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The circular economy and recycling footwear

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The growing focus on the climate crisis, an ever-rising global population now exceeding eight billion, the increasing vulnerability in energy and material supply as well as the post-pandemic market and economic uncertainties, has created a perfect storm in which a sustainable approach to production and consumption of manufactured goods is seen as the most vital ingredient of global mitigating strategies.

Footwear manufacturers of various size and reach, from established multi-national volume producers to small innovative entrant companies, are actively researching and proposing solutions to improve the overall sustainability of the footwear sector. Addressing sustainability challenges within any manufacturing sector, particularly footwear, are truly complex, wide-ranging and interrelated. Environmental concerns regarding sourcing of materials, use of chemical substances and enormous transportation impacts as well as dealing with production, retail and post consumer waste, cannot be addressed independently from economic pressures caused by a prevalence of dated business models that often rely on mass volume production and sales. Nor can socioethical issues related to working conditions of employees and increasing demand by consumers for sustainable products. This highlights an urgent need for global coordination of initiatives based on the pre-competitive model which is increasingly being adopted in many other manufacturing sectors in order to deal with footwear's sustainability challenges.

Among these challenges, the ones related to the most efficient use of resources and improving the long-term resilience of the footwear supply chain have been the focus of many recent studies. There is no doubt that the massive and growing footwear industry is resource-imbalanced. Virgin materials go into the front end while used resources are largely wasted at the back end. Industry and consumers recognise that this cannot continue and that the circular reuse of materials and/or products is the only approach to safeguard the future of the industry. The Circular Economy (CE) is a term applied over the last decade to a system in which material resources are retained to perform useful functions rather than being lost in landfills or converted to energy. The CE approach reduces environmental impacts from extraction, transport and preparation of virgin materials as well as total product lifecycle costs, thus benefiting producers, consumers and the environment, as well as the productivity of economies.

CE in the footwear sector

Adoption of a circular approach within the footwear sector could be viewed at product level in terms of life extension through reuse, repair, reconditioning and remanufacturing or at material level by reclamation and reuse of recycled materials based on open- or closed-loop approaches. In this context, several initiatives have been set up for recovery of unwanted used shoes from consumers that could be reused either through exporting them to less developed countries via charitable organisations or by reselling to

second-hand markets after minimal sorting and cleaning. In either of these cases, a substantial proportion are often not suitable for reuse due to poor condition or lack of consumer demand and are currently sent for energy recovery or to landfill.

Whilst repair of footwear is a long-established process, often performed by small independent service providers and is still carried out in some countries, a lack of economic viability and consumer acceptance are increasingly limiting its application within many developed as well as developing countries. Instead, there has recently been a growing number of large-scale take-back (often through sending back via post or collecting shoes in retail outlets), reconditioning and/or remanufacturing services mainly targeted at high value branded shoes due to consumer pressure to provide an alternative to landfill. These services are often initiated and/or directly linked to the original footwear producers. However, the common adoption of such life extension approaches is severely impacted due to the increased design complexity and material mix of modern footwear products. In addition, while a circular approach at product level through reconditioning or remanufacturing often provides more preferential environmental benefits, there is a functional limit to the number of their applications on a particular pair of shoes before reclamation of materials becomes the only viable option to landfill and/or energy recovery.

End-of-Life (EoL) footwear waste requiring material recycling may be generated from different sources at various stages of lifecycle, ranging from shoe prototypes, production rejects and costumer returns to industrial waste (shoes produced but not sold), seized counterfeits and post consumer worn shoes. It is estimated that every year in the UK over 200 million pairs of shoes join a pile of older worn but no longer used or discarded shoes. Worldwide, this is in the order of 20 billion. Dr Mark Zhu, market segment manager for footwear, sports and leisure at BASF Performance Materials North America, is recently reported as saying that, "A circular post consumer life for shoe material needs joint effort from shoe brands, shoe manufacturers, material suppliers and stakeholders in the entire supply chain related to recycling."

