Section 3: Recovery, Recycling & Re-use

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RECYCLING FOR CHARITY'S SAKE

Andrew Stockwell

In scouring and bleaching it is often necessary to remove hydrogen peroxide before dyeing a fabric with peroxide sensitive dyestuffs. Generally,. peroxide removal is achieved after thorough rinsing and possibly the addition of reducing agents. The use of the enzyme catalase allows rapid removal of the peroxide. The dyeing process can therefore, often be carried out in the original treatment bath, which aids water usage, reduces the overall treatment time and is in fact more cost-effective than the conventional reducing agents. The possibility of completing the whole scouring and bleaching process using enzymes (Bioscour) has been examined by a number of workers, utilising pectinases, cellulases, ligninase and lipases with surfactants [2,3]. However, a commercial process is not yet available that gives, a finished cotton of comparable quality to the conventionally scoured material.

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INTRODUCTION

This paper presents Oxfam's view of the relationship between charities and the commercial sector of the textile recycling industry. To do this, an insight into the origins of our side of the industry would be of value. Founded in Morley in the centre of the Industrial West Riding of Yorkshire over 180 years ago a new product was developed that revolutionised the way cloth was produced. That product was wool shoddy and from its humble beginnings a new Industry flourished and evolved into what became a huge export market industry providing raw material to all manufacturing areas around the world. But very little is known about this side of the trade outside the confines of those actually involved - this is the origins of the recycling Industry, or the rag trade as we know it.

Mr Benjamin Law invented shoddy and mungo in 1813. It was he that was credited as being the first to take old worn out garments and by putting them through a rudimentary water-powered grinding machine he could reduce old garments to a fibrous state that could then be re-spun back into yarn to be re-used.

Several of the Yorkshire towns like Batley, Morley, Dewsbury and Ossett have grown up and prospered through the development of this trade. To give some indication as to the size of this developing industry, it has been estimated that in 1858 over 7500 tonnes of shoddy were produced in Batley alone and probably double this volume from the surrounding regions. The value of this was calculated to be £756,000, a price of only

£50 per tonne. But do not forget the wages paid to a rag sorter was 6 shillings and six pence per week.

According to a book written by Samuel Jubb in 1860 there were 80 firms employing over 500 people sorting the mixed rags which were sold to 130 shoddy manufacturers in the West Riding by the year 1850.

The success of those early trials lead to a phenomenal expansion of the use of shoddy and mungo in the area, and the names of several of the great Huddersfield Woollen Mills that grew from the use of this cheap and plentiful source of raw material, reads like a who's who of the Textile Industry. Many of the vast fortunes made locally were built on the back of Benjamin Laws early invention and the whole of this region benefited from the use of wool shoddy and it is from these early roots that Textile Recycling has grown.

The steady declines in demand for locally produced woollen tweeds and duffel fabrics over the last 60-70 years is well charted and documented, but the impact on the shoddy manufacturers, the wool stocking sorters, the rippers, the marine stores, and the rag merchants was never noticed as these were often small companies or old family firms that quietly closed their doors. There was a strong possibility that this was going to be an industry confined to the history books as the forest of mill chimneys in Huddersfield and surrounding areas were demolished as mill after mill closed.

NEW MARKETS OVERSEAS

Very few were able to survive - the old old story - the consequences of the basics of all economic theories, namely, supply and demand. When the market for a product declines and there are no alternative markets it can only be a matter of time before the industry becomes another of the statistics - another casualty of the decline of the local Textile Industry. That was until someone first realised that what was the point in taking a garment, reducing it to fibre, to turn it back into fabric to turn it back into a garment again. Surely a market could be found for it as a garment - after all, the reason most clothing is discarded is not because it is worn out, but the fashion designers and retailers persuade us that last years colours and styles couldn't possibly be worn this year.

It wasn't long before the enterprising rag merchants were beating a path to Africa, Asia and South America in search of new markets. It was from these very humble beginnings that the second-hand clothing trade started to flourish.

It became evident fairly quickly that the problem was not where to sell your product, but how to find enough of the right type of garments to meet the ever growing demand. The sought-after garments for recycling - the woollen knitwear for shoddy, the wool suits and jackets for ripping and overcoats for flock were not those that were in demand from these third world or developing countries whose requirements were for cottons and lightweight clothing - and this is where Oxfam came in.

OXFAM INTEREST IN GARMENT RECYCLING

Back in 1974 Mr John Secker - a former rag merchant from Dewsbury and a trustee of Oxfam, was asked to help in the setting up of a specialist unit to dispose of all the surplus textiles from the nation-wide chain of over 860 Oxfam Shops, a task that has been expertly managed by another former rag merchant for the last 10 years - Michael Oddy. The responsibility for continuing the achievements and successes has now passed to me, and I hope to be able to build on the solid foundations laid by my predecessors.

This led to the formation of Oxfam Wastesaver - an integral and highly profitable part of the Oxfam Trading Division, which is still based in Huddersfield and is one of the largest collectors and sorters of reusable clothing in the UK. It is still the only charity to have its own textile sorting and processing facility. It is estimated that we process in excess of 16 m garments a year which are hand-sorted into over 160 grades and sold into 30 countries world-wide. Of all the black plastic sacks delivered to UK homes through the letter box from one charity or another asking for clothing, textiles or shoes, Oxfam processes the contents of over 2500 of these daily.

Approximately 50% of our product are the heavy garments and even this is now starting to be exported as clothing, as new markets are developed. The collapse of the "Iron Curtain" countries has seen demand for previously unsaleable lines like sheepskins, furs, overcoats and usable knitwear flourish. New enterprising customers include two local Russians who scour the country for second hand Lada cars, which they drive back to Lithuania, stuffed with old denim jackets, anoraks and sweatshirts.

Alongside the commercial aspects of the business we help our overseas divisions by supplying clothing into the refugee camps all around the world. In the last five years Oxfam has been heavily involved in supplying warm winter clothing into former Yugoslavia and other areas of conflict in Eastern Europe. This has enabled Oxfam to provide life saving relief to over 5 million people, an achievement which has been acknowledged by the European Union, Red Cross and the United Nations, and the charity is now recognised as the leading European supplier of emergency relief clothing. Our field staff working in the desperate conditions of the refugee camps in the war torn regions of Mozambique, Angola and Rwanda are extremely grateful to receive the shipments of clothing which not only give relief, but more importantly, some dignity back to people who have suffered beyond our comprehension.

Oxfam has recently taken over the responsibility of sorting, baling and despatching emergency relief blankets and knitted tops which have been hand knitted by thousands of dedicated knitters who give up their spare time to help people who are less fortunate than themselves. It is difficult to try and visualise the quantities that over 25,000 dedicated volunteers can produce - but current expectations are that we will receive, process and distribute over 200,000 garments this year.

As the worldwide market continues to expand, the rag merchants and clothing sorters are always looking for new sources of supply, and the charity clothing shops have proved to be a great provider. This has lead to a mutually beneficial relationship between the charities and the commercial sector.

