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Effect of Dune Sand in Physico-mechanical Properties and Sustainability of Calcareous Mortar Modified by Styrene-butadiene-rubber Latex

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As part of environmental preservation efforts, and to satisfy ecological and environmental requirements, from the recovery of certain materials widely abundant in remote areas, to reduce the excessive exploitation of natural sources, this study aimed to evaluate dune sand and crushed limestone sand. Thirteen mortar mixtures were manufactured, varying the weight substitution rate of crushed limestone sand by dune sand. The substitution rates were set at 0 %, 10 %, 20 % and 30 %. To reduce the impact of the greenhouse effect due to CO_2 emissions resulting from cement manufacture, and as an ecological replacement, we carried out a partial mass replacement of the cement by styrene-butadiene rubber (SBR) latex of the order of 2.5 % and 5 %. This experimental study evaluates physico-mechanical properties such as porosity, absorption and mechanical resistance. As for the great importance of durability, the study of the tests (mass loss, visual examination and X-ray diffraction) after immersion of the samples in the 5% H_2SO_4 are evaluated. The results indicate the possibility of substituting calcareous sand with dune sand at a rate of 30 % and using 5 % of SBR Latex, to obtain beneficial results regarding the tensile strength by flexure by values of 38.83 % and 47.2 % at 28 and 90 days respectively, where the same mixture outperformed (control mortar M1 28 days) by 3.9 % in 90 days in compression, regarding durability, the decrease in mass loss was 28.40 % compared to M1.

Keywords: modified mortar, styrene-butadiene rubber latex, dune sand, physico-mechanical properties, durability.

1. INTRODUCTION

Apart from water, cement matrix materials are the most widely used worldwide. In terms of mass, annual consumption exceeds 30 billion tons and global demand continues to grow [1]. Due to the excellent durability of cement matrix materials and their ease of molding into any shape, the use of concrete and mortar takes the first class compared to any other building materials [2, 3]. Despite the strict instructions against pollution in cement manufacturing plants, the production of 1 ton of cement releases about 1 ton of CO_2 [3]. Polymer mortar and concrete have developed rapidly in their research and application in recent years because of their outstanding performance [4], using the polymer in the formulation of concrete as a cement substitute can reduce the ratios of cement production which will lead to a decrease of CO_2 emissions. Sand extracted from valleys and natural gravel deposits is considered very suitable as fine aggregate in the production of concrete materials. [5]. The construction industry relies mainly on the use of river sand as fine aggregate in the production of concrete. however, the excessive and indiscriminate exploitation of this type of sand has frightening environmental negative effects [6]. To solve the problem of lack of natural fine aggregates (FA). the use of recycled waste and new materials appears to be a good solution [7].

These days the use of polymer in cementitious materials has become popular in repair and restoration works in many specific situations, where these latest demands adhesion, durability and workability [8]. The use of polymer in cementitious materials helps to enhance many of her mechanical properties and durability. The polymer can be used to produce three types of concrete or mortar which are as follows: polymer concrete (PC), polymer-modified concrete (PMC) and polymer-impregnated concrete (PIC) [9 – 16]. Authors of [17, 18] use many types of latexes-modified cement mortars also in different proportions (0, 5, 10, 15, 20, and 30 %), the ratio w/c reduces at the percentage of latexes substitute cement increase, especially in SBR latex modified mortar, and the test of flow increase also. The same results are obtained by [19], the SAE styrene acrylate ester latex gives him a low water-reduction rate related to SBR latex. That means the utilization of latexes in cementitious materials generally enhances the workability. [20] find that adding 25 % of the polymer latexes SBR latex with cement mass ratio in the formulation of concrete increased the level of strength compression to an end of 29 % in 90 days comparable with control concrete, in 7 days the strength was lower by 6.1 % than control concrete.

Despite the abundance of dune sand (DS) in many desert regions worldwide, we have no standards covering this type of sand in concrete or mortar, the effect of using dune sand as river sand is partially at 10 % to 100 %, the result showed that using 50 % of dune sand gives the greatest workability, and in general the compressive strength using dune sands at any percentage in mixtures decreased but not more than 25% of ordinary concrete [5]. The results found that using dune sand and superplasticizer

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in sand concrete manufacturing, remarkable improvement workability and compressive strength [21]. The study of the texturally of dune sands improved the workability of mortar cement and concrete [22]. It was found that there is a positive effect of the physical properties of dune sand in treating workability defects of concrete prepared with crushed sand (CS) [23]. Authors of [24] mixed dune sand and crashed sand with different DS/FA ratios as fine aggregate 10, 20, 40 and 60 %, they found that the DS ratio of 20 % gave the highest tensile and compressive strength values. The optimization of [25] showed that the highest impact coefficient of slump and air content in concrete is the DS/FA ratio. Still, the W/C ratio is mainly responsible for the influence on compressive strength. Increasing the W/C ratio works opposite to increasing the DS/FA ratio on the slump and air content of the concrete.

