Experimental Investigation of Utilizing the Natural Palm Tree Fibers as Thermal Insulator in Brick Industry

Ali M. Othman, Adnan I.O. Zaid

Abstract—Thermal insulation is of prime importance in saving energy both in cold and hot climate countries. In this paper, the effect of utilizing natural palm tree fibers as thermal insulator in the brick industry in general and in the Kingdom of Saudi Arabia in particular is investigated. Its weight percentage addition to the cemented brick on its thermal conductivity and resistivity, their variation with time and temperature are investigated. Furthermore, the effect of the addition on the fracture compressive strength and water absorption are also investigated. It was found that the utilization of the local available material, palm tree fibers, as an insulator in buildings for walls, roofs and windows is effective in reducing the consumption of the used electrical energy in air conditioning which increases the usage of the bricks in construction; hence it widens the use of brick industry and renders it cost effective. Finally, the obtained results are presented and discussed.

Index Terms— Experimental investigation, Thermal conductivity, Resistivity, Effect of temperature and time, Palm tree fibers, Thermal insulation, Cemented bricks, Electrical energy consumption, , Kingdom Saudi Arabia, KSA, Water absorption percent.

1 Introduction and Literature Review

The available literature reveals that thermal insulation is very essential issue in the building industry both in cold and hot climates. Utilization of the available waste materials in the enhancement of soil blocks, clay and cemented bricks has engaged the researchers for a long time to produce more robust and comfortable homes for the poorest communities in Developing Countries. A wide range of these materials such as chopped barley straw, processed waste tea, vegetal, oil palm empty fruit bunches, lechuguilla, pineapple leaves, cassava peel and hibiscus cannabinus have been investigated by many authors either as stabilizers and/or reinforcement elements to enhance the engineering properties of soil blocks and the clay and cemented bricks by many authors, [1-10]. In all these investigations, there were improvements in their engineering properties. This caused more interest to researchers in further investigating the use of the available naturals fibres an attractive alternative materials to the synthetic materials because in addition to their low coststructural benefits they also have economic, environmental and social significance when used in buildings as they present diverse markets for farmers, minimizes the volume, weight of the structure and reduces the emission of carbon dioxide.

Thou the moisture uptake of natural fibres is high [10], the use of the fibres has generated much interest due to their low cost, low density, lo biodegrad-ability, renewability and abundance [11]. [3,4]. Natural fibers offer an attractive alternative to many synthetic building materials. Utilizing the natural fibers in buildings

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An experimental comparison between specimens without and with fibers was conducted, the results showed an improvement in post-crack flexural behavior and toughness of the fiber-reinforced specimens compared to the unreinforced ones. Depending on fiber content, specimens exhibited either a deflection softening or deflection hardening behavior during testing [1].

The effect of aspect ratio (25-125) of agricultural waste (coconut husk, bagasse and oil palm fruit) used as stabilizing materials in the production of soil blocks on the mechanical properties of soil blocks. Experimental results that blocks with coconut and oil palm fibres showed increasing strength with increase aspect ratio, while bagasse fibres showed an initial increase followed by a decline at higher aspect ratio. The study concludes that generally longer aspect ratios produce better mechanical properties of soil blocks. [2]

The Banana-Compressed Earth Block (B-CEB) consists of ordinary CEB ingredients plus banana fibers, is used in different applications in construction and building materials in order to enhance the mechanical properties of the CEBs, studies were conducted on the classic CEB with no fibers and B-CEB were performed, including an axial compression test and flexural test. From the experimental work, it is concluded that the blocks constructed by adding banana fibers (B-CEB) throughout the mix performed better than the block with no fibers (CEB) in both compressive and flexural strength. [3].

