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Viability of Cupola Slag as an Alternative Eco-Binder and Filler in Concrete and Mortars

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Abstract: Obtaining new materials capable of meeting society's demands motivates the search for new solutions that are capable of satisfying twofold requirements: respect for the environment and obtaining more durable and resistant materials. Cupola slag is a by-product generated in the process of obtaining ductile iron. When the slag undergoes rapid cooling, its vitrification is favored, leaving the silica in an amorphous structure and, thus, susceptible to reacting. Through reaction, the slag can develop cementing properties and cement can consequently be partially replaced with residue, providing savings in economic and environmental costs compared to traditional hydraulic binders. In this study, the physical and chemical properties of cupola slag and its recovery process are analyzed. Mortars that incorporate traditional admixtures (fly ash and limestone filler) have been manufactured and consistency and mechanical properties have been compared with mortars that incorporate cupola slag admixture. Mortars have also been manufactured with normalized sand and with Portland cement replacements (0, 10, 20, and 30% by weight) with cupola slag, and both the consistency and the mechanical properties have been compared at 7, 28, 60, and 90 days. The results obtained show the suitability of cupola slag as a binder and as an admixture, with respect to the traditional ones, and how the mechanical properties tend to converge for all of the replacement levels characterized, for ages close to 90 days of age.

Keywords: cupola slag; alternative binder; sustainability; waste recovery; mechanical properties; mortar; concrete

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1. Introduction

In 2017, the iron foundry sector reached a production of 76.2 Mt worldwide and 12 Mt in Europe, 35% corresponding to ductile iron [1]. Cupola slag is a by-product generated in cupola furnaces, which often ends up in landfills. The slag contains oxides coming from impurities in the load material that have not been reduced in the cupola, which are dislodged from the furnace's refractory walls, from coke ash, and from losses in the melting of the loaded metal. As the slag's density is lower than that of iron, it can be easily separated from the metal. As it is not reduced during the iron ore smelting process, it is produced in a proportion of 50–60 kg per ton of molten ore [2]. The pozzolanic properties of cupola slag are influenced by its cooling process, rapid cooling (total immersion in water) leading to greater vitrification of the slag, leaving the silica in an amorphous structure and, thus, susceptible to reaction.

The use of cupola slag as a replacement for cement provides a sustainable application—in which there are hardly any studies—in the context that cement production accounts for 7% of global CO_2 emissions [3]. From an environmental point of view, the use of this waste in the manufacturing of concrete structures could mean, on the one hand, avoiding a generation of waste that would be deposited in a landfill and, on the other, the reduction of the carbon footprint derived from reducing the demand for cement. The immense volume of concrete that is produced every day could absorb all of the production of cupola slag, even in the case of not improving the physical–mechanical properties of the concrete, so that the residue is only encapsulated. Cupola slag, like other wastes generated in the processes of the steel industry, must be reused or recovered following the principles of sustainability that European policies mark in their sustainable development plans.

When discussing waste from the iron and steel industry (mainly slags) for the production of cement, it is essential to speak of ground-granulated blast furnace slag (GGBS). GGBS have been used worldwide for many years, due to their pozzolanic/cementitious properties and their ability to improve many of the performance characteristics of the concrete, such as strength, workability, permeability, durability, and corrosion resistance [4]. Additionally, the use of GGBS as an ordinary Portland cement (OPC) additive also has the advantage of its potential use in waste stream structures as a reducing agent and in immobilizing medium level radioactive waste [5], which confers its countless potential applications.

The slag generated by cupola furnaces is usually composed of 30% refractory material, 10% scrap sand, 40% CaO, 10% coke ash, and 10% burned material [6]. Although studies are rare, the first in 1982 [7] studied the pozzolanic properties of cupola slag, finding little pozzolanic activity, and establishing the limit of ordinary Portland cement (OPC) replacement at 20% (13.5% reduction in strength). The use of cupola slag would significantly reduce the cost of concrete and waste would be disposed of without further applications. The study of this material—with application in cements and concrete mixes—was not reconsidered again until the 2000s, with a few studies on its use, both as an aggregate and as a replacement for OPC.

In the literature studies, it is common to find information on the production of ecological concrete (recycled concrete) through the use of siderurgical aggregates or the use of construction and demolition wastes (C and DWs) of different types [8]. Most of these C and DWs are from building demolition waste; although there are already innovative proposals, such as for use in railway superstructures [9], siderurgical aggregate concrete [10], or the application of multi-recycling techniques [11]. The level of research on these new recycled concretes is very advanced nowadays, with studies on their micro-porosity [12], influence of curing conditions [13], their behavior under fatigue [14], and even on the durability of ecological concrete [15]. The use of another waste, such as cupola slag, as an aggregate or as an admixture, would be another way of obtaining ecological concrete.

