VOLUME 3, ISSUE 2
MAY - AUGUST
YEAR 2019
ISSN 2530-8157

BUILDING & MANAGEMENT http://www.polired.upm.es/index.php/Building & Management

I. Santamaría-Vicario, S. Gutiérrez-González, V. Calderón-Carpintero and A. Rodríguez-Saiz "Declaration of performance (DOP) and CE marking of cement mortars made with recycled steel waste". Building & Management, vol. 3(2), pp. 06-15, 2019
http://dx.doi.org/10.20868/bma.2019.2.3918

PAPER BM_19_08_01 RECEIVED 24/05/2019 REVISED 13/06/2019 ACCEPTED 02/07/2019

GESTION EN EDIFICACION B&M BUILDING & MANAGEMENT
ESCUELA TÉCNICA SUPERIOR DE EDIFICACIÓN
UNIVERSIDAD POLITÉCNICA DE MADRID

Declaration of performance (DOP) and CE marking of cement mortars made with recycled steel waste

Declaración de prestaciones y marcado CE de morteros de cemento fabricados con residuos de acería valorizados

ISABEL SANTAMARÍA-VICARIO
PhD, University of Burgos. Escuela Politécnica Superior. Burgos, Spain
isantamaria@ubu.es

VERÓNICA CALDERÓN-CARPINTERO
PhD, University of Burgos. Escuela Politécnica Superior. Burgos, Spain
vcalderon@ubu.es

SARA GUTIÉRREZ-GONZÁLEZ
PhD, University of Burgos. Escuela Politécnica Superior. Burgos, Spain
sggonzalez@ubu.es

ÁNGEL RODRÍGUEZ-SAIZ
PhD, University of Burgos. Escuela Politécnica Superior. Burgos, Spain
arsaizmc@ubu.es

The process of preparing a "Declaration of Performance" is presented for a masonry mortar manufactured with by-products from the steelmaking industry recycled as aggregates, for subsequent CE Marking, with the aim of promoting its commercialization within the European Union. Specific tests are applicable to construction mortars, both for masonry and rendering and plastering, for the verification of their performance, in accordance with harmonized standards EN-998-1 and EN 998-2. The study likewise sets out the Systems of Assessment and Verification of Constancy of Performance (SAVCP): System 4 for Rendering and Plastering Mortars and Systems 4 and 2+ for Masonry Mortars. Special importance in the new procedures for CE Marking is placed on the manufacturers, as they assume responsibility both for determining the properties of the materials and for establishing a control process in the factory. This document describes the technical development of the tests, in accordance with the applicable harmonized standards, for verifying the performance of the mortars designed with steelmaking slags as aggregates. The study concludes with the presentation of a Technical Data Sheet for the preparation of the corresponding CE marking for these new designed mortars.

Masonry mortar; steelmaking slags; EAFS; LFS; Waste; CE Marking.

Este trabajo recoge el proceso de elaboración de una "Declaración de Prestaciones" de un mortero de albañilería fabricado a partir de residuos de acería valorizados como áridos, para su posterior Marcado CE, con el objetivo de facilitar su comercialización en la Unión Europea. Los morteros para construcción, tanto de albañilería como de revoco y enlucido, disponen de ensayos específicos para verificar sus prestaciones, de acuerdo con las normas armonizadas EN 998-1 y EN 998-2. De igual forma, se establece que los Sistemas de Evaluación y Verificación de la Constancia de las Prestaciones (EVCP) serán el Sistema 4 para los Morteros de Revoco y Enlucido, y los Sistemas 4 y 2+ para los Morteros de Albañilería. Los nuevos procedimientos para el Marcado CE en productos de construcción otorgan especial importancia a los fabricantes, ya que son los responsables de determinar las propiedades de los materiales, así como de establecer un proceso de control en fabrica. En este trabajo se describe el desarrollo técnico de los ensayos realizados para verificar las prestaciones de los morteros diseñados con áridos siderúrgicos. El trabajo concluye con la elaboración de la Ficha Técnica de Características para la elaboración del correspondiente distintivo de Marcado CE de los morteros diseñados.

Mortero de albañilería; escorias siderúrgicas; EAFS; LFS; Residuo; Marcado CE.

1. INTRODUCTION

Regulation (EU) N° 305/2011 of the European Parliament and the Council of 9 March 2011 [1] states that both construction and civil works promoted within the geographic area of the European Union Member States should comply with a set of essential requirements that will guarantee the health of users and environmental protection; and will contribute to energy saving and to constant performance over time. Compliance with all these requirements is oriented towards safeguarding both the public and social interests.

Directive 89/106/EEC [2] established the obligation to produce a "*Declaration of Conformity*"; in which the manufacturer or its representative in the European Union had to declare that the construction product complied with the essential requirements of the relevant Directives that affected it.

Since 2011; the new Construction Products Regulation (EU) N° 305/2011 [1] has replaced the "*Declaration of Conformity*" by the "*Declaration of Performance*"; in which the manufacturers of construction products have clearly to specify "*the performance of the product in relation to its essential*

characteristics"; thereby assuming responsibility for the conformity of the product in relation to its declared performance.

