ACOUSTIC UNDERLAY MANUFACTURED FROM CARPET TILE WASTES

Part 2: Comparative study of optimised underlay with commercial products of similar calibre in accordance to universal standards

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Abstract

Carpet waste has successfully been converted into acoustic underlay materials that compete with commercial counterparts both in terms of performance and costs. This paper builds on an earlier paper [Miraftab et al, Autex Res.J.5(2), 96-105 (2005).] where granular/fibre mixing ratios, binder concentration and particle size distribution were shown to play a major role in maximising impact sound insulation capabilities of developed underlays. Product optimisation with respect to the particle size as governed by the aperture dimension and mean effective fibre length is further explored in this paper, and the developed underlay is compared with a selection of commercially available acoustic underlays. The results show that a 2mm-aperture screen at the granulating chamber output yields a waste stream with grains in the size range of 0.5-1.0mm and a mean effective fibre length of 2.75 mm which was most suitable to work with, and gave rise to samples with the best impact sound reduction performance. The optimised sample of 10mm recycled underlay (U2) appeared to perform better than most commercial systems tested. The manufactured underlay withstood, and in some instances, outperformed, during the standard tests as required within the BS 5808 protocol. The study concludes that recycling carpet waste to produce quality acoustic underlay with desirable impact sound insulation characteristics is technically feasible, and a viable alternative to landfill or incineration.

Key words:

underlay, acoustics, aperture, granulation, effective length, tensile strength, dynamic loading, work of compression, impact sound insulation

Introduction

The first part of this study [1] revealed that the granular/fibre mixture ratio, binder concentration and particle size distribution play an important part in reducing the impact sound capabilities of underlays produced from waste carpet tiles. In the earlier paper, it was shown that the optimised acoustic underlay material should be made by granulating polypropylene pile carpet tile waste in a granulator with a 2mm screen. The resultant 60:40 dry granule/fibre mixture should be blended with 60% SBR binder and cured in an oven at 90^{o}C.

The purpose of this paper is to investigate the role played by the size of the granulated components, its relationship with the size of the screen aperture and their consequential effect on the impact sound reduction of the underlays produced. Furthermore, the properties of the optimised underlay is compared with that observed in a number of commercial underlays of similar quality, using the laboratory impact rig [2] and the standard textile underlay tests BS 5808 [4].

Experimental setup

Optimisation of impact sound properties

Using the vertical rotation granulator and the cyclone system detailed elsewhere [2], three types of underlay were produced according to the methodology described in some earlier papers [1, 3]. The sample classification is given in Table 1. Sample U2 represents the proposed formulation recipe based on the 60:40 grain-to-fibre ratio mixture (G:F) obtained from the granulator with the 2mm-aperture screen and 60% binder concentration. Samples U3 and U4 were made using the carpet waste granulated with 3- and 4mm-aperture size screens respectively. All other variables, including granular/fibre ratio, binder concentration, drying/curing time and temperature, were kept constant and identical to those of the U2 samples.

Table 1. Underlay samples produced using screens of different aperture sizes

Sample	Granular mass content	Fibrous mass content	SBR binder mass content (wet)	Density (kg/m^3)
U2	24% (2mm screen)	16% (2mm screen)	60%	230
U3	24% (3mm screen)	16% (3mm screen)	60%	277
U4	24% (4mm screen)	16% (4mm screen)	60%	180

The laboratory impact transmission rig replicating the standard ISO 140 part 8 test [8] was used in these investigations to determine the impact sound insulation of the material samples developed, and to compare their performance against those of a range of commercial underlays. In this test, the underlay sample is installed on a concrete/wooden slab which is designed to simulate a typical flooring system. The sample is then subjected to impacts of constant force from a brass cylinder of 500g mass, dropped in a vertical tube from a height of 40mm. An accelerometer attached to the underside of the slab measures the acceleration level of the vibration transmitted through the structure. These impact events are recorded digitally using a PC sound reorder software at 16bit, 22050Hz. The experimental setup for this test is detailed in [1].