Studies on the manufacturing of ecological concrete with granulated cupola slag as fine and coarse aggregates (recycled aggregate) have concluded that the material is not viable for this type of application, since the strengths obtained have not been satisfactory [16]. The use of ground cupola slag in the literature has produced both inconsistent and non-significant effects. Stroup et al. [17] found an increase in compressive strength of 8% and a similar flexural strength for mortars after 28 days using cement replacements of 35% with cupola slag. Ceccato et al. [18] characterized the mechanical properties of concrete with granulated cupola slag, replacing cement ratios of up to 50% and testing different water/cement ratios, demonstrating the slowness of the pozzolanic reactions of this material, and showing the conservation of mechanical properties for replacements of 10%. Afolayan et al. [19] analyzed the evolution of compressive strength for various replacements of Portland cement by cupola slag, concluding that replacement proportions of cement greater than 10% may yield a loss in concrete's compressive strength. There are no studies in the literature on the use of cupola slag as an admixture in concrete, except in studies carried out by the authors on its application to high-performance ecological concretes, both its mechanical properties [20] and its durability [9], where cupola slag offers excellent performance when it is recovered in the right way. The use of admixtures in concrete tends to increase its resistance, to a greater extent, when using admixtures with pozzolanic properties. According to Domone [21], the type and proportion of admixture have a greater influence on the compressive strength than the water/fines ratio (cement + admixtures). Rozière et al. [22], observed an increase in compressive strength with increasing admixture content, maintaining the effective water/cement (w/c) ratio and the amount of cement.

This study aims to clarify the effects of the use of value-added cupola slag in standardized mortars, in order to propose recommendations for its use, given that there are practically no studies in the literature. To do this, in the first phase, the mechanical properties of mortars with the addition of ground cupola slag are compared with those produced with the most common admixtures, such as limestone filler or fly ash. A second phase will consist of comparing the mechanical properties of mortars with different levels of OPC replacement by ground cupola slag, performing a final analysis of the benefits of using this by-product.

2. Materials and Methods

2.1. Characterization of the Materials

This section describes, firstly, the slag recovery process and the main properties of the cupola slag, and then the rest of the materials (aggregates, admixtures, and cement) used in the manufacture of mortars.

2.1.1. Valorization and Properties of the Cupola Slag

The cupola slag is removed through a spout at a height slightly higher than the dump spout, at the rear of the cupola furnace. This opening is located below the nozzles to avoid possible cooling of the slag, caused by air currents. The separation of the slag and the liquid metal is possible due to the difference in density between the metal and the slag. This, after being extracted, is collected discontinuously on a conveyor belt equipped with trays, as shown in Figure 1a. Due to the small thickness of the deposited slag, its cooling is fast. Finally, it is deposited, by gravity, in small stockpiles, as can be seen in Figure 1b.

(**a**) (**b**)

Figure 1. (**a**) Transport and cooling of cupola slag in trays; (**b**) detail of the stockpile at the plant.

Slag is produced by reduction of the sulfur content in iron in the foundry. Desulfurization is done with calcium carbide in the production of ductile iron. At this stage of the process, the slag generated can be classified as a waste with a certain hydraulic potential.

The slag recovery process was carried out with a specific methodology (Figure 2), which started with previous crushing in a jaw crusher to guarantee the pulverization of the entire load, reducing the maximum particle size to 10 mm. Subsequently, a wet grinding of the material was carried out to turn it into a filler, using an industrial ball mill. The grinding was carried out at a speed of 45 rpm for 8 h, until a maximum particle size of 100 μm was obtained. Observations were made in a scanning electron microscope (SEM) after different milling times, until the desired maximum size is obtained. Figure 3 shows a micrograph of the cupola slag at 100× magnification, when the measurement of the largest particles was made. Irregular shape of the particles and good homogenization of sizes were also observed.