The products commercialized in the European Union with harmonized standards should carry the "*CE Marking*"; which rather than a quality guarantee is an identification of a technical nature that indicates that the product complies with the standard that affects it; a necessary legal requirement for its commercialization.

The *"CE Marking*" displays all the information referring to a construction product with a specific declaration of its performance and essential characteristics; following the application of either the relevant harmonized standards or the approved European technical tests to which it has been subjected. The product manufacturer must do the "*Declaration of Performance*" or; if applicable; the importer; distributor; or the representative.

This new approach determines that the manufacturers of construction products should establish measures for verification by means of material tests; controlling the manufacturing process or conducting follow-up of their behaviour in terms of performance; in accordance with the requirements and demands of the System of *Assessment and Verification of Constancy of Performance (AVCP)* for the CE Mark.

The new Regulation determines that manufacturers of construction products should prepare a technical data sheet; in accordance with the required AVCP system; to verify the product characteristics and to issue the "*Declaration of Performance*"; a procedure that was not contemplated in Directive 89/106/EEC [2]. The CE marking can only be affixed to the product; if the corresponding technical data sheet has been completed for the "*Declaration of Performance*"; supported by the technical documentation (tests; trials; verifications).

In Spain; the application of the European Rules on Construction Products or Energetic Efficiency was transposed into the "*Código Técnico de la Edificación CTE"* (Technical Building Code) [3]. This document; also based on performance; defines the participation of the different agents in the building process through the sharing of experience acquired in the course of their profession.

In the case of construction masonry mortars; the manufacturers should verify that their products comply with the so-called "*essential characteristics*" according to the applicable harmonized standards; in accordance with a pre-established test plan. In addition; controls over the factory production process must be in place and; after some time; verification of their behaviour at the work site where they have been used.

The aim of this work is to develop a *Process of CE Marking and Certification*; at a laboratory scale; of an innovative cement mortar that is respectful of the natural environmental and manufactured from steelmaking slags; by-products that are generated in the steel industry and recycled as siderurgical aggregates.

Steelmaking slags are classified as industrial waste that can be transformed into products through their recycling; in accordance with Directive 2008/98/EC of the European Parliament and of the Council of the European Union of 19 November 2008 [4]. This action plan constitutes an opportunity to improve environmental conditions in Spain; in accordance with the "*Programa Estatal de Prevención de Residuos* 2014-2020" (State Program for Waste Prevention) [5] and the "*Plan Estatal Marco de Gestión de Residuos"* (PREMAR) (State Waste Management Framework Plan) 2016-2022 [6].

2. METHODOLOGICAL PROCESS

Mortars designed by the Building Engineering Research Group of the University of Burgos have been used for the elaboration of the *CE Marking Technical File* of mortars **manufactured** with steelmaking slags as aggregates. These mortars have been characterized both in fresh and hardened state; and have undergone durability tests [7-9].

Subsequently; in order to determine "Declaration of Performance" of mortars; the rest of the tests included in the Standard EN 998-1 [10] (rendering and plastering mortars) and the Standard EN 998-2 [11] (masonry mortars); have been carried out.

According to the *Systems of Assessment and Verification of Constancy of Performance* (AVCP) for the CE Marking of mortars designed with steelmaking slags as aggregates; System 4 for Rendering and Plastering Mortars and Systems 2+ and 4 for Masonry Mortars were used respectively.

Finally; the CE Marking Technical File of mortars will be completed by the elaboration of the CE Mark; for its inclusion in documents; specifications sheet; packaging and other items necessary for its commercialization.

3. PREPARATION OF THE TECHNICAL DATA SHEET

Two avenues can be followed for the preparation of the technical data sheet:

- CE marking of the product following the ECS (European Committee for Standardization) using the harmonized standards applicable to the product; in this study; Standard EN 998-1 [10] (CE *Marking for rendering and plastering mortars*) and Standard EN 998-2 [11] (CE *Marking for masonry mortars*).
- European Technical Assessment (ETA); through the EOTA

(European Organization for Technical Assessment) process; using the *European Assessment Documents* (EADs).

In this study; the procedure established by the European Committee for Standardization (a) will be followed; because European Harmonized Standards are applicable both to construction mortars and to rendering and plastering mortars. The Resolution of 6 April 2017; from the *Dirección General de Industria y de la Pequeña y Mediana Empresa* (General Directorate of Industry and Small and Medium Enterprises) [12]; updates the list of Harmonized Standards; in accordance with the contents of Regulation (EU) Nº 305/2011 of the European Parliament and of the Council [1]; which establishes the conditions for the commercialization of construction products. The Systems of *Assessment and Verification of Constancy of Performance* (AVCP) for application to mortars designed with steelmaking slags as aggregates are System 4 for Rendering and Plastering Mortars and Systems 2+ and 4 for Masonry Mortars.

Table 1 shows the tasks that the participants in the process have to follow. In this study; the actions of the Notified Body will not be considered; due to the fact that its intervention concerns the *mass production* process.

