Thermal Assessment of a New Bio-Based Insulation Material from Waste Rice

ABSTRACT

Although many advanced insulation materials have been recently developed, very few are eco-friendly, and their production requires a substantial amount of energy and complex manufacturing processes. To address this issue, a new cheap bio-insulation material with huge commercialization potential and environmental footprint is proposed. The main idea is to develop a new material, which is environmentally friendly insulation from waste rice grain. A set of experiments was subsequently carried out to identify the best rice type and the optimal range for the most influential parameters (sample amount, temperature, and moisture level). Our findings revealed that short-grained rice exhibited greater puffing ability and was thus adopted in further material optimization experiments. These assessments indicated that the most optimal thermal conductivity of the insulation material and the highest puffing ratio was attained at 12−15% moisture, 260−270 ℃ temperature, and 15−18 g sample weight.

Keywords: bio-based insulation, thermal conductivity, environmentally friendly, waste rice

1. INTRODUCTION

Buildings are the largest consumer of energy among other sectors. One of the most important challenges of future buildings is the reduction of energy consumptions in all their life phases, from construction to demolition. Global energy consumption is foreseen to be increased by 53% within the next ten years from the International Energy Agency (IEA) prediction, which is as the result of the significant increase in industrial and urban activities due to the intensive country development and dramatic increase of population size in the recent times. The United Nations Environment Program estimates that buildings consume about 40% of the world's global energy. In the UAE, buildings account for a major share of electric energy consumption. Some existing buildings in the UAE consume 220-360 kWh/m2/year [1]. Building air-conditioning and ventilation systems due to prevailing extremely hot climatic conditions use almost 80% of this energy [2]. Therefore, it is significant to search for solutions to reduce energy consumption in buildings [3].

Due to the increasing population energy consumption in the sector of building and the hard-economic situation, it is necessary to control energy during the building process. To achieve an accurate cooling/heating load calculation for buildings, an analysis of conductive heat transfer through the material is very important in energy-efficient building design. Thus, the knowledge of thermal properties and precise evaluation of the heat transfer through the envelope components, particularly thermal conductivity of material construction, are of great importance. This depends mainly on the accuracy of the thermal resistance of the different building envelope components, particularly the insulation materials. It is a layer composed of one material or combination of materials. According to its structure, Papadopoulos classified the insulation material to organic, inorganic, combined and new technology materials [4]. A new classification proposed by Li Fang categorizing the insulations into four main denominations: i) petrochemical & intermediate charcoal chemical material such as Polystyrene and Polyurethane, ii) rocks and slags: glass wool and expanded perlite, iii) metals: radiation plate and metal visor, iv) plants, which include the waste of agriculture, forest, and industrial plant fiber: cotton, corn crops, straws [5].

The implementation of appropriate effective insulation materials could contribute to lower energy consumption and decreases the usage of natural resources (petroleum/gas reserves) which are used for cooling purposes [6]. Also, it essentially contributes to the overall thermal performance of the walls [7-8] possesses the characteristic of high thermal resistance, which exhibits the capability to reduce the heat flow rate into the buildings [11] due to specific thermos-physical properties [9]. However, more consideration should be given for its negative health and environment effects [10] in both the production process and the disposal phases of end-of-life products. Industry Analysis Building Thermal Insulation Market reports that using some insulation materials (glass wool) can lead to environmental issues due to the consumption of nonrenewable materials and end-life processes [11]. Therefore, new "bio-based insulations" have been introduced as thermal insulation products made of natural materials [12-16]. The most common ones are hemp, cotton, sheep wool, flax, linen, and kenaf fibers [17].

The thermal resistance of the bio-based insulation materials is mainly lower than the non-bio insulation materials as well as their structural strength. In a hot and arid climate, the thermal insulation materials comprising the building envelope are exposed to significant and continuous temperature and moisture changes due to the variations in the external conditions, including the outdoor temperature, solar radiation, and air moisture content, which leads to the change of their thermal resistance values [18]. Indeed, the accuracy of the thermal conductivity (k) of the insulation material, which describes the ability of heat to flow across the material in the presence of a temperature gradient, has an important effect on the heat exchange between the building interior and the ambiance. For most materials, the value of thermal conductivity increases as the influencing temperature increases. Therefore, temperature-dependent thermal conductivity is an empirical relationship that is based on experimental data [19]. One of the potential problems faced by building designers when calculating the cooling loads or analyzing the energy performance of any building, is the using of published or manufactures supplied values of thermal conductivity of building insulation, which are evaluated under specific laboratory conditions at 24 °C, according to the American Society for Testing and Materials (ASTM Standards).

