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Performances for the Improvement of Mortars Bi-substituted by Grinding Fly Ash Class F

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Abstract*— In the cement industry, looking for a less expensive binder by using industrial waste, such as the fly ash, has become a major concern to overcome the deficit in the manufacture of Portland cement, for ecological reasons; and the economical optimization may lead to a very high dosage of the fly ash compared to what we use nowadays. In our previous study, we have shown that the substitution of the cement with a high amount of fly ash 50%, causes a considerable reduction of the mechanical properties. To improve the mechanical strength especially at a young age we use two methods. The first is to apply an opposite force to avoid the expansion of mortar. And the second is to introduce cement with a low content in C3A responsible for the formation of a delayed ettringite.The results of mechanical properties show an improvement of 30% by the first method and 35% by the second to 7 days.

***Index Terms*—Fly Ash, Microstructure, Expansion, Swelling, Young age, Compressive Strength, Module of Elasticity.**

I. INTRODUCTION

The usage of industrial products in concrete, both in regard to the environmental pollution and the positive effect on a country's economy are beyond dispute [1]. These waste products are often incorporated into the concrete to improve workability, mechanical and durability properties of the latter.

Fly ash–cement concrete has been utilized in buildings and infrastructure systems for many years as it is useful for modifying many properties of the concrete such as workability, strength, shrinkage and heat evolution [2–7]. The use of these waste products in concrete is increasing because they result in lower cost of construction and improve some physical, mechanical and durability properties of the concrete in aggressive environments. It has been well established that fly ash (FA), despite its slow rate of reaction, induces significantly improved workability and higher long-term age strength by converting the calcium hydroxide into calcium silicate hydrate (C–S–H). Fly ash is also quite effective in producing the concrete with low permeability [8]. The pozzolanic effect is the main benefit of FA, which states that the unfixed Al_2O_3 and SiO_2 in FA can be activated by $Ca(OH)_2$ product of cement hydration and produce more hydrated gel. Since the gel produced from pozzolanic action can fill in the capillary in concrete, it effectively increases the concrete strength [9]. However, the main problem is its slow development of strength at early ages, especially when a large amount of fly ash is used. There were numerous studies [10-11] carried out on the effect of FA in concrete mixture on mechanical properties and durability of the concrete, limited research work has-beens regarding the carried out to improve the mechanical performance at early age with solutions and contributions, to limit or reduce this specific weakness to the substitution of cement by fly ash. So our aim is to improve resistance to early age cement mortars substitute 50% with grinding fly ash (Class F) to 100 µm, the matter which is not yet developed for high levels of substitution and especially its effect adverse to young ages. Two methods will be used to explore the possibility of promoting the use of high levels of fly ash. Thus the aim is twofold, an economic interest by reducing the time of shuttering and environmental interest by substituting cement.

II. EXPERIMENTAL

A. Material

The material used for the formulation of mortars is:

1. Cement

The cement(C) used in the study of mortars is a CPJ 45 a Portland cement with Additions. It must contain a minimum percentage in Clinker of 65%, the rest being additions (lime, fly ash, and pozzolanas).

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Among the main characteristics guaranteed by the standard, the Resistance to Compression to 28 days of CPJ 45 must be greater than 32,5 MPa. The CPJ 45 develops performance which allows it to be used for Reinforced Concrete currents and the concretes designed for work in large masses.

2. Fly Ash

The fly ash (FA) used in this study is produced in the thermal power station of Jorf Lasfar (JLEC) in Morocco, due to the combustion of a coal from South Africa. The chemical compositions of fly ash (Class F: silico-aluminous) have been established by the technique of X-ray fluorescence, were performed to CNRST, Morocco. The results of this analysis are carried over on the table (1).The fly ash has a diameter of 500µm and after a classic grinding the diameter is 100µm.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	TiO_2
50,05	32,13	5,07	5,06	1,08	0,82	0,69	2,13	1,16	1,82

Table 1: The chemical composition (%) of the fly ash

3. Sand

The mortars are manufactured with a clean silica sand (ES= 75 %). Its chloride content is less than 0,2 %.

B. Experimental Procedures

1. Preparation of mortars

The mortar witness, fabricated, is constituting, in mass, C/S=1/3; E/L= 0,4 (C: cement; S: sand; E: water; L: binder (C+FA)). The mortars with additions are obtained in the same conditions by replacing a mass fraction (50% of rate of substitution) of cement by fly ash (100µm) of class F. The manufacture of mortar is carried out within the laboratory in ambient conditions depending on the operating mode of the standard (ASTM 305-12, 2012).

