Study of the physico-mechanical properties of binary and ternary mortars modified with styrene-polyacrylic latex (SPA)

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Abstract - The use of polymer-modified mortars (Polymer-modified Mortars “PMMs”) on the one hand, and the mineral additions in these PMMs on the other hand contribute positively to improving the environmental and economic aspect in addition to their effects beneficial on the physico-mechanical properties of mortars and their durability. This study mainly aims to contribute to the preparation of a PMM, better physico-mechanical properties and durability, by using polymer latex which is polyacrylic styrene (SPA), and by replacing 30% of Portland cement by mineral additions. This research work is devoted to the study of the effect of mineral additions, limestone fillers (LF), natural pozzolan (NP) and silica fume (SF), on the physico-mechanical properties and the durability of PMMs. The study was carried out by examining seven compositions containing binary and ternary binders, with a polymer/cement (P/C) ratio of 7.5%. The results obtained were, each time, compared with those of a control mortar without polymer and without mineral additions. It was found that 7.5% SPA latex appears to be optimal for the properties studied, because this proportion leads to increased tensile and compressive strengths, and reduced shrinkage. Finally, it should be noted that the combination of natural pozzolan and silica fume is considered the best formulation.

Keywords: Polymer modified mortar, SPA Latex, Mineral additions, tensile strength, compressive strength,

I. Introduction

PMMs have proven to be very popular building materials. The main advantage of these materials, when comparing them with Polymer Impregnated Mortars (PIMs) and Polymer Mortars (PMs), it's that their technology is similar to that materials with admixtures commonly used in ordinary Portland cement (OPC) concretes and mortars and their cost is also reasonable [1]. In an effort to improve some disadvantages of ordinary concretes and mortars, adding a small amount of polymer to the cement mix can significantly improve the properties of the resulting materials [2].

The consistency of latex-modified mortars is important, as they are used for the repair, reinforcement and finishing of reinforced concrete structures [3]. Latex-modified mortars and concretes generally offer good workability compared to conventional mortars and concretes. This is mainly explained by the action of the ball rolling of the polymer particles, the entrained air and the dispersing effect of the surfactants in the latexes [4], [5]. Apart from the fact that latex is a cement substitute, it acts as a water-reducing plasticizer [6].

The results have been shown by Jo [3] on the variation of the W/C ratio as a function of the P/C ratio whose workability is acceptable for PMMs using SBR, EVA and SAE. At the same workability, the W/C ratio of PMMs is 30 to 40%, which is lower than that of Portland cement mortar "OPC" (70%), regardless of the type of polymer.

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The W/C ratio of PMMs decreases with increasing P/C ratio.

Polymers, whether aqueous or powdered, increase the flexural and tensile strength of mortars [7]. The mechanical strength of PMMs and PMCs are influenced by various factors which tend to interact with each other. Various methodologies for curing PMMs have been observed. Air hardening is preferable to increase the mechanical strength of PMMs at older ages [8]. In a hot and dry environment, PMM intended for repair shows improved mechanical properties compared to cement-based repair mortars [9]. Prolonged exposure to air after 7 days of initial water immersion appears to be the best cure method for PMMs [10]. A significant improvement in the strength development of PMMs was achieved through wet-dry curing conditions which provided good circumstance of cement hydration and epoxy resin polymerization [11]. These results are in agreement with those reported by Parghi and Alam [6]. We can therefore conclude that the curing conditions of PMMs differ from those of conventional mortars because the hydration of cement requires humidity and the formation of the polymer film requires dry curing.

With regard to the influence of the P/C ratio, the properties of PMMs depend significantly on the polymer content than on the W/C ratio [12].

The use of mineral additions such as limestone fillers, natural pozzolana and silica fume, in the manufacture of SPA latex modified limestone mortars, as a partial replacement for cement, is also a fundamental objective of this research, which allows formulating a resistant, durable and environmental PMM. The originality of the present investigation lies in the incorporation of mineral additions in the PMMs in a separate way (binary mixture of the binder) first and then in a combined way (ternary mixture). So, we will study the effect of SPA latex and mineral additions on the physicomechanical properties and durability of PMMs.

II. Characterization of Materials Used

A. Cement

The cement used is a CEM I 42.5 CRS from the Biskra cement plant (south-eastern Algeria). The physical properties of the cement used are presented in Table 1.