Manny materials, which found applications in engineering like local vegetable fibers (Hibiscus cannabins) and earth composites are one of the promising materials. The results showed that fibers which have been used in the fabrication of Pressed Adobe Blocks (PABs), with the addition with 0.2–0.6 wt. % of 30 mm long fibers reduced the dimensions of the pores in the PABs with the improvement of their mechanical properties. However, the addition of 0.8 wt. % of 60 mm fibers had negative effects on the compressive strength. [4]

Laboratory experiments to investigate theproperties of soil blocks stabilized with fibres from agricultural waste. including density, water absorption, shrinkage, compressive strength, tensile strength, wearing and erosion were conducted on soil blocks made with two soil types and enhanced with three fibre types at 0.25–1 wt.%. It was found that the physical, mechanical and durability properties of the blocks were generally improved and a recommendation of 0.5 wt. % fibre content and high clayey soil are made [6]. Manufactured bricks from cohesive soil, flax, hemp, gypsum and cement because the fibers of their positive impact on the thermal properties of earth building materials and the mineral binders because of their strength properties. The test results of such bricks indicated that the compressive strength is highly dependent on the density of the bricks. The fibers hemp and flax have rather low impact on the compressive strength of earth bricks, but they have strong influence on the breaking behavior. [7]. The mechanical and physical properties of compressed earth block (CEB) stabilized with quicklime and filled with date palm fibers were investigated. The fibers have been chemically treated using an alkaline solution to enhance the fiber/matrix bonding consequently increases the mechanical strength. The investigation results indicated that, the strengths values of CEB filled with alkali treated fibers is slightly greater than that with untreated fibers. The research findings show that the use of date palm fibers lead to a reduction in thermal conductivity and bulk density and increases the capillary absorption of the blocks. An adverse effect on thermal conductivity of CEB with alkali treated date palm fibers was observed, [8]. The water absorption and effect of humidity on thermal conductivity and density of binder less board of date palm fibers (DPF) mesh and a composite based on mortar reinforced with different percentage of DPF mesh varying from 0% to 51% experimentally investigated and the obtained results showed that the thermal conductivity and density of binder less board and composite increase significantly with volumetric water content. The incorporation of DPF mesh in the mortar has a positive effect, regardless of the water content of the composite, as it lowers its density (lightening effect) and decreases its thermal conductivity (insulation effect) owing to the increase of its total porosity. [9]

Thermal conductivity measurements were performed to compare the thermal behavior of Ferro cement panel walls filled with coconut fibre to other typical building materials. The measurements shows that the thermal conductivity of this panel wall is lower than typical materials used for home-buildings [10]

2. Materials, Equipment Experimental Procedures

2.1. Materials

The following materials were used in this paper: palm fibers, desert sand, Portland cement and ordinary water

2.2, EQUIPMENT AND EXPERIMENTAL PROCEDURES

2,2.1. Preparation of the brick specimens

The used palm fibers were cleaned from impurities, washed by worm water, dried in an electric oven at 50 ºC for 24 hours, then ground to small uniform pieces which were mixed with different percentages of sand and cement with the percentages indicated in Table 1. Finally, water is added to the mixture, agitated strongly, placed in wooden boxes of the dimensions 100x100x50 mm, pressed and left to dry in the sun and air for one week. During this period they were sprayed with water twice a day as specified by the brick manufacturers of bricks in the Kingdom of Saudi Arabia, KSA.

Table 1: The prepared bricks mixtures and their corresponding percentages

Sample NO.	Material Percentage
7	0 % palm fiber , 70 % Sand , 30 % Cement
8	0 % palm fiber , 70 % Sand , 30 % Cement
9	2.5% palm fiber , 68.25 % Sand , 29.25 % Cement
10	5% palm fiber , 66.5 % Sand , 28.5 % Cement
11	7.5% palm fiber , 64.75 % Sand , 27.75 % Cement
12	10% palm fiber , 63 % Sand , 27 % Cement

2.2.2. Testing of the produced bricks

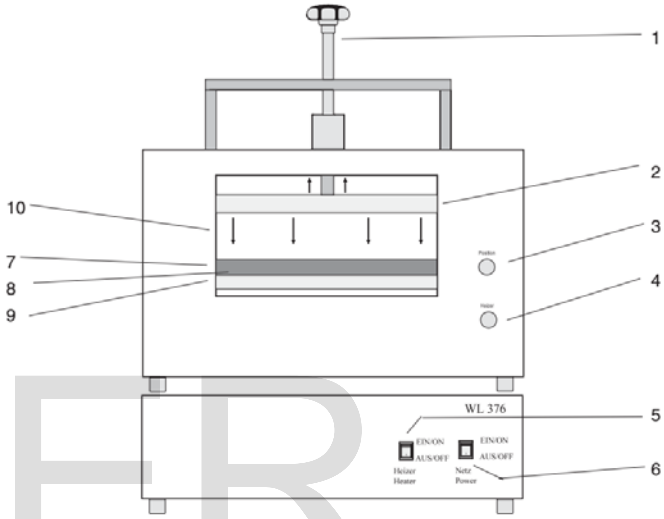
Three types of tests were carried out:

(i). Uniaxial compression tests: these tests were carried out on the Universal Testing machine of 50 KN capacity, at 10 mm / minute cross head speed, having an accuracy of 0.5 %. The tests were continued until the specimen cracks, indicating failure. The autographic record is obtained from which the fracture compressive strength is determined. Some of the cracked specimens are shown in the photograph of Fig. 1.

Fig. 1: Photograph showing some of the cracked, fractured, specimens

(ii). The water absorption tests

This test was carried out on the produced specimens to determine the effect of the palm fibers percentage on the water absorption as follows: the dried specimen was cleaned by wiping its surface with a wet cloth with warm water then



immersed in water at 27°C for 24 hours, removed and dried with a clean cloth and weighed again, m2. The water absorption capacity, w, is determined from: $w = \{(m2 - m1) / m1\} X100 \%$

(iii). Thermal conductivity tests

These thermal conductivity of the manufactured bricks was determined using the Gunt device WL 376 shown in Fig.2. The unit is specially designed for building and insulation materials that do not conduct electricity and have low thermal conductivity. The thermal conductivity was determined by the steady-state techniques, i.e. the measurements were taken when the temperature of the material reached steady state condition and does not change with time in accordance with the International Standards, ISO8301.

1- Pressing spindle

2 - Hot plate

3 - Pressing pressure control lamp

4 - Heater control lamp

5 - Mains switch ON/OFF

6 - Heater ON/OFF

7 - Cold plate

8 - Heat flow sensor

9 - Cooler

10 - Chamber for specimens

Fig.2: Thermal conductivity measuring apparatus

It should be noted that the rear unit has main supply, PC interface and cooling water inlet and outlet. The unit is also equipped with PC data acquisition for the control, regulation and automatic registration of the measured values which allowed convenience in their evaluation. The heating temperature was set in the range of 40-80°C and the cooling temperature in the range of 10-40°C. The time taken to reach the steady state condition ranged from one to two hours and some times more depending on the weight of the specimen. In this work it took six hours for the heaviest specimen to reach the steady state condition.

3. Theoretical Considerations

The thermal conductivity and thermal resistance through a flat wall made of single or multiple layers can be determined from the following equations in accordance with Fourier's and Ohm`s Law:

<u>i). for a single flat layer wall:</u>

$$q = -k.A.\frac{\Delta T}{\Delta x} \quad (1)$$

$$R = \frac{\Delta T}{q} \quad (2)$$

ii). **<u>Through a flat wall with multiple layers</u>**

$$q = \frac{A.\Delta T}{\frac{\Delta x1}{k1}+\frac{\Delta x2}{k2}+\frac{\Delta x3}{k3}} \quad (3)$$

$$R = \left(\frac{\Delta x1}{k1} + \frac{\Delta x2}{k2} + \frac{\Delta x3}{k3}\right) \cdot \frac{1}{A} \tag{4}$$

Where, q : is the heat flow,

k, $k_{1,2,3}$: is the thermal conductivities , W/m ºK,

A : is the specimen area, m^2

Δ x, Δx, $_{1, 2, 3}$ is the wall thickness, m

ΔT : is the temperature difference through the wall , ºC or ºK,

R : is thermal resistance K/ W

4. Results and Discussion

4.1. Effect of the palm fibers percent on the fracture stress

The effect of the palm fibers on the compressive fracture stress is shown in Table 2, from which it can be seen that the palm fibers have adverse effect on the compressive strength e.g. the highest compressive fracture stress is for the brick which has no palm fibers. Furthermore, as palm fiber percentage increases in the brick the reduction in the fracture stress increases as explicitly shown in the results in Table 2.

Table 2: **Effect of the palm fibers percent on the fracture stress**

Percent of palm Fiber (%)	STRESS (N / mm^2)
0	7.6
0	8.82
2.5	4.646
5	2.7
7.5	2
10	1.14

4.2. Water absorption

These tests were carried out to determine the water absorption capacity of the manufactured bricks. The samples used in these tests are the same which were used for determining the thermal conductivity. Six specimens were used and the obtained results are shown in Table 3, It can be seen from these results that as the fiber percentage increases in the brick its capability to absorb water increases. This is attributed to the presence of porosity and voids within the brick which is caused by the fibers addition.

