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Enhancing the Properties of Gypsum as an Indoor Finishing Material Using Palm Tree Residues

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Abstract: Environment-friendly materials are used in natural architecture to protect the buildings from outside environment and to safeguard the resilience of materials used. Palm tree residues are spread in Saudi Arabia on a large scale, and rarely used in the construction. The majority of uncontrolled wastes of palm are accumulated producing serious environmental problems. On the other hand, Gypsum is one of the oldest raw materials used in construction. It is a handy, low cost, and widely spread material that can be utilized for different uses in the built environment. This paper examined the viability of adding palm tree sawdust to Gypsum powder to produce blocks for indoor use. The effects of adding palm sawdust to Gypsum were investigated in the laboratories at the University of Dammam. Different ratios of the admixtures were added by weight. It was concluded that the shrinkage value, weight, and porosity value were significantly reduced by increasing the ratio of sawdust to Gypsum powder, whereas compressive strength was increased at the same time. The study explored the optimum ratio of sawdust to improve the properties of the cubes. Results will encourage industries to produce and improve Gypsum cubes containing agricultural residues to develop low cost building materials.

Keywords: Building, Gypsum, materials, palm, residues

1. INTRODUCTION

Calcium sulfate is the chemical material commonly known as natural Gypsum. It is found in various forms as the dihydrate ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$). There are some famous binding materials produced from Gypsum such as plaster of Paris (β-hemihydrate), known in France as 'plâtre de Paris', in the USA as 'calcined Gypsum', and in Germany as 'Stuckgips'. Some properties of Gypsum paste are related to thermal expansion, volume and linear changes under humidity fluctuations, moisture absorption, paint ability, corrosivity, thermal and acoustic insulation behavior, and fire resistance [1]. Gypsum is a mineral rock originated in the earth's shell, mined, handled and used in construction or ornamentation since 9000 B.C. Gypsum plaster was revealed in Catal-Huyuk in Asia. In the Pharaohs era, Gypsum was used as mortar in the construction of the Cheops Pyramid 3000 B.C. In the Middle and the Renaissance eras, artistic constructions were made of plaster. Since then, the choice of construction-related uses has sustained to multiply. Gypsum has a variety of uses, including Gypsum boards and paints. It has the characteristics and features that always make it at the forefront of basic materials used in building and construction [2].

There are many non-fruit components of the date palm such as frond bases, midrib, leaflets, spikelet, fruit stalks, and spathes. Each component has certain limited value. Leaves are used in fence construction. In addition, palms provide different construction for rooftops, hedges, bags, hoists, fabrics etc. [3].

A palm tree annually generates an average of 35 kg of residues. In Saudi Arabia, the amount of generated waste from date palms is estimated one million metric tons. In third world countries, almost all of the residues are burnt or directed to landfills generating serious environmental problems. Whereas, in developed countries, such residues are utilized as raw material and converted into some other products such as composite panels [4].

Considerable studies have been published on Gypsum admixtures with other materials and their associated properties. This study aimed to produce a type of Gypsum cubes containing the saw dust of palm tree residue to improve its properties as an indoor finishing material. The effects of adding palm sawdust to Gypsum were investigated in the laboratories at the University of Dammam. Different proportions of the admixtures were added by weight.

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2. RELATED WORK

Reference [5] investigated the properties of date palm frond (DPF). The test results showed that the tensile strength of the stalk walls were almost double that of the core. It was also found that elasticity modulus of stalks was between 10 to 30 KN/mm2. Results of chemical tests showed that the alkaline medium of fresh concrete has no effect on the tensile strength of DPF stalks and further stated that coating DPF stalks with varnish greatly improves their long-term durability in concrete.

Reference [6] stated that addition of cotton stalk to Gypsum had a substantial impact on its mechanical properties. Cotton stalk fiber was treated with styrene emulsion that improved the combined state of stalk fiber and Gypsum and enhanced its mechanical properties.

Reference [7] examined date palm surface fibers and determined their properties such as toughness, strength, microstructure, and continuity index. When increasing percentage and length of fiber in both water and hot dry curing improved the post-crack flexural strength and the toughness coefficients, but decreased the compressive strengths.