The footwear sector's response to this urgent need for circular use of material and footwear recycling has been based on three distinct clusters of initiatives. Firstly, through a number of innovative designs and material selection initiatives that aim to adopt a 'design for recycling' approach through producing shoes made from fewer material types such as PET or PE (often in single colour to aid with reuse of recycled material) or use of recycled materials frequently sourced from other industrial applications to produce uppers (recycled plastic yarns), insoles (recycled ETPU foams) and outsoles (reclaimed rubber or mixed recycled foam and rubber).

Secondly, there has been a rapid growth in the range of biomaterials used in footwear production, ranging from fruit, mushroom, mycelium or cactus derivatives, pure natural rubber from FSC and degradable yarns from kelp (algae) to nano-bacterial cellulose,

Figure 1 : Manual disassembly of shoes for component reuse and/or material separation.

SweetFoam, EcoTPU and a variety of other biopolymers. The third cluster is based on collection and grinding of shoes to obtain a range of granulates used in making surfacing and/or underlay materials (open-loop approach) as well as through further processing to produce recycled materials, such as rubber granules used in the production of footwear products (closed-loop approach).

These mechanical material recycling processes, though currently applied to only a subset of shoe types such as trainers or footwear products that do not contain metals, are seen as the only circular option for the very large annual volume of EoL shoe waste that cannot be reused, repaired or remanufactured. However, these existing footwear recycling practices cannot deal with the recovery and reprocessing of mixed post consumer shoes which constitute more than 90% of EoL footwear waste, as dealing with such waste containing a complex mix of materials most of which are in average to poor condition, necessitates a distinctly different and more comprehensive approach.

Current recycling technologies

Centre for SMART has been a leader in exploring how EoL value can be released from footwear products. R&D activities over the last two decades have resulted in significant progress in EoL footwear material reclamation. Shoes are difficult to recycle due to the multiple functions they perform, which require a huge range of material specifications between and within brands. These material specifications vary in terms of many parameters, including material type, mechanical properties such as strength and flexibility, the presence of additive substances including fillers, stabilisers and dyes, and various forms of joining materials. Up to 40 different materials are used, ranging from leathers (tanned and finished using different chemicals and dyes), soft and rigid rubbers, EVAs and other flexible polymers, foams, textiles and metals, all of which are joined together using various stitching materials and adhesives.

Figure 2 : Automatic disassembly of shoes using specially design cutting operation

Figure 3 : Automatic disassembly of shoes by using specially design tools and fixtures.

A number of recycling processes have been developed to improve the quality of recycled footwear materials. Many of these are now commonly adopted and used within emerging commercial footwear recycling companies. These include the manual disassembly of uppers, insoles and outsoles *(Figure 1)* for two purposes: to experiment with reuse of the components in new footwear production and/or shoe repairs and to assess if separation of materials through manual disassembly would improve the quality of recycled materials during downstream processing. Both processes are now applied by several footwear recycling companies, mainly however on a small scale and often for reprocessing new shoe waste such as production rejects, consumer returns and industrial/retail waste. This is because of the higher quality of extracted components and/or materials that can be obtained, as well as concerns over economic viability of large-scale applications due to inherent high labour costs.

The automation of footwear disassembly processes has also been investigated through either simple cutting operations *(Figure 2)* or through specially designed tools and fixtures for ripping apart the upper from the insole and outsole using robots *(Figure 3)*. While the cutting operation works well with shoes with flat and standard profiles, it fails to achieve acceptable separation rates for shoes with complex upper and heel designs *(Figure 2)*. Similarly, automation through specially designed tools and fixtures provides promising results for shoes with simple upper designs, stitching profiles and standard adhesive materials. It performs poorly however with complex shoe designs, particularly those with rubber soles *(Figure 3)*. Future research in footwear disassembly will focus on a mix of thermal and chemical processes using specially formulated adhesive materials.

More recent activities at the Centre have focused on the mechanical recycling of shoes using fragmentation and material separation technologies, many of which are commonplace in recycling many other large-volume manufactured products. However, the specific nature of production methods and materials characteristics in footwear products necessitates a careful and special readaptation of these existing separation technologies. This has led to the development of a number of bespoke processes and equipment designs to improve the material purity and yield from the recycling of a wide range of footwear products *(Figure 4)*. The main objective of the mechanical recycling line, now being further developed and enhanced, is to deal with by far the greatest proportion of global EoL shoe waste currently not dealt with by existing recycling practices, namely multiple brand and multiple material mixed post consumer shoe waste. This requires new technologies for the automatic sorting of shoes prior to commencement of reprocessing, a range of reconfigurable recycling processes to deal with a wider mix of material being processed and inclusion of hybrid processing based on thermal, chemical and biological technologies to improve purity and quality of recycled materials, thereby increasing applications for them within footwear and other industries. Novel footwear recycling lines based on these hybrid applications of recycling technologies are being investigated.

