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Use of cement Portland mortar of stabilised dry sewage sludge in construction applications

A. Yagüe, S. Valls and E. Vàzquez
Dept. of Construction Engineering, Universitat Politècnica de Catalunya, ETSECCPB.

Abstract

Our society generates a large quantity of waste which we should re-use, as is the case with dry sludge from sewage treatment plants. This sludge has been subjected to anaerobic digestion and then to a drying process that partially stabilises the organic matter, eliminates pathogenic micro-organisms and reduces the total volume of sludge to be handled. A DRX study of its crystalline fraction detects the presence of calcite and silica, and the absence of clays.

In this paper we study the influence of the presence of this sludge, used as an additive in Portland cement mortar, on the physical and mechanical properties of this mortar. The addition of sludge reduces the mechanical strength of the mortar, increases its porosity, reduces its density, and also retards the hydration process of the cement.

The use of sludge in mortar is beneficial in that, when it reacts with the cement and comes to form part of the binding matrix, the sludge stabilises and the quantity of leachable heavy ions is reduced in comparison with that of free dry sludge.

1 Introduction

This paper describes the preparation of a construction material containing waste added to a matrix with Portland cement. The waste in question is the dry sludge resulting from waste water treatment, which contains potentially toxic contaminants such as heavy metals.

The sludge used is a dry sludge from Sabadell (Barcelona) produced by anaerobic biological digestion. In the final phase of the waste treatment process, it undergoes a thermal drying process which substantially reduces its volume, thus facilitating handling and eliminating any pathogenic microorganisms that could be present.

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From the biochemical analysis of this sludge, it can be seen that there is a high proportion of carbohydrates (around 65%). These could affect the hydration of the Portland cement when it is used as an additive in mortar and concrete. The addition of small amounts of sludge from waste water treatment plants to mortar and concrete in Portland cement stabilises the toxic components. The heavy metals are fixed within the matrix formed by the hydration of the Portland cement Yagüe [1].

Previous work by the research team with wet sludge, which is more active than dry sludge, has shown that it is possible to stabilise the sludge in a matrix with Portland cement, Yagüe [1] and Valls [2, 3]. It is therefore to be expected that the dry sludge will be successfully stabilised and recycled in the matrix. This previous work showed that the addition of sludge produced a delay in the initial and final setting of the cement, and a decrease in mechanical strength, especially in the short term, Valls [2, 3] and Matamala [4].

2 Characterisation of the dry sludge

The sludge used was an anaerobic biological sludge with the following chemical, organic and microbiological characteristics (see Tables 1 and 2).

The Table 1 shows the results of organic and microbiological characterisation and the Table 2 the heavy metal concentration by the DIN 38414-S4 Leaching test [5] of the Sabadell dry sludge.

Table 1. Organic and microbiological characterisation of dry sewage sludge

Loss mass at 105 °C	19 %	Ashes	31.79 %
Loss mass at 500 °C	41.5-52 %	Aerobics	26 ufc/g
PH	7.1	Enterobacterium	< 10 ufc/g
Proteins	0.41 %	E. Colli	< 3 mnp/g
Fats	0.33 %	Coliform	< 3 ufc/g
Carbohydrates	65.47 %	Fungi	< 10 ufc/g
Organic Nitrogen	0.09 %	Clostridium	< 10 ufc/g
Phosphorus	0.38 %		

Table 2. Results of the heavy metal concentration of Sabadell dry sludge in mg/l by the DIN 38414-S4 Leaching test, and the concentration limits.

Metals	Conc. mg/l	DIN 38414-S4		Metals	Conc.mg/l	DIN 38414-S4	
		A	B			A	B
Ba	0.109±0.001	---	---	Mn	0.23±0.01	---	---
Zn	0.68±0.03	2	5	Cd	< 0.01	0.1	0.2
Ni	1.06±0.001	0.5	1	Cr	0.05±0.01	0.1	0.1
Pb	< 0.05	0.5	1	As	< 0.1	0.1	0.5
Cu	0.31±0.07	2	5				

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Decree 34/1996 of the Generalitat of Catalonia, of 9th January 1996 [6] approved a catalogue of waste, which was classified according to values of leaching obtained by the DIN 38414-S4 [5] leaching test. According to the DIN 38414-S4 leaching test, the dry sludge from the Sabadell treatment plant is a special case because the concentrations of nickel are very slightly above limit B of the standard.

In addition to the classification of the sludge according to the residue catalogue published by the Catalan Government, it is important to establish the availability of heavy metals in the sludge when it is subjected to a more aggressive method such as the Dutch NEN 7341 leaching test [7]. This test measures the fixing percentage of the contaminants in the binding matrix (see Table 3).