Type of Mortar	Rendering and Plastering	Masonry	
Assessment System	4	2+	4
Actions	Responsibility	Responsibility	Responsibility
Factory production control	Manufacturer	Manufacturer	Manufacturer
Further tests on samples taken by the manufacturer	Manufacturer	Manufacturer	Manufacturer
Assessment of Product Performance	Manufacturer	Manufacturer	Manufacturer
Initial inspection (Factory Plant and Production control)	Manufacturer	Notified Body	Manufacturer
Continuous surveillance; assessment and evaluation of Factory Production Control	Manufacturer	Notified Body	Manufacturer

Table 1. Tasks for Assessment Systems 2+ and 4

In accordance with the procedures; a technical data sheet with the standards applicable to the product for the determination of performance will be drafted. In this research work; mortars dosed with steelmaking slags as aggregates either for use as rendering and plastering mortars on vertical surfaces or for use as masonry mortars to lay stone and brickwork will be assessed. This assessment of performance will be based on the laboratory-scale test results.

A Unique ID-Code is assigned to the product (Reference; Commercial Name-Manufacturing Code) for its inclusion in the CE-Mark. In Table 2; the Code assigned to each mortar under study in accordance with its use is shown: MSwr is a mortar dosed with steelmaking slags as aggregates and a water retention admixture and MSap is a mortar dosed with steelmaking slags as aggregates and an air entrainment admixture.

Type of Mortar	Standard	Code
Rendering and plastering mortar	EN 998-1	MSwr
Masonry mortar	EN 998-2	MSap

Table 2. Assignation of ID-codes to the mortars

The essential characteristics with which the mortars have to comply are included in the standards of rendering and plastering mortars EN-998-1 [10] and masonry mortars EN 998-2 [11].

Subsequently; a set of tests will be established; in order to determine the performance of the material and its characteristics; with the objective of proceeding to its classification; in accordance with European standards. In Fig. 1; the set of tests necessary for the Declaration of Performance of CE Marking of both the rendering and plastering mortars and the masonry mortars are shown.

4. PRODUCT DESCRIPTION

Iron and steel production systems generate different types of slag by-products; with different characteristics and properties; in accordance with the raw material in use and the reagents added for their transformation.

The environmental impacts of these waste products range from visual impacts; due to the occupation of extensive surfaces for their deposition and storage; to the filtering of toxic chemicals such as toxic metals into the soil; as these toxins are decomposed by the action of atmospheric agents.

Research have been underway for some time to transform industrial waste slags into raw materials as an alternative to conventional natural resources used in the manufacture of construction products; giving priority to recycling and other forms of reuse; instead of dumping them with no defined usage; in accordance with European Directives 2008/98/EC of the European Parliament and of the Council [4]; and the Programa Estatal de Prevención de Residuos (State Program for Waste Prevention) 2014-2020 [5] and the Plan Estatal Marco de Gestión de Residuos (State Waste Management Framework Plan) (PEMAR) 2016-2022 [6].

Some investigations have demonstrated the hydraulic capacity of ladle furnace slags (LFS) [13]; estimating substitutions in the order of 20-30% cement used in the dosages of mortars and concretes [14; 15]. The existence in their composition of anhydride calcium silicates justifies their reuse as a raw material in the manufacture of cements [16].

Electric arc furnace slags (EAFS) have been used as substitutes for conventional aggregates with good results in the manufacture of concretes due to their properties [17]. In other investigations; the joint use of EAFS and LFS has been studied in the formation of granulometries employed in concretes; yielding varied results [18].

With regard to masonry mortars; previous investigations have designed granulometries using EAFS as a thick component and LFS as filler; producing workable mixes and showing a reliable mechanical performance [7-9].

5. BACKGROUND

The mortars for inclusion in the technical data sheet for CE marking have been characterized in previous studies [7-9]. However; additional tests have to be completed that are described in the Experimental section; in order to finalize the data sheet which is shown in Fig. 1.

CE		CE	
Rendering and plastering mortar		Masonry mortar	
University of Burgos 19 EN 998-1 (2016) Ordinary rendering mortar for exterior usage (GP)		University of Burgos 19 EN 998-2 (2016) Masonry mortar designed for ordinary usage (G) in exterior load-bearing constructions	
Dry bulk density of hardened mortar	EN 1015-10	Workable life of fresh mortar	EN 1015-9
Compressive strength at 28 days	EN 1015-11	Water-soluble chloride content	EN 1015-17
Adhesive strength	EN 1015-12	Air content	EN 1015-7
Water absorption by capillarity	EN 1015-18	Compressive strength at 28 days	EN 1015-11
Water vapour permeability (μ)	EN 1015-19	Initial shear strength	EN 1052-3
Thermal conductivity	EN 1745	Water absorption by capillarity	EN 1015-18
Reaction to fire	EN 13501-1	Water vapour permeability (μ)	EN 1015-19
Workable life of fresh mortar	EN 1015-9	Dry bulk density of hardened mortar	EN 1015-10
Air content	EN 1015-7	Thermal conductivity	EN 1745
Freeze/thaw durability		Freeze/thaw durability	
		Maximum aggregate size	EN 13501-1
		Reaction to fire	

Figure 1. Declaration of performance for CE marking. Left: Rendering and plastering mortar. Right: Masonry mortar

A Portland cement CEM I 42,5 R; with a density of 3150 kg/m^3 is used for the preparation of these mortars. This cement has its own CE Marking; in compliance with the obligation for raw material controls contained in the Spanish regulation Instrucción para la recepción de cementos RC-16 (Instruction for the reception of cements RC-16) [19].

