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Comparison in Thermal Conductivity of Hollow Concrete blocks filled with Straw Bales & Tyre Waste

***Pawan Saini*[*]*, Sumit Gangwar*[**]*, Harsh Mishra*[***]**

M.tech, Scholar[*]*, Assistant Professor*[**]*, Assistant Professor*[***]

Department Of Civil Engineering

Rama University, Kanpur[*, **] *IITM, Kanpur*[***]

Corresponding author's email id: *pawansaini.saini3@gmail.com*[*]

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Abstract

The thermal conductivity of straw bales is an intensively discussed topic in the international straw bale community. Straw bales are, by nature, highly heterogeneous and porous. They can have a relatively large range of density and the baling process can influence the way the fibers are organized within the bale. In addition, straw bales have a larger thickness than most of the insulating materials that can be found in the building industry. Measurement apparatus is usually not designed for such thicknesses, and most of the thermal conductivity values that can be found in the literature are defined based on samples in which the straw bales are resized. During this operation, the orientation of the fibers and the density may not be preserved. This paper starts with a literature review of straw bale thermal conductivity measurements and presents a measuring campaign performed with a specific Guarded Hot Plate, designed to measure samples up to 40 cm thick. The influence of the density is discussed thoroughly. Representative values are proposed for a large range of straw bales to support straw-bale development in the building industry

This paper comprises the tests performed to determine the thermal conductivity of hollow concrete blocks using straw bales filled in hollow concrete block. The purpose of this study is to examine the possibility of *using straw bales in hollow concrete block. The straw bales were used to make concrete block in the masonry units.*

This study examines the thermal behavior of concrete construction elements (bricks, slabs) made filled with different amounts of straw bales particles (80%, 70% and 60%) according with different thickness of concrete. Once the bricks, slabs were obtained, three different closed test cells were built and subjected to several heating/cooling periods. By recording the temperature difference between inside and outside the wall of concrete block, it was found that the thermal behavior depend on the filling percentage of tyre waste particles. This study is based on the human and atmospheric comfort in building structures in different environment conditions

Keywords: *Hollow concrete block, tyre waste, straw bales, heat conductivity*

INTRODUCTION

Straw bale building is constantly developing in Europe and elsewhere. More than a thousand buildings, from dwellings to public buildings, were enumerated, as discussed, in the recent European Straw Bale Gathering. 1 The straw bale community is well organized and straw bale building techniques are still evolving. Among new developments in prefabrication, building certification, fire resistance, and moisture transfer validations, the thermal behavior of straw bale walls is one of the key topics in market development. Despite the straw variability inherent to vegetal materials, the heterogeneous nature of this efficient insulation material is not seen as an obstacle to its development. A rational analysis of the parameters that influence its thermal conductivity can support a rigorous assessment of the energetic and environmental benefits of choosing straw bale building techniques. Straw bales have a larger thickness than most of the insulating materials that can be found on the building market. Measurement apparatus for thermal conductivity is usually not designed for such thickness, and most of the thermal conductivity values that can be found in the literature are defined based on samples in which straw bales are resized according to standard EN ISO 10456. 2 During this operation, the orientation of the fibres and the density may not be preserved. A specific Guarded Hot Plate was designed in Belgium 3 to measure samples up to 40 cm thick, according to the reference standard ISO 8302. 4 This paper starts with a literature review of straw bale thermal conductivity measurements and presents a measuring campaign performed with this apparatus. The influence of each analyzed parameter is discussed thoroughly. Representative values are proposed for a large range of straw bales to support straw bale development in the building industry. **(See Figure:-1)**

Overview of Thermal Conductivity Measurements on Straw Bales-

In most of the available literature, two distinct values for the thermal conductivity of straw bales can be found. The first one gives the thermal conductivity when the straw fibres are perpendicular to the heat flow. The second one gives the measured value when the fibres are parallel to the heat flow. The next paragraph focuses on this specific aspect. It must be noted that this distinction was set up by McCabe 5 in one of the first well referenced works relating to straw bale thermal conductivity. After this work was published, many similar experiments were conducted, such as that performed by as Andersen [6] and Shea. [7] Andersen studied the influence of the density on the thermal conductivity. They studied two sets of samples, one with a density of 75 kg/m3 and the other with a density of 90 kg/m3. The thermal conductivity of the first set of samples was 0.052 W/mK when measured perpendicular to the fibres and 0.056 W/mK when parallel to the fibers.