Table 3. Results of the leaching of the Sabadell (Riu Sec) sludge according to NEN-7341, availability leaching.

Metals	Conc. Mg/l	Conc.mg/kg Dry sample	Metals	Conc.mg/l	Conc.mg/kg dry sample
Ba	0.75±0.001	5.45±0.03	Mn	0.80±0.1	39±6
Zn	1.23±0.06	34±1	Cd	< 0.01	< 0.5
Ni	1.69±0.05	85±3	Cr	0.09±0.012	4.8±0.60
Pb	< 0.05	< 2.5	As	< 0.1	< 5
Cu	0.57±0.04	29±2			

The inorganic composition of the sludge, which was determined by X-ray diffraction, is quartz and calcite. These are two stable minerals which show no expansion behaviour when mixed in a binding matrix such as Portland cement. Furthermore, no clay-type minerals which could potentially increase the need for water in the mixture or generate expansion problems were detected.

We should take into account the fact that the waste, the sludge, is an additive to a building material with a binding matrix such as Portland cement. The granulometric fraction of the waste must therefore be assessed once it has been ground using a jaw grinder (see Table 4).

Table 4. Granulometry of dry sewage sludge

Sieve (mm)	% Past through
4,76	100
2,38	99
2,00	96
1,19	91,4
0,59	74,9
0,42	63
0,29	44,4
0,149	14
0,063	4,2

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3 Method

3.1 Introduction

The addition of dry sludges from the Sabadell waste water treatment plant to Portland cement pastes causes a delay in the hydration, setting and hardening of the paste Yagüe [1] and Valls [2]. This delay worsens with the amount of dry sludge added.

In the light of these facts, we propose to study the effects of adding different amounts of dry sludge in Portland cement mortar, and their influence on the concrete's compressive strength.

3.2 Method

The mortar is prepared as follows: the sludge is dried at 105 °C in order to remove all moisture, and it is then mixed into the cement when it is fed into the mixer.

Because we were expecting a higher water requirement when adding the sludge, we prepared two series of mortars. For one of them, we kept the proportions of water, cement and sand as they are in standard mortar (EN 196-1) [8], simply adding the sludge. For the other, we varied only the percentage of water when adding the sludge in order to keep the consistency as it is in standard mortar (UNE 83,811) [9].

With the exception of this variation in the amount of water, we prepared the mortar as specified by the standard, using standard sand and two kinds of cement: CEM I 52,5 R and CEM I 42,5 R. These high-initial-strength cements were used in order to counter the delay induced when adding sludge.

In addition to the reference series without sludge (1), we prepared mortar with the following proportions of sludge 2.5% (2); 5% (3) and 10% (4) (percentages calculated on the weight of the cement in the mortar).

We limited the addition of sludge to 10% because the tests with pastes Yagüe [1] showed that a 10% sludge content considerably delayed the mixture's initial and final setting (EN 196-3) [10]. The following table shows the dosage used.

Table 5. Dosage of the mortar with various amounts of added dry sludge, according to various standards.

EN 196-1 CEM I 42,5 R and CEM I 52,5 R

% Sludge	Sand(g)	Cement(g)	Water(g)	Sludge(g)
0 (1)	1350	450	225	0
2,5 (2)	1350	450	225	11.25
5 (3)	1350	450	225	22.5
10 (4)	1350	450	225	45.0

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UNE 83.811 CEM I 42,5 R

% Sludge	Sand(g)	Cement(g)	Water(g)	Sludge(g)
0 (1)	1350	450	200	0
2,5 (2)	1350	450	175	11.25
5 (3)	1350	450	180	22.5
10 (4)	1350	450	190	45.0

UNE 83811 CEM I 52,5 R

% Sludge	Sand(g)	Cement(g)	Water(g)	Sludge(g)
0 (1)	1350	450	205	0
2,5 (2)	1350	450	180	11.25
5 (3)	1350	450	185	22.5
10 (4)	1350	450	200	45.0

3.3 Results

The compressive strength was tested after 28 days for the two types of cement, and all mortars made with the same consistency (UNE 83811) [9] showed greater strength than the mixtures prepared with a constant water/cement ratio (EN 196-1) [8] see graphs 1 and 2.