In the context of sustainability, much research has been carried out. According to [26], the polymer emulsion wraps all the particles resulting from the cement hydration effect and also the fines and anhydrous cement, this is due to the polymer emulsion containing active molecules (-COOH) that react with portlandite $Ca(OH)_2$, generating a crosslinked network structure. Polymers are widely used in structural repair works, this is due to the ability of the polymer to effectively improve the bonding strength of old concrete structures which positively influences the strength and durability [27].

This research aims to evaluate the results of an experimental study on the characteristics of a latex polymer-modified mortar, employing local materials in arid areas (dune and crushed sand) in its hardened state and sustainability. The replacement of crushed sand with dune sand varied from 0 to 30 %; the cement was partially replaced by 0 to 5 % by weight of SBR latex to prevent a decline in compressive strength. This mortar can rectify exterior damage to structures in many ways.

2. MATERIALS AND MIXTURES

2.1. Styrene-butadiene rubber latex

The type of polymer used in this study for the modification of mortar is latex, the latest is SBR latex, which has a white milky aqueous appearance, 1020 kg/m^3 density, and 50 % dry extract.

2.2. Admixture

SIKA Tempo 12 was used, it's a new generation of superplasticizer from SIKA ELJAZAIR (high water reducer), and its normal use ranges between 0.2 and 3 % of the weight of binder or cement. It has a light brown color, 1060 ± 10 kg/m^3 density and 4.5 ± 1 pH.

2.3. Cement

Ordinary Portland cement (CEM II/B-L, 42.5 R) as specified in European standards [28] was used, the chemical analysis (the oxides) obtained by X-ray fluorescence (XRF) is presented in Table 1.

2.4. Fine aggregates

In terms of ordinary mortar or control mortar M1, we utilized river (Benaam) sand (RS) of the fraction 0/5 mm, located in the south of the city of Djelfa (south of Algeria). Otherwise, we have the dune sand (DS) of the north town of Laghouat (south of Algeria), the maximum diameter of dune sand grain is 0.63 mm. This study used crushed sand (CS) passing through a sieve of 5 mm.

Table 1 shows the proportions of the various chemicals for all types of sand constituents given by X-ray fluorescence (XRF).

Table 1. Chemical composition of constituents, %

Compounds	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	TiO_2	LOI[a]
CEMENT	75.10	11.00	6.10	3.52	0.51	0.16	0.26
RS	24.62	59.32	8.73	3.64	1.71	1.28	0.65
DS	7.87	76.50	9.75	2.66	2.47	0.56	0.20
CS	90.1	2.3	6.0	0.8	0.1	0.1	0.6

[a] loss on ignition.

Physical characteristics are grouped in Table 2 according to the standards[29 – 31].

Table 2. Properties of fine aggregates

Properties measured	Standard	RS	DS	CS
Loose bulk density, kg/m³	[29]	1600	1597	1393
Particle density on an OD basis, kg/m³	[30]	2379	2613	2648
Particle density on an SSD basis, kg/m³	[30]	2473	2629	2671
Apparent particle density, kg/m³	[30]	2626	2655	2711
Water absorption, %	[30]	3.95	0.6	0.87
Voids, %	[29]	35	39	48
Sand equivalent: SE, %	[31]	88	76	96

According to [32], the curve gradings of the FA are given in Fig. 1.

2.5. Protocol and mixing

Table 3 regrouped the mixtures of mortar proportions without and with the polymer (SBR latex). At the same time, we used the crushed limestone sand and replaced it with 10, 20 and 30 % of dune sand.

