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Properties Evaluation of Composite Materials Based on Gypsum Plaster and Posidonia Oceanica Fibers

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Abstract: Estimating the amount of material without significant losses at the end of hybrid casting is a problem addressed in this study. To minimize manufacturing costs and improve the accuracy of results, a correction factor (CF) was used in the formula to estimate the volume percent of the material in order to reduce material losses during the sample manufacturing stage, allowing for greater confidence between the approved blending plan and the results obtained. In this context, three material mixing schemes of different sizes and shapes (gypsum plaster, sand (0/2), gravel (2/4), and Posidonia oceanica fibers (PO)) were created to verify the efficiency of CF and more precisely study the physico-mechanical effects on the samples. The results show that the use of a CF can reduce mixing loss to almost 0%. The optimal compressive strength of the sample (S1B) with the lowest mixing loss was 7.50 MPa. Under optimal conditions, the addition of PO improves mix volume percent correction (negligible), flexural strength (5.45%), density (18%), and porosity (3.70%) compared with S1B. On the other hand, the addition of PO thermo-chemical treatment by NaOH increases the compressive strength (3.97%) compared with PO due to the removal of impurities on the fiber surface, as shown by scanning electron microscopy. We then determined the optimal mixture ratio (PO divided by a mixture of plaster, sand, and gravel), which equals 0.0321 because Tunisian gypsum contains small amounts of bassanite and calcite, as shown by the X-ray diffraction results.

Keywords: gypsum plaster; Posidonia oceanica fibers; composite materials; correction factor

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1. Introduction

Gypsum is a calcium sulfate hydrate (GBS, $CaSO_4 \cdot 2H_2O$), which converts to hemihydrate ($CaSO_4 \cdot 0.5H_2O$) when heated. This material is known for its low bulk density and relatively good ductility. According to the 2019 Statistical Survey, the importance of this material can be measured by its annual production in the United States (20 million tons (MT)), China (16 MT), Iran (16 MT), Turkey (10 MT), Spain (7 MT), and Thailand (9.3 MT). The amount of plaster (P) produced is used in various fields such as civil engineering (decoration, wall and ceiling mortar, etc.) and medical applications (dental, orthopedics, etc.) [1,2]. In building construction, current scientific trends are moving towards the invention of green materials with excellent thermo-mechanical and acoustic properties. The performance of these properties depends on the material used in the composite design. By-products are often generated during sample preparation (e.g., gravel and sand from dunes, rivers, and crushed stone), as well as organic/inorganic waste (phosphogypsum, lignocellulosic, glass, plastic, basalt fibers, padel ball residuals, etc.”), and recycling materials waste from building demolition [3–8]. For example, researchers have used gypsum waste from construction and demolition processes to produce drywall boards and monolithic gypsum for interior walls [4]. In addition, other researchers used a mix of recycled

manufactured sand (a mix of natural stone particles and a small proportion of old mortar) and recycled fine aggregate from concrete waste to produce high-quality recycled mortar with high strength and good durability [8].

To improve the quality/price ratio of the sample, Posidonia oceanica fibers (PO, Figure 1) are excellent materials from an economical and physical-thermal point of view [9]. Its shape is similar to wood fiber, wool, or algae. The advantage of PO is that they are readily available in large quantities and are easily collected on the beaches of Mediterranean countries (France, Italy, Morocco, Spain, Egypt, etc.). However, such a large amount of PO must be taken into consideration as an issue, requiring clean-ups on affected beaches, especially in tourist areas where this sector plays a vital role in the country's economy. For some researchers who have studied the effects of using PO for lithium–sulfur battery development, removal of one of the most toxic heavy metals in biological systems Cr(VI), and construction materials (production of P materials, lightweight concrete, polymer matrices, etc.), evaluating the material has been a major challenge [10–12]. In this direction, we investigated three mixing plans with Mestaouas P, aggregates (0/2 mm limestone sand (S) and 2/4 mm crushed gravel (G)), and natural waste (PO) untreated and treated with sodium hydroxide (NaOH, POT) to manufacture new building materials that are lightweight, porous, mechanically strong and inexpensive. Furthermore, we have investigated the optimal amount of these compounding elements (P, S, G, PO, POT, and water (W)) to achieve minimal mixing loss after pouring into the prism mold (PSM).

Containers of various sizes and shapes (prismatic, cylindrical, cube, etc.) are commonly used for sample preparation. In the literature, two sample preparation methods are generally known. In one method, the constituent parts of the material "M1"werereplaced with another "M2" so that the volume fraction of the mixture (M1 and M2) was equal to 100% (method (1)). In the other method, various ratios of M1 to M2 were added without removing any material to bring the volume percent of the mixture to over 100% (method (2)) [3,5,13]. Aliabdo et al. demonstrated that the preparation of cement-based samples using method (2) is better than method (1) in terms of the results obtained [13]. The problem is that, in both cases, the composite mixture's volume exceeds the container's volume, which means that extra material must be removed to reach the desired volume. The difference in volume between the mixture and the container (D) will affect the test results (Figure 2). Therefore, to obtain more accurate results, it is necessary to determine an approximate ratio of composite materials such that the volume of the mixture is equal to the volume of the container, this is because the results will become more accurate as the loss of the mixture decreases. In this direction, we are working to solve this problem by developing new methods of composite fabrication. The goal is to determine the amount of material required so that the total volume of the mixture equals the volume of the PSM (100%) by using the formula to estimate the volume percent of the material and a correction factor (CF) for M2, knowing that the volume percent of M1 is unchanged (using method (2)). Based on mathematical calculations, this formula has been practically tested. It can be used in all areas of pouring mixes (casting concrete slabs, making bricks, precast elements and specimens, etc.). Correction factors are any mathematical adjustments made to calculations to account for changes in samples or measurement methods. The use of CFs is well-known in various fields including medicine, civil engineering, mechanical engineering, and the like. For example, insulin-dependent diabetics must adjust the amount of subcutaneous insulin they inject daily based on their current blood sugar levels. Therefore, it is essential to use a CF to determine the point of the total drop in blood sugar per unit of insulin. In addition, when changing car tires from original to aftermarket tires, the speedometer may read incorrectly. Therefore, it is necessary to determine the CF to get the actual speed [14]. Many scientific researchers have also contributed to improved results by using CFs. For example, to analyze weather-driven airflow in a multi-unit residential building, the thermal draft coefficient (TDC) was proposed for estimating leaks accurately using three CFs (envelope area ratio CF, shaft ratio CF, and air density CF) to minimize the TDC uncertainty from different areas of the home envelope, horizontal temperature distribution on each floor,

and multiple shafts in real buildings [15]. On the other hand, Wang tried to incorporate a finite-width CF into an established model for fatigue crack analysis of fiber–metal laminates used in built-up structures [16].

(**a**) GPS (**b**) PO (**c**) POT

Figure 1. (**a**) The slices of gypsum (GPS), (**b**) Posidonia oceanic fibers (PO), and (**c**) the treated Posidonia oceanica fibers (POT).