2. Description of Procedure

1st method

According to the standard, the mixture striker plate is compacted in molds roughly rectangular. A metal plate is deposited on the upper face of the samples for the purpose of exerting opposite force. This force has prevented the expansion of the sample according to the Z-axis (Figure 1). The mortars upset are kept in distilled water up to the maturity of fracture (1, 3, 7, 14, 28 and 90 days). The density of the samples is measured before each test of the uniaxiale compression.

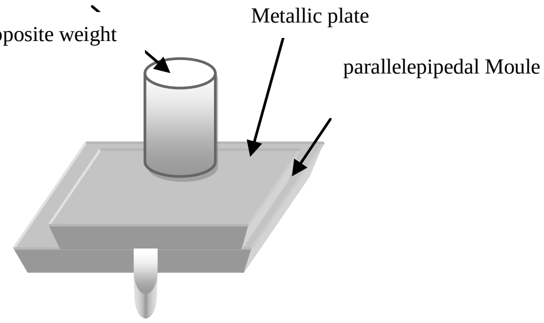

Fig 1: Photo and device mounting used to apply an opposite force

2nd method

To highlight the effect of alumina on our mortars substituted by 50% fly ash, we used cement with a low content in C3A. Instead of CPJ 45 we use cement with a rate of C3A= 2% which is cement Taken Sea (PM) of more than 95% of clinker, it is mainly intended for the work of concrete works submitted to the waters to high concentrations in sulfates or chemical environments moderately and highly aggressive. It can be used for books in reinforced concrete, non-reinforced concrete, prestressed by pre or post-voltage not subjected to heat treatment. This cement is also particularly well suited for the works of industrial Civil Engineering, sewage treatment plants, the work of foundations, the work in underground environment. This cement is not suitable for works requiring high

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resistances in the short term. Demolding of prepared mortars with cement PM and 50% of fly ash is done after 24h of preparation, and then water logging is done in a tray of distilled water up to the maturity of rupture of (1, 3, 7, 14 and 28 Days) .The density has been measured after demolding.

III. RESULTS AND DISCUSSION

1st method

The purpose of the test is to assess the influence of the rate of substitution and the pouzzolanicity on the mechanical properties of the material contrasted at young age. We measured the resistance to compression as a function of time on prismatic specimens with 50% of grinding fly ash. For an E/L= 0,4 fixed after a very detailed experimental study [11]. The witness of our tests is the 50% crushed. The results are presented on figure 2. The application of contrasted force has enabled us to increase the resistance to compression of 25% to 35% in young age (1, 3 and 7 days). However, the opposite force to move closer between the contrasted samples and not contrasted with the time. The difference is only 8% to 90 day. This method has allowed us to have a material that is more compact and therefore more resistant which allows him to resist the forces developed by the expansion of the delayed ettringite. This last was at the origin of the weakening of the resistance to compression in young age.

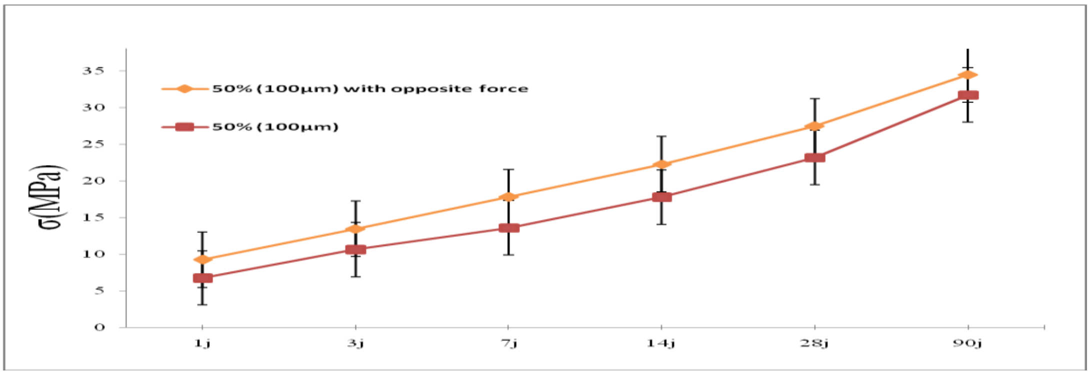

Fig 2: Evolution of resistance in compression as a function of time with E/L= 0,4