This type of cement has been used because it is basically composed of Portland Cement Clinker (≥95%). This avoids possible unwanted reactions between the steelmaking slags and the active and inert additions of the cement.

The aggregate in use has a Maximum Aggregate Size (MAS) of less than 2.00 mm; and it presents a uniform particle size distribution; as indicated in Fig 2. It consists of EAFS and LFS; in accordance with the following criteria:

- Sieve sizes between 0.063 mm and 2.00 mm: EAFS; with a density of 3645 kg/m^3; principally consisting of Fe_2O_3; CaO; SiO_2; and Al_2O_3.
- The fine components; with a sieve size lower than 0.063 mm or aggregate filler: LFS; with a density of 2860 kg/m^3; consisting of SiO_2; CaO; MgO and Al_2O_3.

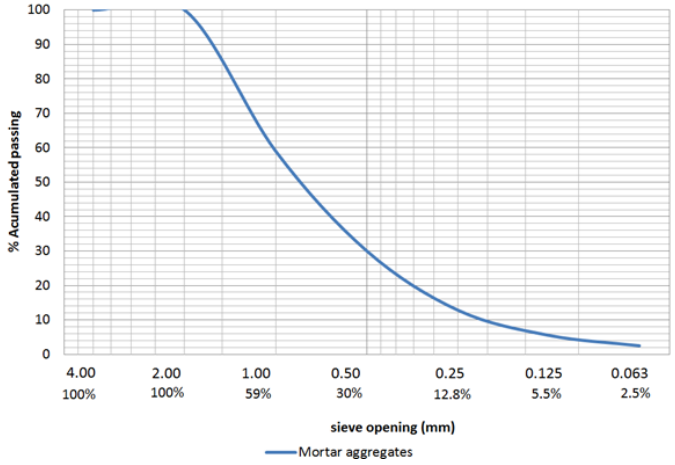


Figure 2. Particle size distribution for aggregates

The CE Marking of these aggregates; steelmaking slags; is dependent on the Evaluation System 2+ and the harmonized standard EN 13139:2002/AC: 2004 [20]. The manufacturer-supplier of slag aggregate (EAFS-LFS) is expected to prepare the Declaration of Performance of the Aggregate and its CE Marking. A Notified Body will issue the corresponding Certificate of Conformity with Factory Production Control.Two cement mortars were designed with these materials with the technical label "dry industrial mortars" and with an identical particle size distribution for aggregates; for which reason their Fineness Module were also the same.

As indicated; the maximum aggregate size was 2.00 mm; similar to the one used for conventional commercial cement mortars. The dosage in weight used for the preparation of the mixtures was 1 part of cement to 6 parts of aggregate.

Different admixtures are added to the mortars; so that they are workable and can be used on building sites: a water retention admixture [wr] and an air entrainment-plasticizer [ap]; with the objective of reducing the exudation of water; increasing its retention; reducing the density and increasing the occluded air content of the mortars.

The siderurgic mortars [MS] are abbreviated as MSwr when the water retention admixture is used and as MSap for the air entrainment-plasticizer. The characterization in both the fresh and the hardened state of the mortars is reflected in Table 3 and has been described in previous investigations [7-9].

	Test method	MSwr	MSap
Water/ kg dry mortar (gr) [7]	EN 1015-3	136	119
Bulk density of fresh mortar (kg/m^3) [7]	EN 1015-6	2103	2201
Air content (%)[7]	EN 1015-7	24	22
Water retention (%) [7]	UNE 83-816-93	88	79
Workable life of fresh mortar (min) [7]	EN 1015-9	451	213
Dry bulk density of hardened mortar (kg/m^3) [7]	EN 1015-10	1982	2080
Flexural strength at 28 days (N/mm^2) [7]	EN 1015-11	2.8	3.6
Compressive strength at 28 days (N/mm^2) [7]	EN 1015-11	10.6	11.5
Adhesive strength (N/mm^2) [7]	EN 1015-12	0.62	0.64
Water absorption by capillarity (kg/m^2·min$^{0.5}$) [9]	EN 1015-18	0.15	0.16
Water vapour permeability (μ) [9]	EN 1015-19	15	9
Durability – freeze/thaw cycles [8]	EN-12371 (56 cycles)	Without alterations	Without alterations

Table 3. Mortars characterization

6. EXPERIMENTAL. PROCESS OF CE MARKING

In this section; the tests will be described that are required; in accordance with the regulation; to complete the technical data sheet of the mortars shown in Fig.1.

6.1. WATER SOLUBLE CHLORIDE CONTENT

The procedure detailed in standard EN 1015-17 [21] was followed to establish the water soluble chloride content.In keeping with the requirements of a dry industrial mortar; the sample was milled until it passed through a 10 mm sieve. Then; the sample was reduced to 50 gr and milled until it all passed through a 0.125 mm sieve. Two mortar samples were prepared of 'MSwr' and two of 'MSap'.

