



Thermal performance of scrap tire blocks as roof insulator



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ABSTRACT

This work shows a feasible re-use of scrap tires as thermal insulator for residential building roofs. The main focus of this study was to test the use of natural color and white-painted scrap tire blocks (STBs) as insulating material in a residential building prototype (RBP) and to compare their performance with a common insulating material (polystyrene). The STBs were prepared with a simple method using isoBond adhesive and tire particles from different suppliers. The thermal conductivity and water absorption of the materials were recorded. Moreover, several statistical parameters such as range, time lag and decrement factor were analyzed. The results showed that the STBs had higher thermal conductivity than polystyrene however, the ability to maintain the interior temperatures was nearly similar. This fact was explained by the combined convection–conduction heat transfer mechanism inside STBs. The water absorption of the STBs was relatively low in comparison with other organic insulating materials, such as palm fibers. The STBs performed better as insulating material when the outer-facing side was painted white, leading to an increase in the decrement factor (f) and the rate of heat loss as well as a decrease in the rate of heat gain. Finally, STB's are a practical option as insulating material for residential buildings in warm climates.

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1. Introduction

Scrap tires (STs) represents environment contamination and a public health concern because they can easily become mosquito-breeding sites or can harbor other plagues that transmit diseases. In Mexico, the Mexican Ministry of the Environment and Natural Resources (SEMARNAT) [1] estimates that around 27 million tires are disposed of every year. Most of them end up in stockpiles along the United States–Mexico border region that also receive scrap tires from the United States, resulting in a combined annual total of 40 million scrap tires [2]. However, some countries recycle scrap tires for other uses. In the United States, for example, STs are recycled to produce tire-derived fuel or for civil engineering and ground rubber applications [3].

In Mexico, the residential sector accounts for over 17% of total energy consumption; 17% of this energy is consumed by air conditioning [4]. The use of thermal insulation to reduce energy consumption in residential buildings is not a common practice. When insulation is used, traditional materials with low thermal conductivity, such as polystyrene, are common [5]. The development of new insulation materials represents an opportunity since

there are several disadvantages to using polystyrene, such as its poor mechanical resistance, solar degradation and high cost.

Accordingly, two indirectly related problems exist: the high energy consumption due to the poor insulation of buildings and the misuse of land for ST landfills. These problems can be simultaneously solved if the number of disposed STs is reduced by using them as insulation material in residential buildings and other applications. Some applications of ST have been previously reported. For instance, Yesilata et al. [6] reported that STs may be mixed with concrete for use as construction material in exterior walls in order to increase thermal protection. A reduction in heat transfer is observed in rooms with rubberized walls, and thus, these rooms have a more stable temperature in comparison with rooms constructed with conventional walls.

Kader et al. [6] determined that the thermal conductivity of waste rubber composites is similar to that of the range exhibited by traditional insulation materials. Its density is within the range of lightweight materials. Even so, the addition of STs to concrete as insulation material is not a widely applied practice. For instance Uruburu et al. [7] reported that only the 0.04% of granulated rubber in Spain is destined for this purpose.

Regarding insulating materials, other studies have shown that outer wall insulation performs better than inner wall insulation. Kolaitis et al. [8] reported a reduction of up to 89% in total energy consumption using only external thermal insulation. According to

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Fig. 1. Non-scaled Scrap tire block (STB) of 1 inch thickness painted white on the outer-facing surface.

their previous results and considering the properties of STs, these authors showed evidence that STs may be used as insulation material on external building elements, resulting in energy savings and a more stable temperature inside residential buildings. In addition, STs have presented certain positive characteristics such as resistance to mold, mildew, heat, humidity, ultraviolet rays (from the sun), acids and other chemicals. Moreover, STs show retardation of bacterial development [9], making them attractive for several applications.

A novel use for STs is proposed in this paper in which STs are evaluated for use in external thermal insulating blocks on residential building roofs that have been painted in white. Experiments were carried out on a residential building prototype. Since scrap tire blocks (STB) are porous and permeable, we expected that they would allow for absorbed heat to be transmitted and/or radiated/dissipated to the air surrounding the blocks.

