Part I

Recycling and use of waste as raw materials

PERCEPTIONS TOWARDS CLOTHES WITH RECYCLED CONTENT AND ENVIRONMENTAL AWARENESS: THE DEVELOPMENT OF END MARKETS

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ABSTRACT

UK waste is growing steadily every year by 2–3 per cent, despite the fact that our government encourages us to recycle more. Due to a lack of landfill sites, we need to reduce our waste drastically. However, developing end markets for recycled materials is necessary for recycling to be successful, and the achievement of those markets depends on consumer demand for products.

This study has explored the public perception towards clothes with recycled content and was designed as a guide to clothing industries that are, or will be, dealing with recycled materials for their products. The public survey aimed to identify the potential market for clothes with recycled content, particularly those made from plastic (PET) bottles using a fleece jacket as an example.

The findings reveal that there is a contradiction between the public reaction towards products with recycled content and their awareness of environmental issues.

INTRODUCTION

Pressure to meet EU landfill regulations, a lack of available landfill sites and a growing concern for environmental hazards such as land, water contamination and air pollution associated with incineration and landfill sites have pressurised the UK Government to take action and raise the recycling rate. They indicated a target in Waste Strategy 2000 for England and Wales to recycle 25 per cent of household waste by 2005.[1]
However, in 2001/02, we created 28.8 million tonnes of municipal waste of which 22.3 million tonnes went into landfill. This was an increase of 2.4 per cent compared to 28.1 million tonnes in 2000/01 with 22.1 million tonnes going into landfill. Parallel to this development there was also a 1.2 per cent increase in recycling municipal waste from 12.3 per cent in 2000/01 to 13.5 per cent in 2001/02.[2] This clearly shows that although the recycling rate has seen a rise, this is not sufficient to reduce the amount of waste going into landfill sites, as the total amount of waste produced has increased at a faster rate than recycling. If our pattern of consumption keeps to its current trend and we do not reduce our waste, it is clear that in the near future there will be no available landfill sites.[3]

One significant contributor to this situation is the plastic beverage bottle. It is derived from crude oil and the rapid growth of plastic bottle consumption combined with its short life cycle, results in its continuous entry as waste into landfill sites and incinerators.[4] Looking at waste by weight, approximately 10–11 per cent of household wastes is plastic.[5] Around 1.6 per cent of this comprises plastic bottles. However, looking at waste by volume, plastic bottles would represent more than 5.4 per cent of the waste.[6]

In England recycling plastic started in the 1990s, since then the development of plastic recycling has been slow: approximately 3% (14,000 tonnes) in 2001.[7]
The main key barriers to the successful implementation of plastic bottle recycling have been identified as the lack of an efficient recycling infrastructure and an unstable market for collected materials.[8] While improving the recycling infrastructure is a relatively straightforward task, which some local authorities may already have started addressing, developing end markets for recycled materials provide bigger challenges. As Sutherland mentions, developing end markets for recycled material is vital for recycling to be able to grow.[9] He also suggested that success of the market development relies on consumer demand for goods with recycled content.[10]

The RECOUP survey shows that approximately 10% of local authorities are not collecting plastic bottles because they have no confidence that there is a market for the collected materials.[11] The recent WRAP study also pointed out that the plastic industry's preconceptions towards recycled plastic materials have been hindering market development. The industry believes that recycled materials are of inferior quality to virgin materials and therefore hesitate to use them.[12] Nevertheless, advances in recycling technology have made it possible to produce desirable quality goods from recycled plastic. In order to encourage industries to change the current practice it is necessary to convince them of the quality of recycled materials and to examine the public acceptance towards products with recycled content.

This study concentrates on clothing with recycled content, particularly those made from plastic (PET) bottles. In order to examine the public perception towards clothes with recycled content, a survey was carried out using a fleece jacket as an example. The fleece jacket is a product that can be made from recycled materials and it is a particularly good example of recycled clothes currently available in the market place as it shows that recycled materials are no longer inferior quality to virgin materials. The survey aimed to identify the potential market for clothes with recycled content. This study and the resulting information was designed as a guide to clothing industries that are or will be dealing with recycled materials for their products. Shopping behaviour and environmental awareness, especially attitudes towards recycling were closely scrutinised. Analysis of previous consumer attitudes[13] towards products marketed as environmentally friendly have contributed to the design and the analysis of the survey.

BRIEF HISTORY OF THE GREEN MOVEMENT IN THE CLOTHING INDUSTRY

In the early 1990s, we all experienced an increased interest in the green movement. The products e.g. biodegradable washing detergent, organic cotton and paper made from controlled forests, marketed as 'environmentally friendly' were sold everywhere. Yet, consumers were soon disappointed with lesser quality and the premium price of its products compared to conventional ones.

The clothing sector tells a similar tale. Esprit launched 'Ecollection' using mainly organic cotton with natural colours. This was initially an overwhelming success but soon consumers moved to more colourful clothes.[14] Patagonia invented a fleece jacket made from recycled PET plastic bottles. The product was very successful and many companies followed suit and produced a fleece jacket made from plastic bottles. However both the jacket's popularity and the high price gave rise to cheaper copies by non-high market clothing manufacturers that used virgin materials. As a result, there are plenty of low priced fleeces in the market place but they are not made from recycled materials.[15]

The green movement in the early 90s was a fashion. It arrived suddenly and disappeared the next season, just like other fashion trends. In order to sustain such a movement, it cannot be based on short-term trends, but needs to be linked to real long-term benefit. In the US, organic fibre (cotton) production followed the growth of the organic food movement.[16] It seems the UK followed a similar trend. The recent food scares in the UK triggered many to search for safer food. People have started to look into where products come from and how they are produced. As a result there has been a rapid growth of organic and fair-trade food products and the certified organic cotton and fair trade textile/clothing businesses have recorded sales growth. For instance, the organic baby and toddler brand 'Green Baby' recorded more than £2m in sales in 2003/04 and expects sales to go up to £5m by 2006.[17] The fashion designer Katharine Hamnett has also recognised the opportunity and is planning to launch an ethical fashion business in spring 2005.[18]

It seems that certified products are widely acknowledged and have become desirable products in recent years. The pressing question is whether products with recycled content could follow suit and see increased popularity. Both organic and recycled products have some benefits towards our environment. However, there are fundamental differences between these type of product. Organic fibre has added value compared to conventional cotton fibre. Neither pesticides that are considered toxic nor fertilisers are used during production.[19] So that organic cotton offers assurance that the skin is not in direct contact with chemicals. This represents a significant benefit for those with a sensitive skin, e.g. babies.

Recycled fibre on the other hand does not offer immediate benefits or reassurance. On the contrary, recycled fibre is often associated with having been "used", and is thought of as having as inferior quality to new materials. It is therefore necessary to investigate public perception towards clothes with recycled content in order to identify a potential market for clothes with recycled materials.

METHODOLOGY USED IN THE SURVEY

The public survey was carried out in the city centre of Newcastle-upon-Tyne over a period stretching from the 26th January to 3rd February 2001. The particular location was considered the most suitable, following McCormack and Hill's (1997) suggestions, Eldon Square was chosen as a location for the survey because it is seen as a busy retail centre and is easily accessible to a a cross-section of the population in a relatively short period of time.[20] The data were collected from 95 respondents mainly aged between 19 and 60 years old. Particular attention was paid not to collect data from only certain groups e.g. gender and age. In order to avoid irrelevant respondents, filter questions were asked before filling in the main questionnaire. Respondents in the survey choose outer clothes by themselves and their occupations were not related to fashion, textiles or clothing retail, and are not dealing with environmental issues as part of their occupations. Face-to-face interviews were used to collect data and the interviewer could also answer the respondent's questions. Though efforts were made not to create bias, it may have arisen through the interviewer's sub-conscious non-verbal signals or through misunderstanding of questions and answers.

The sample range

48.4 per cent (n*=46) of the respondents were male and 51.6 per cent (n=49) were female. The respondents fit into age groups of 46 to 60 (28.4 %, n=27), 26 to 35 (18.9 %, n=18), 19 to 25, 36 to 45 (16.8 %, n=16), the age group of under 18 (10.5 %, n=10) and the age group above 61 (8.4 %, n=8). More than 80 per cent of the respondents were aged between 19 to 60 years old. The population of Newcastle-upon-Tyne at the time of the survey was 259,536 and approximately 10 per cent of its population were aged 20 to 24. This could be explained by the concentration of universities and colleges within and around the city. The economically active population in the city was reported to be 58.5%, which is lower than the England average of 66.9%.[21] *(n stands for number of respondents)

The questionnaire was divided into several sections. Firstly filter questions were asked. Then in section one, respondents were asked about their knowledge of, and reaction towards, eco-clothes made from recycled materials using the fleece jacket as an example. A fleece fabric sample made from recycled plastic bottles was used to help the respondents get a realistic idea of what recycled products could look like. Some of the questions were multiple choice questions and dichotomous (yes, no) questions. The option 'do not know' was given with the appropriate questions. These questions were particularly useful as they allow respondents to miss out irrelevant questions.[22]

In section two and three, the respondents were asked about their shopping behaviour in relation to clothes and their attitudes towards products which were marketed as environmentally friendly. In section four, they were asked about their awareness towards environmental issues especially recycling.

