Mechanical-strength characteristics of concrete made with waste iron and steel industry as binders

Abstract

One of the problems of steelworks referring to the steel manufacture, are secondary products produced, resulting in recent years new types of industrial waste according to the environmental sustainability, reused or treated . This paper proposes resistant behavior analysis of different types of waste concrete specimens, such as smoke powder and slag caused by electric arc furnaces, when melting of the materials occurs.

Palabras Clave: Concrete, Fume dust, compression, *Flexural strength*

1. Introduction

One of the biggest problems today is the steel industry is the production of waste in varying amounts depending on the type of scrap used and steel that want to process, we will need certain types of additives, generating various types of steel between which It is ferritic. We will focus on the study of ferritic steel for our study. These materials produce large amounts of waste that are entering the fume dust. These are expensive to recycle or reuse and difficult inerting. Generating large amounts of debris from entering those found fume dust.

From the environmental point of view, the American Environment Agency (EPA) [1] .classifed to these materials as toxic and dangerous products, just as they are the under Spanish legislation. The toxicity of these materials is based on their content in non-ferrous metals, mainly, chromium, zinc, lead, nickel and magnesium, all of them easily leachable metals and consequently accumulated in soil and water.

The high content of these components in oxides forced to seek solutions. Would be significant recovery of certain metals for its economic importance in the steel advances have been verified recovery rates around 2% of gross production that is processed [2].

The solution is to incorporate article presents the steelmaking waste in concrete, either complete or partially recovered and after conducting the appropriate tests, verify the correct behaviour in the different stresses to which it will be exposed the new material. Different proportions of addition was studied.

The steel produced worldwide last year, is about 1597 million tonnes according to International Iron and Steel Institute (IISI) Conferences 2015 [3]. Powder EAF is generated in quantities appreciable when casting steel is made, volatilized certain elements of a very fine powder subject of this application.

This transformation creates environmental problems in the steel industry. Today the reuse of waste caused by metallurgical processes does not exist or is inappropriate. His final, to be deposited in landfills them.

Given its characteristics powders smoke have binding properties if incorporated into appropriate systems so that its reuse does not contaminate and exert a favorable effect on the system.

The results of the trials demonstrate out below improving the mechanical strength of the material.

2. Materials

2.1 Study fume dust

Most of our steel industry uses collection and purification systems. The collection system is mainly used in the aspiration through a fourth hole in the roof of the furnace, and subsequent uptake by bells installed in various parts of the mill, mainly above the ovens. The gases captured by the hood are conducted through channels to the fourth filter or bag filters. Emissions generated in the AOD converter are also captured and directed to the channel and filtered together with the gases of the electric furnace. The solid thus obtained is a dust very finer material with a moisture content below 1% also coproduces between 15 to 25 kg of dust per ton of steel.

Morphologically, fume dust ferritic consists of spheroidal particles of highly variable diameters (Figure 1), ranging from 50 microns. It is a material with very finer moisture content below 1% by weight.

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As shown in the (Figure 2), fume dust while a residue, falls within what we can consider as ultra high concrete in principle as an addition. Some of this material as discussed below, grain talking can say that drives like nanoparticles that give the cementitious matrix a modification of the gel structure, and that fill the gaps between the grains of cement and various aggregates increasing hydration cement.

