Thermal properties of plaster and plaster mortar filled with date palm rachis

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Abstract

Climate data show that the elements of climatic comfort in desert buildings are not available most of the year, as desert areas are characterized by hot and long summers and cold winters, so it is necessary to use techniques and methods that reduce temperatures inside buildings. To achieve this, and in order to contribute to the valorization of local resources, we studied the effect of adding date palm rachis on the thermal properties of plaster and plaster mortar. Where we added date palm rachis in the form of gravel and in the form of layers for plaster and plaster mortar by 1% to 5%. The results of the experiments showed a noticeable improvement in the thermal conductivity and specific heat of the samples. As the thermal conductivity of plaster samples reinforced with date palm rachis in the form of layers decreased by 34% and by 20% when adding granulated date palm rachis, and the specific heat decreased by 27% for multilayered date palm rachis reinforced plaster samples and 20 % for granulated date palm rachis reinforced plaster samples.

Keywords: plaster, plaster mortar, thermal conductivity, specific heat

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1. Introduction

Thermal insulation of buildings is one of the most important ways to save energy consumption, as it saves 40% of the annual energy consumption in the world [1], [2]is mostly exploited in heating and air conditioning systems, so there is a need to rationalize the uses of energy used in buildings by improving the thermal insulation of materials used in construction [3], [4].

Concrete and cement bricks are among the most commonly used building materials, and despite their high mechanical properties, they have weak thermal properties [5]that make their use without air conditioners or adding insulating materials uncomfortable for humans. It is necessary to think about alternative solutions aimed at improving the thermal insulation of materials used in construction by the use of low-cost local materials and low environmental impact.

Plaster is one of the materials that provides many solutions due to its availability in large quantities [6]and its interesting mechanical and physical properties, such as low thermal conductivity [7]and high burning resistance. Several studies were made on plaster in order to improve thermal performance by adding materials such as synthetic fibers and plant fibers [8], [9] and gave varying results with improvement rates between 16% to 30 %.

In this paper, we will study the effect of adding date palm waste to plaster on thermal conductivity and specific heat, for this purpose, we have done an experimental study by adding date palm rachis in the form of layers and granulated date palm rachis in variable proportions and their effect on thermal conductivity.

Abbreviations

P Plaster

S dune Sands

W Water

PP Plaster paste

PM Plaster mortar (plaster + sand)

DPR Date palm rachis

MDPR multi-layered date palm rachis

GDPR Granulated date palm rachis

2. Materials and experimental methods

2.1. Plaster

Plaster used to prepare plaster paste and plaster mortar is the commercial plaster from the area of ouled djellal Algeria with an apparent volumetric mass of (875 kg / m3), plaster or calcium sulfate produced by heating gypsum stone to a temperature of 150 ° C according to the equation:

$$2CaSO4.\ H\ 2O\text{-------}2CaSO4.H\ 2\ O+3H2O$$

Chemical analysis of plaster (Table 1) shows that plaster composed mainly of the two elements Calcium oxide (CaO) and Sulfur dioxide (SO2), For the complete hydration of plaster the theoretical amount of water required is 0.25 by weight of plaster. In construction uses, and for good workability, we take the W/P ratio between 0.6-0.8 [10]

Table 1: Chemical analysis of used plaster

Content	**SiO**	**AL_2O**	**In_2O**	**CaO**	**Mg**	**SO_2**	**Me_2**	**KO**	**CL**
%	3.5	0.10	0.08	35.20	0.53	52.95	0.09	0.03	0.002

2.2. Date palm rachis

The date palm rachis used in this study is taken from the palm leaf. It is abundant in the El Oued area, where one palm produces annually about 45.57 kg of waste, of which 27% is from the leaves [11], the palm leaf is in the form of a feather with a length up to 4.5 m depending on the age of the palm tree (Figure.1). Cut green and then leave to dry in the open air. Then we remove the fronds.