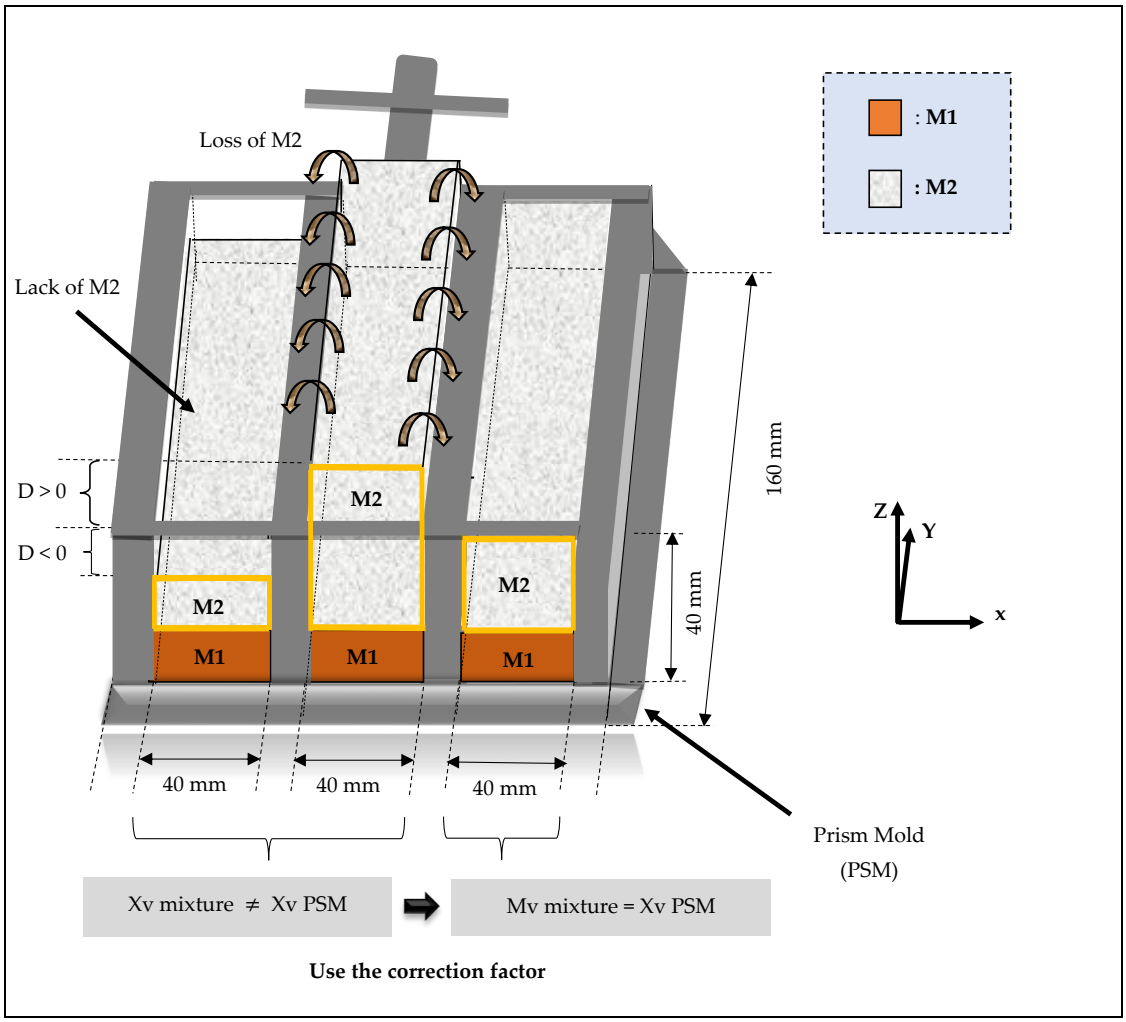


Figure 2. Pouring into molds before and after using the volume percentage correction factor.

In this study, we first characterize the materials used (GPS, P, S, and PO) using XRD, SEM, LDA, and MF. Second, to increase the accuracy of the results, we used a CF to prepare samples with minimal mixing loss after pouring them into the PSM. Finally, we examine the effect of the materials on the physical and mechanical properties of the samples.

2. Materials

Gypsum plaster: the British Standard EN 13279-1 specifies the use of hemihydrate gypsum in construction and civil engineering [17]. The commercial P used was from the Mestaoua geological formation in southern Tunisia. It is ISO 9001 certified. The slices of GBS were dried, crushed, and sieved (<150 mm) for proper sample analysis (Figure 1). The chemical formula for the conversion of gypsum to plaster is as follows:

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 + 0.5H_2O \quad (1)$$

Aggregate: the aggregate comes from a quarry in southern Tunisia. The sieve of this material is sand (S, 0/2 mm), and the residue is gravel (G, 2/4 mm).

Posidonia oceanica fibers: Posidonia oceanica fibers (PO) were collected on the beaches of Gabès in Tunisia.

Treated Posidonia oceanic fibers: thermo-chemical PO treatment (POT) was carried out using a method similar to Hamdaoui et al., including two immersions of PO in 2% NaOH for 2 h at 80 °C [12].

The physical properties of these materials are shown in Table 1.

Table 1. Materials' physical properties.

Materials	P	S	G	PO	POT
Apparent volumic mass [kg/m^3]	0.80	1.34	1.37	0.08	0.07
The fineness modulus	-	1.15	-	-	-
Sieve size (<80 µm) [%]	≤80	36	-	-	-

3. Composite Preparation

3.1. Before Volume Percentage Correction (BVC)

The prepared composite material was made of Mestaoua GPS, calcareous S (0/2), G (2/4), PO, and POT according to method (1) with the following mixtures plans (Table 2):

- Mixing plan (A): The composites were obtained by mixing several S (10% → 50%) with P (90% → 50%) so that the two materials (M1= S and M2 = P) were changed in 10% steps;
- Mixing plan (B):The composites were obtained by mixing several G (15% → 60%) with P and S (85% → 40%). Change steps for both materials (M1 = G and M2 = P + S, where S/P = 0.5 (recommended in most studies [3,5,18])) were 15%;
- Mixing plan (C):The composites were obtained by mixing several fibers (15% → 60%) with P and aggregate (85% to 40%). Change steps for both materials (M1 = PO or POT and M2 = P+S + G where S/G = 0.3 (Djoudi et al. recommend this value in composite manufacturing before adding date palm fibers [19])) were 15%.

For each mixing plan, the volume percentage (Xv) of M1 and Xv M2 was determined using the following formula:

$$\text{Xv mixture} = \text{Xv PSM} \pm \text{D} \quad (2)$$

$$\text{Xv M2} = \text{Xv PSM} - \text{Xv M1} \pm \text{D} \quad (3)$$

$$\text{Xv M2}_{\text{BVC}} = \text{Xv PSM} - \left[\text{Average}\left(\left(\frac{\text{Xv B}_0 + \text{Xv W}}{2}\right) + \left(\frac{\sum_{i=1}^{i=n} \text{Xv B}_n}{n}\right)\right)\right] \pm \text{D} \quad (4)$$

where Xv mixture is the addition of Xv M1 and Xv M2, Xv PSM is the volume percentage of prism mold at 100%, Xv B_0 is the volume percentage of the base material of M2, Xv B_n is the volume percentage of other M2 composite materials with "n" is the whole number of these materials, Xv W is the volume percentage of water [%], and D is the difference between Xv mixture and Xv PSM, knowing that if:

- D < 0: Lack of quantity of mixture in PSM;
- D > 0: Loss of quantity of mixture in PSM;
- D = 0: Volume equivalent between Xv mixture and Xv PSM.

