Advanced Wood-Based Solutions for Mid-Rise and High-Rise Construction: Acoustic Performance of Innovative Composite Wood Stud Partition Walls

April 2018

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ACKNOWLEDGEMENT

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DATE:  April 18, 2018
SUMMARY

Airborne sound insulation performance of wall assemblies is a critical aspect which is directly associated with the comfort level of the occupants, which in turn affects the market acceptance.

In single-family and low-rise residential buildings, the partition walls, whether loadbearing or non-loadbearing, are commonly framed with studs of solid sawn lumber of 2x4, 2x6, and 2x8. In commercial buildings and multi-storey residential buildings, the partition walls, are commonly framed using light-gauge steel studs.

Light-gauge steel studs are typically C-shape channels. Comparing with the solid sawn lumber studs, they are lighter in weight and dimensionally more stable with less likelihood of bowing and warping. Bowed and warped solid sawn lumber studs need to be straightened before they could be used properly, and such corrective actions are tedious and increase the construction cost. Moreover, it is found that that the 25 gauge steel studs have better sound insulation performance than solid sawn lumber studs in partition wall applications.

The shortcomings for solid sawn lumber studs identified above form the motivation for this project to develop wood studs that would address these shortcomings so to promote wood greater use in partition walls.

To achieve the objective, the following steps were taken in this study:

- Selection of a steel stud as the base reference;
- Conceptual design of innovative lightweight composite wood studs;
- Development of the manufacturing process for the innovative lightweight composite wood studs;
- Fabrication of the innovative lightweight composite wood studs;
- Measurements of the mechanical properties of the composite wood studs;
- Design and fabrication of steel-stud and composite wood-stud wall specimens for sound insulation tests;
- Measurement of airborne sound insulation performance of the stud wall specimens using reference steel stud wall as the base for the comparison.

Four types of innovative composite wood studs were developed and fabricated. They were lighter weight and more flexible than the reference of the 25 gauge steel stud. All the walls specimens of the composite wood studs achieved at least the same ASTC ratings as the reference of the 25 gauge steel stud wall.

In general, the conceptual design and fabrication work and the preliminary test results have shown that a partition-wall stud made out of composite wood material could have same or better airborne sound insulation performance as compared to the 25 gauge steel stud. The concept is promising, with a manufacturing process and fabrication that would work or be practical.

It is recommended to:
1) File a concept disclosure document of the design, manufacturing process and fabrication of the innovative composite wood studs;

2) Extend the design and fabrication to use other wood composites;

3) Optimize the design and fabrication for the innovative composite wood studs to achieve higher ratio of performance to cost than the 25 gauge steel stud;

4) Enhance FPI's current mock-up capacity to include the wall test facility;

5) Examine the effects of various design and fabrication parameters on the various performance aspects for the optimization using the enhanced mock-up.
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1 BACKGROUND

Airborne sound insulation performance of wall assemblies is a critical aspect which is directly associated with the comfort level of the occupants, which in turn affects the market acceptance. Minimum performance level for partition walls is specified in the building codes for airborne sound insulation. The 2015 National Building Code of Canada (NBCC) (NRC: IRC 2015) specifies the minimum requirement of apparent sound transmission class (ASTC) rating of 47 for walls separating two adjacent units.

In single-family and low-rise residential buildings, the partition walls, whether loadbearing or non-loadbearing, are commonly framed with studs of solid sawn lumber of 2x4, 2x6, and 2x8. Figure 1 shows such a traditional wood stud wall frame. Various acoustical solutions have been developed for wood stud walls to meet the code requirement for airborne sound insulation, or beyond the requirement, and are provided in the 2015 NBCC.

![Figure 1. Solid sawn lumber stud walls in a wood building](image)

In commercial buildings and multi-storey residential buildings, the partition walls, are commonly framed using light-gauge steel studs. Figure 2 shows such steel-stud wall frame in a cross-laminated-timber (CLT) 8-storey multi-family building.
Light-gauge steel studs are typically C-shape channels. Comparing with the solid sawn lumber studs, they are lighter weight, dimensionally more stable with less likelihood of bowing and warping. Bowed and warped solid sawn lumber studs need to be straightened before they could be used properly, and such corrective actions are tedious and increase the construction cost.

