Recycled polyamide mortars modified with non-ionic surfactant: physical and mechanical strength after durability tests

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Abstract This paper presents an investigation into the incorporation of polyamide powder waste in mortars with a polymeric organic soluble non-ionic surfactant. Several samples were prepared by replacing the aggregate with amounts of 0, 25, 50, 75 and 100 % polyamide powder, to obtain lightweight materials. It was found that the presence of powder waste modifies the characteristics of fresh and hardened mortar while maintaining suitable properties such as workable life, water retention, vapour permeability and bonding in mixtures with up to 50 % of sand replaced by polyamide. The surfactant modifies the matrix microstructure and contributes to the hydration of the various cement phases. The assessed mechanical strength after performing the accelerating ageing tests remains sufficient with moderate amounts of waste, meaning that these mortars possess good overall durability. The experimental results showed that the addition of polyamide waste makes it possible to obtain lightweight materials more environmentally sustainable for use as masonry mortars.

Keywords Lightweight mortar · Polyamide · Durability · Surfactant

Résumé Cet article a pour objectif d'étudier l'incorporation de déchets de polyamide réduits en poudre dans des mortiers additivés avec un tensioactif non-ionique. Afin d'obtenir des matériaux plus légers, plusieurs échantillons ont été préparés en remplaçant des proportions grandissantes de sable par de la poudre de polyamide (0, 25, 50, 75 et 100 % de substitution). Il a été constaté que la présence des déchets de poudre de polyamide influence les caractéristiques du mortier à l'état frais, tout comme à l'état durci. Néanmoins, des propriétés suffisantes en termes d'ouvrabilité, de rétention d'eau, de perméabilité à la vapeur d'eau et d'adhérence peuvent être conservées jusqu'à une substitution de 50 % du sable par des particules de polyamide. L'utilisation d'un tensioactif non-ionique modifie la microstructure de la matrice cimentaire comprenant des particules de polyamide et tend à favoriser l'apparition de certains hydrates. Les résistances mécaniques mesurées après des tests de vieillissement accéléré se maintiennent à des niveaux satisfaisants en présence d'un quantité modérée de polyamide recyclé, ce qui permet d'envisager une bonne durabilité de ces mortiers. Les résultats expérimentaux ont aussi montré que l'addition de poudre de polyamide permet d'obtenir des matériaux légers plus respectueux de l'environnement pour une utilisation en tant que mortier de maçonnerie.

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1 Introduction

In an attempt to reduce dependence on finite raw materials and the amount of plastic waste at disposal sites, numerous policies on waste reuse and recycling have been drawn up, leading to the development of new techniques for the recycling of waste for building materials [1, 2].

The properties of polyamides are generally the following: low viscosity before curing, thermal stability, chemical resistance, low yield stress and stress relief. They are therefore widely used for different applications in both the building and the industrial sectors. In this latter field and more specifically in laser sintering, they are commonly used as raw material for the manufacture of functional parts, due to their low density and their excellent mechanical properties. However, in terms of powder morphology, after polyamide has been used a limited number of times, it no longer fulfils its initial function because its particle size shrinks and its properties diminish. It then becomes a waste product, the value of which should be assessed [3].

Of the 57 million tons of polymers produced in Europe in 2013, polyamide production represents around 2 % or over a million tons [4]. Although there are no specific statistics regarding the amount of PA waste generated in the course of laser sintering, the estimated quantity of waste amounts to 20 % of the total, which represents approximately 200,000 tons of PA per year. Given the increasing demand for these types of polymers in recent years, which is far more than that of other plastics, this type of product must be taken into account in the appropriate management of sustainable development.

Polyamide powder waste was chosen to replace the aggregate on the basis of acquired experience and the preliminary studies that have been performed [5], with reference to the various dosages defined in investigations by other authors [6].

Although the density of polyamide powder waste is low, its value is compatible with some acceptable mechanical properties. Hence, it is very interesting to include these types of compounds as recycled and reusable materials to produce new lightweight building mortars. In this regard, it is essential to study the properties of these compounds as well as their performance and their long-term viability.

A soluble polymeric non-ionic surfactant, which limits the requirement of water to be dosed in order to obtain a good workable life, was chosen in this study. These types of additives can be adsorbed by the non-hydrated cement particles, thus avoiding water attack, as they contain various hydroxyl groups that facilitate the formation of hydrogen bonds, with oxygen ions on the surface of anhydrous products [7]. As a result, it is a cement surface activating agent, which modifies the hydrophobic capacities of pastes. As the additive is found in a liquid state, it may be dispersed more easily in the paste than in solid state, making the mortars more homogeneous [8].