TABLE I
PHYSICAL CHARACTERISTICS OF CEMENT

Bulkdensity(g/cm^3)		1.03
Absolutedensity(g/cm^3)		3.1
Blaine specific surface (cm^2/g)		3200
Finenesscharacteristics	d_{10} (mm)	1.14
	d_{50} (mm)	11.27
	d_{90} (mm)	41.35

B. SPA latex

The Styrene-polyacrylic latex (SPA), known under the trade name "TEKWELD" and supplied by the company "TEKNACHEM", was used. It comes in the form of an aqueous solution of milky white color (Fig. 1). This polymer is stable in alkaline media and the films formed by this latex do not dissolve in hot or cold water. The main characteristics of SPA latex are summarized in Table 2.

Fig. 1 General appearance of SPA latex

TABLE II
MAIN FEATURES OF LATEX SPA

Shape	Color	Density (à 20°C)	pH (à 20°C)	Dry extract
Liquid	Milky white	1.040±0.02	4±1	26%±2%

The choice of this polymer is based on the one hand on the fact that the SPA latex is new compared to other latexes such as SBR, SA and EVA [13], and on the other hand, that the influence of the latex SPA on the physico-mechanical properties of PMM has not received any detailed study although there are researches interested in studying the combined effect of this latex with mineral additions [14], [15].

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C.Limestone sand

The sand used is crushed limestone sand with a maximum diameter of 5mm. It comes from a crushing station located north of the town of Laghouat. The main physical characteristics of the sand used, measured according to the standards in force, are summarized in Table 3.

TABLE III
MAIN PHYSICAL CHARACTERISTICS OF LIMESTONE SAND

Characteristic	Result
Granular class	0/5
Absolutedensity(g/cm^3)	2.59
Apparent density(g/cm^3)	1.49
Compactness(%)	74
Sand equivalent(SE) (%)	68
% of elements<0.08mm	7.5
Fineness module (FM)	3.21
Water absorption coefficient (WA$_{24}$) (%)	4.70

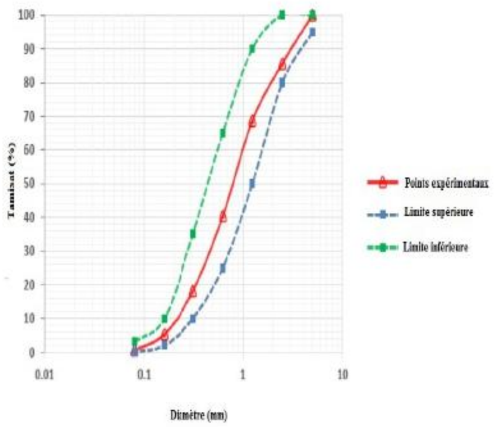

Fig. 2 Granular distribution of limestone sand

From Fig.2, it is clear that the sand used is a medium coarse sand with a continuous and spreading grain size and its grain size curve is inside the normalized spindle.

Crushed limestone aggregates are still characterized by good mechanical strength, and a reduction in the drying shrinkage of mortars and concretes [16], [17].

D.Superplasticizer

The adjuvant used is a superplasticizer manufactured by the company "TEKNACHEM" and marketed under the name "SUPERIOR 9WG".

According to the technical sheet of this admixture, the recommended range of use is between 0.6 and2% of the weight of the cement. It comes in the form of a brown liquid with a dry extract of 33 ± 2%. Its density is 1.10±0.03 and its pH (at 20°C) is 5.5±1.

E.Mineral additions

Three often used mineral additions such as limestone fillers, natural pozzolan and silica fume were chosen.Three often used mineral additions such as limestone fillers, natural pozzolan and silica fume were chosen.

1) Limestone filler

The chemical composition and the different physical characteristics of the limestone filler, the natural pozzolan and the silica fume are gathered in Table 4.