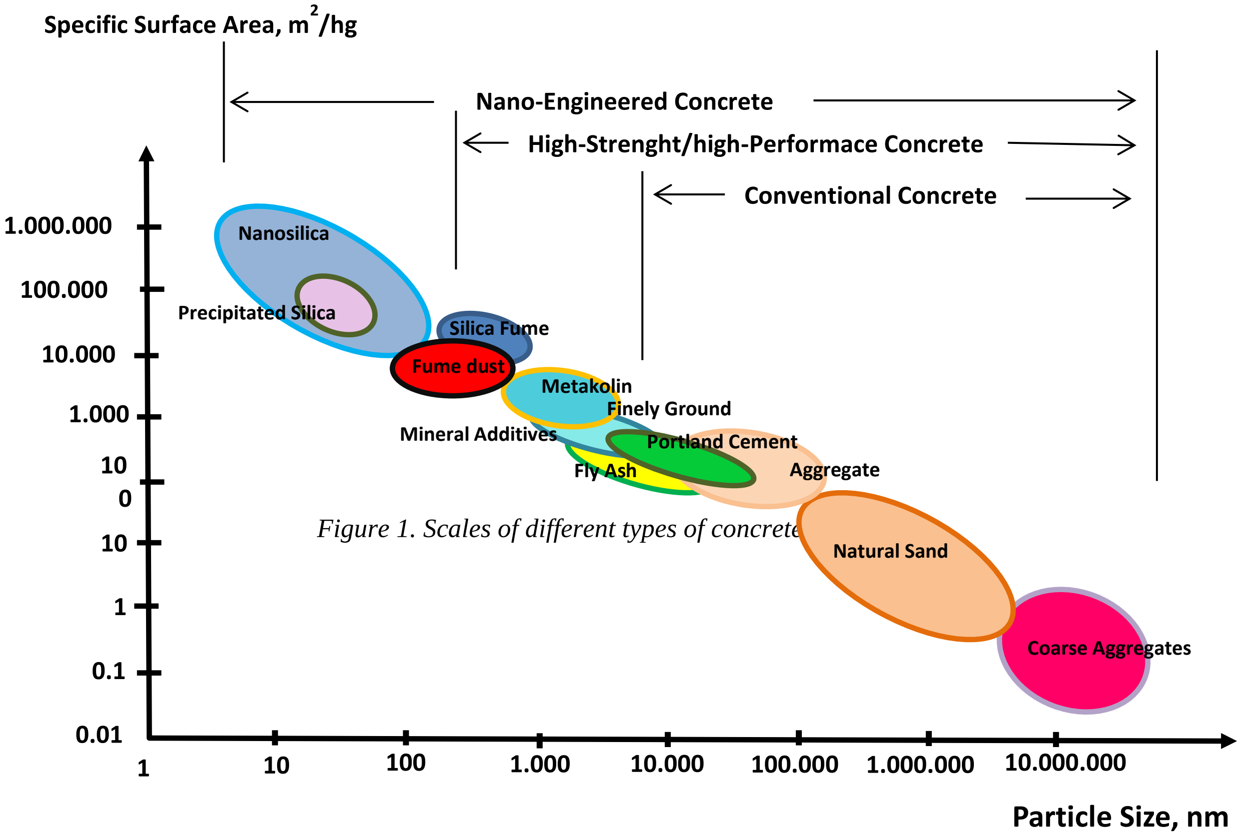


Figure 1.Escalas of different types of components

Figure 2. Fume dust ferritic

The sample used in this study was obtained from a random fraction contained in the bags filters where the waste is stored. From each of these samples they were taken approximately 50 kg, always preserved in closed containers to prevent the action of moisture. Then 250g of both samples were taken to proceed then to make a granulometric study.

Figure 3 shows the results obtained where the amount of material that does not cross the corresponding reflected sieve are collected. It is noted that the maximum is reached around the range 53-297 microns.