Although there are previous studies on the influence of certain recycled compounds used as aggregates in mortars and concretes [9, 10], there are very few specific references related to the manufacture and the determination of ageing stability of conglomerates recycled with polyamide [11]. The object of this study is therefore considered useful for future applications of these materials as outdoor products.

2 Raw materials

Portland cement type CEM IV/B-(V) 32.5 N, commonly used in masonry, with a density of 3030 kg/m^3 was selected for the mortar mixes. Its chemical composition is 45–64 % clinker, 36–55 % fly ash (V) and 0–5 % of minority constituents, according to Standard EN 197-1:1994. *Cement composition, specification and conformity criteria. Part 1: common cements.*

Granular sand with a particle size of 0/4, a density of 2600 kg/m^3 and less than 0.2 % of fines was used, in compliance with European Standard EN 13139:2002 *Aggregates for mortar.*

Polyamide powder waste (PA) was obtained from raw waste material generated in an industrial laser sintering process. The microstructure was analysed by scanning electron microscopy, showing rounded particles with no roughness, of a more or less homogeneous size of between 40 and 70 Lm (Fig. 1). The real density of the PA is 1070 kg/m^3.

A surfactant additive in a liquid state from the BASF group of non-ionic surfactants, of the C13-oxo alcohol ethoxylate type, was used. A specific dosage of 2 % by weight of cement was tested, as already used in a previous study to promote a durable adhesion of pigmented particles into the skin of cement-based mortar [12].

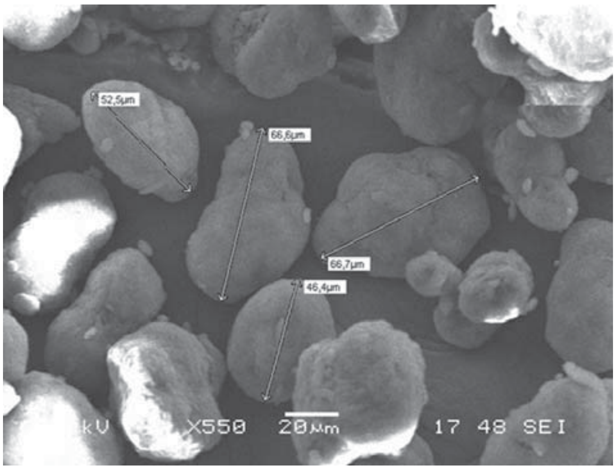


Fig. 1 Microstructure and particle diameter of waste polyamide

3 Mixtures

The manufacture of mortars using additives was carried out by following the standard operating procedure. The only difference relates to the incorporation of the additive. First, water, cement and additive were mixed, to optimize the effect of the surfactant on the cement clinker, then polymer waste and aggregates were added, prior to a conventional mixing process.

A 1/4 cement/aggregate ratio was dosed, where the aggregate is the sum of sand plus polymer waste. Sand was replaced by PA in amounts that varied between 25 and 100 %. Furthermore, reference samples were kept, in order to carry out a comparative study of their properties Table 1.

It has been demonstrated that the incorporation of certain surfactant additive in designed mortars could permit us to fix a 0.8 water/cement concentration, ensuring an appropriate consistence according to standard EN 1015-3:1999. *Determination of consistence of fresh mortar (by flow table).* Previous experiences show that the incorporation of polyamide in the mortar usually increases proportionally with the water needed to achieve a good workable life [13]. However, the incorporation of surfactant stabilise the amount of water required to achieve a good workable life. The additive reduces the surface tension and consequently the intake of water that this type of polymer waste usually requires when added to different binders [14], due to its small size and its large specific surface.

4 Properties of mortars

4.1 Water retention

The water retention capacity of mortars was determined with the standardized procedure in EN 83-816:1993. *Fresh mortars. Determination of water retentivity.* Water retention is useful to ensure that a mortar retains a sufficient amount of water for its curing process when high suction is applied.

