Discovering and Manufacturing a New Natural Insulating Material Extracted From a Plant Growing Up in Saudi Arabia

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ABSTRACT

Insulating materials are very important in our daily life. They are used in building walls, refrigerators, some electrical devices, in insulating the electrical cables and in many other applications. This study presents experimental work done to determine the thermal conductivity of a new insulating natural material. This new material is extracted and developed from a plant, which grows in the desert areas of Saudi Arabia. Experimental results show that their thermal conductivity is comparable to that of the Rockwool mineral fiber. The thermal conductivity of the new material is measured for some samples with different densities. Other samples are made in the form of boards with different thicknesses using resins such as Phenol-Formaldehyde or cornstarch solution (Formaldehyde free). The thermal conductivity test is conducted at various mean temperatures from 10 to 90 ^{o}C and compared to that of the Rockwool material of similar density. The advantage of using such natural insulating materials with cornstarch as a binder is that they are not hazardous to human beings.

Keywords: Thermal conductivity, Insulating material, Calotropis procera, Phenol-Formaldehyde resin, Cornstarch, Formaldehyde free binder, Insulating board.

INTRODUCTION

In this study, a new natural material extracted from the seedpods of a plant (scientific name: Calotropis procera) can be used as an insulating material. The native living range of this plant covers southwest of Asia and Africa. It occurs also on the Caribbean islands, in Central and South America and has been introduced to South Africa. Calotropis procera is assumed to be an environmental invasive and it is commonly harvested for its medicinal properties. The advantages of using this insulating material are relative safety for human beings, not absorbing water, and having low thermal conductivity.

Calotropis procera has different other names such as: Giant milkweed, Sodom apple, French cotton, small crown flower (English), algodon de seda, bomba (Spanish), cotton-france, arbre de soie, and bois canon (French) (Howard [1], Liogier [2], Neal [3], Parrotta [4]). It is also known as Ashir or Ishir in Arabic. This plant is a soft-wooded, evergreen, perennial shrub. It has one or few stems, few branches, and relatively few leaves, mostly concentrated near the growing tip (Francis [5]) as seen in *Figure 1*. The bark is corky, furrowed, and light grey. A copious white sap flows

FIGURE 1. The Calotropis procera tree could be a short tree or as long as about 5 m.

whenever the stems or leaves are cut. This plant has a very deep, stout taproot with a few or no near-surface lateral roots. Their roots are found to have few branches and reach depths of 1.7 to 3.0 m in the Indian sandy desert soils (Sharma [6]). The plant's leaves are 7 to 18 cm long and 5 to 13 cm broad, slightly leathery, and have a fine coat of soft hairs that rub off. The flower clusters are umbelliform cymes that grow at or near the end of twigs. The flowers are shallowly campanulate with five sepals that are 4 to 5 mm long, fleshy and variable in color from white to pink, often spotted or tinged with purple (Francis[5]) as seen in *Figure 2*.

FIGURE 2. Different colors of the Calotropis procera tree's flowers could be pink or white and blue.

The fruits are inflated obliquely ovoid follicles that split and invert when mature to release flat, brown seeds with a tuft of white hairs at one end (Howard [1], Liogier [2], Little et. al [7]). *Figure 3* shows a seedpod (fruit) and *Figure 4* shows the seedpods and their fibers. The plant grows in dry habitats (150 to 1000 mm precipitation) and sometimes in excessively drained soils in areas with as much as 2000 mm of annual precipitation. It may be found in areas up to 1000 m in elevation in India (Parrotta [4]). Its roots grow very deeply and rarely grow in soils that are shallow or over unfractured rock. Flowering and fruiting takes place throughout the year (Little et al [7]). Hundreds to thousands of seeds may be produced per plant each year. Eighty-nine percent germinations took place in potting mix between 7 and 64 days after sowing (Francis [5]). Half of the seed's weight is found in the wing (silk). The seeds are dispersed by the wind and may fly for several hundred yards in gentle breezes. Seedlings may arise in abundance after rainy periods, but only a few survive the first season. Using the reserves in its large taproot, this plant can re-sprout year after year when burned or cut. Calotropis procera usually reaches heights of about 2 m, but may occasionally reach 5 m in height and a stem diameter of 25 cm (Little et al [7]). Establishing Calotropis procera has been advocated for environmental protection and as a nurse crop for more valuable species (Campolucci and Paolini [8]). This can be done easily by planting containerized seedlings or rooted cuttings. Calotropis procera tissues, especially the root bark, are used to treat a variety of illness including leprosy, fever, menorrhagia, malaria, and snakebites (Parrotta [4]). The latex is toxic and can cause blisters and rashes in sensitive persons. This plant is easy to propagate and manage, it is also recommended as a host plant for butterflies (Mikula [9]). In the past, the silky hairs were used to stuff pillows (Little et al. [7]). In addition to that, it was tested as a host for sandalwood and a partial root parasite. It resulted in greater growth of sandalwood than all other species tested (Shinde et al [10]). Although it is lightweight, the wood is used in impoverished desert areas for cooking fuel (Varshney and Bhoi [11]). The literature survey mentioned above has showed that the fiber material developed from the seedpods of this plant is never tested for its use as an insulating material, which motivates the current discovery. In addition to that, those plants are grown and spread all over the desert area of Saudi Arabia since it needs only a little amount of water. It should be mentioned that, these fibers and similar fibers can be mixed with plaster to absorb sound (Bamberger [12]). These fibers or similar ones are also used for surgical wadding by Benedek [13]. This material can be collected from the seedpods of the Calotropis procera, which grows up in the Kingdom. In this study, samples of such materials are collected in order to measure their thermal conductivity at different temperatures and densities. Accurate measurements of the thermal conductivity are made and compared to other known insulating materials. Therefore, some insulating boards of different thickness are manufactured out of these materials using some resins.