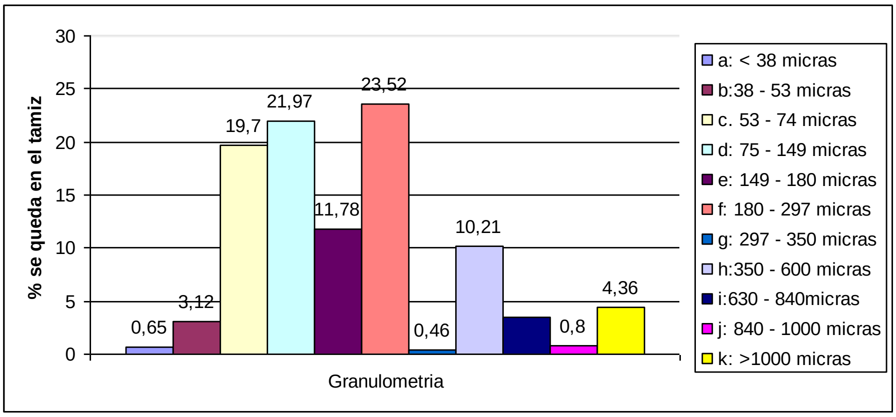


Figure 3 Particle size of fume dust

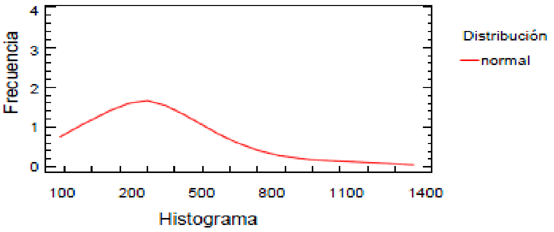


Figure 4 Particle size of fume dust. histogram

Set to a curve (Figure 4) data observed a 76.97% of the grains are in the range being 53 and 297 microns. The setting is not distributed symmetrically shaped but right correspond one 19.17% and to the left a 3.77% of the material analyzed.

For the determination of the chemical composition of the powders smoke two techniques were used, the X-ray diffraction and thermogravimetric

Table 1 shows, as above indicated results obtained with this technique.

Elementos químicos	**Contenido%**
Carbon	0.20-0.50
Silicon	2.00-4.00
Manganese	1.50-2.50
Tin	<0.010
Nickel	<0.30
Copper	0.20-0.50
Chrome	7.00-9.00
Molybdenum	0.10-0.20
Iron	23.00-32.00
Calcium	6.50-8.00
Lead	1.00-1.50
Zinc	10.00-20.00
Magnesium	2.00-3.00

Table 1. Chemical composition of ferritic smoke powder obtained by X-ray difractomía

Table 2 shows the analytical results are shown termogravimetrías being for fume dust sample (PDH).

Sample PDH Sample weight = 61.00 mg			
Rango	Δt (ºC)	ΔW (mg)	Porcentaje de variación
1 – 2	27 – 111	-0.248	-0.406 %
2 – 3	111 – 235	-0.261	-0.428 %
3 – 4	235 – 382	-0.176	-0.228 %
4 – 5	382 – 443	-0.229	-0.375 %
5 – 6	443 – 560	+0.154	+0.253 %
6 – 7	560 – 634	-0.232	-0.380 %
7 – 8	634 – 743	+0.060	-0.098 %
8 – 9	743 – 999	-0.154	-0.252 %

Table 2 termogavimétricos ferritic powder smoke

Figure 4 thermograms are shown, with the curve (TG) which is displayed in red (in which the variation of the mass or percentage variation from baseline versus time or observe the temperature) and (DTG) which is shown in green (in which the time derivative of the loss is also observed in function of time or temperature).