Figure 1 straw bale

The thermal conductivity obtained for the second set of samples was slightly higher; 0.056 W/mK when perpendicular and 0.06 W/mK when parallel. These values point out the first result regarding the evolution of the thermal conductivity with the studied parameters. When the density is 75 kg/m3 and the investigated direction evolves from perpendicular to parallel, the measured thermal conductivity increases by 0.004 W/mK; for a 90 kg/m3 density and measurement directions evolving from perpendicular to parallel, the same variation of magnitude is observed for the thermal conductivity. Consequently, the thermal flux measured by these authors can be modeled considering the density and the flux direction independently.

The measured thermal conductivities ranged from 0.059 W/mK for a density of 63 kg/m^3 to 0.064 W/mK for a density of 123 kg/m^3. Shea proposed a reference value of 0.065 W/mK. FASBA, the German association for straw bale buildings, led numerous researches on straw bales and obtained in 2010 very good thermal conductivity, around 0.045 W/mK, when the heat flow was perpendicular to the fibers. [8]

Many other data on thermal conductivities can be found in the literature. Among them, the value validated by the German Centre of Competence for Construction (DIB). [9]

Generally, the main objective is to comparison of thermal conductivity of hollow concrete block filled by straw bales and tyre waste.

METHODOLOGY

The method of study designed for this research included tests for three concrete blocks. In Each block straw bales were filled. Main purpose is to control the thermal conductivity from the atmospheric effect. The thermal conductivity test was conducted with different amounts of straw bales particles (80%, 70% and 60%) according with different thickness (2mm, 3mm & 4mm respectively) of concrete blocks. [10]

Three concrete batches were prepared to determine the thermal conductivity of hollow concrete blocks.

Table 1 Different concrete tyred filled blocks

S.No	Sample Code Number	Description
1	CTFB-1	The straw bales particles filled 80% by thickness of 2mm of hollow concrete blocks.
2	CTFB- 2	The straw bales particles filled 70% by thickness of 3mm of hollow concrete blocks.
3	CTFB- 3	The straw bales particles filled 60% by thickness of 4mm of hollow concrete blocks.

Preparation of mould- In our study, Firstly we prepared the mould with the help of plywood sheets in designed dimensions-

Table 2 different size of concrete blocks

S.No	Sample Code Number	Dimensions	
		Internal	External
1	CSFB-1	36cm x 16cm x 16cm	40cm x 20cm x 20cm
2	CSFB- 2	34cm x 16cm x 16cm	40cm x 20cm x 20cm
3	CSFB- 3	32cm x 16cm x 16cm	40cm x 20cm x 20cm

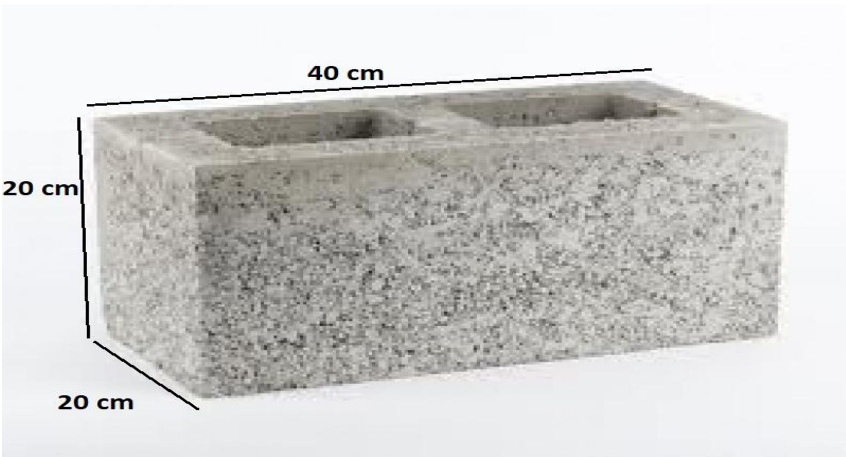

Figure 2 Hollow concrete block

Here, we are changing only one dimension of the block i.e. thickness, because we are studying about the thermal behavior of concrete blocks filled with straw bales particles which is totally depend on the wall thickness.