Moreover, it is found that that the 25 gauge steel studs have better sound insulation performance than solid sawn lumber studs in partition wall applications (NBCC NRC:IRC 2015). Table 1 provides acoustics design examples of a 2x4 (38 mm by 89 mm) wood stud wall and a 25 gauge steel stud wall, and their sound transmission class (STC) ratings as published in the 2015 NBCC(NRC:IRC 2015). Both walls use two layers of gypsum boards directly attached to each side. The steel stud wall achieves the STC that is 16 points higher than the STC of the similar wood stud wall, even though the 2x4 wood wall had deeper cavity (89 mm) than the steel stud wall (64 mm). To achieve the same sound insulation performance as the 25 gauge steel stud wall, i.e. STC 54, the 2x4 stud wall has to add the 25 gauge resilient channels between the lumber studs and the gypsum board to decouple the gypsum board from the lumber wall frame.

It is known that the deeper the cavity of a wall, the higher the STC of the wall.
### Table 1. Comparison of STC ratings of solid sawn lumber stud and 25 gauge steel stud non-loadbearing walls in 2015 NBCC (NRC: IRC 2015)

<table>
<thead>
<tr>
<th>Top view of cross-section of stud wall</th>
<th>Description of wall details</th>
<th>Fire resistance rating</th>
<th>STC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- 2 layers of 15.9 mm Type X gypsum boards</td>
<td>2 h</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>- 2x4 (38 mm by 89 mm) studs at 400 mm or 600 mm on centre (o.c.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 89 mm thick absorption materials in cavity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 2 layers of 15.9 mm Type X gypsum boards</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Same as above except for adding resilient metal channels at 400 mm o.c. between the studs and the gypsum boards</td>
<td>2 h</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>- 2 layers of 15.9 mm Type X gypsum boards</td>
<td>2 h</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>- 0.46 mm (25 Gauge), 31 mm x 64 mm non-loadbearing steel studs at 400 mm or 600 mm o.c.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 65 mm absorption materials in cavity and 2 layers of 15.9 mm Type X gypsum boards</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The shortcomings for solid sawn lumber studs identified above form the motivation for this project to develop wood studs that would address these shortcomings so to promote wood greater use in partition walls.

### 2 OBJECTIVE

The objective of this one-year project is to develop a conceptual design and fabrication process for innovative lightweight composite wood studs with similar or better sound insulation performance than light-gauge steel studs for non-loadbearing partition wall application.

Due to confidentiality, this report does not include the technical details of the innovative composite wood stud design and fabrication process, and their properties. They will be described in a “Concept disclosure” document separately.
3 APPROACH

To achieve the objective, the following steps were taken in this study:

- Selection of a steel stud as the base reference.
- Conceptual design of innovative lightweight composite wood studs.
- Development of the manufacturing process for the innovative lightweight composite wood studs.
- Fabrication of the innovative lightweight composite wood studs.
- Measurements of the mechanical properties of the composite wood studs.
- Design and fabrication of steel-stud and composite wood-stud wall specimens for sound insulation tests.
- Measurement of airborne sound insulation performance of the stud wall specimens using reference steel stud wall as the base for the comparison.

4 TECHNICAL TEAM

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Principal Scientist and Associated Research Leader  
Research Leader  
Principal Technologist  
Principal Technologist  
Principal Technologist  
Principal Technologist  
Senior Technologist

5 SELECTION OF A REFERENCE STEEL STUD

It was decided at the start of the project to select the 0.46 mm (25 Gauge), 31 mm x 64 mm C-shape steel stud as the reference because this particular size of steel stud is commonly used in non-loadbearing partition walls in commercial, multi-storey buildings.

The innovative wood studs would be designed and fabricated to have approximately the same size as this reference steel stud.
6 DEVELOPMENT OF MANUFACTURING PROCESS QND FABRICATION OF THE INNOVATIVE COMPOSITE WOOD STUDS

Two types of composite wood materials were used to make the wood studs that have the size as the reference steel stud. One was made of multi-layer of veneer, called LVL in this study, and the other was made of middle density fiber, called MDF in this study. The manufacturing process of the composite wood studs was developed.

6.1 LVL Studs

Two wood species veneers were used to fabricate LVL studs. White birch veneers (123" long x 8" wide x 1/38" thick) were purchased from Columbia Forest Product, Maine, USA, and poplar veneers (70" long x 8" wide x 1/38" thick) from Masonite, Lac Mégantic, QC. The veneers were oriented with the grain direction parallel to the length of the studs for the white birch veneers and perpendicular to the length of the studs for the poplar veneers. Purbond HBE452 was used as binder to manufacture the 4-ply LVL studs. The coated veneers after layup were pressed into C-shape using specially designed molds under specific pressure, temperature and time.

