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Performance Approach the Durability of High Volume Fly Ash Concrete

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Abstract*— More than 500 000 tons of fly ash is produced each year in Morocco. Most fly ash type F, the percentage of use in the Moroccan cement is about 6%. Partial replacement of cement with supplementary cementing materials SCMs) results in a proportional reduction in emissions of greenhouse gas (GHG) emissions and the production of concrete "greener", because the manufacture of the latter requires less energy (necessary for the manufacture of cement) and prevents emissions from the process of transformation necessary (calcination of limestone). Other benefits include minimizing the disposal of industrial waste (in landfills), a reduction in the demand for natural resources and, with judicious use of supplementary cementing materials, production of concrete which has properties and durability. To increase its percentage of use, a thorough investigation was conducted for use in concrete. This article presents the results of an experimental study containing large volumes of fly ash Moroccan class F. Cement has been replaced by two percentages (25% and 50%) of Class F fly ash [500µm].

This incorporation affects the properties of fresh concrete and mechanical properties and durability of concrete. The magnitude of this effect depends on the nature and proportion of fly ash used.

The replacement of cement by this fly ash reduces the compressive strength, the tensile strength, the flexural strength and modulus of elasticity of the concrete at early age which has been improved in this study, and there continuous improvement and significant strength properties beyond 28 days.

The reactivity of fly ash [500 µm] is increased by grinding them up to an average size of particles between [63-100] µm. The cement was replaced by 25% and 50% ground FA, so to produce a high performance concrete.

The cement paste containing 25% FA enables a mortar having the same resistance to compression and the same elastic modulus as the mortar to 0% FA. Against by the mortar with 50% FA shows a decrease in mechanical properties at young age but the 28 days compressive strength of about 30 MPa.

The morphological effect of fly ash and substituted the material microstructure have a significant influence on sustainability.

Index Terms— Compressive Strength, Concrete, Durability, Fly Ash, Microstructure.

I. INTRODUCTION

Sustainable development is a challenge for the future of our planet and its inclusion should lead many changes in the coming decades in terms of energy consumption...Morocco has embarked on a proactive environmental approach in all sectors, like all developing countries, faces major challenges and urgent development, is fully aware of the need to preserve the environment and meet environmental requirements.

The state of the environment in Morocco shows its progressive degradation and dangerous at all levels. This sharp decline has forced the implementation of a comprehensive national strategy for environmental protection and preservation of national resources. It is on the one hand to initiate and implement an effective plan of action for sustainable development the fight against pollution, improving waste management to contribute to solving major environmental constraints.

The field of construction, and in particular those based on the use of cementitious materials will not escape this trend. We recall that this industry generates direct and indirect emissions of greenhouse gases [1]-[2]. In addition, this sector consumes a large amount of non-renewable resource, it is imperative to recognize and conserve natural resources while improving the properties of materials and use of structures and ensuring the quality and comfort of people. The objective of our study is twofold:

- Develop new materials (ecomatérials) Conceived from this perspective, the usual eventually replace materials.

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- Develop new performance standards for industrial by-products in order to promote the use of SCMs replacement.

The development of blended cement is a fundamental step to prepare the development of co-products of the boiler in the civil engineering sector.

As such, the new binders high in mineral additions (in our case Fly Ash), their use has become commonplace for ecological and economic reasons.

In Morocco, the production of fly ash from thermal power plants is estimated at 570 000 tons per year (400 000 tons are recoverable in the dry state). These ashes were usually discarded or stored in dams. However, they are polluting the soil and groundwater and affect the marine fauna and flora. Profession Cement created a Moroccan Economic Interest Group, to promote the use of fly ash in the cement industry which saves natural resources and reduces CO_2 emissions

Fly ash, are products of the combustion of coal in power plants or cement. In general, they are obtained by electrostatic separation or precipitation mechanical flue gases. The ash may be siliceous, sulfo-calcium (Class C) or silico-aluminous (class F), these alternative raw materials with pozzolanic and hydraulic properties.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

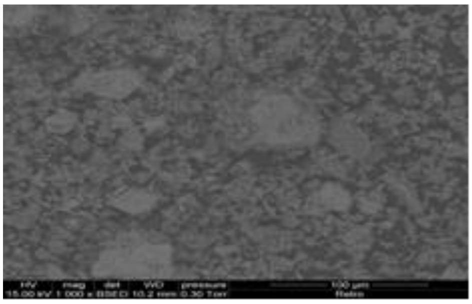
Materials

The materials used for the formulation of mortars are:

A. Cement

The cement used in the study of mortars is a CPJ 45 is a Portland cement with additions (photograph 1). It must contain a minimum percentage of 65% Clinker, the remainder consisting of additions (limestone, fly ash, pozzolans).

