies for recycling polyurethane and its derivatives are energy recovery, mechanical recycling and chemical recycling. The lack of a collection, sorting and processing infrastructure has somewhat blocked the recycling of this waste.

In addition, the construction sector plays an important role in the economy. It generates almost 10% of GDP (Gross Domestic Product) and provides 20 million jobs in Europe, mainly in micro and small companies. Moreover, the materials used in building and civil works represent 42% of our final energy consumption, approximately 35% of our greenhouse gas emissions and more than 50% of all the materials removed.

This research is about the use of waste from complete roofs generated in the automobile industry, valued as raw material with added value for its incorporation into the precast

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industry of the construction sector, less technical and consumer of a huge amount of natural resources (aggregates, cement, energy, water, CO_2 emissions, etc.)

The replacement percentage depends on the properties of the final product required in each case, with final properties in the hardened state enough to be able to apply the current legislation.

It is proposed as the basis for a circular economy network and reuse of a waste found in large quantities, and the development of sustainable innovation solutions for cement mortars in construction.

2 RAW MATERIALS

Prefabricated fire-resistant cement lightened with industrial waste of polymeric origin, from recycled vehicle roofs. We have manufactured it with the form of blocks.

The characteristics and nature of construction materials, based on cement, make possible to enhance foams that come from polyurethane insulating panels with remains of other materials (adhesives, metal oxides, remains of paint and/or plastering, etc.) to avoid the difficulties to reuse the material and prevent its shipment to landfill.

The precast is composed of the raw materials detailed below:

- Commercial cement;
- Arid;
- Shredded waste with polyurethane matrix;
- Additives;
- Water.

The cement/aggregate dosage is 1/6 by weight, considering the aggregate as the addition of sand plus the polymer residue. The precast cement lightened with polymer matrix residues, provides improvements in the physical characteristics of the precast, with weight reductions of up to 70%.

2.1 Cement

The cement is the CEM I 52.5 R. type according to the UNE-EN 197-1: 2011 “Cement” standard, Portland Cement with a mass composition of 95–100% of clinker and 0–5% of minority components. These values refer to the cement core excluding calcium sulphate and any additives. The mechanical requirements are right with a compressive strength at 2 days more than 30 MPa and at 28 days more than 52.5 MPa. The beginning of setting is more than 45 min and the expansion is less than 10 mm, which meets the physical requirements according to the regulations. The chemical requirements are also adequate, with loss on ignition less than 5%, insoluble residue less than 5%, sulphate content less than 4% and chloride percentage less than 0.10%.

2.2 Aggregates

The aggregates used in the preparation of mortars follow the standard UNE-EN 13139: 2003 “Aggregates for mortars”, with the use of particles smaller than 4 mm and with a sand with rounded and not very angular shapes, typical of granular natural aggregates.

The content in fines for this 0/4 aggregate has a maximum percentage in passes through the sieve of 0.063 mm of 5%. The bulk density is 1,670 kg/m^3.

2.3 Polyurethane

The polyurethane waste comes from recycled vehicle roofs, with a bulk density of 92.5 kg/m^3 and a density of 1,681 kg/m^3.

Two different types of additives have been used (non-ionic surfactants, hydrophobic/ hydrophilic composition) in the manufacture of mortars, which modifies the chemical properties of their components. It produces an improvement in the hydration of the cement (they reduce the amount of water needed in dosages) and improve their properties. We used a percentage of additives of 1% in relation to the weight of cement.

This alteration in the components of the precast cement helps to maintain their mechanical strength, obtaining recycled materials with structural properties, and at the same time, with a low density in relation to conventional light mortars.

2.4 Water

We added water in an amount that guarantee an appropriate consistency, good workability and a plastic state in the mixtures, in accordance with the UNE-EN 1015-3: 2000 standard "Test methods for masonry mortars. Part 3".