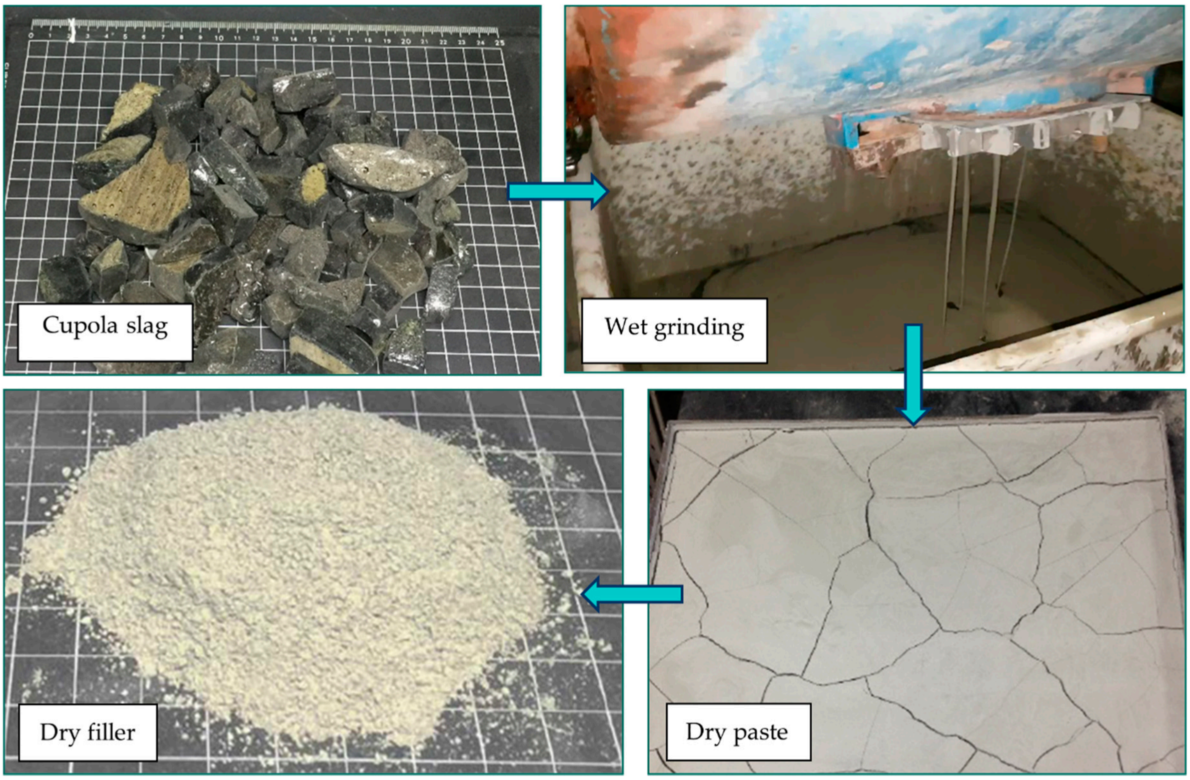


Figure 2. Scheme of the recovery process of cupola slag.

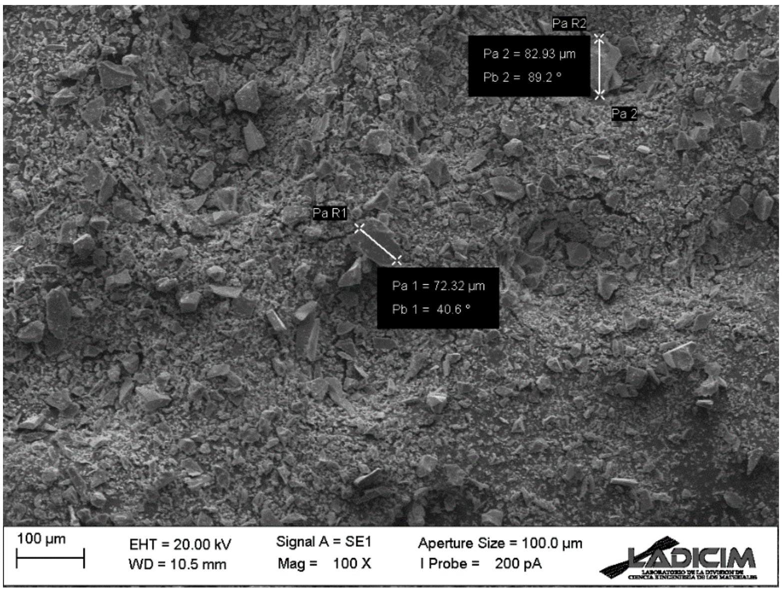


Figure 3. Determination of the maximum particle size of cupola slag by SEM.

After grinding, the material was removed and deposited on metal trays. The crushed slag was decanted into these containers and the water was removed, introducing the tray with the material in a ventilated oven at 110 ± 5 °C, where the material remains until reaching a constant mass (0.1% wt.). Finally, the material is shredded with the help of a spatula or a tamper, obtaining a powdery material that is stored in drums. This recovery process is associated with an energy cost that results in the emission of CO_2 (grinding +

drying), but much lower than the energy cost derived from the production of cements (grinding + heating to 1450 °C to achieve clinkerization + grinding); therefore, there is an obvious economic saving and a reduction in CO_2 emissions. On the other hand, the cupola slag does not currently have any application, so if it is not recovered, it will be deposited in landfills, with the associated environmental cost.

The crystalline composition of the slag was determined by X-ray diffraction. Bruker D2 equipment was used, fitted with a Cu tube that generates X-rays with a wavelength of $\lambda = 1.5418 \cdot 10^{-10}$ m, at a working power of 30 kV/10 mA. The samples were previously pulverized, and the spectrum was collected at 2θ angles in a range of 6–80° (Δ2θ = 0.02°) at room temperature, with an integration time of 10 seconds per pass. The diffraction of cupola slag is shown in Figure 4.

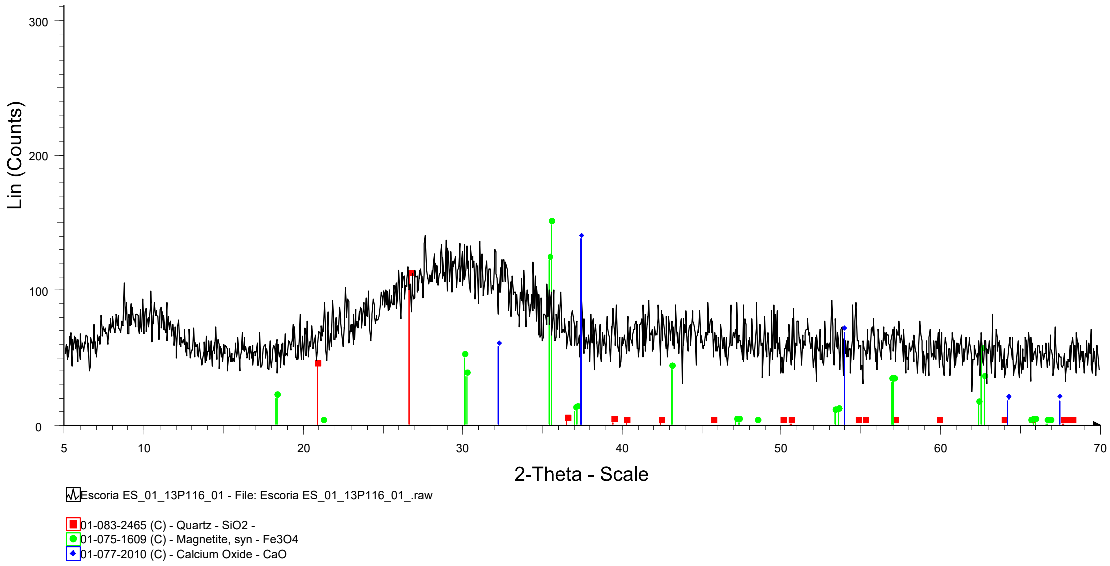


Figure 4. Diffractogram of the cupola slag.