The optimised underlay sample U2 and a selection of commercial underlays were also subjected to the tests in accordance with BS 5808 [4]. This is a standard textile underlay test which was carried out by SATRA, a specialist testing house for floor coverings. The tests included in this standard are BS EN ISO 13934-1:1999 (tensile properties of underlay in machine and cross-machine direction), BS 4939 (determination of thickness loss of textile floor coverings after prolonged heavy static loading), BS ISO 2094:1999 (determination of thickness loss under dynamic loading) and BS 4098 and BS ISO 2094 (work of compression and compression after dynamic loading). Additional tests which are not specified within the BS 5808 requirements for underlays, i.e. the BS 4790 Hot Nut Method [5], were also carried out for further comparisons.

The thickness loss under dynamic loading was measured when the underlays were subjected to cyclic loading treatment. In this experiment, a weight-piece with two steel feet on its underside is repeatedly dropped freely onto the specimen. The specimen is slowly traversed so that the vertical shearing forces produced by the edges of the feet act on the requisite area of the specimen. The thickness loss is then determined after 1000 cycles. The sketch in Figure 1 shows the salient features of this apparatus.

The compression and work of compression of a specimen of underlay, before and after being subjected to a specified dynamic loading regime, are determined over a given pressure range. This is a measure of the likely performance on the floor, and is used to grade underlays into performance categories. Compression and work of compression are calculated between 2kPa and 100kPa before and after dynamic loading for 1000 cycles, in accordance with BS ISO 2094 [6].

The hot nut test involves a heated stainless steel nut that is placed on the test material. The times of flaming, afterglow and the greatest radius of the effects of ignition from the point of application of the nut are measured.

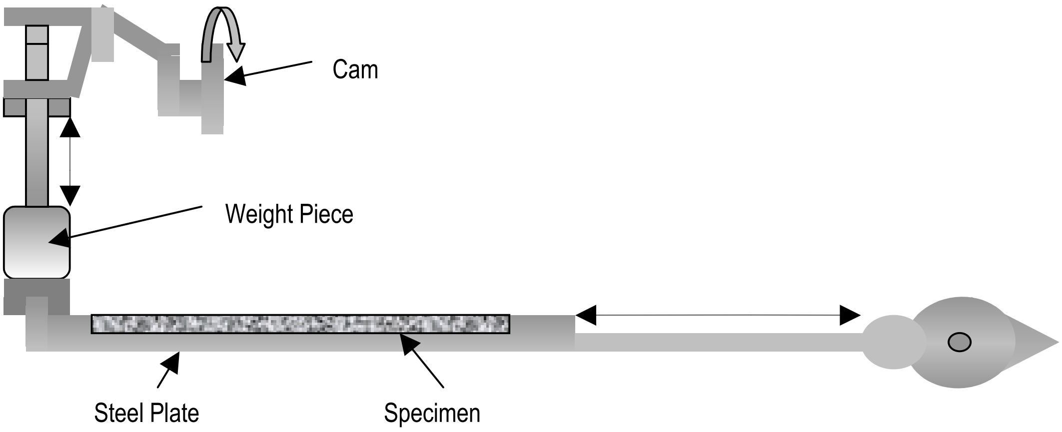


Figure 1. Cross-sectional view of the dynamic loading machine

Results and Discussion

Effect of screen aperture and fibre length

Figures 2 to 5 present the results for the impact sound insulation for the developed samples of underlay. The results are shown in the form of the normalised acceleration amplitude of the transmitted vibration. The lower the amplitude of the transmitted vibration, the better the sample under test has performed. Accordingly, the acoustic performance of the recycled carpet underlays was determined.

The results show that sample U2 provides the best impact sound reduction capabilities when used on timber or concrete substrate without a carpet overlay. This material was developed using recycled carpet waste obtained from the granulator with a 2mm-aperture screen. Samples U3 and U4 were developed using recycled carpet waste obtained from the granulator equipped with 3mm- and 4mm-aperture screens respectively. These material samples offer inferior acoustic performance in the absence of the carpet overlay. Material sample U4 provides the best impact sound insulation performance when lined with a carpet overlay, and offers a comparatively lower impact sound insulation performance, particularly in the higher frequency band. A similar level of impact sound insulation performance is achieved in the case of sample U3 in the absence of the carpet overlay. This sample was developed using recycled carpet waste obtained from the granulator with a 3mm-aperture screen.