Given the expanding retail market in the UK, there could be room for 5, 6 or 7 charity shops in every High Street and the current forecast is that by the year 2000 there will be over 4500 charity shops nation-wide. These shops are responsible for collecting and disposing of approximately 40,000 tonnes of clothing each year, which is worth over £15 million pounds in cash to the charity sector.

We estimate that in total there is over 120,000 tonnes of surplus clothing in the UK from various sources - the equivalent of around 250 million garments which is approximately 5 garments per head of population. Given that over 350,000 tonnes of new textiles are sold in the UK every year, only about a third of the volume that is available is currently recycled so there is still much to do.

THE EUROPEAN DIMENSION

In Europe there are very few charity clothing shops, and those that do exist are to support locally based charities, so a completely different approach to collecting is used. The Red Cross has developed a highly successful scheme whereby a town is targeted and by involving local community groups in conjunction with local business and charities a very large volume can be collected and transported to a commercial rag merchant. He will then pay an agreed sum per tonne collected, which is distributed between the local community and the Red Cross.

Through schemes like this, approximately 200,000 tonnes are collected from both Germany and France, and there are equally well-established collections in Holland, Belgium and the Scandinavian countries. With help from the Federal Government the population in Germany is recycling a far larger percentage of its domestic waste stream, and they currently collect approximately 65% of the surplus textiles available.

The easier access to the new East European markets from Germany and Finland has helped to push previously unsaleable grades like fur coats, heavy overcoats and sweatshirts, and this in turn has enabled UK suppliers to find a market via the European merchant. These new markets have a certain danger associated with them as some of the stories about the hijacking of lorry loads at gun point and the mysterious disappearance of large sums of money from bank accounts must make even the most committed merchant pause for thought. But this highlights the co-operation that exists between the charity collectors and the commercial sector working on a worldwide basis.

COMPETITION, INCREASING COLLECTION AND NEW MARKETS

As this number of charity retailers increases, the need to think up new and imaginative ways of sourcing good quality clothing also increases. There has been an explosion in the number of textile bins around the country and there can be few supermarket or municipal car parks, which do not have a clothing bank alongside the bottle or paper banks. The latest estimate is that there are approximately 6000 currently on site. Hardly a week goes by without somebody putting a bin liner through the letter box asking for your unwanted textiles, books and bric-a-brac as the volume of donated product coming through the front door of shops goes down and down as the competition gets harder and harder.

Oxfam was one of the first charities to employ this method of sourcing product but it is now finding increased competition, not only from official registered charities but also from unofficial operators who either falsely claim to represent a charity or worse still, use a recognised charity name on their literature for which they give a donation of a fraction of the true value of the goods they collect.

With the recent changes to the laws governing the disposal of domestic wastes many Councils are experimenting with different systems of separating recyclable products from the households waste system. These kerbside collections take many forms, but the most successful are those that guarantee a product free from contamination. We have, unfortunately, received some clothing from systems where everything is collected in the same "wheely bin". The state of a once decent T-shirt has to be imagined when it has been compacted along with old cat food tins, milk cartons and wine bottles. It may take a long time to perfect these systems but they are potentially a regular and reliable source of product.

Oxfam Wastesaver are expanding our production to help meet the current demand and this has lead to the creation of a further 20 permanent jobs this year. Every week brings a flood of new inquiries from all Four Corners of the world, and recently a container of clothing was sold to Togo, which contained an unusual request. We were asked to put in at least 50 bales of men's ties - not that unusual until you realise that there are at least 25 ties per kilo, and 55 kilos in a bale. That works out to 69,000 ties, enough unwanted Christmas presents to last a long long time!

There have also have several embarrassing incidents, like the time a Kenyan customer when asked to pay for a container load, stood up and dropped his trousers. It was a great relief when we realised that he had a money belt on underneath and that he was only trying to get his money out, although our accountant did comment that the bank notes appeared to be quite warm.

Nothing that is donated to us is wasted - sheepskin coats go to Afghanistan, men's suits go to Jordan, dresses and skirts go to Uganda, nightwear goes to Togo and raincoats go to Liverpool, where they are turned into sound insulation pads for Jaguar cars. The only thing we cannot find a home for is old tights and stockings.

Although the recycling industry is much smaller than in the past, those parts that have survived are now flourishing. The greater use of synthetic fibres in knitwear production has lead to a new demand for shoddy made from old acrylic jumpers in places like Morocco, Tunisia and South Africa where it is spun back into yarns for blanket production. Unusable cotton clothing is still turned into Industrial wiping cloths, the best dusters or polishing cloths are still made from old towels or flannelette sheets cut up into squares. There is now quite a shortage of items like candlewick as this is used by car garages as polishing cloths for new cars, but because most people now have a duvet there are few left in circulation.

Unusual contracts include an order from a local washing machine manufacturer who buys old towels, which they can, wash and wash until destruction to test their new machines. The London Feather Company buys all the old eiderdowns and pillows from which they reclaim the feathers to be used for stuffing new duvets. All Harris Tweed jackets are saved for a German customer who has a chain of shops in Berlin that specialises in the English country gentleman look.

Shoes

A recently opened bag of mixed shoes for a potential new customer from Togo contained a surprise for even the best salesman would have been hard pushed to persuade him that the 2 pairs of ice skates had a use in this market. But used shoes have become a major part of our business and Oxfam has budgeted to receive and sell approximately 32 tonnes a month every month over the next financial year. Unfortunately, there is no easy way to handle them - each bag of approximately 10 kg has to be taken off the trailers or lorries and put into large cages. After weighing the contents each cage is manually emptied into either a deep-sea container or delivery vehicle – a labour-intensive task.

The only criteria for the shoes we collect is that they should be of a reasonable condition and a pair - not that difficult you would think - but it is amazing how wrong things can go. Some people are convinced that they are for recycling - but unfortunately there is no recycling market for shoes. Over the years various people have experimented with making carpet tiles or tractor tyres but until the technology to separate the component parts is available the only thing to do with the worn out or single shoes is land fill them.

But the demand for good quality second-hand shoes continues to be the fastest growing part of our business and we are always looking for new ways to persuade the public to part with as many pairs as we can, even if there is a lot of blood, sweat and tears shed before they leave our shores.

Problems and conflicts

It is quite surprising to receive enquiries from some of the new markets that are opening up. Recently several orders have been for Saudi Arabia, which as one of the world's wealthiest countries was most unusual, where the clothing was not intended for the local population but was for the imported immigrant labour from Bangladesh, Pakistan and the Philippines as these people were unable to afford the prices of the "designer-label" clothing on offer locally.

Some orders are not always quite what they seem - we know of a recent order for single colour wool overcoats - velours to those in the trade - which were destined for India. Because of an import ban on second-hand clothing, these garments have to be cut in half, and each part packed in a separate bale so they can only be used for recycling. It must be quite a sight when the bales arrive and are opened, to see a woman walking around with the left hand half of a ladies navy blue coat, size 14 from Marks and Spencer looking for the other half so that they can be sewn together again!

