Recycling materials from worn shoes

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In the EU alone, it is estimated that the amount of waste arising from worn or unwanted footwear could become as great as 1.2 million tonnes per year. The vision of 'Zero Waste to Landfill' thus remains a major challenge for the footwear industry. This is an extremely ambitious target as less than 5% of the 20 billion pairs of shoes produced worldwide every year are currently recycled or reused. Nevertheless, increased raw material costs, producer-responsibility and forthcoming environmental legislation look set to force the issue.

It is a widely held view that material recycling is often the best means of dealing with discarded shoes that are potentially unsuitable for reuse. However, for the long-term sustainability of such an approach, an economically viable material recycling system is essential. The automotive and electronic industries already have established recycling chains mainly because their products contain a large percentage of easily recoverable metallic materials of sufficient residual value to make it financially viable. Footwear, on the other hand, typically contains a complex mixture of leather, rubber, textile, polymers and metallic materials that make this difficult to achieve as most have relatively low recycled value.

BACKGROUND

There are in fact four main options for dealing with used footwear: landfill, incineration/gasification, reuse and recycling. Landfill is the most undesirable due to environmental impact, depletion of resources, increasing landfill taxes and, in some countries, lack of available land. Incineration remains controversial due to environmental concerns over polluting emissions. Reuse involves collection for distribution to mainly developing countries. It is likely

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however, that as their economic power increases, demand for second hand shoes will fall. Furthermore, not all shoes can be reused due to their poor condition and, in such situations, material recycling is the best option.

Nike is currently the only footwear manufacturer to recycle on a commercial scale within its so called 'reuse-a-shoe' scheme. Consumers can return any brand of unwanted athletic shoes via a worldwide network of collection points in retail stores. These then go to recycling plants in either the USA or Belgium for shredding and mechanical recycling to separate them into three material streams: Nike Grind (rubber), Nike Foam and Nike Fluff (textiles). These are then used for various sports related applications such as running track underlay, playground surfacing and basketball court underlay. It is not however designed to recycle other types of footwear, so a more generic approach must be found.

A typical sports shoe with main parts and commonly used materials.

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CHALLENGES

Worn footwear constitutes a largely untapped commodity with a significant potential for recycling with both economic and environmental benefits. Current material recycling facilities and operators are, however, either incapable of dealing with the specific material mix in footwear products or do not provide the best method of recovering the maximum value. This is hardly surprising as there are serious challenges involved, namely the diversity of shoe types and constructions, plus the significant number of materials involved and their individual characteristics.

At their most simple as for example with flip-flops, a shoe may consist of only two components, a sole and a strap. At the other extreme, it can be highly complex with as many as 60 or more components. The majority, however, can be said to have a subset of parts generally common to all types of shoe. These include upper materials, soling components (insoles, mid-soles and soles), reinforcements (counters, toe puffs, metal shanks and eyelets) and fastenings (laces, zippers and buckles). A typical footwear product will be assembled from a number of components using a variety of joining technologies, such as gluing, stitching and moulding.

To recycle such a complex product calls for an automated process based on feasible and commercially viable recycling technologies. Recycling products in this manner generally involves shredding or granulation, such that the product is split into different components and/or material types. Separation machines that exploit differences in material properties, such as magnetic or electromagnetic properties, size and density are then used to provide automated separation into different material streams. Generally speaking these technologies are effective for separating materials such as plastic and metal which have distinctly different properties. However, problems often arise when trying to separate materials with similar properties, such as the different types of polymers and rubbers commonly found in footwear.

At present, material separation based upon particle size and weight is probably the most cost-effective, high-capacity process that could be used on an industrial scale. A recycling system based upon fragmentation and air-based separation has therefore been developed for footwear at the Centre for Sustainable Manufacturing and Recycling Technologies (SMART) at Loughborough University. The process has been designed to cover the vast majority of footwear types and styles and involves three stages: sorting, metal removal and material separation.

SORTING

Any commercial footwear recycling system will need a sorting stage to separate shoes into categories that can then be processed in batches so the yield and purity of the target material types (leather, foam, rubber, textile and metal) can be improved. To reclaim foam materials such as EVA and PU in the appropriate manner means that footwear having high foam content (sports shoes) should be recycled separately from those that are leather-based. This is because separation of low density foams from leathers using air-based technology poses a significant challenge at the present time.

METALS

Several options are being considered, the first being to remove the metal manually, which is only feasible for shoes that are very simple in design. Alternatively, shoes could be pre-shredded to expose embedded metal parts which would then be sent to a picking line for manual sorting and removal of the individual items. Initial trials have shown that, depending upon the labour cost involved, these options might not be economically sustainable. The second is mechanical separation using specialist equipment such as shredding followed by magnetic, eddy current and induction sensor based 'detect and eject' chutes. When processing metal parts, shredding is generally necessary because granulators are often unable to process metals without incurring unacceptable wear and damage. It does of course add cost and complexity.

