International Journal of Engineering & Technology, 7 (4.20) (2018) 205-208

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Effect of Temperature and Sisal Fiber Content on the Properties of Plaster of Paris

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Abstract

Recent developments in the production of ecologically friendly building composites have led to a renewed interest in the use of vegetable fibers as a reinforcement element. Traditional pure Plaster of Paris (POP) can suffer from the development of micro-cracks due to thermal expansion. Therefore, sisal fiber was studied for its potential as an ecological element to restrict and delay the development of micro-cracks in POP. Different sisal proportions of 0, 2, 4, 6, 8 and 10 wt. % of POP were used to characterize the physical and mechanical properties of POP at the ambient temperature. Then, the effects of temperatures of 25, 100, 200, 300, 400 and 500 ℃ were investigated. Results proved that the composite of 10% sisal fiber had the best mechanical properties. Also, when the fiber content was increased, the composite's performance was enhanced, becoming better able to resist elevated temperatures. However, raising the temperature to 300 ℃ or above had a negative effect on the mechanical properties, which were significantly decreased due to the degradation of the sisal fiber.

Keywords: *Characterization; Effect of Temperature; Plaster of Paris; Sisal Fiber..*

1. Introduction

In the new global ecology, vegetable fiber has become a central issue as an alternative choice for reinforcing brittle material instead of using synthetic fibers [1]. Carbon fiber is very expensive [2] while glass fiber is very toxic. For composites of less than 30% vol. of fiber, sisal fiber-gypsum composites have better mechanical performance than glass fiber-gypsum composites of the same fiber fraction [1].

Long fibers can be used to attain maximum strength [3] while, on the other hand, short fibers can be used to manufacture complex architectural shapes [4]. Short sisal fibers (which are accessible after the longer ones have been extracted) are one of the least expensive vegetable fibers [5,6,7]. Their critical length (aspect ratio) can be calculated based on the fiber strength, the interfacial bonding strength with the matrix, and the fiber diameter [8]. The matrix is responsible for transferring the stresses between the fibers, as well as redistributing the stress even when individual fibers break. The matrix also has an influence on the mechanical properties, micro-crack propagation, and ultimate deformation [8,9]. Therefore, the maximum resistance of composite materials can be achieved when the components reach their ultimate strengths at the same time. Hence, critical fiber length increases when a weak matrix is reinforced [9]. However, long fibers increase the agglomeration (balling) of fiber during the mixing and placing process. Such fiber agglomeration causes some difficulties in obtaining a homogeneous composite [10]. Short sisal fibers of 3∓1 mm allow for the attainment of a quasi-homogeneous mixture of well distributed fiber, as well as for increasing the fiber proportion. Plaster of Paris (CaSO4. 1/2H2O) is derived from a natural resource by heating and pulverizing gypsum rocks to drive off about 150 % of the combined water [11]. Plaster of Paris (POP), which is widely used for finishing interior walls and ceiling linings, is a thin layer that suffers from the development of micro-cracks due to thermal expansion or differential movement [1,12]. Using randomly short sisal fibers can modify its mechanical properties, delay the development of micro-cracks, and prevent brittleness failure [7]. Thermal degradation of sisal fiber starts above a temperature of 200 ℃ [13] while the gypsum (CaSO4.2 H2O) starts to lose its chemical combined water at 100 to 170 ℃. The thermal degradation of sisal fiber which is embedded in a gypsum matrix has remained unclear under the effect of elevated temperatures because gypsum envelops sisal fiber and protects it against the direct heat effect. Therefore, this research explores, for the first time, the effects of sisal fiber proportion, as well as elevated temperatures, on the mechanical and physical properties of POP.

2. Materials and Sample Preparation

2.1. Materials

Plaster of Paris (SAHAND BURAKR) in compliance with the requirements of Iraqi standard No. 28/1988 was used. Sisal fibers, which were purchased from an Iraqi market, were washed in distilled water and chopped to be 2 to 4 mm in length. These fibers were then soaked in water for 24 hours and air-dried for one hour to achieve saturated surface dry fiber.