The amorphous structure of cupola slag prevents diffraction peaks from being detected. This result is still interesting, because its majority composition corresponds to silica oxide, which, being in an amorphous state, is an indicator of the possible reactivity of the material.

To contrast the mineralogical composition obtained by X-ray diffraction, the presence of the compounds in the cupola slag was determined by infrared spectroscopy. A Nicolet Nexus diffractometer from the Thermo brand with a microscope attached to the bench was used, a service performed by the SERCAMAT of the University of Cantabria (Spain). For the analysis, the sample was combined in mortar with potassium bromide in a 1:20 ratio. The mixture was subsequently compacted in a press to form a compressed capsule. The spectrum obtained is shown in Figure 5.

The identification of the crystalline compounds present was carried out by means of the Fourier transform. These results confirm the analyses performed by X-ray diffraction and the spectrum obtained enabled the following compounds to be detected:

- Mainly silicates and aluminosilicates, with vibration bands in range 800–1100 cm^{-1} and 500 cm^{-1}.
- Calcium oxide due to its peaks at frequencies around 1400–1500 cm^{-1} and at 910 cm^{-1}.
- Iron oxides, peaks at 2400 cm^{-1}, 1400–1500 cm^{-1}, and 300–600 cm^{-1}.

SEM images were also obtained using a Zeiss SEM, model EVO MA15. In Figure 6, the appearance of the material is observed at two different scales, observing some microporosity on the surface of the particles (Figure 6a) and also an irregular shape of the particles when viewed together (Figure 6b).

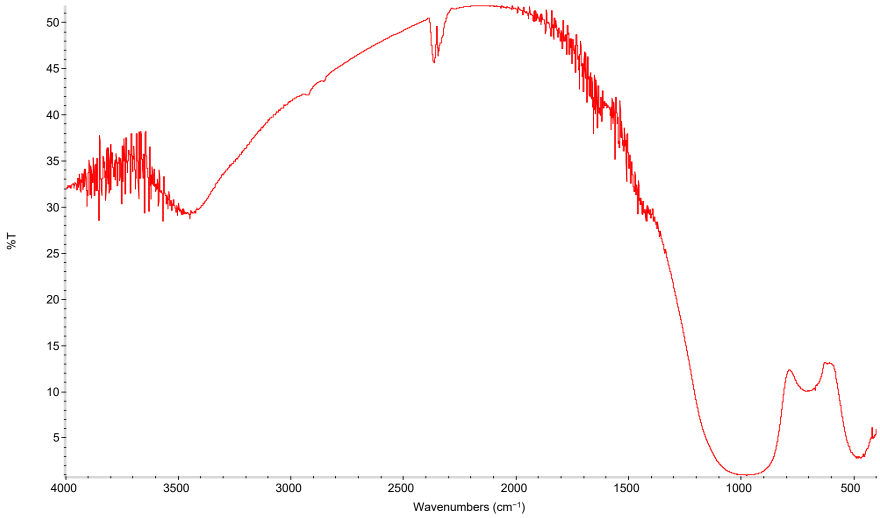
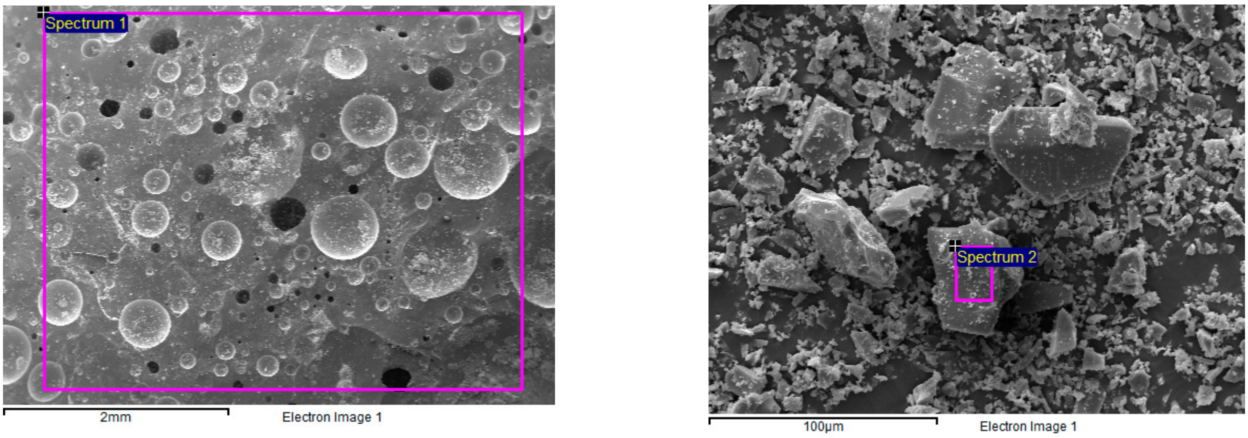


Figure 5. Infrared spectrum of cupola slag.