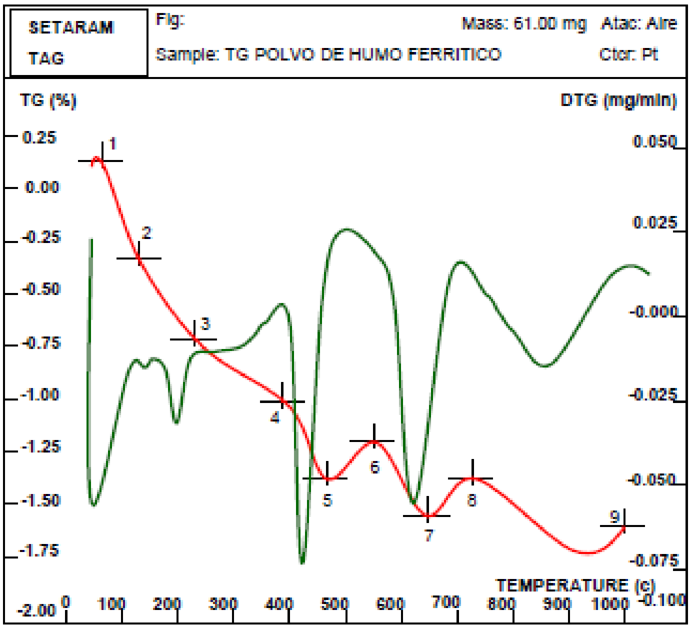


Figure 5 Thermogram ferritic smoke dust

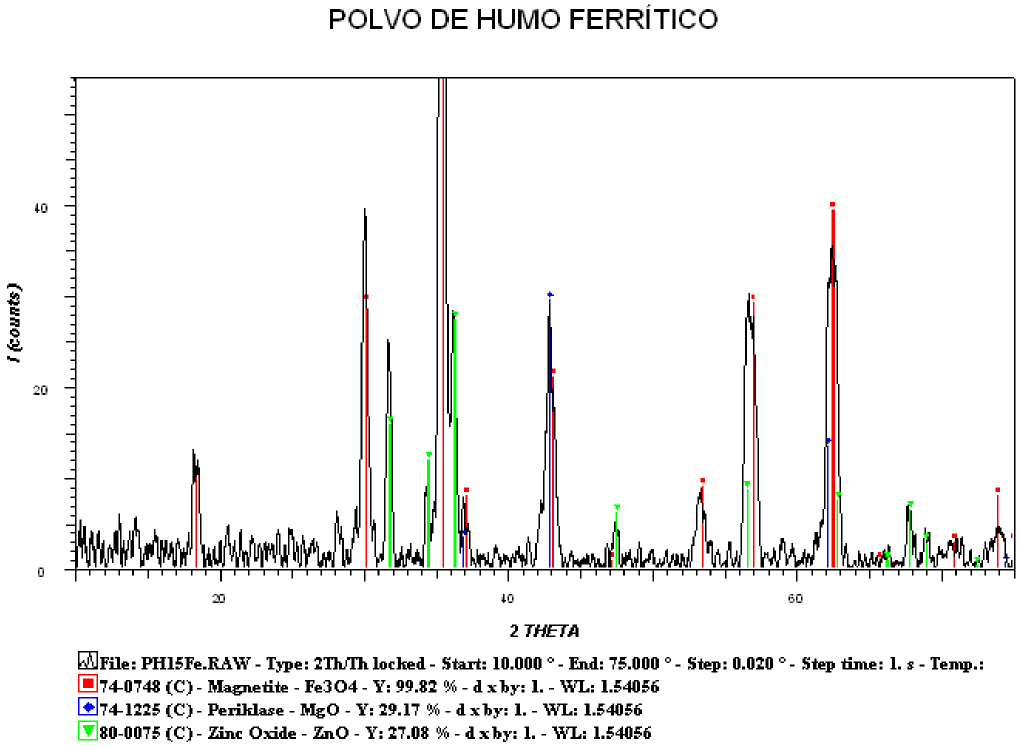


Figure 6 Diffraction X-ray powder sample ferritic smoke

Powders from the manufacture of stainless steels, consist mainly of magnetite and to a lesser extent, hematite, also appearing, although a minority, calcium and silicon oxides.

Thermal analysis shows an initial zone of continuous loss of mass assignable in principle to dewatering processes commonly occur in materials having such a fine particle size. However, this loss of absorbed / water constituent peak coincides with the first carbon graphics and humidity obtained by the determiner. This leads us to believe that in this area (below 400 ° C) also is producing a decomposition produces carbon and water, possibly allocable to organic carbon from oil products. Around 400ºC a marked loss occurs due probably to dehydration processes free calcium hydroxide, which coincides with the second peak of the graph determiner water.