The date palm rachis contains 54.02% cellulose, 42% imcellulose and 33% lignin, (Table 2) shows the results of chemical analysis by electron microscopy.

Figure 1: Date palm rachis

Table 2: Chemical analyses of date palm rachis by MEP

Component	O	C	Cl	Ca	Mo	Te
Atom (%)	45.32	52.99	0.86	0.56	0.21	0.07
Weight (%)	50.25	44.11	2.11	1.55	1.40	0.59

Table 3: Physical properties of date palm rachis

Porosity %	**Water absorption to saturation %**	**Natural moisture content %**	**Absolute Density Kg/m3**	**Bulk Density Kg/m3**
17.88	85.04±10.51	7.55±2.16	867±22	675±38.45

2.3. Sand :

In our study, we use sand from the dunes of El-Oued, Algeria. (Table .4) and (table 5) shows its chemicals and physicals properties:

Table 4: Chemical analysis of sand used in the study

CL	CaO_4	insolubl	NaCL	CaCO3	SO_3
0.02%	1.92%	82.97%	0.03%	2.10%	1.16%

Table 5: Physical analysis of sand used in the study

Bulk density (kg / m 3)	ρa = 1501.00
Absolute Density (kg/m3)	ρs = 2608.55
ES_v%	93.60
ES_p%	91.80
Fineness Modulus%	1.25

2.4. Mixing water

The water used came from the drinking water network of El-Oued, Algeria. (Table 6) shows chemicals properties of mixing water

Table 6 Chemical analysis of mixing water

Components	The concentration (mg/l)
Ca++	245
Mg++	120
K++	25
Na+	532
CL-	750
TYPE-	13.5
SO4-	750
HCO3-	125
PH	7.70

3. Samples preparation

All samples of plaster and plaster mortar prepared for the study were made with dimensions of (16 x 10 x 8) cm^3. For plaster paste samples, we took a percentage of water from the weight of plaster W/P = 0.6, for plaster mortar samples we took a percentage of sand from the weight of plaster S/P = 0.5 and a percentage of water from the weight of plaster plus sand W/(P+S) = 0.6[12].

Date palm rachis were prepared from dried palm leaves in the open air after removing the fronds, cut into 150 mm long (figure.3) for multilayered form, and 5 mm to 15 mm for the granulated form (figure. 2), weighed dry and submerged in water until saturation [13].

Figure 2: Granulated date palm rashis(GDPR) Figure 3: Multilayered date palm rashis(MDPR)

The samples with dimensions of (16x10x8)) cm3 were prepared at normal temperature according to the following protocol:

For PP filled with GDPR samples:

-Mixing plaster with GDPR in the dry state

-Gradually pour the mixture into the necessary amount of water

-Mixing for 02 minutes

-Pour the mixture into the mould

For PP filled with MDPR samples:

-Gradually pour the plaster into the necessary amount of water

-Mixing for 02 minutes

-Pour a layer of PP into the mould

-Putting a layer of DPR

-Apply a second layer of PP

-Repeat the process according to the number of layers

In the same way, PM filled with GDPR and PM filled with MDPR samples were prepared with the addition of sand to plaster at a ratio of S/p = 0.5.

4.Measurement method

The samples are left to dry for 28 days inside the laboratory at 30±2°C and relative humidity RH=48±2%, and then we measure the weight.

Volumetric mass measured with electronic scale with a precision of (0.001g) according to ASTM C2206 75.

Thermal conductivity λ and heat capacity Cp were measured at 30±2°C and relative humidity RH=48±2% by the CT Meter device (figure 4) developed by CSTB, and which relies on the hot wire method according to the standards NF EN 933-15

Figure 2: CT meter

5.Results and discussions

5.1. Bulk density

The bulk density is determined after dividing the weight of the samples by their volume, (Table 7) shows the results of the bulk density of the plaster and plaster mortar samples filled with date palm rachis.

