Fire hazard of compressed straw as an insulation material for wooden structures


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SUMMARY
The construction sector continues to adapt to the challenges posed by climate change. Architects and engineers aim to build sustainable, energy, resource, and cost-efficient structures by increasingly using bio-based building materials. However, fire safety has always been a significant concern for timber building construction internationally. The objective of the study presented in this article is to document fire hazards of compressed straw when used as thermal and acoustic insulation within wood-framed building assemblies. Three densities of compressed straw (75, 125, and 175 kg/m³) were selected and their combustion and thermal responses were evaluated at various scales, in attempt to define the optimal density considering various factors. The performance of the straw was also compared with commercially available insulation materials and then tested under exposure to severe heating in medium-scale wood-framed assemblies to evaluate the impacts of the straw as compared with a noncombustible insulation. The compressed straw with a density of 75 kg/m³ was found to have the best behavior with respect to both reactions to fire and insulation properties. The results suggest that compressed may have similar or better behavior under the heating conditions investigated when compared to a commercially available combustible insulation material. The use of this material as a primary insulation in a buildings is considered manageable by thoughtful design, construction, and building use without unduly increasing risks associated with fire.

KEYWORDS
bio-based material, compressed straw, fire behavior, fire hazard, insulation, wood frame

INTRODUCTION
Sustainable development is a significant challenge in modern times. The building sector is responsible for about 40% of the global annual natural resource consumption and contributes up to 30% of all greenhouse gas emissions.1,2 In recent decades, raw material consumption has increased significantly as has the trend of buildings' energy consumption.1,3 Stakeholders in the building sector increasingly strive to build sustainable, energy, resources, and cost-efficient structures by using bio-
based building materials. Their excellent environmental performance, as well as their physical properties, are the basis of more sustainable designs.

Wood-frame systems insulated with bio-based material represent an effective strategy to create biogenic carbon sinks at comparatively low-cost. In recent years, interest has increased in these low embodied carbon and local building materials. Using cereal crop by-products in buildings is an attractive alternative to using conventional insulation materials. The revaluation of existing natural resources from accumulated agricultural waste does not require significant manufacturing costs, and generates almost no construction waste. These beneficial aspects encourage their use in building insulation.

However, fire safety has always been a concern to combustible bio-based building materials. As naturally growing materials, timber structures and bio-based insulation materials consist mainly of organic compounds and are combustible. Whilst currently compressed straw insulation is currently only occasionally used in buildings, wood is more commonly used and specific fire protection regulations for timber are available. A paucity of information regarding the fire hazard of compressed straw insulation, however, leads to its limited use.

Some limited evidence exists from fire resistance tests performed in the recent years that non-load-bearing walls insulated with straw bales can achieve 2-hours of fire resistance when tested under standard fire exposure according to ASTM E-119 or ISO-834. It is well known that combustion processes typically require sources of heat, fuel, and oxygen. By compressing straw it is possible to dramatically decrease the ability of oxygen within a straw insulation product. However, the fire behavior of this material may change under different conditions, such as with varying density, the type of cover material (i.e., gypsum board, plaster, or stucco), the use of furring strips (metallic resilient channels).

Fire testing of construction materials has traditionally relied on the use of a standard reaction to fire test, for materials and construction products, and fire resistance test (i.e., furnace test), for structural elements and assemblies, to ensure compliance and to unify all fire tests under one single standard for the purposes of comparison. Reaction to fire is related to the flammability of materials and construction products, that is, combustibility, ignition, heat release, spread of flame, and evolution of smoke and toxic gases. Fire resistance is related to the ability of a building element to resist a severe fire, defined as the time for which the element meets mechanical resistance (R), integrity criteria (E), and insulation criteria (I) when exposed to a standard test fire. Such standard tests also aimed to provide limited information on the structural response to fire. Originally developed in the early 1900s, the furnace test has remained largely unchanged. Despite some technical improvements, numerous problems remain until now such as high operating costs, poor repeatability, unrealistic and/or inappropriate boundary conditions, and poor statistical confidence.