However, in the thermogram, this process is interrupted to 450 ° C by a gain region whose origin could be presumed oxidation phenomena associated with some kind of structural transformations or present. One hypothesis to consider structural change poses magnetite to maghemite, according to the reaction

$$\mathrm{Fe_3O_4} \rightarrow \gamma - \mathrm{Fe_2O_3} \qquad [1]$$

This phenomenon repeats itself later around 600 ° C, and obeys a second transformation of maghemite to hermatites according to

$$\gamma - \mathrm{Fe_2O_3} \rightarrow \propto - \mathrm{Fe_2O_3} \qquad [2]$$

Both phenomena of structural transformation (transition from one stage to another) mask in the thermogram, losses due to decomposition of carbon and calcium (about 600 ° C), seen in the second peak of the graph, which gives information from the decomposition of alkali carbonates is at temperatures around 800 ° C.

The actual densities (3.76 g / cm3) and density (1.06 g / cm3) of the powder sample were obtained using a pycnometer to subsequently make a comparison of densities in the compact.

2.2. Conventional concrete

It began with the following properties and initial conditions:

Cement content 325 kg / m3. CEM I type with a density 3.1 g / cm3.
Relationship w / c 3.1≤ 0.5
Proportion gravel / sand = Arena 50% 50% gravel
Consistency soft = 6 and 9 cm cone Abrans
Approximate target category resistant H-35

The components used were limestone aggregates, from crushing, both the size of the sand and in the remaining sizes, aggregates were from commercial manufacturing plants located in the Campo de Gibraltar.

2.3. Silica fume

It develops as a comparison to the extra resistance that gives the concrete [2]. It is proven that such material higher strengths are obtained and therefore agreed to conduct a comparative study of it.

Appearance	Gray powder
Density at 20 ° C (real)	>2.3 g/cm^3
Apparent density	Aprox. 0,2 g/cm^3
content SiO_2	> 90%
Chloride content	< 0.1 %

Table 3. Properties of Silica Fume

3. Process description

The process for the manufacture of concrete described below according to the different proportions or values depending on the additions. Analysis of different items [3], referred to silica fume, adecuaron these proportions to 5, 10 and 15% of powdered ferritic fume dust, and 10 additions and 15% silica fume.

The nomenclature used for the concrete produced, object of this study is as follows:

- PHF 5 = concrete with an addition of 5% (spc) ferritic fume dust.
- PHF 10 = concrete with an addition of 10% (spc) ferritic fume dust.
- PHF 15 = concrete with an addition of 15% (spc) ferritic fume dust.
- PHS 10 = concrete with an addition of 10% (spc) silica fume.
- PHS 15 = concrete with an addition of 15% (spc) silica fume.
- NA = conventional concrete.

The A / C that has been chosen, in all cases, 0.5.

These concretes were manufactured in a kneader with rotating vertical axis and fixed blades cube, with a capacity of 80 liters.

Once kneaded proposed concretes were emptied into molds at a table vibrated for compaction, at a frequency of 42 Hz (2400 cycles per minute) according to UNE 12390-2 [4].

Specimens were covered with plastic for 24 hours and then were demoulded and brought into a moist chamber for curing, this being an enclosure that keeps inside a relative humidity less than 95% and a temperature of 20 ± 2 ° C. Finally, the extraction control specimens with which the test [18] were performed occurs.

These specimens have been kept in the chamber until use, 24 hours before testing.

For performing compression tests they have been used, for each, three specimens, 7, 28 and 90 days, respectively.

By contrast, in the flexural tests we were used three specimens 40 days.

4. Geometry of the specimens

Regarding the geometry of the test pieces are cylindrical according to standard dimensions of diameter *d* and height *2d* in our case their dimensions correspond with 45 mm diameter and 90 mm height as shown in Figure 7

1. These specimens will be made part of the compression tests.

Cylindrical specimens were cut without alteration of mortar and coarse aggregate, as the surface was flat is dispensed with the facing of the same.

Figure 7 Shows a cylindrical specimen. *Figure 8. Sample prismatic specimen.*

The tests flexotraction with the same characteristics were performed using prismatic specimens with dimensions according to regulations square section edge *d* and length *2d* or *4d*, in our case the dimensions of these specimens are 40 x 40 x 160 mm as shown in Figure 8.