Table 3. Effect of palm fibers percentage on water absorption

Sample	Fibers %	M1	M2	W%
1	0 %	6.1	6.5	6.56
2	0 %	6.1	6.4	4.92
3	2.5 %	5.3	5.8	9.43
4	5 %	4.9	5.6	14.29
5	7.5 %	4.8	5.5	14.58
6	10 %	4.2	5.2	23.81

3 Results and Discussion

In this section the obtained results are presented and discussed which include:

i).Variation of thermal conductivity, λ, with time.

ii). Variation of thermal resistance with time.

iii). Variation of hot plate temperatures, both measured and reset, with time.

iv) Variation of thermal conductivity, λ, with temperature.

V). Effect of the reinforcement fibers weight percentage on the compressive fracture strength of bricks.

vi). Effect of the reinforcement fibers weight percentage on the water absorption percent of bricks.

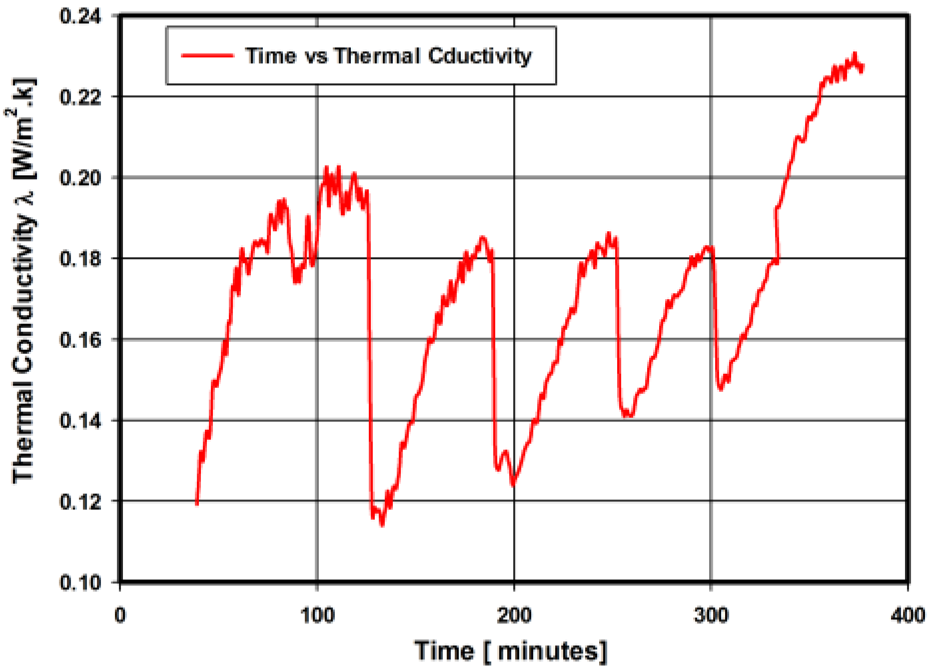
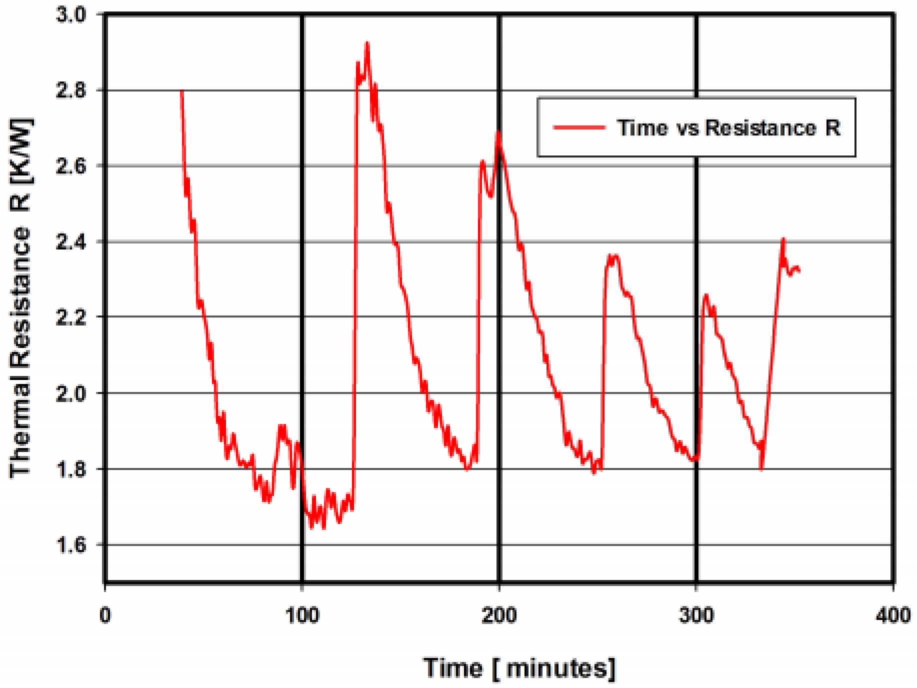