Table 3. Mortar mix proportions

Mixtures	Cement, g	Latex, %	R.S, g	C.S, g	D.S, g	SP, %
M1	450.0	–	1350	–	–	–
M2	450.0	–	–	1350	–	0.70
M3	438.8	2.5	–	1350	–	0.32
M4	427.5	5.0	–	1350	–	0.33
M5	450.0	–	–	1215	132.9	0.73
M6	438.8	2.5	–	1215	132.9	0.31
M7	427.5	5.0	–	1215	132.9	0.33
M8	450.0	–	–	1080	265.8	0.73
M9	438.8	2.5	–	1080	265.8	0.36
M10	427.5	5.0	–	1080	265.8	0.37
M11	450.0	–	–	945	398.7	0.44
M12	438.8	2.5	–	945	398.7	0.30
M13	427.5	5.0	–	945	398.7	0.31

The modes of preparation polymer modified mortar by w/c ratio are two [33], “iso-w/c” formulation which consists of fixing the w/c to obtain the same rate of cement hydration for all mixtures [34, 35], and the other consists of adjusting the water for given the similar workability of all mixtures and is called “iso-rheology” [36, 37]. In the present study, the water/cement (w/c) ratio is set at 0.45, and to satisfy the plastic consistency for all the mixes, the superplasticizer rate varies between 0.31 and 0.73 %.

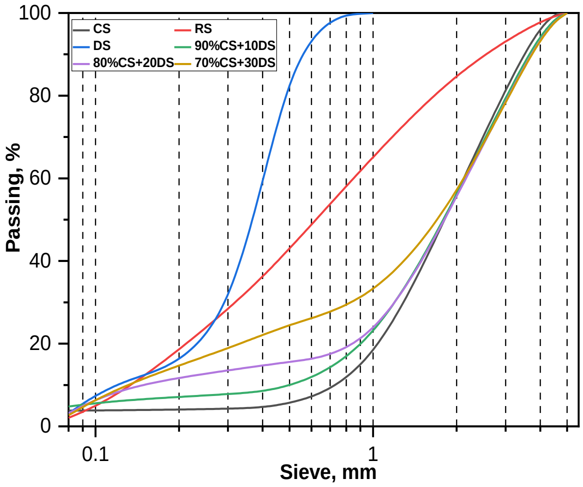

Fig. 1. Sieve analysis of sands

We used the ratios of 2.5 and 5 % of weight substitutions of cement (polymer/cement) P/C by dry extract of (SBR latex). The mixtures without SBR latex are mixed by [38] protocol and the C/S (cement/sand) rapport is 1/3, the molding and cure of specimens follow the [39] standard and conserve them by [40] standard. The protocol of the mixtures containing SBR latex is carried out according to the [41] standard, molds of 4 × 4 × 16 cm dimensions were filled after mixing and covered by a plastic film to prevent water evaporation, the samples are preserved according to the [42] method, the recommendation of this method is to put the samples for 72 h in water at a temperature of 20 °C, after that, the specimens were removed from the water and placed in the open air at laboratory temperature until the day of testing.

3. EXPERIMENTAL PROGRAMS

The determination of the consistency of the mortars in the fresh state was carried out using the LCL workability measuring device (type B) according to [43] standard. When performing the workability test of the mixtures, it was considered to maintain the time limit of the flow of the mortars between 7 and 11 seconds.

The flexural and compression strength of mortar specimens in a hardened state were determined following the [44] standard. Press machine type “MATEST” with a maximum load of 200 kN was used to affect a flexural test at 7, 28 and 90 days, the results are obtained by Eq. 1\

$$\sigma_f = \frac{3 \times F \times l}{2 \times b^3}, \tag{1}$$

where F is the load strength at deformation; b is the width of the test specimen.

The resulting half-samples by the flexural test were examined to determine the compression strength in the press machine “MATEST” with a maximum load of 3000 kN, it was tested on a section 4 × 4 cm^2.

According to [45], the saturated water absorption and void volume values of mixture specimens were calculated following Eq. 2 and Eq. 3.

$$A\ (\%) = \left[\frac{W_2 - W_1}{W_1}\right] \times 100; \tag{2}$$

$$V\ (\%) = \left[\frac{W_3 - W_1}{W_3 - W_4}\right] \times 100, \tag{3}$$

where A is the water absorption by weight; V is the volume of permeable pore space(voids); W_1 is the mass in air of samples after more than 24 h in oven at T°= 105 ± 5°C; W_2 is the mass of saturated surface dry of samples; W_3 is the mass of saturated surface dry after boiling 5 h and allow them to cool by natural loss of heat until 14 h to a final T° of 20 to 25 °C; W_4 is the apparent mass in water after immersion and boiling.