(**a**) (**b**)

Figure 6. Micrograph of a cupola slag particle at two different scales: low (**a**) and high level of magnification (**b**).

The analysis of the leachate from the cupola slag was carried out in accordance with the provisions of the European standard EN 12457-4 [23]. For this, 2 kg of sample were used without being subjected to a previous treatment. The results obtained were compared with the limits defined in Annex I of Decree 104/2006 of the Community of Cantabria (Spain) [24], which is one of the most restrictive regions in Europe. The results are compiled in Table 1.

Cupola slag is a material that does not pose any environmental risk; the concentrations of dangerous elements in the leachate test are even significantly lower than with electric furnace slag, comparing the values with those obtained in other studies [25].

2.1.2. Other Mixing Materials

The chemical composition of the materials used in this study was determined by energy dispersive X-ray spectroscopy (EDX), the results of which are shown in Table 2.

Hydraulicity is defined as the ability of a compound to harden as a result of chemical reactions with water to obtain calcium silicates and calcium aluminate hydrates. A first approximation to the pozzolanicity of the material can be obtained by the hydraulicity index (HI) [26], defined according to the expression:

$$HI = \frac{\%Al_2O_3 + \%Fe_2O_3 + \%SiO_2}{\%CaO + \%MgO} \quad (1)$$

Table 1. Results of the cupola slag leaching test.

Parameter	Unit	Limit Value	Obtained Value
Conductivity	μS/cm	-	72.8 (20 °C)
Acidity	pH	-	10.41 (21.6 °C)
Chemical oxygen demand	mg/kg m.s.	500	<50
Chlorides	mg/kg m.s.	800	<50
Phenols	mg/kg m.s.	1	<1
Total solid solved	mg/kg m.s.	4	480
Sulfates	mg/kg m.s.	1000	60.4
Antimony	mg/kg m.s.	0.06	<0.01
Arsenic	mg/kg m.s.	0.5	<0.02
Barium	mg/kg m.s.	20	<0.10
Cadmium	mg/kg m.s.	0.04	<0.01
Copper	mg/kg m.s.	2	<0.17
Total chromium	mg/kg m.s.	0.5	<0.06
Mercury	mg/kg m.s.	0.01	<0.02
Molybdenum	mg/kg m.s.	0.5	<0.20
Nickel	mg/kg m.s.	0.4	<0.08
Lead	mg/kg m.s.	0.5	<0.12
Zinc	mg/kg m.s.	4	<0.55
Selenium	mg/kg m.s.	0.10	<0.10

Table 2. Composition in oxides of the materials used (% wt.).

Material	Fe_2O_3	CaO	SiO_2	Al_2O_3	MgO	MnO	Cr_2O_3	TiO_2	Na_2O	SO_3	K_2O	Others
Diabase sand	13.7	11.1	46.5	13.6	12.4	-	-	-	2.8	-	-	-
Silica sand	-	-	96.0	4	-	-	-	-	-	-	-	-
Cupola slag	6.3	30.0	43.6	13.6	2.1	2.8	-	0.5	-	-	-	<0.5
Limestone filler	-	100	-	-	-	-	-	-	-	-	-	-
Fly ash	7.0	6.1	55.0	20.4	2.6	-	-	0.9	1.2	4.0	2.0	-
CEM I 52.5 R	3.4	66.6	17.8	4.8	1.3	-	-	0.2	-	4.5	0.8	-

The hydraulicity index obtained for OPC is 0.4, while that obtained for cupola slag is 2, which shows the high hydraulicity of this compound. The GGBS shows, in the literature, SiO_2 values typically 10% lower, and CaO values around 7% higher than that of the cupola slag [27]. The rest of the components are in a similar proportion, so a slightly higher hydraulicity would be expected in the case of the cupola slag. This difference in composition is due to the fact that blast furnaces melt and reduce iron minerals, while cupola furnaces melt mainly material from blast furnaces and scrap metal.

Table 3 shows the real density values, following the indications of the Spanish standard UNE 80103 standard [28] for cement testing. The same table shows the Blaine specific surface, for all admixtures and cement used, by application of the EN 196-6 standard [29]. In the comparison between cement and ground cupola slag, it is observed that the latter has a density 7% lower, and a fineness 13% lower. This value, which proportionally influences the speed of hydration reactions, gives an initial advantage to cement.

Table 3. Real density and Blaine specific surface of the materials used.

Material	Real Density (g/cm^3)	Blaine Surface (m^2/kg)
Diabase sand	2.89	-
Silica sand	2.61	-
Cupola slag	2.89	429.4
Limestone filler	2.65	274.1
Fly ash	2.13	400.3
CEM I 52.5 R	3.11	495.7

2.2. Design and Testing Methodology

2.2.1. Mix Design

As already explained, in this study, there are two experimental phases. The first phase consists of comparing the properties of mortars that incorporate cupola slag with mortars that use other admixtures. The second phase consists of checking how different replacements of cupola slag by Portland cement affect standard mortars.