Novel methods have emerged to undertake tests to study the performance of materials and assemblies to severe heating by controlling a fire experiment using an incident radiant heat flux rather than the gas phase temperature at the exposed surface. Using an incident radiant heat flux for fire science experiments is not, however, a recent concept; it has been widely used over the past 50 years in a variety of studies. Several commercial fire testing apparatus using a radiant heat source are widely available, such as the Fire Propagation Apparatus or Cone Calorimeter and these are routinely used for small-scale tests with a controlled incident radiant heat flux. Several authors have also suggested using a time-history of incident radiant heat flux, rather than a prescribed time-history of temperature when describing a fire.

The main scientific advantage of testing via heat flux rather than using gas phase temperature is associated with the capacity to control thermal boundary conditions directly at the exposed surface of a test specimen. Other advantages include the ability to impose a range of thermal exposures, outstanding repeatability, and operation at low economic and temporal costs. This is the approach taken in the current research.

The research presented in this article aimed to partially document some of the fire hazards associated with compressed straw when used as a primary insulation material within wood-framed assemblies. Specifically, the study evaluated the thermal response of three different densities of compressed straw insulation. The optimum density, based on the results of those tests, was selected and compared against test results for commercially available combustible insulation material that was previously tested using similar methodologies by Dagenais et al. The selected density was installed within a wood-framed assembly to evaluate the comparative performance of compressed straw under severe heating from one side, as compared with an assembly traditionally insulated with mineral wool. This was done using a Heat-Transfer Rate Inducing System (H-TRIS) apparatus. The assembly method used in this study was intended to some aspect of reaction to fire of the insulation materials in a wood-frame assembly.

2 | MATERIALS AND METHOD

2.1 | Materials

A number of insulation materials have been evaluated to assess and compare their thermal responses individually or when used within a wood-framed assembly. These materials are:

- Compressed straw (CS) at three different densities: 75, 125, and 175 kg/m$^3$. The straw did not contain any fire retardant or any other additives. The straw was wheat straw sourced from Lévis, Quebec, Canada. No specific direction was used for the orientation of the straw.
- Wood fiber insulation: Gutex Multitherm, 40 mm thick, 140 kg/m$^3$ density manufactured by Gutex Holzfaserplattenwerk, Germany. The wood fiber insulation did not contain any fire retardant. Prior to the cone calorimeter testing, the specimens were cut to a thickness of approximately 25 mm. The measured density of the specimens ranged between 184 and 195 kg/m$^3$.
• Wood fiber insulation: Gutex Thermowall-gf, 40 mm thick, 190 kg/m³ density manufactured by Gutex Holzfaserplattenwerk, Germany. Prior to the cone calorimeter testing, the specimens were cut to a thickness of approximately 25 mm. The wood fiber insulation did not contain any fire retardant. The measured density of the specimens ranged between 219 and 226 kg/m³.35
• Extruded polystyrene foam (XPS) insulation: Owens Corning Foamular, 25 mm thick, manufactured by Owens Corning, Gresham, Oregon. The measured density of the specimens ranged between 25 and 28 kg/m³.35
• Mineral wool (MW): Comfortbatt, 89 mm thick, 32 kg/m³ density manufactured by Rockwool. This insulation was used only for the test using the H-TRIS apparatus.

2.2 | Cone calorimeter testing

Six products were selected and evaluated following the cone calorimeter test method ISO 5660-1.18 The apparatus used was the dual cone calorimeter produced Fire Testing Technology Ltd. The specimens were exposed to a heat flux of 50 kW/m², when positioned horizontally 25 mm below the conical heat source. To perform the cone calorimeter tests, the straw was restrained within a 25 mm thickness using a metallic wire mesh (6.35 mm mesh) (Figure 1). No adhesive was used to secure the straw within the wire mesh. Additional testing was conducted on the selected straw density (75 kg/m³) with decreasing heat fluxes, that is, 35, 20, 15, and 10 kW/m², to calculate the critical heat flux for piloted ignition ($q_{cr}$) and the ignition temperature ($T_{ig}$) according to Grenier and Janssens method.37

All cone calorimeter tests were conducted at FPInnovations’ Materials Evaluation Laboratory in Quebec City, Canada, including those of Dagenais et al.35 Prior to testing, all specimens were conditioned to a constant mass at FPInnovations’ facilities at a temperature of 23°C ± 2°C and a relative humidity of 50% ± 5%.