Initial experiments with an over-band magnetic separator during shredding trials with commercially available equipment indicated good recovery of ferrous metals when shoes were shredded to 20–30 mm. As they contain both ferrous and non-ferrous metals (e.g. aluminium and brass), there will naturally be a certain percentage of non-ferrous metals still present after separation.

A subsequent stage is therefore needed to remove these non-magnetic metal particles. This could be done with an eddy current separator although this might not prove to be the best solution either technically or economically. An alternative inexpensive method is to use a sensor-based 'detect and eject' chute such as those employed to protect plastic process equipment from foreign metal parts. However, in this case, a certain amount of additional non-metallic material will be ejected together with the metal parts, which may reduce the overall yield of recycled materials.

Another idea has been to use a simple sink-float liquid based density separation process and a commercial dense media separator such as a hydrocyclone. Magnetite powder is dissolved in water to create a liquid with a medium density of 2.00 g/m. Metals have a density of >2.00 g/m and will sink. All other footwear materials have one of <2.00 g/m and will float.

Concerns still remain however over the technical feasibility of completely removing all metallic content with any of these technologies and, as metal contamination can significantly reduce the value of the other recycled materials, it would suggest there is a need to reduce or even eliminate metallic components at the footwear design stage.

SEPARATION

Once metal parts have been removed, additional fragmentation is needed to further liberate materials and generate the required yield and purity from the developed air separation stages. Experiments have shown that optimal results occur when the waste stream is fragmented down to 3–6 mm in size.

Lab-scale footwear recycling rig.

Fewer particles will remain interconnected (e.g. particles consisting of both leather and rubber), enabling higher purity material to be recovered. A granulator provides the most practical approach as they are available in a range of specifications and throughput rates enabling a system to be easily scaled up for commercial implementation. A key aspect of the research has been the development of a low cost, air-based separation technology to separate the various granulated materials.

Air-based separation technologies rely predominately on the exploitation of the terminal velocity difference between dissimilar material particles. This in turn is dependent upon both its size and weight. Both of these parameters have been exploited for the separation of footwear materials. First, different footwear materials tend to fragment in different ways. For example, textiles tend to fragment into a fine dust that has a low terminal velocity and can then be separated from larger rubber and foam particles which have higher terminal velocity. Second, a difference in material density exists between certain footwear material types providing different terminal velocities so, as rubber particles are heavier than foam particles, they can be effectively separated.

Following these principles, experiments with zigzag columns, air-cascades, aspirators and vibrating air-tables have proven that it is technically possible to reclaim four of the most widely used footwear material types: leather, rubber, foam and textiles. At present, the most economically viable system appears to be a two-stage process using an air-cascade separator to remove the lighter textile, leather and foam residues, followed by a vibrating air-table for final separation of rubber from foam or leather. However, other novel air separation processes are also under development to provide higher purity and yields of material sub-sets such as thermoplastic rubber from leather.

COST

A number of specific factors must be considered before the commercial implementation of a footwear recycling system, including factors such as market conditions, material revenues, local and geographical influences (e.g. cost of labour, transport, landfill taxes, etc.). All the work carried out by Loughborough has been UK-based, so any values given here are of necessity based on conditions prevailing there.

For a small scale system processing 0.5 tonnes per hour, the total equipment investment costs are likely to be in the region of £160,000. Energy will be approximately £5.80 per tonne and labour based upon three people on a minimum wage of £6.08 per hour for sorting, loading and material packing will be £36.48 per tonne. There are, of course, other indirect costs such as maintenance, management, buildings, etc., which would also have to be considered. At present, due to the lack of established values for recycled footwear materials, there are also uncertainties regarding the revenue streams that could be generated.

One way to offset this would be to charge a gate fee to end users such as textile/shoe reuse companies or local waste authorities that would otherwise be sent to landfill and so incur fees and taxes. This is in fact common practice in the UK recycling industry. According to a recent study, this varies between £57 and £100 per tonper ton, with £84 being the average. Thus for footwear recycling it would be justifiable to charge a minimum gate fee of £57 (currently below UK landfill tax plus gate fee). This income would then, at the very least, offset the direct energy and labour costs and leave the potential for a profit to be made from recycled material sales.

APPLICATIONS

Using this recycling process, it is possible to liberate four different and commonly used footwear material types—leather, rubber, foam and textiles. If footwear recycling is to become widespread, it is vitally important that these reclaimed materials have viable applications. A preliminary study has therefore been carried out by researchers at Loughborough to this end. The fibres contained in tannery and shoe factory leather scrap have long been used to produce leatherboard and similar products. It could be possible to use recycled leather granules in the same way. They can also be treated to remove chromium and then used as fertiliser. Leather's acoustic and thermal insulation properties make it a candidate for insulation.