Among the main characteristics guaranteed by the standard, Compressive Strength at 28 days CPJ 45 must be greater than 32.5 MPa. CPJ 45 developing performance allowing it to be used for common reinforced concrete and concrete for work in large masses. The results of this analysis are reported in Table (1).



* Photograph 1: Cement (SEM)

B. Fly Ash

The fly ash used (photograph 2) in this study are produced in the Thermal Power Plant Jorf Lasfar (JLEC) in Morocco, following the combustion of coal from the South Africa.

The chemical compositions of fly ash (Class F: Silico-aluminous) were established by X-ray fluorescence technique.

The results of this analysis are reported in Table (1).

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	Fly Ash	Cement
SiO_2	50,05	18,14
Al_2O_3	32,13	3,77
Fe_2O_3	5,07	3,02
CaO	5,06	67,58
MgO	1,08	1,4
SO_3	0,82	4,26
Na_2O	0,69	0,29
K_2O	2,13	1,18
P_2O_5	1,16	0
TiO_2	1,82	0,34

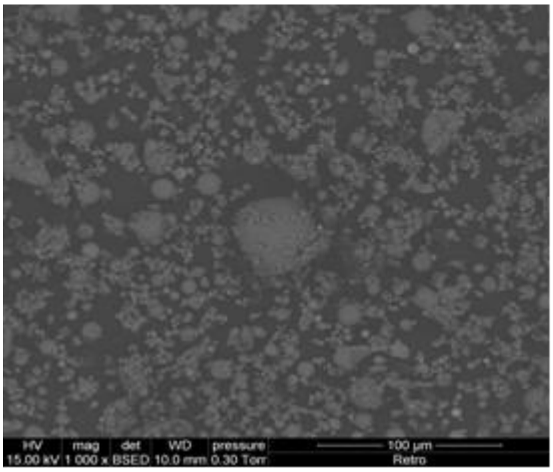

Table 1: *Chemical composition (%) Fly Ash and Cement

*Photograph 2: Fly Ash (SEM)

*: X-ray Fluorescence Analysis and Scanning Electron Microscopy were performed to National Centre for Scientific and Technical Research (CNRST), Morocco

C. Sand:

Mortars are made with clean silica sand (ES = 75%). Its chlorine content is less than 0,2%.

Experimental procedures:

A. Preparation of Mortar:

The mortar consists crafted witness mass C/S = 1/3, W/C = 0.5 (C: cement, S: sand W: water).Mortars with additions are obtained under the same conditions by replacing mass fraction (substitution rate) of cement by fly ash (500 µm) Class F.

In fixing the amount of water, water-reducing effect of certain additions is not put to use, but this approach reduces the number of parameters varying simultaneously. The mass substitution rate is studied 5, 10, 25 and 50% (0% as Reforme).

The prismatic specimens are kept in the water to rupture maturities (1, 3, 7 and 28 days).

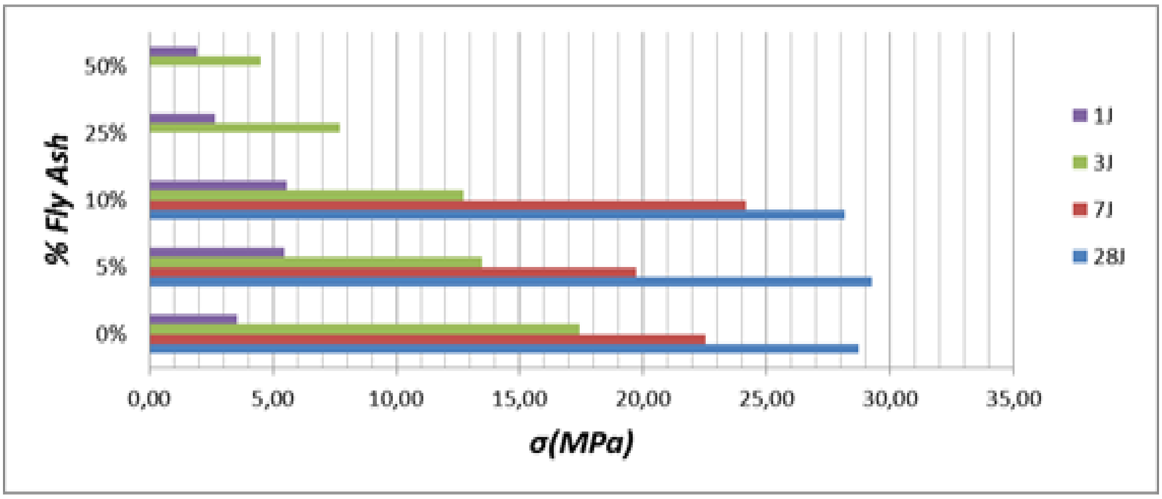

Fig 1: Evolution of the compressive strength as a function of Fly Ash content. Average of 3 specimens with W/C = 0,5