TABLE IV
CHEMICAL COMPOSITION AND PHYSICAL CHARACTERISTICS OF MINERAL ADDITIONS

Element (%)	FC	PN	FS
SiO_2	0.76	46.10	94.61
Al_2O_3	54.90	17.10	0.32
Fe_2O_3	0.61	10.60	1.21
CaO	0.41 *	10.20	0.43
MgO	0.23	4.38	0.39
SO_3	0.61	0.50	0.10
K_2O	0.24	0.30	0.53
Na_2O	0.04	2.80	-
Loss on ignition	36.30	4.20	1.98
Densité (g/cm^3)	2.70	2.73	2.20
Finesse (cm^2/g)	3600	3900	220000

2) Natural pozzolan

The NP was completely homogenized, dried in an oven at 105±5°C for 24 hours to eliminate any moisture and facilitate its grinding. We then crushed it and sieved it with an 80 µm sieve [18]. The NP used is essentially composed of silica and aluminate (more than 60%) (Table 4).

3) Silicafume

The SF used is known under the trade name "SILTEK POWDER" from the company

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"TEKNACHEM". The main physical properties of the SF used are presented in Table 5.

TABLE V
MAIN PHYSICAL CHARACTERISTICS OF SILICA FUME

Physical state	Color	Particle size	Density (at 20°C)	Solubility in water
Powder	Silver	0.05-0.15µm	0.3 g/cm^3	Insoluble

III. Experimental Program and Test Methods

A. Composition of mortars

Seven different binder formulations were studied, including two control compositions such as the classic cementitious mortar with P/C=0% as well as the polymer-modified mortar without mineral addition with P/C=7.5% [19]. Additionally, an "iso-rheology" formulation approach has been adopted, where the consistency is kept constant by adjusting the W/C ratio.

TABLE VI
COMPOSITIONS OF BINDERS

N°	Designation	P/L (%)	Cement (%)	FC (%)	PN (%)	FS (%)
0	**M0**	0	100	0	0	0
1	**PMM**	7.5	100	0	0	0
2	**PMM+FC**	7.5	70	30	0	0
3	**PMM+PN**	7.5	70	0	30	0
4	**PMM+FS**	7.5	70	0	0	30
5	**PMM+(FC+PN)**	7.5	70	15	15	0
6	**PMM+(FC+FS)**	7.5	70	15	0	15
7	**PMM+(PN+FS)**	7.5	70	0	15	15

B. Mixing Procedures

The latex-modified mortars (SPA) were prepared according to the Japanese industrial standard [20], while the unmodified (SPA latex-free) mortar was prepared following the guidelines of the standard [21].

C. Modes de cure

The physico-mechanical and microstructural properties of PMMs are significantly influenced by the curing conditions, which differ from those of traditional mortars [3]. The various curing methods adopted are listed in Table 7.

TABLE VII
CONDITIONS OF STORAGE OF PMMS AND CEMENT-BASED MORTAR

Sample Type	Name of treatment	Conditions of conservation
Cement-basedmortar	Immersion in water	Recommended conservation for pure hydraulic mortars
PMMs	Mixed conservation	Immersion dans l'eau pendant 6 jours + cure sèche à 25±3°C, 50±10% HR jusqu'à l'âge de l'essai.

D. Test methods

1) Dry bulk density

The apparent density of the hardened mortar was evaluated in accordance with standard [22], by measuring the dry mass of 4×4×16 cm3 specimens using a balance with a resolution of less than one tenth of a gram. Three samples of each composition were tested after being subjected to a 28 day cure time.

2) Measuring mechanical strength

These are tensile tests by bending and compression strength carried out according to standard [23] on prismatic samples 4×4×16 cm3 at different times: 3, 7, 28, 90, 180 and 365 days.

IV. Résultsand Discussions

A. Apparent density in hardened state

Fig. 3 illustrates the evolution of the apparent density of mortars in the hardened state according to the nature and rate of mineral additions.

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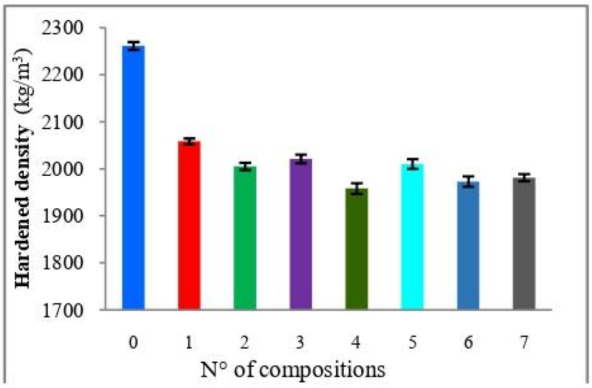

Fig. 3 Variation in the bulk density of hardened PMMs as a function of the nature and the substitution rate of the mineral additions.