The above data is obtained for using un-sieved grain mixes, i.e. the natural grain size distribution resulting from the granulation process. Although attempts have been made to use a singular particle size in the material mix [1,2], they did not result in any improvement in the impact sound insulation performance in the resultant mix. We note that any active process of sieving the granulated waste to separate it into individual classes of particle size would clearly add extra costs to the manufacturing process. There does not therefore seem to be any performance-related, practical or financial benefit in sieving the granular component or attempting to fix its particle size distribution.

From a practical manufacturing viewpoint, sample U2 was easier to mix than samples U3 and U4. This appeared to be due to differences between the mean lengths of the fibrous component used for each sample. The fibres were studied under a microscope, and the effective fibre lengths of a random selection of 50 fibres from each batch were measured. The effective fibre length is the natural, curled length of the fibres as measured without attempting to straighten it out (see Figure 6). The mean and standard deviation of the effective fibre length for each batch were calculated, and the results are given in Table 2.

It was observed that the mean effective fibre length decreased as the granulator screen aperture through which the fibres passed was reduced. The mean fibre length resulting from use of the 6mm-aperture screen was 4.81 mm, compared with a mean length for fibres that had passed through the 2mm-aperture screen of 2.75 mm, i.e. almost half the length.

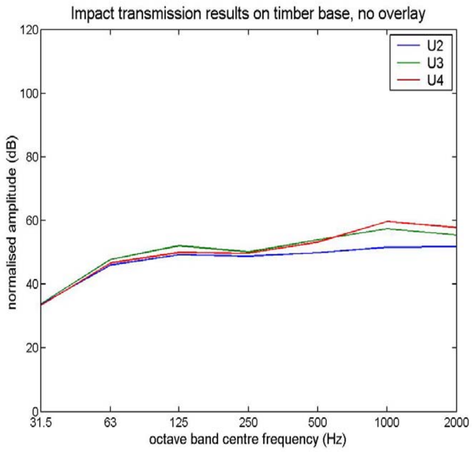
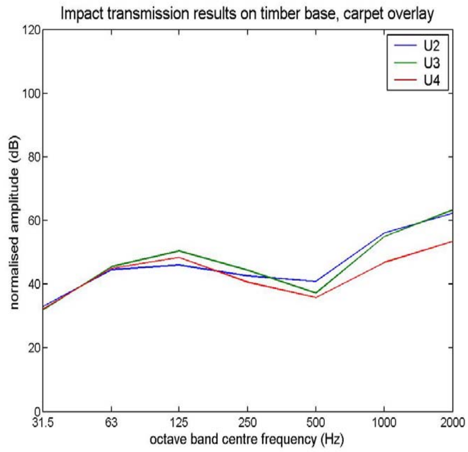


Figure 2.



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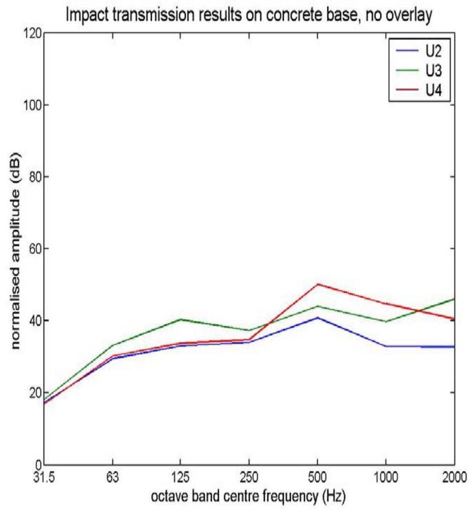


Figure 4.