There is some conflict within many charities on the ethics of selling clothing into the third world or developing countries. Are we putting a local textile manufacturer or garment maker out of business? Are we destroying local jobs and local economy?

Much research has now been done in this area, and the consensus of opinion is that there have been very few cases of any damage done to any local manufacturer, particularly in the East and West African counties where there have been large quantities of clothing imports. In contrast there have been several positive benefits as there are now several thousand people who earn their living by wholesaling, retailing or repairing the clothing, and there has been enormous benefit to the local economies from the distribution of the import taxes that are levied on second hand clothing. A recent example of this was when the Kenyan Government decided to ban the import of second-hand clothing - this decision was overturned one month later when the exchequer realised that the amount of import duty raised had fallen by 50% in that month.

The prices charged on the local second hand clothing markets around the world are very carefully controlled by the economies of supply and demand. Because there is clothing coming from across Europe, North America and the Southern Hemisphere, if any supplier tries to push prices too high there is enough competition to bring prices back down to an affordable level. It must be remembered that the people who buy second hand clothing are only doing so because they cannot afford the price of a new garment, and to people who have very little money, they are delighted to be able to buy good quality clothing at very cheap prices even if it comes from the throw away societies in the developed West.

OXFAM'S CURRENT POSITION

After the National Trust and the Life Boat Institute, Oxfam is the third largest charity in the UK. This year it expects and hopes to distribute both direct emergency relief and development aid for specific projects to the value of £87 million in 85 countries around the world. To help raise this money, the Trading Division, which comprises the Oxfam shops, the catalogue and Wastesaver, have a turnover in excess of £70 million, which gives a profit of over £17 million. A dedicated workforce of 28,000 volunteers working in the shops that sort, wash, press and sell the clothing donated by the public achieves this.

Alongside the cash generated, we expect to distribute blankets, shoes and clothing to a value of £11 million in conflict areas in Eastern Europe and Africa. The demands on Oxfam and the other Relief Agencies never diminishes and it is a permanent up-hill struggle to generate more and more money to fund an ever increasing list of needy projects from desperate people who need our help.

In conclusion, this brief history of the textile recycling industry shows how this has developed and changed into what is now a huge international multi-million pound export market in second hand clothing. This has not happened because of the charity's involvement, but with the charities as the provider of the raw material. We in the charity sector have a great future in partnership with commercial industry that continues to provide charities with the greatly needed funds to continue the work we do. It is a mutually beneficial partnership.

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RESEARCH AREAS FOR UPGRADING TEXTILE RECYCLING

Hans de Groot, Anton Luiken

INTRODUCTION

Notwithstanding a considerably increased consumption of textiles, the amount of textiles recycled has decreased over the last decades, due to low prices of virgin fibres and a higher level of prosperity. Sustainability as well as producer responsibility requires integrated resource management (IRM). This demands for an increase of textile waste recycling. Modern textile waste recycling should be carried out in an ecologically and economically sound way. In order to reach these goals innovative research and technological developments are required. Properly identifying and sorting textile waste streams in a limited number of well-defined materials is the key to producing high quality recycled fibres and for generating realistic market opportunities. However it is only automated technologies, based on rapid and clear identification of textile materials, which will be able to meet today's stringent requirements on costs, quality and quantity.

The consumption of textiles and clothes is still increasing and on a global scale the textile fibre consumption is estimated at 7.5 kg/person, which is expected to grow by 1 kg/person by 2025. In the countries of the EU the textile consumption is presently about 15-20 kg/person. This implies that in the countries of the EU about 5 million tons of textiles and clothes will be discarded every year. If the German figures hold for all the countries in the EU only about 1.5 million tons are reused some way or another while about 3.5 million tons are landfilled or incinerated.

Textile recycling on an industrial scale has existed for over 130 years in Europe. High recycling rates were realised until the 1970's but by then the price of virgin fibres decreased and the amount of textiles and clothes per capita increased. The percentage of textile recycling dropped in most EU countries. In Germany in 1970, 90 % of textiles and clothes were reused; in 1991 this percentage had dropped to 32%. The main applications of the recycled textiles and clothes were secondhand use (1991-18%; 1970-30%) and wiping rags, secondary fibre production and application in the paper industry (1991-14%; 1970-60%).

The textile waste recycling methodology presently employed has several drawbacks:

- only the best quality is gathered; other textiles (e.g. curtains) and excessively worn clothes are not gathered at all at the moment in most countries of the EU;
- the recycling of textiles and clothes is a trade in which the intrinsic value of the product is not fully realised; and
- in the present consumer-driven world, textiles and clothes the products are very quickly downgraded.

Currently there is no good alternative for the lower grade textile waste. Incineration (with or without energy recovery) or landfilling are current methods to dispose of these grades.

The energy consumption to manufacture fabrics with a high content of recycled fibres is often much lower compared to the energy use in the production of virgin materials. Savings of 50% and more are reported in the literature.

A more sophisticated textile recycling strategy according to the principle of cascading can have great environmental benefits. Some of these benefits are:

- less use of raw materials, fertilisers, pesticides and energy for the production of textile fibres;
- less area needed for cotton growing; this leaves more room for food production and organic cotton growing; and
- less waste production.

Textile recycling has to be undertaken on a higher technological level using an integrated approach by applying new technologies in order to regain fibres of a higher quality than presently is the case. The improvements in textile recycling required will concern each different aspect in the recycling chain. A general scheme of textile recycling is depicted below in Figure 1 and in the next paragraphs the bottlenecks and areas for further research will be described.

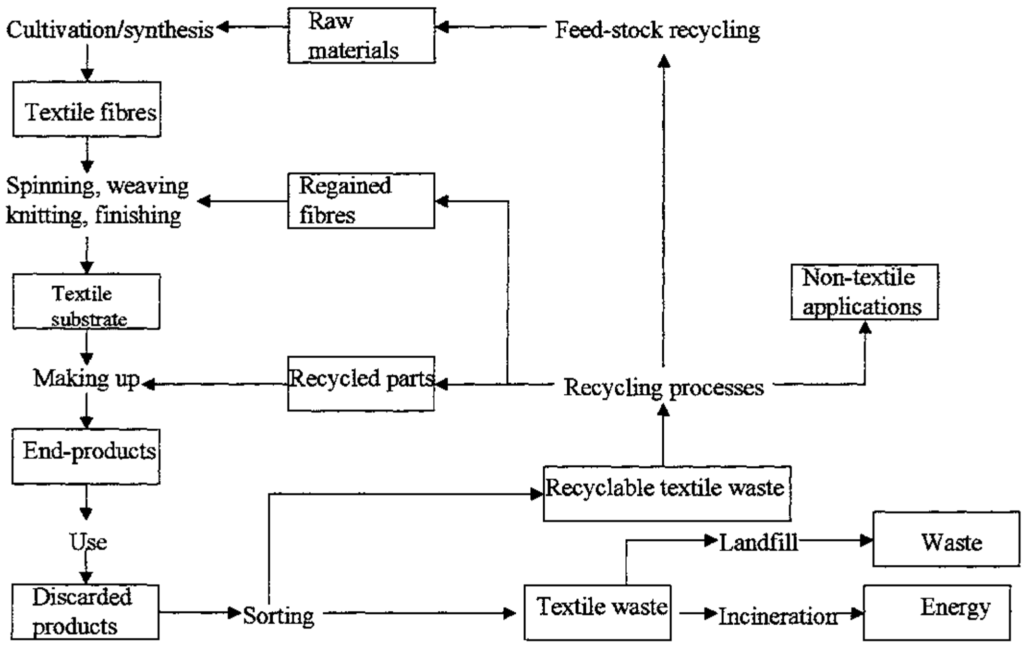

Figure 1: General scheme of textile recycling

This paper gives an overview of the bottlenecks and research needs for the upgrading of textile waste recycling and summarises the conclusions from the recent Textiles Workshop at R'97 in Geneva [1].

