Acoustic underlay manufactured from carpet tile wastes. Part 1: Effect of variation in granular/fibre dry ratio, binder concentration, and waste particle size on impact sound insulation of the produced underlays.

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ACOUSTIC UNDERLAY MANUFACTURED FROM CARPET TILE WASTES

Part 1: Effect of variation in granular/fibre dry ratio, binder concentration, and waste particle size on impact sound insulation of the produced underlays

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Abstract

Carpet waste is of growing concern both to environmentalists and manufacturers pressured by increasing costs of landfill dumping. The challenge for carpet producers is to find ways of minimising their waste or find alternative uses for their unwanted by-products. This paper builds on an earlier study (Taylor, A.: ‘Novel underlays from carpet waste’, Ph.D. thesis, Bolton Institute, U.K., 2004) where carpet tile wastes have been successfully used to produce underlays for domestic as well as commercial markets. To add value, the acoustic behaviour of these underlays, where granular/fibre mixing ratios, binder concentration and particle size distribution play a major role, has been examined in this study. The results show that it is possible to maximise the impact sound insulation capabilities of these underlays by selective control and adjustment of the above variables. Manufacturing formulation consisting of 60:40 granular/fibre mixture ratio, 60% binder concentration and granule particle size dimensions of <2mm is shown to be most appropriate in achieving effective impact sound insulation.

Key Words:

underlay, acoustic, granulation, particle size, binder concentration, impact sound insulation

Introduction

The global market for soft floor covering is estimated to reach $63 billion in 2006, equivalent to 8.2 billion square meters [1]. The market is largely dominated by US and Belgian manufacturers, who together supply approximately 50% of the world’s carpet demand. Processed or clean waste associated with these large production rates are estimated to be around 7%, amounting to ~$4.5 billion worth of goods which are currently destined for landfill sites and/or incinerators [2]. However, growing public concern for the environment and tighter restrictions/costs on landfill sites in recent years has forced many carpet producers to look for more efficient manufacturing methods and/or alternative uses for their inevitable waste.

In an earlier paper, Miraftab et al [3] identified the most likely sources of waste generation in the carpet manufacturing chain, and reviewed some of the existing methods intended to address these issues. Recent research at the Bolton Institute [4] has shown that it is possible to use granulated recycled carpet waste to manufacture viscoelastic underlay that would comply to standard tests and regulations, with the additional benefits of resilience and non-slip characteristics. Further work by Vitamvasova et al [5] and Swift & Horoshenkov [6, 7] have shown that polymeric granulates and fibres, as found in industrial and post-consumer material waste handling processes, may be recycled into materials that have desirable acoustic and physical properties. These novel materials can provide alternatives to virgin products in a number of commercial and environmental noise control applications, including building, automotive, business services and traffic noise abatement.
Further preliminary investigations commissioned by the Institute using the developed underlays, showed [8] that the inherent granular/fibrous combination in these underlays could improve impact sound insulation in flooring applications. This would be beneficial for noise control in buildings in accordance to the current British noise control legislation such as Building Regulations Approved Document E [9].


Production Methodology

Laboratory-scale samples

PVC-backed nylon and polypropylene-tufted tiles obtained from Milliken Carpet and WRACE Technology Group were granulated using a triple-blade, vertical rotation granulator fitted with interchangeable aperture screens to control the particle size outlet. The granulated material was subsequently directed into a cyclone system to separate out the material into granular (PVC backing) and fibrous (from the piles) entities. The granulator and the cyclone system were specifically acquired for this project from Hosakawa Micron Ltd. and Thelcastle Ltd. respectively.

The separated components were then mixed together in controlled ratios in company of a Styrene Butadiene Rubber (SBR) binder supplied by Polymer Products Ltd. To assist uniformity and reduce mixing time, measured quantities of the binder were first ‘foamed’ using a mechanical blender before being mixed with the granular and fibrous components. The mixture was then poured and spread into a mould, ensuring uniform material thickness. The mould was subsequently placed in an oven to allow drying and curing at 130°C for 1-1.5 hours.