5. Tests uniaxial compression

In Table 4 the results of tests with cylindrical specimens are detailed, have been considered the average values of the efforts obtained after breaking three specimens in each case, being the valuation of rupture, according to regulations, satisfactory.

Mixed description	7 days (MPa)	28 days (MPa)	90 days (MPa)
PHF 5	38.3	41.7	45.3
PHF 10	41.3	40.2	54.8
PHF 15	50.6	51.6	61.8
PHS 10	43.1	46.2	59.5
PHS 15	38.3	42.2	52.5
NA	37.3	39.1	51.3

Table 4. Results of cylindrical specimens. Compression tests.

This type of test was performed according to standard UNE-EN 12390-3 [5].

5.1 Cubic specimens

Rupture of the prismatic specimens for flexural two pieces originate from each specimen that remain unchanged. As the section is square, one can obtain a modified or equivalent bucket load applied by square plates with the same dimensions of the cross section of the prism.

Figure 9. Charging device cubic specimens for compressive

According Neville [6] the resistance of the specimen cube modified, would be 5% higher than the normal cube specimen of the same size, because of the lateral containment due to excesses in relation to the hub. In this study a relationship is obtained average, since only the test was performed using 2 buckets for each of the specimens tested for flexural strength:

Mixed description	Break to 40 days (MPa)
PHF 5	55.71
PHF 10	54.80
PHF 15	70.25
PHS 10	69.87
PHS 15	57.54
NA	57.44

Table 5. Results of cubic specimens. Compression tests.

5.2 Methodology and results

To carry out the tests flexural prismatic specimens with square base made with the same component as cylindrical specimens were uses.

The modls of prismatic specimens were dimensions, according to UNE-EN 12390-5 regulations [7], square section edge lengh *d* and *4d*. In our case the dimensions of said specimens were 40X40X160 mm, as shown in figure 10.

On the other hand, flexural strength tests were performed to concretes consecutive 28-day performing all tests on the same day and accoding to the UNE-EN 12390-5 [7].

The type of device used (Figure 10) loaded at a central point

Figure 10 Charging device used in the test specimens (central point)

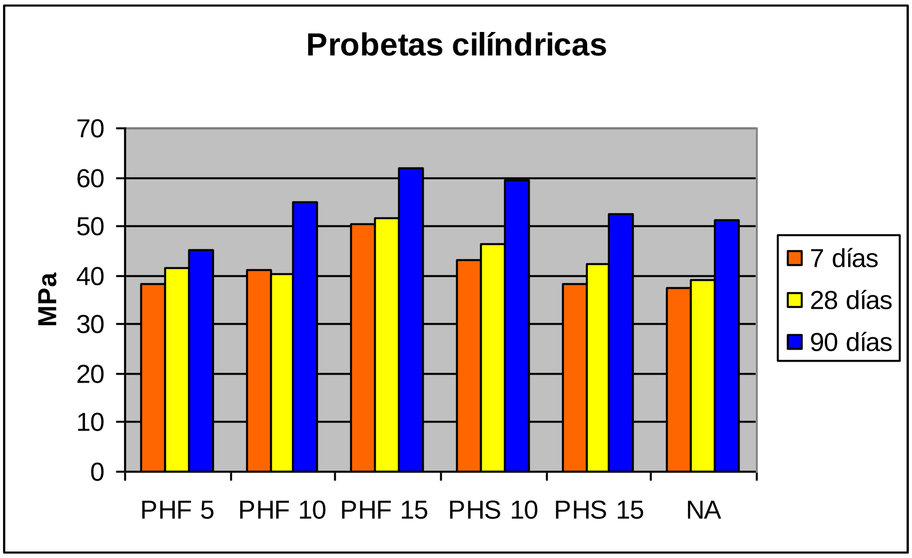
The test results are shown flexural strength in Table 6. Flexotraction results are treated with an approximation of 0.1 N / mm2, these being:

Sample	28 days (MPa)
PHF 5	13.9
PHF 10	12.6
PHF 15	11.1
PHS 10	11.9
PHS 15	11.1
NA	8.65

Table 6 Results of prismatic specimens, flexural tests.