In practice, we found that the mixing volume differs from PSM volume (lack or loss of composite material, Figures 2 and 3). The sample with the best D score (closer to 0) will serve as the reference sample for the next hybrid plan. In this case, we tried to determine the volume percent of the material, for which we obtained $D_{pratical} \simeq 0$. Samples P Ref, S_2 (A) Ref, and S_1 (B) Ref met our requirements with a ratio W/P equal to 1.24 (this value applies to wall plastering) [17]. The reference (ref) for the samples is as follows: P Ref, S_2 (A) Ref, and S_1 (B) Ref were replaced by Xv S (10%, 20%, 30%, 40%, and 50%) and Xv G (15%, 30%, 45%, 60%) and eventually fibers (Xv PO or Xv POT) with the same Xv G (Table 2).

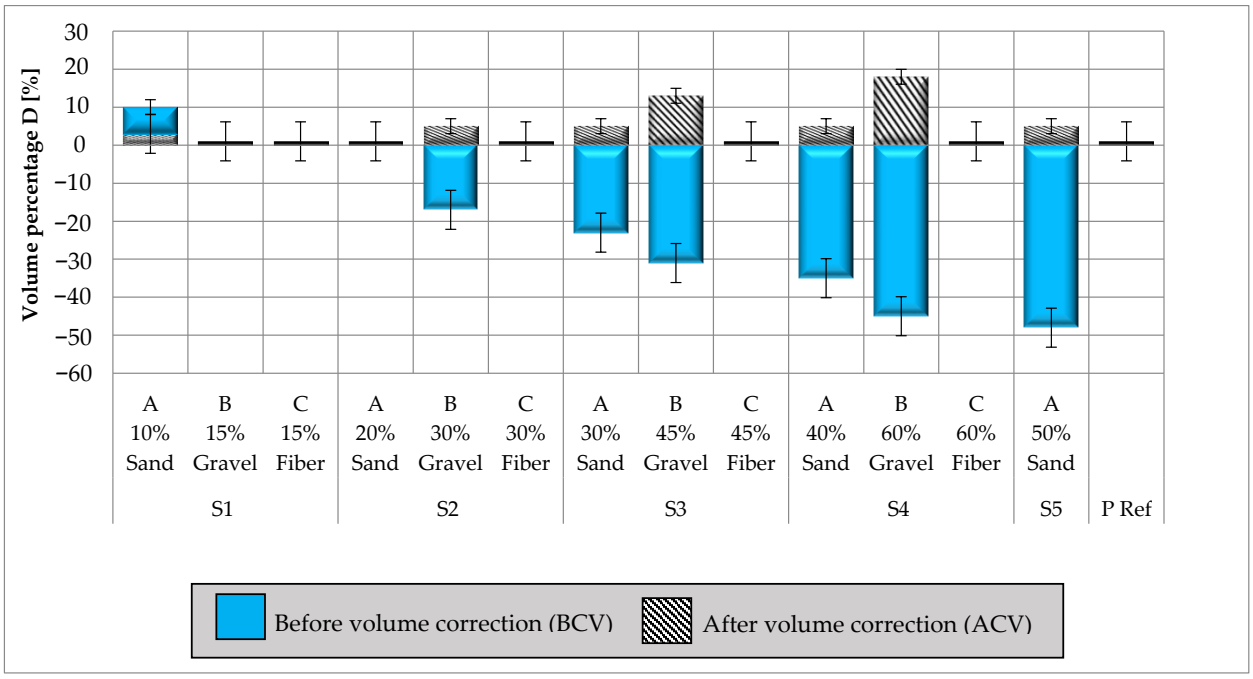


Figure 3. Comparison between the difference in volume percentage of mixture and prism mold 'D' before and after using the volume percentage correction factor.

Table 2. Volume percentage of gypsum mortar [%].

Material (M1)		Material (M2)			
		Before Volume Correction (BVC)		After Volume Correction (AVC)	
	Xv M1 %	Xv M2 %	W/(M1 + M2)	Xv M2 %	W/(M1 + M2)
Mixing plan (A): M1 = S; M2 = P					
P Ref	0	100	1.24	100	1.24
S_1	10	90	1.05	81.6	1.24
S_2	20	80	0.88	80	0.88
S_3	30	70	0.72	78.3	0.64

Table 2. *Cont.*

	Material (M1)	Material (M2)			
		Before Volume Correction (BVC)		After Volume Correction (AVC)	
	Xv M1 %	Xv M2 %	W/(M1 + M2)	Xv M2 %	W/(M1 + M2)
S_4	40	60	0.59	76.7	0.47
S_5	50	50	0.47	75	0.34
Mixing plan (B): M1 = G; M2 = P + S					
S_2(A) Ref	0	100	0.88	100	0.88
S_1	15	85	0.75	85	0.75
S_2	30	70	0.64	86.9	0.54
S_3	45	55	0.55	88.9	0.41
S_4	60	40	0.48	90.9	0.33
Mixing plan (C): M1 = PO or POT; M2 = P + S + G					
S_1(B) Ref	0	100	0.75	100	0.75
S_1	15	85	0.8	85	0.8
S_2	30	70	0.88	70.9	0.86
S_3	45	55	0.98	56.8	0.95
S_4	60	40	1.13	42.7	1.06

3.2. After Volume Percentage Correction (AVC)

The main goal of AVC is to reduce the percentage of error ($D \simeq 0$) between the Xv PSM and Xv mixture to avoid residual or lack of mixture after pouring into PSM. Figures 2 and 3 provide a good illustration of the problems encountered after casting and the effectiveness of the CF (Formula (6)) in the sample volume. In practice, we developed a volume correction formula (Formula (6)) that can still be developed by examining the mixing situation and various assumptions from laboratory experiments. To investigate the effect of additive material (M1) on samples with D close to zero, we changed the amount of composite material from M2. This change was made according to a correction factor (Formula (5)) for the levels Xv B_0 and Xv B_n, according to the following formula:

$$K_i = \frac{Z_i - \overline{Y}}{C_{ref}} \times 100 \quad (5)$$

$$\text{Xv M2}_{AVC} = \text{Xv PSM} - \left[\text{Average}\left(\left(\frac{[\text{Xv B}_0 + \text{K}] + \text{Xv W}}{2}\right) + \left(\frac{\sum_{i=1}^{i=n}[\text{Xv B}_n + \text{K}]}{n}\right)\right)\right] \pm D \quad (6)$$

where K_i is the correction factor [%], Z is the amount of M1 where $D \neq 0$ [kg], Y is the amount of M1 where $D \simeq 0$ [Kg], and C_{ref} is the amount of M2 in the reference material [kg].

Adding K to the Formula (4) helps reduce D. Physico-mechanical properties were tested for each of the mixtures given in Table 2 after correction of the Xv M2 of the material. The results of these tests are nicely shown in Figure 3.

4. Experimental Methods

4.1. Physical Properties Testing

Laser diffraction analysis (LDA):sand particle size distribution was measured using a Microtrac S3500 Laser Particle Size Analyzer.

Scanning electron microscope (SEM):the morphology of GPS and P were examined with a Quanta 650 FEG scanning electron microscope. PO and POT were examined with LEO 435 SEM equipment.

X-ray diffraction (XRD): X-ray diffractometry of the GPS, P, and S samples was carried out with a Siemens D500 diffractometer using Cu Kα radiation. The powder X-ray diffrac-

tion pattern was analyzed with EVA evaluation software to determine the mineralogical composition of the samples.