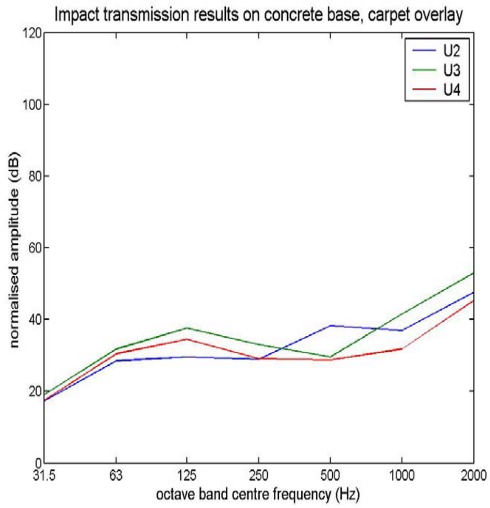


Figure 5.

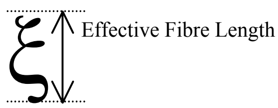


Figure 6. Illustration of effective fibre length

Shorter fibres are less likely to become entangled with each other and ‘ball up’, and are therefore more easily dispersed in the liquid binder. Thus, the extent of the difficulty in dispersing the fibrous waste component into the binder solution during the sample production was dependent on the variations in the mean fibre length, which was in turn dependent on the screen aperture through which the waste had passed in the granulator.

Table 2. Effect of aperture size of different screen on effective fibre lengths

Aperture of granulator screen used to obtain fibrous waste component	Mean effective fibre length (mm)	Standard deviation (mm)
6 mm	4.81	1.27
4 mm	4.27	0.95
3 mm	3.51	1.19
2 mm (fibre passed through once)	2.75	0.86
2 mm (fibre passed through twice)	1.89	0.58
2 mm (fibre passed through thrice)	1.24	0.42

It was considered possible to further reduce the mean fibre length in order to facilitate easier mixing. Because it was impossible to acquire a granulator screen with apertures smaller than 2mm, the further reduction in the mean fibre length was achieved by successively re-passing the fibrous material through the granulator equipped with the 2mm-aperture screen. This effect is illustrated in Table 2, which shows that the mean fibre length in the 'second-pass' fibrous waste was 1.89mm, which is 30% shorter than for the 'first-pass fibres'. The third pass through the granulator and the 2mm screen caused a further noticeable reduction in the mean fibre length, and there appeared to be a greater proportion of powder-type component present in the material mix after it had passed through the granulator three times.

In practical terms, the 'second-pass' and 'third-pass' fibrous components were easier to mix with the foaming binder and granular waste than the 'first-pass' fibre, but the resulting mixtures were slightly more difficult to spread into the sample mould.

There are three more factors to consider with regard to fibre length distribution. The first is that it consumes more energy and time to produce the second-pass and third-pass fibre components (that is, the throughput rate is decreased). The second factor is that the shorter fibre lengths are likely to result in reduced tensile strength [2]. Thirdly, shorter fibres may result in an increased compressional modulus and reduced loss factor, as the grains are closer together in their equilibrium position, which results in reduced acoustic performance [2,3].

On balance, therefore, it is preferable to keep the granulating operation as simple as possible in order to minimise production time and energy consumption. Subjecting the carpet tiles to a single granulation process, with a 2mm-aperture screen at the granulating chamber output, yielded a material stream with grains in the size range of 0.5-1.0mm and a mean effective fibre length of 2.75mm, which was easiest to work with in terms of handling/mixing issues. This material stream allowed samples to be produced which displayed the optimal impact sound reduction performance. These are important findings, which should enhance the possibility of a cost-effective full-scale manufacturing process.

Optimised underlay versus commercial underlays

Fifteen commercially available carpet underlays were subjected to impact testing on a timber substrate with and without a 8mm-thick carpet overlay. A comparative assessment was made of the impact sound insulation performance of the optimised recycled underlay U2 against the performance of these commercial products. The thickness and density of each commercial sample is tabulated in Table 3. The results of impact-testing these underlays are shown in Figure 7a-7f.