	1j	3j	7j	14j	28j
50%(100µm with Opposite Force)	2,132	2,191	2,164	2,181	2,217
50%(100µm)	2,009	2,098	2,073	2,100	2,191

Table 2: The density of materials with E/L= 0,4 in g /cm^3

The opposite constraint applied on our mortar during its hardening and the development of the pressure of crystallization, decreases the entry of waters, the movements reagents [12] and the improvement of the compactness of the skeleton (cement fly ash sand). Of this fact, there is a reduction of the initial porosity of the materials responsible for the fall of mechanical resistance in young age simultaneously with an improvement of 4% of the density (Table 2). Moreover, when it is a mortar in young age, we have to take into account: In 1st place, the evolution of viscous materials to a rigid material or a state of suspension to that of a solid porous. In 2nd place, the absorbance in water which is one of the properties of fly ash thanks to its delicate thing that could form tiny cracks responsible gradients of the water within the material [13]. The beneficial use of this contrasted force has allowed us to fight or to decrease several adverse effects of the substitution of 50% of CV (100 µm) of class F. This can be explained by the decrease of capillary pressure which generates a contraction of the matrix that can lead to cracking that appears in a material if the constraints are subject to exceed the mechanical resistance. This is confirmed by an increase in the value of the module of elasticity measurement on a contrasted mortar and a non-contrasted one (figure 3). This elevation is more pronounced between first day and seventh day. We recall that the module of elasticity is proportional to the mass density and it is a function of number of links formed. Therefore our case, we can assume that when we apply an opposite force we are approaching the particles constituting the one of the other and therefore by promoting the formation of new links which will allow the

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increase of the rigidity of the material. This higher rigidity thus allows the material to resist the forces developed by delayed ettringite.

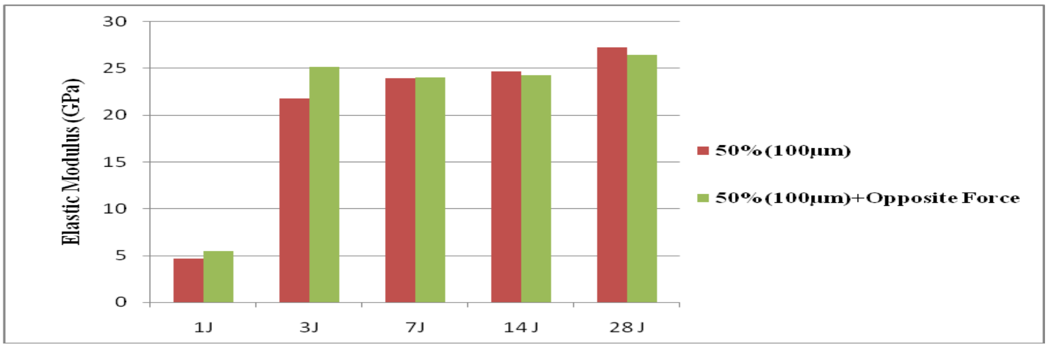

Fig 3: Evolution of the elastic Module as a function of time with E/L= 0,4

The levels of chemical composition and the substitution of cement by fly ash siliceous promote the formation of C-S-H compared to C-H, this calcium silicate hydrate represents a means of storage of reagents on the one hand, and on the other hand, the nature of the C-S-H affect the response of materials against pressure developed during the crystallization of ettringite as well as its transfer properties, governing the phenomena of Ionic diffusion among others.

The considerations formulated in the framework of the theory of the pressure of crystallization [14] indicate that the precipitation of blocking ettringite which is formed during the first minutes [15] and primary ettringite formed after 24 h [15], both do not have a sufficient condition for the development of swelling because the latter is used to delay the hydration and assure; therefore, the maneuverability of the concrete required for its establishment and for the regulation of the reactions of cement, nevertheless the secondary ettringite, (formed between the 2^{nd} and 7^{th} days), was regarded as responsible for the disorder then the pressures of swelling attributed to his formation [16].These pressures will lead to cracking or to the dimensional changes of important material, a phenomenon well perceived on figure1, an improvement of 35% in 7 day, and also for the density table 2. After hardening and ripening the substituted material has formed of connections so it has a correct mass density, a pore volume very least inconvenient, therefore the material resists the force of compression with or without application of force, very noticed by the 8% of the gap between the two materials. According to (Ping &Beaudin) [17], the constraint in a material from the development of pressures of crystallization is a function of the fraction of surface crystals in contact with the matrix is therefore a function, among others, of the nature of the porosity of the cement paste. Thus, according to Taylor et al [18], the expansions are all the more important that the pores are small and little connected. Similarly Grabowski et al [19] noted the importance of the density of cracking, and of the distribution of pores and the porosity to the development of swelling. For Petrov [20], the nature of an expansion is related to the volume of cement paste in the material, important thing to consider from of the tempering. Consequently we have been able to fight against all these problems with the application of contrasted force.