BOTTLE-NECKS FOR UPGRADING

Major bottlenecks for upgrading textile recycling are:

- low gathering or collection rate;
- unsorted gathering or collection;

- fibre damage in opening the fabrics;
- impurities in the gathered material;
- manual handling required; and
- low number of end-markets.

The currently low and intermittent gathering rate is a bottleneck because for a given end product, a continuous stream of waste material of a certain quality is needed. Only if a constant source of recycled material is available can a feasible market for the end-product be developed. In the past, many recycling projects terminated due to lack of recycled material.

A high quality end-product can only be produced if the gathered materials can be sorted in an efficient way. Sorting is carried out manually, based on colour and or chemical composition. A more sophisticated and automated sorting system will improve the quality of the obtained fractions.

In opening fabrics, fibres are often damaged severely by tearing and cutting processes. Thus the average length of the fibres is decreased enormously, leading to fibres which have a lower potential usefulness and value.

Due to, in general, the poor quality of recycled fibres, only the low quality markets can be served, resulting in marginal business profits.

ITEMS FOR THE IMPROVEMENT OF TEXTILE RECYCLING

Collection

There are different sources of textile wastes. The highest quality is production waste originating from the textile and clothing industry. This waste stream is relatively clean and well defined (chemical composition known), although the volumes are restricted. A second important waste stream originates from commercial or institutional organisations like professional clothing and textile rental companies and from industrial laundries. The composition of this (post-consumer) textile waste stream is often less complex compared to textile waste from households gathered by charities. This last stream constitutes by far the largest but also the most complex and most contaminated part of the total textile waste. The gathering of this diffuse waste stream to its full content is very difficult, especially with respect to logistics and economy.

The gathering of the production waste as well as institutional waste is only covered to a certain extend. The gathering of the post-consumer waste from households can be largely improved by new collection concepts, like deposit systems, return shops, creation of higher density of containers for textile waste and curb-side collection on a more regular basis. Only in this way with a maximisation of the collected quantities, combined with advanced recycling technologies resulting in high-end applications, can an economical feasible processing of post-consumer textile waste be realised.

Automated identification and sorting

In order to implement textile recycling on an industrial scale, the waste requires sorting according to demands put forward by the specific end-markets or end-users (e.g. colour, chemical composition). Automation of this process is also desirable, in order to reduce the sorting costs and to enhance the quality of the resulting fractions. Conceivable concepts for automatic colour sorting include the use of image-processing systems, for example, which already represent established facilities for similar identification tasks in other areas. Identifying the fibrous materials and chemical composition of textiles involves considerably more complex tasks. In other areas, such as the sorting of plastics, the NIR method (near-infrared spectroscopy) is employed to identify material composition. Due to the complex composition of textiles, this technology is presently not yet able to provide satisfactory results except in the carpet area where collection and sorting of post-consumer waste is being established within the USA, for example.

Other fast identification technologies include laser induced breakdown spectroscopy (LIBS) and thermal impulse response (TIR). LIBS is based on a plasma locally induced by a short laser pulse at the surface. The analysis of the plasma spectrum yields information about the composition of the fibrous material. This technology possibly also enables the identification of dyes and finishes. TIR uses the temperature and cooling curves of materials, upon heating by laser.

The software used to process the analytical data is a key element for identification technologies. Further improvements will make this tool even more powerful. Looking toward the future, neural network technologies and artificial intelligence will be leading the identification process. Further improvement in "remote sensing" from greater distances, increased analysis and identification speed, automatic focusing on parts, and the combination of various methods will enable the industry to advance identification capabilities.

The currently available identification techniques are often developed for the identification of specific materials or products like plastic bottles and metals. These techniques have to be adapted for the recognition of the chemical composition of textile wastes. Many of the devices in use today are based on research instruments. In the future they have to be tailored to industrial applications, making them simpler, smaller and lighter, more robust in rough conditions, easier to handle and less expensive.

Fibre identification has to be carried out on single piece of textile. This requires a resolution-capable technology for use on the entangled textile mass. Due to the complex structure of textile products, including the use of different materials, some degree of pre-shredding may be required as well. The technology of this pre-treatment (resolution and pre-shredding) has to be (further) developed.

Following identification a separation step is necessary. This physical separation has to be carried out by a mechanical or pneumatical devices or by air-jets. The interface between identification and separation equipment has to be developed.

As a result, the textile waste is sorted into a limited number of categories in order to make textile waste recycling economically feasible. Most important categories of textile apparel wastes are: 100% cotton, 100% wool, 100% polyester and blends of cotton and wool with polyester. Furthermore there will be a large remaining category of less common fibres and fibre mixtures. This latter can be mechanical recycled as well, but generally into low value end-uses. These complex mixture can also be incinerated in combination with energy recovery.

Cleaning, washing and disinfection

For certain reprocessing variants, textile waste requires to be cleaned of impurities and/or disinfected. This is carried out by means of washing or chemical cleaning processes before or after sorting. At present there is no urgent need to modify the washing and cleaning processes for textile waste which are employed today.

Decolouration

In order to obtain more valuable uncoloured materials, in some cases a decolouration step could be favourable to the economics of textile recycling. The decolouration can be combined with the disinfection of the textile waste and a removal of a number of finishes. Only a number of dye-classes, like azo-dyes, can be easily and fully decolourised. However, it has to be realised that decolouration can have a negative effect on the mechanical properties of the fibres. As an alternative, separation of fibres based on colour can be employed and this current, often manual operation made to be automated.

Unravelling or disintegration

The disintegration of textile materials into fibres can be performed on an industrial scale. Specialised machinery is available to open the textile materials to fibrous form. Total opening is very important for the subsequent processing of the fibres on textile machinery normally in use in the textile industry.

The quality of the regained fibres can vary greatly, depending on the origin of the textile waste, the chemical nature of the fibres and the way the opening is performed. The length and the mechanical properties of the regained fibres are important and determine the application of the regained fibres. Also colour and purity of the fibres are important: white or uncoloured materials and homogeneous and mixtures of materials with a known composition can be used in high quality end-products. Only then can textile waste recycling on an industrial scale be economically favourable.