Table 2 shows the water retention values of the different mortars. At first, it has a slight tendency to decrease when the waste is added, including the PA50TO3 dose, probably due to the lower water retention capacity of the polyamide and to the smaller quantities of cement with which the additive can interact. However, when the PA75 mixture was added, the effect was reversed, possibly due to lower porosity caused by the aggregation of the polymer particles, as observed in previous studies [15]. Nevertheless, there was no significant difference and the additive may be considered to lead to a similar performance in all the mixtures with regard to water retention, as is reflected by the numerical values in the table.

4.2 Workable life

The workable period of the mortars was determined in accordance with EN 1015-9:1999. *Determination of workable life and correction time of fresh mortar.* Workable life is defined as the time interval during which a mortar has a sufficient and appropriate consistency to be used without any subsequent addition of water. During this period, the mortar must not reach a hardening level caused by the setting principle, which would prevent its correct use.

The results obtained (Table 2) show that, as more polyamide is added, workable life increases considerably in a proportional way, i.e. a longer time period is required to reach the hardened state. This increase could be because there is less and less binder in the mixture, which slows down the setting process [16]. The explanation for this might be that the polyamide which is used as a substitute of sand first absorbing some water during the mixing and the beginning of the setting and later on dropping these matters during the setting. Thus, the result of adding PA leads to a change in the rheological properties of the material, obtaining materials with a low tendency to segregation, which in

Table 1 Dosage of the samples

Samples	Aggregate (%)		Aggregate (%)		Cement (g)	Additive (g)	w/c
	Sand (%)	PA (%)	Sand (g)	PA (g)			
RTO3	100	–	2400	0	600	1.2	0.8
PA25TO3	75	25	1800	279.1	600	1.2	0.8
PA50TO3	50	50	1200	558.2	600	1.2	0.8
PA75TO3	25	75	600	837.3	600	1.2	0.8
PA100TO3	–	100	0	1116.4	600	1.2	0.8

Table 2 Water retention, workability and density results for the mortars with and without surfactant T03

Sample	Water retention (%)	Workability (min)	Density with T03 (kg/m^3)		Density without T03 at 28 days (kg/m^3)	Decrease of density (%)
			7 days	28 days		
RTO3	91.0	254	2120	2048	2050	0
PA25TO3	89.9	321	1791	1764	1850	5
PA50TO3	87.6	310	1259	1271	1540	17
PA75TO3	89.0	600	908	886	1270	30
PA100TO3	91.0	1.035	699	662	950	30

turn could facilitates its application. In any case, the increase in workable life could imply slower production to put on site.

4.3 Density

Hardened density was measured at 7 days and at 28 days, at a temperature of 20 ± 1 ºC and at a relative humidity of 50 ± 1 %, according to standard EN 1015-10:2000. *Determination of dry bulk density of hardened mortar.*

Table 2 shows the results with regard to the density of wet-prepared masonry mortars. As expected, the mortar density in a hardened state is inversely proportional to the added quantity of polyamide. Furthermore, the density decreases over lengthier time spans from 7 to 28 days as a consequence of the mortar hardening process. If we compare the apparent densities of mortars modified with additives after 28 days with those of mortars without any additives, the results of which have previously been published, the values indicated a small reduction in density, which corresponded to 5 % in samples with 25 % added waste. When 50 % or more waste is added, the percentage density declined considerably from 17 to 30 %. Out of the 5 different dosages, the PA50TO3, PA75TO3 and PA100TO3 mixtures had a density of below 1300 kg/m^3 and these mortars may therefore be considered as lightweight.

4.4 Water vapour permeability

Water vapour permeability in a steady state was determined according to standard EN 1015-19:1999. *Determination of water vapour permeability of hardened rendering and plastering mortars*. This standard specifies that, in order to determine permeability, it is necessary to determine the water vapour flow that passes through an area of the mortar in a steady state, due to the pressure difference between both sides of the material. For this test, five cylindrical test samples were prepared for each mortar dosage, with a diameter of 160 mm and a thickness of 15 mm.

As more and more sand is replaced by polyamide waste, permeability is shown to increase considerably (Table 3). High vapour permeability in PA50TO3, PA75TO3 and PA100TO3 mortars (with 50, 75 and 100 % aggregate being replaced respectively) has a direct relation with the reduction of density and therefore with the increase of porosity. This property makes these mortars suitable for outer lining as well as for refurbishing mortars.