EXTRACTING AND PREPARING THE FIBER

In order to get this material, a good amount of the seedpods at their mature times is collected as seen in *Figure 3*. These (seedpods) fruit are of grey-green color, inflated, 8 to 12 cm long, containing numerous seeds (*Figure 3*) with tufts of long silky hairs at one end (*Figure 4*). These seeds must be separated from the silky hairs then the silky hairs alone are the ones to be collected.

FIGURE 3. The seedpod showing the brown seeds hugging the fibers.

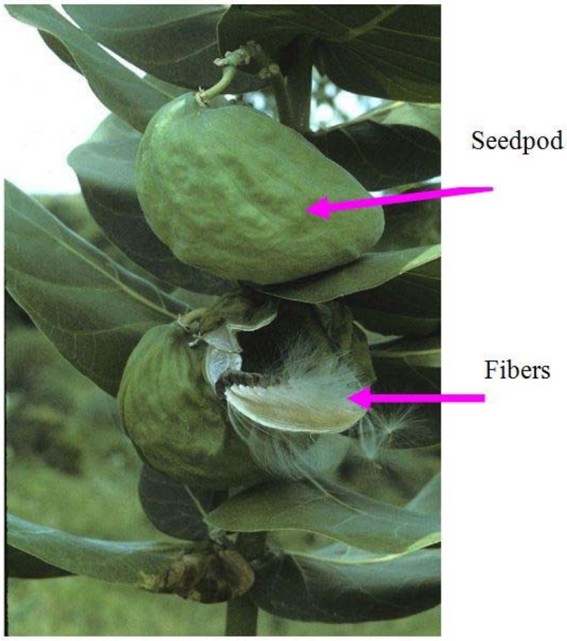

FIGURE 4. The fibers and the seed pod.

Phenol-Formaldehyde Resin

The second phase is to make some boards out of these insulating materials using Phenol-Formaldehyde resin as a binder. In the first sample, 196 grams of the dry fibers are used and saturated in Phenol-Formaldehyde resin (Product: Bakelite Resin 0421 M). The characteristics of the resin are given in *Table I*. Then the fiber is compressed to a thickness of 0.0235 m in a compressed box of size 0.3 x 0.3 m^2 and then put in a 100^{o}C oven to obtain a complete dry board as seen in *Figure 5*.

TABLE I. Characteristics of the used Phenol Formaldehyde resin.

Characteristic	Lower Limit	Upper Limit	Value	Unit
Total solid 3g/1h/135°C/7 5 mm Schalchen	51	53	51.2	%
Water dilutability DIN 16916	250	250	250	
PH- value DIN ISO 8975	8.4	8.6	8.5	
Content of free phenol DIN 16916-02-L1	1.1	1.5	1.37	%
Content of free formaldehyde DIN 16916	5	7	6.5	%
Specific gravity at 20°C DIN 51757	1.165	1.175	1.168	g/cm^3

FIGURE 5. Insulating material board using the Phenol - Formaldehyde resin (0.3 x 0.3 x 0.0235 m)

The mass of the dried sample is found to be 227 g, which increased by 31 g. These 31 grams representing the mass of the polymerized resin in the sample. The measured density of the sample shown in *Figure 5* is 107.17 kg/m^3. The averaged maximum non-fibrous (shot) content of dry fiber products is 15.82% which in the range of ASTM [14]. Another sample is prepared using a density of 117.44 kg/m^3 with a resin ratio of 43.83% as shown in *Figure 6.*

FIGURE 6. Insulating material board using the Phenol-Formaldehyde resin (0.283 x 0.283 x 0.02477 m).