After 7, 14, 28, 45, and 60 days of immersion in 5 % (H_2SO_4) sulfuric acid solution according to [46]. To remove damaged mortar, the samples are cleaned with fresh water and then left in the open air for 30 minutes before weighing. A decrease in the pH of the attack solution with time due to the leaching of the cementitious materials following the decalcification of the portlandite, The acid solution is renewed after each reweighing [47]. The mass variation is calculated according to the Eq. 4.

$$\Delta W = \left[\frac{W_0 - W_i}{W_0}\right] \times 100, \tag{4}$$

where ΔW is the change in mass, %; W_0 is the mass of the specimen before exposure to acid attack, g; W_i is the mass after (i) days of attack, g (i = 7, 14, 28, 45, and 60).

Digital photos were taken for visual examination and XRD analysis was performed on the outer face in contact with the acid solution.

4. RESULTS AND DISCUSSION

4.1. Mechanical properties

4.1.1. Flexural strength

Fig. 2 illustrates the evolution of the flexural tensile strength in 7, 28, and 90 days of the mixtures according to the variations of the sands and the latex.

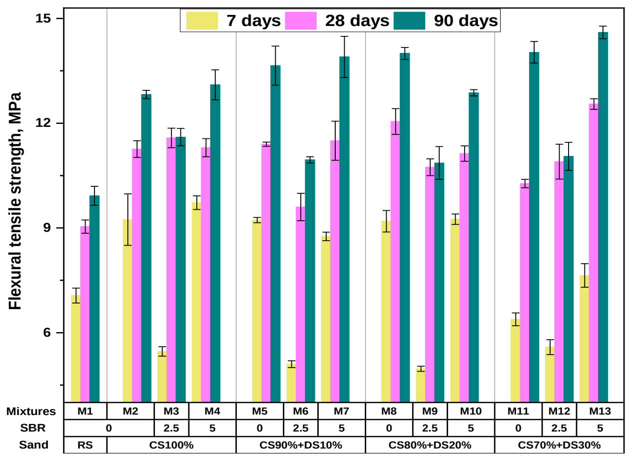

Fig. 2. Tensile strength of the mortars versus SBR latex and sand

Generally, the tensile strength evolves positively over time, especially for the mixtures undergo the increase of

SBR latex and the incorporation of dune sand, this is due to the formation of a polymer film, especially in old age for modified mixtures [33], and also be attributed to the form factor of crushed sand in unmodified mixtures.

In 7 days, the tensile strength results of all the mixes except that which contains 2.5 % SBR latex are higher than the reference mortar M1, this is due to the curing mode of the mixes having 5 % SBR latex which led to the formation of a polymer film at a young age with the water retention property that the cement needs to complete the hydration process [42]. Contrary, the mixtures have 2.5 % of SBR Latex, which gives results lower than the reference mortar, ranging from 4.96 MPa to 5.58 MPa, this explains the reduction in the quantity of cement and the weakness of the polymer film formed compared to mixtures with a polymer percentage of 5 %.

The incorporation of dune sand in the 5 % latex mixtures at 28 and 90 days gives better tensile strength results than the reference mortar M1, and this can be explained by the intervention of dune sand which filled certain voids [48], and Fig. 5 shows this. Mixes with a polymer percentage of 2.5 % improved their tensile strength results compared to the reference mortar with age since the increased value for these mixes was between 6.2 % and 16.9 %. However, the results of mixes with a percentage of 5 % SBR latex varied between 25 % and 47.2 %, where the best result was for M13 with values of 38.83 % and 47.2 % at 28 and 90 days respectively, this is because the polymer retains quantities of water that complete the hydration process of the cement and preserve moisture over time, which is consistent with the results of [4, 33].

4.1.2. Compressive strength

The compressive strength results of mixtures are plotted in Fig. 3.