2^{nd} method

The cement chosen for the experimental study is characterized by a low content in C3A= 2% (it is a cement Taken Sea), in order to obtain comparative values with that of the references where the cement with a high content in C3A = 6 %. The role of C3A is not limited to that of a single source of alumina; it seems in this specific case, play a role of "catalytic converter" which the swelling is the only factor influencing on the expansion of a mortar substituted for high content in fly ash even if these contain a high content of alumina. For the aluminate of Portland cement is under two crystalline forms. The first is the C3A the more reactive and is soluble in the first minutes of the hydration; the second is the C4AF is distinguished from the C3A by kinetics of dissolution much lower. That is why; we have sought to know if the form where the alumina cement is expressed plays a role in the swelling for our study, since the substitution is done with the fly ash of 32% of the compound Al_2O_3. With the aim of highlighting the influence of the quantity of alumina with the responsiveness of the fly ash influencing factor on the formation of the ettringite, we made a follow-up to the resistance to compression as a function of time. Figure 4 clearly indicates that the mechanical results are improving from 25 % to 35 % at young age (3 and 7 days respectively) for a mortar to low content in C3A substituted by 50% of fly ash of 100µm in relation to the witness. The use of fly ash can be effective in certain conditions; their ability to control the swelling seems primarily a function of their content in CaO [21]. The texture and the character saturated or none of the porosity of the paste

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(caused by the fine), seem to be the characteristics the most critical in relation to the risk of swelling and also the two gives us a drop of resistance to compression in the early days the figure 3, of this fact the material has been able to improve its texture at the link level even if with a rate of 5% in lime. Santos Silva and al [22] do not observe a correlation between the consumption of portlandite in concretes studied and the reduction of swelling of RSI. They attribute the reducing effects of this addition to its content in aluminates Al_2O_3, determining parameter against of the possibility of formation ettringite.

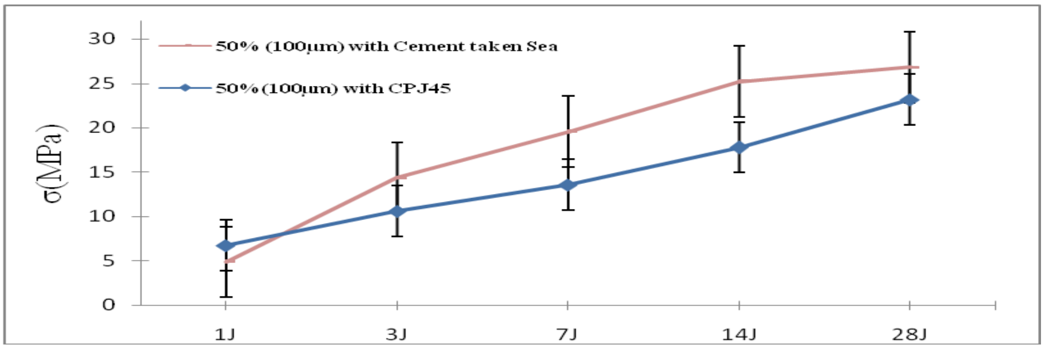

Fig 4: Evolution of resistance in compression as a function of time with E/L= 0,4

	1j	3j	7j	14j	28j
50%(100µm with)	1,930	1,904	1,921	2,010	2,101
50%(100µm)	2,009	2,098	2,073	2,100	2,191

Table 3: The density of materials with E/L= 0,4 in g/cm^3

The nature of cement as much influence on the texture of the cement paste to the early days of tempering. In effect the cement sea outlet, used for specific work in water, this is the main cause of the slow evolution of these grains to young age (table 3), on the other hand, they show the progress to resistance levels, more or less compacted agglomerations micro-grains assembling taller grains have been highlighted.