According to this figure (Fig1), we note that the mortars 5% and 10% develop mechanical strength, which remain more or less like that of the control mortar (0%) at all ages (1, 3, 7 and 28 days).
In fact, for the values of the compressive strength of mortars prepared with substitution rates higher FA (25 and 50)%, are still lower than the control mortar for all maturities rupture, and at early ages (1, 3 and 7 days), increased dosage of FA has a negative effect on the mechanical strength, in fact, the difference of 20% and 40% 1day and 45% and 70% at 7 days for 25% and 50% FA respectively (compared to our control). This difference tends to decrease over time because it is reduced to 18% at 28 days by 25% where the beneficial effect of the ash flying for long-term substitution rate, Jaturapitakkul et al, produced by substituting concrete coarse FA between 15% and 50%. And the best results were achieved for a replacement rate of 25% of cement which is confirmed by our study.
0The substitution of 25% FA (500 µm) with a W / C of 0,5 is more efficient for the resistance of mortars in the long term and this is attributed to the pozzolanic activity of setting portlandite $Ca(OH)_2$ liberated by the hydration of C3A to give birth to calcium silicate hydrate CSH occupying an important space in the cement matrix and contributing to the development of resistance.
Drop resistance for mortars containing 50% (45% decrease compared to the CPJ45 (28J)) in FA can be attributed to the insufficient amount of lime liberated during the hydration of cement CPJ 45 and therefore exothermic chemical reactions incomplete.
To demonstrate the effect of fly ash on the mechanical strength, an experimental campaign was conducted to determine the compressive strength as a function of important contents FA (25% and 50%).
The mortar consists crafted control mass C/S = 1/3, W/C = 0.5; 0.4 and 0.35
(C: cement, S: sand, W: water).
Mortars with additions are obtained under the same conditions by replacing mass fraction (substitution rate) of cement by fly ash and fixing the amount of water, the effect of water reducing FA due to thin is not put to use, but this approach reduces the number of parameters varying simultaneously, and other confections we reduced the amount of water. Thing that we could explain the low mechanical stress at all ages. Also have optimum resistance, the prismatic specimens (4x4x16) cm, are kept in the water to break his maturity (1, 3, 7, 28, 90 and 365 days).

B. Mechanical strength

We studied the compressive strength at different maturities, 1, 3, 7, 28, 90 and 365 days. The tests are performed on prismatic specimens of mortar, the same dimensions (4x4x16) cm. They are tested in compression according to the standard EN 196-1. Each test gives two compression results. Each result is the average of 6 measurements.

C. Mass changes

This step consists in observing the swelling mortar retain water in which the binder consists of fly ash and cement. Once made up, the specimens are seven days left in the molds. The waiting time between mixing and stripping is necessary for the test to be strong enough to be handled.
Once stripped, after seven days of storage in pans, mortars are immersed in a tank of distilled water and protected from evaporation of water in a plastic envelope and kept in a room at 20 °C for the swelling test in water. The samples are weighed several deadlines. The reference measurement is carried out after the stripping just prior to immersion of the specimens. Thus, swelling to seven days is the linear expansion of the test piece between its release and a maturity of seven days. Taking into account that these pieces are an additional seven days in the molds before release, then the maturity of seven days, the specimens were tempered for fourteen days.
Each measurement is an average of three values.

III. RESULTS AND DISCUSSION

The purpose of the test is to evaluate the influence of the substitution rate and pozzolanicity on the mechanical properties of the material. We chose to test the strength as a function of time three compositions: % FA = 0; 25 and 50 (Diameter: 500 µm), for W/C = 0.5; 0.4 and 0.35. Results are shown in the following figure.

