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Heavy fillings on CLT floors I – Comparative Analysis of Impact Sound Pressure Levels in Small-Scale Tests

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Abstract

Elastically bound granular chippings are widely used in cross-laminated timber (CLT) floor constructions to improve the impact sound insulation of the construction. Although laboratory measurements often demonstrate very low normalized impact sound pressure levels for such systems, significant variability has been observed in practice. In the present study the impact sound pressure measurements of different chipping types in small-scale tests are shown. Various parameters – including impact sound insulation, type of chippings, filling height, and binding agents – are investigated. The results are presented in terms of impact sound reduction in order to more clearly identify frequency ranges of improvement and deterioration, enabling robust conclusions to be drawn. The material properties of the different heavy fillings and binding mechanisms were also investigated and are shown in the second part of this paper.

Keywords: *cross-laminated timber (CLT) floors, impact sound pressure level, elastically bound fillings, small-scale tests*

1. Introduction

Cross-laminated timber (CLT) floor constructions with floating screeds and granular chippings (Figure 1) are commonly used in multi-storey timber buildings. Elastically or mechanically bound fillings are frequently applied as levelling layers and additional mass to enhance airborne and impact sound insulation. Previous research [1, 2] also supports the assumption that the type of chippings and their binding agent strongly influence the acoustic performance. Measurements by Holzforschung Austria have shown that floor assemblies with apparently identical configurations may exhibit normalized impact sound pressure levels $L_{n,w}$ (in dB) differing by more than 10 dB, depending primarily on the binding type of the granular filling (Figure 3).

In the worst case, elastically intended fillings behave acoustically like rigid cement-bound layers due to improper binder ratios or unsuitable material properties. However, the threshold at which a filling can be considered "elastically bound" remains undefined, and no standardized classification exists.

To improve planning reliability in timber construction, systematic laboratory investigations were conducted. The study comprised:

- **Small-scale tests**, enabling controlled variation of impact sound insulation mats (different types), gravel types, filling heights binding agents. The results are presented in this study (Part I).
- **Full-scale tests**, representing realistic floor constructions and focusing on reproducibility. The results were published in [3].
- **Material characterization**, including determination of longitudinal wave velocity and loss factor of the fillings. the results and its influence on the impact sound pressure levels are presented in the second part of this study [4].

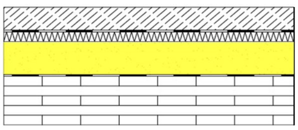

Figure 1. Cross-laminated timber (CLT) floor structure with a ballast layer (yellow) and floating screed. Component gdmnxn06 on www.dataholz.eu [5].

Similar experiments with small-scale specimens have been conducted on timber beam floors in [6].

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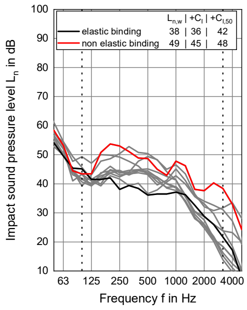

Figure 2. Various measurements of "elastically" bound fillings from Holzforschung Austria; indicating the least favorable (red) and the most favorable (black) variant.

2. Material and method

2.1 Measurement of the Normalized Impact Sound Pressure Levels in Small-Scale Tests

All impact sound pressure measurements were carried out in the M-test facility of the Acoustic Center Austria [7] in accordance with ÖNORM EN ISO 10140-3:2021 [8]. While the full-scale tests, with a radiating area of 19,8 m², meet the normative requirements, the radiating area of 1,2 m² in the small-scale tests is significantly below the required minimum. The volume of the receiving room was 55 m³ for the small-scale tests and 59 m³ for the full-scale tests. The measured sound pressure levels were corrected for background noise, which, if required, was limited to high frequencies above 3150 Hz. No correction for flanking transmission was required in any of the measurements. The frequency range from 25 Hz to 5000 Hz was recorded in all cases. For the measurement of the normalized impact sound pressure level, eight fixed microphone positions were used. These positions remained unchanged throughout all tests, ensuring consistent measurement conditions and enabling reliable comparisons between different configurations. Additionally, the acceleration level was recorded using five sensors; however, these data are not presented in this study.

2.2 Investigated Variants

All systematic laboratory investigations were conducted as part of a bachelor's thesis [9]. All measurements were performed on a CLT floor. Except for the bare floor measurements, a prefabricated cement screed was additionally applied. The configurations are defined as follows:

- 160 mm CLT floor (5-layer), (1,31 × 1,11) m², surface mass m' = 73,8 kg/m²
- 80 mm cement screed (prefabricated), m' = 207,0 kg/m²

In the first step, four types of impact sound insulation mats (see Table 1) were tested on the bare CLT floor with floating screed to evaluate their properties. The stiffnesses of all insulation materials were measured according to [10]. From these measurements, the damping coefficient was also determined following [11]. The standard impact sound insulation mat used was MW1.