An amount of 10gr±0.005 gr of the sample; milled at a temperature of 20°C±5°C; was weighed out and poured into a 150 ml polyethylene tube. Then; 100 ml of distilled water was added; the tube was sealed and agitated in a magnetic agitator with a polyethylene coated bar for 60 min. The tube with its content was left to rest for (a minimum of 15 h and a maximum of 24 h) one night.

Subsequently; the fraction of the sample that was in suspension was separated by filtration; recovering the filtrate in a 250 ml borosilicate glass beaker. The residue remaining in the filter was washed with 25ml±5 ml of distilled water. The

filtrate was acidified by adding 20 ml of diluted nitric acid (1+2) and brought to boiling point.

By means of a pipette; 5 ml of the solution of silver nitrate 0.10 mol/l was added to the acidified solution. It was immediately brought to boiling point for 1.5-2 min; and left to cool to a temperature below 25°C. The contents of the beaker were passed to a 500 ml Erlenmeyer flask. 5 drops of the indicator solution of ammonium sulphate and iron III [$NH_4Fe(SO_4)_2 \cdot 12H_2O$] are added.

A 10 ml burette is filled with an ammonium thiocyanate solution. The solution of the burette in the previous mixture is added; turning a light brownish-red colour; which disappears under vigorous agitation. The test ends when the colour is remained visible following agitation (Fig. 3). The volume; V_1; of the solution of ammonium thiocyanate solution consumed in the assay was noted.

The previous procedure was repeated without the mortar sample and the volume; V_2; of the solution of ammonium thiocyanate necessary for this assay was noted.

The content of chloride ions; expressed by mass % in reference to the sample of dry mortar was calculated by means of the following equation:

$$Cl(I)\% = (V_2 - V_1) \times f \times \frac{3.545}{10 \times m} \qquad (1)$$

Where:

V_1 is the volume of the ammonium thiocyanate solution; 0.1M (ml); consumed during the assay of the test solution.

V_2 is the volume of the ammonium thiocyanate solution; 0.1M (ml); consumed in the dummy assay.

m is the mass of the test sample (gr)

f is the molarity factor in relation to the solution of ammonium thiocyanate (usually 0.10 mol/l)

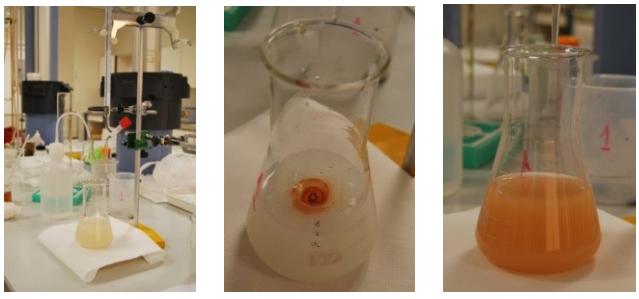


Figure 3. Operating procedure. Calculation of the water-soluble chloride content.

6.2. DETERMINATION OF SHEAR STRENGTH

CE-markings of the masonry mortars that will be employed for masonry walls need to include the characteristic shear strength. To do so, the procedure described in EN 1052-3 [22] was followed. The sample specimens consisted of three bricks with mortar bonds placed on a larger surface, as shown in Fig 4. Double hollow bricks with dimensions of (240x110x90) mm and with a water absorption coefficient to saturation of 18% were used.

To prepare the sample specimens, three ceramic bricks, previously dried in an oven, were placed in water for 1 min. Within that time, the bricks had absorbed 9% of water, so that they presented a known humidity level that had not reached saturation point, but that avoided absorbing the mortar mixing water.

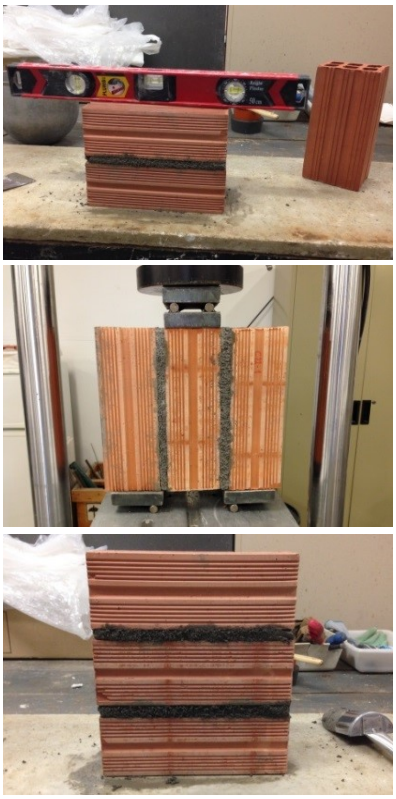


Figure 4. Operating procedure. Preparation and breakage of sample specimens under shear stress

Having prepared the samples, they were placed in a polyethylene bag and compressed, with a mass uniformly distributed, to give a vertical tension of between $2x10^{-3}$ N/mm^2 and $5x10^{-3}$ N/mm^2, in accordance with the specifications of the harmonized standard. The specimens remained unaltered over a period of 28 days in a humid chamber, under a constant temperature of 20 °C and a relative humidity of 95%. At the end of the curing period, the specimens were tested in a Suzpecar model MEn 101 multi-test machine, with a load capacity of 20 tn. '*Procedure B*', detailed in the standard and shown in Fig 4 was followed.