2.2. Sample Preparation

A reference mixture of Plaster of Paris was prepared by mixing POP with 100 % water. This plaster/water ratio was chosen after many trials to obtain high workability (≥250 mm spillage), in

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order to minimize the effect of the sisal fiber on the workability of the POP. The initial setting time was 8 to 10 minutes. The workability decreased when the sisal fiber in the mixture increased due to agglomeration. The agglomeration increased when the fiber proportion and the fiber length increased [14]. Therefore, the sisal fibers were chopped and used as a weight replacement. The chopped sisal fibers were added as a replacement proportion of 4, 6, 8, and 10% wt. from POP. 150 cubic samples of (50×50×50 mm) and 90 prism samples of (50×50×150 mm) were prepared, considering an average of 5 samples for the compressive test (according to ASTM C317) and an average of 3 samples for the flexural test (according to ASTM D790, ISO 187). All the composites were heated in an electric oven with an elevated temperature capacity of 1000 ℃. The ambient temperature (≅25 ℃), 100, 200, 300, 400 and 500 ℃ were used for 2 hours to investigate the effects of temperature and sisal fiber content on the mechanical properties of plain and reinforced POP composites. In Table 1, which represents the composite names, the abbreviation "Ref" refers to the reference composite that did not contain sisal fiber. And, "Comp" refers to the composite of POP with sisal fiber, while the first subscript number refers to the sisal fiber percentage and the second subscript number refers to the temperature in degrees. Figure 1 shows the five series of composites.

Table 1: Composite names according to mix proportions and temperatures.

Content of Sisal Fiber (%)	Temperature (℃)					
	25	100	200	300	400	500
0	Ref0,25	Ref0,100	Ref0,200	Ref0,300	Ref0,400	Ref0,500
4	Comp4,25	Comp4,100	Comp4,200	Comp4,300	Comp4,400	Comp4,500
6	Comp6,25	Comp6,100	Comp6,200	Comp6,300	Comp6,400	Comp6,500
8	Comp8,25	Comp8,100	Comp8,200	Comp8,300	Comp8,400	Comp8,500
10	Comp10,25	Comp10,100	Comp10,200	Comp10,300	Comp10,400	Comp10,500



Fig. 1: 5 Series of Composites after 28 Days of Drying at Ambient Temperature (Laboratory Temp. ~25℃).

3. Results and Discussions

The effects of sisal fiber proportion and temperature on the density, compressive strength, flexural strength, modulus of elasticity, and mode of failure were investigated.

3.1. Apparent Density Test

Apparent density was calculated according to ASTM (D1895) in the following manner: The mass of the sample was measured by using an electrical balance with an accuracy of 0.01 gm. The mass was then divided by the volume of the sample, which was calculated by multiplying the average of 3 measurements for each side. Then the results were plotted according to sisal fiber content, as shown in Figure 2.

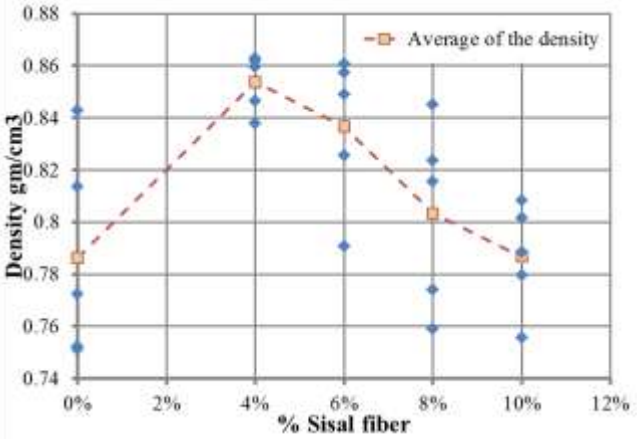


Fig. 2: Effect of Sisal Fiber Proportion on Apparent Density of Different Composites.