Corn Starch Resin (Formaldehyde free)

In 2004, the World Health Organization's International Agency for Research on Cancer (IARC) changed the classification of Formaldehyde from Group 2A 'probable carcinogen' to Group 1 'known carcinogen' [15]. Therefore, in this case an organic material such as cornstarch (Formaldehyde free) resin is used as a binder for the fiber insulating boards. In the first sample, 151 grams of dry fibers are used and saturated in a cornstarch resin. In this experiment, 403 grams of cornstarch are used to make the resin solution and the developed dried board is shown in *Figure 7*.

FIGURE 7. Insulating material board using Corn Starch resin (0.28 x 0.28 x 0.02113 m^3) with density of 265.63 kg/m^3.

The density of the developed board in this experiment is 265.63 kg/m^3. The averaged maximum non-fibrous (shot) content of the dry fiber products are estimated to be 191.4% of the original dry fiber. A second sample board is prepared using a cornstarch as a binder with a density of 130.47 kg/m^3 and with a resin ratio of 30.73% of the original used fiber as seen in *Figure 8*, which is almost compatible with ASTM standards [14].

FIGURE 8. Insulating material board using cornstarch resin (0.30 x 0.29 x 0.020615 m^3) with density of 130.47 kg/m^3.

THERMAL CONDUCTIVITY MEASURMENT

The thermal conductivity of various boards, defined earlier, is measured using the state-of-the-Art Heat Flow Meter (HFM 436/3/1 Lambda) instrument manufactured and provided by NETZSCH-Gerätebau Gmbh. *Figure 9* shows a schematic of the instrument where the sample is placed between two heated plates, set at different temperatures. A calibrated heat flux transducer measures the heat flow q through the sample. After reaching a thermal equilibrium, the test is done. Only the sample center (100x 100 mm) is used for the analysis. The heat flux transducer output is calibrated with the standard. The magnitude of the heat flow q depends on the thermal conductivity of the sample k, thickness of the sample Δx, temperature difference across the sample ΔT and the area through which the heat flows A. Fourier's law of conduction gives the relation between these parameters:

$$Q = k A \frac{\Delta T}{\Delta x} \tag{1}$$

One or two heat flow transducers (as provided by the manufacturer) measure the heat flow through the sample as seen in *Figure 9*. The signal of a heat flow transducer (in volt) is proportional to the heat flow through the transducer. In the HFM 436 Heat Flow Meter instrument, the area of the heat flow transducer represents the area through which the heat flows and is the same for all samples; therefore:

$$Q = N V \tag{2}$$

Where N is the calibration factor that relates the voltage signal of the heat flow transducer to the heat flux through the sample. Solving Eqs. (1) and (2) for k we derive the thermal conductivity [16]:

$$k = \frac{N V}{A} \frac{\Delta x}{\Delta T} \tag{3}$$

As provided by the manufacturer, the heat flow meter method is a standardized test technique for measuring the thermal conductivity of insulating materials following the standards ISO 8301, ASTM C518, DIN EN 12667/12939 and DIN EN 13163 respectively. The insulation sample size to be used by the instrument is 300x 300 mm with a thickness between 5 to 100 mm. It should be noted that, the instrument is equipped with a transducer to read the thickness of the sample in cm and up to four decimals accuracy. The error in reading the thickness of the sample is ± 0.0001cm, in measuring the average temperature is ± 0.01 °C and in measuring the thermal conductivity is ± 0.000001 W/mK as provided by the manufacturer. The standard deviation of the thermal conductivity is 0.00004 as specified by the software of the instrument. The error in measuring the mass and the volume of the insulating boards is ± 0.001 kg and ±7.6 x 10^{-6} m^3, respectively. These errors lead to uncertainty in determining the density of 1.44 % at most.