6.2 MDF Studs

MDF studs were made based on conventional MDF process in the upstream process and then with the modified process for fibre mat formation, molding and hot pressing. Two types of wood fibre-based composites studs were made: higher density stud and lower density stud. The manufacturing process includes wood fibre refining of softwood chips using a disc refiner at FPInnovations’ MDF Pilot Plant, UF resin blending through the blowline, drying of resinated wood fibre, mat forming and hot press into the desired shape and dimension.

7 MEASUREMENTS OF MECHANICAL PROPERTIES

To examine whether there is some correlation between the stud bending stiffness and the ASTC ratings of the walls made of the studs, the dynamic bending stiffness of the innovative composite wood studs and the reference steel stud in flatwise and edgewise were measured using free-free beam vibration technique as shown in Figure 3.
The stud specimen's fundamental natural frequency was measured through the free-free beam vibration. Along with the measured linear density of the stud, the bending stiffness of the stud was calculated using the equation below:

$$EI = \frac{f_1^2 m l^4}{12.68}$$  \hspace{1cm} (1)

where

- $EI$ = bending stiffness of the stud specimen in N-m$^2$,
- $f_1$ = fundamental natural frequency of the free-free beam stud specimen in Hz,
- $m$ = linear density of the stud specimen in kg/m,
- $l$ = the length of the stud specimen in m.

8 DESIGN AND FABRICATION OF STUD WALL SPECIMENS FOR SOUND INSULATION TESTS

To fabricate the stud wall specimens, the first step is to design the stud wall specimen. Several principles guided the design. First, the wall specimens should be simple. Then, the STC of the reference 25 gauge steel stud wall should be known so that the ASTC of the steel stud wall
specimen can be approximated from the known STC. The estimated ASTC of the steel stud wall will be used to verify the measurement of the ASTC of the steel stud wall specimen to ensure the test procedure is valid.

Due to the limitation of the wall test facility, the wall specimens should be not highly insulated. Therefore, the 25 gauge steel stud wall No. S1a published in 2015 NBCC (NRC:IRC 2015) of STC 43 was selected as the reference wall. The NBC reference steel stud wall was made of 0.46 mm thick, 31 mm x 64 mm 25 gauge of C-shape steel studs spaced at 600 mm o.c. with 65 mm thick absorptive material in cavity and one layer of 15.9 mm Type X gypsum board on each side. Therefore, all innovative composite wood stud wall specimens including the steel stud reference wall were fabricated using the NRC wall No. S1a design except for the stud spacing. To fit the opening size in the test facility, the stud spacing had to be reduced from 600 mm to 490 mm.

The wall specimens measuring 1.47 m (58") by 1.47 m (58") were used to fit the opening of the facility for testing the wall sound insulation. Each specimen was made by 4 studs at 0.49 m (19.3") spacing o.c. and the 15.9 mm (5/8") type X gypsum boards on each side. The studs were inserted between two steel runners at the top and bottom of the wall specimen as shown in Figure 4 according to the steel wall frame guide of the steel stud producers. No. 6 Type S Hilo bugle head, self-driving, self-tapping steel screws were used to attach the gypsum board to the studs. The screws were spaced at 200 mm (8") o.c. at periphery of gypsum boards and located 10 mm (3/8") in from board edges and spaced 300 mm (12") o.c. in the field according to the steel stud producer’s installation guide. The wall cavity was filled with R12 glass fiber of around 65 mm thick. Figure 4 illustrates such a stud wall specimen.

![Figure 4. A typical stud wall specimen](image-url)
9 MEASUREMENTS OF ASTC OF INNOVATIVE COMPOSITE WOOD STUD WALL SPECIMEN AND THE REFERENCE STEEL STUD WALL

The airborne sound insulation performance of the 4 innovative composite stud wall specimens along with the reference steel stud wall was tested in Soleno acoustics test facility in Montreal on February 1, 2018.

All measurements were made in general conformance with the specified standards and protocols (identified in the sections below). The precision levels were in accordance with the technical requirements.