Table 1. Examined types of impact sound insulation mats. The dynamic stiffness (s' in MN/m³) and the damping coefficient (c in N/(ms)) were measured.

Name	Material	dynamic stiffness s' in MN/m³	Damping coefficient c in N/(ms)
MW1	mineral wool	12	251
MW2	mineral wool	6	168
EL1	Polyurethane foam with nubs	12	620
EL2	Polyurethane elastomer with nubs	21	486

In the second step, different loose filling variants were investigated, beginning with chipping types according to Table 2. The standard chippings were paving chippings 2/4. Subsequently, three filling heights of 80 mm, 100 mm, and 120 mm were tested.

Table 2. Examined gravel types.

Material	grain size in mm	bulk density in kg/m³
paving chipping 2/4 (edged grain)	2 – 4	1300
gravel 3/5 (round grain)	3 - 5	1500
gravel 4/8 (round grain)	4 - 8	1500
basalt chipping 2/4 (edged grain)	2 - 4	1300

In the third step, different types of binding agents were evaluated according to Table 3. First, mechanical bindings were tested, using either a batten grid or cardboard honeycombs. The fillings were loosely placed in these structures, as the binding is realized through the respective containment system. Following the mechanical bindings, chemical binding agents for the fillings were tested (see Table 3).The material properties of the different fillings and binding mechanisms are presented in [4]

Table 3. Examined binding types.

Binding type	Binding agent
without	loose
mechanically bound	batten grid with 20 mm chipping overlap
mechanically bound	batten grid without overlap
mechanically bound	cardboard honeycomb (two layers: 60 mm and 40 mm)
nonelastic bound	cement
"elastically bound"	polyurethan (3 variants)
"elastically bound"	Latex
"elastically bound"	Polymer + cement (3 variants)
"elastically bound"	Polymer

3. Results and discussion

3.1 Comparison of Small- and Full-Scale Tests of the CLT Floor

In Figure 3 on left side, the measurements of the basic CLT floor are shown in black. The results of the small-scale tests are represented by solid lines, while those of the standard-size specimens are shown by dashed lines. As can be seen the impact sound pressure levels of the small specimens are lower compared to those in standard size. However, the qualitative trend of the normalized impact sound pressure levels is similar. The configurations, including basic CLT floor with floating screed on mineral wool are illustrated in red. Again, the solid line represents the small-scale specimen, while the dashed line represents the full-scale specimen. As in the previous case, the normalized impact sound pressure levels of the small specimens are lower than those of the standard-size specimens. Overall, the qualitative trend differs more noticeably than in the case of the bare slabs. This can be attributed to the fact that, in the low-frequency range, the smaller area is not able to radiate vibrations in the same manner as the larger one. In the mid-frequency range, distinct eigenmodes develop in the small-scale cement screed, which are clearly visible. For the larger screed, these modes occur at significantly lower frequencies. These results indicate that the data of the small- and large-scale measurements cannot be directly compared. Particular caution should be exercised when considering the single-number quantities of the small-scale tests. Nevertheless, a parametric study based on relative comparisons between the variants is feasible and allows conclusions to be drawn regarding the behavior of full-scale specimens. The low-frequency range from 25 Hz to 100 Hz is not considered in further analysis of the small-scale tests. The analysis is therefore limited to the frequency range from 100 Hz to 5000 Hz. Figure 3 on right side shows another investigated floor configuration measured at both small and large scales. The filling consists of 100 mm of loose chipping (paving chipping 2/4), placed within a batten grid and covered by 20 mm. The small-scale specimen again exhibits lower impact sound pressure levels. The qualitative trend shows better agreement compared to previous cases, although the eigenmodes of the screed plate remain clearly visible. These results indicate that such configurations are also suitable for parametric investigations. The analyses in the following sections were all conducted using data from the small-scale tests.

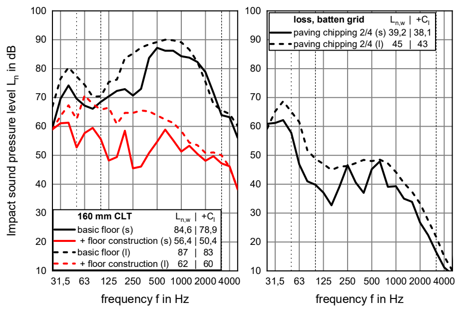

Figure 3. Left side: Impact sound insulation of a bare 160 mm CLT-floor in small scale (s, solid black) and large scale (l, dashed black). Furthermore, the same CLT-floor with impact sound insulation mat (MW1) and floating screed is shown for the small-scale (s, solid red) and the large scale (l, dashed red) element. Right side: Impact sound insulation of a 160 mm CLT-floor in small scale (s, solid black) and large scale (l, dashed black) with a 100 mm heavy filling in batten grid with 20 mm overlap beneath the floating screed on mineral wool (MW1).