Table 3 Water vapor permeability test results

Sample	Permeance (kg/m^2 s Pa)	Permeability (kg/m s Pa)
RTO3	3.57E-10	5.35E-12
PA25TO3	7.76E-10	1.16E-11
PA50TO3	2.71E-09	4.07E-11
PA75TO3	3.32E-09	4.99E-11
PA100TO3	3.85E-09	5.08E-10

4.5 Adhesion

Adhesive strength was determined in accordance with standard EN 1015-12:1999. *Determination of adhesive strength of hardened rendering and plastering mortars on substrates*. The purpose of this test is to determine the adhesive strength between a rendering and plastering mortar and a ceramic support. The adhesive strength was determined by measuring the maximum pull-out traction supported by the mortar previously applied to the support.

The fracture in all the cases was classified as an adhesive type fracture (Table 4). In these cases, the standard indicates that the numeric value of the adhesive strength must reach a minimum required value of 0.1 MPa. This value is exceeded in mixtures that have a waste concentration of up to 75 %.

Although the incorporation of the surfactant additive entails a higher wetting capacity and therefore better hydration, the addition was not sufficient for the PA100TO3 mixture, which failed to comply with the minimum value required by the standard. This failure might be because the adhesive bonding stress reached in the mortar-ceramic support interface, which depends on the cement crystals anchoring in the pores of the support, does not occur appropriately in mixtures without sand, probably because the lower hydration degree of cement (more water bound to fine particles: high capillary head) so that less needles to adhere at the substrate.

4.6 Thermogravimetry

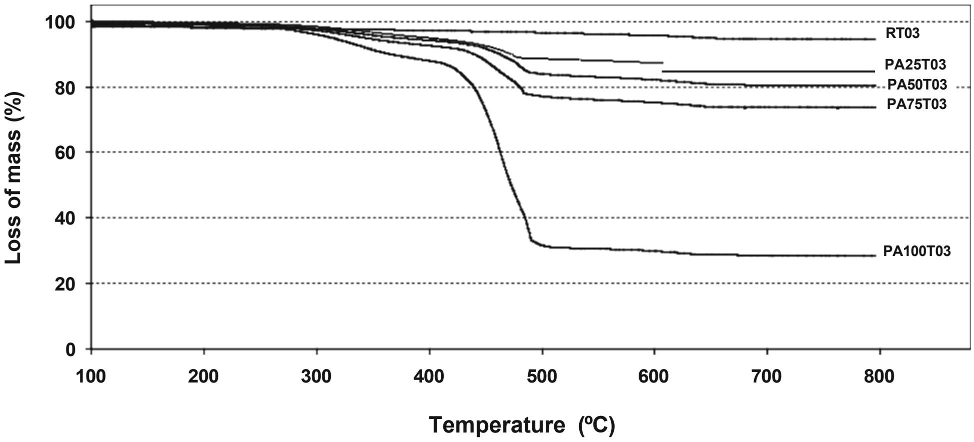
This test is very interesting when assessing performance against temperature, i.e. with a view to studying the loss of material that arises as the temperature increases. The results were recorded for 15 mg of sample in an air atmosphere, with a Mettler-Toledo TGA/SBTA851 analyser, at a scan rate of 10 ºC/min from 100 to 800 ºC.

Figure 2 shows the thermogravimetric curves obtained for the whole series of mortars that include surfactant, which represent the percentages of weight loss depending on the temperature. The test conditions consisted of an increase in atmospheric temperature by 10 ºC/min, from 100 to 800 ºC. The results indicated that, as organic matter was added, the loss of weight increased in proportion to the quantity of polymer. In any case, except for the mixture in which 100 % aggregate was replaced by polyamide, all the other

Table 4 Adhesion test procedure and results

Sample	Adhesion (MPa)
RTO3	0.35
PA25TO3	0.20
PA50TO3	0.16
PA75TO3	0.11
PA100TO3	0.08

Fig. 2 TGA in air, T_{max} and loss of mass for all the samples



Sample	Ti (ºC)	Tmax (ºC)	Loss of mass at Tmax (%)
RTO3	450	423	1.20
PA25TO3	450	474	10.2
PA50TO3	450	480	13.2
PA75TO3	450	481	19.3
PA100TO3	450	488	62.0

mixtures at different dosages showed a good performance, as the weight losses ranged between 15 and 20 % of the total weight. This indicates that there was a relatively small loss of material.

The TG derived curves indicate the speed of weight loss depending on the temperature, as well as the maximum average temperature for every dosage and the percentage of weight loss at that temperature (Fig. 2). As waste was added, the maximum temperature reached higher values. This temperature increase was probably due to rising interaction between the polymer waste and the cement paste, which delayed the waste decomposition. The cement would therefore have a protective effect against polyamide hydrolysis, shifting the material degradation temperature to higher values.