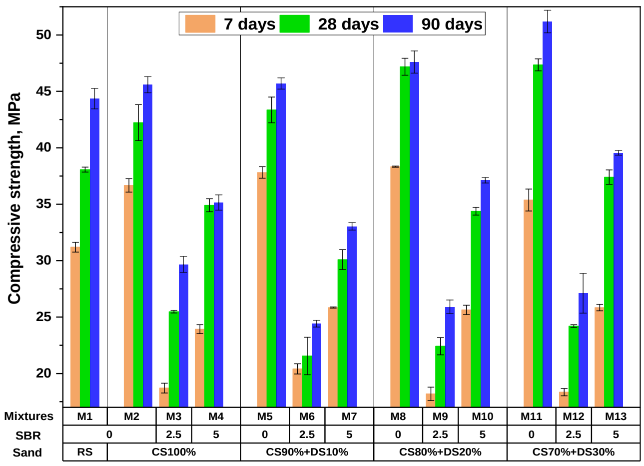

Fig. 3. Compressive strength of the mortars versus SBR latex and sands

Generally, the compressive strength of all mortars increases with time like the case of tensile strength, the compression of mixtures of mortar modified by latex is lower than mixtures without SBR latex and also lower than the reference mortar M1, this is due to the decrease in the amount of cement these results are similar to the results obtained by [33], the mixtures without SBR latex have compressive strength higher than that of the reference mortar M1 at all ages which explains the angularity of the grains of crushed sand. We also notice an increase in compressive strength with increasing dune sand, this is due to the effect of filling the voids with fine regularly shaped grains of dune sand these results were also found by [5]. However, [19] showed that SBR latex-modified mortar has the maximum compressive strength when the dose is 20% and the cement dosage is constant.

Fig. 4 shows the compressive strength ratio result of mortars Mi in all ages by the reference mortar M1 in 28 days. All mortars gave results lower than M1 in 7 days. Still, in 28 days, the results of mixtures without SBR latex improved comparatively with M1 in varying proportions 10.9, 13.9, 23.9, and 12.4 % for M2, M5, M8 and M11, respectively, with increasing the dune sand in mixtures, and they improve their results in 90 days by enhancement of 19.8, 20, 25, and 34.5 %.

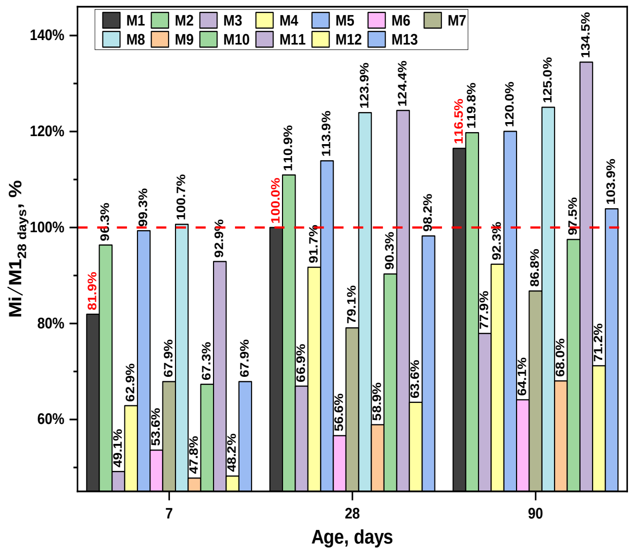

Fig. 4. Compressive strength ratio of the mortars as a function of M1 $_{28\ days}$

The results of the mixtures containing 2.5 % SBR latex did not reach 70 % of the required strength in 28 days, nor did they reach 80 % in 90 days, as they reached a maximum at 90 days for the M3 by 77.9 %. The mixtures modified by 5 % of SBR latex, give results less than 70 % related to (M1 $_{28\ days}$) in 7 days. However, in 28 days they enhanced to exceed 90% by increasing the dune sand by 20 % and 30 %, where M10 arrived at 97.5 % and M13 surpassed (M1 $_{28\ days}$) by 3.9 % in 90 days.

4.2. Physical properties

4.2.1. Absorption and porosity

From Fig. 5, we notice that the mixtures with 2.5 % SBR latex record values of absorption coefficient and porosity are lower than those of the mixtures without SBR latex, unlike the mixtures with 5 % SBR latex which record values of absorption coefficient and porosity better than the other mixtures with 2.5% and without SBR latex. Regarding the effect of substituting calcareous sand with dune sand, there is a decrease in the absorption coefficient and porosity with the increase in the percentage of dune sand. The reductions in the absorption of 5 % SBR latex mixtures corresponding to mixtures M4, M7, M10 and M13 compared to the control mixture M1 are respectively 23.96, 27.43, 31.98, and 34.36 %, and the improvement in the porosity of the same mixtures compared to the control mixture gives a decrease of 18.57, 17.92, 21.78, and 24.77 %. This implies that the use of 5 % SBR latex and 30 % dune sand recorded the best results for absorption and porosity. Water absorption was influenced by SBR latex similarly to that of other latexes such as SPA, PAE, and VAE [33, 49].