Fig. 3: Variation of thermal conductivity with time



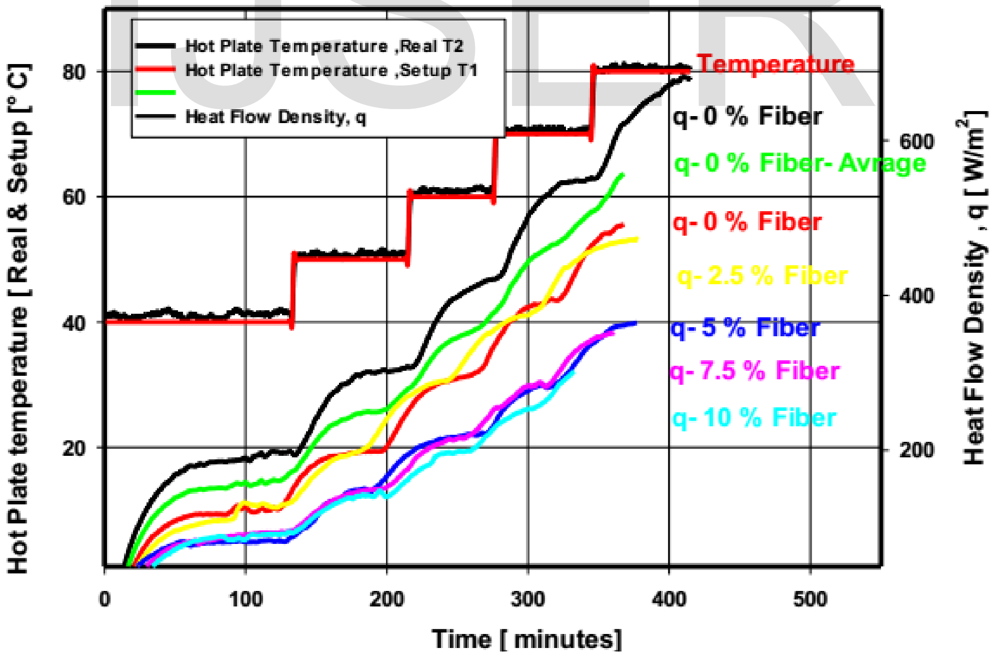


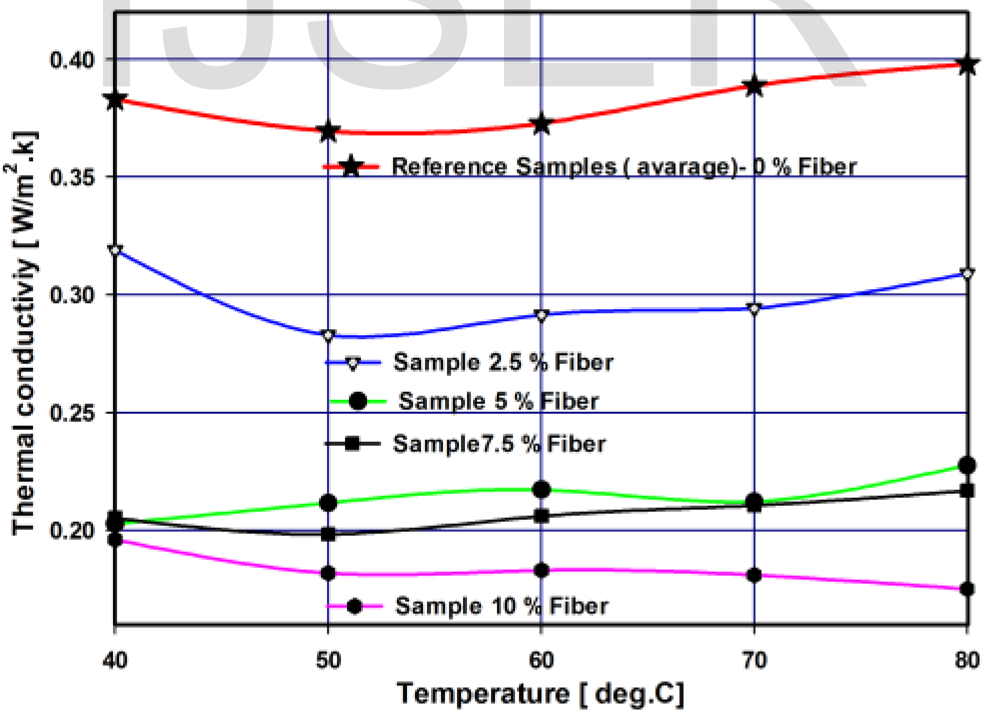
Fig. 4: Variation of thermal resistance with time

Fig. 5:Variation of hot plate temperatures, both measured and reset, with time.

The used device is the thermal conductivity device for building materials, which is used for low thermal conductivities. The thermal conductivity of each specimen was measured five times at different temperatures at increasing increments of 10°C; namely: 40, 50, 60, 70 and 80 °C. The time required to reach the steady state condition for each specimen was about five hours. **Figures (4.1 & 4.2)** show the relationship between the time required to reach the steady state condition, which is the needed time for measuring the thermal conductivity (λ) and thermal resistance (R). Figures shows the time requir thermal resistance (R). It is also seen that the values of the thermal conductivity (λ) and thermal resistance (R) rapidly changed when the setup temperature is changed to higher