The manufacturing of standard mortars, incorporating different admixtures, was carried out by manufacturing three mixes that use the same amount of fly ash (FA), limestone filler (LF), and cupola slag (CS) to be able to compare the effect of the cupola slag with that of two of the most common admixtures. To compare only the effect of the admixture, the same amount of CEM I 52.5 R, diabase sand (high quality sand) silica sand (because the diabase sand lacks fines), and 2% plasticizer additive (CEM% wt.) were used. The optimal amount of additive was thoroughly analyzed, since it is the key factor in workability [30]. The only parameter that varies between the three mixes is the w/c ratio, which has been established at 0.43 for the reference mortar (LF) and has been modified for the FA and SC mix to obtain the same consistency. In this way, it has been possible to make a comparison of the mechanical properties of mortars at different ages.

The manufacture of standardized mortars incorporating different levels of cement replacement was carried out by manufacturing four mixes that use the same amount of silica sand and water. Only the amount of CEM I 52.5 R has been varied, applying ground cupola slag replacements of 0%, 10%, 20%, and 30% (CEM% wt.), obtaining the mixes M-0%, M-10%, M-20%, and M-30%, respectively. In this way, a comparison of the slump and the mechanical properties at different ages can be made. All the mix proportions used in this study were produced following the specifications of EN 196-1 [31] and the proportions appear in Table 4.

Table 4. Mix proportions of the manufactured mortars (g).

Material	FA	LF	CS	M-0%	M-10%	M-20%	M-30%
Diabase sand	435	435	435	-	-	-	-
Silica sand	390	390	390	1450	1450	1450	1450
Cupola slag	-	-	200	-	41.8	83.6	125.5
Limestone filler	-	200	-	-	-	-	-
Fly ash	200	-	-	-	-	-	-
CEM I 52.5 R	450	450	450	450	405	360	315
Water	211.5	193.5	180	225	225	225	225
w/c ratio	0.47	0.43	0.4	0.50	0.60	0.70	0.80
SP	9	9	9	-	-	-	-

The mortars were mixed in a standard planetary mixer. The mixing method for all of the mortars produced consists of a first phase of mixing the cement (plus cupola slag or admixture if applicable) with water for 30 s at slow speed, 30 s incorporating the sands at slow speed, 60 s at high speed, 90 s with the mixture at rest, and 60 s at fast speed. Standard molds (EN 196-1) were used to manufacture 160 × 40 × 40 mm specimens. The mortars, once manufactured, were covered with plastic wrap in order to avoid moisture loss, and were removed 24 h after mixing. The specimens were cured by immersion in water at a controlled temperature of 20 ± 2 °C for the corresponding curing ages.

2.2.2. Standardized Tests

Mortars manufactured with various admixtures were tested to determine consistency in the fresh state, according to the EN 1015-3 standard [32]. Due to the large amount of admixture used, a moderate consistency was obtained for all of the admixtures, so these mortars were subjected to 15 strokes on the shaking table and the diameters of the cones obtained were measured.

Mortars made with various cement replacements by cupola slag were subjected to a fresh consistency determination, according to EN 1015-3 [32]. In this case, due to the self-compacting nature of the mortar, the runoff of the mortar was determined after filling the mold on the shaking table and without any means of compaction. The mixture was kept at rest for 20 s, at which time the measurement of two conjugated diameters of the cake was carried out.

The mechanical tests, consisting of the determination of the compressive strength and flexural strength, were carried out in a servohydraulic press with a capacity of 250 kN and in accordance with EN 196-1 [31]. The application rates of the load were 2500 N/s for the compressive strength test and 50 N/s for the flexural strength test. Four test specimens were tested per mix and per age. For mortars with different admixtures, tests were carried out at 7, 28, and 60 days of curing (12 specimens), and for mortars with different levels of cupola slag replacements, tests were carried out at 7, 28, 60, and 90 days of curing (16 specimens).

3. Results

3.1. Consistence of Fresh Mortars

Table 5 shows the results of the consistency on the mortars that incorporate various admixtures. It can be seen that cupola slag requires a lower effective water/cement ratio to obtain the same slump as the LF. This is in part contradictory to the fineness obtained for both compounds, since having a higher specific surface should require more water than LF. This effect is probably offset by the shape of the cupola slag, which would not offer great resistance to paste runoff, and as can be seen after applying 15 strokes on the shaking table (the runoff increase is 30% higher).

Table 5. Mortar consistency with different admixtures.

Admixture	W/c Ratio	Average Diameter (mm)	Diameter after 15 Strokes (mm)
Limestone filler	0.43	155	190
Fly ash	0.47	160	215
Cupola slag	0.40	150	200

Figure 7 shows the results of the consistency test on mortars with different replacement levels in the fresh state. It can be observed that the consistency increases as the replacement does, in a linear and proportional manner, as shown by a correlation coefficient over 0.99, and increasing by 12.5% with replacements of 30%, with respect to the control mortar (0%). This increase in the workability of the mortar is because the effective water/cement ratio has remained constant, while the fineness of the cupola slag is 13% lower, which would generate a greater volume of free water.