Table 7: Summary of obtained results for bulk density

% DPR	Bulk Density	
	Plaster Paste (PP)	plaster Mortar(PM)
0	1210.26±8	1350.62±12
1	1203.86±5	1341.25±16
2	1194.95±3	1326.03±9
3	1181.32±8	1314.20±11
4	1162.34±7	1289.49±12
5	1141.40±7	1260.35±18

From (Table 8), we can see that the bulk density of plaster without DPR is equal to (1210.26 kg/m^3), which is approximately half less than the bulk density of cement mortar (2233.20 kg//m^3) obtained in previous studies [14].

Also, the plaster mortar samples gave a larger bulk density than the plaster samples because they contain a percentage of sand, as the density of sand is higher than the density of plaster, when dune sand is added by S/P = 0.5, the bulk density increased by 11%.

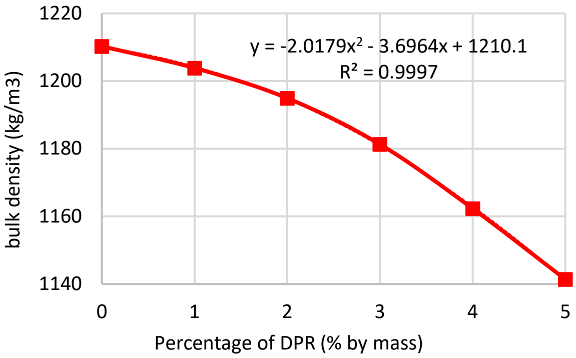

Figure 3 :the change of bulk density of plaster paste (PP) in terms of DPR percentage

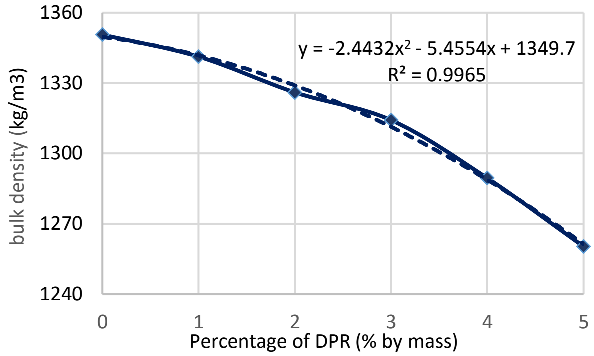

Figure 4: the change of bulk density of plaster mortar (PM) in terms of DPR

Through (Figure2) and (Figure3), we notice that the bulk density of plaster and plaster mortar is inversely proportional to the DPR ratio, where the bulk density of plaster and plaster mortar gradually decreases as the percentage of DPR increases.

5.2. Thermal conductivity

Table 8: Summary of obtained results for Thermal conductivity

% DPR	Thermal conductivity (W/m.C°)			
	Plaster Paste PP		Plaster Mortar(PM)	
	MDPR	GDPR	MDPR	GDPR
0	0.570±0.011	0.570±0.011	0.621±0.012	0.621±0.012
1	0.554±0.013	0.560±0.035	0.596±0.020	0.610±0.026
2	0.524±0.012	0.551±0.012	0.572±0.018	0.591±0.013
3	0.478±0.021	0.531±0.013	0.531±0.020	0.580±0.014
4	0.410±0.013	0.494±0.022	0.482±0.023	0.562±0.026
5	0.375±0.010	0.456±0.030	0.429±0.028	0.529±0.007

Through (Table 9), which shows the results of the thermal conductivity of the samples, we observe:

- Plaster samples and plaster mortar have a relatively weak thermal conductivity (0.375 W/m.C°) to (0.621W/m.C°) compared to the thermal conductivity of cement mortar (1.990

W/m.C°) obtained in previous studies [14],Plaster as a building material has a low thermal conductivity.