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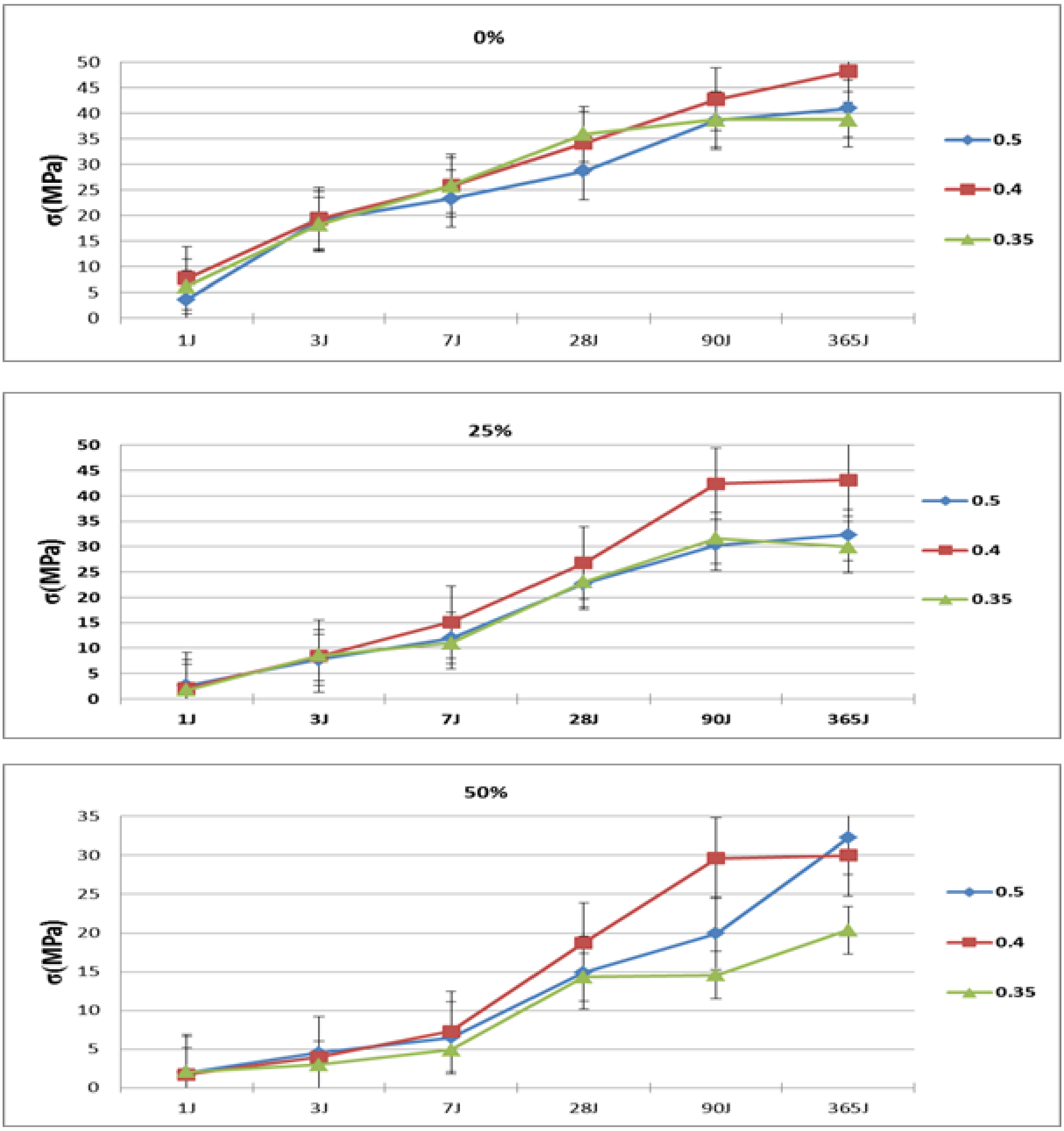

Fig 2: Evolution of compressive strength as a function of age for mortars W/C = 0.5, 0.4 and 0.35 with different levels of cement replacement by Fly Ash 25%,50% and 0% as reference. Average of 3 specimens.

The use of fly ash as original equipment in the production of pozzolanic cement gives us a high mechanical strength, however the water absorbance increases with a low reaction activity [3].

The increase in resistance over time is evident (Fig 2). For specimens where the cement is replaced by fly ash, the young resistance is low because there is less available for cement hydration due to the dilution effect. While pozzolanic reactions are not yet activated at this stage [4]. It should be noted that for a material with low W/C, the grains are initially very close. The influence of the amount of water this time reflects a lack of space between the cement hydrates to form new. Hydration is so delayed [5].