values, this can be explained by knowing that the most of heat flowing from heater goes directly to the plate rather than to the specimen and after certain time it flows the cold plate through the specimen.

Fig.3 shows the step change in setup temperatures and the actual temperature of hot plate and the change of corresponding heat flow during the experiments of determination of thermal conductivity of samples, The figure shows the increase of heat flow with time and setup temperature.

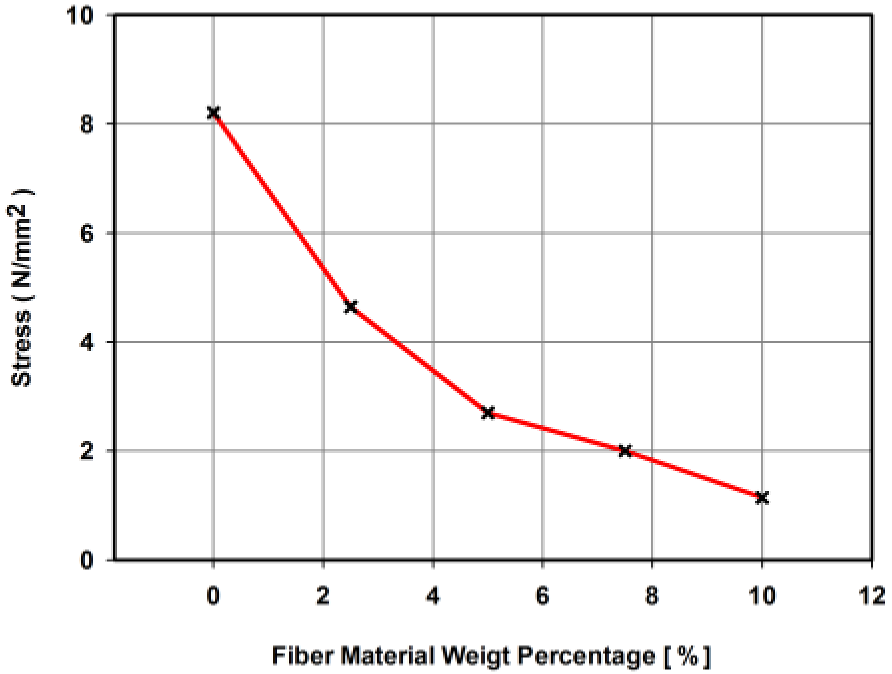
Fig.4 shows the results for specimens of building bricks with different percentages of palms fibers. These λ values are within the range 0.1 W/m.K to 0.4 W/mK over the mean temperature range from 40°C to 80°C.which is normally used for thermal building insulation. It can be concluded from Fig.4 that the addition of palms fiber decreases the thermal conductivity of the samples and there is an improvement in the thermal properties of the bricks. Also it is seen that there is little change due to temperature difference.