Table 3. The physical properties of a number of commercially available underlays, which were subjected to comparative assessment against the recycled samples

Commercial underlay	Thickness (mm)	Density (kg/m^3)	Laminate underlay	Thickness (mm)	Density (kg/m^3)
Durafit 650	6.5	437	**Cush 'n' Wood**	4	160
Monarfloor Impact Mat	7	395	**Floorwise Wonderlay**	3	730
Gaskell Fomalux	10	268	**Floorwise Whisper**	2.5	21
Anglofelt Silver	10	215	**Floorwise Whisper Plus**	2.5	32
Duralay System 10	9.2	435	**Ecolay**	2.5	22
Cloud 9 Cumulus	11	101	**Ecolay Laminated**	2.5	30
Floorwise Satellite	9	183	**Acoustalay 3**	3	33
Texfelt Envirolay 42	11	129	**Acoustalay 5**	5	33
Texfelt Envirolay 33	9.5	118	**Acoustalay CPM**	3.5	97
Cloud 9 Super Contract	10	160	**Textfelt LamiMate* (PE foam layer)**	2.5	20
Ultimate Grand Reservé	11	412	**Textfelt LamiMate* (felt layer)**	4	176
Acoustilux A5518	15	53	* Dual-layer system		
Acoustilux A5569	8	88			
Acoustilux A5501	8	125			
Acoustilux A5050	8	38			
Optimised underlay sample (U2)	**10**	**230**			

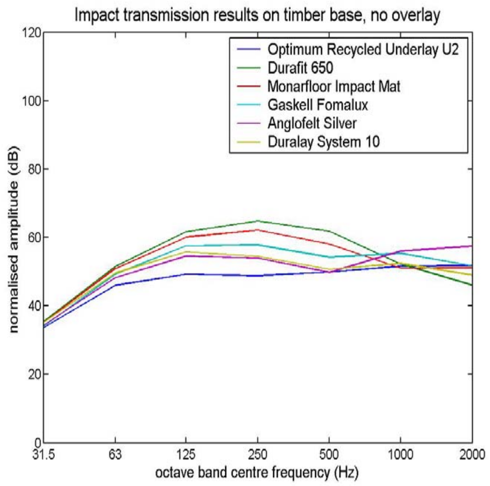


Figure 7a.

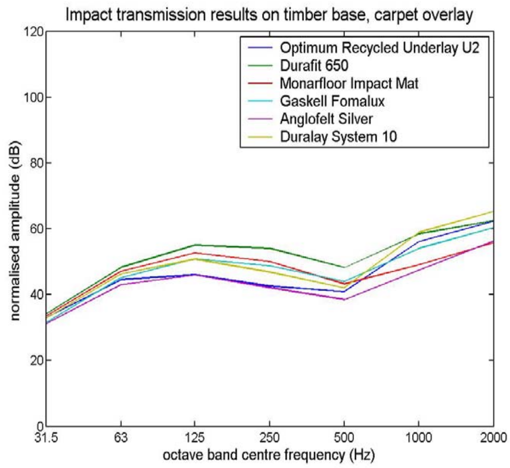


Figure 7b.

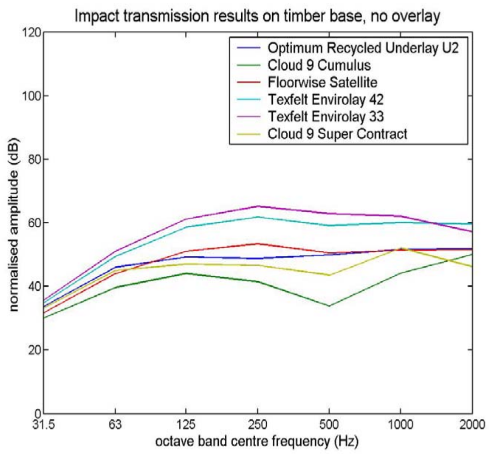


Figure 7c.