Concrete Mix Design-

Generally, we are using M25 grade of concrete for making the concrete blocks. Hollow Concrete blocks were tested to determine the thermal conductivity and then comparing of thermal conductivity of solid concrete blocks by Heat conductivity law***. (See Table:-3)***

Concrete blocks filled with straw bales-

After final setting of hollow concrete blocks, then these remove from the moulds. The size of concrete block filled with straw bales that is using in this study is crumb material. The straw bales will remove hollow space in the concrete blocks.

After filling the straw bales particles into the hollow concrete blocks, covered it with layer thickness of 2cm of concrete.

ANALYSIS

This analysis based on the human comfort conditions inside building in different environment conditions. In summer, the average environment temperature is approximate 400 C and for human comfort temperature in that season is approximate 220 C. [11] Heat conductivity of normal weight concrete is about 1.95 W/mK. [12] Thermal conductivity of straw bales particle is 0.052 W/mK. [13]

Table 3 Concrete mix design

Materials for concrete mix design	Value
Cement	Portland Cement
Slump	50 mm
Fine aggregate size	0-4.75 mm
Coarse aggregate size	4.75-10 mm
W/C	0.50

The heat transfer rate from solid concrete block is higher than the heat transfer rate through tyre waste filled block. However the heat transfer rate from hollow concrete blocks is least valued among all but the other criteria of construction are not fulfilled. So whenever we will use CTFB (concrete tyre filled block) for the preparation of wall of any buildings then the temperature inside the building found lower than the surroundings in summer season and vice-versa condition in winter season. 13

Concrete Block filled with straw bales particles-

CSFB 1-

Thickness of outer most cell of concrete = 2cm.

Thickness of layer of tyre waste particle = 16cm.

Area of concrete cell = 40 x 20

= 800 cm2 = 0.08 m^2

Area of straw bales layer = 36 x 16

= 576 cm2 = 0.576 m^2

Because straw bales layer will be in parallel combination with concrete layers then-

Heat transfer rate with HBC 1 in given temperature range-

$$Q = \frac{(t1 - t2)}{\left(\frac{L1}{K1A1}\right) + \left(\frac{L2}{K2A2}\right) + \left(\frac{L3}{K3A3}\right)}$$

$$Q = \frac{(40 - 22)}{\left(\frac{0.02}{1.95 \times 0.08}\right) + \left(\frac{0.16}{0.052 \times 0.0576}\right) + \left(\frac{0.02}{1.95 \times 0.08}\right)}$$

Q- 0.3353 Joule/ sec

CSFB 2-

Thickness of outer most cell of concrete = 3cm.

Thickness of layer of tyre waste particle = 14cm.

Area of concrete cell = 40 x 20

= 800 cm^2 = 0.08 m^2

Area of tyre layer = 36 x 16

= 576 cm2 = 0.576 m2

Heat transfer rate with HBC 2 in given temperature range-

$$Q = \frac{(t1 - t2)}{\left(\frac{L1}{K1A1}\right) + \left(\frac{L2}{K2A2}\right) + \left(\frac{L3}{K3A3}\right)}$$

$$Q = \frac{(40 - 22)}{\left(\frac{0.03}{1.95 \times 0.08}\right) + \left(\frac{0.14}{0.052 \times 0.0576}\right) + \left(\frac{0.03}{1.95 \times 0.08}\right)}$$

Q **= 0.3819 Joule/ sec**

CSFB 3-

Thickness of outer most cell of concrete = 4cm.

Thickness of layer of tyre waste particle = 12cm.