A significant amount of dispersion was observed in the composite density, except for a sisal fiber proportion of 4%. In fact, adding water to the dry POP caused a chemical reaction which led to elevated temperatures and gas generation during the hydration process. Upon visual examination, the reference samples (0% sisal fiber) contained many more gas bubbles than did those containing sisal fiber. Interestingly, the fibers may helped the interrupted gas to exit from the matrix. Therefore, the composites of 4% sisal fiber had higher density than the reference. Then, the density slightly decreased when the proportion of sisal fiber was increased because the fiber has a lower density than POP.

3.2. Mechanical Properties

3.2.1. Effect of Sisal Fiber Proportion and Temperature on Flexural Strength

Prism samples of different sisal fiber proportions (0, 4, 6, 8, and 10% wt. of POP) were heated for two hours at different temperaturesof 100, 200, 300, 400 and 500℃, then they were cooled in an oven to prevent any thermal deformation.

The modulus of rupture (MOR) was evaluated using three points of load with a universal machine. An average of three samples for each composite was adapted to determine the effects of fiber proportion and temperature on the modulus of rupture (see Figure 3).

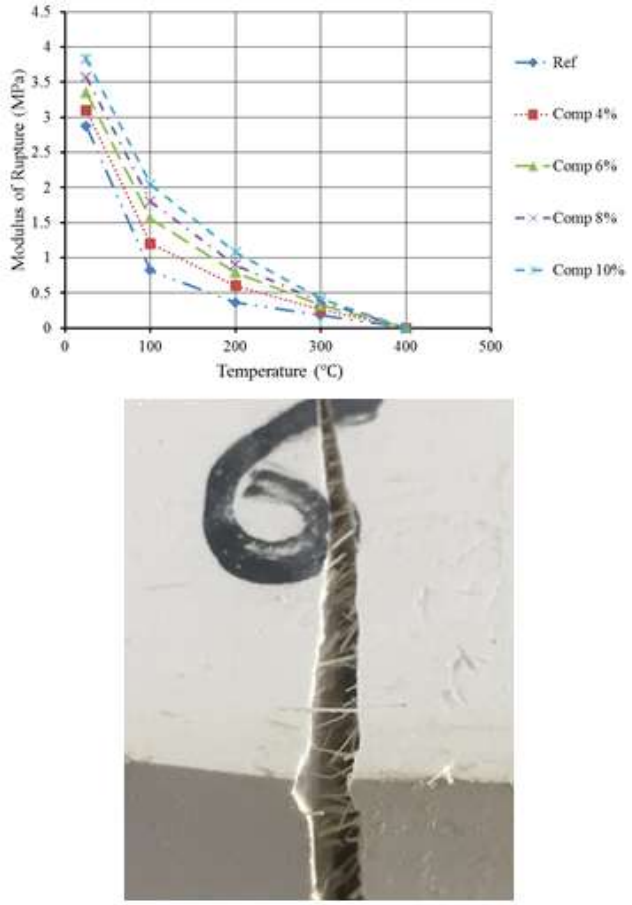


Fig. 3: Effects of Sisal Fiber Proportion and Temperature on Modulus of Rupture.

At the ambient temperature (~25℃), the composite resistance increased when the sisal fiber content was increased. The flexural strength increased by about 33% when a sisal fiber content of 10% was added. In contrast, the temperature had a negative effect on the flexural strength. The sample without sisal fiber (Ref0,100) lost 71% of its strength when heated at 100℃ for 2 hours. On the other hand, the composite of 10% sisal fiber (Comp 10%) lost only 46% of its strength when heated at 100℃ for 2 hours. These results demonstrate that the temperature caused thermal expansion created by internal stresses that could generate micro cracks, and the sisal fiber reinforced the matrix, preventing and restricting the generation and propagation of micro-cracks during the ultimate stresses. Therefore, flexural strength was very well improved due to the fiber participation when the internal stresses were redistributed.