Finally, classification questions such as age and residential location were asked. The questionnaire was designed with closed-ended questions using semantic differential scales for most of the questions in order to gain 'the closest to true internal data'.[23] Some of the questions asked to list options e.g. 'Paper' and 'Plastic Bottles', prompting the respondents to show a degree of preference according to a scale from one (not at all) to five ('all the time'). 'Other' was included in the list to allow for further options. This enabled respondents to express themselves by filling in their own option,[24] in case they could not find a suitable option in the list.

The data was analysed using a software package called Statistical Package for the Social Sciences (SPSS). A significance level of 95% (or 0.05) was set.

THE SURVEY FINDINGS

The survey was designed to:

- identify the public reaction towards clothes with recycled contents using a fleece jacket as an example;
- examine key drivers when they purchase clothes;
- find out public awareness of environmental issues especially recycling; and
- identify the potential market for clothes with recycled content.

The survey results and questions are outlined below:

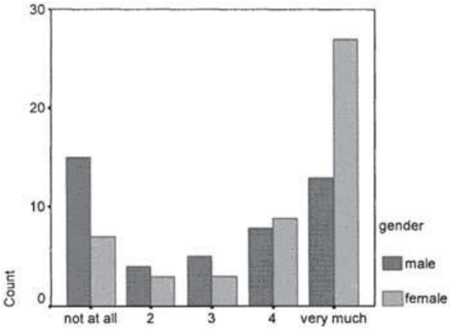

Fig 1 Plastic bottles/gender (n=94)

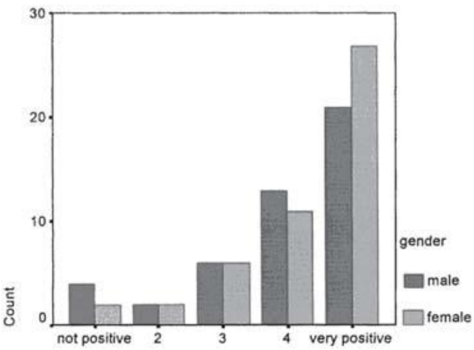

Fig 2 Reaction/Gender (n=94)

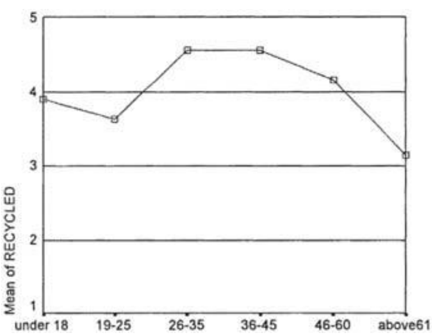

Fig 2.1 Reaction/Age (n=94)
1=Not satisfied, 5=very satisfied

Question 1—Would it surprise you to know that fleece garments can be made from recycled plastic bottles?

The data is divided into 'not at all surprised' (23.4%, n=22) and "very much surprised' (42.6%, n=40). It seems that is a knowledge gap among people. Females are more surprised to know that fleece jackets can be made from recycled plastic bottles than males (Sig* .04) (see Fig 1). *(Sig stands for significant value)

Question 2—If you are told that your fleece garment is made from recycled materials, what would, be your reaction?

This question was asked in order to investigate the reaction towards recycled materials especially for clothing. 51.1% (n=48) of the respondents chose 'very positive'. 76.6% (n=72) of the respondents chose 'positive' and 'very positive' (see Graph 2). The majority of people seem not to discriminate against recycled materials. Digging deeper, we can see that the age group 26 to 45 could be a target for clothes made from recycled materials. Fig 2.1 clearly shows that the age group '26–35' (mean 4.56) and '36–45' (mean 4.56) have the highest mean values among the age groups implying that they have a positive reaction towards recycled materials more than any other age group. The t-Test results shows that there is significant difference between the age group 'under 25(n=26)' vs '26–45(n=34)' (Sig .002) and '26–45(n=34)' vs 'above 46(n=34)' (Sig .024).

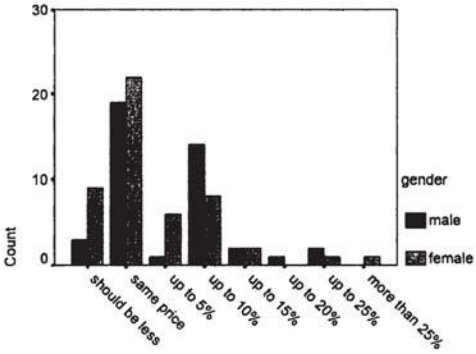

Fig 3 Extra pay/Gender (n=91)

<u>*Question 3—Recycled materials cost more at the moment. How much extra would you be prepared to pay for a garment made from recycled materials compared to new materials?*</u>

45.1% (n=41) of the respondents are prepared to pay the same price for recycled materials as for new materials and 31.9% (n=29) are prepared to pay up to 10% more than for new materials. If products made from recycled materials cost more than 10% than products made from new materials, they will not appeal to people (see Fig 3).

89.9% (n=80) of the respondents did not know of any clothing companies, which are dealing with environmental issues. 60.7% (n=54) of the respondents never bought environmentally friendly clothes and 36% (n=32) are not aware of such products. Only 3.4% (n=3) of the respondents actually have bought eco-clothes. Only 9.1% (n=8) said that they consider the environment when they shop for clothes.

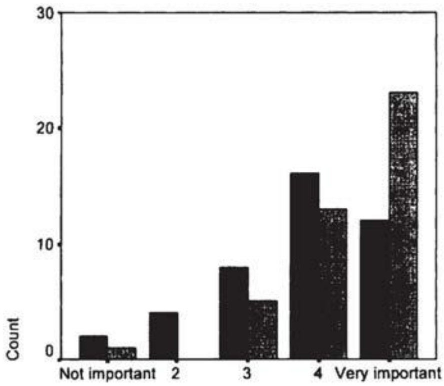

Fig 4 Touch/gender (n=84)
1=Not important 5=Very important

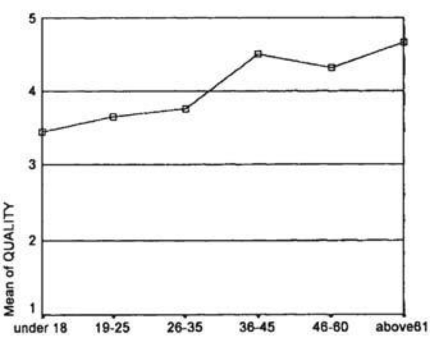

Fig 4.1 Quality/Age (n=81)
1=Not important 5=Very important

<u>*Question 4—Think about the last knitted item (e.g. jumper, sweater…) you purchased. What influenced your decision?*</u>

This question was asked to find out the respondents' purchasing decisions for knitwear, 'colour' (n=82, mean 4.26, SD* .90) and 'Design' (n=81, mean=4.15, SD .91) are top of the list, followed by 'comfort' (n=86, mean=4.06, SD 1.01), 'touch' (n=84, mean=4.06, SD 1.05) and 'quality' (n=81, mean=4.05, SD 1.09). *(SD stands for standard deviation)

'Touch' seems more important to females (n=42, mean 4.36, SD.88) than males (n=42, mean 3.76, SD1.12) (Sig .031) (see Graph 4). Also the data indicates that the age group 36 plus (n=42, mean 4.43, SD.94) is likely to care more about the 'Quality' of knitwear garments than age groups under 36 (n=39, mean 3.64, SD=1.11) (Sig .001) (see Fig 4.1).

26.7% (n =24) of the respondents do not buy particular branded clothes at all. However, the rest of the respondents choose 'quality' (n=69, mean 4.25, SD.86) as the main reason for them to purchase branded clothes followed by 'design' (n=67, mean 3.96, SD1.11) and 'value for money' (n=68, mean 3.88, SD1.06).

Question 5—Do you buy environmentally friendly products? (e.g. washing detergent, toilet paper, car etc)

60.5% (n=52) of the respondents have bought products that were marketed as environmentally friendly and 23.3% (n=20) of the respondents said that they have never bought any environmentally friendly products. 16.3% (n=14) of the respondents are not sure if they have or not.

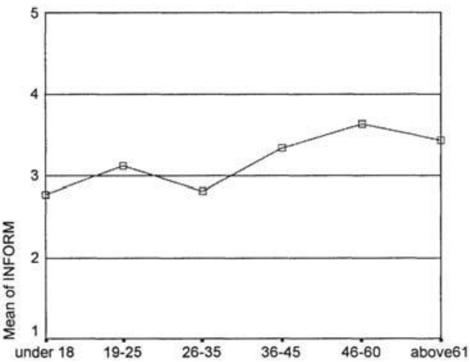

Fig 6 Inform/age (n=85)
1=Not at all, 5=All the time

Question 6—Do you try to inform yourself about environmental issues, or not?

The data did not indicate a significant gender difference. However, there is a difference among the age groups. Fig 6 shows that the '36 and over' age group (n=44, mean 3.50, SD 1.15) seem to be trying to inform themselves more about environmental issues than 'younger than 36'year olds (n=41, mean 2.93, SD .88) (Sig .012). The age group 26–35 (n=16, mean 2.81, SD .98) shows less interest than the other groups.