The initial shear stress, f_{voi}, was calculated with the following expression (2):

$$f_{voi} = \frac{F_i}{2A_i} \qquad (2)$$

Where:

F_i is the shear stress (N)

A_i is the transversal area of a sample parallel to the horizontal bonded joints (mm^2)

On the basis of these individual results, the average initial shear stress strength, f_{vo}, was estimated.

The characteristic shear strength, f_{vok}, was calculated according to the following expression (3):

$$f_{vok} = 0.8 x f_{vo} \quad (3)$$

Where:

f_{vo} is the average initial shear strength (N/mm^2)

6.3. THERMAL CONDUCTIVITY

The test for the determination of thermal conductivity followed the guidelines established in standard ASTM C 1114-06 [23]. To do so, 6 specimens of each mortar type were prepared with the following dimensions (110x70x6.5) mm^3. The specimens remained in the humid chamber for 28 days.

A THASYS thermal conductivity Measurement System was employed, a machine that is based on a laminar heat transfer method, in accordance with the requirements of Annex 1 of the aforementioned ASTM, consisting of a thin heater apparatus THA01 and a measurement control unit MCU01, from HUKSEFLUX THERMAL SENSORS.

It ran on a Thasys v0909.CR1 data acquisition and control software version of the "Campbell Scientific LoggerNet".

6.4. FIRE RESISTANCE

Cylindrical samples with a diameter of 75 mm and a height of 150 mm were prepared to classify the behaviour of the mortars when exposed to fire. These specimens were cured in a humid chamber for 28 days at a temperature of 20ºC and a relative humidity of 95%.

The non-combustibility test was completed as described in standard EN ISO 1182 [24]. The specimens were conditioned for 72 h at a temperature of 23±2ºC and a humidity of 50±5%. They were then dried in a ventilated oven at a temperature held at 60±5 ºC for 24 h.

The samples were introduced in an oven equipped with thermocouples for temperature control, and the oven temperature was increased at a constant speed that was stabilized for at least 10 min at 750±5ºC.

The test was stopped when the equilibrium temperature was reached or after 60 min had elapsed. The increased temperature of the oven throughout its central axis, the persistence of flames (sec.) and mass loss (%) were all recorded.

7. RESULTS AND DISCUSSION

7.1. WATER-SOLUBLE CHLORIDE CONTENT

The results for each of the test samples and the average for each mortar type appear in Table 4.

Water-soluble chloride content (%)		
	MSwr	MSap
Sample 1	0.005	0.007
Sample 2	0.007	0.005
Average	0.006	0.006

Table 4. Water soluble chloride content in relation to the mass of dry mortar.

Standard EN 998-2 [11] indicates that the mortar manufacturer must declare the chloride content. This value must not be greater than the declared content and must never exceed 0.1% in relation to the mass of dry mortar.

The mortars in this study presented a lower content than the standard specification, which was expressed in the data sheet specifications: Content of chloride ions <0.01%.

7.2. DETERMINATION OF SHEAR STRENGTH

In Fig 5, the breaking load under shear stress, Fi (kN), of the test samples is shown as a function of displacement in the test machine. The construction specimen formed by the three bricks and mortar bonds presented an initial breakage point in the brick. Nevertheless, the specimens were sufficiently strong to support a higher shear load, up until complete breakage. The value of the breaking load that was registered was the first breakage value. The average values from the test are shown in Table 5.

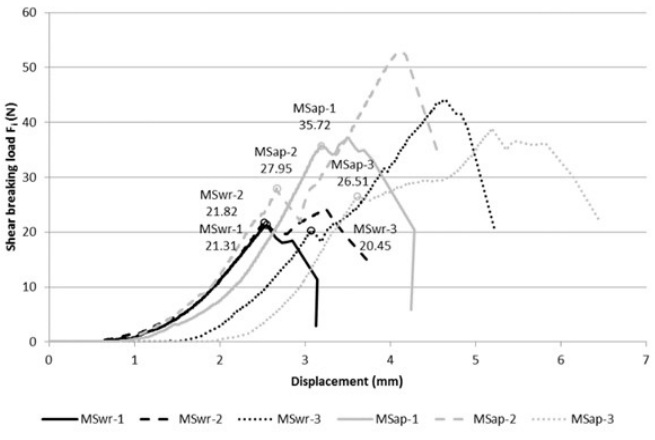


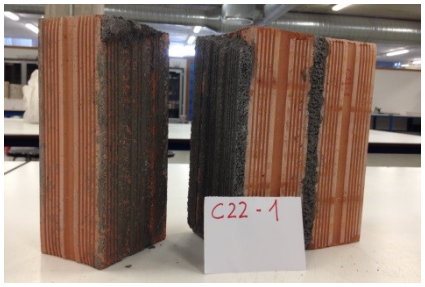
Figure 5. Breaking load under shear stress (kN)