3.2 Comparison of Impact Sound Insulation Materials

In this section, the four impact sound insulation materials listed in Table 1 are compared. These were placed on the CLT floor and covered with a prefabricated floating screed. The comparison is shown in Figure 4. For the evaluation, the impact sound reduction is used, as it allows improvements and deteriorations to be visualized more clearly. Values below zero (negative) indicate a deterioration compared to the reference, while values above zero (positive) indicate an improvement. Additionally, the single-number quantities $\Delta L_{n,w}$ and $\Delta L_{n,w} + C_I$ (in dB) are provided to quantify the changes relative to the weighted normalized impact sound pressure level, with and without the spectrum adaptation term C_I. The reference in Figure 4 on left side is the impact sound insulation MW1. When considering variant MW2, an improvement over the entire frequency range from 100 Hz onwards can be observed. This meets the expectations of using a mineral wool with lower dynamic stiffness. In contrast, the elastomer variants EL1 and EL2 exhibit different behavior. Both show a reduction in impact sound insulation in the frequency range from 100 Hz to 500 Hz (EL1) respectively 800 Hz (EL2). Significant improvements are only observed in the high-frequency range. All three insulation materials improve the weighted normalized impact sound pressure level compared to the reference, even though only MW2 has a lower dynamic stiffness. When including the spectrum adaptation value C_I, a significant increase is observed for MW2, whereas it decreases for the elastomer systems. The comparison of impact sound insulation materials was also conducted Con cement-bound fillings. The impact sound reduction curves are shown in Figure 4 on right side. The results differ from those obtained for the basic CLT floor. Using MW2 generally results in improvements across most of the frequency range, although less pronounced than in the bare slab case. The elastomer-based insulation materials show a reduction in performance across almost the entire frequency range, with EL2 exhibiting a more pronounced effect. This is also reflected in the single-number values: MW2 increases the value by approximately 1 dB, whereas the elastomer systems decrease it by more than 1 dB.

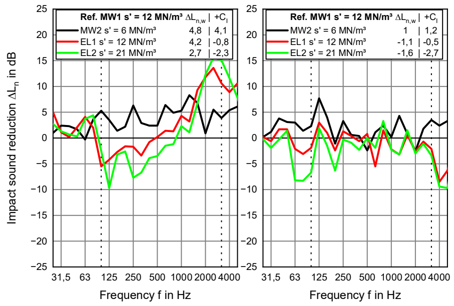

Figure 4. Left side: Impact sound reduction of insulation materials on a 160 mm CLT-floor with floating screed. The reference is the impact sound insulation mat MW1. Right side: Impact sound reduction of insulation materials on a 160 mm CLT-floor with cement bound filling and a floating screed. The reference is the impact sound insulation MW1.

3.3 Comparison of Different Types of Chippings

In this section, the four types of chipping listed in Table 2 are compared. These fillings were loosely placed within a batten grid with a 20 mm covering layer and measured in combination with impact sound insulation mat MW1 and a floating screed. Figure 5 on the left side shows the impact sound reduction. The reference configuration consists of 100 mm of paving chipping 2/4. The most significant differences occur in the frequency range from 200 Hz to 800 Hz. The two rounded-grain gravel types show improved performance in the mid-frequency range compared to the reference. In contrast, the basalt chipping 2/4 exhibits a significant reduction in impact sound insulation in the mid- and high-frequency ranges. This is also reflected in the weighted normalized impact sound pressure levels, which increase by more than 2 dB for the rounded gravel variants, whereas a reduction of nearly 1 dB is observed for basalt chipping. The reasons for this behavior require further investigation. One possible explanation is that rounded grains have smaller areas compared to crushed materials, resulting in higher internal damping and thus improved performance in small-scale specimens. The different types of chippings were also tested with cement binding to determine whether similar trends as in loose fillings occur. The results are shown in Figure 5 on right side. In contrast to the loose filling, frequency ranges that previously showed improvements now exhibit reductions, and vice versa. This indicates that the influence of the chipping type changes significantly when a binding agent is used. Between 100 Hz and 400 Hz, improved impact sound insulation is observed for gravel 4/8 and basalt chipping 2/4. Between 400 Hz and 1000 Hz, all variants show reduced performance. At higher frequencies, performance improves again for all systems.