5.3 Comparison and analysis of results

In various tests, particularly for cylindrical samples, we note the increased compressive strength as is increased the amount of powder of ferritic fume dust in the concrete composition, while the addition of silica fume decreases effect and Kadri referenced by Duval and [8].



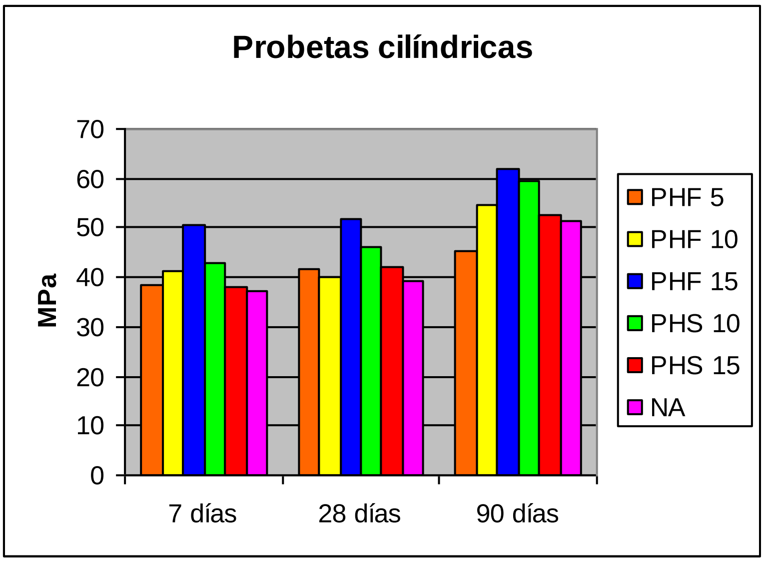


Figure 11. Compressive strength on cylindrical specimens.

Figure 12 Compressive strength on cylindrical specimens

To 7 days appreciate that increasing the strength of the material begins to be significant primarily with the addition of 15% fume dust as surpasses even high strength concrete made adding silica fume.

At 28 days the increase is quite relevant, compared to the rest, when the addition is 15% ferritic fume dust.

90 days note that unlike what happens with silica fume powder, the higher the addition of powdered ferritic smoke, compression strength of the material increases, reaching a difference of 9.3 MPa with respect PHS15% of more than 15% increase, although with PHS10% is 2,3MPa only slightly less than 5% increase. Draw attention to the strong improvement produced with the addition of fume dust respect to silica fume.

If the PHF15% compared with conventional concrete gain it is 10.5 MPa, up from 15% the difference with NA.

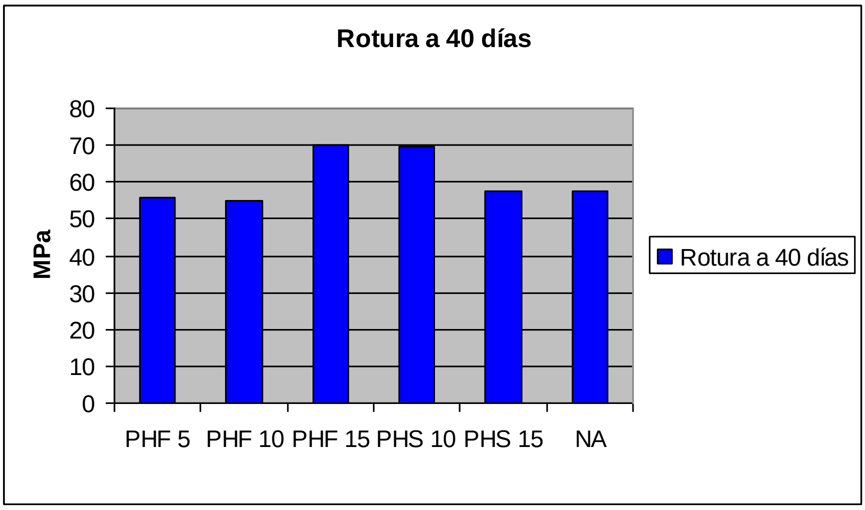


Figure 13 compressive strain cubic specimens

As shown in Figure 13, studies with cubic specimens provide superior to those obtained with the cylindrical specimens results. This result is justified by the greater height / length in the case of cubic specimens [6].