An experimental study examined the possible uses of a lightweight and low-cost building material produced from dust of limestone and saw dust of wood. The recorded values of weight, compression strengths and flexure, and water absorption fulfilled the appropriate international standards. Results also showed that the effect of high-level replacement of limestone dust and wood sawdust does not show a rapid brittle fracture, indicated an increase in the capacity of absorption, and dramatically reduced the weights of the unit, besides introducing a smooth brick surface. The product showed a potential to be used for many building components such as: walls, wooden boards, blocks, ceiling and sound panels [8].

Reference [9] discussed the aspects inducing the performance of Gypsum-based composite material. They tested the components, water/cement ratio, and retarder quantities. They concluded that the strength and coefficient of softness had increased compared to Gypsum. When mixing Portland cement it quickened the thickening and also improved the strength and softness coefficient of composite but over dosage will cause fall of its strength and softness coefficient.

Reference [10] studied the relationship between Wood-Gypsum ratio and water Gypsum ratio. They explored the effects of temperature on hydration process and the Gypsum morphology. They also analyzed the properties of the Gypsum sawdust board. They concluded that both Water-Gypsum ratio and Wood-Gypsum ratio are essential to enhance the properties of the boards in 40℃ and to shorten the hydration time to strengthen the boards.

The impacts of adding sawdust and wood ash admixtures to clay mix to produce bricks were examined with different combinations of proportions. The results showed that the key influence of the sawdust admixture was reducing the dry density of the brick. Furthermore, the wood ash admixture attained denser products with higher compressive strength, lower water absorption rates, lower saturation coefficients and lower abrasion indexes [11].

Reference [12] conducted a research to develop a new energy saving composite building material from foam Gypsum with fibrous hemp reinforcement. The coefficient of sound absorption increased when using hemp's reinforcement with foam Gypsum. The absorption coefficient increased more with long fibers than with short fibers. Increasing the concentration of short fibers' reinforcement in the foam Gypsum increased its density, but decreased the density for the foam Gypsum with long fibers.

Reference [13] investigated solid waste materials from the desert area and added them to a clay matrix, and studied their properties. He mixed Clay and fronds with pits of dates arranged horizontally, vertically, at 45º angles. Adding crushed pits significantly improved the properties of clay bricks, making them 85% and 15% tougher and stronger respectively.

Gypsum-based composites were produced mixing the powder of Gypsum with latex and Polyvinyl Acetate (PVA). The study investigated the release time, density and impact strength in different ratios of water/cement, PVA/cement and glue/cement. The results showed that PVA contributed to delay the time release and increased impact strength. Whereas, density was reduced by the sawdust [14].

Reference [15] prepared two composites of polyethylene glycol with Gypsum and natural clay as new kinds of building materials to study low temperature-thermal energy storage. The results showed the presence of worthy compatibility between the components due to capillary and surface tension so that the composite can be used for passive thermal energy storage applications in buildings under different climatic conditions.

Reference [16] addressed the development of green composite from Gypsum and sawdust by using a water-based epoxy spray coating technique. Results showed that the sawdust water could increase the flexural and compressive strength of Gypsum by 10% and 7% respectively. It addition, further analysis with optical microscopy demonstrates that the reduction of water uptake has led to an increase of the Gypsum covering ratio from 42% to 68%. In addition, Reference [17] studied Bio-composite made of wood sawdust and Gypsum. Mechanical testing of the composite showed that the light weight composite with promising mechanical performance could be obtained: for 20% sawdust addition, the flexural strength and compressive strength of composite were 4.59 MPa and 13.25 MPa, respectively; for 30% sawdust addition, the flexural strength and compressive strength of composite were 3.36 MPa and 8.73 MPa, respectively.

3. MATERIALS AND METHODS

Materials used for this paper are Gypsum, and Palm tree particles. The Gypsum used was purchased from local resources in Dammam and the Palm tree fine particles were prepared from the Date Palm Fronds which were brought from Al-Ehssa and then sawed in a carpentry workshop. Therefore, the materials are prepared to carry out the tests of: weight, shrinkage, compression, and porosity. The particle size distribution of palm tree particles was obtained using No. 20 and 40 sieve sizes as shown in Fig. 1.