Area of concrete cell = 40 x 20

= 800 cm2 = 0.08 m2

Area of tyre layer = 36 x 16

= 576 cm2 = 0.576 m2

Heat transfer rate with HBC 3 in given temperature range-

$$Q = \frac{(t1 - t2)}{\left(\frac{L1}{K1A1}\right) + \left(\frac{L2}{K2A2}\right) + \left(\frac{L3}{K3A3}\right)}$$

$$Q = \frac{(40 - 22)}{\left(\frac{0.04}{1.95 \times 0.08}\right) + \left(\frac{0.12}{0.052 \times 0.0576}\right) + \left(\frac{0.04}{1.95 \times 0.08}\right)}$$

Q **= 0.4442 Joule/sec**

Now determine the heat transfer rate from solid concrete block and hollow concrete block for comparison with our tyre waste filled block.

Data taken from reference (13), the heat transfer rate for tyre filled concrete block-

Now determine the heat transfer rate from solid concrete block and hollow concrete block for comparison with our tyre waste filled block.

Data taken from reference (13), the heat transfer rate for tyre filled concrete block-

Table 4 Heat transfer rate for tyre filled concrete blocks

S.No	Name/type of Concrete block	Test conditions	Heat Transfer Rate (Q) (Joule/sec)
1.	CTFB-1	Thickness of concrete cell = 2cm	1.52
2.	CTFB- 2	Thickness of concrete cell = 3cm	1.71
3.	CTFB- 3	Thickness of concrete cell = 4cm	1.95

TABLE OF COMPARISON-

Table 5 comparison

S.no.	Type of block	Thickness(cm.)	Heat transfer rate(Q) for tyre filled block (Joule/sec)	Heat transfer rate(Q) for straw filled block (Joule/sec)
1	Block- 1	2	1.52	0.33
2	Block- 2	3	1.71	0.38
3	Block- 3	4	1.95	0.44

CONCLUSION

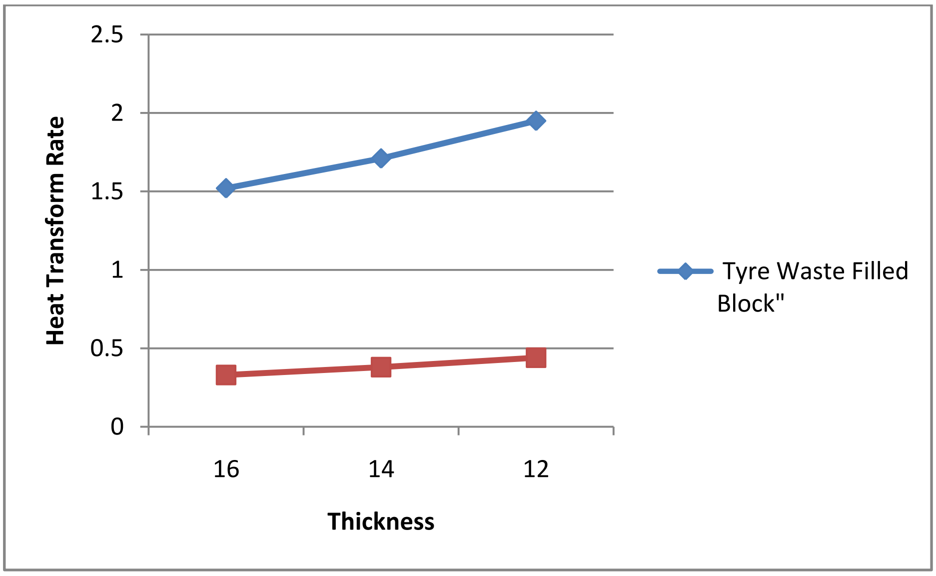

Figure 3 Graph between the heat transfer rate of tyre filled and straw bales filled concrete block

Here we can see that heat transfer rate from tyre filled concrete block is higher than the heat transfer rate through straw bales filled block. So whenever we will use CSFB (concrete straw bales filled block) for the preparation of wall of any buildings then the temperature inside the building found lower than the surroundings in summer season and vice-versa condition in winter season. Hence by using these blocks the thermal condition of the buildings can be maintained and will give better comfort level to the occupants in addition the economical point of view.

This research gives us more advantages in different atmospheric field such as in environment point of view as well as human comfort with efficient load requirement to maintain the temperature in buildings and other infrastructures.

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