2.3 | Thermal conductivity

The thermal conductivities of the three compressed straw specimens were evaluated with a heat flow meter according to ISO 830138 with a temperature range of 15°C to 40°C. The apparatus used was a FOX 314 produced by TA Instruments. The straw was restrained in a wooden box of 305 x 305 x 102 mm, built using 19.1 mm thick standard CSA O121 Douglas Fir Plywood. Since the straw was restrained within a wooden box, the thermal conductivity of one layer of plywood (same as that used for the box) was evaluated to subtract its thermal contribution according to the method described by Drysdale 2011.39 The thermal conductivity tests were conducted at Laval University, Canada. Prior to testing, all specimens were conditioned to a constant mass at University Laval’s facility at a temperature of 21°C ± 1°C and a relative humidity of 60% ± 5%. The thermal conductivities of the combustible commercial insulation materials, that is, Multitherm, Thermowall-gf, and XPS, were taken from the manufacturers’ websites.40-42

2.4 | Heat-Transfer Rate Inducing System

The H-TRIS apparatus, originally developed at the University of Edinburgh and shown in Figure 2, was used for evaluating the heat transfer within the wood-framed assemblies. Rather than using a standard fire test curve in a furnace such as CAN/ULC S101,22 the H-TRIS apparatus allows direct and independent control of the thermal boundary condition by controlling the time-history of the incident radiant heat flux impinging at the exposed surface of a test specimen.36 The H-TRIS apparatus consists of four propane-fired radiant panels mounted to a metal frame to form a 200 x 400 mm² radiant array. The panels are installed on a linear motion system, which allows the incident radiant heat flux to be varied by changing the distance.
between the radiant panels and the exposed surface of the test specimen.

A time-history of incident radiant heat flux corresponding to the standard fire curve ISO-834 was applied to the exposed surface of the specimens for a test duration of 60 minutes. The specified heat flux time-history is shown in Figure 3.

2.5 Wood-frame assemblies

Two different wood-framed assemblies were built for the medium-scale tests in H-TRIS. The only parameter that varied between these was the cavity insulation. Manually compressed straw at 75 kg/m³ was used in all cavities, whereas mineral wool was placed on the exposed side. For the wood-framed assemblies, 302 mm depth I-joists manufactured by Nordic Engineered Wood were used. These were spaced at 406 mm on center and made with 63.5 mm wide and 38.1 mm thick finger-jointed black spruce lumber flanges and a 9.5 mm thick oriented strand board (OSB) web panel. The exposed side was covered by one layer of 12.7 mm Fireguard C (Type C) gypsum board and two horizontal 12.7 mm deep resilient metal channels spaced at 600 mm on center. The unexposed side was covered by one layer of 19.1 mm of standard CSA O121 Douglas Fir Plywood. Metallic wire mesh was used to restrain the compressed straw in the cavity on the side of the resilient channel and to maintain the air gap. The height of the assemblies was 762 mm. Plywood was used to seal top and bottom end. These tests were conducted at the University of Edinburgh, Scotland. Prior to testing, all specimens were conditioned to constant mass at the University of Edinburgh's facilities at a temperature of 20°C ± 2°C and a relative humidity of 40% ± 5%.

2.6 Instrumentation

Between 15 and 21 high temperature glass insulated Type K thermocouples were positioned throughout the assemblies. The locations of the thermocouples for the test assembly with compressed straw are shown in Figure 4. The thermocouple locations were as follows:

1. Two thermocouples at the unexposed surface of the gypsum board. One in the center of the assembly and one at mid-height and mid-way between two joists.
2. Four thermocouples on the middle joist of the assembly. Two on the exposed flange at 20 mm from the exposed edge, one on each side of the flange; two at mid-depth of the joist, one on each side of the OSB web panel.
3. There were two rows of thermocouples within the insulation. One at midway of the central and side joists, one at quarter distance

![FIGURE 2](image2.png)  
**FIGURE 2**  H-TRIS test setup at The University of Edinburgh. H-TRIS, Heat-Transfer Rate Inducing System.
between central and side joist, closer to the central joist. Rows started at 20 mm depth in the insulation and at every 20 mm thereafter. There were seven thermocouples per row for the assembly insulated with compressed straw and four thermocouples per row in the assembly insulated with mineral wool, due to their varying thicknesses.