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The mixing water plays a vital role in the hydration process of cementitious materials: it provides an environment for both dissolution and dispersion of the cement grains and especially a source of water for the hydration reactions [6]-[7]. According to Fig 2, we can conclude that the W/C ratio for the most adaptable garment is 0,4. In blended cements, sulfate SO_3 content of cement composed of tricalcium aluminate and C3A portland cement predict the risk of swelling in water due to ettringite formation [5].

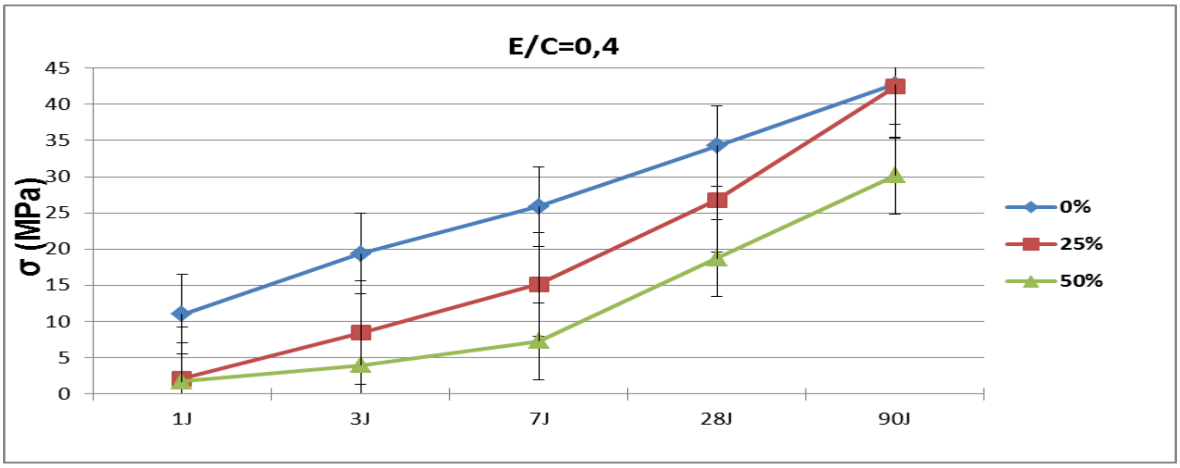
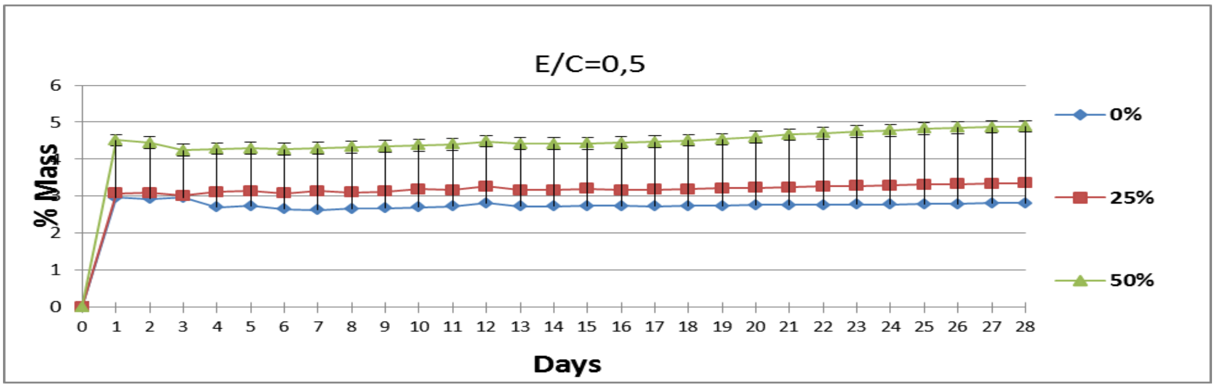


Fig 3: Evolution of the compressive strength as a function of the content of Fly Ash. Average of 3 specimens.

Fig 3shows that the compressive strength decreases to 28j in the order of 45% fly ash content reached 50%. By mortars against the content of FA of 25% to a compressive strength of the same order of magnitude as the mortar with 0% FA to 90 days. Nevertheless, it should be noted that young age the development of compressive strength at 7d is less than 70% and 40% respectively for 50% and 25% FA versus 0% FA.
The low resistance young age is due to the decrease in the number of bonds formed between the cement hydrates due to the dilution effect. While pozzolanic reactions are not activated at this stage [8]. In a strong economy, the dosage of fly ash must be defined taking into account all the parameters of the formula whose behavior differed the appearance of the early-age strength (1, 3, 7 days) 25%, 50% on the one hand and on the other from 0% (control), the decrease in resistance as a function of the ash content can also be explained by the expansion of mortar caused by the reaction of sulphates present in both the cement and fly ash, with the tricalcium aluminate (C3A) [9]. Concerning the swelling associated with the formation of the secondary ettringite, corresponding to the hydrate that is formed after solidification of the material and the formation of the primary ettringite.
This type of ettringite formed in a rigid matrix, where it will cause stress swelling very important. These pressures will lead to cracking or dimensional variations of the material (Fig 4).