4.7 Scanning electron microscopy (SEM)

The samples were studied under a JEOL JSM-6460LV scanning electron microscope with an INCA system for X-Ray elemental analysis, using samples with a double gold coating to make them conductive.

The SEM images of Fig. 3 (in secondary electron mode) show that the addition of recycled polyamide entails a coarser interfacial transition zone, due on the one hand to the size of the polyamide particles and, on the other hand, to the existence of a larger transition zone induced by the water released by the waste material (that initially absorbs large quantities of water) [17].

Besides, due to the action of the TO3 surfactant, a significant amount of needle crystals can be seen around the polyamide particles, which are probably caused by the early formation of ettringite (hydrated calcium sulfoaluminate, which is formed in the early stages of cement hydration) [18]. Calcium hydroxide crystals can also be seen, i.e. the hexagonal portlandite particles that grow during cement hydration and occupy a large volume of the hydrated cement paste [19]. Indeed, the surfactant influences the interfacial transition zone by modifying the growth and the distribution of various hydrated cement phases. As studied also by other authors [20], this kind of crystallised microstructure could be due to the

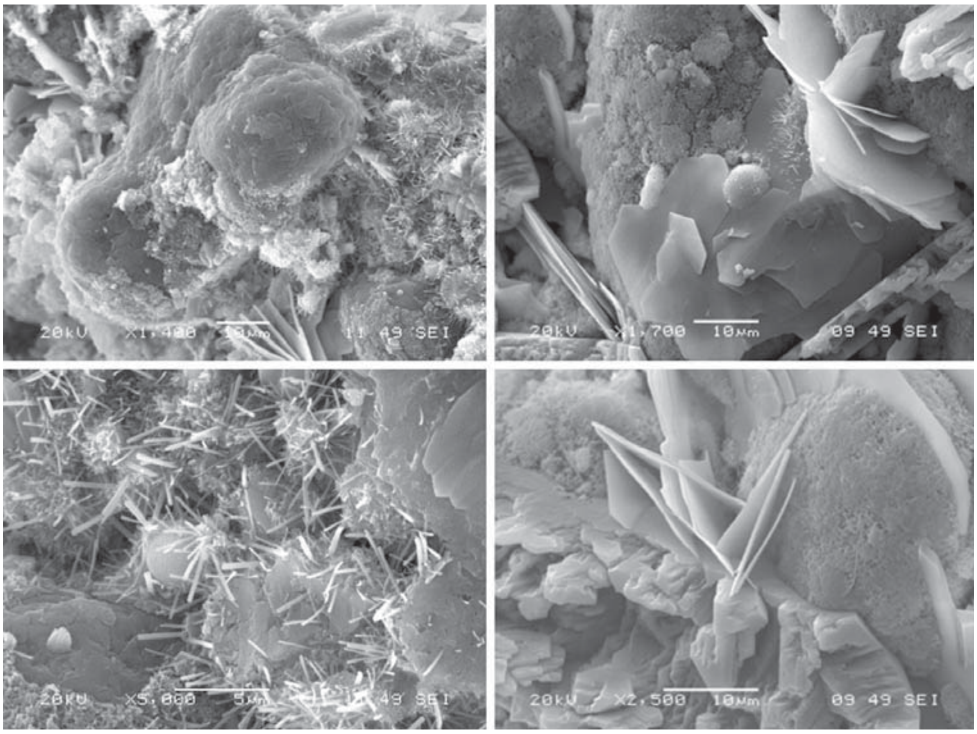


Fig. 3 Scanning electron microscopy (SEM) in secondary electron mode. *Top* sample PA25TO3. *Bottom* sample PA50TO3

surfactant that seems to promote a homogeneous nucleation by reducing the nucleus/water interfacial energy.