4 One thermocouple was located on the unexposed side of the assembly at its center.

**FIGURE 4** Thermocouple locations (plan view) in the test assembly with, A, compressed straw, B, mineral wool

**TABLE 1** Average cone calorimeter test results and thermal conductivity of three densities of compressed straw under 50 kW/m² heat flux

<table>
<thead>
<tr>
<th>Density (kg/m³)</th>
<th>Ignition time (s)</th>
<th>Peak heat release rate (kW/m²)</th>
<th>Heat release rate (kW/m²)</th>
<th>Mass loss rate (g/s)</th>
<th>Effective heat of combustion (MJ/kg)</th>
<th>Thermal conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>6</td>
<td>171.42</td>
<td>60.74</td>
<td>0.046</td>
<td>11.61</td>
<td>0.049</td>
</tr>
<tr>
<td>125</td>
<td>6 (+4%)</td>
<td>178.88</td>
<td>73.21 (+21%)</td>
<td>0.062 (+34%)</td>
<td>10.42 (−10%)</td>
<td>0.052 (+5%)</td>
</tr>
<tr>
<td>175</td>
<td>8 (+33%)</td>
<td>177.41</td>
<td>70.06 (+15%)</td>
<td>0.061</td>
<td>10.14 (−13%)</td>
<td>0.059 (+20%)</td>
</tr>
</tbody>
</table>

Note: The percentages in brackets refer to the relative difference between the specimen and the 75 kg/m³ compressed straw’s values.
3 | TEST RESULTS AND ANALYSIS

3.1 | Combustion properties and thermal conductivity

A summary of the cone calorimeter test results from the different densities of compressed straw is presented in Table 1, calculated over a 300 seconds burning duration after the ignition ($t_{ig}$) of all specimens. The analysis time was selected due to the shortest burning duration of the 75 kg/m$^3$ compressed straw. All the results were compared to the 75 kg/m$^3$ density as a benchmark.

Despite increasing the density of compressed straw, it was observed that the average peak of heat release rate after ignition only increased by 3% and 4% for the 125 and 175 kg/m$^3$ specimens, respectively, suggesting little influence due to the density. However, the heat release rate (HRR) was higher for the 125 and 175 kg/m$^3$ densities by 21% and 15%, respectively. This could be explained by the fact that the 75 kg/m$^3$ compressed straw was completely at the end of the test period, whilst the other two samples still had fire load which could continue to contribute to heat release. Similarly, for the mass loss rate, higher densities had a higher mass loss rate and the fire load was consumed at a rate of 31% to 34% more rapidly than that of the lowest density. In contrast, the effective heat of combustion was lower for the higher densities than for the 75 kg/m$^3$ compressed straw suggesting that the fire load of the lowest density released more energy during the 300 seconds burning duration. Nevertheless, the 75 kg/m$^3$ compressed straw burning period took less time than the denser ones resulting in a smaller amount of total heat released. Furthermore, its lower thermal conductivity makes it a more effective insulation material when compared to the other densities. As such, a density of 75 kg/m$^3$ was selected for further tests and comparisons.

A summary of the test results of the selected density of compressed straw (75 kg/m$^3$) and a number of commercially available combustible insulation materials is presented in Table 2, calculated over a 180 seconds burning duration; after the ignition of all specimens. The analysis time was selected due to the shortest burning duration of the XPS. All the results were compared to the 75 kg/m$^3$ density, in parentheses, as a benchmark. Figure 5 shows the heat release rates of these insulations.

A significantly lower average peak of heat release rate was observed for compressed straw than for Multitherm, Thermowall-gf or XPS. The XPS peak HRR was more than three times higher than that of the compressed straw. The compressed straw, as well as Multitherm and Thermowall-gf, burned more slowly throughout the tests whereas XPS burned vigorously after melting. XPS released heat 16 seconds later than the others specimens due to the melting time. These results confirm that compressed straw would have a lower contribution during a fire than XPS. The results also suggest that compressed straw, if used as an insulation material, would be less prone to contribute in the early stages of a building fire when compared to the Multitherm, Thermowall-gf, or XPS. The thermal conductivity of the compressed straw was, on the other hand, higher than all other materials.