Effect of reinforcement fibres percentages on fracture compressive strength of clay bricks

Fig.5: Effect of palm fibers weight percentage on the compressive fracture stress of clay bricks

Fig.5 shows the effect of palm fibers weight Percentage on the compressive fracture stress of specimens 7, 8 , 9 , 10 , 11 , and 12. It can be seen from this figure that as the palm fibers weight percentage increases the crack initiation starts earlier i.e. at lower stress level. However complete fracture of all the specimens including the palm fibers did not take place. This



indicates that the palm fibers arrests the crack propagation as illustrated in the photographs of Fig.1. Hence it can be concluded that in design of structures addition of palm fibres can stop the complete collapse of the structure but do not strengthen it, i.e. makes it more vulnerable.

Fig. 6 shows the effect of palm fibers weight percentage on the water absorption of the bricks for specimens 1, 2 , 3 , 4 , 5 and 6. It can be seen from this figure that the increase of the fibers weight % in the brick caused increase of the water absorption % of the bricks. This is expected because the palm fibers absorb more water than the cemented bricks material due the existence of the porosity among the fibers. This introduces an extra advantage for the addition of palm fibers to cemented bricks

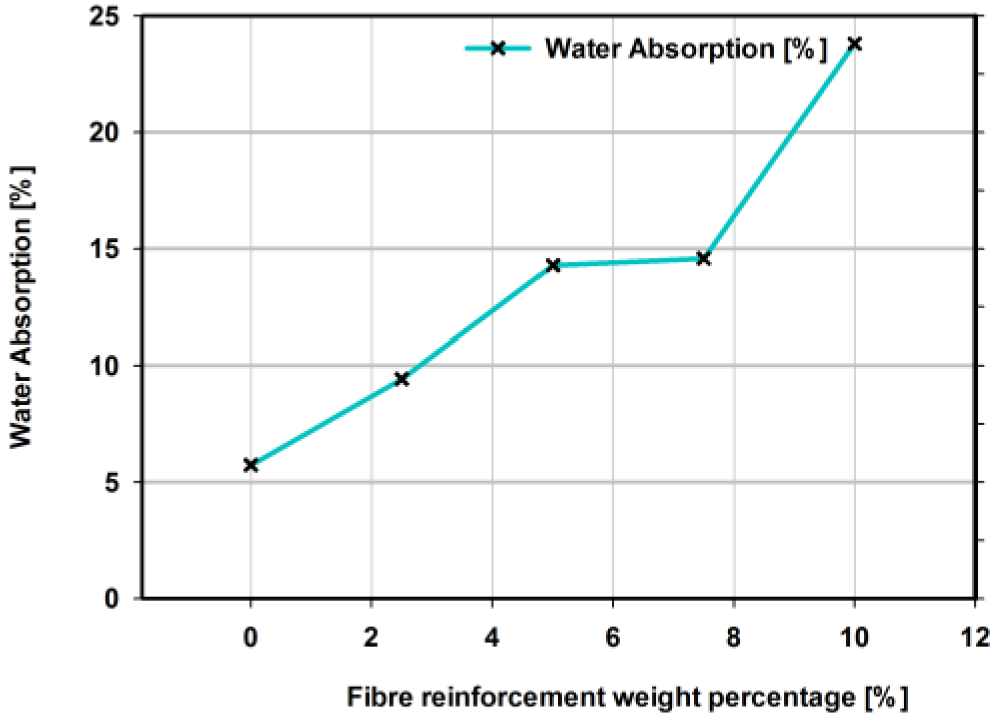


Fig.6. Effect of the fibre reinforcement weight % on the water absorption % of bricks