Source: the authors

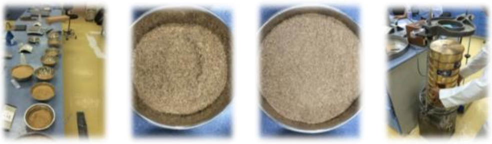

Fig. 1. Palm tree particles preparation (the authors)

Materials mixing

The mixing ratios used in the tests are mostly used in many similar tests by other authors who investigated the effects of different additives on building materials such as cement, clay, brick, etc. Palm tree particles are added in 5 different ratios by weight, 0%, 1%, 2%, 3%, and 6%. The 0% palm specimen is used as a control specimen. The experiment technique is based on the concept of addition on equal weight. Table 1 shows the ratios used compared to Gypsum weight and shows water added as well. The ratios below were added in the dry state. Then water was added afterwards.

TABLE I: MXING RATIOS

Gypsum (gm)	Palm Tree Particles		Water (gm)
	%	(gm)	
3000	0	0	1950 (65% of Gypsum weight)
	1	30	
	2	60	
	3	90	
	6	180	

Source: the authors

The Specimens

As per the standards, cubes of (5cm x 5cm x 5cm) are used. For each test of a certain mixing ratio, five specimens were prepared and the recorded test results for this ratio is the average of the five recorded values. Meaning that for each test type (weight, shrinkage, porosity, compression) 25 specimens were needed. Therefore, the total number of specimens used are 100 for the four tests. Some extra specimens were made as a spare to overcome any mistake that might occur during the tests and this has raised the total number of specimens prepared to more than 150 specimens.

4. RESULTS

Weight Test

After 24 hours of casting the specimen, the weights were measured by a digital balance. The recorded value of each mixing ratio is the average of the recorded values of five specimens of the same mixing ratio as indicated in Table 2 and Fig. 2.

TABLE II: AVERAGE WEIGHTS OF CUBES OF DIFFERENT MIXING RATIOS

Mixing ratio	Average weight (gm) (After 24 hours)
0%	±183.1
1%	±181.6
2%	±179.2
3%	±178.6
6%	±174.2

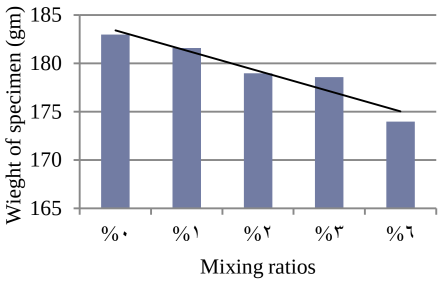

Fig. 2. Average recorded weights of the specimens of different mixing ratios (the authors)

Fig. 3 shows that palm tree particles effectively reduce the weight of the specimen of Gypsum blocks. The more the percentage of the particles the less the weight of the block. The reduction rate (expressed in the slope of the lines) in the weight of the Gypsum blocks is the much more in the high mixing ratios than in the low mixing ratios as noticed in 3% and 6% ratios.

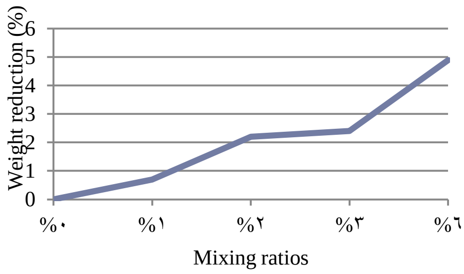

Fig. 3. Percentage of weight reduction in different mixing ratios (the authors)

Shrinkage Test

The specimens were weighted by the digital balance after 24 hours of casting, then inserted into the oven at 110 °C for 24 hours to ensure total dryness. Afterwards, each specimen was weighed again to measure the effect of the palm tree particles on its own weight. Table 3 summarizes the findings of the shrinkage test. Fig. 4 shows that palm tree particles effectively reduced the shrinkage value of the specimen of Gypsum blocks. The more the percentage of the particles the less the shrinkage value of the block. The reduction rate (expressed in the slope of the lines) in the shrinkage of the Gypsum blocks is much more in the lower mixing ratio of 1% than in the medium 2% and the higher 6% mixing ratios as noticed in the figure.