Figure 6 shows the ignition times of 75 kg/m$^3$ density straw exposed to different heat fluxes. These results allow calculating the critical heat flux for piloted ignition ($q_{cr}$) and the ignition temperature ($T_{ig}$) to be calculated, which are determined as 7.5 kW/m$^2$ and 240°C, respectively.

### Table 2: Average cone calorimeter test results and thermal conductivity of combustible insulations under 50 kW/m$^2$ heat flux

<table>
<thead>
<tr>
<th>Material</th>
<th>Ignition time (s)</th>
<th>Peak heat release rate (kW/m²)</th>
<th>Heat release rate (kW/m²)</th>
<th>Effective heat of combustion (MJ/kg)</th>
<th>Thermal conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw</td>
<td>6</td>
<td>171.42</td>
<td>81.05</td>
<td>10.673</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>(–)</td>
<td>(–)</td>
<td>(–)</td>
<td>(–)</td>
<td>(–)</td>
</tr>
<tr>
<td>Multitherm$^a$</td>
<td>6 (+6%)</td>
<td>254.14</td>
<td>104.56</td>
<td>12.53</td>
<td>0.041$^b$</td>
</tr>
<tr>
<td></td>
<td>(+48%)</td>
<td></td>
<td>(+29%)</td>
<td>(+17%)</td>
<td>(–17%)</td>
</tr>
<tr>
<td>Thermowall-gf$^a$</td>
<td>6 (+6%)</td>
<td>224.91</td>
<td>104.49</td>
<td>11.84</td>
<td>0.043$^b$</td>
</tr>
<tr>
<td></td>
<td>(+31%)</td>
<td></td>
<td>(+29%)</td>
<td>(+11%)</td>
<td>(–13%)</td>
</tr>
<tr>
<td>XPS$^a$</td>
<td>22 (+288%)</td>
<td>750.77</td>
<td>141.48</td>
<td>27.45</td>
<td>0.035$^b$</td>
</tr>
<tr>
<td></td>
<td>(+338%)</td>
<td></td>
<td>(+75%)</td>
<td>(+157%)</td>
<td>(–29%)</td>
</tr>
</tbody>
</table>

Note: The percentages in brackets refer to the relative difference between the specimen and compressed straw's values.

$^a$Results from Dagenais et al$^{35}$

$^b$Value from the manufacturers' website.
less spectacular. Some steam and smoke appeared slightly earlier than in the compressed straw test, but the intensity remained lower. Small flames were visually noticed after 44 minutes at the junction of the gypsum board and the top plywood. The intensity of the flaming was not seen to increase significantly.

### 3.2.1 Average temperatures on the unexposed side of the gypsum board

Two thermocouples were located on the unexposed surface of the gypsum board, as detailed in Section 2.6. The average temperatures measured between these two positions are shown in Figure 7.

The average temperature profiles followed the same trends in the early stages of the test, and then diverged due to the insulation configurations:

1. An initial temperature rise with temperatures at the back face reaching 88°C to 90°C at about 3.5 minutes.
2. The initial temperature rise was followed by a gradual temperature rise during the calcination of the gypsum board. For all tests, the temperature measured at the back exceeded 100°C between 6 and 8 minutes.
3. After the gypsum board was calcinated, there was a more rapid increase in the average temperatures measured at the back. After 17 minutes, when the temperature measured was between 150°C and 155°C, the trend changed.
4. After 17 minutes, the temperature measured behind the gypsum board in the assembly insulated with compressed straw increased very rapidly as compared to that of the assembly insulated with mineral wool. This indicates that another heat source other than the H-TRIS apparatus was present and suggests that the straw began to combust. The high increase of temperature started to reduce at 23 minutes and reached a slow increase of temperature rate from 36 minutes until the end of the test. For the assembly insulated with mineral wool, the temperature increased more rapidly after 20 minutes and maintained a relatively constant rate of increase until the end of the test.
5. There was a considerable difference in the final temperatures between the assemblies. The compressed straw assembly reached 780°C peak temperature, whilst the mineral wool assembly reached about 600°C suggesting that the compressed straw increased the heat release.