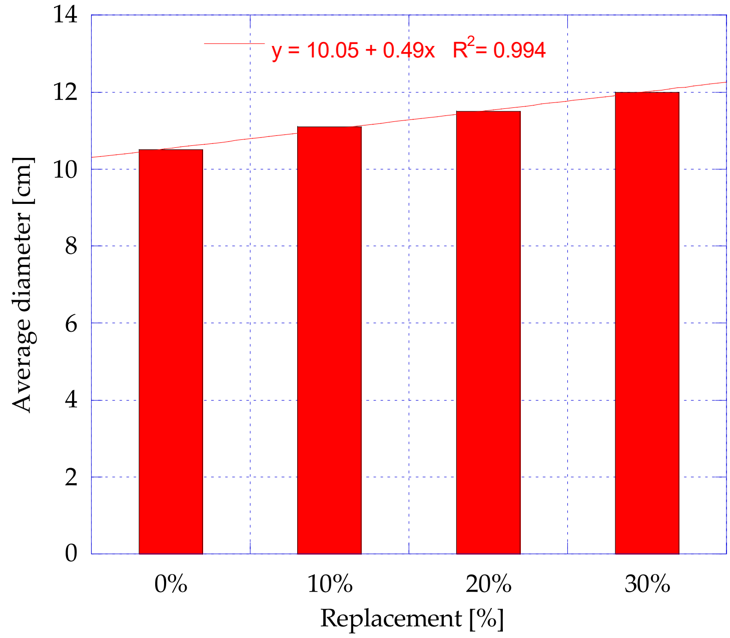


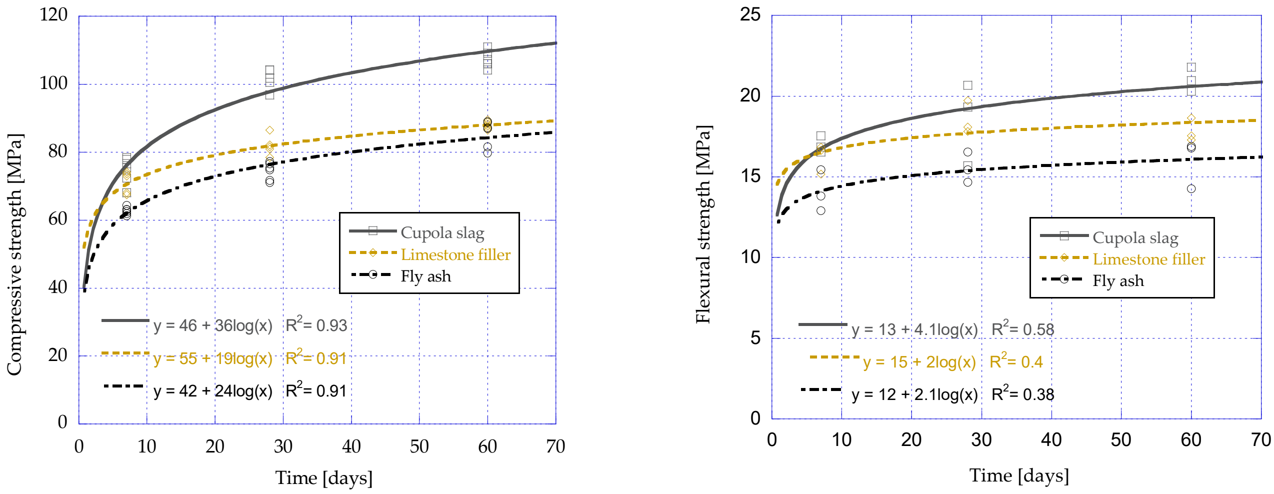
Figure 7. Mortar consistency with different cupola slag replacements.

3.2. Mechanical Properties

3.2.1. Mortars with Different Admixtures

Figure 8 shows the compressive and flexural strength of mortars incorporating the three admixtures under study, at different ages. Compressive strength increases logarithmically with the curing age, with very high correlation coefficients close to 0.9. The use of limestone filler has been demonstrated in the literature as an option to improve the mechanical properties and durability of concrete and mortar due to its ability to fill the voids in the paste [33]. Fly ash has shown the worst behavior of the three admixtures studied, although the gain in strength generated over time tends to converge for ages over 60 days with the limestone filler admixture. This slow gain is due to the fact that fly ash reacts with the cement by joining the $Ca(OH)_2$ with free silica, with a pozzolanic reaction that forms an insoluble calcium silicate hydrate (CSH) structure [34]. Finally, the use of cupola slag provides the mortar with a strength that is clearly superior to that of the rest of the admixtures. The strong pozzolanic character of this admixture enables gains of more than 20% in compressive strength to be obtained with respect to the other admixtures studied, and an even greater increase in gain than fly ash for between 30 and 60 days. The evolution shown by the cupola slag shows a certain slowness in the hydration processes for early ages; however, in the long-term there is a significant gap with respect to the reference mix. The development of long-term strengths leads to a reduced setting speed, so the use of this admixture is especially interesting for applications in which short-term strengths are not needed, or when a binder that generates less heat of hydration than Portland cement.

Flexural strength also increases with curing age, although in a less dependent way than with compressive strength. In this case, mortars with fly ash show 15% lower strength than mortars with limestone filler, while mortars with cupola slag show strengths 25% and 10% higher than mortars with fly ash and limestone filler, respectively. The obvious pozzolanic properties of ground cupola slag, thus, justify its use in the manufacturing of mortars and concretes with a low environmental impact.