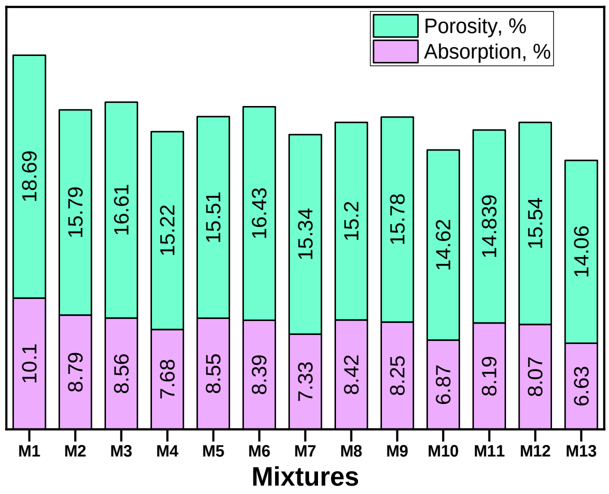

Fig. 5. Absorption and porosity of mixtures (after 28 days)

4.3. Sustainability

4.3.1. Loss of mass

The results obtained from Fig. 6 show the same degradation trend, and it can be noticed that there is a proportional increase in the mass loss of the samples with the immersion time in 5 % H_2SO_4, the same observation noted by [50].

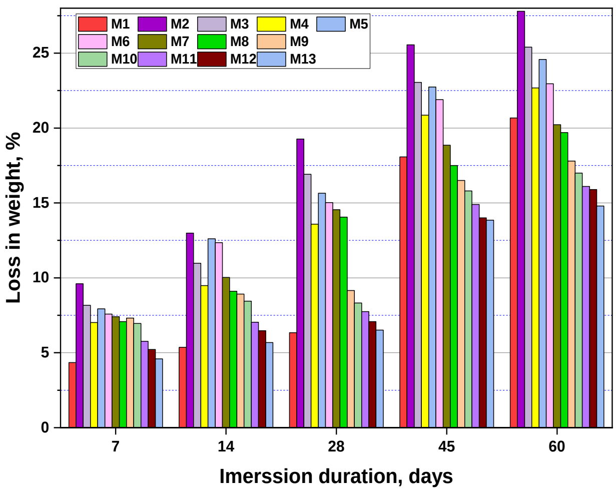

Fig. 6. Mass loss of mixtures as a function of immersion time for 5% H_2SO_4

A slight difference in behavior is noted after 8 weeks, and it is pointed out that the mixture M2 with 100 % calcareous sand without latex suffered the most significant mass loss. However, using 2.5 % and 5 % SBR Latex made a clear and positive difference in the decrease of mass loss compared to the mixtures without latex, especially with the substitution of calcareous sand by dune sand when compared with M2 and the control mixture M1. The mass losses of the mixtures of 5 % SBR latex with 10, 20, and 30 % dune sand corresponding to the mixtures M7, M10 and M13 are 20.22, 17, and 14.8 %, compared with the mass loss of the control mixture M1 20.67 %, records a decrease ratio of the mass loss of 2.18, 17.76, 28.40 % respectively. This implies the beneficial effect of the use of 5 % SBR Latex with the replacement of calcareous sand by dune sand precisely 30 % of substitution.

4.3.2. Visual examination

The formation of gypsum following the chemical reaction (Eq. 5) of sulfuric acid with portlandite resulted in a whitish-colored layer on the external surface of the samples, which was easily cleaned.

$$H_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4 + 2H_2O. \quad (5)$$

Sulfuric acid + calcium hydroxide ⟶ calcium sulfate + water

Fig. 7 shows the photos of the samples before and after 60 days of sulfuric acid attack which were taken after washing the gypsum layer. Before the acid attack, the surface color of the samples was blue-gray, but after exposure to 5 % sulfuric acid, white crystals accumulated on the external surface of the samples, clearly showing the surface degradation of the samples same observation was found by [51] after 70 days of immersion of ordinary Portland/calcium sulfoaluminate cement in 5 % H_2SO_4.