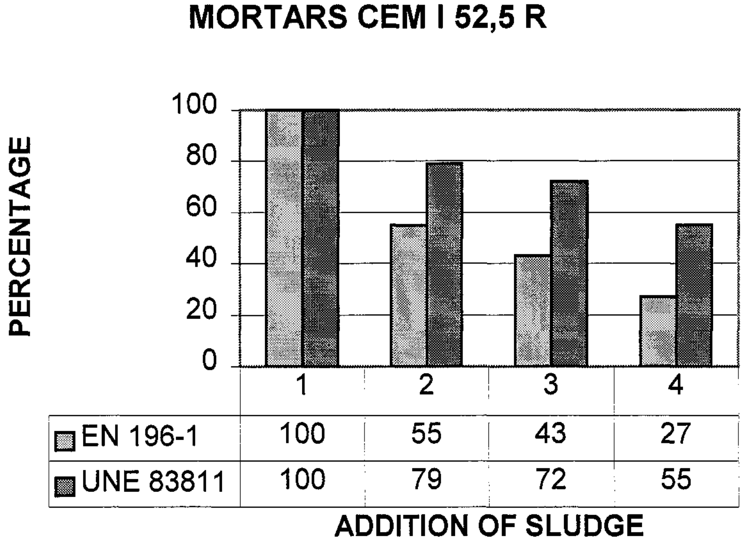

Figure 1. Compressive strength at 28 days, as a percentage, using series (1) as the reference, with various amounts of dry sludge: (1) 0% sludge; (2) 2.5% sludge; (3) 5% sludge; (4) 10% sludge, in a matrix with Portland cement (CEM I 52.5 R)

Paper from: *Waste Management and the Environment*, D Almorza, CA Brebbia, D Sales & V Popov (Editors).
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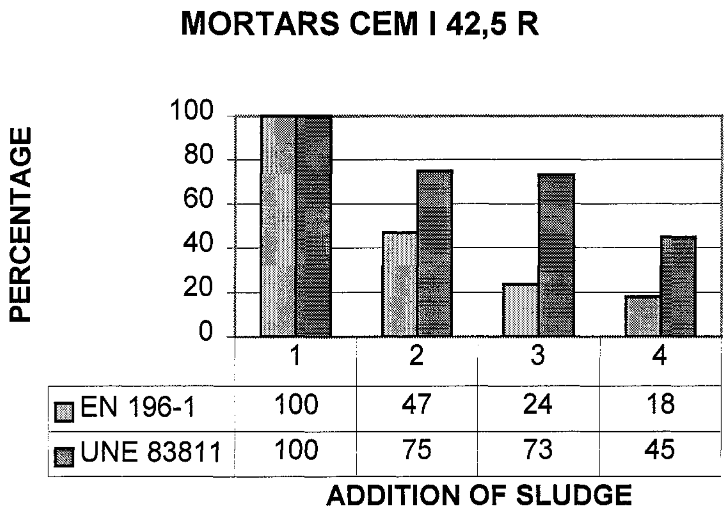

Figure 2. Compressive strength at 28 days, as a percentage, using series (1) as the reference, with various amounts of dry sludge: (1) 0% sludge; (2) 2.5% sludge; (3) 5% sludge; (4) 10% sludge, in a matrix with Portland cement (CEM I 42.5 R)

4 Environmental Impact Assessment

4.1 Introduction

One of the aims of this work is to present an efficient alternative to the final destination of the sludges produced during waste water treatment, by using it as an additive in mortar with Portland cement. In order to guarantee that can be used in construction, the environmental quality of mortar containing dry sludge must be established. The amount of toxic substances released into the environment must be as low as possible, and within the established limits. Leaching tests are required in order to determine the concentration of contaminants. There are currently no official regulations regarding the environmental impact of construction materials in Spain. Other European countries such as Holland, however, do have such regulations in place (The Netherlands Tank Leaching Test, NTLT).

4.2 The leaching process in construction materials

4.2.1 The NEN 7345 leaching test

Various types of monolithic leaching tests have been developed in Europe in order to assess the long-term potential and velocity of leaching in matrices with long-term stabilised waste products. The most common is the Dutch test, the

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Netherlands Tank Leaching Test (NTLT). According to the classification of the type of specific leaching tests, the NEN-7345 test is a *migration velocity* test. [11]. The cumulative leaching in mg/m^2 for each pollutant is calculated from a total of 8 extractions over 64 days.

The Dutch legislation classifies materials into three categories according to the leaching values obtained. Category 1 corresponds to material that can be used without any environmental restriction. Category 2 can also be used without environmental restrictions, but the pollutant that exceeds the lower limit must be extracted at the end of the material's useful life. In Category 3 the cumulative leaching values are above the upper limit and use of the materials is restricted.