At 200℃, all the composites lost a lot of their flexural strength due to the micro-cracks, without any degradation in sisal fiber strength. The main components of sisal fiber (cellulose and hemicellulose), which represent about 77 to 90 %, didn't have significant degradation below the temperature of 200 ℃ [15], while the other components (lignin and pectin) may soften before reaching 175 ℃ [13]. Moreover, the matrix (POP) protects the sisal fiber against the direct heat effect.

At 300℃, the compensation effect of micro-cracks and sisal fiber degradation significantly decreased the composite strength. Consequently, at 400 ℃ and 500 ℃, the prism composites were already deteriorated upon removal from the oven. Inside these composites, the burned sisal fibers could be easily observed.

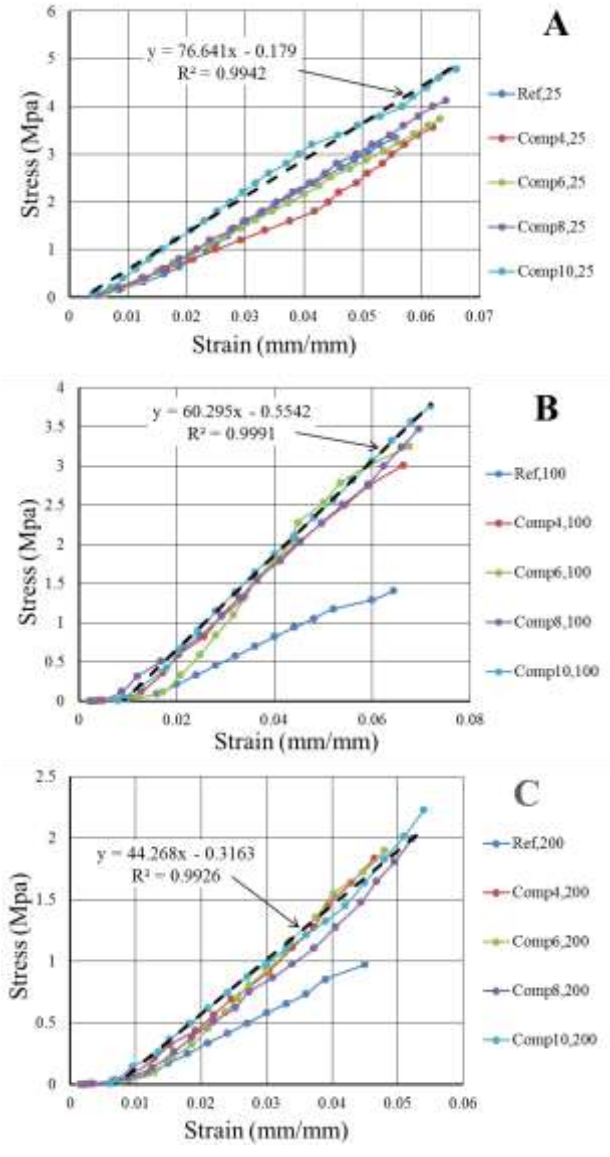
3.2.2. Effect of Sisal Fiber Proportion and Temperature on Compressive Strength

Cubic samples were dried for 28 days in order to investigate the compressive strength. They were tested by the universal machine using a load cell of (10 KN), as shown in Figure 4.



Fig. 4: Images of samples after rupture: (a) Comp 10, 25 during compressive test; (b) Ref0, 25; (c) Ref0, 500; (d) Comp 10, 100; (e) Comp 10, 200; (f) Comp 10, 300; and (g) Comp 10, 400.

Next, the effects of sisal fiber proportion and temperature on the compressive strength were investigated (Figure 5).