TABLE III: AVERAGE DIMENSIONS OF SPECIMENS AFTER DRYING IN THE OVEN

Mixing ratios	Average dimensions before drying (cm)	Average dimensions after drying (cm)	Shrinkage %
0%	5 cm	±4.90 cm	±2.1
1%	5 cm	±4.94 cm	±1.2
2%	5 cm	±4.95 cm	±1.1
3%	5 cm	±4.97 cm	±0. 6
6%	5 cm	±4.98 cm	±0.4

Source: the authors

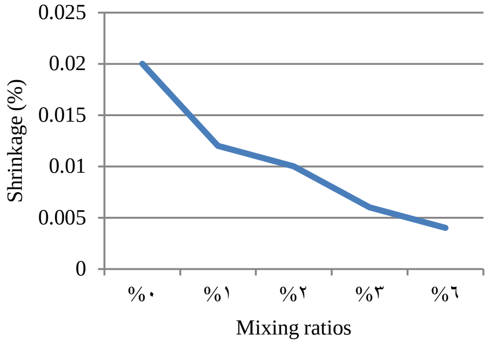

Fig. 4. Percentage of shrinkage values in different mixing ratios (the authors)

Porosity Test

The specimen was immersed in water for 24 hours, and then taken out and weighted directly. Table 4 shows the average porosity values of the specimen what were calculated using the next formula [18].

$$Porosity(\%) = \left(1 - \left(\frac{\text{Oven-dried Weight (kg) - Submerged Weight (kg)}}{\text{Sample Volume (m}^3\text{). Density of Water (kg/m}^3\text{)}}\right)\right)100\%$$

TABLE IV: AVERAGE POROSITY OF SPECIMENS

Mixing ratios	Average Porosity %
0%	±34.20
1%	±33.82
2%	±33.33
3%	±33.14
6%	±32.91

Source: the authors

Fig. 5 shows that palm tree particles had and effective reduction effect on the porosity of the specimen of Gypsum blocks. Higher percentage of palm tree particles produced lower porosity values of the Gypsum blocks. The reduction rate (expressed in the slope of the lines) in the porosity of the Gypsum blocks is much more in the low mixing ratios than in the high mixing ratios as noticed in 1% and 2% ratios.

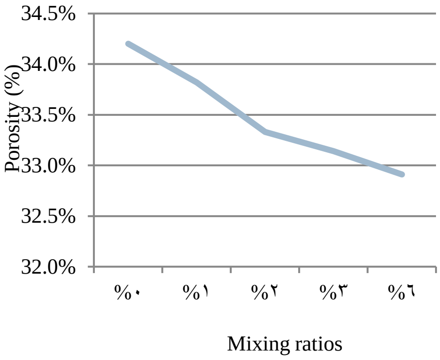

Fig. 5. Percentage of porosity values in different mixing ratios (the authors)

Compression Strength Test

In order to conduct the test, five cubic specimens for each mixing ratio were prepared. Therefore, a total of 25 specimens were tested for the compression strength instrument. From Fig. 6 and Table 5, it is noticed that palm tree particles have a good impact on increasing the compression strength of the Gypsum specimens. The more the mixing ratio, the more the compression strength which reached 17.48 KN in the mixing ratio of 6%, which is 150% higher compared to the control specimen. These results give a direction to use the palm tree particles to enhance the compression properties of Gypsum works in indoor applications.

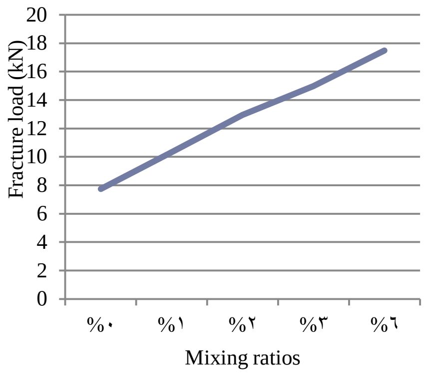

Fig. 6. Fracture loads of different mixing ratios (the authors)