Reclaimed rubber also has a variety of established uses and initial studies indicate that it may also be feasible to finely grind some types of footwear rubbers into a remouldable material that can be used in the manufacture of new products. For recycled foams, applications can be found in underlay material for laminate floors and carpets and for sports pitches. The mixed textile (lighter fluff) reclaimed from footwear can be used for a variety of applications, such as mixing with cement as a filler for construction work, insulation materials for buildings and, once again, sound-proofing materials.

Although the majority of these material applications for footwear waste are considered down-cycling there is clearly still considerable environmental benefit when compared with disposal to landfill. In addition, due to the variety of potential applications there is real potential for economic value to be gained from each of the four reclaimed material streams, clearly highlighting that further development of a material recycling system for shoes shows promise.

STUDIES

Recovery trials with a lab-scale prototype system have been carried out with three different shoe types, namely sports shoes, men's leather shoes with compact rubber soles and men's leather shoes with foamed rubber soles. For each trial there are three output fractions, heavies, lights and fines, each with associated target materials. The material is pneumatically removed from the bottom of a granulator and taken into an air-cascade which removes the majority of the textile fluff. The remaining rubber foam/leather then falls into the middle of an air-table where it is separated into different factions.

An important consideration has been scalability and the developed technology can be easily scaled up to reach the higher throughputs needed for a commercial system simply by using a larger granulator and multiple air separation units in a modular fashion. In these trials, a 3-4mm average particle has proved to be the optimum size. Larger particles were found to include a significant proportion of mixed material while smaller ones significantly reduced process throughput. As the lab system does not include metallic separation, this was carried out before granulation and separation.

During the lab trials there was an issue in obtaining a balance between yield and purity. For example, it was possible to improve the purity of the rubber stream,

Sports shoes separated (left to right) into foam, textile and rubber at 3-4mm average particle size.

Leather-based shoes with high density rubber soles separated (left to right) into foam, textile and rubber again at 3-4mm average particle size.

but only with a reduced yield, since more of the smaller particles of rubber were found to report to the foam waste stream. This yield-purity balance in a commercial recycling operation would most likely be directed by the configurations of material value chains and the specific requirements of the final applications for the recovered materials.

The study has shown that the proposed air-based recycling system can successfully separate certain sub-sets of used footwear products into distinct material categories. For both sports shoes and leather-based footwear with compact rubber soles, separation of rubber with over 80% purity and yield is possible. For textiles, leather and foams, both values are considerably lower. Furthermore, for shoes with foamed rubber soles, there is clearly a poor level of separation using the developed system. In particular the separation of foamed rubber from leather shows only 58% purity and 60% yield. Further work is therefore necessary using different technologies and particle sizes.

In spite of the varying degree of separation purity and yield the resulting materials would be satisfactory for the down-cycled applications mentioned earlier. For example, the purity of textiles for insulation is not as important as being light and fluffy. Rubber has the greatest potential to be reused into higher values applications such as manufacture of new shoe soles. As rubber forms a large material percentage in many shoes, this proposed recycling system would appear to have potential.

CONCLUSIONS

The increasing scarcity of virgin material, the existing and forthcoming European producer responsibility directives and ever-increasing landfill charges necessitates that the appropriate end-of-life management and recycling of products are implemented in every manufacturing sector. In waste from electrical and electronics and end-of-life vehicles, there has been a rapid growth in recycling activities driven largely by the economic value of materials they contain. For consumer products such as footwear with limited valuable material content there are significant challenges for establishing an economically sustainable recovery and recycling process.

Until legislation arrives, the establishment of a sustainable footwear recycling system is at present very much dependent upon the economic viability of the operation. To this end an automated recycling process, based on low cost air separation technologies, has been developed. The four primary recycled material streams examined (rubber, leather, foam and textiles) all have potential applications as surfacing, insulation and underlay products. It must be noted, however, that this is essentially a down-cycling approach and may not necessarily offer the greatest environmental benefit, thus highlighting the need for further investigation into higher grade recycling scenarios in order to support long term recycling activities for the industry.

For high value applications on the other hand, such as the manufacturing of new products, it is widely acknowledged that the reclaimed material stream requires purity in excess of 95%. Clearly it may not be possible to achieve this with the proposed system. Further work therefore needs to be done to investigate the technical feasibility as well as the economic and environmental impacts of alternative recycling approaches (e.g. sensor based sorting or electrostatic separation).

Improved material recovery can also be achieved through proactive approaches, such as better footwear design to support recycling, improved reverse logistics and collection and the creation of novel recycled materials applications. In particular footwear design is seen as a key factor to enable significant improvements to material reclaim yield and purity. Thus we are currently working with producers to investigate the implementation of ‘design for recycling’ within the industry. It is also our view that such a proactive approach will give early adopters a significant competitive advantage when environmental legislation becomes mandatory.