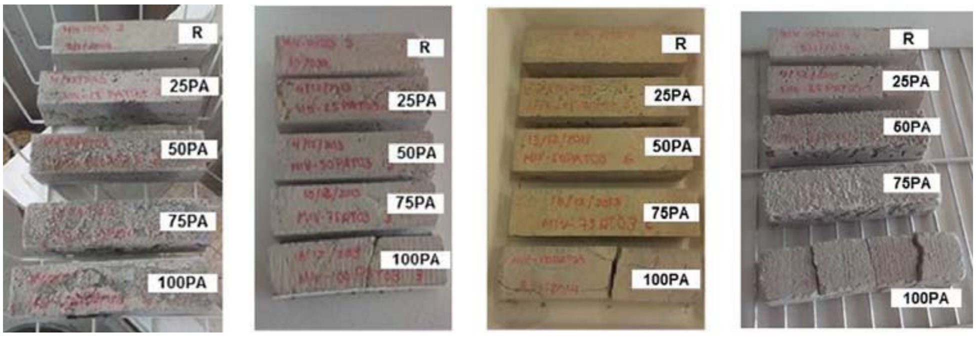
5 Durability test

The tests used to assess mortar mixture durability were the determination of frost formation, saline water, salt crystallization and thermal breakage. Five samples filled with $40 \times 40 \times 160$ mm^3 of every prism-shaped mortar dosage were used, to carry out each durability test. The non-existence of specific durability test specifications together with the similarity between the behaviour of natural stone and cement mortars permitted different standardised durability tests for natural stones.

5.1 Frost resistance

Performance tests against frost/thaw cycles assess the resistance of mortars that will be used as outdoor materials and indicate the parameters regarding the degree of internal cohesion of the particles that make up the mortar. Standard EN 12371:2010 *Determination of frost resistance* was adapted to carry out this test. The previously saturated specimen underwent 25 frost/thaw cycles: 6 h of air freezing saturated at −12 ºC, followed by an 18-h thawing period immersed in water at 20 ºC.

The frost/thaw test is based on the intermittence of frost formation and thawing inside the specimen and on the resulting changes in volume, which gives a characteristic pattern of final material breakage known as frost resistance. This factor depends on the degree of water intake that can be reached and varies according to the pore system within the material (open pores, closed pores, capillary pores, interconnected pores, etc.), which facilitate or hinder water entry. A test tube of each type of mixture was been taken (Fig. 4), for a comparative visual assessment of the dosages. The result was that the mass loss in the samples increased slightly when the polymer was added. In any case, although this might visually appear to be a negative aspect, if the weight variation before and after the frost resistance test is numerically quantified (Table 4), there were no significant variations even in the most unfavourable dosage, PA100TO3, which has no fines. Therefore, mortars with recycled polyamide may generally be considered frost resistant.



Frost resistance Thermal shock Hot salt water Salt crystallization after 9 cycles

Fig. 4 Samples after different durability test

Table 5 Loss of mass after each durability test

Sample	Loss of mass after durability test (%)			
	Frost resistance	Thermal shock	Hot salt water	Salt crystallization
RTO3	−4.4	0.8	−4.4	−0.6
PA25TO3	−5.8	0.5	−5.2	−1.8
PA50TO3	−3.3	0.1	−4.7	−3.0
PA75TO3	2.4	0.4	−4.2	−3.6
PA100TO3	1.4	–	–	–

5.2 Thermal breakage

Changes in temperature cause expansion and shrinkage depending on the material thermal expansion coefficient. This can cause breakage during shrinkage as a consequence of the retention from the bond between the finishing surface and the support. Standard EN 14066:2013 *Determination of resistance to ageing by thermal shock* was followed to perform the thermal shock resistance test. The operating procedure consists of changes in the temperature of the dry samples: 18 h in a kiln at 70 ºC followed by 6 h in water at 20 ºC. The complete cycle was repeated 20 times.

Resistance to ageing by thermal shock was assessed through the mass variation of the specimen at the end of the test (Table 5). After visually inspecting the samples (Fig. 4), the PA100TO3 mixtures that underwent the humid-dry test broke in the first 2 or 3 cycles, indicating that these specimens were unable to withstand the changes in strain or dimension that resulted from the thermal shock. All the other dosages resist without any problem.

5.3 Hot salt water

This test method is used to evaluate the expansion produced in mortar aggregates that contain hydratable components, and to determine ageing by verifying the potential expansion of the materials. The test procedure may be found in the American Standard ASTM D-4792:1999 *Standard Test Method for Potential Expansionof Aggregates from Hydration Reactions*.

In this test, some relevant chemical reactions are accelerated, such as the expansive hydration of calcium and magnesium oxides and some alkali-aggregate reactions, or hydraulic or pozzolanic reactions between mortar components and seawater, the final results indicating the global evolution of these mixtures over time.