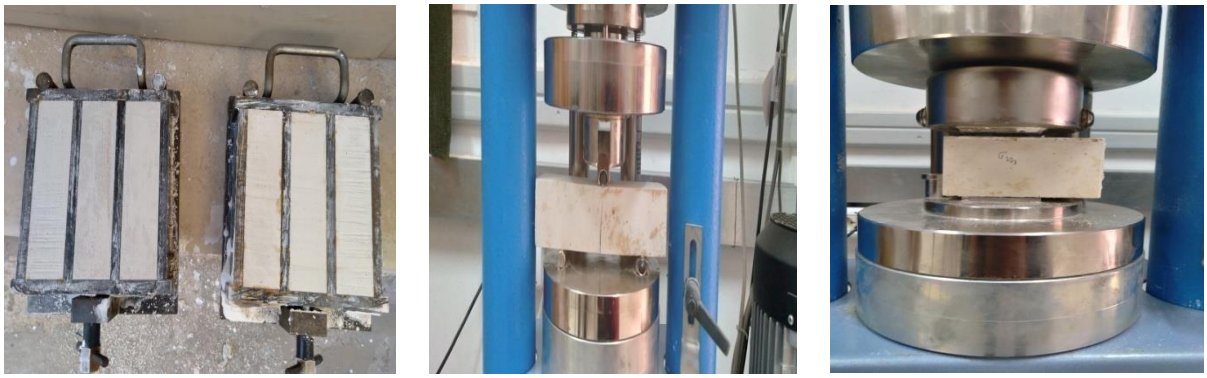
Fineness modulus (MF):the MF was determined according to the European standards EN 12620 [20].

Bulk density (ρ_{app}):for each mixing case (Table 2), three test samples measuring $4 \times 4 \times 16$ cm^3were de-molded after one night and stored in the laboratory for over 28 days for weight measurement. The ρ_{app} of the material was calculated from the (weight/volume) ratio according to the European standard NF EN 1097-6 [21].

Open porosity (θ): after mechanical testing, the samples were dried at 80 ± 5 °C until their weight became approximately constant. They were then put into a water bath less than 10 cm below the surface. The sample remained in the water until the bubbles were released. The cumulative volume of water entering the pores was measured. The opening rate was calculated according to the Chinese standard GB/T 3810.3-2016/ISO 10545-3:1995 after curing for 28 days. Researchers used this criterion to determine the porosity of β-hemihydrate materials made with phosphogypsum [22].

4.2. Mechanical Properties Testing

After 28 days of drying in the laboratory, the composites were mechanically tested (Figure 4).



(**a**) (**b**) (**c**)

Figure 4. (**a**) Preparation of samples, (**b**) Flexural strength test, (**c**) Compressive strength test.

Flexural strength (Rf):the sample was placed on two holders fixed at a distance of 10 cm between them. The load was applied in the middle of these two holders above the sample. A three-point bend test was performed until the test sample bisects (Figure 4). This test aimed to determine the maximum resistance of the specimen under bending.

Compressive strength (Rc):compression testing was determined by a portion of the specimen retained in the flexural strength test.

Mechanical properties were calculated according to the European standard NF_196-1 [23].

5. Results and Discussion

5.1. Physical and Morphological Properties

Diffraction laser (LD): Figure 5 shows that the crushed stone S is calcareous S with an average particle size of 150.80 μm and a distributed particle size (uniformity coefficient (Cu) = 25 > 2), which is a well-graduated S (coefficient of curvature (Cc) is 1 < Cc = 1.2 < 3).

Scanning electron microscope (SEM): SEM was used to analyze the morphology of GPS, P, PO, and POT (Figure 6). GPS crystal grains are needle-like and plate-like, with smooth surfaces and curved edges. After the GBS dehydration process (P), the voids increased significantly, reflecting the high θ of the material. Regarding fibers, Figure 6 shows the impurities on the PO wrinkled surface. These folds are linearly oriented with parallel and symmetrical filaments, forming fibers of suitable thickness. Our thermochemical treatment

of PO helps clean the fiber surface and remove these creases, making the surface rougher, which can explain fiber bundle breakage.

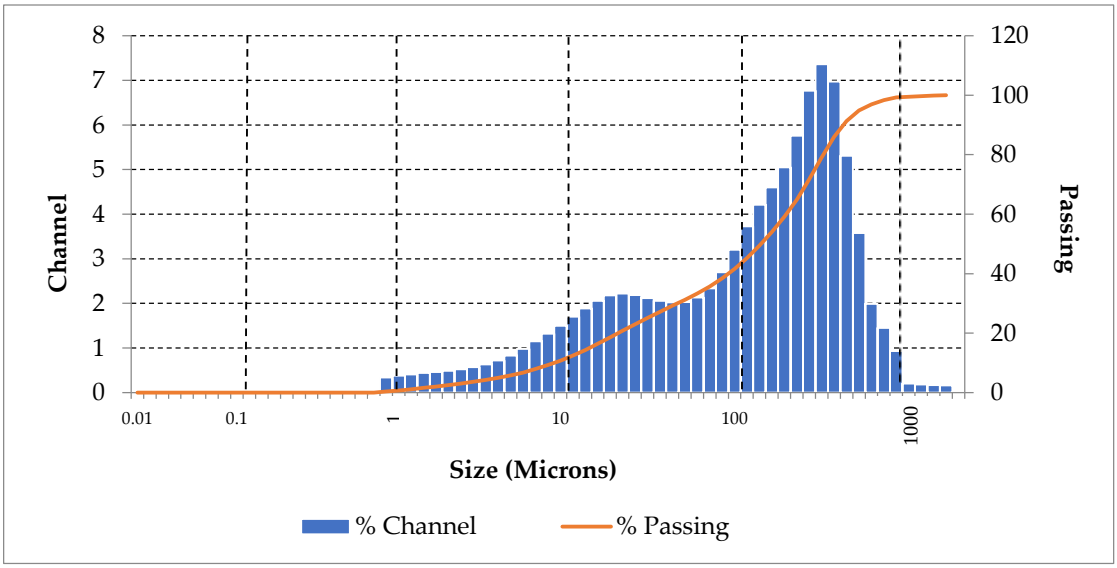


Figure 5. Cumulative sand passing percentage and channel–size distribution values.