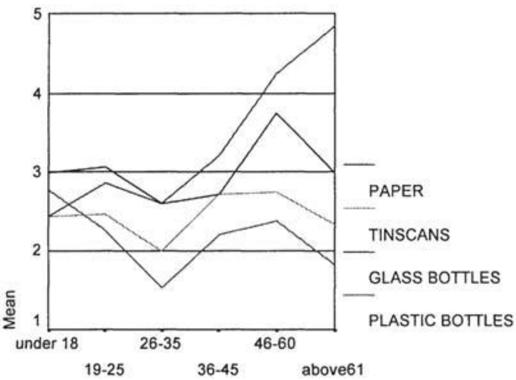

Fig 7 Recycled materials/age
1=Not at all, 5=As much as possible
Paper (n=85), Tins & cans (n=81), Glass Bottles (n=85), Plastic bottles (n=79)

Question 7—Do you recycle any of the following material; paper, tins/cans, glass bottles and plastic bottles?

Fig 7 shows that the age group 46–60 (n=21) seems keener on recycling compared to other age groups. The data indicates that there is no significant difference between female and male for recycling. The results indicate that the age group 26–35 (n=17) does recycle less, people aged 46–60 (n=21) do recycle most and the 36–45 (n=15) group seem ambivalent in being both least and most keen.

SUMMARY OF THE FINDINGS

The survey was conducted to find out about consumer reactions towards recycled materials for clothing, their shopping behaviour and their environmental awareness, especially in relation to recycling. It also aimed to identify the potential market for clothes made from recycled materials. The outcome is beneficial to the designers, buyers and manufacturers who might consider using recycled material for their products. However, the survey has been relatively small in size due to limitations of time and resources. Nonetheless some key issues have arisen.

General reactions

75.6% of the respondents have favourable reactions towards clothes made from recycled materials. Within this, 51.1% show that they are strongly positive towards recycled materials for clothing. The age group 26 to 45 are more positive than the rest of the age groups.

Pricing

It seems people are not prepared to purchase recycled products if the price of products exceeds more than 10% compared to that of products made from new materials. This suggests that recycled clothes should be priced the same as clothes made from new materials. This result confirms the findings of Buwalda (2001)[25], Rowledge et al. (1999)[26] and Mackenzie (1997)[27]. They noted that consumers are not willing to pay more just because of the product's environmental benefit. Environmental benefit should be extra value along with a high standard of performance, quality and value for money.

Awareness of environmental clothes

Considering the high rate of 83.2 per cent of respondents that own a fleece jacket, only 42.6 per cent of respondents knew that a fleece jacket can be made from recycled plastic bottles and 10.1 per cent of respondents knew a clothing company that is aware of environmental issues. Nobody mentioned Patagonia (USA) who produced the first fleece jacket made from recycled plastic bottles. This indicates that there is a lack of information/awareness towards the products we purchase. This runs parallel to the findings that only 3.4 per cent of respondents have bought environmentally friendly clothes in the past and 9.1% consider the environmental impact when they buy clothes.

Thus it seems that the biggest obstacle that averts people from purchasing environmentally friendly clothes is that they do not know if such products exist. In addition, eco-clothes are not easily or widely available at the moment.

Clothing purchase decisions

The key drivers for a clothing purchase decision, especially knitwear, are 'colour' and 'design'. 'Touch' is also important, particularly for women. It seems that the age group 36 plus care more about 'quality' and that consumers often associated 'quality' with 'branded' clothes. In order to investigate these shopping behaviours further, more research into the particular area of spending would be necessary as spending may vary according to socio-economic status.

Awareness of environmental issues especially recycling

60.5 per cent of the respondents have bought products marketed as environmentally friendly in the past. The data suggested that the age group 36 plus are keen on informing themselves about environmental issues. The age group 46–60 are the most keen on informing themselves as well as doing recycling.

A potential market

According to Marquardt[28], women in their 30–50's in U.S. and Europe are keen on products which have environmental benefits. This survey's results reflect Marquardt's findings. The age group 26 to 45 has a more positive reaction towards clothes made from recycled materials than the other age groups.

Nonetheless, we should not conclude hastily. The survey results show that particularly the age group 26–35 seem least keen on environmental issues, despite their positive reaction towards recycled materials. In comparison while the age group 46–60 do inform themselves about environmental issues and do more recycling than the other age groups, have a less favourable attitude towards recycled materials for clothes than the age group 26–45. They may associate recycled materials with lower quality, since this age group seeks 'Quality' for their clothes more than any other age group.

Overall, the survey result suggests that a major campaign to raise awareness towards 'recycled materials' may be necessary in order to inform the public of the potential of recycled materials.

Limitation of the survey

The data in the survey were collected in the city centre of Newcastle-upon-Tyne and it may be necessary to take into consideration that Newcastle has a high percentage of students in its population. During the process of the data analysis, it was necessary to sum up the data due to the small sample size in particular the age groups. Therefore, some of the results have been explained through two or three age groups rather than the six age groups that were initially used in the questionnaire. Further research would be required if there was a need to acquire more detailed outcomes such as socio-economic status in relation to detailed age groups.

CONCLUSIONS

This study was conducted in order to identify possibilities for clothes with recycled content by exploring public perceptions towards recycled materials and their awareness of environmental issues. The findings that have been derived from the study could be useful indicators for clothing industries that may be using recycled materials for their products.

There could be a few scenarios that would encourage wider use of recycled materials in the clothing industry; such as enforcement by legislation, low prices of recycled materials and an increased demand from consumers. Obviously it would be an ideal situation if these three conditions were to occur simultaneously. Enforcement by legislation and low prices of recycled materials are objectives that could be achieved in a relatively short time. However, these favourable conditions once achieved could as easily be overturned by changes of government policy or a sudden change in oil prices as has occurred during the 2004–2006 period. In both scenarios there is little space for the consumers to control the situation.

On the other hand, creating demand from consumers for recycled materials would need time and effort. People need to realise that we cannot carry on consuming huge amounts of resources and not recycle. However, the rapid growth of certified fair trade goods in the UK indicates a change of consumer shopping behaviours. People have started to show an interest in the origin of products and in their production history. Thirty years ago Schumacher noted that ‘The buyer is essentially a bargain hunter’ and his main concern is to obtain the highest valued goods for the slightest spending, rather than where or how the goods were produced.[28] Nowadays we are still bargain hunters, but there are signs that we want to take more responsibility for our shopping. Vidal remarks that the reason for this trend is the availability of information. People inform themselves and the simple shock of knowledge can inspire action.[29]

If the availability of information is the key for a change in consumer attitudes, recycled materials may have potential. The survey revealed that people do not know if such products exist, especially for clothing. For instance the age group 46–60 may become more sympathetic towards recycled materials for clothing as they already appear to be keen on informing themselves about environmental benefit. The reason they are not as positive towards clothes made from recycled materials as the age group 25–46 may stem from an association of recycled materials with low quality. If people started realising that recycled materials can be as good quality as virgin materials, there might be an increase in demand for such products and with it an increase in choice at a reduced price.

Consumers need clearer information about products that have environmental benefits and these products would also need to be more readily available. However availability of recycled clothes and assurance of their quality alone would not suffice to convince the consumer. The survey outcomes clearly indicate that people choose clothes by ‘colour’ and ‘design’ initially. If ‘colour’ and ‘design’ do not appeal to the consumers, there is little chance that they would purchase environmentally friendly clothing. It is thus important that products from recycled materials should be treated as being equal to products produced from virgin materials by designers, buyers and manufacturers in order to guarantee the same standards as the consumer demands from normal clothes.

This research will continue in the future to determine the designers, buyers and manufacturers’ reaction towards recycled materials in the clothing industry. In order to have products, which contain recycled materials available for consumption, it is vital to promote awareness of the key players in the industry who are working in this area. This ought to improve the reaction of the industry towards recycled materials and sould eventually lead to the creation and opening of new markets for recycled materials in the textile and clothing industry.

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ACOUSTIC AND MECHANICAL PROPERTIES OF UNDERLAY MANUFACTURED FROM RECYCLED CARPET WASTE

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ABSTRACT

In the U.K., carpet waste from manufacturing and fitting operations is estimated to be around 10.5 million m^2 or £70 million per year (Miraftab *et al* 1999). The majority of this waste is either land-filled or incinerated. Growing public concern for the environment and increased landfill taxation is forcing manufacturers to look into alternative uses for their waste. An earlier paper (Rushforth *et al* 2003) demonstrated that it is possible to use recycled carpet waste to manufacture underlay with impact sound insulation performance that is comparable to that of commercially available underlays. The current paper summarises this earlier work and describes the results of standard testing of the optimised recycled underlay and commercial products for impact sound insulation performance (ISO 140–8) and for other standard textile properties (in accordance with BS 5808). Industrial-scale manufacturing trials for the recycled underlay are also described. The results of static loading ('Instron') testing indicate that the use of an appropriate backing material (scrim) in the manufacturing process is likely to improve further the impact performance of the recycled underlay, by spreading the applied load laterally across the material. It is also demonstrated that using a scrim improves the tensile strength of the underlay.

INTRODUCTION

Manufacturers are increasingly looking into alternative uses for their waste output as landfill tax rates increase and public concern for the environment grows. Recent studies by Vitamvasova *et al* **[1]** and Swift & Horoshenkov **[2, 3]** 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. The use of recycled materials reduces the manufacturing costs, the demand for raw materials and the required energy.