From Fig. 3, it can be seen that the partial replacement of the cement by mineral additions slightly lightens the PMMs. The weight reduction rates of PMMs based on binary and ternary binders vary between 1 and 5% compared to the control PMM. The lowest dry bulk density value was observed in PMM+SF, PMM+(LF+SF)and PMM+(NP+SF) blends. This demonstrates that the addition of SF reduces the bulk density of cured PMM more than other additions (LF and NP) due to the low density of SF. In addition, it has been observed that the substitution of cement by LF in large quantities (>30%) leads to completely filling the voids and occupying the place of grains of sand, hence a decrease in the proportion of sand and hence the density of the mixture. Similarly, the incorporation of NP in the PMMs leads to a decrease in the values of the apparent density of 1.8% compared to the reference PMM. This result is logical, because the density of NP is lower than that of cement.

B.Mechanical properties

1)Tensile strength by bending

Fig. 5 illustrates the development of the bending tensile strength of PMMs with binders obtained with a single then two mineral additions, limestone fillers, natural pozzolana and silica fume at different ages.

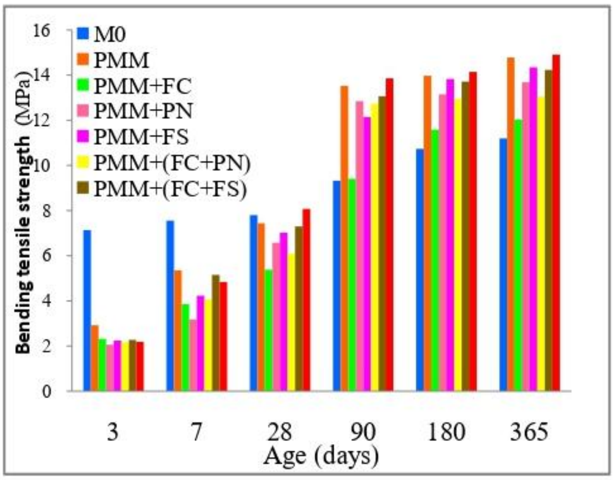

Fig. 5 Evolution of the bending tensile strength of PMMs with binary and ternary binders as a function of age.

At short-term, the tensile strengths of the cement mortar and the control PMM composed of 100% OPC are constantly the highest. This observation prevails until the 7th day. For PMMs with binary binders, the tensile strengths at 3 days of the mixtures of PMM containing limestone fillers are the highest, followed by that of the mixture PMM+SF and finally the mixtures of PMM with natural pozzolan whose early resistance to traction is lower (2.06 MPa). This illustrates the importance of incorporating FC into PMMs on their early tensile strengths.

Au-delà de 28 jours, tous les PMMs à liants binaires et ternaires développent des résistances à la traction les plus élevées que celle du mortier ordinaire. Néanmoins, ces résistances restent inférieures à celle du PMM témoin, excepté celle du mélange PMM+(NP+SF). Ce constat demeure valable à toutes les échéances. Ce mélange ternaire montre des gains de résistance à la traction, par rapport à celle du PMM de contrôle. Latroch [15] recorded that the flexural tensile strengths of all PMMs remain, in all cases, lower than that of cement mortar and the combination that seems the most effective is the one that combines (25% NP+5 %SF and P/C=5%). On the other hand, PMMs with ternary binders, including SF, seem to be optimal especially in the long term. This can be explained by the fact that SiO2 in SF reacts with cement hydrates, decreasing the amount of $Ca(OH)_2$ and producing CSH during the pozzolanic reaction, thereby reducing the pores in the cement paste by therefore improving mechanical performance [24]. These results are consistent with those reported in the study by Gao et al. [25], where the authors

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showed that the flexural strength of PMMs increases with increasing SF content up to 15%. For a P/C ratio of 15% and a SF content of 15%, the flexural strength can reach twice the strength of normal mortars. The reinforcing effect of PAE latex and SF on flexural strength is also more pronounced. The combination of polymer and silica fume to produce mortars results in remarkable properties, ideally suited to repair and coating work requiring high performance [24].