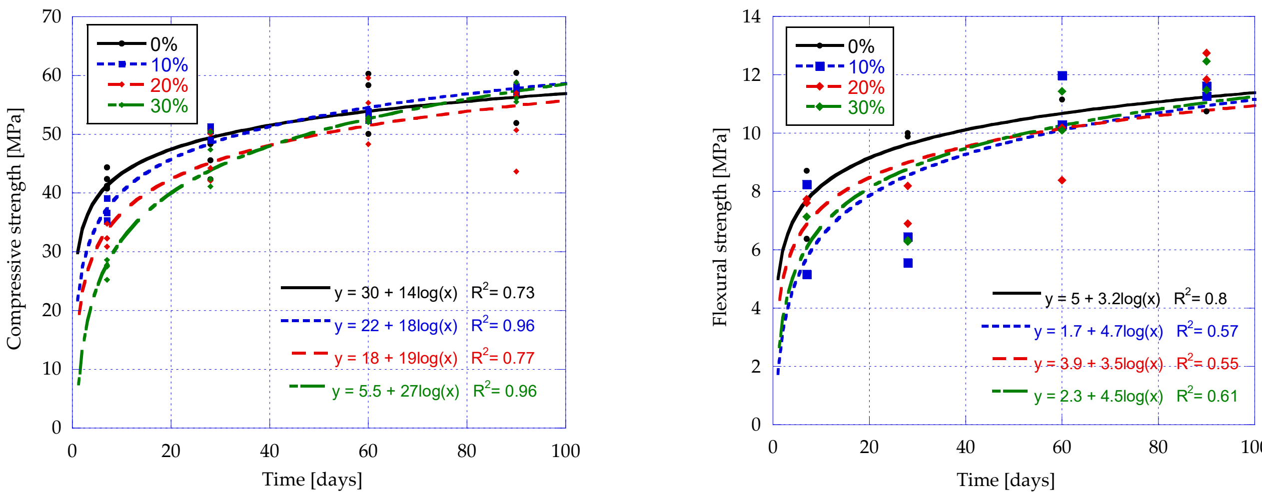


(**a**) (**b**)

Figure 8. Mechanical properties of mortars with different admixtures: compressive strength (**a**); flexural strength (**b**).

3.2.2. Mortars with Different Replacement Proportions

Figure 9 shows the results of the mechanical characterization of mortars incorporating various levels of Portland cement replacement. The compressive strength (Figure 9a) increases with curing age for all replacements following a logarithmic trend ($R^2 \approx 0.85$), while intermediate replacements show intermediate behaviors between maximum replacement and reference mortars. After 7 days of curing, mortars with 30% replacement show a 27% loss in compressive strength, with respect to the reference mortar, demonstrating slow hydration reactions. This loss is reduced to 12% after 28 days and 5% after 60 days of curing. At 90 days of curing, the strengths shown for all replacements tend to converge because wing hydration onset and hydration peak occur much later when cupola slag is used than when using Portland cement [17]. ASTM C311 [35] defines the pozzolanicity index (strength activity index) of supplementary cementitious materials as the relationship between the compressive strength of mortars, incorporating 20% replacement, and mortars without replacement, for ages 7 and 28 days. The studied mortars present a pozzolanicity index of 73% and 92% at 7 and 28 days, respectively, active admixtures being considered those that reach 75%.



(**a**) (**b**)

Figure 9. Compressive strength (**a**) and flexural strength (**b**) of mortars with various cement replacements by cupola slag.

Flexural strength (Figure 9b) also increases with the curing age for all replacements and in a manner analogous to compressive strength. After 7 days of curing, the strength shown by replacements of 30% is 25% lower than that obtained with the reference mortars. For 28 and 60 days of age, the losses reach 10% and 6%, respectively. Again, there is a more pronounced age strength development when cupola slag is incorporated into the mortar. For ages over 90 days, the values tend to converge once more, showing once again the slowness of the reactions and demonstrating the strong pozzolanic character of the ground cupola slag.

4. Conclusions

After the analysis of the results obtained both in the comparison of cupola slag with other admixtures, and in the comparison with Portland cement, the following conclusions have been obtained:

- The recovery of cupola slag and its use in construction materials means a reduction in CO_2 emissions generated by the manufacturing of cement, and preventing this waste from going to landfills.
- The diffractogram, the chemical composition, and the infrared spectrum confirm the presence of an amorphous structure in the slag cupola that makes it susceptible to reacting.
- The cupola slag studied does not pose any environmental risk since concentrations of dangerous elements in the leachate test are very low.
- Compared to limestone filler and fly ash admixtures, the evolution of strength is similar up to ages close to 7 days, but more than 20% higher in the long-term, for ages close to 60 days. This shows a greater hydraulicity of the slag cupola with respect to the other admixtures used.
- A greater replacement of cupola slag by Portland cement produces a greater consistency in the fresh mortar, but a loss of compressive strength of up to 27% after 7 days. The slowness of the pozzolanic reactions makes the resistances tend to converge at 90 days for any replacement.
- Future work will attempt to quantitatively clarify the environmental and economic costs associated with the recovery process, which is very important to establish the sustainability of the material.
- The results obtained show that it is feasible to use the slag cupola in the manufacturing of mortars/concrete when high initial strengths are not required or when a binder that generates less heat of hydration than Portland cement is desired.

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