In the U.K., carpet waste from manufacturing and fitting operations is estimated to be around 10.5 million m^2 or £70 million per year **[4],** the majority of which is land-filled and the remainder is incinerated. Miraftab *et al* **[4, 5]** devised a process that could form carpet waste into a viscoelastic material with potential applications as a carpet underlay. Preliminary tests conducted on samples of these underlays **[6]** indicated that the materials could improve impact sound insulation in flooring applications. This would be beneficial for noise control in buildings in accordance with noise legislation such as the UK Building Regulations Approved Document E **[7]**. Such an approach also addresses the problem of disposal of carpet waste, thus reducing environmental pollution and usage of virgin material, as well as potentially reducing production costs.

This paper outlines the results of research **[8]** into the impact sound insulation performance of recycled underlays that were laboratory produced from granulated carpet tiles. A comparison with commercially available acoustic underlays was carried out. Industrial-scale manufacturing trials also took place. An optimised recycled acoustic underlay product was developed and submitted for standard acoustic testing at accredited facilities. The static loading behaviour of the samples was also investigated, and the results enabled a better understanding of the impact results and highlighted the potential to improve further the acoustic performance of the recycled underlay.

MANUFACTURING PROCESS

Laboratory-scale samples

The manufacturing of underlay samples in the laboratory from recycled carpet waste is outlined below. For a detailed description of the manufacturing methodology, see **[8]**.

PVC-backed carpet tiles with nylon/polypropylene pile were passed through a granulator and cyclone separation system, yielding granular (backing) and fibrous (pile) components of carpet waste. The separated fibrous and granular components were then mixed together again in controlled ratios and consolidated using a pre-foamed styrene-butadiene rubber (SBR) binder. The mixture was then spread into a mould, ensuring a uniform material thickness, and the mould was placed in an oven at 130°C for approximately 1½ hours until the sample had dried and cured.

A number of samples were manufactured in the laboratory according to the above method, to a standard thickness of 10mm, whilst varying parameters such as grain:fibre ratio of the dry component, binder concentration, particle size distribution, etc.

Industrial-scale production

The laboratory sample that performed best in indicative impact testing, U2, **[8]** was reproduced on an industrial scale at a textile mill of *Anglo Felt Industries Ltd,* in order to investigate the viability of industrial-scale production of underlays from recycled carpet waste. The optimised formulation was coated onto a polypropylene carrier material (scrim), which was conveyed through a fan-assisted industrial heater. The coating assembly could be adjusted to control the thickness of the material prior to heat treatment, and the product emerged from the oven having dried and cured at a considerably greater rate that that observed under laboratory conditions.

The industrial trials indicated that production of underlays of a homogeneous nature and constant thickness, from recycled carpet waste, is potentially viable on an industrial scale. However, the thickness of the resultant materials from these initial trials was in the range of 5–6mm, rather than the standard thickness of 10mm.

EXPERIMENTAL METHODOLOGY

Impact 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.

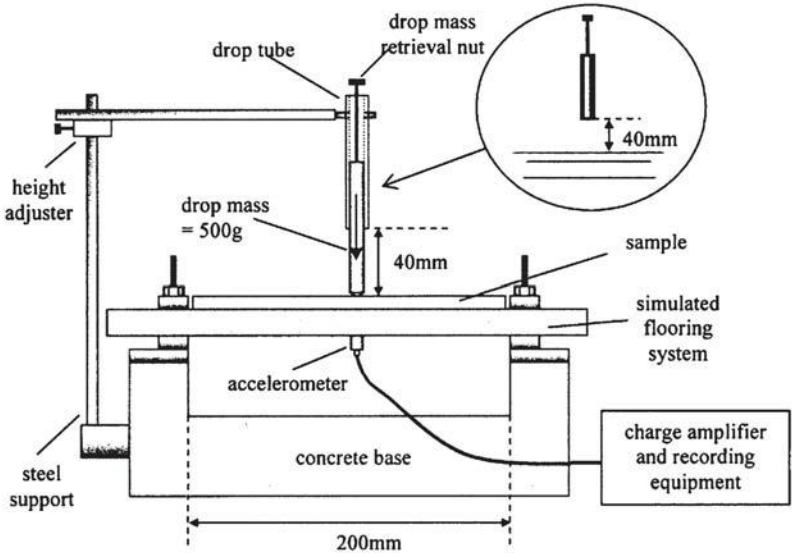

Figure 1: *Schematic diagram of the impact transmission test rig.*

The experimental methodology is summarised below; for a full description see **[8]**.

The recycled underlay samples were fixed to a timber plank, 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 from a height of 40mm in the tube as shown in **Figure 1**. An accelerometer attached to the underside of the plank measured the acceleration level of transmitted vibration through the structure.

Impact events were recorded digitally and subjected to Fourier analysis to calculate octave band spectra of the relative acceleration levels. This procedure was carried out for each laboratory-produced carpet waste underlay sample, as well as for several high-performing acoustic underlays available commercially. By comparing the octave band spectra attained, the relative degree of attenuation of impact sound by each sample was assessed. The lower the magnitude of the transmitted vibration, the better performing the sample under test. Accordingly, the acoustic performance of the recycled carpet underlays was determined.

Standard test for impact sound insulation

The standard test for impact sound reduction of floor coverings, ISO 140 part 8 **[9]**, was carried out on the optimised recycled underlay U2 and on two of the commercial underlays that had performed well in indicative impact tests. This was conducted at specialist testing facilities at Salford University. The test procedure is as follows.

Each underlay is installed on a concrete floor above a reverberant chamber. A tapping machine containing five impact hammers is placed on the underlay, and used to generate impact sound. The tapping machine is also operated when placed on the bare floor. Sound pressure levels within the reverberation room below are measured and spatially averaged using an array of fixed microphones. A correction is made for the reverberation time of the receiver room. The result is given in terms of the weighted reduction of impact sound pressure level, ΔL_W, averaged over three 1.0m×0.5m specimens.

For the purpose of this test, twelve 10mm-thick specimens of optimised underlay U2 were produced in the laboratory, each of dimensions 375mm×330mm, i.e. sufficient to make up the total area of 1.5 m^2 required by the ISO 140–8 test, although in separate smaller pieces than specified in the standard. The selected 375mm×330mm size of specimen was restricted by the available laboratory facilities at Bradford University. The commercial specimens were also 10mm thick but were cut to the specified dimensions.

Tensile strength and other textile tests

The tensile strength of the optimised recycled underlay was measured both in terms of maximum loading to failure and percentage extension-to-break, in accordance with BS EN ISO 13934–1 **[10]**. These properties were measured for both laboratory and industrially-scale samples in order to assess the effect of differences in the production process, such as the use of a carrier material (scrim) in the industrial trials, on the tensile strength of the underlay.

The optimised recycled underlay was also subjected to a series of standard tests in accordance with BS 5808 **[11]** and compared with commercially available underlays of similar calibre. The tests were carried out by SATRA, a specialist testing house for floor coverings.

Static loading

In order to understand more fully the behaviour of the samples in impact tests, the static loading behaviour of the test specimens was investigated using an 'Instron' mechanical loading machine. Stress versus strain curves were plotted during compression of the samples up to a high value of stress of around 800 kPa (approximately equivalent to a load of 80 kg transmitted through an area of 10^{-3} m^2 i.e. an average adult stepping on the floor with the heel of a shoe).

RESULTS

Impact rig

A detailed description of the results of laboratory impact testing and optimisation of the recycled carpet underlay is given in **[8]**. **Figure 2** shows the most salient results, with the performance of the optimised recycled sample U2 plotted against two of the best-performing commercial underlays. Note that all samples were 10mm thick, and that low amplitude of transmitted vibration corresponds to effective impact sound insulation performance.

Overall, the impact results from laboratory tests suggest that the impact sound reduction capability of the optimised recycled underlay U2 is similar to, and in some cases considerably better than, the commercial products.

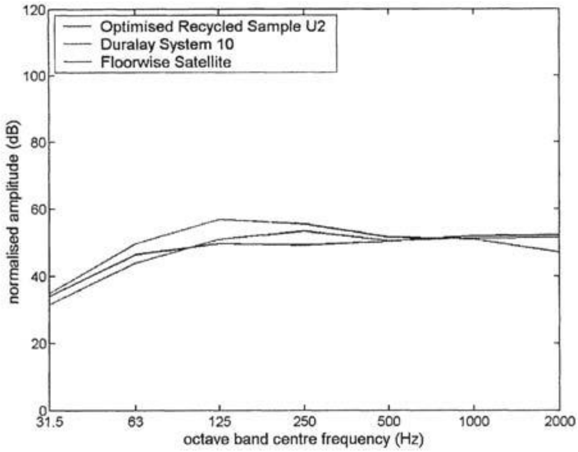

Figure 2: *A comparison of the impact sound insulation performance of the optimised recycled underlay U2 and two commercially available underlays (middle line shows optimised recycled underlay U2).*

Impact testing of one of the industrially produced samples from the *Anglo Felt* trials was also carried out. Two 5mm-thick specimens were stacked up to obtain a thickness of 10mm, in order to allow a controlled comparison with the 10mm-thick laboratory produced sample of the same formulation. The results shown in **Figure 3** demonstrate that the transmitted vibration spectra for this industrial sample and for the laboratory specimen of identical formulation were very similar. This suggests that it should be possible to reproduce the acoustic performance of the laboratory samples on an industrial scale.