At the end of the salt-water test (Fig. 4), the final stage of the samples can be seen, where the mixtures corresponding to the 100 % replacement of sand by polyamide had broken into two or more fragments, even before the end of the test cycle (14 days). It can therefore be concluded that the test failure for this PA100TO3 dosage was not due to problems of reactivity with salt water, but to the problems encountered by this composition with thermal shock.

5.4 Salt crystallization

Salt crystallization is one of the most important and most aggressive alteration mechanisms that a material can undergo, especially if it is porous. Although there is no specific standard to determine the expansion of mortars due to the presence of soluble salts, standard EN 12370:1999 *Determination of resistance to salt crystallization* was adapted for that purpose. The aim of this test consist to analyse the degree of resistance to salt crystallization when mortars are exposed to 14 cycles of 4 h immersed in saturated salt water with $Na_2SO_4 \times 10H_2O$, following 2 h at air temperature and finally 18 h into an oven at 100 ºC. This test is extremely aggressive as, once water evaporates, the salt left in the mortar crystallizes and occupies 17 times more than in solution. If an excessive degradation occurs during the test, it is stopped and the number of cycles performed is registered. Resistance to soluble salt crystallization is calculated by the mass loss in the samples at the end of the test.

Figure 4 shows how degradation becomes visible after a few ageing cycles for all the dosages. In fact, all the PA100TO3 dosage samples break up, which means that they must be separated before the end of the test. When analysing both the surface and the internal matrix of the mortars after analysing them through scanning electron microscopy, salt deposits were observed (Fig. 5), which entails efflorescence phenomena on the surface and internal expansions, which cause tensions that lead to total or partial disintegration of the samples [21].

A weight gain occurred after the test, due to the presence of salts from the saturated sodium sulphate solution (Table 4), which was greater as the quantity of polymeric waste increased up until substitutions of 50 %. On the contrary, as from the PA75TO3 dosage, the weight of the samples decreased due to the loss of material during the sample disintegration.

5.5 Average weight variation

The samples were visually examined and their average weight variation was determined before and after each test, to verify the degree of disintegration (Table 5). All the mixtures underwent a loss of material after undergoing accelerated ageing tests, except in the case of thermal shock, where a weight gain occurred after the test, which may have been caused by the presence of salts from the salt-water test. These experiments were not correlated with field performance and are not necessarily indicative of the expansion that can occur under service conditions.

5.6 Mechanical properties

Five different test specimens were tested under flexion for each composition and ten under compression, before and after the durability test: EN 1015-11:2000 *Determination of flexural and compressive strength of hardened mortar*. The test samples measured 40 mm × 40 mm × 160 mm, and the bottom support rollers were separated at intervals of 100 mm. The resulting fragments in this test broke under compression using a load surface of 40 mm × 40 mm.

A comparative study was carried out about the effect of these ageing tests on the flexural and

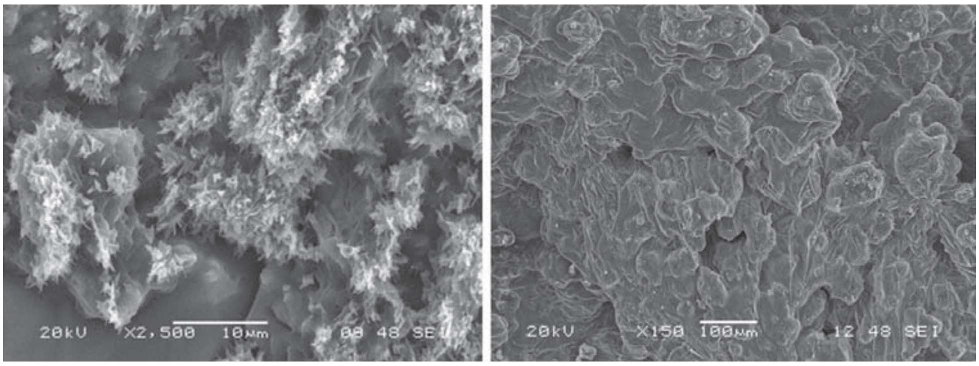


Fig. 5 Scanning electron microscopy of samples after durability test. *Left* Crystallization salt in the internal matrix. Sample PA75TO3. *Right* Deposition of salts on the specimen’s surface