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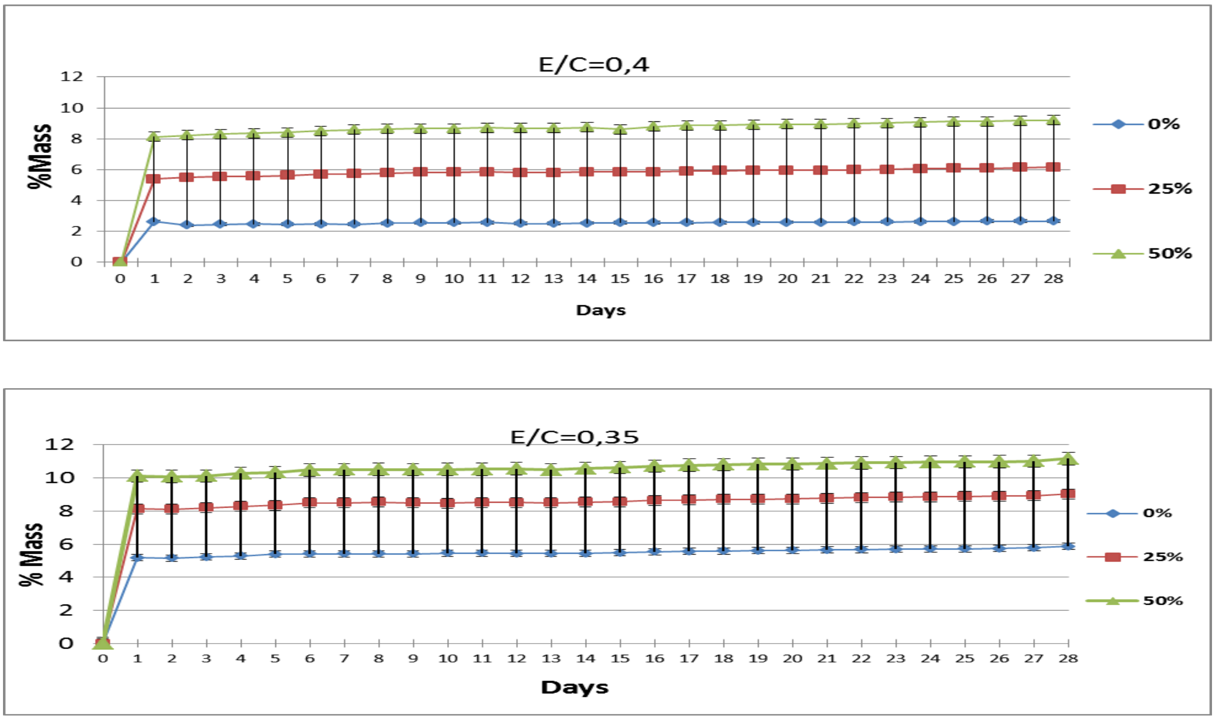

Fig 4: Evolution of the percentage mass based on treatment days for W/C good for determining each rate of replacement of cement by Fly Ash 0%, 25% and 50%. Average of 3 specimens.

The amount of ettringite formed remains the same whatever the compactness of the material [5], something that could be avoided especially in the early days and also in order to reduce cost of formwork day. At sustainability, the need for a rigorous and cure most obvious and also the permeability is lower.
The use of fly ash as original equipment in the production of pozzolanic cement gives a high mechanical strength, however, the absorbance increases with water low reaction activity.
In order to highlight this phenomenon, we followed the mass variation a function of time and percent fly ash. Figure 3 shows that as the fly ash content, the higher we witness a significant caking that can reach a factor of 2, between 0% to 50%. Swelling caused by the ash characterized by a kinetic that is to say a velocity and a swelling time.
This kinetics and the final value of the swelling are dependent on the amount of sulphate that contains the binder. We can conclude that the expansion stops when the potential of swelling associated with ettringite is used [5].
This mass variation (Fig 4) caused by this swelling is coupled by an increase in the mass of the test specimens, which seems to correspond to an outdoor water use to crystallize ettringite [10].
A test specimen in preserved in blended cement water immersion after cure will always increase its weight by water uptake. This weight gain can quickly reach 10% at 28 days. Some authors [11] observed a relationship of proportionality between the measured expansion and mass gain but this correlation differs according mortars.
It seems that such commonly intake corresponds both to the water used to form ettringite and water trapped in the pores of the material. The difficulty is to know the proportion of each of these two phenomena.