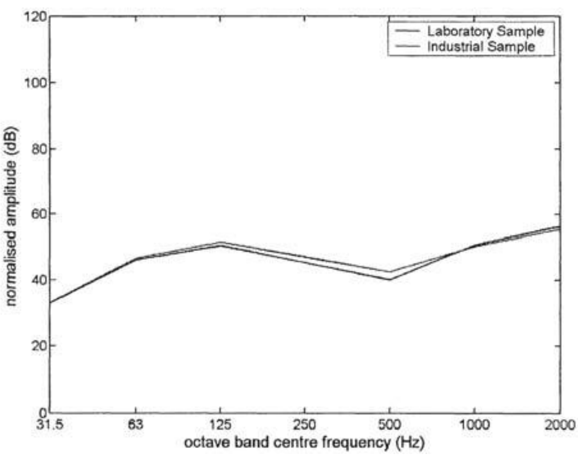

Figure 3: *A comparison of the impact sound insulation performance of industrial-scale and laboratory-scale samples of recycled underlay (top line shows industrial sample).*

Standard test for impact sound insulation

The value of ΔL_w for the optimised recycled underlay U2, obtained in accordance with ISO 140–8, was found to be 28 dB; this compares favourably with the minimum value of 17 dB stipulated in the Building Regulations **[7]**. In addition, the performance of U2 showed no sign of deterioration with time over the duration of the test.

Two commercial acoustic underlay samples were also tested on the same occasion. One of these, Duralay System 10 (which had performed similarly or slightly worse than U2 on the indicative impact rig in the laboratory—see **Figure 2**), yielded a slightly higher value of ΔL_w=31 dB. The other commercial sample, Floorwise Satellite (which had performed better overall in indicative tests) yielded a noticeably better value of ΔL_w=37 dB in ISO 140–8 testing. Both commercial samples also showed no deterioration in performance over the duration of the test.

Thus the optimised recycled underlay U2 performed reasonably well in this standard test, but not as well as the two commercial samples tested. There are, however, two factors that should be taken into consideration, which may have reduced the performance of U2. Firstly, the sample U2, unlike the commercial samples, was not tested in the form of three whole pieces (each 1.0m×0.5m) as recommended in the ISO standard. Whilst care was taken to avoid any of the tapping machine's hammers falling on a 'seam' during the test, the effect of the discontinuous specimens may have been to degrade performance by several decibels.

Secondly, both commercial underlays have stiff backing materials (scrim), whereas the recycled underlay U2 produced in the laboratory had a thin, highly permeable, low strength backing. The Floorwise Satellite commercial underlay in particular has a crepe paper backing. The effect of this stiff backing may be to spread the load over a wider area than the immediate point of impact during testing, resulting in the highest value of ΔL_w in the ISO test. This 'load-spreading' effect would not be observed in the case of sample U2, due to the very low stiffness of the scrim on which the wet formulation was spread during sample production.

Tensile strength and other textile tests

The tensile properties of laboratory and industrially-produced samples of the recycled underlay were determined. As shown in **Table 1,** the tensile strength of the industrially-produced sample is considerably greater than that of the laboratory sample. It would appear that the carrier fabric (scrim) used during the industrial trials contributes considerably to the overall tensile strength of the underlay, both in terms of maximum loading to failure and percentage extension to break. This is confirmed by the results shown in **Table 2**, which shows the tensile properties of the backing material alone, in both machine and cross machine direction.

The optimised recycled underlay and commercial underlays were also tested in accordance with BS 5808 **[11]**. The results of these tests are outlined in full elsewhere **[12]**, but to summarise the optimised recycled underlay was rated as L/U—Luxury use, domestic/contract, i.e. for use where high energy absorption is desirable. In contrast, the commercial underlay that had performed best in the ISO 140–8 test for impact sound insulation, namely Floorwise Satellite, was rated as GD/U—General Domestic use.

Industrial Sample						Laboratory Sample		
Mean Load at Maximum Load (kN) (Machine Direction)	S.D.	Coef. V.	Mean Load at Maximum Load (kN) (Cross Machine Direction)	S.D.	Coef. V.	Mean Load at Maximum Load (kN)	S.D.	Coef. V.
0.511	.0157	3.08	0.38	.0593	15.27	0.0237	0.001	4.34
Mean Displacement at Maximum Load (mm)	S.D.	Coef. V.	Mean Displacement at Maximum Load (mm)	S.D.	Coef. V.	Mean Displacement at Maximum Load (mm)	S.D.	Coef. V.
64.78	7.97	12.31	31.16	3.29	10.54	20.18	1.12	5.56

Table 1: *A comparison of the tensile properties of industrial-scale and laboratory-scale samples of recycled underlay.*

Polypropylene Scrim					
Mean Load at Maximum Load (kN) (Machine Direction)	S.D.	Coef. V.	Mean Load at Maximum Load (kN) (Cross Machine Direction)	S.D.	Coef. V.
0.603	.6027	2.27	0.4114	0.0250	6.09
Mean Displacement at Maximum Load (mm)	S.D.	Coef. V.	Mean Displacement at Maximum Load (mm)	S.D.	Coef. V.
65.92	2.38	3.61	28.20	2.70	9.57

Table 2: *Tensile properties of the polypropylene scrim used as a backing material during industrial trials.*

Static loading

The ‘load-spreading’ effect described earlier was investigated in the laboratory at Bradford University, by studying the static loading behaviour of the test specimens using the ‘Instron’ mechanical loading machine. **Figure 4** shows stress versus strain curves during compression of the samples up to 800 kPa.

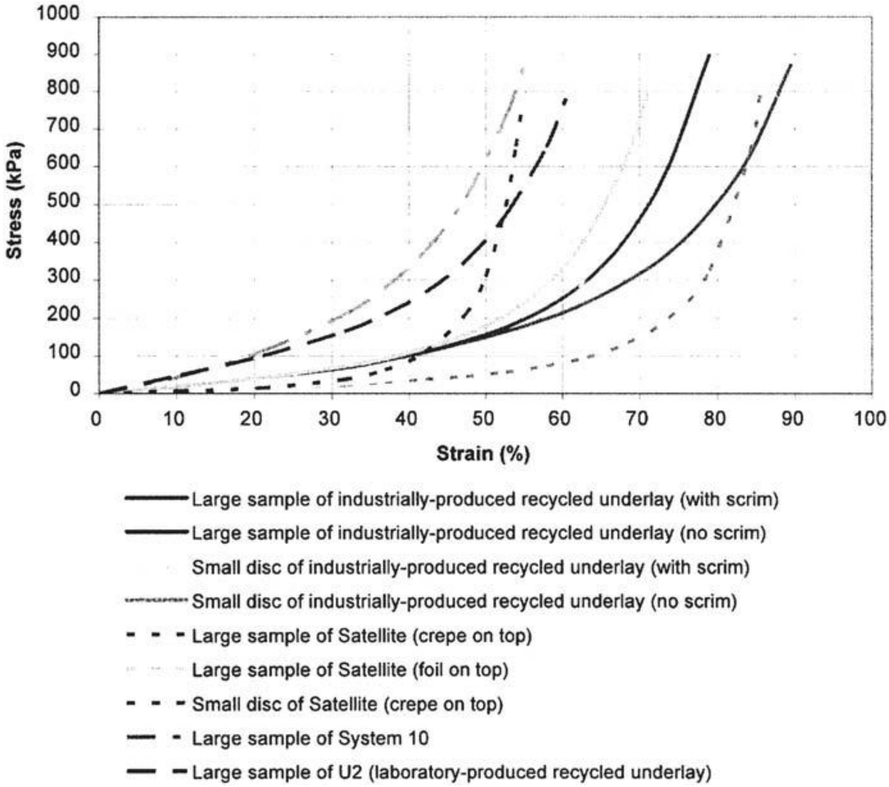

Figure 4: *Stress versus strain curves, illustrating the static loading behaviour of the optimised laboratory and industrially produced recycled underlays along with two commercial underlays, and the influence of a stiff backing on the results.*

The shorter dashed curve at the far right of the figure shows the behaviour under compression of a large sample[1] of the Satellite commercial underlay placed the right way up (i.e. crepe paper backing on top), whilst the lighter dot-dash curve at the left of the figure applies to a large sample of System 10 commercial underlay and the dark longer dashed curve at the left of the figure applies to lab-produced sample U2 (large sample).

It can be seen that for a high value of stress (e.g. 800 kPa), the Satellite sample can take up a much higher degree of strain than the other two samples, which explains its superior performance in impact sound insulation tests. The System 10 and U2 samples display similar stress-strain curves, suggesting similar impact reduction abilities. (The sample U2 has undergone slightly higher strain for a given stress than System 10; U2 performed slightly better in small-scale impact tests but System 10 yielded better performance in the ISO 140–8 tests.)

[1] A large sample may be defined as one that extends radially beyond the circumference of the compression 'footprint' of the Instron machine by a significant distance i.e. at least several times the radius of the 'footprint'.