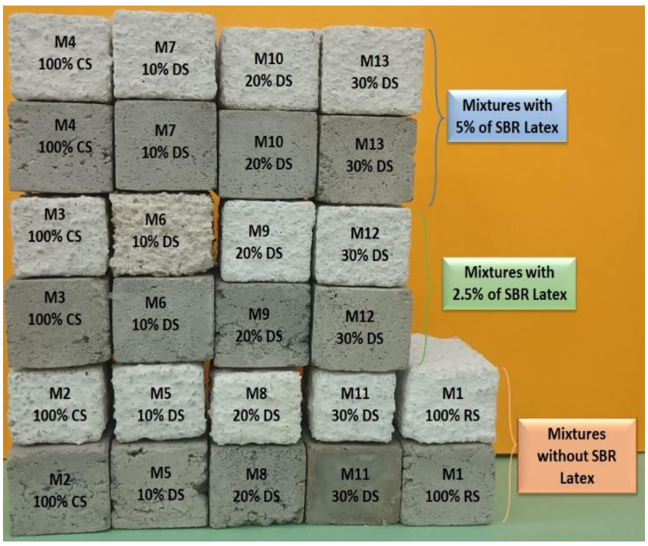

Fig. 7. Samples of degradation of different mixtures after 60 days of attack by 5 % H_2SO_4

4.3.3. Mineralogical analysis

X-ray diffraction analysis was performed before and after 60 days of attack by 5 % H_2SO_4 solution. Fig. 8 shows the superposition of the two analysis spectra which compares the state of the external surfaces before and after the attack. From the comparison, the presence of portlandite peaks $Ca(OH)_2$ at 18° and 34° is recorded which seems to disappear after its dissolution caused by the attack of the acid H_2SO_4, the reaction between the acid and portlandite following the chemical reaction (Eq. 5) leads to the formation of $CaSO_4$ which appears strongly by several picks which explains the intense degradation of the surface. In addition, we record the formation of delayed ettringite resulting from the reaction of calcium aluminate cement (C_3A) with calcium sulfate $CaSO_4$ formed by the first reaction (Eq. 5).

Quartz peaks are present in the diffractograms, which means that quartz exists in the surface part of the material since both clinker and dune sand contain a significant proportion of silica, the latter being found mainly in the C-S-H.

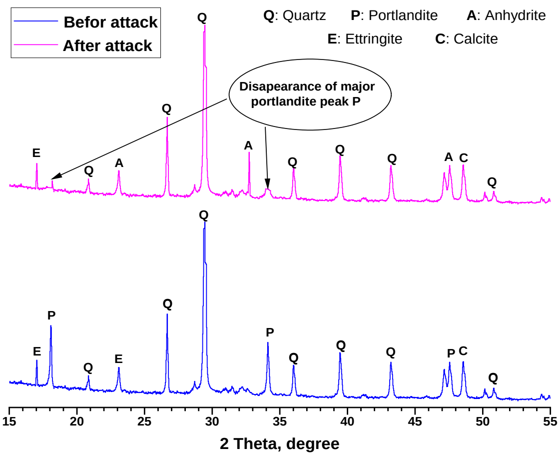

Fig. 8. The XRD spectra before and after the attack of H_2SO_4

5. CONCLUSIONS

The experimental study showed the positive effect of replacing SBR latex and dune sand simultaneously. We can draw the following conclusions:

1. The increase of dune sand in the mixtures increases compressive strength.
2. The substitution of calcareous sand for 20 % and 30 % dune sand of the modified mortars of 5 % SBR latex gives results of compression 97.5 % and 103.9 at 90 days, respectively, related to the control mortar at 28 days.
3. Using dune sand in the mortars modified 5 % SBR latex has a beneficial effect in the enhancement of tensile strength by flexion.
4. The reductions in the absorption of 5 % SBR latex with 10, 20, and 30 % of dune sand are 27.43, 31.98, and 34.36 % to the control mortar, respectively.
5. Using 10, 20 and 30 % dune sand in the mortars modified 5 % SBR latex decreased the porosity compared to the control mortar by 17.92, 21.78, and 24.77 %, respectively.
6. Incorporating 20 % and 30 % dune sand into the 5 % SBR latex modified mortars has a beneficial effect on the attack of 5 % (H_2SO_4).
7. The decrease in mass loss of 5 % SBR latex-modified mortars containing 20 % and 30 % dune sand compared to the control mortar is 17.76 and 28.40 %, respectively, which shows the beneficial use of SBR latex and dune sand.
8. From the preceding studies, the optimal mixture that accomplished most of the desired physico-mechanical and durability outcomes is 70 % CS + 30 % DS with 5 % SBR latex.

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