TABLE V: FRACTURE LOADS AND SHAPES OF THE SPECIMENS

Fracture load (kN)	After test	Before test	Mixing ratio
7.74			%0
10.33			%1
12.96			%2
14.97			%3
17.48			%6

Source: the authors

5. DISCUSSIONS

The justification of the previous results can be explained when studying the chemical properties of palm tree saw dust. Palm contains some chemical components such as Wax, Phenol compounds and Pectin [19]. The chemical properties of these compounds helped improving the characteristics of Gypsum cubes as follows:

Wax material present in remnants of palm tree is a fatty substance that solidifies at normal temperature and melts when heated [20]. When adding water to the mixture of Gypsum powder and palm sawdust, the wax melts by the heat emitted and diffuses within the particles of Gypsum. Then the mixture cools down and the wax hardens increasing the paste cohesion which blocks the pores of

Gypsum. Thus, porosity value of the cubes reduces, while the strength increases.
Pectin material forms the cortex cells of the plant skin and gives its usual rigidity [19] and therefore, addition of Pectin to Gypsum paste helps to increase its hardness and strength against compression.
Phenol compounds in palm tree residues are moderately soluble in water in an acidic medium [21]. Thus they interact with Gypsum and produce salts and water, which helps to continue the interaction and overlap between the granulated Gypsum and palm granules, therefore reducing porosity as well.

6. RESEARCH LIMITATIONS

It is important to note the methodological limitations of the tests involved in this paper. As previously discussed, an important limitation in this paper is the reliance of the saw dust obtained from only one source in Al-Ahsaa, which could have limited the results. Different types of palm dates might have different chemical composition and therefore might obtain slightly or marginally different results. it possible to examine more complex relationships between gypsum powder and palm tree saw dust in other mixing ratios and after drying the sawdust so that to eliminate the its humidity impacts on the results. However, the conclusions from these tests are limited to the conditions the test have been carried out in. Future research would benefit from the use of a larger sample of different parts of the palm tree itself.

7. CONCLUSIONS

Adding palm tree sawdust to the Gypsum powder has many positive impacts on the properties of the resulting admixture that encountered much enhancement in many aspects. Based on the results of the previous tests the following can be concluded:

Gypsum cubes weight is inversely proportional to the content of sawdust, where lower values of weight was recorded with higher content of sawdust in the specimen, which contributes to reduce the loads on the structure of buildings. The similar trend has been reported by the researchers of the references [6] and [7]. The maximum reduction of sample weight reached 10% in the specimen containing 6% of sawdust.

Shrinkage value of Gypsum cube specimens is inversely proportional to the ratio of the amount of sawdust, where lower value of shrinkage is recorded with higher content of sawdust in the specimen, which helps to improve the characteristics of Gypsum cubes in the applications of interior finishes. The similar trend has been reported by reference [11].

Porosity value in the specimen of Gypsum cubes is inversely proportional to the content of sawdust, where porosity value was smaller in the greater ratio, which helps to improve the characteristics of Gypsum cubes in the internal uses of the buildings. The maximum reduction of porosity value reached 8% in the mixing ratio of 6% of sawdust. The attained result is consistent with the findings in reference [11].

Compressive strength of the specimen of Gypsum cubes is directly proportional to the amount of sawdust, which is consistent with the findings in reference [11]. Results attained showed that higher values of compressive strength were recorded in higher ratios of sawdust in the specimen, the highest value of compressive strength obtained with the mixing ratio of 6% of sawdust, which exceeded the control value by 150%. The result reflects the potential of the improvement of the characteristics of Gypsum cubes for internal uses in buildings.

Finally, it can be concluded that the 6% mixing ratio of saw dust of palm tree is the optimum ratio among the tested specimens in respect to the enhancement it achieved in all the applied tests. Hence, being able to enhance the properties of Gypsum as a construction material using residues of palm tree -and considering the low cost of both Gypsum and palm tree residues- the potential of producing cheaper building materials- which Gypsum and palm tree residues are its main constituents- will be more feasible.

FUTURE WORK

The research team plans to continue studying the thermal and acoustical properties of the composite of Gypsum and agricultural residues in order to produce an environmental friendly building material with relevant properties consistent with the international standards.

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