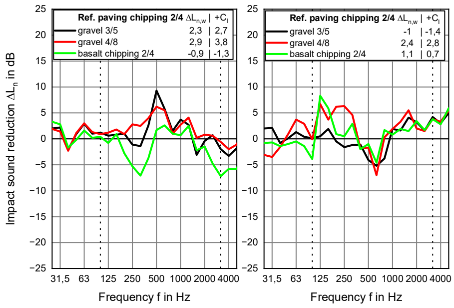

Figure 5. Left side: Impact sound reduction of 100 mm filling types in batten grid with 20 mm overlap on a 160 mm CLT-floor with impact sound insulation mat MW1 and floating screed. The reference is 100 mm paving chipping. Right side: Impact sound reduction of 100 mm filling types with cement binding on a 160 mm CLT-floor with impact sound insulation mat MW1 and floating screed. The reference is 100 mm paving chipping with cement binding.

3.4 Comparison of Filling Heights for Loose Fillings

This section compares three different filling heights. The fillings were applied to the basic CLT floor and tested in combination with impact sound insulation mat MW1 and a floating screed. The results are shown in Figure 6. The 80 mm filling exhibits slightly lower sound insulation compared to the 100 mm reference, with the largest differences occurring between 200 Hz and 400 Hz. The single-number values are also slightly reduced, which is within expectations. The 120 mm filling fluctuates around the reference, showing both slight improvements and deteriorations across the frequency range. However, the difference of the single-number value indicates a reduction similar to that observed for the 80 mm filling. The reduced performance of the 120 mm filling was not expected. Measurements on full-scale specimens with filling heights between 80 mm and 120 mm showed small improvements in the single-number value with increasing thickness.

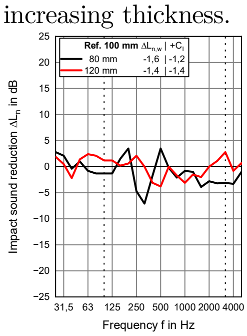

Figure 6. Impact sound reduction of heights of a loose filling on a 160 mm CLT-floor with impact sound insulation mat MW1 and floating screed. The reference is 100 mm paving chipping 2/4.

3.5 Comparison of Loose Mechanically Bound Fillings

In this section, four mechanically bound fillings (see Table 3) are compared. All configurations have a height of 100 mm and consist of paving chipping 2/4. The impact sound reductions are shown in Figure 7. The reference is a 100 mm thick loose filling with MW1 insulation and floating screed. The cardboard honeycomb system shows reduced performance between 100 Hz and 400 Hz, followed by a significant improvement at higher frequencies, resulting in an improved single-number value. The two batten grid variants exhibit similar trends. At 600 Hz, the variant without covering performs better, whereas it loses performance in the high-frequency range compared to the covered variant. Both variants show an increase in the single-number value, with the uncovered version performing slightly better. Overall, the honeycomb system provides the best impact sound insulation, followed by the two grid systems. For comparison, a cement-bound variant of the same height is included. This configuration shows a significant deterioration between 100 Hz and 400 Hz and again between 630 Hz and 5000 Hz, leading to a more than 4 dB higher weighted normalized impact sound pressure level.

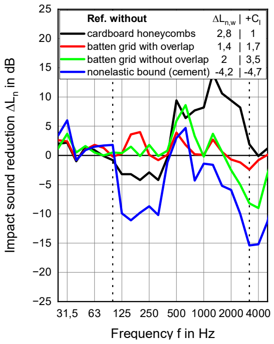

Figure 7. Impact sound reduction of mechanically bound of a loose filling on a 160 mm CLT-floor with impact sound insulation mat MW1 and floating screed. The reference is 100 mm paving chipping 2/4 without bonding. A cement binding with a height of 100 mm is also included (blue).

3.6 Comparison of Intact and Broken Specimens with Binding Agents

Since many of the bound fillings were prefabricated, some specimens were damaged during installation. It was observed that broken specimens exhibited lower measured values compared to intact ones. To investigate this effect, two specimens (with different binders) were deliberately broken after the initial measurements and tested again. The results are shown in Figure 8. For both specimens, an improvement in impact sound insulation is observed in the mid- and high-frequency ranges. Consequently, the single-number value improves by more than 4 dB for the polyurethane-bound system and by more than 2 dB for the cement-bound system. This behavior is likely due to increased internal damping and reduced stiffness of the bonded filling caused by the fractures.