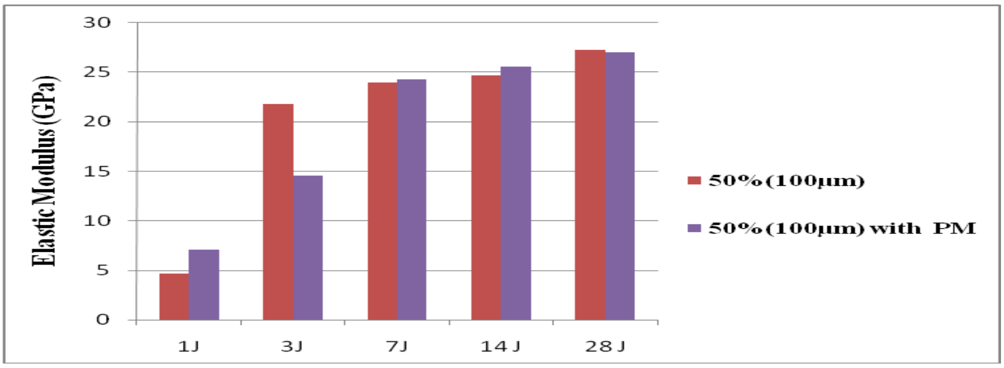

Fig 5: Evolution of the elastic Module as a function of time with E/L= 0,4

The value of the module of elasticity measure on mortars of 50% of fly ash with CPJ45 and with Sea Outlet (figure 5), it has the same trend of 7day to 28 day. Consequently, the formation of new links that will allow the increase of the rigidity of the material has been promoted. The replay of the evolution of the module of elasticity at the early ages (1 day to 3 day) is due:

- ✓ To the activity pouzzolanicity delayed and the lack of links C-H, for the strengthening of the material, for the mortar of 50% fly ash with a CPJ 45.
- ✓ The delayed taking (a special character of this type of cement for work in high water content in sulphate), for the mortar of 50% fly ash with a sea Outlet.

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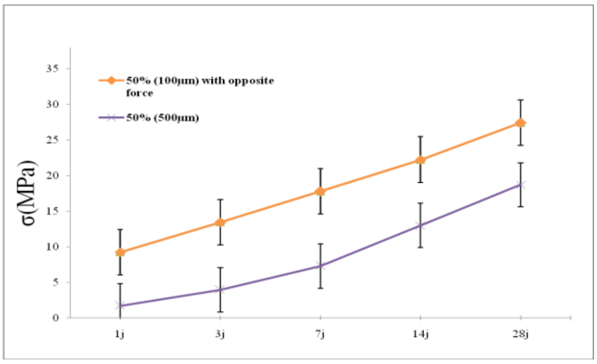
The evolution and improvement are very significant of the compression results with the two methods used compared to the results obtained in the previous article [11].

We can use this judicious mix (50 % (100µm) of CV with E/L= 0,4) with one of these two methods of strengthening and having a material which meets the criteria of performance (Figure 6).



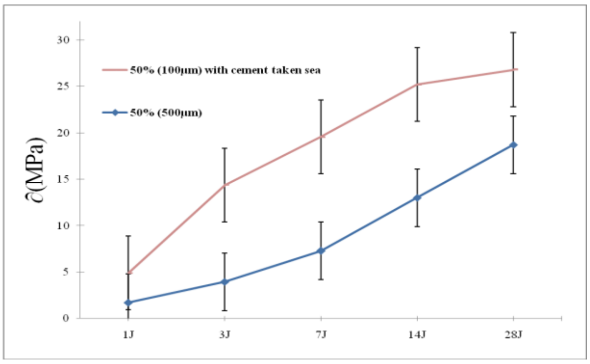


Fig 6 (Left and Right): Evolution of resistance in compression as a function of time with E/L= 0,4

IV. CONCLUSION

The addition of mineral fly ash, seem to have the properties of control against the swelling, therefore an adverse effect on the mechanical properties at young age. In addition to their chemical contribution, the fly ash has often the effect of densifying the structure of the cement paste, thus limiting the possibilities of ion exchange favorable to the ettringite precipitation. In the light of this study, it is possible to conclude that the porous structure of the cement paste substituted by fly ash class F (100µm) is an important parameter with regards to the behavior of the material. The application of a contrasted force in this material can modify the behavior of the swelling or porosity, and guiding the directions of ettringite crystallization. And also for the use of cement with a low content in C3A with our substitution because the kinetics of the depended reaction on the quantity of alumina that contains the binder is stopped by the exhaustion of a reagent. Therefore, we have been able to improve 30% to the method of the contrasted force and 35% for the use of cement with a low content in C3A, at young age (7 days) for the substitution rate of 50 %. For the continuity of our study, we are going to try to do a thermal research on the mortars with high content of Fly Ash, in order to improve the Pozzolanic effect of the mortars from the first days of tempering.

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