9.1 Test Facility

Solenos acoustics test facility is a mock-up of side by side duplex. The mock-up had two chambers side by side. The chamber was 4.45 m (172 in.) long, 3.61 m (142 in.) wide, and 2.82 m (111 in.) high. The exterior walls of the chambers were built with 200 mm (8 in.) thick reinforced concrete. The interior walls were built with 100 mm (4 in.) reinforced concrete. There was a 50 mm (2 in.) air gap between the two interior walls separating the two chambers. On the interior walls, there were openings of 1.486 m by 1.486 m for mounting the test wall specimen. The specimen was mounted to the openings using clips. The gaps between the stud wall specimens and the opening frame were about 6 mm – 13 mm and were filled with insulation materials and covered with 2 pieces of 2x6 lumber wrapped with 6 mm rubber. Figure 5 (a) shows the stud wall specimen and its mounting jigs. A steel frame made of 3 mm steel strips of 86 mm wide was on the other side of the opening to hold the back of the specimen as shown in Figure 5 (b).

![Front view of the wall specimen mounted in the opening](image1)

![Back view of the wall specimen mounted in the opening showing the steel frame](image2)

Figure 5. Wall specimen and its mounting in the Soleno test facility
The two chambers have the same size, and are almost identical, except for the roofs. Figure 6 shows the roofs of the source and receiving chambers. The roof in the chamber that was used as receiving room was built with a 200 mm (8 in.) thick reinforced concrete slab (Fig. 6(b)). The roof in the other chamber that was used as source room was also built with a 200 mm (8 in.) thick reinforced concrete slab but having a 2.44 m (8 ft.) by 3.05 m (10 ft.) opening. During testing, the opening was covered with a 175 mm CLT panel (Fig. 6 (a)).

![Source chamber showing the CLT roof](image1)

![Receiving chamber showing the concrete roof](image2)

**Figure 6. Roofs of source and receiving chambers in the Soleno test facility**

As observed in Figure 6, all concrete walls had sound absorber boards of 0.6 m (2 ft.) wide by 2.4 m (8 ft.) long. There were four boards on each wall except the wall with the door. There were three sound absorber boards on the wall with the door. The sound absorber boards were made of 19 mm (3/4 in.) thick wood fibreboards (Sonopan) and 5 mm thick AcousticTech 5000 on the surfaces of SonoPan.

The test facility was built in a warehouse with a reinforced concrete ground floor. The floors in the chambers had an additional 76 mm (3 in.) thick reinforced concrete slab above the concrete ground floor. The chamber floors were covered with carpet. The chambers had no window and only had the double-skin wood doors. The temperatures of the two chambers at the testing were around 16°C - 18°C.

### 9.2 Test Equipment

The acoustic test system used for the tests was acquired in 2010 and consisted of a building acoustic source kit, which includes a sound source, sound pressure level meters, and data acquisition and analysis software. Specifications provided by the equipment supplier indicated that the measurement systems were designed to conform to the requirements of the appropriate standards. The calibration data sheets provided by the equipment suppliers indicated that the instruments were calibrated in 2010 to the appropriate standards. The detailed descriptions of the instruments of the kit are as follows:
• Precision integrating sound level meter, Larson Davis Model 831, with frequency analysis function and automatic acquisition of reverberation times;

• Post-data analysis software, Larson Davis DNA4-4.5.1.0, continually updated, frequency analysis to obtain the spectrums, single number ratings, and reverberation time spectrums;

• Precision ½-inch microphone, PCB model 377B20, with pre-amplifier;

• Calibrator, Larson Davis model CAL200, for all microphones;

• Omnidirectional source with amplifier, Larson Davis model ODS12.

9.3 Test Method

The microphone was calibrated before testing started and verified after measurements. The fixed microphone position method was used for the tests to measure the average sound pressure levels of the source room and the decay rates of the receiving room measured by the microphone at various positions. The omnidirectional source was located in the centre of the source room.

As required in the ASTM E1007 method, reverberation times were acquired with a pink noise interrupted source, in order to calculate equivalent sound absorption in the receiving room, in accordance with ASTM E2235 (ASTM 2004b).

The background noise was measured in the receiving room, in accordance with ASTM E1007 (ASTM 2011). The airborne sound transmission through the wall assembly was also measured in the receiving room, using the omnidirectional source located on the source room, in accordance with ASTM E336 (ASTM 2011). The single number rating of the airborne sound insulation performance of the specimen, in terms of ASTC, was calculated in accordance with ASTM E413 (ASTM 2010), using normalized test data. Figure 6 as shows the airborne sound transmission test.

Larson Davis DNA software was used to perform calculations to obtain the ASTC ratings.