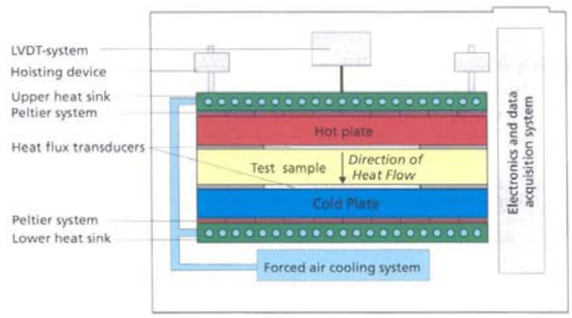

FIGURE 9. Measuring principle of heat flow meter [16].

ROCKWOOL FIBERS CHARACTERISTICS

As provided by the Saudi Rockwool Factory [17], the Rockwool board is made from Rockwool fibers, bonded by a thermosetting binder to acquire rectangular shape boards according to ASTM C-612 and faced with aluminum foil. The following technical properties are also provided: thermal conductivity range from 0.035 to 0.042 W/mK, temperature range – 40 to 750 ^{o}C, none-combustible and non-corrosive material. It should be noted that the Rock (stone) wool is under Group 3 of the World Health Organization's International Agency for Research on Cancer (IARC) and therefore, it is not classifiable as to its carcinogenicity to humans [18].

RESULTS AND DISCUSSION

The thermal conductivity of the two samples shown in *Figure 5* and *Figure 6* are measured by the heat flow meter apparatus described in section 3. Those thermal conductivity measurements are shown in *Figure 10* in comparisons with that of the Rockwool boards, incorporated into resin as mentioned earlier in section 4, at density of 131.23 kg/m^3 and 122.67 kg/m^3. In addition to that, the thermal conductivity of the loose fibers is also shown for density of 26.25 kg/m^3. This figure shows that using insulating board of natural material are comparable to that of the insulating material made of Rockwool at almost the same density of order of 100 kg/m^3. It also shows that as the density of the fiber board's decreases the thermal conductivity of the insulating material decreases. Furthermore, using loose low-density fibers (26.25 kg/m^3) with no resin have a lower thermal conductivity than the ones made in a board form using Phenol-Formaldehyde resin. Moreover, this figure shows also that the thermal conductivity of this natural insulating material is temperature dependent. The percentage increase of the thermal conductivity between the minimum and maximum temperatures shown in *Figure 10* for loose fibers, for the board of ρ = 107.17 kg/m^3 and for the other board of ρ = 117.44 kg/m^3 are 35.39%, 31.59% and 29.04% respectively.

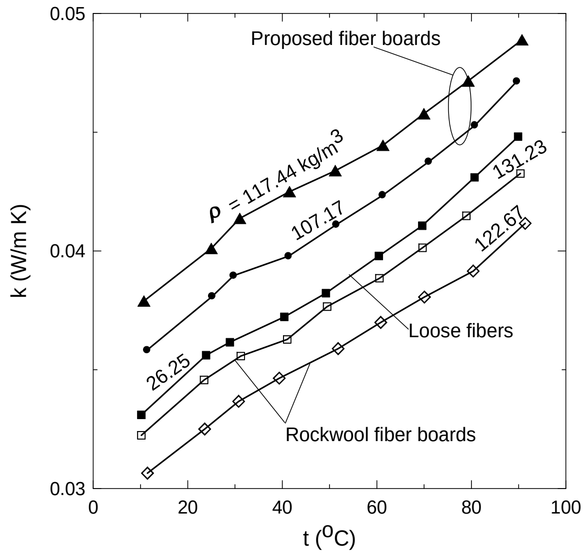

FIGURE 10. Comparison between the proposed insulating boards and that of Rockwool material using Phenol-Formaldehyde resin.

On the other hand, these percentages are obtained as 34.31% and 34.20% for the Rockwool fiberboards of densities 122.67 kg/m^3 and 131.23 kg/m^3 respectively. Therefore, using the new fibers as insulating materials is promising when used either as loose fibers or as solid boards. *Figure 11* compares the new natural loose fiber with the Rockwool loose fibers, which are not incorporated into any resin. It should be noted that different densities of the fibers are obtained since the same volume are considered for both cases and the mass of the Rockwool is heavier than the new fibers. This figure shows that the thermal conductivity for the new fiber is lower than that of the Rockwool material at the same temperature range. Furthermore, the thermal conductivity differences increase as the temperature increases. Therefore, the new fibers are promising as an insulating material when used in a loose form. Moreover, the percentage increase of the thermal conductivity between the minimum and maximum temperatures shown in *Figure 11* for loose natural fibers and for the loose Rockwool fibers are 35.39% and 49.95% respectively.