3 RESULTS

3.1 Properties in fresh and hardened state

We have mixed cement type CEM I 52.5 R, the crushed waste from recycled vehicle roofs with a polyurethane matrix (with particle sizes less than 4 mm) and aggregates (the amount of sand is replaced by different percentages of the polymer waste by volume). The cement/aggregate dosage is 1/6 by weight, considering the aggregate as the addition of sand plus the polymer waste. We added different additives to each dosage: one very hydrophilic and the other slightly hydrophilic to study their influence.

We made different dosages and measured the properties in fresh and hardened state.

1. Substitution of 50% of aggregate with polymer waste, and a hydrophilic unit 3 EO (very hydrophilic) in relation to the weight of cement.
2. Substitution 100% aggregate with polymer waste, and a hydrophilic unit 3 EO (very hydrophilic) in relation to the weight of cement.
3. Substitution of 50% aggregate with polymer waste, and a hydrophilic unit 10 EO (little hydrophilic) in relation to the weight of cement.
4. Substitution of 100% aggregate with polymer waste, and a hydrophilic unit 10 EO (little hydrophilic) in relation to the weight of cement.

The tests were carried out in accordance with the UNE-EN 1015 standard "Test methods for mortars for masonry", with all the requirements in all cases. For a good interaction, we mixed on the one hand, the cement, the water and the additive, to improve the effect of the surfactant on the cement.

Then, we added the mixture of waste and aggregate, and then we continue with the manufacture of the mixture with the conventional method.

The properties in fresh and hardened state are described in Tables 1 and 2.

Table 1: Properties in fresh and hardened state.

Dosages	Density (kg/m^3)	Shore hardness (Shore C)	Flexural strength (MPa)	Compressive strength (MPa)
1	1,667	81.3	5.38	13.27
2	873	46.7	2.52	4.05
3	1,250	84.5	2.85	5.13
4	763	57.1	1.62	3.71

Table 2: Properties in fresh and hardened state.

Dosages	Water absorption due to capillarity ($kg/m^2 \cdot min^{0.5}$)	Mortar classification	Absorption
1	4.24	W0	12.2
2	9.95	W0	48.6
3	7.15	W0	24.2
4	11.35	W0	59.5

3.2 Non-combustibility test

With the mixes described above, large blocks were manufactured to be able to place on site in a simple way as prefabricated products. We made the dosages described in Table 3.

Table 3: Dosages for large blocks.

Dosages	Cement (kg)	Aggregate (kg)	Polymer waste (kg)	Water (kg)	Additive (g)
1	6.67	20	1.12	5.63	66
2	5	–	1.62	5.10	50
3	3.75	12.3	0.63	2.73	38
4	3.75	–	1.25	3.60	38

The above mixtures have been tested to the "Non-combustibility test" that is defined in the UNE EN-ISO 1182: 2011 "Reaction to fire tests of products". The results obtained are described in Table 4.

Table 4: Results obtained in the non-combustibility test.

Dosages	Oven temperature increase (Δt) (°C)	Persistence of the inflammation (t_f) (s)	Loss of mass (Δm) (%)
1	41.6	368	10.72
2	48.5	1,072	32.31
3	29.2	517	14.24
4	81.3	745	38.17

Taking into account only their contribution to the flammability of the materials, these results indicate that all mixtures except number 4 can be classified on fire as Euroclass A2, that is, non-combustible, without contribution to fire, according to the UNE-EN standard. 13501-1: 2007 + A1: 2010 "Classification based on fire behaviour of construction products and building elements. Part 1: Classification from data obtained in Reaction to fire tests".

4 CONCLUSIONS

We have made a precast concrete lightened with the shape of a block with industrial waste of polymeric origin from recycled vehicle roofs that is fire resistant. For this, residues have replaced different percentages of aggregate from the precast mortar. Different additives, with polymeric constitution, have also been added to study their influence. In this way, mechanical resistance is maintained and even improved in relation to the reference values required by European regulations.

The density decreases as residue is added in relation to reference precast currently on the market, which means savings in the base structure and better workability when placing them on site.

In addition, these eco-precast mortar have a lower thermal conductivity as residue is incorporated, which greatly favours the thermal insulation of the final product, as well as a good behaviour against temperature and against fire, measured in terms thermogravimetry and non-combustibility (reaction to fire).

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