	Breaking load under shear stress (kN)	Initial shear strength, f_{voi} (N/mm²)	Initial average shear strength, f_{vo} (N/mm²)	Initial characteristic shear strength, f_{vok} (N/mm²)
MSwr1	21.31	0.403	0.401	0.320
MSwr2	21.82	0.413		
MSwr3	20.45	0.387		
MSap1	35.72	0.677	0.570	0.456
MSap2	27.95	0.530		
MSap3	26.51	0.502		

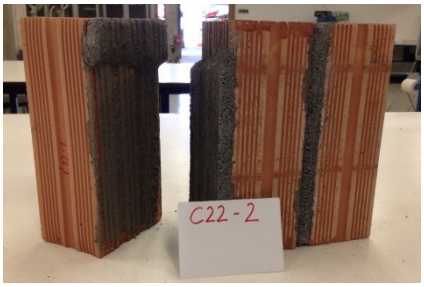
Table 5. Initial and characteristic shear strength

		Avg. Tª (°C)		Λ (W/m·K)	
MSwr	Samples 1-2	10.70	10.27	0.59±0.02	0.56±0.02
	Samples 3-4	9.98		0.57±0.02	
	Samples 5-6	10.14		0.51±0.02	
MSap	Samples 1-2	10.71	10.31	0.60±0.02	0.61±0.02
	Samples 3-4	10.09		0.64±0.02	
	Samples 5-6	10.12		0.60±0.02	

Table 6. Thermal conductivity coefficient



MSwr 1
Shear stress breakage of the brick/mortar bond



MSwr 2
Shear stress breakage of the brick/mortar bond

MSwr 3
Shear stress breakage of the ceramic brick

MSap 1
Shear stress breakage of the ceramic brick

MSap 2
Shear stress breakage of the ceramic brick

MSap 3
Shear stress breakage of the ceramic brick

Figure 6. Types of shear stress breakage in the different samples

The standard indicates that, in addition to the initial shear stress value, the type of breakage of the test samples has to be specified. Fig. 6 shows the type of breakage that occurred: in some cases, breakage of the brick/mortar bond, on other occasions breakage of the brick sample.

7.3. THERMAL CONDUCTIVITY

The faces of the specimens were polished until perfectly flat before the start of the test. The samples were grouped by each mortar type (MSap and MSwr) into three pairs, in other words, three tests were completed for each mortar type. The average temperature values of the test and the thermal conductivity coefficient, Λ (W/m·K), are shown in Table 6.

The thermal conductivity values were very similar in both mortars. These values represent approximately half of the tabulated value, normally set at a density of 2100 kg/m³: 1.20 W/m·K for cement mortars.

7.4. FIRE RESISTANCE

The non-combustibility test results (Table 7) confirmed that the samples produced no continuous flame, the oven temperature increased was less than 30°C (ΔT≤30°C) and the mass loss was less than 50% (Δm≤50%). According with this results and the requirements of standard EN 13501-1:2007 [25] the mortars can be classified as Euro-class A1 (a non-combustible materials that will not at any stage add to the fire, including the totally developed fire).

	ΔT (°C)	Flame persistence (s)	Δm (%)
MSwr	4.8	---	7.53
MSap	4.5	---	7.46

Table 7. Coefficient of thermal conductivity

CE		CE	
Rendering and plastering mortar		Masonry mortar	
University of Burgos 19 EN 998-1 (2016) Ordinary rendering mortar for exterior usage (GP)		University of Burgos 19 EN 998-2 (2016) Masonry mortar designed for ordinary usage (G) in exterior load-bearing constructions	
Dry bulk density of hardened mortar	1982 kg/m^3	Workable life of fresh mortar	213 min
Compressive strength at 28 days	10.6 N/mm^2	Water-soluble chloride content	< 0.01%
Adhesive strength	0.62 N/mm^2	Air content (%)	22%
Water absorption by capillarity	W2	Compressive strength at 28 days	11.5 N/mm^2
Water vapour permeability (μ)	15	Initial shear strength	0.46 N/mm^2
Thermal conductivity	0.56 W/m·K	Water absorption by capillarity	0.16 kg/m^2·min$^{0.5}$
Reaction to fire	A1	Water vapour permeability (μ)	9
Workable life of fresh mortar	451 min	Dry bulk density of hardened mortar	2080 kg/m^3
Air content	24 %	Thermal conductivity	0.61 W/m·K
Freeze/thaw durability	Without alterations	Freeze/thaw durability	Without alterations
		Maximum size of aggregate	MSA≤2 mm
		Reaction to fire	A1

8. Conclusions

In accordance with the characterization of the dry industrial mortars under study and the results of the present research, the data sheet of the mortars dosed with steelmaking slags as aggregates, with regard only to the material specifications, would be as presented in Fig. 7.

9. References

[1] Regulation No. 305/2011 (Construction Products Regulation, or CPR) of the European Parliament and of the European Council of 9 March 2011 that lays down harmonized conditions for the marketing of construction products and replaces Construction Products Directive (89/106/ECC), 2011.

[2] Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products 1988.

[3] Ministerio de Vivienda. Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación.

[4] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives of 19 November 2008 on waste and repealing certain directives de 19 de November de 200.

[5] Resolución de 20 de diciembre de 2013, de la Dirección General de Calidad y Evaluación Ambiental y Medio Natural, por la que se publica el Acuerdo del Consejo de Ministros de 13 de diciembre de 2013, por el que se aprueba el Programa Estatal de Prevención de Residuos 2014-2020.