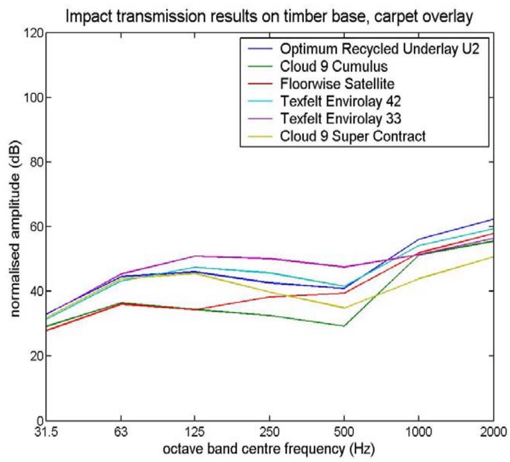
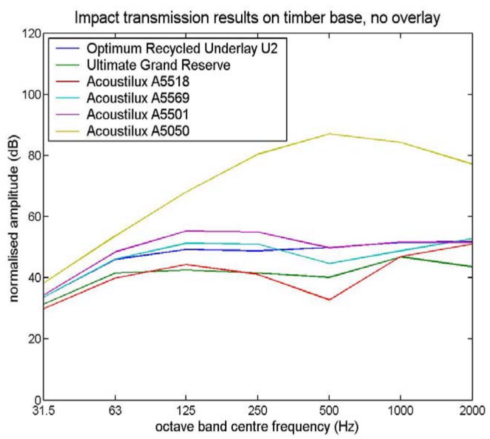


Figure 7d.



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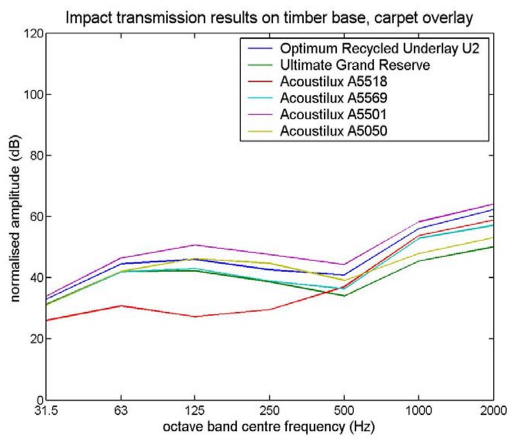

Figure 7f.

The results suggest that the impact sound insulation capability of the optimised recycled underlay U2 is similar to the majority of these commercial products, and in some cases appears to be considerably better. Some of the commercial samples, namely Cloud 9 Cumulus, Floorwise Satellite, Ultimate Grand Reserve, Acoustilux 5569 and Anglofelt Silver, performed better than the recycled sample U2 in these indicative tests by up to 10 dB, especially at lower frequencies (see Figures 7). The Acoustilux 5518 test specimen transmitted impact sound levels ~20 dB lower than U2 at low frequencies, but this is an unfair comparison as the Acoustilux 5518 underlay is 15mm thick (see Table 3). It should also be noted that some of the commercial products, such as Durafit 650 and Monarfloor, were slightly thinner than the 10mm standard thickness of the recycled underlays.

It is also worth noting that the density of the recycled underlay sample U2 is comparatively low (230 kg/m³, compared with the densities of commercial underlays in Table 3), and this could be a potential advantage where lightweight applications are required.

Ten commercial underlay products designed for use with laminate flooring systems (Table 3) were also tested on the impact rig under an 8mm-thick piece of laminate, and a similar comparative assessment was made of their performance against sample U2. These are presented in Figures 8a-8b.

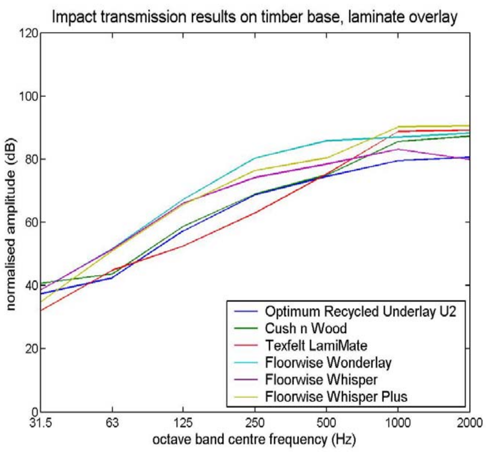

Figure 8a.

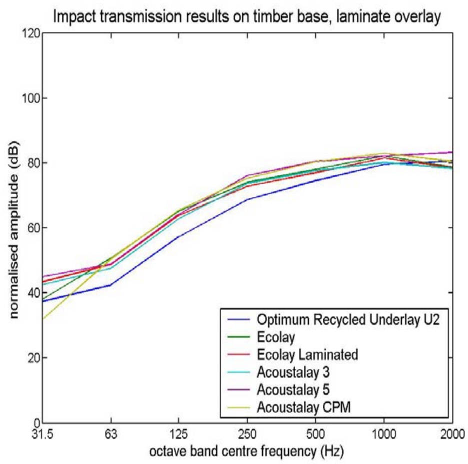

Figure 8b.