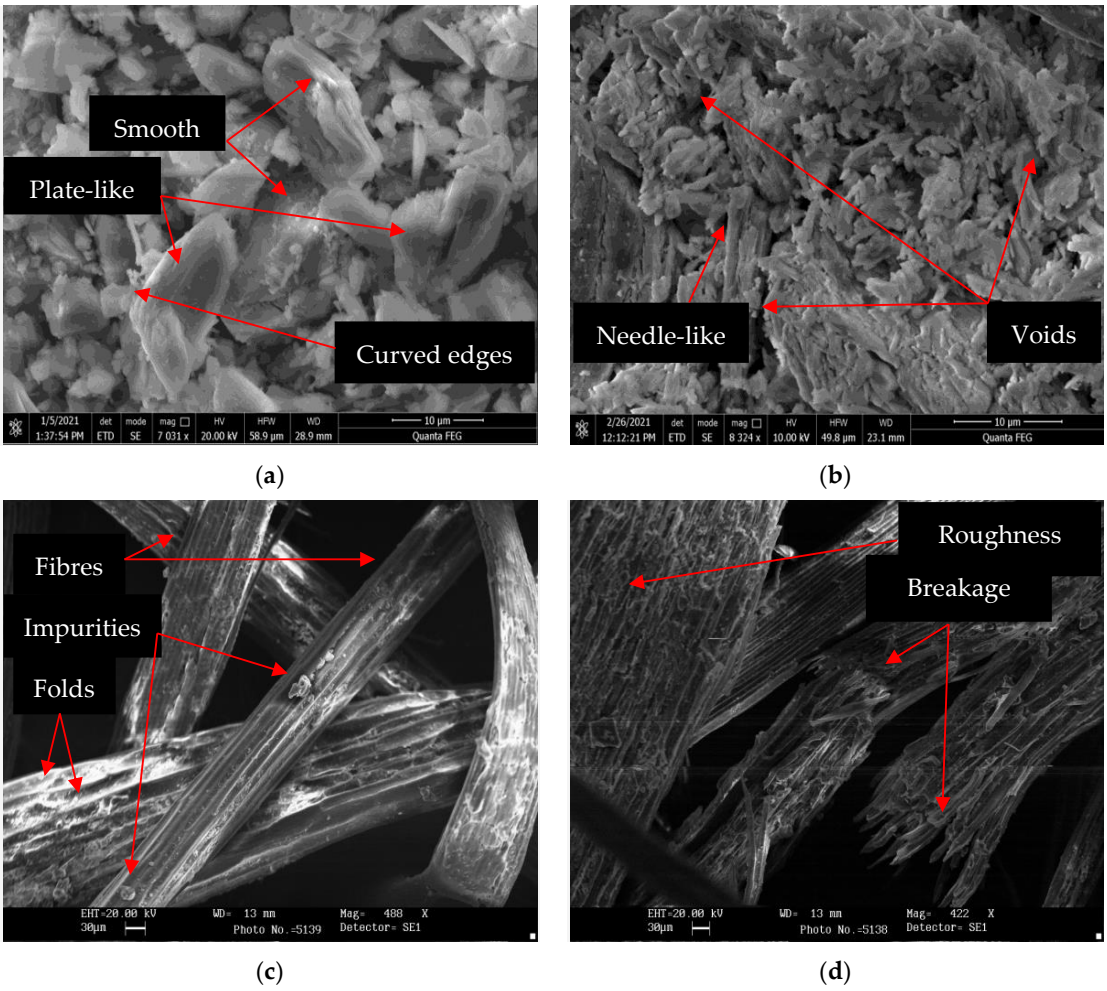


Figure 6. SEM images of (**a**) gypsum, (**b**) plaster, (**c**) Posidonia oceanic fibers (PO), and (**d**) POT with magnification of (**a**) 7031×, (**b**) 8324×, (**c**) 488×, and (**d**) 422×.

X-ray diffraction (XRD):the Mestaoua gypsum (GPS) is mainly composed of gypsum (Figure 7). The diffractogram also shows calcite and less bassanite. After dehydration of GPS to produce P, basanite is formed due to water loss, according to Formula (1). The sand (S) is mainly composed of dolomite and calcite (in minor proportions). It also contains traces of quartz.

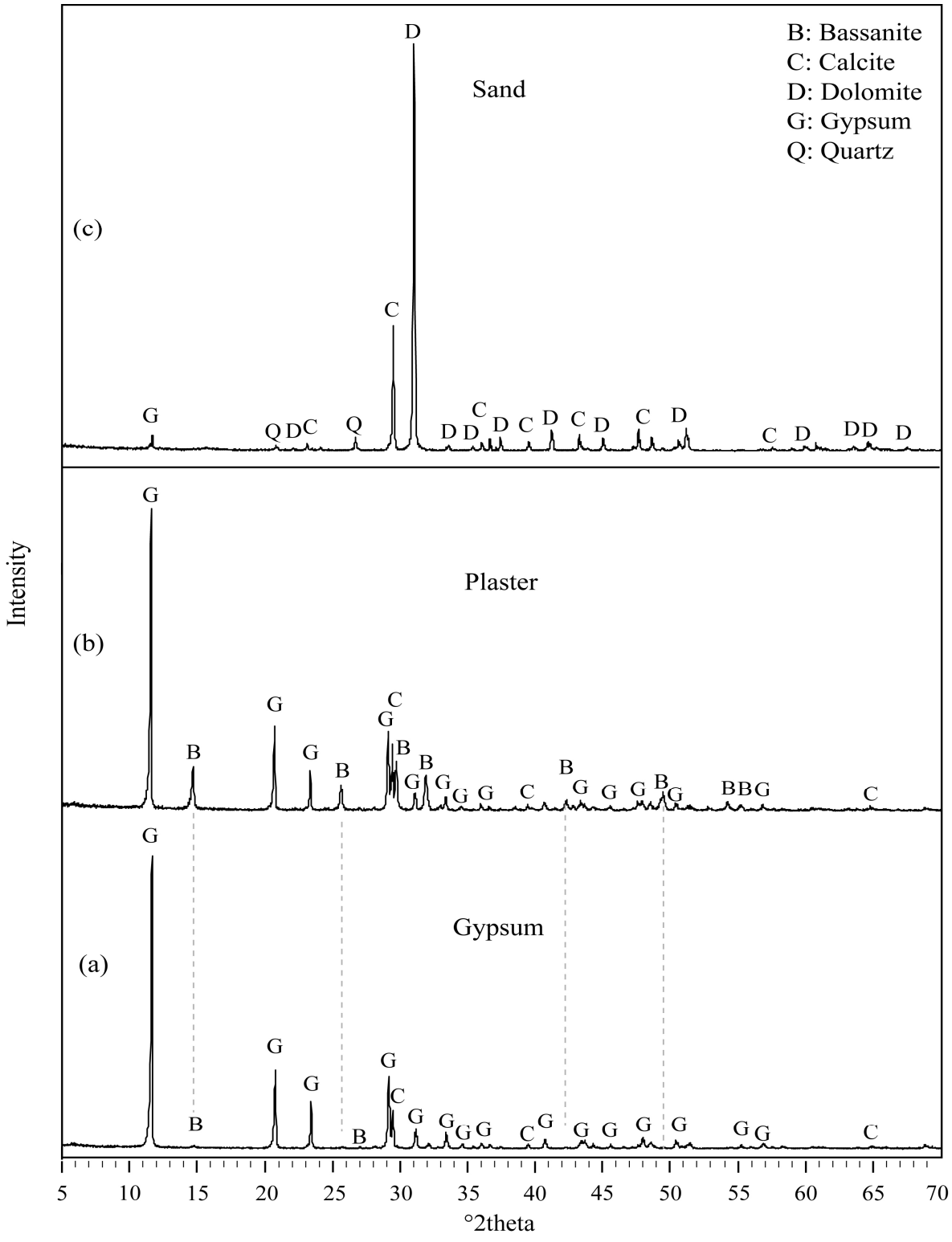


Figure 7. XRD pattern of (**a**) gypsum, (**b**) plaster, and (**c**) sand.