Non woven production

In terms of quantity, the use of reprocessed fibres in the production of nonwoven bonded fabrics is the most important area at present. Familiar products here include hat racks and insulating mats for cars. Deficiencies still exist in this area with regard to the processing of only coarsely opened reprocessed material and special bonding processes.

Existing fabric-forming systems require adaptation to enable processing of the particle range which results from the highly productive tearing of textile waste (short fibres, yarn pieces, flat pieces). Opening of the reprocessed material up to the individual fibre is unnecessary for many applications involving bonded fabrics, such as insulating fabrics for thermal and sound insulation. At present, existing web-forming machines, which function according to the aerodynamic principle, are not ideally adapted to the processing of only partially opened waste textiles.

Further research within the field of non-woven-fabric manufacturing is also required on the subject of the strengthening of bonded fabrics. It should be possible to expand product diversity with regard to appearance and/or functions by means of a supplementary thermal treatment process for reprocessed-fibre bonded fabrics containing bonding agents.

Yarn and fabric production

The area of yarn and fabric production covers the spinning of reprocessed fibres into yarns and the further processing of these yarns into textile fabrics, such as woven fabrics, knit fabrics and other structures. These fabrics are employed in the areas of household and home textiles (blankets, upholstery fabrics, and carpets), in the clothing sector (pullovers, jackets, and suits) and in technical textiles (filters).

Yarn manufacture is carried out in two stages - spinning preparation and spinning. Different spinning lines can be used and in the area of spinning preparation various machine constellations are available for opening, cleaning and blending the most diverse fibre materials, and these configurations are able to fulfil the processing requirements for secondary raw materials. Development work is required in the area of the mechanisms to remove remaining non-textile components, which can cause damage to machine elements and lead to problems in the subsequent processes.

The various reprocessed fibre yarns are subsequently processed into textile fabrics and other structures by means of fabric-forming and finishing processes. For this purpose, the fabric-forming and finishing processes require to be adapted to the yarn properties, which result from reprocessing, so as to enable the most diverse possible range of further processing.

Product development

Recycled fibres are inherently of lower quality than virgin fibres. The only way to add value to products made from recycled fibres and raise their image is to improve the performance qualities and the design of end-products. Involving designers throughout the whole recycling and product development process does this most effectively. Working concurrently with all parties involved in the recycling process will create space to cross-link technology, science, manufacturing, business and marketing. This is where ideas for new applications and designs will grow . Focusing on research and design maximises the potential to create innovative new products for both textile and non-textile applications.

Good design will create new markets with products that close the loop of the recycling supply chain, inevitably creating demand for recycled fibre products.

CONCLUSIONS

Textile recycling can be brought on a higher level when several bottle-necks in the presently employed recycling are solved. Main bottle-necks are the collection of textile waste in order to obtain large enough quantities in order to be able to guarantee a continuous stream of end-products. In order to improve the quality of the end-products a fast and reliable identification and sorting system has to be developed. Also the opening process has to be optimised in order to minimise fibre damage. However, the pre-requisites for specific recycling processes are defined by the specifications of the end-products. As such product development plays an important role in obtaining commercially attractive new products out of reclaimed or secondary fibres.

REFERENCE

1. H van de Groot and A Luiken (eds). *Proceedings of the Textile Recycling Workshop* at the international conference *Recovery, Recycling and Re-use, R'97*, Volume VII, EMPA, Geneva, February 1997.

AN OVERVIEW OF ACTIVITIES ON RECYCLING OF FIBROUS TEXTILE & CARPET WASTE AT THE GEORGIA INSTITUTE OF TECHNOLOGY

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About 4 million tons of post consumer and industrial fibrous textile and carpet waste is landfilled each year in the US. Many private companies and research institutions have been working on various approaches aimed at alleviating the waste disposal problem and at utilizing this vast amount of resource for new business opportunities. Researchers at the Georgia Institute of Technology (Georgia Tech) along with industry partners have conducted a broad range of research on fibrous waste recycling, including depolymerization, melt processing, recycling logistics, waste characterization, and products for various applications.

This paper provides an overview of activities and technologies for fibrous waste utilization in the U.S., especially those conducted at Georgia Tech. In particular, the use of carpet waste for concrete and soil reinforcement in construction will be described. The project, including both laboratory study and field trials, shows great promise for high-volume, cost-effective applications of fibrous waste.

INTRODUCTION

According to the US Environmental Protection Agency (EPA) [1], the municipal solid waste generated in the US is about 200 million tons per year, among them about 40% being paper products, 8% plastics, and 2% carpets and textiles. It is estimated that the textile (including carpet, textile and apparel) waste disposed of in landfills each year is about 4 million tons. This practice requires constant creation of new landfill spaces, which is in contradiction to the nation's environmental goals including ecosystem protection. Some fibrous waste (e.g., carpet) is in large strong pieces, which are difficult to handle with the landfill equipment. Consumers on the other hand are less willing to purchase a new product if it is not recyclable. Clearly, there is an urgent need to address the problem of fibrous waste disposal.

Most of the fibrous waste is composed of materials such as cotton, polyester, nylon, polypropylene, among others. It represents a vast amount of resource as raw material for useful products. Typically recycling technologies are divided into primary, secondary, tertiary, and quaternary approaches. Primary approaches involve recycling a product into its original form; secondary recycling involves melt processing a plastic product into a new product that has a lower level of physical and/or chemical properties. Tertiary recycling involves processes such as pyrolysis and hydrolysis, which convert the plastic wastes into basic chemicals or fuels. Quaternary recycling refers to waste to energy conversion. All these four approaches exist for textile recycling.

Many carpet and textile manufacturers, fibre and chemical suppliers, recycling companies, and academic institutions are actively pursuing various methods to recycle fibrous waste [2-7]. In the past decade a broad-based research program has been carried out at the Georgia Institute of Technology (Georgia Tech) on carpet and textile recycling in close cooperation with the industry. These approaches include depolymerization, melt processing, recycling logistics, life cycle analysis, waste characterization, material component separation, composite materials, and reinforcements for concrete and soil. This paper provides an overview of some of these activities and technologies for fibrous waste utilization.

CARPET RECYCLING LOGISTICS TOOL [8]

Many technologies, including those being developed at Georgia Tech, are available to convert textile waste into usable products, and as a result, the demand for the recycled materials will increase. For textile recycling to be economical, the process of collecting, sorting, and distributing the fibrous waste must be optimized. A recycling logistics tool is being developed by Drs. M. Realff and J. Ammons to help the industry to make sound economic decisions regarding these operations. The tool consists a generic model that evaluates the economic feasibility of establishing and operating a carpet recycling network consisting of strategically located collection sites, sorting facilities, and a distribution system to transport the waste. The initial studies have focused on carpet waste recycling. The tool has been applied in the decision making process for a limited number of commercial recycling networks in the US.