The optimised recycled underlay U2 appeared to perform better than most of the systems designed for laminate flooring applications. However, it should be pointed out that U2 is thicker than some laminate flooring underlays, which are generally between 2-4 mm thick. It is noted that the best performing commercial laminate underlay, the only one that reduced impact sound more than U2, is the dual-layer Texfelt LamiMate system, which is composed of a felt layer top and polyethylene foam layer with a total thickness of 6.5 mm.

Standard textile tests (BS 5808) for optimised acoustic underlay

Tensile tests were carried out along and across the underlay to highlight differences in directional behaviour. Due to limited sample availability, only one of the better performing commercial underlays (Satellite) was tested against U2 as shown in Table 4. The minimum and maximum requirements of BS 5808 [4, 9] are given alongside these results.

Table 4. Assessment of optimised sample U2 and 'Satellite' commercial product against BS 5808 requirements for tensile properties of underlays

Property	Optimised recycled underlay U2	Satellite	BS 5808 requirement
Breaking strength in machine direction (N)	100+	100+	40.0 N minimum
Breaking strength in cross machine direction (N)	49	100+	40.0 N minimum
Elongation in machine direction (%)	3	1	10% max. elongation at 40N
Elongation across machine direction (%)	7	1	10% max. elongation at 40N

The optimised recycled sample is weaker than the Satellite commercial underlay in the cross machine direction; nevertheless it does pass this test. Further improvement in manufacturing technique could improve these results. Use of an appropriate backing material (scrim) would improve the performance of the recycled underlay U2 in tensile strength tests. Table 5 shows comparative results from the static loading test for U2 and the Satellite sample.

Table 5. Assessment of optimised sample U2 and 'Satellite' commercial product against BS 5808 requirement for loss in thickness after static loading of underlays

24 hr recovery period	Optimised recycled underlay U2	Satellite	BS 5808 requirement
% loss of thickness	16.7	25.2	15% Maximum

The commercial sample loses up to one-quarter of its thickness after static loading, whereas the loss of thickness in the optimised recycled underlay is just above the maximum requirement of 15%. This can be improved further with better manufacturing techniques than those used in the laboratory. Comparative results for the samples U2 and Satellite undergoing the dynamic loading test are given in Table 6.

Table 6. Assessment of optimised sample U2 and 'Satellite' commercial product against BS 5808 requirement for loss in thickness after dynamic loading of underlays

	Optimised recycled underlay U2	Satellite	BS 5808 Requirement
% thickness loss after 1000 cycles	4.9	9.55	15% maximum

The optimised recycled underlay is well within standard limits in this test, and performs better than the satellite commercial sample. Comparative results for work of compression and compression after dynamic loading of underlays are given in Table 7.

Table 7. Assessment of optimised sample U2 and 'Satellite' commercial product against BS 5808 requirements for work of compression and compression after dynamic loading of underlays

After dynamic loading	Optimised recycled underlay U2	Satellite	BS 5808 requirements
Compression	4.81mm	6.70mm	2mm min., 7mm max.
Work of compression	144.7 J/m^2	100.82 J/m^2	50 J/m^2 min., 200 J/m^2 max.
Retention of original work of compression	77.3%	68.0%	40.0% min.

The optimised recycled sample falls well within the limits stipulated by this standard, as does the Satellite commercial underlay.

Both underlays may be classified as suitable for different intended use/applications in accordance with the performance levels for work of compression after dynamic loading versus compression after dynamic loading. The optimised underlay would accordingly be rated L/U- Luxury use, domestic/contract, where high energy absorption is desirable. The Satellite commercial underlay would be rated GD/U-General for domestic use.

Additional BS 4790 [18] Hot Nut Method tests, which are not part of the BS 5808 requirements for underlays, were also carried out for further comparison. The results for the Satellite and System 10, along with the optimised underlay sample U2, are presented in Table 8.