In addition to this technological focus, the latest footwear recycling

Figure 4 : Fragmentation and separation of footwear materials.

R&D activities at the Centre have also explored a range of whole system considerations for wide-scale applications of CE within the footwear sector, including the development of computer aided 'design for circularity' tools to improve recyclability of future footwear products, conducting LCA (Life Cycle Assessment) studies to support the environmental benefit analysis of alternative EoL options, such as recycling versus energy recovery and landfill, and investigating alternative circular business models to assess the economy of scale and financial viability of material recycling particularly for post consumer worn shoes.

Conclusions

Developing a holistic long-term sustainability strategy for modern footwear manufacturers must be based on a Life Cycle Sustainability Assessment, which includes not only environmental considerations but also the economic and socioethical implications of their products as well as their production and supply chain systems. Moving from linear to a circular use of products and materials forms an integral part of safeguarding the future sustainability of the footwear sector. While there has been a significant increase in efforts and investments throughout the last decade directed at improving footwear circularity and resulting in many advancements, the careful analysis of current progress and proposed solutions leads to a reiterating observation that in most applications a limited, disperse and piecewise approach has been adopted without considering the wider implications of proposed solutions or taking in to account the bigger picture as listed here.

1. While re-manufacturing services appear to provide the many reported benefits of extending the life of a product, the environmental impacts of reverse logistics, cleaning and reconditioning processes in smaller scales needs to be carefully assessed against benefits of large-scale batch production of footwear products.

2. Footwear products made from fewer material types will undoubtedly simplify recycling at end-of-life. However, this necessitates a bespoke take-back and collection infrastructure, possibly based on a multi-brand initiative, because mixed collection and reprocessing of these shoes with other general footwear products nullifies any potential benefits gained through simplification of material selection and use.

3. Shoes made from biomaterials may provide many potential environmental benefits, though this needs to be carefully analysed and assessed in each case using a detailed LCA study. However, often no specific EoL option has been proposed for such products. If their biodegradability characteristics are to be taken advantage of, this again requires a bespoke take-back and collection infrastructure to ensure a bioenergy recovery route as opposed to landfill in order to avoid the greenhouse gas generation associated with biodegradable waste. In addition, a mixed collection and reprocessing of these shoes at end-of-life with other footwear products would again add to the complexity of material separation during recycling processes, as well as the quality and consistency of recycled footwear materials.

4. Current trends in large-scale granulation and downcycling of footwear materials (e.g. as surfacing or underlay products) will subsequently generate low value complex waste, often after a short second life for these materials, which are more challenging to recover and recycle. Such downcycling applications, therefore, represent a 'delay time to landfill and/or energy recovery' rather than a long-term circular use of footwear materials.

This lack of whole-system thinking for the application of a circular economy in the footwear sector highlights the need for a joined-up cooperative global initiative based on the aforementioned pre-competitive model, as the size and complexity of the challenges faced by the footwear industry often make it unfeasible for any single manufacturer to address them on their own.

Whilst progress is being made by many other apparel manufacturers on the circularity of their products, the footwear sector is lagging behind and appears to still be stuck in a linear economy. There is no doubt that the recent and gradual advances in redesigning footwear products as well as collection and reprocessing of EoL shoes within many communities and countries represent very positive developments. At the same time, there is no hiding from the fact that as much as 90% of footwear waste, mainly post consumer unwanted and old worn shoes is still ending up in landfill. This, clearly, cannot continue due to many current and upcoming legislative, societal and environmental pressures. At Centre for SMART, we are committed to the vision of zero-waste landfill for footwear products and are looking forward to working with key stakeholders and industry leaders to fully implement a circular approach in which materials are not consumed but only borrowed to address current needs and returned for further reuse.