Table 1. A summary of the laboratory produced underlay samples and material parameters

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density (kg/m³)</th>
<th>Granular mass content</th>
<th>Fibrous mass content</th>
<th>SBR Foaming Binder mass content (wet)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>255</td>
<td>0%</td>
<td>40%</td>
<td>60%</td>
<td>255</td>
</tr>
<tr>
<td>N2</td>
<td>231</td>
<td>12%</td>
<td>28%</td>
<td>60%</td>
<td>231</td>
</tr>
<tr>
<td>N3</td>
<td>277</td>
<td>24%</td>
<td>16%</td>
<td>60%</td>
<td>277</td>
</tr>
<tr>
<td>N4</td>
<td>355</td>
<td>32%</td>
<td>8%</td>
<td>60%</td>
<td>355</td>
</tr>
<tr>
<td>N5</td>
<td>568</td>
<td>40%</td>
<td>0%</td>
<td>60%</td>
<td>568</td>
</tr>
<tr>
<td>BC60</td>
<td>277</td>
<td>24%</td>
<td>16%</td>
<td>60%</td>
<td>277</td>
</tr>
<tr>
<td>BC50</td>
<td>285</td>
<td>30%</td>
<td>20%</td>
<td>50%</td>
<td>285</td>
</tr>
<tr>
<td>BC40</td>
<td>356</td>
<td>36%</td>
<td>24%</td>
<td>40%</td>
<td>356</td>
</tr>
<tr>
<td>P1</td>
<td>292</td>
<td>24% (particles &gt;3.35mm)</td>
<td>16%</td>
<td>60%</td>
<td>292</td>
</tr>
<tr>
<td>P2</td>
<td>288</td>
<td>24% (2.47-3.35mm)</td>
<td>16%</td>
<td>60%</td>
<td>288</td>
</tr>
<tr>
<td>P3</td>
<td>302</td>
<td>24% (2.0-2.47mm)</td>
<td>16%</td>
<td>60%</td>
<td>302</td>
</tr>
<tr>
<td>P4</td>
<td>316</td>
<td>24% (1.4-2.0mm)</td>
<td>16%</td>
<td>60%</td>
<td>316</td>
</tr>
<tr>
<td>P5</td>
<td>305</td>
<td>24% (1.23-1.4mm)</td>
<td>16%</td>
<td>60%</td>
<td>305</td>
</tr>
<tr>
<td>P6</td>
<td>329</td>
<td>24% (1.0-1.23mm)</td>
<td>16%</td>
<td>60%</td>
<td>329</td>
</tr>
<tr>
<td>P7</td>
<td>247</td>
<td>24% (0.68-1.0mm)</td>
<td>16%</td>
<td>60%</td>
<td>247</td>
</tr>
<tr>
<td>P8</td>
<td>267</td>
<td>24% (0.50-0.68mm)</td>
<td>16%</td>
<td>60%</td>
<td>267</td>
</tr>
<tr>
<td>P9</td>
<td>348</td>
<td>24% (particles &lt;0.5mm)</td>
<td>16%</td>
<td>60%</td>
<td>348</td>
</tr>
</tbody>
</table>

A number of samples were manufactured in the laboratory to a standard thickness of 10mm using the material production technique described. The following material and process parameters were varied: the granular/fibre (G:F) ratio of the dry component, binder concentration and particle size distribution. Table 1 presents a summary of the laboratory-produced underlay samples and the material parameters. Samples N1 to N5 in Table 1 correspond to changes in combined granule/fibre content whilst SBR concentration is kept at 60%. Samples BC60 to BC40 correspond to changes in SBR concentration.
binder concentration whilst maintaining the G:F ratio of the dry component at 60:40. P1 to P9 refer to changes in PVC grain or granular size. The variations in size were achieved by passing the granules through a series of meshes of decreasing aperture size.

**Experimental Methodology**

**Impact Transmission rig**

Underlays designed for use in acoustic flooring systems must comply with Building Regulations Approved Document E [7] and ISO 140 part 8 [9]. However, it is both impractical and expensive to conduct these tests at accredited facilities for a large number of samples. In order to enable a comparative assessment of impact sound insulation performance, a small test rig (see Figure 1) was constructed which allowed for much smaller specimens to be tested efficiently in the laboratory. The testing of optimised samples in accordance with international standards is discussed in Refs. [11-12]

**Figure 1.** Schematic diagram of the impact transmission test rig

Prepared underlay samples were fixed to an 18mm-thick timber plank or a 25mm-thick concrete slab, designed to simulate a typical flooring system. The samples were then subjected to impacts of constant force from a brass cylinder of mass 500g, dropped in a tube from a height of 40mm as shown in Figure 1. An accelerometer attached to the underside of the plank/slab measured the acceleration level of the vibration transmitted through the structure.