However, **Figure 4** also shows (short dashed curve towards the left of the figure) that placing a large sample of Satellite with the crepe paper backing underneath reduces significantly the degree of strain at a given high stress level. The thin foil backing exposed on the top is more malleable than crepe paper and less stiff, leading to a reduced capability to spread the load over a wider area.

This is demonstrated further by the short dashed curve in the middle of the figure **(Figure 4),** which shows the behaviour under compression of a small disc-shaped sample of Satellite (crepe paper backing on top), which was cut so that the diameter of the sample was equal to that of the Instron 'footprint', i.e. the area of contact on the sample during the compression test. In this case, there was no possibility for the load to spread over a wider area rather than the immediate point of contact. Consequently, the compressional modulus behaviour was similar to that of the other two samples (U2, long dashed curve at the left, and System 10, dot-dash curve at the left).

Thus it may be inferred that the compressional modulus values of the core material of the investigated samples are similar. Furthermore, as reported elsewhere **[12],** the recycled underlay has a higher value for loss factor (tan δ) than any of the commercial underlays, possibly due to the interaction between the grains and fibres. A combination of low compressional modulus and high loss factor is indicative of good impact sound insulation performance.

Further Instron measurements were carried out on the recycled underlay produced in industrial trials at *Anglo Felt,* which was backed with a superior, stiffer scrim than the laboratory sample U2. Note that the thickness of the industrially produced specimens was in the range of 5–6mm, rather than the standard thickness of 10mm. Therefore, two 5mm thick specimens were selected for each run of the Instron and were stacked up to obtain the required 10mm thickness. It is possible that in this arrangement, some of the strain may be dissipated by air gaps between the layers or by slippage across the lamination (between the doubled-up pieces).

Both large and small circular samples (for definition of 'large' and 'small' see earlier footnote) were tested with and without the scrim on the upper surface during the tests. The solid curves (first and second from the right respectively) in **Figure 4** correspond to the larger samples with and without the scrim, respectively. The presence of the scrim increases the strain dissipated by the sample for a given applied stress. This suggests that spreading of the applied load across a wider area than the immediate point of contact is taking place as a result of the stiff backing material.

Furthermore, comparison of the solid and the shorter dashed curves at the right suggests that the industrially produced recycled underlay sample with scrim, is capable of taking up similar amounts of strain at high stress levels as the commercial underlay Satellite (correctly installed with crepe backing on top). It may be inferred that the recycled underlay with stiffer scrim produced on an industrial scale could yield improved performance in the ISO 140–8 test compared with the lab-scale recycled underlay, and perhaps comparable with the high performance standard of Satellite in the ISO test (ΔL_w=37dB).

The fourth and third solid curves from the right in **Figure 4** correspond to the mechanical behaviour of the small samples of the industrially produced recycled underlay, with and without scrim respectively. The behaviour of these two samples is similar. Additionally, the two large samples are capable of dissipating a greater strain per applied stress than either of the small samples. These results confirm that the lateral load-spreading effect occurs rather efficiently in the large sample with scrim, but also suggest that a lesser degree of lateral distribution of load can take place in the large sample without scrim. When small discs of underlay are subjected to loading, there is no opportunity for the stress to be distributed laterally whether a scrim is present or not.

In conclusion, the use of a high quality, stiff backing when producing the recycled underlay, as well as facilitating the manufacturing process and improving the tensile strength and structural integrity of the material, would serve to enhance the impact sound insulation performance of the product by increasing the degree of lateral 'load-spreading' occurring within the underlay.

CONCLUSIONS

It has been demonstrated that it is possible to recycle carpet waste into an acoustic underlay product. Underlay samples were developed by granulating PVC-backed, nylon/polypropylene-pile carpet tiles and binding the waste together with an SBR binder. The construction of a specially designed rig allowed the impact sound insulation capability of the recycled materials to be assessed and compared with commercially available underlay products.

The recycled underlays manufactured in this way performed well in the ISO 140–8 test for impact sound insulation of floor coverings, and in the BS 5808 standard textile tests for underlays. Although some commercial underlays performed better in the ISO 140–8 standard test, the use of an appropriate backing material (scrim) in the recycled underlay should improve the impact performance further, by spreading the applied load laterally across the material, as well as increasing the tensile strength of the underlay.

Initial industrial trials demonstrated that production of homogeneous recycled carpet underlays of consistent thickness is technically viable on an industrial scale, and that it should be possible to reproduce the acoustic performance of the laboratory samples at that scale.

Landfill tax rates are on the increase but by adopting the process outlined in this paper, carpet manufacturers could reduce their landfill costs by recycling their waste output. Therefore, since the raw material is cheap and readily available, and the liquid binder used (SBR) is relatively inexpensive, the production of recycled acoustic underlay could be commercially viable.

To summarise, this study demonstrates 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.

ACKNOWLEDGEMENTS

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CARPET FIBER RECYCLING TECHNOLOGIES

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ABSTRACT

Significant progress has been made in waste minimization and pollution prevention in textile manufacturing processes. Because most carpets and textiles are for replacement, recycling post-consumer fibrous waste should be an integral part of sustainability for textile products. Currently in the United States alone, over 2 million tons of post-consumer carpet waste is discarded into landfills each year, and the amount is expected to increase to over 3 million tons by 2012. Very little post-consumer carpet at present is recycled. To establish a sustainable commercial network to recycle fibrous waste, operations based on different technologies must coexist such that different types of materials collected can be recycled to the greatest extent. This paper reviews technologies for carpet waste recycling.

INTRODUCTION

The US carpet industry is responsible for 45% of world's carpet production [1]. The great majority of carpet is made by tufting. In this typical construction, face fibers are tufted on to a primary backing and locked into place by an adhesive layer (latex filled with $CaCO_3$) and a secondary backing fabric. The backing fabrics are normally made of polypropylene, while the face fiber is often made of nylon, although polyester, polypropylene and wool fibers are also used for some carpet.

The entire US textile industry consumes 8 million tons of fibers with 1.6 million tons used in carpet manufacturing. Most of the fibrous products are purchased as replacement, resulting in over 7 million tons of fibrous waste (apparel, carpet, and textiles) being disposed of in landfills each year. Due to demand for recycled products, landfill costs and environmental regulations, treating this large amount of fibrous waste as a resource for raw material by converting it into useful products is the most desirable solution. The industry has taken a proactive approach by partnering with private and public sectors to divert carpet waste from landfills. The Carpet America Recovery Effort (CARE) has set a goal of recycling 0.7 million tons of carpet waste (22%) per year by 2012 in the U.S. There has been significant effort on developing technologies to recover materials from carpet waste, including some large industrial operations to convert carpet waste into plastics and chemicals. Unfortunately some of the operations discontinued for economic reasons. To have a sustainable commercial network to recycle fibrous waste, operations based on different technologies must coexist and work in a concerted manner. This paper reviews technologies for carpet waste recycling [2]. The basic approaches are chemical (e.g., depolymerization), physical (e.g., solvent, supercritical fluid), and mechanical (e.g., size reduction and density differentiation).

COLLECTION AND SORTING

Collecting and sorting are necessary steps for carpet recycling. After collection, the post consumer carpet (PCC) is transported to sorting facilities, where the collected PCC is either manually or automatic sorted according to the face fiber. For many recycling processes such as nylon depolymerization and polymer resin recovery, it is desirable or required to sort the feedstock according to the fiber type. A melt pointing indicator is an inexpensive instrument that can identify most fiber types, but it is generally slow and cannot distinguish between nylon 66 and polyester. Infrared spectroscopy is a must fast and accurate technology. A typical instrument consists of an A/C powered base unit for data acquisition, analysis and display, and a probe connected to the based unit via a fiber-optical cable. Such units are suitable for carpet sorting in a central warehouse. A portable infrared spectrometer has been developed by Kip et al [3], which is a lightweight, battery operated unit. It is designed to identify the common carpet face fibers: nylon 6, nylon 66, polypropylene, polyester, and wool. Unidentifiable fibers, either due to operating conditions or fiber types other than those in the above list, would be shown as “unknown”.

MECHANICAL SEPARATION OF CARPET COMPONENTS

Mechanical methods have been utilized to separate carpet components. One or more segregated components then are recycled into products that generally compete with products produced from virgin polymers.

In a process developed by DuPont [4,5], nylon 66 carpet first is passed through dry processes consisting of a series of size reduction and separation steps. This provides a dry mix of 50–70% nylon, 15–25% polypropylene and 15–20% latex, fillers and dirt. Water is added in the second step where the shredded fiber is washed and separated using the density differences between the fillers, nylon and polypropylene. Two product streams are obtained: 98% pure nylon and 98% pure polypropylene. The recycled nylon is compounded with the virgin nylon at a ratio of 1:3 for making automotive parts.

The United Recycling process [6,7] starts with clipping the face fibers on loop carpet to open the loops. The next step is debonding, in which the carpet is bombarded with a combination of air and steam to loosen the calcium carbonate-filled latex backing. The secondary backing then is peeled off mechanically, exposing the primary polypropylene backing. Next mechanical picks pluck the face fibers. It is claimed that the cost of this process is low and that it yields a product stream with 93–95% pure face fibers. Other devices employing water jet [8], dry ice [9] or mechanical actions [10] for size reduction and separation of carpet have also been reported. Many types of equipment are commercially available for processing textile and carpet waste.