We measured the dry bulk density samples; Table (2) shows a variation of the Density depending on the fly ash content of 12%. This decrease can be explained by an increase in pore volume due to the phenomenon of expansion. This may justify the reduction in compressive strength.
However, additional measures and more comprehensive the evolution of the structure and texture of the material depending on the content of fly ash are needed to better understand the evolution of mechanical properties.

Table 2: The Gravity of Materials at different % FA with W/C = 0,4
ρ_h : Wet Density and ρ_s: Dry Density

%FA	ρ_h (g/cm^3)	ρ_s (g/cm^3)	$\Delta\rho$(%)
0%	2.201	2.048	6.95
25%	2.126	1.909	10.2
50%	2.043	1.799	11.94

It is likely that the ettringite swelling that does not involve a question of chemical stoichiometry. Additional physical parameters involved in the development of these swellings, such as porosity.
To address these phenomena weak mechanical strength and water absorbance due to the effect of expanding the availability of fines and the dilution effect, we made a conventional milling, our fly ash [63- 100] µm. And we have prepared mortar prism to determine their compressive strength.

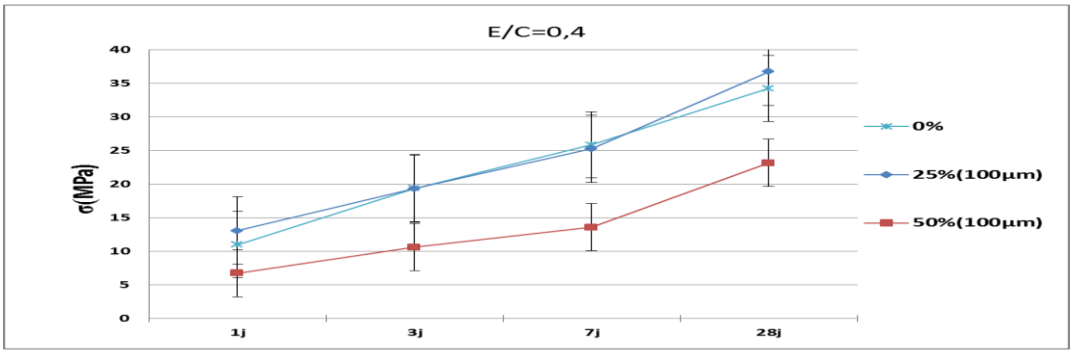

Fig 5: Evolution of the compressive strength as a function of the content of Fly Ash.
Average of 3 specimens

Growth resistance as a function of fly ash content can be explained by the improvement of our material at compactness, Table 3 shows the evolution of the density of mortar and pore volume decrease, because we reduced the swelling rate of the formation of more connections.

Table 3: Density Materials (g/cm^3) at different % Fly Ash (grinding) with W/C = 0,4

Days	1	3	7	14	28
25%	2,05	2,13	2,18	2.21	2,16
50%	2,01	2,09	2,07	2,1	2 ,19

So, we have increased the number of bonds formed between the cement hydrates due to the dilution effect. While pozzolanic reactions are activated, the grinding process cenospheres fly ash increases the density and fineness, and consequently the pozzolanic reactivity to gradually reform [12]-[13].
The grinding process has no significant impact on the chemical properties of coarse fly ash [14]. Kiattikomol et al. [15] observed five types of FA Class F from various sources in Thailand and concluded that the fineness of fly ash, the chemical composition is the main factor affecting the compressive strength of cement mortars.
The use of fly ash finer reduces the water needs of the cement mortar substituted. This reduction of water needs with the greater reactivity of fine fly ash increases the strength of the mortar.
According to Cornelissen et al. [16], the use of coarse fly ash as a pozzolanic material in concrete performance results in a higher resistance, without a negative effect on handling. However, water requirements increase with an activity index effective reduced for a certain type of fly ash due to the increase of irregular migration in particle shape and surface. Bouzoubaa et al. [13] showed that beyond an optimal time grinding (2h), the beneficial effect of