The results show that concrete with 15% ferritic fume dust (PHF15) acquire a higher resistance again in respect of comparative equivalent performed for cylindrical specimens for both concretes with added silica fume 15 % and 10% and conventional concrete. That is, PHF15 increased by 2% over the PHS10, up 18% compared to PHS10 equal increment on concrete NA.

Contrary to the results obtained for compression, and as shown in Table 6, in the case of the flexural strength, are higher values as decreases powder addition ferritic fume dust, jumping almost 14 MPa of PHF5 the value of 11 MPa for the addition PHF15. This is a loss of about 25% of the addition as we increase resistance of ferritic fume dust. This fact must be taken into account as previously exhibited levels of fissuring obtained by the addition, resulting in a positive development since the flexural strength obtained by adding

PHF15 is similar to that obtained for concrete with addition powder silica fume, then the levels of cracking in the absence of a formal verification is not the subject of this work, will be equivalent.

If we make a comparison with conventional concrete, increased flexural strength is notorious for each addition PHF15, PHF10 and PHF5 rising from just over 25% to almost 60%, respectively. This data supports the idea of the decrease in cracking of concrete with added ferritic fume dust.

In Figure 14 the bar chart with this line down on resistance just discussed is located.

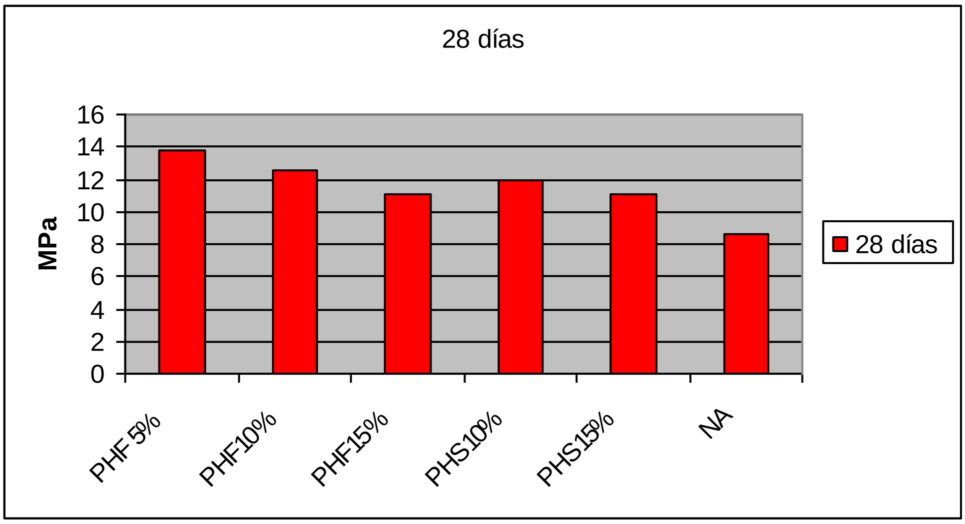


Figure 14. Flexural strength of concrete

The main findings throughout the work are listed below:

9. Conclusions

- Ferritic fume dust used as additive to concrete, gives a good workability, compactness and rigidity hardened material.
- Improves resistance to other components such as silica fume powder, and contrasted and employee resistant concrete.
- The mechanical behavior, concrete made with ferritic fume dust get compressive strength and superior to conventional concretes tensile elastic behavior as to not introduce significant changes.
- This material is classified as a special waste because it exceeds the limit of chromium, but this and other contaminants are stabilized in the cement matrix, as we have seen in the leaching of the concrete.