[6] Resolución de 16 de noviembre de 2015, de la Dirección General de Calidad y Evaluación Ambiental y Medio Natural, por la que se publica el Acuerdo del Consejo de Ministros de 6 de noviembre de 2015, por el que se aprueba el Plan Estatal Marco de Gestión de Residuos (PEMAR) 2016-2022.

[7] I. Santamaría-Vicario, A. Rodríguez, S. Gutiérrez-González, and V. Calderón, "Design of masonry mortars fabricated concurrently with different steel slag aggregates," Construction and Building Materials, vol. 95, pp. 197-206, 10/1/ 2015. http://dx.doi.org/10.1016/j.conbuildmat.2015.07.164

[8] I. Santamaría-Vicario, A. Rodríguez, C. Junco, S. Gutiérrez-González, and V. Calderón, "Durability behavior of steelmaking slag masonry mortars," Materials & Design, vol. 97, pp. 307-315, 2016. http://dx.doi.org/10.1016/j.matdes.2016.02.080

[9] I. Santamaria-Vicario, A. Rodriguez-Saiz, J. Garcia-Cuadrado, C. Junco-Petrement, and S. Gutierrez-Gonzalez, "The influence of porosity on the behaviour in humid environments of mortars made with steelmaking slags and additives," Dyna, vol. 92, pp. 220-225, Mar-Apr 2017. http://dx.doi.org/10.6036/8193

[10] EN 998-1 Specification for mortar for masonry - Part 1: Rendering and plastering mortar. European Committee for Standardization, 2016.

[11] EN 998-2 Specification for mortar for masonry. Part 2: Masonry mortar. European Committee for Standardization, 2016.

[12] Resolución de 6 de abril de 2017, de la Dirección General de Industria y de la Pequeña y Mediana Empresa, por la que se amplían los Anexos I, II y III de la Orden de 29 de noviembre de 2001, por la que se publican las referencias a las Normas UNE que son transposición de normas armonizadas, así como el período de coexistencia y la entrada en vigor del marcado CE relativo a varias familias de productos de construcción.

[13] J. Setién, D. Hernández, and J. J. González, "Characterization of ladle furnace basic slag for use as a construction material," Construction and Building Materials, vol. 23, pp. 1788-1794, 2009. http://dx.doi.org/10.1016/j.conbuildmat.2008.10.003

[14] A. Rodríguez, J. M. Manso, Á. Aragón, and J. J. González, "Strength and workability of masonry mortars manufactured with ladle furnace slag," Resources, Conservation and Recycling, vol. 53, pp. 645-651, 2009. https://doi.org/10.1016/j.resconrec.2009.04.015

[15] I. Papayianni and E. Anastasiou, "Production of high-strength concrete using high volume of industrial by-products," Construction and Building Materials, vol. 24, pp. 1412-1417, 8// 2010. https://doi.org/10.1016/j.conbuildmat.2010.01.016

[16] A. S. D. Vilaplana, V. J. Ferreira, A. M. Lopez-Sabiron, A. Aranda-Uson, C. Lausin-Gonzalez, C. Berganza-Conde, et al., "Utilization of Ladle Furnace slag from a steelwork for laboratory scale production of Portland cement," Construction and Building Materials, vol. 94, pp. 837-843, Sep 2015. https://doi.org/10.1016/j.conbuildmat.2015.07.075

[17] C. Pellegrino and V. Gaddo, "Mechanical and durability characteristics of concrete containing EAF slag as aggregate," Cement & Concrete Composites, vol. 31, pp. 663-671, Oct 2009. https://doi.org/10.1016/j.cemconcomp.2009.05.006

[18] J. A. Polanco, J. M. Manso, J. Setien, and J. J. Gonzalez, "Strength and Durability of Concrete Made with Electric Steelmaking Slag," ACI Materials Journal, vol. 108, pp. 196-203, Mar-Apr 2011. https://doi.org/10.14359/51682313

[19] Ministerio de Fomento. Real Decreto 256/2016, de 10 de junio, por el que se aprueba la Instrucción para la Recepción de Cementos (RC-16).

[20] EN 13139:2002/AC: 2004 Aggregates for mortar. European Committee for Standardization, 2004.

[21] EN 1015-17 Methods of test for mortar for masonry. Part 17: Determination of water-soluble chloride content of fresh mortars. European Committee for Standardization, 2000.

[22] EN 1052-3 Methods of test for masonry. Part 3: Determination of initial shear strength. European Committee for Standardization, 2003.

[23] ASTM C 1114-06 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus, 2013.

[24] EN ISO 1182 Reaction to fire tests for products. Non-combustibility test. European Committee for Standardization, 2010.

[25] EN 13501-1: Fire classifications of construction products and building elements. Part 1: Classification using data from reaction to fire tests. European Committee for Standardization, 2010.

WHAT DO YOU THINK?

To discuss this paper, please submit up to 500 words to the editor at bm.edificacion@upm.es. Your contribution will be forwarded to the author(s) for a reply and, if considered appropriate by the editorial panel, will be published as a discussion in a future issue of the journal.