In the cumulative leaching process (mg/m^2) of the tested material, the following pollutants were considered using Dutch standards: Ba, Cd, Mn, Cr, Cu, Ni, Pb, Zn, As Table 8 expresses the concentration of these heavy metals obtained by leaching in mortars with constant consistencies (UNE 83811) [9], with and without dry sludge.

In the majority of mortars tested, the concentration of heavy metals was below the sensitivity threshold of the testing method used (ICP -- Inductively Coupled Plasma mass spectrometry). It is therefore far lower than the limit established by regulations for the use of these materials in construction. The mortars are thus classified as inert material.

Table 8. Concentration of the heavy metals in the leachate obtained from the mortars with and without dry sludge from the waste water treatment plant, according to the NEN-7345 test.

Morter	HEAVY METALS CONCENTRATION (mg/m^2)								
	As	Ba	Cd	Mn	Cu	Ni	Pb	Zn	Cr
Sludge	CEM 42.5 R								
0%	<2.3	<0.44	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
0%	<2.3	<0.44	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
5%	<2.3	<0.44	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
5%	<2.3	2.8	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
10%	<2.3	6.7	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
10%	<2.3	6.5	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
Sludge	CEM 52.5 R								
0%	<2.3	<0.44	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
0%	<2.3	<0.44	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
5%	<2.3	2.8	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
5%	<2.3	2.8	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
10%	<2.3	6.6	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
10%	13.3	6.9	<0.44	<0.44	<0.44	<2.20	<4.40	<0.88	<0.88
U_l	40	600	1	---	50	50	100	200	150

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4.2.2 The NEN 7341 leaching test

In order to evaluate the degree of fixing of toxic pollutants in the binding matrix, Portland cement, the results obtained from the availability leaching test (NEN 7341) in the non-stabilised waste (Table 3) were compared to the materials containing sludge. The results are shown in Table 9.

Table 9. Concentration of the heavy metals in the mortars according to the NEN-7341 leaching test.

HEAVY METALS CONCENTRATION (mg/l)- NEN 7341	MORTERS			
	CEM 42.5 R		CEM 52.5 R	
	5% Sludge	10% Sludge	5% Sludge	10% Sludge
As	<0.1	<0.1	<0.1	<0.1
Ba	0.15±0.02	0.13±0.00	0.04±0.01	0.06±0.01
Cd	<0.025	<0.025	<0.022	<0.022
Mn	0.20±0.05	0.24±0.01	0.10±0.02	0.13±0.02
Cu	0.07±0.00	<0.05	0.06±0.02	0.08±0.02
Ni	<0.1	<0.1	<0.1	<0.1
Pb	<0.1	<0.1	<0.1	<0.1
Zn	0.31±0.7	0.31±0.01	0.27±0.11	0.28±0.10
Cr	<0.1	<0.1	<0.1	<0.1

Table 10. Percentage of fixing of heavy metals in the binding matrix, mortar, as per standard NEN-7341.

Percentage of fixing of heavy metals	MORTERS			
	CEM 42.5 R		CEM 52.5 R	
	5% Sludge	10% Sludge	5% Sludge	10% Sludge
As	100	100	100	100
Ba	86	83	95	92
Cd	100	100	100	100
Mn	75	70	87.5	84
Cu	88	100	89.4	86
Ni	100	100	100	100
Pb	100	100	100	100
Zn	75	75	78	77.2
Cr	100	100	100	100

5 Conclusions

From these results, we can deduce that mortars prepared at a constant consistency (UNE 83811) show greater compressive resistance than mortars with constant water/cement ratios (EN-196).

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The behaviour of the two types of cement was similar, and the values obtained with CEM I 52.5 R were slightly higher than those obtained with CEM I 42.5 R.

The loss of mechanical strength when adding 10% sludge, as well as the longer initial and final setting times, would suggest that higher percentages of dry sludges in the mortar are impossible. If it were necessary to increase this percentage, some kind of agent for accelerating the setting and hardening process would be required. Another option would be to increase the curing temperature for the mortar.

The strengths of the 2.5 and 5% mortars are relatively similar, and there is a considerable fall in strength at a 10% sludge content.

The environmental impact attributable to the addition of the sludge is negligible. The concentrations of the heavy metals in the leachate are so low that in most cases they were undetectable by the analysis technique. When detectable, the concentrations were well within the limit established by standard NEN 7345. The material is thus classified as inert.

The degree of fixing in the binding matrix is high, especially in matrices with CEM 52.5 R high-strength Portland cement. The heavy metal that showed the least degree of fixing in the matrix was manganese. It showed 70% fixing at a 10% dry sludge content.

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