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this process was negligible. The morphology of the fly ash was modified by grinding. Kayali and Haque [17] showed that concrete and with greater early strength development has excellent resistance. Concrete produced with fine fly ash
Showed resistance values 20% higher compared to control samples. In addition, the water permeability of the concrete was about 28% less than the control concrete. Jaturapitakkul et al, For our case study, the rate of substitution with 25% fly ash fine (100% microns) gave us a beneficial effect (Fig 5), (the curves for 0% and 25% crushed almost confused) on rate of 50% substitution process and grinding allows us to raise its compressive strength over 80% in early ages (1, 3 and 7 days) and 90 days, we can observe the resistors 50 % fly ash with and without grinding the same point reached (Fig 6). This result allows us to have a material more compact and more resistant to the swelling force suffered by the ettringite formed at a young age, so we could improve our resistance to these days and identified the difference in strength of compression report our witness CPJ45.

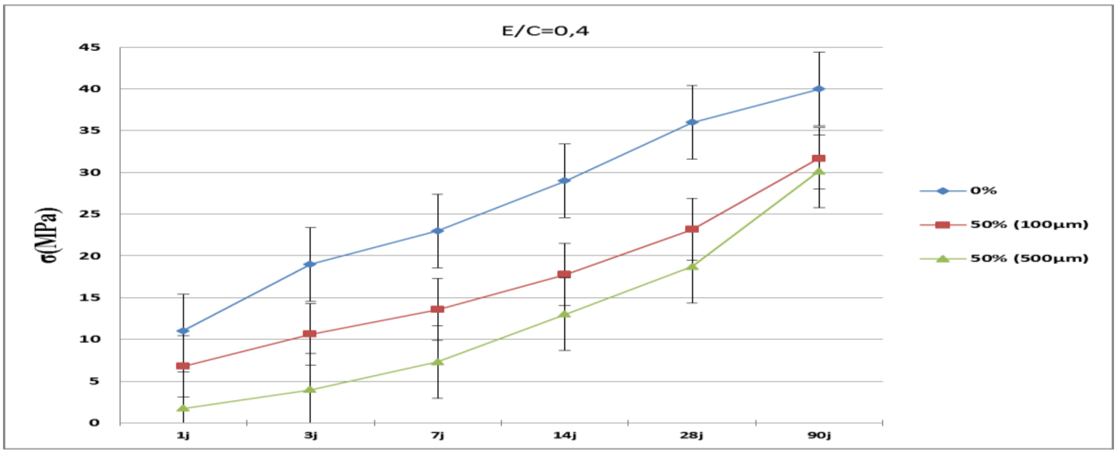

Fig 6: Evolution of the compressive strength as a function of the content of Fly Ash. Average of 3 specimens.

The fineness of fly ash does not depend on the type of coal and probably depends on combustion conditions. However, fly ash with high fineness can also be produced by placing or grinding [13]-[18]. These have no major effects on the chemical properties, although these ashes can sometimes have a greater SO_3 content and ignition loss as original fly ash [19]. The glassy phase contained classified fine fly ash is also higher than the original fly ash [20]- [21]. The fineness of fly ash is the main factor affecting the compressive strength of cement mortars [22].

IV. CONCLUSION

An experimental campaign was carried out on cement pastes with different percentages of fly ash class F and W/C. Monitoring the evolution of mass is used to estimate the evolution of the intrinsic permeability of the material during its maturation. The impact of the pozzolanic activity of fly ash on the structure of the material was also evaluated in long-term experiments on mortar with different rates of replacement of cement by fly ash. The evolution of the compressive strength of the specimens was also presented. The influence of fly ash on the original 500 µm strength at a young age is enhanced with a conventional grinding of 10 min to a diameter of [63-100µm]. Based on the results, the following conclusions can be drawn:
Mortars containing fly ash ground generally showed a smaller pore size (than Portland cement) with improved density.The hydration reaction and the pozzolanic reaction have been improved by the incorporation of fine fly ash. As a result, the dough becomes more homogeneous, dense in its structure and lower $Ca(OH)_2$ paste with fly ash coarse 500 µm in diameter. Substitutions for the rate of 25% fly ash 100µm.
In continuation of our work, we will try to do a more comprehensive study on concrete with high fly ash content in microstructure, we will mostly increase the percentage (over 50%) targeted by our study. We plan to improve this resistance is a suitable choice of cement with low C3A content to reduce the possibility of delayed ettringite

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formation. Another possibility is to apply a constraint to upset the mortars with fly ash ground to limit the effect of the expansion.

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