10 RESULTS AND DISCUSSIONS

Table 2 summarises the information on the measured ASTC of the stud walls. Appendix I provides the apparent transmission loss in 1/3 octave frequency band spectrums of steel stud and innovative composite wood stud non-loadbearing wall specimens.
Table 2. Measured stud wall ASTC

<table>
<thead>
<tr>
<th>Stud and Wall ID</th>
<th>Wall ASTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference steel stud wall specimen</td>
<td>37</td>
</tr>
<tr>
<td>Innovative composite wood stud wall specimen-1 (White birch LVL)</td>
<td>38</td>
</tr>
<tr>
<td>Innovative composite wood stud wall specimen-2 (Poplar LVL)</td>
<td>38</td>
</tr>
<tr>
<td>Innovative composite wood stud wall specimen-3 (low density MDF)</td>
<td>38</td>
</tr>
<tr>
<td>Innovative composite wood stud wall specimen-4 (high density MDF)</td>
<td>38</td>
</tr>
</tbody>
</table>

All the innovative composite wood stud walls specimens achieved at least the same ASTC ratings as the reference of 25 gauge steel stud wall.

It was also noticed that all the innovative composite wood studs had lower bending stiffness than the 25 gauge reference steel stud. But, in this limited study, there was no strong correlation observed between the stud mechanical properties (such as density and bending stiffness) and the ASTC.

It was also noticed that the ASTC seemed not very sensitive to variation in the stud mechanical properties. There is no explanation for this observation. Further study is needed to examine the effects of stud mechanical properties on the stud wall sound insulation performance to optimize the innovative composite wood stud design.

For confidentiality reason, values of the measured mechanical properties are not shown in this report.

11 CONCLUSIONS

In general, the conceptual design and fabrication work and the preliminary test results have shown that a partition-wall stud made out of composite wood material could have same or better airborne sound insulation performance as compared to the 25 gauge steel stud. The concept is promising, with a manufacturing process and fabrication that would work or be practical.

12 RECOMMENDATIONS FOR NEXT STEPS

It is recommended to:

6) File a concept disclosure document of the design and fabrication of the innovative composite wood studs;

7) Extend the design, manufacturing process and fabrication to use other wood composites;
8) Optimize the design and fabrication for the innovative composite wood studs to achieve higher ratio of performance to cost than the 25 gauge steel stud;

9) Enhance FPI’s current mock-up capacity to include the wall test facility;

10) Examine the effects of various design and fabrication parameters on the various performance aspects for the optimization using the enhanced mock-up.

13 REFERENCES


ASTM E413-10. 2010. Classification for Rating Sound Insulation. ASTM International. West Conshohocken PA, USA.


APPENDIX I

Apparent transmission loss in 1/3 octave frequency band spectrums of steel stud and innovative composite wood stud non-loadbearing wall specimens
Figure 7. Measured apparent transmission loss in 1/3 octave frequency band spectrum (in blue) through the steel stud wall assembly on February 01, 2018.
Figure 8. Measured apparent transmission loss in 1/3 octave frequency band spectrum (in blue) through the innovative composite wood stud wall assembly-1 on February 01, 2018
Figure 9. Measured apparent transmission loss in 1/3 octave frequency band spectrum (in blue) through the innovative composite wood stud wall assembly-2 on February 01, 2018.
Test specimen area S: 2.2 m²
Source room volume: 44.0 m³
Receiving room volume: 44.4 m³

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>ATL dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>17.7</td>
</tr>
<tr>
<td>160</td>
<td>26.4</td>
</tr>
<tr>
<td>200</td>
<td>32.2</td>
</tr>
<tr>
<td>250</td>
<td>34.2</td>
</tr>
<tr>
<td>315</td>
<td>34.8</td>
</tr>
<tr>
<td>400</td>
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<td>500</td>
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<td>630</td>
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<td>39.4</td>
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<td>2500</td>
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<tr>
<td>3150</td>
<td>39.0</td>
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<tr>
<td>4000</td>
<td>42.7</td>
</tr>
</tbody>
</table>

Classification based on ASTM E413 - 04
ASTC = 38

Test report number: Acoustical testing laboratory name: Soleno acoustic laboratory
Date: 01/02/2018 Signature:

Figure 10. Measured apparent transmission loss in 1/3 octave frequency band spectrum (in blue) through the innovative composite wood stud wall assembly-3 on February 01, 2018
Figure 11. Measured apparent transmission loss in 1/3 octave frequency band spectrum (in blue) through the innovative composite wood stud wall assembly-4 on February 01, 2018