**Figure 2.** Time history of a typical impact event showing selection of the ‘first arrival’

Impact events were recorded digitally using PC Sound Recorder software at 16bit, 22050 Hz sampling rate. The resulting time histories were analysed using MATLAB™ software. A typical example of the recorded time histories is shown in Figure 2. This figure shows that two impacts by the cylinder are
typically observed. The second impact, which is due to the cylinder bouncing from the material surface, was excluded from the analysis. Only the first impact was selected (the signal shown in Figure 2 within the dotted red lines), and from this signal the octave-band relative acceleration levels were calculated. This procedure was carried out for each laboratory-produced carpet waste underlay sample. By comparing the octave band spectra attained, the relative degree of attenuation of impact sound by each sample was assessed. Accordingly, the acoustic performance of the recycled carpet underlays was determined.

Results & Discussion

Although airborne sound absorption and transmission loss in an underlay are two important parameters, the ability of the underlay to insulate against transmission of impact sound is the most critical acoustic attribute with regards to the suitability of the produced samples for application as a carpet underlay. Hence, the influence of physical modification in underlay makeup on impact sound insulation of these samples was the subject of this study.

Effect of granular/fibre mixing formulation

The first set of results shown in Figures 3 and 4 refer to the impact sound responses of bare (untreated) timber and concrete-simulated floors. These results provide a baseline for comparative assessments for the impact sound insulation performance of the timber and concrete floors insulated with a recycled acoustic underlay. Figures 5-8 show the influence of each underlay with and without a carpet overlay on the impact sound insulation on both timber and concrete flooring. We note that the lower the magnitude of the transmitted vibration, the better the sample performs under test.
The results shown in Figures 3 and 4 demonstrate that a bare wooden floor is a bad impact sound insulator. The inclusion of an underlay significantly improves impact sound insulation for both timber and concrete flooring, as illustrated in Figures 5 and 7. The introduction of a carpet overlay improves impact sound insulation further, with a particularly pronounced reduction in the acceleration level.
observed in the case of the concrete floor (see Figure 6 and 8). The results also show that neither purely fibrous (sample N1) nor purely granular (sample N5) provide the best acoustic performance (see Figures 5 – 8 and Table 1). It is also shown that granular/fibre mixed underlays appear to show better performance in their impact sound insulation capabilities. Sample N3, a 60:40 granule/fibre mixture (see Figures 5-8), shows the best sound insulation performance compared to other granular/fibre permutations, e.g. sample N2 (30:70 mixing ratio) and sample N4 (80:20 mixing ratio).

These findings have a number of implications. Firstly, these suggest that purely fibrous or purely granular formulations are not well suited for use as acoustic underlays. This conclusion fits in well with characteristics deemed undesirable in a normal underlay application. A purely fibrous based underlay would be easily distorted upon application of a load, and would not be able to recover effectively. In the purely fibrous sample, compression occurs in a single stage as the pore space between the fibres is squeezed and the fibres move closer together. The purely granular sample also compresses in a single stage; the grains are in contact from the offset, and are merely distorted and flattened along the axis of compression. A purely granular sample tends to attain a much higher value of the compressional modulus, resulting in the reduced impact sound insulation performance for a given value of the impact force.

In the mixed (granular & fibre) samples, the grains are held apart in a loose matrix by the fibres, and therefore compression occurs in two stages. First, the pore space is reduced as the fibres move closer together. Second, the grains come into contact and begin to be distorted and flattened. There may also be some overlap between these two stages. By spreading a given impact over a longer time period in this way, the total amount of impact energy that passes from one surface of the sample to the other may be reduced. The interconnected granule/fibre configuration also helps the recovery, as the fibrous components are not necessarily aligned along the axis of compression, and can therefore recover more effectively once the load is removed. The fact that the 60:40 mixture behaves better than the other mixing permutations would probably require further investigation, but it conveniently coincides with the natural PVC/fibre content of the original tiles, hence alleviating the need for separation and subsequent mixing for commercial production.