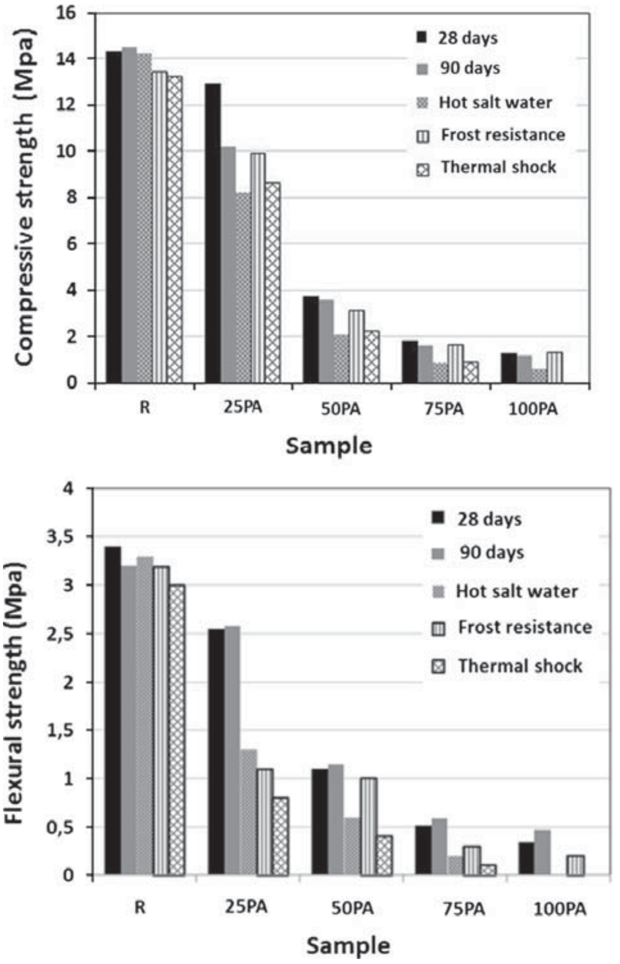


Fig. 6 Compressive strength and flexural strength before and after durability tests

compressive mechanical properties. This study considered the results obtained with 28-day and 90-day-old reference specimens with additives (that were not subjected to any durability tests) and specimens without any surfactant that might have an influence on the properties of the material (Fig. 6).

The progressive replacement of sand by polyamide entails a reduction in both flexural and compressive mechanical strength, which becomes greater as the cement/(aggregate ? PA) ratio increases.

Besides, the mixtures are shown to maintain their compressive strength more or less in all cases except for the salt-water test (hot salt water) where a decrease in the compressive mechanical strength is only observed in mixtures that include polyamide waste. This is probably due to the larger quantity of polymer in the mortar matrix together with the progressive elimination of aggregate, which facilitates the attack of salts diluted in hot water during the test and contributes little to the final strength [22].

With regard to mechanical strength after subjecting the samples to all of the other accelerated ageing tests, there was no excessive variation, which means we may assume that performance in service would be similar to the performance of materials without any waste in their matrix.

6 Conclusions

The fabrication of mortars containing polyamide powder waste and surfactant (using conventional procedures) has proved to be viable. Increasing amounts of polyamide particles contribute to slower setting processes, which is reflected in the findings regarding workable life, which rise as more waste is added.

Among other effects, the presence of surfactant causes relatively constant water retention, regardless of the quantity of polyamide, which means it is possible to achieve lower densities and mortars considered as lightweight with a replacement of aggregate by polymer of 50 % onwards. The additive also contributes to the hydration of the mortar, which is observed with the presence of ettringite particles and portlandite hexagonal crystals in the early stages of material hydration.

The thermal performance of these mortars is considered appropriate, including a substitution of as much as 75 % of aggregate. The ever-increasing presence of waste causes an increase of the maximum operating temperature of the material, although with more and more substantial weight losses.

The durability tests have shown that the performance regarding accelerated ageing is acceptable, except in test-tube specimens with a total replacement of aggregate by waste, where the matrix does not have sufficient internal bonding to withstand long-term outdoor exposure in situ. For the other mixtures with replacement lower or equal to 75 %, the mechanical strengths recorded in the tests are sufficient for the use of these materials as masonry and cladding mortars. In any case, mortars with PA and surfactant are more susceptible to durability tests showing lower residual mechanical characteristics in comparison to the control mixture. Applicability depends on application conditions: for heavy-duty use (for instance high salt attack conditions) lower replacement of than under constant dry application conditions.

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