### 3.2.2 Average temperatures in the insulation materials

The average internal temperature profiles in the compressed straw and mineral wool insulation are shown in Figures 8 and 9, respectively. For both insulation materials, there was an increase in the temperature starting at approximately 3 minutes for the nearest thermocouples to the exposed surface. In the compressed straw, this was characterized by a short rise of temperature for the first thermocouples reaching 70°C at 5 minutes and then a more gradual
temperature rise. In the mineral wool, the temperature reached 70°C after 14 minutes. In the insulation materials, the heat transfer was low due to the calcination of the gypsum board. The distinctive plateau in the mineral wool was also due to the internal evaporation of the material. During that time, the temperature profiles of both insulation materials were practically the same for a short period until the effect of the gypsum board became less important between 18 and 20 minutes.

In the compressed straw, the temperature started to increase very rapidly at the first three thermocouples while the plateau extended for the other thermocouples, creating a temperature gradient in the material. This phenomenon was due to the compressed straw combustion at the center of the target surface. The unexposed side of the gypsum board reached 240°C at 18.5 minutes, which is the theoretical ignition temperature of the compressed straw calculated from the cone calorimeter tests. The first thermocouple in the row reached the ignition temperature at 20 minutes while the temperature at the back of the gypsum board was then 330°C, suggesting that the compressed straw at the center of the target surface started to burn between 18.5 and 20 minutes. Figure 10 shows the straw inside the assembly after the test. The compressed straw burned only on the surface and deeper at the center of the target surface, highlighting that the combustion did not spread easily within the material during the test. The temperature reached 300°C rapidly at 20.5 minutes. The combustion of the straw accelerated the heat transfer and accelerated the combustion of the I-joist, which in turn released increasing amounts of heat and accelerated the combustion of the straw, and so on. The curve of the highest temperature profile started to decrease and became almost linear at around 32 minutes until the end of the test, when the temperature was 600°C.

In the mineral wool, the temperature increased about the same time as it did in the compressed straw, but conversely, the temperature rise was almost uniform and followed the same trend depending on the depth of the thermocouple. Since the mineral wool is a non-combustible material, the temperature profiles followed the same trend. The slope became linear around 45 minutes when the measured temperature was 630°C.

For the temperatures measured on the unexposed face of the assemblies, no significant temperature rise was expected due to the
thickness of the wall and the comparatively short test time. The temperature rise was little to none during the tests, as shown in Figure 11. At about 20 minutes, a small gap was created between the assembly with compressed straw and the one with mineral wool. Since the mineral wool did not fill all the cavity (only 89 mm in thickness), the heat transfer was slightly faster in the air cavity due to the air convection. However, this temperature gap tended to decrease by 40 minutes due to a temperature increase in the assembly with compressed straw. As suggested from the previous graphs, when the compressed straw began to combust, the temperature increased in the material.

### 3.2.3 Average temperatures on the I-joist

Four thermocouples were located on the middle I-joist within the assemblies. Two were placed on the exposed flange at 20 mm from the exposed edge and two at mid-depth of the joist web panel. The locations of the thermocouples were chosen with the aim of characterizing the heat transfer along the joist depending on the insulation configuration. The average temperature profiles of the middle joist are shown in Figure 12.

For the exposed flange, the average temperature profiles followed the same trend for the first 18 minutes. In the assembly insulated with compressed straw the temperature then rose rapidly to 300°C at 19.5 minutes. Since the I-joist reached this temperature before the thermocouples in the compressed straw, it suggests that combustion of the wood flange contributed to burning of the straw. A constant and lower rate of temperature increase was maintained from 22 minutes until the end of the test. In the assembly with mineral wool, the temperature increased more rapidly at about the same time (19.5 minutes), but at a lower rate. These rises matched with the time when temperature on the back of the gypsum board rose more rapidly, as already discussed.

The temperature profiles at mid-depth of both assemblies followed the same trend until 18 minutes when the straw started to combust. The combustion released additional heat which reached the mid-depth web. There was then a lengthy temperature plateau corresponding to evaporation of the compressed straw and wood until a rapid measured temperature increased toward the end of the test. For the assembly insulated with mineral wool, the measured temperature increased at a lower and constant rate.