**Effect of binder concentration**

The results showing the effect of the binder concentration on the impact sound insulation are presented in Figures 9-12. In this experiment the grain: fibre ratio was maintained at a constant of G:F = 60:40. The results suggest that the effect of this binder concentration is relatively small.

The method of mixing rather than binder concentration appeared to have a more pronounced effect on these results. Reducing the binder concentration from 60% to 50% as shown in these figures does not significantly change the impact sound insulation performance (see Figures 9-11). However, dropping the binder concentration down to 40% affected the mixing efficiency of the grain/fibre/binder mix, and resulted in the reduced impact sound insulation performance at around 500 Hz, as illustrated in Figures 9 to 12.
Effect of granule size distribution

The granulated output from the triple-blade, vertical-rotation granulator passes through a screen of a particular aperture size before being separated into fibres and granules in the cyclone system. The particle size distribution is therefore a function of the aperture of the screen installed at the time of granulation. In fact, four screens with aperture sizes of 2mm, 3mm, 4mm and 6mm were used in this
study. Figures 13 to 16 display the measured particle size distribution for the granulated carpet mix, which results from the granulation process with a screen with a particular aperture.

Figure 13.

Particle Size Distribution from 3mm Screen

Figure 14.

Particle Size Distribution from 4mm Screen

Figure 15.

Particle Size Distribution from 6mm Screen

Figure 16.
To control the particle size further, the post granulated and screened granules were subjected to a sieving process. This involved passing the granulated material through a stack of meshes of decreasing aperture size installed on a vibrating table. This process separated the granules into different particle size components in the following manner: >3.35mm, 2.47-3.35mm, 2.0-2.47mm, 1.4-2.0mm, 1.23-1.4mm, 1.0-1.23mm, 0.68-1.0mm, 0.5-0.68mm and <0.5mm. However, the particle size distribution obtained by sieving was dependent on the size of the screen that had been used during the granulation process (i.e. with a 2, 3, 4 and 6mm aperture).

The sieved granular waste was separated, and 9 samples (Table 1, P1 to P9) were produced using the 60:40 grain to fibre ratios and binder concentration of 60%. Sample P1 contains the coarsest grains, (>3.35mm) and sample P9 contains the finest grains (<0.5mm). Figures 17 to 20 present the dependence of the relative acceleration levels on the particle size of the granular mix used in the laboratory production process.

The results indicate that particle size does have a strong effect on the impact sound insulation performance. Generally, the smaller particle size samples, i.e. P6-P8 (> 0.5mm <1.23mm), seem to perform best. It is also interesting to note that these particle sizes correspond well to particle distribution obtained using the 2mm screen (Figure 13), hence alleviating the need for sieving post granulation and screening.

Conclusion

This study has shown that it is possible to produce and develop acoustic underlays from PVC-backed, nylon or polypropylene carpet tile wastes. It has shown that variables such as dry granule to fibre ratios and particle size distribution play a major role in optimising impact sound insulation properties. More specifically, the study has shown that a 60:40 granule/fibre mix, which also corresponds to
natural PVC/fibre mix of the original tiles, provides the best impact sound insulation efficiency, thus alleviating the need for deliberate granule/fibre separation when considered for commercial exploitations. Furthermore, it has shown that binder concentration is not significant in its effect on impact sound insulation, so long as it is maintained within a 50% to 60% range and effective binder/ingredient mixing is achieved. Finally, it has demonstrated that finer particle size granules, i.e. ≤ 2mm, provide the most effective impact sound insulation when using the established formulation, i.e. 60:40 (G:F), and 60% binder concentration. This allows granulated samples to be used straight after passing through a 2mm aperture screen. Part 2 of this study will report on the optimised production know-how of these underlays, and compare their acquired properties with commercially available underlays of similar calibre in accordance with universal standards.

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References

12. ACOUSTIC UNDERLAY MANUFACTURED FROM CARPET TILE WASTE
13. Part 2: Comparative study of the optimised underlay and commercial products of similar calibre in accordance with universal standards, to be published.