SOLVENT EXTRACTION OF NYLON FROM CARPET

Solvent extraction has also been used to separate the high value nylon from carpet waste. The solvents used are aliphatic alcohol [11], methanol [11], alkyl phenols [12], and hydrochloric acid [13]. Typically, the yield of nylon is high and no degradation of the recycled nylon is observed., but the drawbacks of solvent extraction are the chemicals involved, modest temperature and pressures required, and time required. Some solvents, such as hydrochloric acid, are not recyclable due to reaction with the calcium carbonate filler in the carpet waste.

Another approach to separate carpet components is to use a supercritical fluid (SCF) method [14,15]. The solubility of a polymer changes with the variation in pressure and temperature of the SCF. After nylon is dissolved in a solution such as formic acid, a supercritical CO_2 as an anti-solvent is added to precipitate the nylon out of the solution. Both the solvent and the anti-solvent can be recycled.

DEPOLYMERIZATION OF NYLON

Recovery of raw chemicals that can be used to produce virgin-quality nylon is a very attractive approach. Chemical recycling of nylon 6 carpet face fibers has been developed into a closed-loop recycling process for waste nylon carpet [16,17,18,19]. The recovered nylon 6 face fibers are sent to a depolymerization reactor and treated with superheated steam in the presence of a catalyst to produce a distillate containing caprolactam. The crude caprolactam is distilled and repolymerized to form nylon 6. The caprolactam obtained is comparable to virgin caprolactam in purity. The repolymerized nylon 6 is converted into yarn and tufted into carpet. The carpets obtained from this process are very similar in physical properties to those obtained from virgin caprolactam.

The "6ix Again" program of the BASF Corp. has been in operation since 1994. Its process involves collection of used nylon 6 carpet, shredding and separation of face fibers, pelletizing face fiber for depolymerization and chemical distillation to obtain a purified caprolactam monomer, and repolymerization of caprolactam into nylon polymer [19].

Evergreen Nylon Recycling LLC, a joint venture between Honeywell International and DSM Chemicals, was in operation from 1999 to 2001. It used a two-stage selective pyrolysis process. The ground nylon scrap is dissolved with high-pressure steam and then continuously hydrolyzed with super-heated steam to form caprolactam. The program has diverted over one hundred thousand tons of post consumer carpet from the landfill to produced virgin-quality caprolactam [17,18].

Depolymerization of nylon 66 to recover adipic acid and hexamethylene diamine (HMDA) has also been demonstrated [4,20,21,22] but has not been implemented in commercial operation.

GLASS FIBER-REINFORCED THERMOPLASTIC COMPOSITES [23,24]

Recycling post-consumer carpet is difficult due to the co-mingling of incompatible polymers and the general level of contamination encountered. If the polymers are cleaned and separated, the recycled polymers can achieve reasonable property levels to qualify for a variety of applications. Unfortunately, separating certain polymeric products, like post-consumer carpet, can be difficult and costly. The focus of this research is to develop economically attractive technology to recycle post-consumer carpet by using sufficient fiber reinforcement that the fibers dominate the properties of the composite. Post-consumer nylon 6, nylon 66 and polypropylene carpet was shredded and converted into pellets using an NGR A-Class Type 55 VSP Repelletizing system. To prepare laminates the pellets were converted into a coarse powder using a Wiley mill. Powder was interleaved with glass mats to achieve a laminate with 30 or 40 wt % glass. Laminates were also made without the pelletizing step, by first debulking the shredded carpet in a hot press, and then compression molding with glass mats. Properties from these processes are reported in Table 1. The laminates exhibit mechanical properties similar to commercial glass mat-reinforced thermoplastics (GMT). Further improvements are expected through the addition of compatibilizers and appropriate adhesion promoters.

Table 1. Mechanical Properties of Glass Fiber-Reinforced PCC

PCC material, process and % Glass Fiber	Flex. Strength *MPa*	Flex. Modulus *GPa*	Drop Impact *J (@4mm thick)*
PP debulk-comp mold-30%	54	2.2	23
-pellet-comp mold – 30%	68	4.8	20
-pellet-comp mold – 40%	94	6.2	31
N6 debulk-comp mold – 30%	70	2.0	20
-pellet-comp mold – 30 %	135	4.6	19
-pellet-comp mold - 40%	157	4.2	24
N66 debulk-comp mold - 30%	113	3.2	
-pellet-comp mold - 30%	147	5.7	
-pellet-comp mold – 40%	179	8.1	
PP Azdel – 32% (*)	104	4.6	9
PP Azdel – 40% (*)	146	5.5	10

* Commercial products of Azdel, Inc. (www.azdel.com)

CARPET WASTE FIBER FOR CONCRETE AND SOIL REINFORCEMENT

Nylon and polypropylene fibers from carpet can be used for concrete reinforcement. A laboratory study on concrete reinforcement was carried out using carpet waste fibers (Typical length 12 to 25 mm) at fiber volume fractions from 1–2% [25,26]. Four point flexural test and cylinder compressive test were conducted. In the compressive tests, the plain concrete specimens failed in a brittle manner and shattered into pieces. In contrast, all the FRC samples after reaching the peak load could still remain as an integral piece, with fibers holding the concrete matrices tightly together. In the flexural test, it was observed that the plain concrete samples broke into two pieces once the peak load was reached, with very little energy absorption. The FRC specimens, on the other hand, exhibited a pseudo ductile behavior and fibers bridging the beam crack can be seen. Because of the fiber bridging mechanism, the energy absorption during flexural failure was significantly higher than that for plain concrete. A construction project by the Shaw Industries, Inc. demonstrated the feasibility of using large amount of carpet waste for concrete reinforcement in a full scale construction project.

It has been widely reported that the properties (especially the shear strength) of soil can be enhanced by fiber reinforcement, resulting in a more stable soil structure with improved load-bearing capacities and durability. The feasibility of using shredded carpet waste for soil reinforcement was investigated [27]. A series of laboratory strength and deformation tests are performed to evaluate the relative performance of unstabilized and carpet waste fiber stabilized soils. Test results indicate that under certain conditions such as large deformation, fibers are especially effective in enhancing the performance of the soil. Several promising applications have been identified.

SUMMARY

Large amounts of carpet waste landfilled each year has created social, economical and environmental concerns. On the other hand, there is an abundance of mixed polymers that may be harvested as raw material for the fibers, nonwovens and plastics industries. For example, about 0.8 million tons of nylon, one of the most expensive commodity plastics, can be found in discarded carpet alone in the US each year. There has been significant effort on developing technologies to recover materials from carpet waste, including some large industrial operations to convert carpet waste into plastics and chemicals. To have a sustainable commercial network to recycle fibrous waste, operations based on different technologies must coexist and work in a concerted manner. This paper provides an overview of technologies for carpet waste recycling. It also discusses the research conducted at the Georgia Institute of Technology to develop low-cost composites from post consumer carpet.

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USE OF WASTE AS RAW MATERIALS: EFFICIENT RECYCLING TECHNIQUES

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INTRODUCTION

Most of us are generally aware of waste. We now are required to recycle our newspapers and plastic containers, and go to the bottle bank. Some of us take our old clothes to the charity shop.

This is entirely admirable. But what use is put to that material in the recycling process—how does the market operate, especially with regards to textiles. High value materials (e.g. Nomex, Kevlar etc.) have always had a ready recycling route and market outlet but this paper focuses on the economics of low value waste and the way that a company, like Anglo Felt Industries, is developing end-uses for this waste.

First of all consider three major 'fibre waste streams' that we deal with:

1. Garment waste—300 tonnes clothing collected per week (via charity shops)
2. Carpet waste—2% of all landfill is carpet waste
3. Closed loop recycling, specifically between businesses.

How does this market look?

The first thing to say is that it doesn't look healthy and a personal opinion is that it is characterised by under-capitalised companies, many of which are leaving the market. Several well known names have pulled out in recent years and others have diversified into non-recycled areas for new growth. A number of small businesses have gone into receivership and as with much of the traditional textile industry in Yorkshire, some of the fibre re-pullers are exiting the market.

This is a shame for 'UK plc' because the government talks a lot about recycling. Even if the UK no longer manufactures large quantities of clothing, a garment or textile item from China, or other 'low cost' country, will still need to be disposed of after being worn or used in the UK. While government help is limited, the UK Department of Trade and Industry (DTI) has set up the Waste and Resources Action Programme (WRAP), although at present textiles is not a waste stream that it funds, concentrating on plastics, wood etc. WRAP has, however, supported a co-operative project between University of Bolton with University of Bradford to look at recycling carpet tiles.

In other countries, governments have taken a more active approaches to recycling for example; in Germany, the Association of Environmentally Favourable Carpets was formed with Euro5.5m support in 1990.

However, contact with a recycling expert at the DTI in London, indicated that DTI policy on recycling was driven by the EU agenda. Textiles are not on that EU agenda—an interesting insight with the way UK government is now working.

Why are companies in this market struggling in the UK?