DEPOLYMERIZATION OF NYLON [9]

Several depolymerization processes are available to convert nylon and other polymers into monomers, but most of them involve extreme processing conditions. The objective of this study, led by Dr. M. B. Polk, is to develop a low temperature, atmospheric pressure process for the depolymerization of nylon 6 and nylon 6,6 utilizing phase transfer catalysis. A series of experiments were run in order to examine the applicability and efficiency of benzyltrimethylammonium bromide (BTEMB) as a phase transfer catalyst in the depolymerization of nylon 6,6.

It was discovered that the product of the run with no phase transfer agent showed a 16% increase in weight compared to the weight of the original nylon 6,6. The oligomer obtained had a viscosity-average molecular weight of 1644 (the original nylon 6,6 had a molecular weight of 30,944). The other runs with phase-transfer agent produced oligomers with decreases in weight of about 40—50% in each case. These results suggest that in the absence of phase transfer agent, only oligomers are formed; however, soluble low molecular weight products are formed in the presence of phase transfer agent at relatively low temperature and atmospheric pressure.

GLASS MAT THERMOPLASTICS [10]

Glass mat reinforced thermoplastic (GMT) using virgin materials has been attracting growing attention, particularly for use in the automotive sector. Polypropylene is a commonly used thermoplastic matrix in GMTs. Carpet typically consists of two layers of backing (usually polypropylene), joined by $CaCO_3$ filled styrene-butadiene latex (SBR), and face fibbers (the majority being nylon 6 and nylon 66) tufted into the primary backing. In the studies led by Drs. J. Muzzy and S. Kumar, two types of carpet waste have been used: one is edge trim carpet waste, the other is separated polypropylene from post-consumer carpet waste.

The GMT preparation included three steps: debunking, stacking with glass mats and consolidation. The properties of GMT using carpet waste have been compared with the commercial GMT, which uses virgin polypropylene, and similar (or better) results in tensile strength, modulus and elongation have been observed. GMTs manufactured using carpet and other textile waste are currently being studied in greater depth from the point of view of optimization of consolidation and processing parameters.

COMPOSITES AND LAMINATES FROM CARPET AND TEXTILE WASTE[11,12]

Dr. A. Kotliar is exploring another approach to use the face yarn in carpets and the fibres in textiles as a fibrous filler for a composite or laminate and the polypropylene component to supply the necessary flow in processing. Because of the fine diameter of the fibres involved, a low viscosity prepolymer in a water base is used to insure complete coverage of the fibres. The proper choice of the adhesive will result in a high modulus material that is creep resistant and has good weathering characteristics.

The initial work emphasized shredded carpet selvage to which various amounts of cut waste fibres such as nylon 6, nylon 66, polyester and cotton were added. Fabric bits of waste denims and cotton-polyester fabrics were also used. The waste carpet blend was then coated with phenolic or urea formaldehyde resins that were dispersed in a water base. Composite compositions containing between 12 to 100 percent fibre or fabric were examined using 7.5 to 20 weight percent adhesive solids with respect to the face yarn and added fibre content. The fibres were spray coated and molded in a heated press at 150 to 200°C and 3.4 MPa. Test results show that one can achieve high flexural moduli of 2.4-2.8 GPa with face yarn, i.e., fibres that bind to the matrix such as nylon, polyester and cotton. These values together with flexural strengths of 34-48 MPa can find many outdoor applications in the replacement of marine plywood and metal in the transportation area.

Laminates directly from waste carpet pieces were also made. The mechanical properties of laminates made by coating the face yarn with a phenol formaldehyde resin and molding the carpet pieces back to back with the face yarn on the outside to achieve the higher flexural modulus. It was observed that the interfacial strength between the carpet backing and the face yarn is somewhat low. Pressing holes into the carpet prior to spray coating the face yarn so that protrusions of the matrix material flows into the backing during the molding process doubles the flexural modulus of the material. Additional work has been done to make honeycomb sandwich structures for high flexural stiffness and light weight.

REACTIVE EXTRUSION OF CARPET WASTE [13,14]

The basic polymeric components (nylon and polypropylene) in carpet do not mix and bond well when melted. The use of maleic anhydride grafted polypropylene (PP-g-MAH) as a compatibilizer for reactive extrusion of carpet face (nylon) and backing (polypropylene) could produce low cost plastic parts with reasonable mechanical properties [14]. Experimental work on the reactive extrusion at Monsanto [15] and at Georgia Tech led by Dr. S. Kumar [14], has demonstrated a potential for the utilization of carpet as a plastic resin. The initial experiments showed that by blending, compatibilizing, and extruding the carpet, the tensile strength as good as or better than the tensile strength of polypropylene could be achieved. However, the tensile failure strain of the extruded carpet was rather low. Attempts to improve the tensile strain have been made by altering the composition and processing conditions.

Densified nylon 6 carpet in the form of pellets were extruded with two compatibilizers: Polybond™ (PP-g-MAH) from BP Chemicals and Kraton G1921x

(SEBS-g-MAH) from Shell Co. The carpet waste and the compatibilizer were blended in a twin screw extruder. Extruded samples were compression molded at 235 and 260° C. For the carpet system studied, Kraton was found to be a more effective compatibilizer than the polybond 3002. Work of rupture of the samples utilizing 15% Kraton is excellent. Variation in extrusion temperatures and in the molding temperatures result in small variation in properties.

INJECTION MOLDING AND PRESS MOLDING [16]

In the injection molding study led by Drs. J. Muzzy and S. Kumar, shredded selvage trim was debulked at 204°C in the compression molding press. The debulked sheets were cut or ground into small pieces suitable for injection molding. Tensile bars were injection molded at temperature profile of 204°C (rear) and 260°C (nozzle). This sample contained polypropylene, nylon 6, nylon 66, and calcium carbonate. The molded samples resulted in a tensile strength of 180 MPa and strain to failure of 9.4%. These samples exhibited brittle tensile fractures. Injection molding experiments have also been carried out on nylon lint from several carpet mills. Test results indicate that the lint samples have tensile strength similar to that of virgin nylon, though the strain to failure is much lower than the virgin material.

In the press molding study, carpet waste was debulked at 204°C using a compression molding press. The surface of these debulked sheets was quite rough. To give a smooth finish to these sheets, the debulked sheets from carpet waste were hot pressed between virgin polyethylene films. The carpet sheets sandwiched between the virgin polyethylene sheets had an excellent texture. Such are excellent candidates for potential vinyl floor tile replacement. The density of these sheets was measured to be 1.15 gm/cm^3. Further processing development work is needed to reliably measure the properties of such sheet material and compare them to the properties of the currently used vinyl floor tiles.