5.2. Composites Physical-Mechanical Properties

This section will outline the effect of the sand volume fraction on the composites (mixing plan A). Figures 8 and 9 show the best values for Rf (4.12 MPa) and Rc (9.94 MPa) at the S4 level. At the S1 level, θ and ρ_{app} reached 60% and 0.73 g.cm^{-3}, respectively (Figures 10 and 11). Figure 11 shows that as Xv S increases, the ρ_{app} of the sample also increases because ρ_{app} sand is larger than ρ_{app} plaster (Table 1). Meanwhile, θ decreases due to a decrease in W/(P + S) and the amount of porous material (plaster), and an increase in the amount of low-porosity material (sand) in the sample composition. Furthermore, as W/(P + S) decreased, an increase in Rc levels was observed in Figure 8 in all samples except S5 levels. At this level (S5), Rc and ρ_{app} dropped from 9.94 MPa to 6.43 MPa (35.31%) and from 1.4 g.cm^{-3} to 1.2 g.cm^{-3} (14.28%), while θ increased from 0.32 to 0.45 (40.62%) compared with that of S4. In this particular case, the reason for these results may be mainly due to the wetting of the sand before mixing, which contributed to the slight increase in the volume of the mixture (almost 5%) and adapted to the volume of the PSM (Figure 3). Regarding the Rf of P Ref, no satisfactory results were obtained, perhaps due to the very fragile sample (W/P > 1). Therefore, it can be said that mixing W can increase the void index of the material, which can negatively affect the mechanical properties (MP) of samples. A poor estimate of this liquid (lack or excess) can lead to a poor PM interaction between solid particles in the mixture. This result is consistent with Vegas et al. [24]. Based on the results in Figures 3–9, the best sample in terms of mechanical properties is S3 with an S/P ratio of 0.58 and a W/(P + S) of 0.64. These reports are often used in scientific research [3,5,18]; however, the physical properties and D of S2 are better than those of S3, as θ, ρ_{app}, and D are improved to 25.45%, 33.72%, and 5%, respectively, while Rf and Rc are reduced to 0.51% and 26.01%, respectively. Therefore, adding S to the mixture can minimize the manufacturing cost and help improve the mechanical properties of the samples. However, this process damages physical properties compared with P Ref. To improve the mechanical properties and the accuracy of the results, we chose S2 as the reference sample for the next mixing plan (mixing plan B) and G as an additive material (M2).

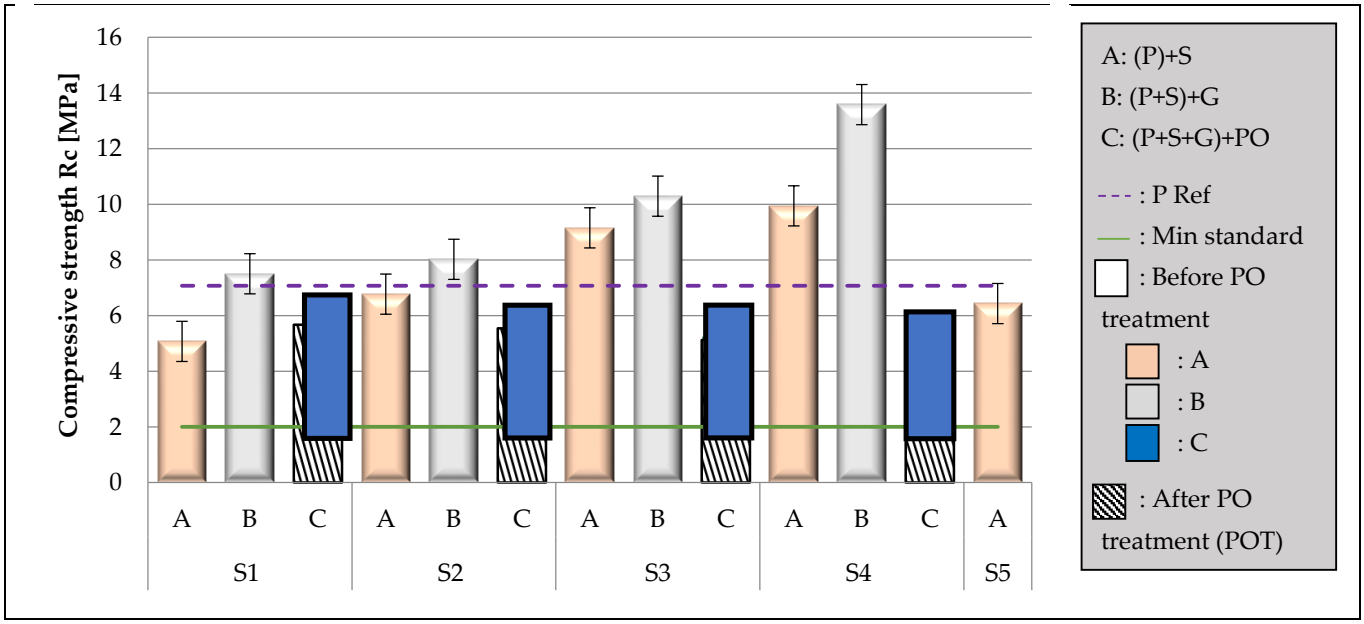


Figure 8. Variation in compressive strength of composites in the different mixing plans.

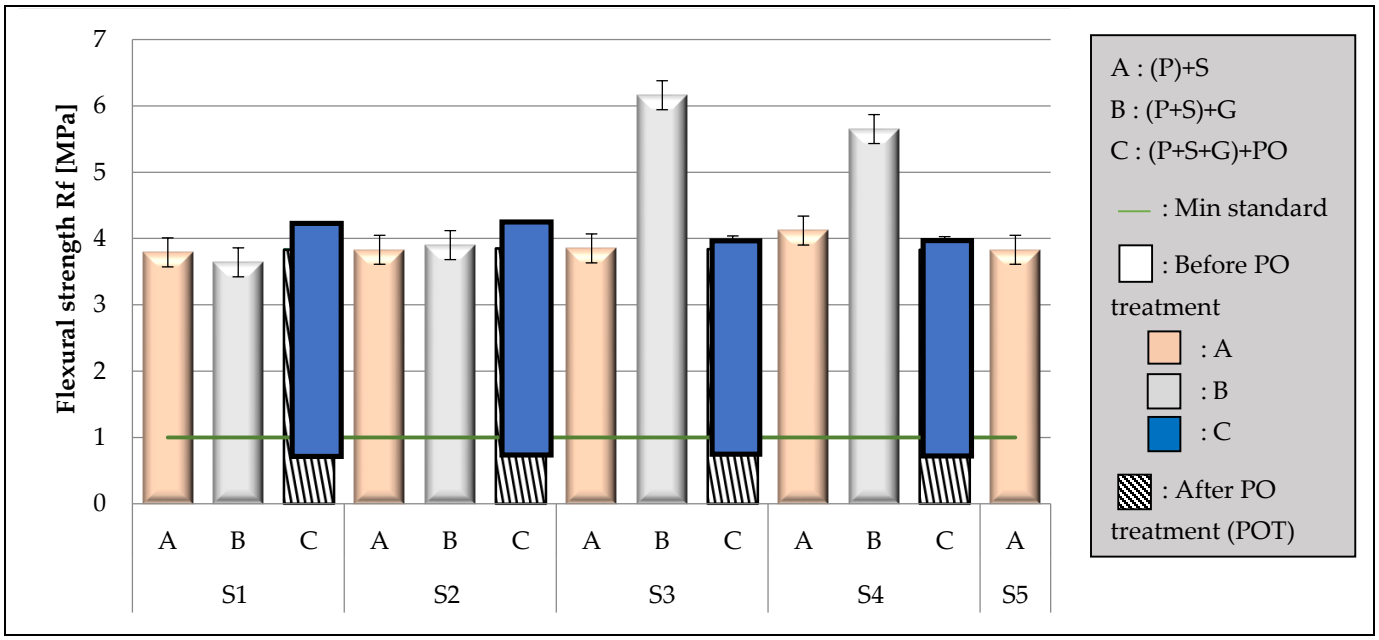


Figure 9. Variation in flexural strength of composites in the different mixing plans.