A personal view suggests it is all down to the economics of the market and the low 'added value' products currently produced from re-cycled textile waste, coupled also with waste penalty costs. Landfill tax in the UK is reasonably low—£13/tonne against, for example, £45/tonne in the Netherlands. This is planned to increase to £35/tonne by 2012 and means that it only costs around £50/tonne to put waste into landfill in the UK. People therefore have no major incentive to recycle so we send 80% of our waste to landfill—in Switzerland the figure is 7% where different cost structures exist. This will change as the landfill tax and the bureaucracy of recycling increases.

RECYCLING STREAMS

Garment waste

Recycling garments is very well organised and the work of charities is significant with around 300 tonnes of clothing collected every week. The Salvation Army for example, run 1800 clothing banks and collect an average of 6.5 tonnes per bank per year. Only 10% by the way is sold in shops.

Much of this clothing waste is handled at the Oxfam waste-saver plant in Huddersfield, which processes 120 tonnes of material per week. 70% goes as second hand clothing—mainly to Africa and 25% is repulled in to fibre form or used as wipes. A world leader in this area is a German company who sort all their clothes via a tiered selective system:

- Special clothing to theatrical hire companies for costumes
- 'Hip' clothing to boutique-type second-hand shops
- Normal second-hand clothing for charity shops and Third World areas
- The residue is pulled back in to fibre—often after sorting into fibre type/colours.

In the UK this is an innovative and well-developed, quasi-commercial market. Incidentally, one reason it works is that people tend to wash the clothes before taking them to the clothing banks—'post consumer' carpet by contrast is often dirty, giving a different set of problems.

Carpet waste

To illustrate the challenges here, let us consider then for a minute recycling the carpet waste from a new hotel. An Anglo Felt customer, Brintons, is the supplier of the carpet and they may get up to 10% waste during fitting. It will cost them £30-£100/tonne to get that carpet back to a re-puller. This is because the carpet fitters will probably not have access to a baler so the carpet will be bulky to transport. Pulling back in to fibre form will cost around £120-£150/tonne. The problem is that the market price for low-grade waste is only £180-£200/tonne so the economics are not currently viable.

This is one reason why an innovative venture in Liverpool, UK failed. Carpet manufacturers in the Yorkshire/Lancashire area supported a company called WRACE Technology. Despite getting their carpet waste from the manufacturers delivered nicely baled, significant financial help from government agencies and state of the art Italian re-cycling machinery, this company failed—the economics just didn't seem to work.

Closed Loop recycling

Finally, let us consider business-to-business waste briefly where the market can operate successfully. Here, goods are generally presented to the waste merchant compressed so that transport costs are minimised. For example, fibre extrusion waste (from denier, colour changes etc) can be reprocessed and there is a ready market. It gets more complicated further downstream, however.

We have looked at reprocessing cotton gloves from car makers whose operators on the car assembly line typically get through 1 tonne of gloves per month. Anglo Felt has looked at reprocessing these back into sound insulation material in the car. This works fine in principle, but the problem was that the gloves needed cleaning before repulling. At present, the economics again do not stack up.

However, we have just started a co-operative project with Brintons, taking carpet edges from production in Kidderminster, re-pulling them back into fibre form and then putting them into carpet underlay. Because the waste is generally 80% wool or so, it is eminently suitable and provides good compression performance in the underlay and the product passes BS5808, the Industry standard.

How can companies develop and grow in this area?

A personal view, is that the key is designing and developing products to meet a technical specification for use in 'added value', technically demanding applications. This may be in a number of areas e.g.:

- Resiliency and compression recovery
- Flame retardancy.
- Sound insulation.
- Water holding.

Resiliency and compression recovery: Wool and wool/synthetic recycled fibre combinations can provide good recovery properties, which traditionally have been used in carpet underlay felts. Using modern foam bonding techniques, with high performance chemical binders, Anglo Felt has developed a new generation of underlay with enhanced properties whilst still retaining the proven properties of the traditional felt. This is the WoolSpring range which combine lightweight with easy-fitting together with excellent "under foot" performance, sound insulation and point-of-sale appearance for retail applications.

Flame retardancy: Flame retardancy (FR) is about using the natural retardant properties of re-cycled fibres (e.g. wool, hair) and perhaps improving them with specialist chemical treatments that are designed to enhance these inherent FR properties. In this area Anglo Felt has developed a sound insulation material that goes under theatre stages where Class 1 Building Regulations on flame retardancy apply and other more specialised materials for marine applications where FR properties are particularly demanding.

Sound insulation: In building/construction applications there are many opportunities for sound insulation, absorbent and transmission reduction materials. High loft materials from recycled fibres can provide excellent, cost effective performance.

In automotive, absorptive and anti-vibration properties are used more and more for additional performance and comfort in the vehicle. Recycled materials from renewable sources (e.g. wool, jute, hemp, flax etc.) are now accepted as high performance, cost-effective materials which can also help as the impact of the End-of-Life Vehicle Directive begins to be felt. Car makers want to use more recycled materials (some even use this in their advertising) and Anglo Felt are working to produce lighter weight products with higher acoustic performance using a systematic, scientific approach.

Water holding: A big area for us is using the natural water holding properties of wool and other natural fibres to produce a range of capillary mattings. These are extensively used in horticultural growing applications and in "Point-of-Sale" displays of flowers and shrubs in supermarkets and garden centres.

Our recently developed Algon capillary matting, a recycled fibre product with additional laminated surface layer to provide improved appearance and additional control of water release, is finding widespread use in many well known retail supermarket and garden centre outlets.

Appearance

Finally, mention must be made of appearance. It took five years to realise that even though the bulk of our products are out of sight, customers value how the product looks. We have discovered a way of foaming on colour on to our needle felts and can now offer a range of colours to meet our customers' requirements. This is useful to cover the range of coloured fibres, which inevitably arrive in the re-cycled fibre raw materials. An example is our WoolSpring range of bonded underlays, which meet the modern requirements for a light, easy-to-handle product that have visual impact, important in the retail underlay market.

Innovative products

Special products generally come from co-operation with like-minded, go-ahead customers and may often be relatively low volume but attractive margin, 'niche' products.

For example we use the following innovative effects:

- carbon impregnation for anti-static felts
- polypropylene blends and surfacing tissues for pre-finished mouldable parts
- coarse particle-coating to produce resilient underlays and mattings as well as sound absorbent and anti-vibration materials.
- Infra-red banks and specialist binders to produce:
  - tough anti-rub felts for the automotive industry,
  - anti-fatigue matting for warehouses and factories where tough disposable flooring options are required, and
  - water and oil absorbent matting, which have to be fork lift truck resistant!

Anglo Felt's motto is 'Innovating with Recycled Fibre' and at a time when many UK manufacturers are exiting this area, the company has invested more than £0.5 m, in the last 5 years, in additional manufacturing equipment. Basic raw materials are recycled fibres, both natural (wool, jute, cotton, hair etc.) and synthetic (polypropylene, acrylic, polyester) fibres. These materials are selected for product properties and performance e.g.

Flame Retardancy	– Wool, animal hair,
Resilience	– Wool, PP, acrylic, animal hair,
Water Holding	– Wool, cotton, jute
Sound Absorbency	– Wool, cotton, acrylic
Biodegradeability	– Wool, cotton, jute
Mouldability	– Polypropylene

Web-forming is selected from carding, cross-folding or air laying depending on end-use requirements. Bonding can by needling, thermal or chemical methods to provide the final properties and performance. Chemical bonding can be by full impregnation or one or two-sided foam bonding, which enables finishes or colour to be applied throughout the product or in a controlled layer on each side of the product. These techniques produce basic roll goods products with weights from 90 to 2000 g/m^2 and widths up to 4.5m.

A range of after-treatments to confer additional properties is also available, these include impregnation, coating, infra-red singeing, calendering and lamination, to complete the manufacturing process.

To complement the roll goods manufacturing Anglo Felt has developed a significant slitting, sheeting and cut parts converting operation and distribution business in order to provide maximum service for the customer. This versatile operation has provided the possibilities for development of specialist technical products from recycled fibres.

Although there is significant ‘in company know-how’, many of the products we develop are designed in partnership with our customers where we can both benefit from our own specialist know-how and application knowledge. We are only a small company and there are many opportunities for co-operation with academic institutions where there is an enormous, untapped wealth of knowledge and ideas.

We have co-operated closely with Bolton, Bradford and Leeds Universities and we anticipate more of this type of co-operation in the future but we need to be involved at an early stage of the project.

Finally, the result of our focus on innovation over the last few years has been significant. Turn-over has increased by 50% and traditional, low value carpet underlay production, which was over 75% of turnover 10 years ago, is now less than 20% of our business. In its place Anglo now supplies a wide range of technical products for an increasing range of market applications.

CONCLUSION

In conclusion then, Anglo Felt have shown there is plenty that can be done with low cost, recycled fibres. However, the economics are often not very favourable at present and so the bad news for ‘UK plc’ is that plenty of companies are exiting the market. This is not really what we want—but the future may be brighter as progressive rises in landfill tax will make it more worthwhile for companies to consider recycling. Once people have to pay significant costs to have waste taken away and disposed of, then the market can begin to open up and develop. This will happen at some point, as environmental policy will gradually reduce the amount of material sent to landfill and Anglo Felt will be ready to meet this future challenge.