CARPET WASTE FIBRE FOR CONCRETE REINFORCEMENT [17-19]

A carpet typically consists of two layers of backing (usually fabrics from polypropylene tape yarns), joined by $CaCO_3$ filled styrene-butadiene latex rubber (SBR), and face fibres (majority being nylon 6 and nylon 66 textured yarns). Such nylon and polypropylene fibres can be used for concrete reinforcement. A laboratory study led by Dr. Y. Wang on concrete reinforcement with carpet waste fibres was carried out at Georgia Tech. The concrete mix weight ratios are Type I Portland cement (1.0), river sand (0.85), crushed granite (0.61), water (0.35) and a small amount of superplasticizer. Recycled carpet waste fibres used were disassembled from hard carpet waste (Typical length 12 to 25 mm). Fibre volume fractions for the waste fibres were 1% and 2%. Only the actual fibre portion was included for calculating fibre volume fractions for the waste fibre reinforced concrete. FibreMesh®, a virgin polypropylene fibre (19 mm long), at 0.5% and 1% volume fractions was also included in this study for comparison purposes.

Four point flexural test and cylinder compressive test were conducted on a hydraulic testing machine. 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 fibres 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 fibres bridging the beam crack can be seen. Because of the fibre bridging mechanism, the energy absorption during flexural failure was significantly higher than that for plain concrete.

The laboratory study has indicated that the carpet waste fibre was very effective in improving the toughness and shrinkage properties of concrete. Shaw Industries, Inc. in 1994 completed an 11,000 m^2 R&D Center in Dalton, Georgia which used concrete reinforced with carpet waste fibres in the construction project. About 20 tons of carpet production waste was consumed in the project, which would otherwise be sent to a landfill. The concrete mix followed a typical design for concrete with a 28 MPa (4000 psi) compressive strength, consisting of cement, sand, and rock. The water cement ratio was 0.5 and the cement content was about 260 kg/m^3. Superplasticizer was added to maintain the desired workability. The amount of waste fibre included was 5.95 kg/m^3. Mixing was done by adding fibres to the mixing truck directly, after which the fibres were found to be uniformly dispersed in the concrete without balling or clumping. Mixing, pouring, and finishing followed standard procedures, used conventional equipment, and went smoothly. The compressive and flexural strengths exceeded specifications, and reduced shrinkage cracking was observed. Such concrete containing waste fibres was used for floor slabs, driveways, and walls of the building. The project demonstrated the feasibility of using large amount of carpet waste for concrete reinforcement in a full-scale construction project. Besides reducing the need for landfilling, the use of low-cost waste fibre for concrete reinforcement could lead to improved infrastructure with better durability and reliability.

CARPET WASTE FIBRES FOR SOIL REINFORCEMENT [20,21]

At Georgia Tech, Drs. Y. Wang and J. D. Frost are investigating the feasibility of using shredded carpet waste for soil reinforcement in road construction. Significant research has been conducted since 1960s on soil reinforcement with natural and man-made fibres. It has been widely reported that the properties (especially the shear strength) of soil can be enhanced by fibre reinforcement, resulting in a more stable soil structure with improved load-bearing capacities and durability. Fibres specifically engineered for soil reinforcement are available now (e.g., Fibergrids® by Synthetic Industries) and have been successfully used in many construction projects in the U.S. The novel approach, if proven feasible, could have significant impact on the textile solid waste disposal problem, as it could lead to the use of large amount of carpet waste. It would also lead to improved durability and performance of road; reduced cost for road construction as less land, soil and chemical stabilizers are needed.

The study involves the carpet/fibre industry, several Georgia counties, Georgia Department of Transportation and Georgia Institute of Technology along with other government agencies. Field trial sites for unpaved county roads were selected to represent typical types of soils found in Georgia. Trial sections with carpet waste fibres and virgin fibres were installed in a few unpaved roads. Preliminary assessment by visual inspections confirms that fibres in soil can indeed improve the durability of unpaved roads, and thus reducing the need for frequent regrading. Base on the experience gained during these trials, installation procedures and equipment are being improved.

To evaluate materials for use in improving soil performance, it is vital to have a fundamental understanding of the mechanisms controlling the behavior of the material and soil. This can be done through an integrated set of laboratory tests, which assess the mechanical properties, and engineering behavior of fibre-soil systems prepared under controlled conditions. This task is carried out at Georgia Tech where a series of laboratory strength and deformation tests are performed to evaluate the relative performance of unstabilized and carpet waste fibre stabilized soils. These tests give consideration to the performance of these materials under both as-compacted and long-term conditions. For example, depending on the as-compacted conditions, the long-term performance, as a result of in service saturation, can lead to strength loss and failure of such structures. The tests also investigate the performance of stabilized soils with different amounts and types of waste materials added. In addition, a number of tests are performed in the laboratory to study the effects of non-optimum conditions such as compacting dry of optimum and uneven distributions of the fibre.

In order to convert the fibrous waste into an engineered product for soil enhancement, quantitative assessment of the characteristics of the processed fibres is needed. As it is anticipated that carpet waste may be processed at certain local facilities across the country, an objective method for fibre characterization is essential for quality control and quality assurance. This task is carried out to develop an objective test procedure for fibre geometric characteristics using the image analysis and light transmission methods. Promising results have been obtained, and further work on refining sample preparation, statistical data processing is still underway.

SUMMARY

Because of the large amount of fibrous waste generated each year and the potential for significant economical benefit, many promising technologies are being developed to convert the fibrous waste into useful products, and some of them have been commercialized. To facilitate the exchange of information on the latest developments in fibrous waste recycling technologies and applications, Georgia Tech has organized two conferences on "Recycling of Fibrous Textile and Carpet Waste" in the past two years. The conferences were well attended and well received by the attendees. A third conference on the subject is scheduled for April 30—May 1, 1998 in Atlanta, Georgia.

Significant research and development has been conducted at the Georgia Institute of Technology as part of its mission to serve the industry. A brief description is provided in this paper on studies of recycling logistics, waste fibre depolymerization, melt processing, waste characterization, composite products derived from fibrous waste, and the use of waste fibres for concrete and soil reinforcement. More detailed information on these studies can be obtained from publications cited in this paper, or by contacting the researchers.

REFERENCES

1. U.S. Environmental Protection Agency, Report PB90-215112, Springfield, VA, 1990.
2. S. Kumar and Y. Wang (ed.), Proceedings of the *Conference on Recycling of Fibrous Textile & Carpet Waste* (June 1996, Cartersville, GA). School of Textile & Fiber Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0295
3. S. Kumar and Y. Wang (ed.), Proceedings of the *Second Conference on Recycling of [1]Fibrous Textile & Carpet Waste* (May 1997, Atlanta, GA). School of Textile & Fiber Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0295.