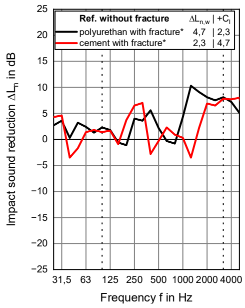

Figure 8. Impact sound reduction of broken filling specimens with different binding agents (marked with *) on a 160 mm CLT-floor with impact sound insulation mat MW1 and floating screed. The reference is respectively the intact (non-broken) specimen of the same variant.

3.7 Comparison of All Investigated Binding Agents with Loose Fillings

In this section, all investigated binding agents are compared with a loose filling. All configurations are shown in Figures 9. Three specimens (marked with *) were damaged during installation, and their results should therefore be interpreted with caution. It is assumed that their single-number values are underestimated by approximately 2 dB to 5 dB (compared to Figure 8). Notably, these correspond to the polymer–cement combinations (Figure 9 right side). All binding agents show reductions in the high-frequency range: from approximately 800 Hz in Figure 9 left side and from approximately 2000 Hz in Figure 9 right side. This shift may partly be attributed to the damaged specimens (see Figure 8). Without such defects, the transition is expected to occur closer to 800 Hz. The cement-bound system exhibits the largest reduction in impact sound insulation between 100 Hz and 400 Hz, consistent with full-scale test results. This results in the largest negative change in the single-number value, exceeding 4 dB. The largest improvement is observed for the latex-bound system in the range from 100 Hz to 1000 Hz, corresponding to an increase of more than 2 dB in the single-number value. Polyurethane-based systems show reductions in the weighted normalized impact sound pressure level between 0 dB and 3 dB. Pure polymer system achieves the largest improvement, exceeding 5 dB. No definitive conclusion can be drawn for the polymer–cement combinations, as all corresponding specimens were damaged.

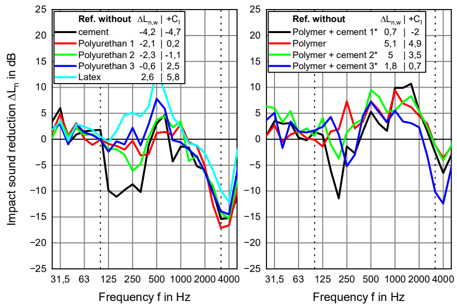

Figure 9. Impact sound reduction of different binding types on a 160 mm CLT-floor with floating screed. The

specimens with fractures are marked with *. The reference is the impact sound insulation of a filling without bonding and MW1.

4. Conclusions

This study systematically investigated the impact sound performance of CLT floor structures under various conditions using small- and full-scale measurements. Key conclusions can be summarized as follows:

1 Scale Effects: Small-scale specimens consistently exhibited lower normalized impact sound pressure levels compared to standard-size specimens, while maintaining similar qualitative trends. The differences are most pronounced at low frequencies and in the presence of screed, due to limited vibration radiation and the occurrence of eigenmodes in smaller specimens. Despite these limitations, small-scale tests are suitable for parametric studies and relative comparisons.

2 Impact Sound Insulation: Mineral wool insulation with lower dynamic stiffness (MW2) provided improvements across almost the entire frequency range, particularly when applied to basic CLT floor or loose fillings. Elastomer-based insulations (EL1 and EL2) showed reductions in mid-frequency ranges, with improvements limited to high frequencies. The spectrum adaptation value C_I amplified the performance differences, highlighting the importance of considering frequency-dependent effects.

3 Filling Materials and Heights: The type of loose filling and its height significantly influenced impact sound insulation. Rounded-grain gravel improved performance in the mid-frequency range, whereas basalt chipping reduced insulation. Filling heights between 80 mm and 120 mm showed minor variations, with the 100 mm standard height generally providing optimal results.

4 Binding Systems: Mechanically bound fillings and various chemical binders demonstrated distinct behaviors. Cardboard honeycombs provided the best overall insulation among mechanically bound variants. Cement-bound systems exhibited substantial reductions in the low- to mid-frequency range, while latex-bound fillings yielded the highest improvements. Broken specimens showed improved performance due to increased internal damping and lower stiffness, highlighting the sensitivity of measurements to material integrity.

5 Interaction Effects: The influence of chipping type and insulation material is highly dependent on the presence and type of binder. Trends observed in loose fillings did not necessarily carry over to cement-bound configurations, indicating that material interactions play a critical role in impact sound behavior.

Overall, the results demonstrate that careful selection of insulation, filling type, height, and binder can substantially influence the impact sound performance of CLT floors. While absolute comparisons between small- and full-scale specimens are limited, relative trends are consistent and can guide design decisions for optimized acoustic performance.

5. Acknowledgments

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