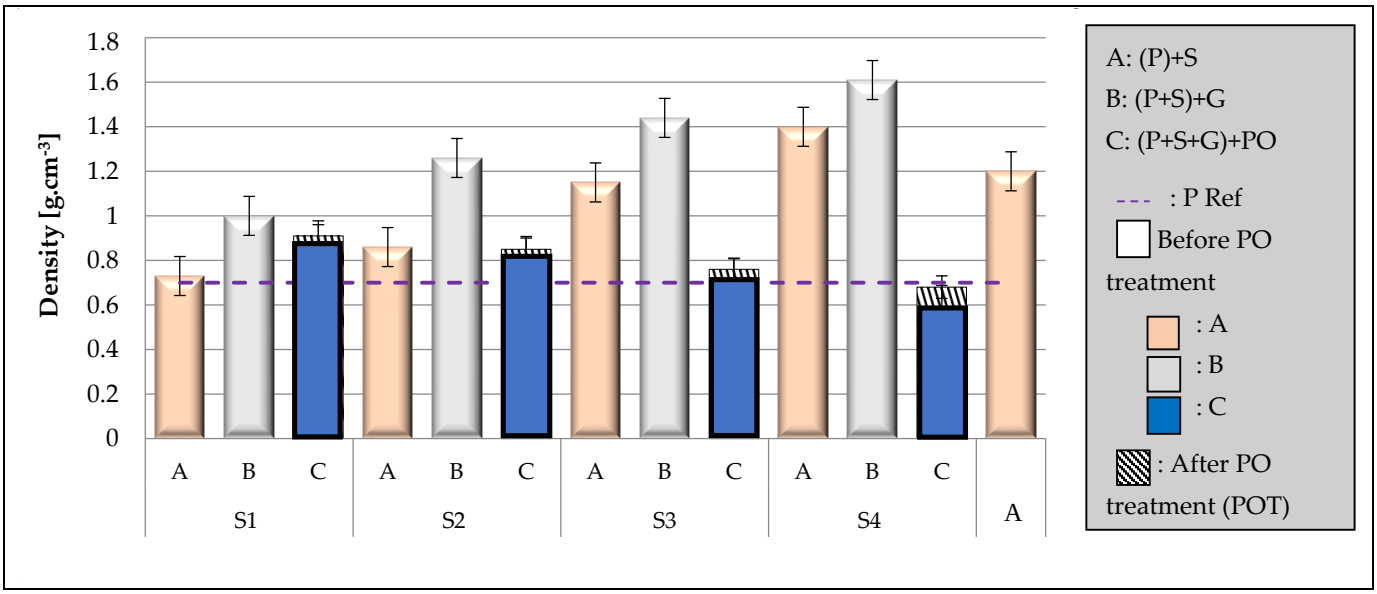


Figure 10. Variation in density of composites in the different mixing plans.

The effect of the gravel volume fraction on the composites (mixing plan B) will be discussed in this section. Figures 8 and 11 show that Rc and ρ_{app} increase in parallel to 13.58 MPa and 1.61 g.cm^{-3}, respectively, at the S4 level as the amount of G in the mixture increases. On the other hand, there is a very pronounced drop in the θ of the samples from 0.54 in S2 (A) Ref to 0.28 in S4 (Figure 11). The explanation for this drop is mainly due to the decrease of W/(P + S + G) and the presence of G in the mixture, because this element is considered a very weakly porous solid. Therefore, it can be said that the increase in G volume leads to a decrease in the surface area of the intergranular voids present in the sample. Concerning Rf, the maximum value recorded at the S3 level is 6.16 MPa. The increase in Rf is due to the decrease of Xv S and W/(P + S + G) and the parallel increase of Xv P and Xv G in the mixture. In practice, we found difficulty in casting the S4 mix due to a reduction in W/(P + S + G) to 0.33 (very low workability), reflecting the decrease in Rf

from 6.16 MPa to 5.65 MPa compared with the S3 announced. A further decrease in Rf from 3.83 MPa to 3.64 MPa was observed in S1 compared with S2 (A) Ref, although W/(P + S + G) decreased from 0.88 to 0.75 (Table 2). This drop confirms that W is not the only element affecting the Rf of the sample but also has a P effect. As we can see in Table 2 and Figure 9, increasing the P level helps increase the sample's Rf. Figures 10 and 11 show a similar situation at the θ and ρ_{app} levels while showing a significant increase in Rc due to the increase of Xv P and Xv G, and the decrease of Xv S and W/(P + S + G). Therefore, P helps to increase Rf, G helps to increase Rc (much better than S), and S is considered to be the least effective "θ reducer" compared with G. These results are consistent with those obtained by Djoudi et al. [19]. Based on these results in Figures 3–9, S2 is considered the best in terms of mechanical properties, comparable to other samples, especially because its S/G mass ratio is equal to 0.3. This report was used by Djoudi et al. to manufacture composite materials [19]. However, the physical properties and D of S1 are better than those of S2, as θ, $\rho_{app,}$ and D are improved to 19.23%, 20.63%, and 5%, respectively, while Rf and Rc are reduced to 6.66% and 6.48%, respectively. Therefore, adding G to the mixture helps to improve the mechanical properties of the composites. However, it also negatively affected the physical properties compared with the S1 (A) Ref and the results of previous mixing plans. To improve the physical properties and the accuracy of the results, after enhancing the mechanical properties in the A and B mixing plans, we chose S1 as the reference sample for the next mixing plan (C) and the "Posidonia marine fiber" as an additive material (M2).