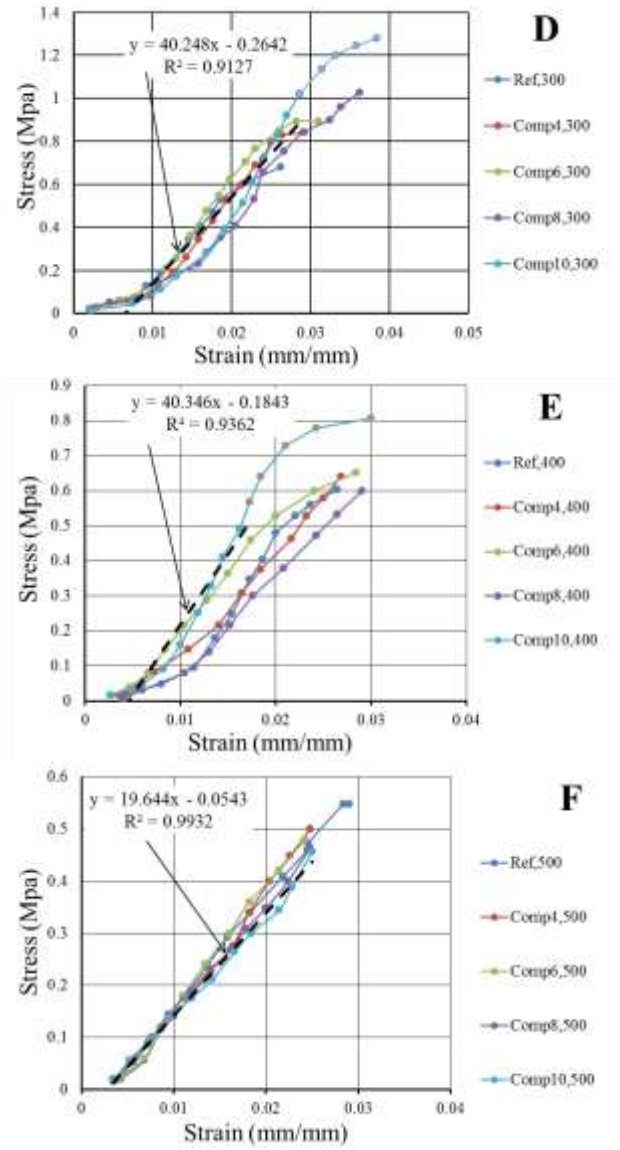


Fig. 5: Stress-Strain Diagram Affected by Sisal Fiber Proportion and Temperature Degree: (A) at ambient temperature 25℃; (B) at 100℃; (C) at 200℃; (D) at 300℃; (E) at 400℃; and (F) at 500℃.

4. Conclusion

This study was designed to determine the effects of sisal fiber content and temperature on the physical and mechanical properties of Plaster of Paris. The results indicate that by adding a sisal fiber content of 4% to POP, its density will increase due to a decrease in gas bubbles inside the matrix. If the sisal fiber proportion is increased to more than 4%, the density of the POP will then decrease. In spite of this, it's preferable to add a sisal fiber proportion of 10% to obtain the maximum mechanical properties. By doing this, the compressive strength increased by about 43%, and the flexural strength increased by about 33%, above those of the reference composites (without sisal fiber).

Interestingly, the sisal fiber proportion was limited to 10% in this study due to the fiber length (3∓1mm), which caused an agglomeration (balling) leading to non-homogeneous distribution of components. It would be possible to overcome this challenge by reducing the fiber length to shorter than (2 mm).

Sisal fiber reduced the effect of temperature on the mechanical properties of POP. The composite without sisal fiber lost about 57 % of its compressive strength and 71% of its flexural strength when heated at 100℃ for 2 hours, while the composite of 10% sisal fiber lost about 21% of its compressive strength and 46% of its flexural strength in the same condition of heating at 100℃ for 2 hours.

The evidence from these experimental results shows the importance of reinforcing Plaster of Paris with natural fiber to improve the mechanical performance, as well as to prevent the sudden failure of some decorative elements due to its weight. It would be interesting to investigate the thermal and acoustic properties of POP as well.

Acknowledgement

The authors would like to thank 1) the Ministry of Higher Education; and 2) the University of Al-Qadisiyah (Iraq) for their financial support.

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