In reality when it comes to UAE, hot and arid climate. the thermal insulation materials comprising the building envelope are exposed to significant and continuous temperature and moisture changes through the day and over the seasons, due to the variations in the external conditions, including the outdoor temperature, solar radiation, and air moisture content, which leads to the change of their thermal conductivity values. The impact of temperature difference on the thermal conductivity of some insulation materials produced by Saudi insulation manufacturers has also been investigated [20]. In addition, the effect of operating temperature change on the thermal conductivity of polystyrene insulation material has been studied extensively by the author [18, 21] concluding that the thermal conductivity of four different density levels of polystyrene samples is affected by the operating temperature linearly. The material moisture content, on the other hand, has been considered a major factor affecting the thermal conductivity of insulation materials [22]. Many researchers reported the effect of the moisture on the heat transfer through building insulation material concluding that the higher the material moisture content, the higher the thermal conductivity [23-25]. The research aims to propose a new bio-based insulation material from grains and thermally evaluate its performance compared with the standard insulations in both dry and humid extreme temperature exposure to be suitable to deploy in hot-humid climates as of UAE.

2. METHOLOGY AND EXPERIMENT SETUP

In order to have a better understanding of the cooling performance of the new bio-based insulation material in buildings, well-designed experiments and simulations well carried out. At this stage, the standardized experimental methods have been adopted to produce a novel insulation from the grain by investigating the different types of materials to be used as insulation then applying different production process to achieve the proposed new bio-insulation. The sample of the new bio-insulation material will be test and analyze to confirm the thermo-physical properties of the proposed new bio-insulation material and compared with some available insulation material (EPS): first, the thermal conductivity measurements at standardized conditions for some of the existing insulation material have been conducted to verify their catalogue data as a reference. Secondly, the thermal conductivity values of the proposed bio-insulation material have been tested and the thermal performance of proposed new bio-insulation material and the existing insulation material have been evaluated by employing various temperatures and humidity ratios.

Prior to puffing, raw rice was soaked in water for about 12 hours to remove starch as it prevents grain expansion. Next, the rice was dried by exposing it to room temperature for 12 to 24 hours during which the moisture level was assessed using a moisture analyzer device to ensure that the desired moisture percentage was achieved, as shown in Fig. 1.

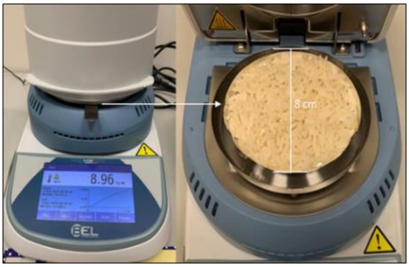

Fig. 1. Moisture analyzer device to control the moisture level of the raw material.

Once the required moisture level had been attained, rice grains were exposed to high temperature (250−270 °C) and 40 bar pressures. The apparatus used in the production of the bio-insulation samples has a small gear-shaped motor, driven by a protruding wheel, as well as a temperature and pressure controllers, as shown in Fig. 2. The adjusted mold had a circular shape of 8 cm diameter.

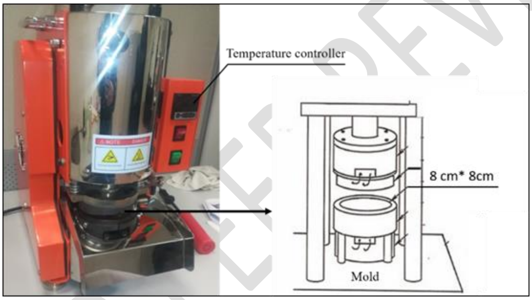

Fig. 2. Experimental setup to produce the proposed new bio-insulation material.

3. RESULTS AND DISCUSSION

3.1. Screening Study

Once the pre-soaked and dried rice grains were subjected to high temperature and pressure, sudden evaporation transformed the starch that remained inside the grains from hard to a rubbery state. When the heat and pressure were suddenly released from the mold, the grains rapidly expanded. A set of screening experiments was carried out to determine whether long- or short-grained rice was more suited for puffing and establish the optimal values of other influential parameters. One factor at a time was tested in the screening step to determine the significant factors affecting the sample thickness, sample shape, surface smoothness, and puffing ratio.