Table 8. Assessment of optimised sample U2, Satellite and System 10 commercial products against BS 4790 (Hot Nut Method) for fire retardancy

Sample	Time to extinction of flame (seconds)	Radius of char (mm)
Optimised recycled underlay U2	Flames reached outer ring in 536s	75+ mm
Satellite	Flames ceased at 93s and smouldering at 125s	35 mm
System 10	Flames ceased at 227s and smouldering ceased at 320s	35 mm

The results in Table 8 indicate that the optimised recycled underlay as produced in its current experimental form shows a greater tendency to burn and leaves a bigger char area than the two commercial samples when tested in the absence of a carpet overlay. As mentioned earlier, this test is not part of current BS 5808 standard requirements for underlays, and for this reason the research programme did not place special emphasis on optimising the recycled underlay for fire retardancy. If required, improvements can be made by adding an appropriate fire retardant agent to the formulation, without any detrimental effect on the other material properties.

On the whole, the optimised recycled underlay samples yielded good performance results in standard textile tests when compared with their competitors. The notable difference was in the flammability tests, although the optimised underlay could be improved in this regard by including appropriate fire retardant ingredients and an appropriate type of scrim backing.

Conclusion

It has been demonstrated that carpet waste can be recycled into an acoustic underlay product that would adequately compete with commercially available acoustic underlays, and would in some aspects even excel conventional acoustic underlay properties/attributes.

Analysis of the aperture of the granulating screen and the mean fibre length of the granular and fibrous waste facilitated the optimisation of the impact sound reduction capabilities of the samples, as well as an increased understanding of the system. However, regulating the size/length distribution of the waste streams to below that of a 2mm aperture size and a 2.75 mm mean effective fibre length was not shown to be beneficial when considering either performance or efficiency.

The optimised recycled underlay samples yielded good performance results in standard textile tests when compared with the competitors. The notable difference was in the flammability tests, although these did not for part of BS5808 requirements. The optimised underlay could be improved in this regard by including appropriate fire retardant ingredients and a suitable type of scrim backing.

To summarise, this study has demonstrated that recycling carpet waste to produce quality acoustic underlays with desirable impact sound insulation characteristics is technically feasible and a viable alternative to landfill or incineration [7]. Landfill tax rates are on the increase, but by adopting the process outlined in this and previous papers [1,2], carpet manufacturers could reduce their landfill costs by recycling their waste output. Because the raw material is cheap and readily available, and the liquid binder used (SBR) is relatively inexpensive in terms of the machinery and energy requirements, the production of recycled acoustic underlay could be commercially viable.

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References

1. *Miraftab, M., Rushforth, I., Horoshenkov, K., "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 insulation of the produced underlays, AUTEX Research Journal, Vol. 5, No2, pages 96-105, June 2005.*
2. *WRAP report: "Recycling Carpet Waste into Acoustic Underlay for Commercial Production", Waste & Resources Action Programme, available at www.wrap.org.uk (2004).*
3. *Rushforth, I., Horoshenkov, K., Miraftab, M. and Swift, M.: "Impact Sound Reduction and Viscoelastic Properties of Underlay Manufactured from Recycled Carpet Waste", Applied Acoustics 66 (2005), 731-749.*
4. *British Standards Institute: "Specification for underlays for textile floor coverings", BS 5808 (1991).*
5. *BS 4790: 1987, Method for determination of the effects of a small source of ignition on textile floor coverings (hot metal nut method).*

6. *BS ISO 2094:1999, Textile floor coverings. Determination of thickness loss under dynamic loading.*
7. *Miraftab, M., Horrocks, R. and Woods, C.: "Carpet waste, an expensive luxury we must do without", AUTEX Research Journal **1**, pp.1-7 (1999).*
8. *British Standards Institute: "Acoustics - Measurement of sound insulation in buildings and of building elements – Part 8: Laboratory measurements of the reduction of transmitted impact noise by floor coverings on a heavyweight standard floor", BS EN ISO 140-8 (1998).*
9. *British Standards Institute: "Textiles - Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method", BS EN ISO 13934-1 (1999).*

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