On the other hand, the thermal conductivity of the two other boards using a corn starch **(**Formaldehyde free**)** as a binder is obtained at different temperatures and presented in *Figure 12* in comparison with the Rockwool insulating material and with that given by ASTM standard [14] for mineral insulating material at density of 128 kg/m^3. The percentage increase of the thermal conductivity between the minimum and maximum temperatures shown in the *Figure 12* for the boards of ρ = 265.63 and 130.47 are 30.00%, 32.27% respectively. This figure shows also that the natural insulating board of low density (ρ = 130.47 kg/m^3) incorporated into cornstarch resin is close to the ASTM standard than the others in the same temperature range. *Figure 13* shows comparisons between the thermal conductivity of the proposed insulating boards using either the Phenol-Formaldehyde or the corn starch as resins with that of the Rockwool fiber board and that given by ASTM standard [14] for mineral insulating material at a density of 128 kg/m^3. This figure shows that both of the proposed new insulating boards are close to the ASTM standard, which gives a promising future of this new insulating material.

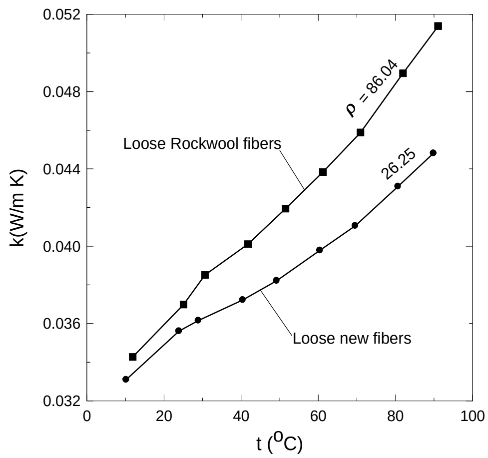

FIGURE 11. Comparison between the proposed insulating material in a loose form and that of the loose Rockwool material, which are not incorporated into resin.

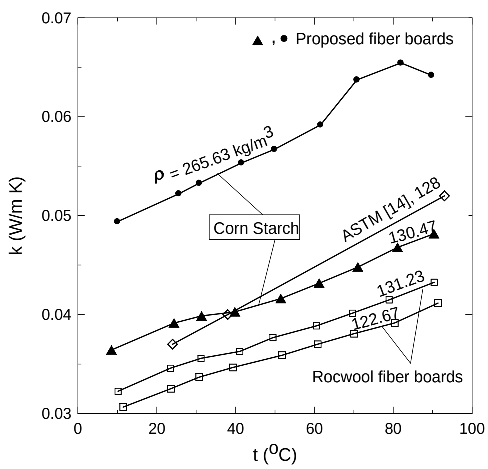

FIGURE 12. Comparison between the proposed insulating boards and that of Rockwool and ASTM [14] material using cornstarch resin.

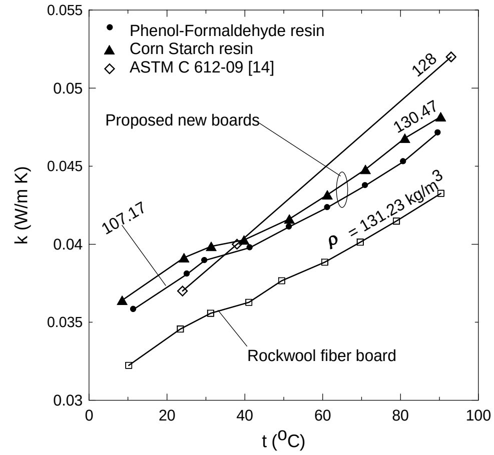

FIGURE 13. Comparison between the proposed insulating boards and that of Rockwool and ASTM [14] materials using corn starch or Phenol-Formaldehyde resins of order ≈ 100 densities.

CONCLUSIONS

New different insulating boards are manufactured using new insulating material with resins as binder for its fibers. These boards can be made using Phenol-Formaldehyde or cornstarch as resins. Results show that using cornstarch or Formaldehyde boards are comparable to that of Rockwool boards. However, using cornstarch as a binder is a promising future since it is an organic material and more safe for human beings. Results also show that the proposed boards are close to the ASTM standard than the Rockwool boards. Therefore, it is suggested that the cornstarch can be used as a resin with different concentrations to make the new boards. It is also noted that as the density decreases the thermal conductivity decreases which means an enhancement effect of the insulating boards. The ratio of the resin to the dry fiber is found to be density dependent. Finally, using this new fiber as an insulating material turns to be a promising future when used either as loose fibers or as solid boards.

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