Our findings revealed that shorter grains exhibited grater puffing ability, while also yielding better results in terms of the puffing ratio, sample thickness, circular shape, and surface smoothness. Thus, in the subsequent steps, short-grained rice was used in the material optimization, aiming to improve thermal conductivity and the overall performance.

3.2. Applicable Experimental Range of Sample Weight, Temperature, and Moisture Level

As some samples burned when exposed to 280°C, while moisture ratio was too high for sufficient puffing to occur in others, or the sample shape was inconsistent due to the variations in the amount of raw material used (Fig. 3), these issues were eliminated by restricting the temperature, moisture level, and sample weight to 260−270°C, 12−16%, and 15−17 g, respectively.

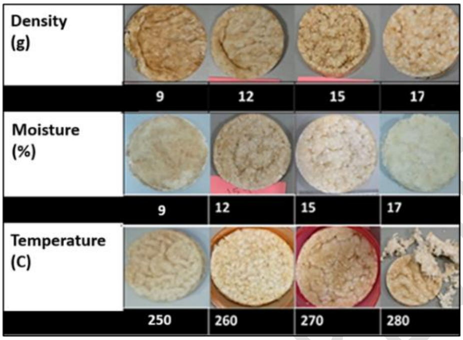

Fig. 3. The produced insulation samples with different levels of moisture, density, and temperature.

3.3. Thermal Conductivity Test

The thermal conductivity of the proposed new sample "puffed rice insulation" was tested using the thermal conductivity device Fox 200, as well as a low-density polystyrene as it is the insulation material commonly used in the UAE construction market. A dry samples of 8 cm length and 1 cm in thickness was prepared to be investigated for both specimens. The device is a multilateral instrument and well-suited to measuring slices with different thicknesses to 0.025 mm according to ASTM C518 and ISO 8301. Fox 200 has an upper and lower thermal plate to hold the sample, the centers of both plates start to generate a heat flux at the beginning of the test. The thermal conductivity tests were performed at five different mean temperatures 5, 15, 25, 35, and 45ºC. The daily average temperature ranges from 18°C in January to around 35°C in August which is covered in the used device minimum and maximum temperature rangeability for each run providing a rapid and accurate results. The thermal conductivity values measured at deferent temperatures for both insulation samples are reported in Table 2.

Table 1. The thermal conductivity values for Puffed rice insulation and polystyrene insulation samples.

Temperature [˚C]	Thermal Conductivity W/(mK)	
	Bio-insulation material	Polystyrene
5	0.04156	0.03541
15	0.04473	0.03790
25	0.04672	0.03985
35	0.04834	0.04187

The results show that, according to the thermal conductivity k-values, the newly developed bio-insulation material “puffed rice insulation” is suitable for use as insulation material, especially when compared with other commercially available alternatives, as shown in Fig. 4.

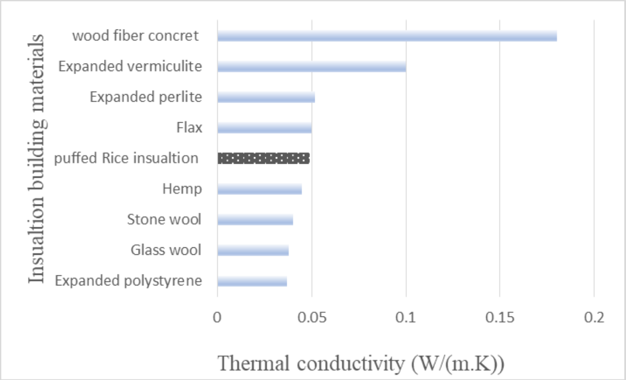

Fig. 4. Thermal conductivity comparison between building insulation materials.

4. CONCLUSION

In this research, a bio-based thermal insulation material was developed using short-grained puffed rice and was subjected to extensive tests to optimize its thermal conductivity. These assessments indicated that the most optimal thermal conductivity of the insulation material and the puffing ratio was attained at 12−15% moisture, 260−270 °C temperature, and 15−18 g sample weight. The thermal conductivity and thermal performance of samples obtained using these parameters were similar to those of the common insulation materials such polystyrene.

CONSENT (WHERE EVER APPLICABLE)

NA

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

NA

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