The time at which the average temperatures on the I-joist reached 300°C for the assembly insulated with compressed straw and the assembly insulated with mineral wool were 19.5 and 26 minutes.
respectively. Despite the combustible nature of the compressed straw, the delay to cause combustion of the timber was less important than expected when compared to mineral wool. If the compressed straw ignition temperature was the same as the one calculated in Section 3.1, the ignition temperature would have been reached 6.5 minutes (25%) faster in the assembly the thermal conductivity of which was 26% higher than in the assembly insulated with mineral wool (thermal conductivity of 0.036 W/mK for Comfortbatt). It would most likely suggest that, in a wooden structure, the fire risk of compressed straw is not necessarily proportional to its fire load, but also to the heat transfer occurring due to a greater thermal conductivity.

Insulation is used as a protective material to enhance the thermal and acoustic performances of a structure/assembly at ambient temperature. However, researchers have stated that cavity insulation reduces the fire performance of a load-bearing structure. In cavity-insulated wall or floor, the insulation acts as a heat barrier and thereby heating the flanges faster, regardless of the combustibility of the insulation. Figure 13 shows the significant damage on the assembly flanges. None of the thermocouples on the webs of the joists reached 300°C on the web of the joist. Burned wood reached 145 mm deep (almost half-depth) in the assembly with compressed straw whereas it reached 97 mm deep (almost one-third of the depth) in the assembly with mineral wool.

4 CONCLUSION

This article aimed to partially document some of the fire hazards associated with compressed straw when used as a primary insulation material within wood-framed assemblies. This was done by evaluating the thermal responses of three different densities of compressed straw insulation. The optimum density, based on the results of the tests performed, was selected and compared against test results for one particular commercially available combustible insulation material; this was previously tested using similar methodologies by Dagenais et al. The selected density was installed within a wood-framed assembly to evaluate the comparative performance of compressed straw under severe heating from one side, as compared with an assembly traditionally insulated with mineral wool. This was done using a H-TRIS apparatus. The assembly method used in this study was intended to evaluate some aspect of reaction to fire of the insulation materials in a wood-frame assembly.

According to the cone calorimeter test results, the lowest density of compressed straw (75 kg/m³) emitted less energy for the peak and heat release rate, when burning compared to the other densities (125 and 175 kg/m³) and compared to the commercially available combustible insulation materials. The heat release rate was lower than the bio-based insulation materials (Multitherm and Thermowall-gf) and was much lower than that of the XPS, suggesting that the compressed straw is less prone to contribute energy in the early stages of a building fire under conditions similar to those tested herein.

The medium-scale reaction to fire experiments on wood-frame assemblies insulated with compressed straw and mineral wool highlighted the impact of the fire load from the bio-based insulation material compared with a noncombustible cavity insulation. These tests used the H-TRIS test method and apparatus. All of the assemblies were constructed in a similar manner, with the exception that the cavity filling material was different between specimens. The test duration was 60 minutes using a calibrated time-history of incident radiant heat flux which was intended to be similar to a standard fire curve according to ISO-834.

Temperature measurements were made throughout the test assemblies. The data were used to investigate the thermal conditions within the test assemblies. The results indicated that one layer of 12.7 mm Type C gypsum board provided approximately 18 minutes encapsulation time (delay) before the effect became less important. The measured temperatures showed that the compressed straw had a similar temperature profiles to mineral wool in the early stages of the tests. However, combustion of the compressed straw influenced the heat transfer and accelerated the ignition of the wood, which in turn accelerated combustion of the straw. Using furring strips (metallic resilient channels) may have contributed to this behavior due to a free air flow feeding oxygen into the assembly to sustain combustion.

In light of these results, and under the conditions tested, compressed straw appears to pose a lesser risk in terms of reaction to fire as compared to conventional combustible insulation materials which are currently being used in practice.

Further research must be performed on different assembly configurations to further investigate delaying the ignition of the straw (ie, additional gypsum board, avoiding loose straw, removal of the air gap) before confident conclusions for application in real buildings can be given. Like many other commercially available combustible insulation materials, the fire hazard of compressed straw appears to be manageable by careful design and construction. It is expected that continued research in this area will allow confident guidance for building designers to be proposed.

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