2)Compressive strength

The study of the influence of the incorporation of mineral additions on the compressive strength of the elaborated PMMs led to the results illustrated in Fig. 6.

From 3 to 28 days, it is obvious that the compressive strength of the OPC mortar is systematically the highest. Therefore, what can be concluded from these results is that the addition of SPA latex has a non-beneficial effect on compressive strength at an early age [26], [27], whether in the presence or absence mineral additions. The latter also have a detrimental effect on the initial compressive strength, in particular natural pozzolana and silica fume, due to their slow pozzolanic activity. However, from the 28th day, the PMM+SF and PMM+(NP+SF) mixtures show higher resistances than that of the reference PMM, with gain rates of 15% and 11%, respectively. In addition, PMMs with binary bonds have lower compressive strengths at 28 days than those of PMMs with ternary bonds.

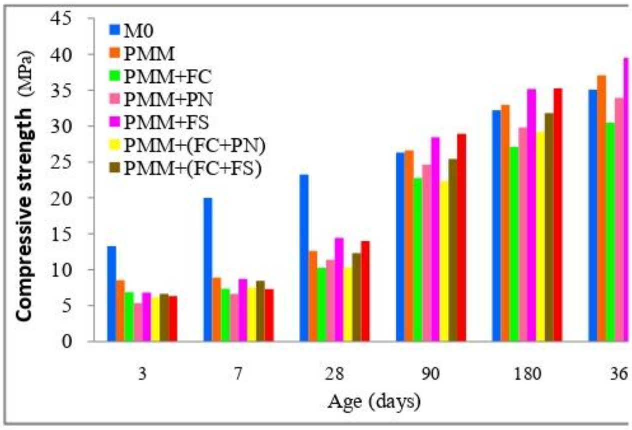

Fig. 6.Evolution of the compressive strength of PMMs with binary and ternary binders according to the age.

In the long term, the combination of pozzolan-silica fume shows compressive strength gains over the control PMM on the order of 8 and 4% for 90 days and 180 days, respectively. This shows the advantageous contribution of the PMM+(NP+SF) mixture in terms of long-term tensile and compressive strengths, the consequence of which is the combination of the filler effect and the pozzolanic effect of these additions. The filler effect leads to the formation of a less porous interfacial transition zone from which the microstructure is denser and more compact and the material is more resistant [28]. The effect of high pozzolanic activity contributes to the formation of CSH gels by binding to the portlandite released during cement hydration, resulting in a denser structure and therefore increased strength. In other words, the CaO of the portlandite which will enter into combination with the SiO_2 of the FS or of the PN or of the cement itself to give CSH.Latroch [15] discovered that the composite (25%NP, 5% LF and P/C=5%) has better strength to compression, especially in the long term.

Similarly, it is found that the substitution of cement with 30% SF in the PMM contributes to the significant improvement in compressive strength at 365 days. In contrast, the PMM composite containing 30% LF recorded the lowest compressive strength at 365 days (30.49 MPa). This is attributed to the dilution effect which becomes more important, leading to a reduction in compressive strength as the addition of limestone filler increases. Moreover, the incorporation of 30% of NP does not bring a positive effect on the compressive strength of the PMM in the long term. This can be explained by the effect of the high percentage of substitution by pozzolan, because the quantity of cement decreases, and subsequently, the quantity of portlandite, with which the pozzolan reacts, decreases and consequently generates a decrease in the amount of CSH.

Regarding the PMMs with ternary bonds, the PMM with LF and NP gives the lowest compressive strength, on the other hand the PMMswith LF and SF could develop a suitable long-term compressive strength.

V. Conclusions

The results of the tests obtained led to the following conclusions:

• The incorporation of mineral additions in PMMs causes a decrease in the density in the hardened

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state. This lightening may be due to the density of the mineral additions.

• At all ages, the tensile strength of the control PMM composed of 100% OPC is constantly higher than that of the PMMs with binary and ternary bonds, except that of the PMMs + mixture (NP+SF) which shows a weak gain in long-term tensile strength.

• At 365 days,the substitution of cement with 30% of the silica fume in the PMM contributes to the notable improvement in compressive strength. In contrast, the PMM composite containing 30% limestone fillers recorded the lowest compressive strength.

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