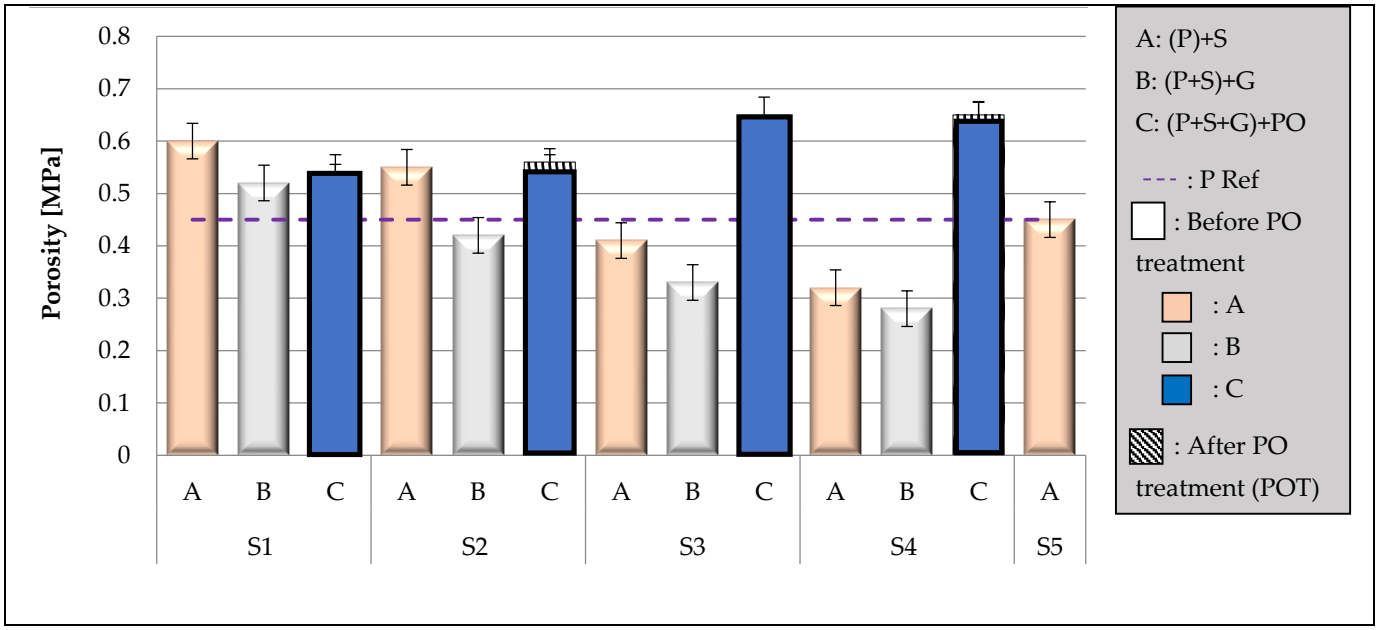


Figure 11. Variation in porosity of composites in the different mixing plans.

The effect of the Posidonia oceanica fiber volume fraction on the composites (mixing plan C) will be discussed in this section. Figure 9 shows that with 1.67 wt% S2, the best Rf is achieved at 3.85 MPa, which is a 5.45% improvement over S1 (B) Ref. At the level of S4, we noticed improvements in θ from 0.52 to 0.64 and in ρ_{app} from 1 g.cm^{-3} to 0.60 g.cm^{-3} compared with S1 (B) Ref (Figures 10 and 11). Regarding Rc, there is a gradual decrease to 24% from S1 (B) Ref to S4. This decrease is mainly due to the reduction of Xv P and Xv G in the mixtures where they were replaced with Xv PO, as the researchers showed that lignocellulosic fibers could slightly increase the Rc of the samples [5,25]. However, PO was shown to improve the Rf, $\rho_{app,}$ and θ of samples even though the amount of P in the mixture was reduced. As we have previously verified, P is an important element that helps improve the samples' Rf and θ. Based on the results in Figures 3–9 and S2 is considered to have the best physico-mechanical properties compared with other samples, especially because the mass percentage (wt) of S2 is equal to 1.67%. Researchers used

an approximation of this percentage for the manufacture of composite materials using lignocellulosic fibers [18,26]. Therefore, when we used 1.67 wt% PO (S2) in the fabrication of composite materials based on P, the addition of PO to the mixture of S1 (B) Ref resulted in an increase of Rf, ρ_{app}, and θ to 5.45%, 18%, and 3.70%, respectively. The optimal PO/P + S + G is 0.0321, where W/PO + P + S + G equals 0.86 (Table 2). In addition, the best results for volume correction were obtained using PO (D = 0 for all the samples) compared with the effects of mixing plans A and B (Figure 4). On the other hand, numerous studies suggest removing the organic lignin layer and the hemicelluloses on the surface of the lignocellulosic fibers by industrial detergents to improve their tensile strength, elongation at break, and roughness [5,27]. With this in mind, the treatment of PO with NaOH according to the Hamdaoui et al. method is proposed in the following mixing plan [12].

The effect of the Posidonia oceanica fiber-traited volume fraction on the composites (mixing plan C) will be discussed in this section. Figures 3–9 show the difference in the results between adding PO in raw and NaOH-treated cases in the mixture. When comparing S2 PO with S2 POT, using treated fibers instead of PO resulted in 3.97% and 3.57% improvement in Rc and θ, respectively. The explanation for these improvements can be traced back to thermo-chemical treatment with NaOH, which helps to eliminate organic lignin layers and hemicelluloses, increase voids on the fiber surface (Figure 6), and improve material-fiber adhesion [5]. However, the overdose of this alkali leads to a reduction in fiber diameter and a deterioration of the tensile strength [27]. Conveniently, since the weights are very similar, we use the same value of ρ_{app} of PO for POT (Table 2). The results after pouring, as seen in Figure 4, show that the Xv mixture of S4 POT is slightly smaller than the Xv PSM, which confirms the effectiveness of CF. In this case, two solutions were proposed: adding a small amount of P at the end of the casting, or adding a small amount of W, since some fibers have high W absorption capacity. This can serve as a convincing reason to find $D \neq 0$. To avoid the same situation with S5 results in mixing plan A, in this investigation, we added a small amount of P mix at the end of pouring instead of wetting PO. This addition is a logical explanation for the increase in ρ_{app} for the sample in Figure 11 because ρ_{app} typically decreases as POT's ρ_{app} is slightly lower at PO. Therefore, wetting the added material is not recommended, but it is better to add a small dose of P to correct the sample volume in the PSM. The results obtained with PO and POT are almost identical. Hamdaoui et al. also achieved the same effect when they used POT to study their thermo-physical properties [12].

In Figures 3 and 8–11, θ decreases and mechanical strength increases with decreasing W, knowing that the minimum allowable values for Rc and Rf according to standards are 2 MPa and 1 MPa, respectively. As conditions of use are always different, it is essential to experiment and validate before using scientific research results. According to the three mixing plans, the best results were obtained at the level of D and physico-mechanical properties when the ratios of S/P, S/G, and PO/P+S + G were equal to 0.5767, 0.3056, and 0, 0321, respectively.

6. Conclusions

In this work, we used the mixing correction factor (CF) to determine the amount of composite material required to make the mixing volume equal to the prismatic volume. In fact, the proposed correction factor can be used for future scientific research in various fields (agri-food industry, civil engineering, cooking, etc.) as long as there is mixed casting material in the prism mold (PSM). In practice, the effectiveness of this formulation has been demonstrated when applied to gypsum-based composites. The practical results show that the correction factor can be used to accurately determine the number of substances under production conditions with an error percentage reaching about 0%.

This study presents the results of investigations carried out on gypsum plaster using sand (S), gravel (G), and Posidonia oceanica (PO) fibers as added materials. The main results of the identification methods and physical and mechanical characterization before and after the NaOH chemical treatment of PO (POT) are summarized as follows:

1. XRD analysis shows that Tunisian gypsum (GPS) contains small amounts of bassanite and calcite. After the dehydration process of GPS to produce plaster, bassanite is formed. At the same time, we can also clearly see the positive effect of dehydration on the porosity of plaster in the MEB images;
2. The sand used is calcareous sand with a good particle size distribution, good gradation, and low fineness modulus; it is mainly composed of dolomite, gypsum, calcite, and quartz according to LDA and XRD analysis;
3. The best mechanical strength was recorded when only sand and gravel were added. The addition of PO or POT has shown their effectiveness in increasing the sample flexural strength, density, and open porosity;
4. The microscopic results clearly show the effect of NaOH thermo-chemical treatment on the POT surface, which positively affects the compressive strength results compared with PO;
5. The best PO/P +S + G ratio obtained is 0.0321, where we achieved zero mixing losses (D = 0%) and good physic-mechanical properties;
6. Assuming the sample volume is insufficient after pouring the mixture into the PSM due to a correction factor CF applied, adding some plaster rather than wetting calcareous sand is advisable to make up for this deficiency and avoid water affecting the results.

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