- The thermal conductivity of plaster without adding DPR is equal to (0.570 W/m.C°) , while the thermal conductivity of plaster mortar without DPR was(0.621 W/m.C°) , when sand was added by S/p = 0.5, the thermal conductivity increased by 9%, This is due to the fact that the thermal conductivity of dune sand is greater than that of plaster
- Plaster samples containing MDPR gave less thermal conductivity than samples containing GDPR, when MDPR was added by 5% the thermal conductivity decreased from (0.570 W/m.C°) to (0.375 W/m.C°), a decrease of 34%, and when GDPR was added by 5%, the percentage decrease in conductivity was 20%. Placing the fibers in the form of parallel layers inside the plaster formed an insulating layer that does not allow heat to pass through, while when placing the fibers in the form of gravel, leaving voids that formed a heat bridge that allowed increasing thermal conductivity.

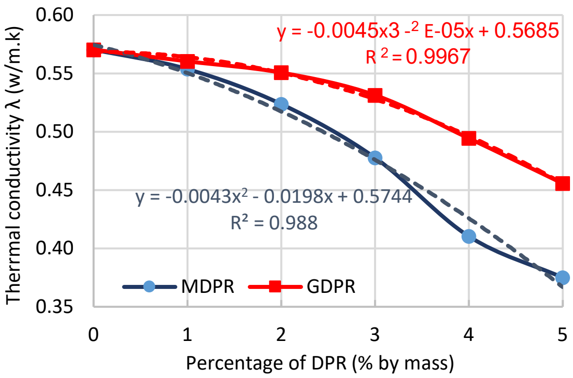

Figure 5 :Thermal conductivity of plaster paste for MDPR and GDPR

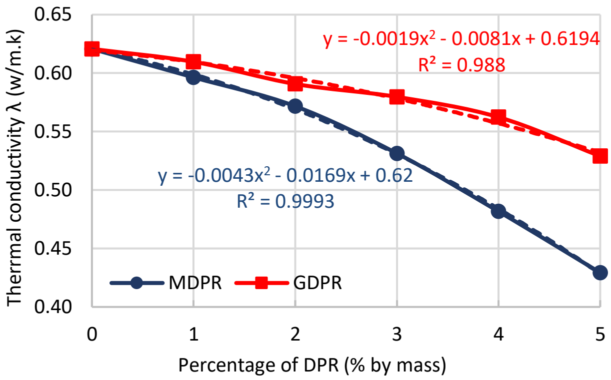

Figure 6 :Thermal conductivity of plaster Mortar for MDPR and GDPR

Through (Figure 4) and (Figure 5), which shows the relationship between the percentage of fiber and the thermal conductivity of plaster and plaster mortar, we notice

- The thermal conductivity is inversely proportional to the percentage of fiber, When the percentage of fiber increases, the thermal conductivity decreases
- Samples containing GDPR have a greater thermal conductivity than samples containing MDPR This difference in conductivity increases as the fiber percentage increases.
- The thermal conductivity of plaster and plaster mortar changes in terms of the fiber ratio according to a second-order equation of the form y = ax2 + bx +c

where:

y: represents thermal conductivity.

x: represents the percentage of fiber.

5.2. Specific heat

Table 9 Summary of obtained results for Specific heat

% DPR	Specific heat (Kj/m³. k)			
	Plaster paste (PP)		Plaster mortar (PM)	
	MDPR	GDPR	MDPR	GDPR
0	1566. 31±74	1566. 31±74	1476.13±37	1476.13±37
1	1501.30±14	1522.32±32	1395.48±45	1416.26±76
2	1429.35±19	1456.32±23	1295.96±51	1373.75±20
3	1325.24±13	1394.62±16	1225.25±29	1287.52±38
4	1255.43±22	1301.20±41	1150.73±50	1234.28±35
5	1145.55±40	1235.24±15	1076.17±21	1171.75±19

(Table 9) shows the results of the specific thermometry of plaster and plaster mortar samples, through the results we observe:

- The plaster mortar samples have a lower specific heat than plaster samples, where the plaster mortar samples without DPR gave a specific heat of (1476.37 Kj/m³. k), while plaster paste samples without DPR gave (1566.31 Kj/m³. k), the specific heat decreased by 6% when adding dune sand by S/P = 0.5,
- The specific heat is inversely proportional to the DPR ratio, where the specific heat of plaster samples and plaster mortar gradually decreases as the fiber percentage increases (see Figure 8 and Figure. 9) according to the equation of a line with a negative orientation coefficient.
- When MDPR was added by 5 % to plaster paste samples, the specific heat decreased by 27 %, and when the same percentage of GDPR was added, the specific heat decreased by 21%.

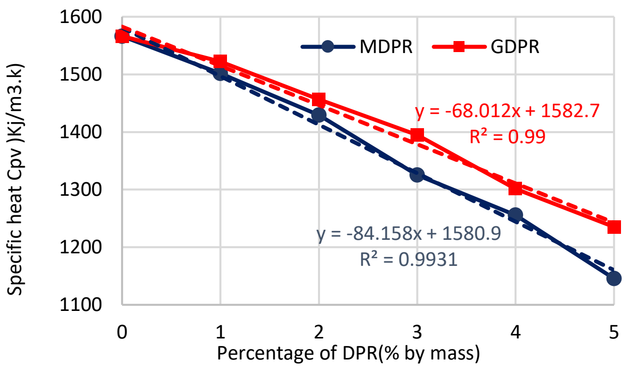

Figure 7 :Specific Heat of plaster Mortar for MDPR and GDPR

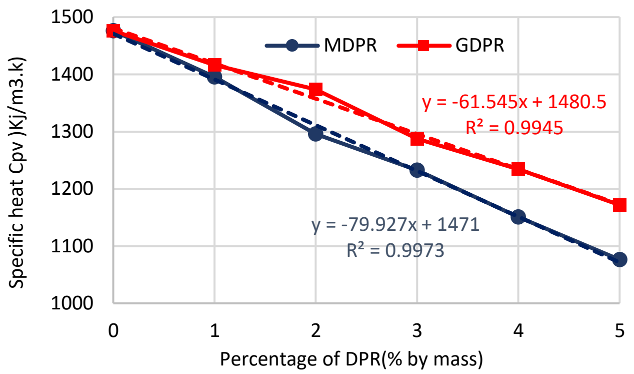

Figure 8 :Specific Heat of plaster paste for MDPR and GDPR

6. Conclusion

At the end of this study on the addition of date palm rachis to plaster and plaster mortar in order to improve thermal properties, we summarize the following results:

- Plaster as a building material is considered a good heat insulator, as the results of experiments on plaster samples gave a thermal conductivity of (0.57 W/m.C°) for plaster, which is half less than the thermal conductivity of cement mortar (1.99 W/m.C°) [14].
- The addition of sand by S/P = 0.5 led to an increase in thermal conductivity by 10 %, as thermal conductivity increased from (0.621 W/m.C°), this value remains Below the thermal conductivity of cement mortar and within the recommended values for heat-insulating building materials (less than 0.75 W/m.C°).
- plaster filled with date palm rachis contributed positively to reducing the thermal conductivity of plaster and plaster mortar, as the thermal conductivity of plaster decreased by 34 % when adding MDPR and 17% when adding GDPR, and the thermal conductivity of plaster mortar decreased by 30 % and15 %. When MDPR and GDPR were added respectively, samples containing MDPR gave lower thermal conductivity than samples containing GDPR.
- Adding MDPR by 5 % to plaster paste samples contributed to reducing specific heat by 27 %, and adding the same percentage of GDPR reduced specific heat by 21 %.
- Adding MDPR by 5 % to plaster mortar samples contributed to reducing specific heat by 27 %, and adding the same percentage of GDPR reduced specific heat by 20 %.

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