2. Materials and methods

2.1. Preparation of the scrap tire blocks (STB)

The procedure for preparing scrap tire blocks was as follows: (1) Tire particles with 4–6 mm of size were obtained from several providers. (2) Tire particles were then mixed with IsoBond adhesive (water based glue) (10% wt of glue) to form a blend (at room temperature). (3) The blend was quickly poured into a mold (30 cm × 30 cm × 2.54 cm) and aged for 48 h. This procedure was reported previously in [10]. A STB with white paint is shown in Fig. 1.

The water absorption and thermo-physical experiments were performed using sample sizes of 60 mm × 30 mm × 25.4 mm and 100 mm × 110 mm × 25.4 mm, respectively.

2.2. Thermal conductivity tests

Thermal conductivity tests of 5 STB samples (two test on each sample) were performed according to ASTM D5930-09, using the DK-2 Pro device. This measurement method is based on the line source technique that enables the thermal conductivity of a material to be estimated. The probe consists of a long metal needle of 2.4 mm in diameter and 100 mm in length that is immersed into the material to be analyzed. The sampling time is chosen by the user depending on the material and the type of sensor used. Fifteen minutes must be allowed before every reading in order for the temperature to equilibrate between the sample and the needle. The

results are displayed directly on the device screen. The accuracy of this setup is ±10%. A range of thermal conductivity measurements may be obtained from 0.02 to 2 W m⁻¹ K⁻¹. Five thermal conductivity samples of STB were taken to test for reproducibility. All the samples were first pre-dried in an oven at 65 °C until reaching constant weight.

The experimental thermal conductivity was compared with the weighted model [11].

$$k = k_1 (1 - \varphi) + k_2 (\varphi) \quad (1)$$

Where k is the estimated thermal conductivity of the STB, k_1 and k_2 the thermal conductivities of the tire and air, respectively, and φ the porosity of the STB (Volume fraction of air), which was measured by the simple method of water displacement.

The thermal conductivity of the residential building prototype was also measured for later calculation purposes using the same line source technique.

2.3. Water absorption tests

Water absorption tests were conducted according to ASTM D570, which quantify the increase in the weight of the material after exposure to water. Before performing the water absorption experiments, the composite samples were dried at 65 °C until a constant weight was obtained. The weight gain was calculated using the following formula:

$$H(\%) = \frac{w_h - w_d}{w_d} * 100 \quad (2)$$

Where $H(\%)$ is the moisture content (%), w_h the moist weight (kg) at time (t) and w_d the dry weight (kg). In order to compare with other published materials, the water absorption coefficient A_w (kg/m² s^{1/2}) was estimated using the equation reported before by [12]:

$$A_w = \frac{m_w - m_d}{A} (t)^{1/2} \quad (3)$$

Where m_w is the wetted mass weight, m_d is the dried mass weight, A is the contact area and t is the time in seconds.

2.4. Residential building prototype (RBP) and heat source description

In order to assess the insulating properties of STs, a series of experiments were conducted under controlled conditions in a laboratory equipped for this purpose. Granular ST particles of 4–6 mm in size were used to manufacture the ST blocks (STB). Each block had a width of 30 cm, length of 30 cm and thickness of 2.54 cm in addition to a nominal weight of around 1300 g. The experimental conditions were selected to emulate real climate conditions; for this reason, a prototype residential building and an artificial heat source were used. The roof of the prototype was covered with four ST blocks.

A 1:5 scale residential building prototype (RBP) (Fig. 2a) was built using mortar with a 2:1 ratio of sand: cement. The roof and the walls were manufactured separately and were assembled from the same mortar. A steel mesh reinforcement was placed in the middle of the roof. The thickness of the walls was 1.0 cm, and the thicknesses of the roof and the floor were 2.4 cm and 3.0 cm, respectively. The prototype had a total of four window spaces that were left completely open during the experiments. The roof was covered with white paint to reduce energy absorption. The dimensions of the RBP are as follow: 1.2 m W × 1.3 m L × 0.6 m H.

Solar radiation was emulated using a previously assembled apparatus (Fig. 2b). The heat radiation source came from 6 UV bulbs (20 W/bulb), 2 white light bulbs (500 W/bulb) and 1 infrared

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