The insulation materials are usually subjected to different temperatures during their service lives. In this research work the thermal conductivity of each spacemen was measured over the temperature range from 40°C to 80°C as shown in figure (4.4 & 4.5). It can be observed from this figure that for most of the samples their thermal conductivities (λ) have small changes with temperature variation. However, it was found that both thermal conductivity and thermal resistance showed appreciable variation with time as illustrated in Figs.1 and 2.

ed for each setup temperature to reach the steady state value of the thermal conductivity (λ) and

4 Conclusions

The main objective of this research wok is to investigate the possibility of utilizing the local available material namely the palm tree parts e.g. the fibers and seeds as thermal insulators in the brick industry in KSA. This necessitated the investigation of the variation of thermal conductivity with time and temperature. This parameter was measured at different temperatures and time together with other important parameters e.g. thermal resistivity, effect of the weight percentage of the palm fibers addition on water absorption and the fracture compressive strength of the tested brick specimens, from which the following points are concluded:

1. The thermal conductivity was successfully determined for all the tested samples using the International Standards for steady-state measurement, ISO8301.
2. Within the experimental limitations, the thermal conductivity did not show any appreciable variation within the investigated temperature. range, between…….and………oC.
3. Both the heat flow density and the hot plate temperature showed increase with increase of time, whereas the cold plate temperature and the cooling water temperature did not show any practical variation with time and remained almost constant.
4. Increasing the addition of weight % of palm fibers resulted in earlier initiation of the crack in the brick specimen, at lower stress level during the compression test which resulted in decrease of the compressive strength. However, complete fracture of the specimen and the fibers did not take place. This indicates that the palm fibers arrests the crack propagation.
5. Increasing the addition of weight % of palm fibers resulted in increase of the water absorption of the bricks, the increase of fibers content of the brick increases the water absorption % of the brick.

On the whole, it can be concluded that utilization of the local available material, palm tree fibers, as an insulator in buildings for walls, roofs and windows is of prime importance as it plays a major role in reducing the consumption of the used electrical energy in air conditioning in KSA and other hot countries.

Figure 6 and Table (3.2) of **samples (1 , 2 , 3 , 4 , 5 , and 6)** shows the effect of Palm Fiber Percentage on the water absorption of the bricks, it is seen from the figure that the increase of fiber content of the brick increases the water absorption of the brick. The palms fiber absorbs more water than bricks materials

Together with the other tested palms specimens in this research work have a good potential in utilizing them as thermal insulators in buildings and reduces of walls weight but they can increase the water absorption which made the bricks suitable in hot climate countries as KSA .

The insulation materials are usually subjected to different temperatures during their service lives. In this research work the thermal conductivity of each spacemen was measured over the temperature range from 40°C to 80°C as shown in figure (4.4 & 4.5). It can be observed from this figure that for most of the samples their thermal conductivities (λ) have small changes with temperature variation. However, it was found that both thermal conductivity and thermal resistance showed appreciable variation with time as illustrated in Figs. (4.1 & 4.2).

3.1 Conclusions

The main objective of this research wok is to investigate the possibility of utilization of the local available material namely the palm tree parts e.g. The fibers, seeds as thermal insulators in the clay brick industry. The main parameter for this purpose is the thermal conductivity. This parameter was determined at different temperatures and time together with other important parameters e.g. density, thermal resistivity. Water absorption and compressive strength are also studied in this research work.

The following points are concluded.

The thermal conductivity was successfully determined for all the above mentioned samples using the International Standards for steady-state measurement, ISO8301.

For most of the tested material within the experimental limitations, the thermal conductivity did not show any appreciable variation with temperature changes.

Both the heat flow density and hot plate temperature showed increase with increase of time, whereas the cold plate temperature and the cooling water temperature did not show any practical variation with time and remained almost constant.

Utilization of the local available materials as insulators in buildings for walls roofs and windows is of prime importance as it plays a major role in reducing the consumption of electrical energy used for air conditioning.

Palm fiber increases the water absorption of the bricks, the increase of fiber content of the brick increases the water absorption of the brick.

It can be seen from compression strength test that as the palm fiber percentage increases the crack initiation starts earlier i.e. at lower stress level. However complete fracture of all the specimens including the palm fibers did not take place. This indicates that the palm fibers arrests the crack propagation.

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