4. Y. Wang, S. Kumar, and M. Polk, "Fundamental Studies for the Utilization of Carpet Industrial Waste", *The Fiber Society Spring Technical Conference,* May, 1994, Annapolis, MD.
5. H. C. Gardner, "Carpet Recycling Technology", *Int. Fiber J.,* August 1995, p36.
6. "Partnership for Carpet Reclamation", DuPont Flooring Systems, Dalton, GA, 1995.
7. J.H., Schut, "Big Plans for Carpet", *Plastics World,* December 1995, p25.
8. M. Realff, J. Ammons and D. Newton, "Systems Modeling in the Design of Reverse Logistics Infrastructure for Carpet Recycling", *Second Conference on Recycling of Fibrous Textile & Carpet Waste,* May 1997, Atlanta, GA.
9. M. B. Polk, "Depolymerization Processes in the Recycling of Nylon 6, Nylon 66, and PET", *Conference on Recycling of Fibrous Textile & Carpet Waste,* June 1996, Cartersville, GA.
10. Y. Zhang, S. Kumar and J. Muzzy, "Glass Mat Reinforced Thermoplastics from Carpet Waste", The Third International Conference on Composites Engineering, July 1996, New Orleans, LA.
11. Kotliar and S. Michielsen, "Plastic Laminates from Recycled Carpets", *Conference on Recycling of Fibrous Textile & Carpet Waste,* June 1996, Cartersville, GA.
12. Kotliar, "Physical Properties of High Modulus Composites and Laminated Made from Waste Carpets and Fabrics", *Second Conference on Recycling of Fibrous Textile & Carpet Waste,* May 1997, Atlanta, GA.
13. S. Kumar, "Polymer Blends and Their Relevance to Fiber, Textile, and Carpet Waste Recycling", *Conference on Recycling of Fibrous Textile & Carpet Waste,* June 1996, Cartersville, GA.
14. R. K. Datta, M. B. Polk, and S. Kumar, "Reactive Extrusion of Polypropylene and Nylon", *Polymer-Plastics Technology and Engineering,* Vol. 34, No. 4, 1995, p. 551.
15. U.S. Patent No. 5,294,384, "Thermoplastic composition and method for producing thermoplastic composition by melt blending carpet", March 15, 1994.
16. Y. Zhang, J. Muzzy and S. Kumar, "Recycling of Carpet Waste by Injection and Compression Molding", *Second Conference on Recycling of Fibrous Textile & Carpet Waste,* May 1997, Atlanta, GA.
17. Y. Wang, A. Zureick, B.S. Cho, D. Scott, "Properties of Fiber Reinforced Concrete Using Recycled Fibers from Carpet Industrial Waste", *J. of Materials Science,* 29 (16), 1994.
18. V.F. Long, "A new life for waste carpet at Shaw", *Citizen-News,* Dalton, GA, Business Section, January 23, 1994.
19. Y. Wang, "Reuse of Carpet Industrial Waste for Concrete Reinforcement", in *Disposal & Recycling of Organic and Polymeric Construction Materials,* Edited by Y. Ohama (E & FN Spon, London) 1995, p297.
20. Y. Wang, "Carpet Waste Fibers for Soil Reinforcement in Road Construction", The Fiber Society Fall 1996 Technical Conference, October 1996, Newport, R.I.
21. Y. Wang, "Carpet Waste for Soil Stabilization", *Second Conference on Recycling of Fibrous Textile & Carpet Waste,* May 1997, Atlanta, GA.

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CARPET WASTE, AN EXPENSIVE LUXURY WE MUST DO WITHOUT !

Mohsen Miraftab, Richard Horrocks and Colin Woods

INTRODUCTION

The United States and Belgian manufacturers who account for approximately 50% of world's total production largely dominate the global carpet industry. In 1994 Europe alone produced nearly 1 billion square metres of carpet and United Kingdom ranked 5th internationally and was responsible for 15% or 150 million square meters of it. This amounts to nearly £1 billion worth of business for the UK manufacturers. However, annually 7% or £70 million of possible additional earnings is lost in the form of waste.

The term "waste" is a collective expression usually meaning surplus or substandard left-overs from fittings and replacement carpets. In fact, waste occurs at all levels of production and increases exponentially along the entire manufacturing route with post-consumer waste accounting for most of this. The carpet waste is eventually incinerated or preferably, as is the case in the UK, dumped into landfill sites at a further annual cost of £750,000 [1].

In manufacturing, the potential value of waste or loss factor increases the further it is created along the production route. The earlier this problem is diagnosed and a solution offered the greater would be the potential savings. However, this may not be, as yet, an easy task given the current manufacturing machineries and established marketing structures. But with an average estimate of 2.5% rise in carpet manufacture per year and increasing costs of landfill dumping, this tradition may soon have to change. Already, in Germany costs of landfill have tripled since 1992 to almost 400DM per tonne and further restrictions introduced in 1996 prevent dumping of any waste with calorific value greater than 11MJ/kg, which includes most carpets[2].

In the United Kingdom, landfill taxes were only introduced for the first time in 1996 at a comparatively modest charge of £7 per tonne, but this figure is expected to rise by the turn of the century.

CARPET MANUFACTURING ROUTES

There are at least four methods of making carpets. They include woven carpets, which had up to the late 1950s dominated the carpet market. Axminster and Wilton are two well-known types of woven carpet manufacturing where colour and design freedom in Axminsters is often compromised for greater strength and durability of the Wilton types. Relatively low speeds of production (averaging to around 70 rows per minute) in both methods of manufacture and their subsequent high costs have been the reasons for their gradual downfall since the introduction of comparatively cheap tufted carpets. Tufted carpets were first introduced into Europe in the 1950s and by late 1970s had dominated the market. The reasons for their swift adoption and subsequent rapid growth are primarily their speed of production (averaging to around 2000 rows/min) and hence their availability in large volumes at relatively low cost. Tufted carpets today account for over 85% of all the carpets produced in Europe and around 76% of all carpets manufactured within UK. Woven carpet speeds of up to 200 rows per minute have recently been reported [3] but, by and large, they remain uncompetitive. Needle- punching is the third method by which carpets are made, but they only account for 9% of the carpet market. This method of carpet production knots substandard or/and coarse fibres together with the aid of barbed needles, which penetrate the fibrous assembly.

Subsequent heat or resin treatment to reinforce the carpet could also follow. Although reasonably durable and cheap to produce, they are in no way comparable to tufted carpets. The remaining carpet market, amounting to around 3%, is covered by a range of production techniques too insignificant in size to be considered in this paper.

In light of their popularity and growth within Europe and in particular UK, tufted carpet manufacturing route will be used as the main focus of this paper to highlight waste generation and their subsequent accumulation. Cross-references to carpet weaving will also be made when comparative routes are considered.

Types of fibres used and their conversion to carpet yarns

Both natural and man-made fibres are used in manufacturing carpet yarns. Wool or fleece sheered from the back of sheep is expensive to produce and is limited by the available number of animals. However, hardwearing, warm feeling and comfort are associated with wool fibres, which account for nearly 31% of the carpet market. Silk and other natural fibres are also used in the carpet industry but their relative consumption is much too small for consideration here.

Man-made fibres, today, dominate the carpet industry with nylon and polypropylene accounting for approximately 65% of the total market. Nylon fibres have traditionally been preferred for their resilience, good compressive recovery and low moisture uptake. However, polypropylene with properties not too different to nylon and with additional advantage of availability in large quantities and hence low costs, has become the second most important man-made fibre in carpet manufacturing. Acrylic fibres are also used in carpet yarns but their relative consumption is low amounting to around 3%. They are often used in blends with other natural and man-made fibres. The remaining 1% is covered by considerably less popular man-made fibres [1].

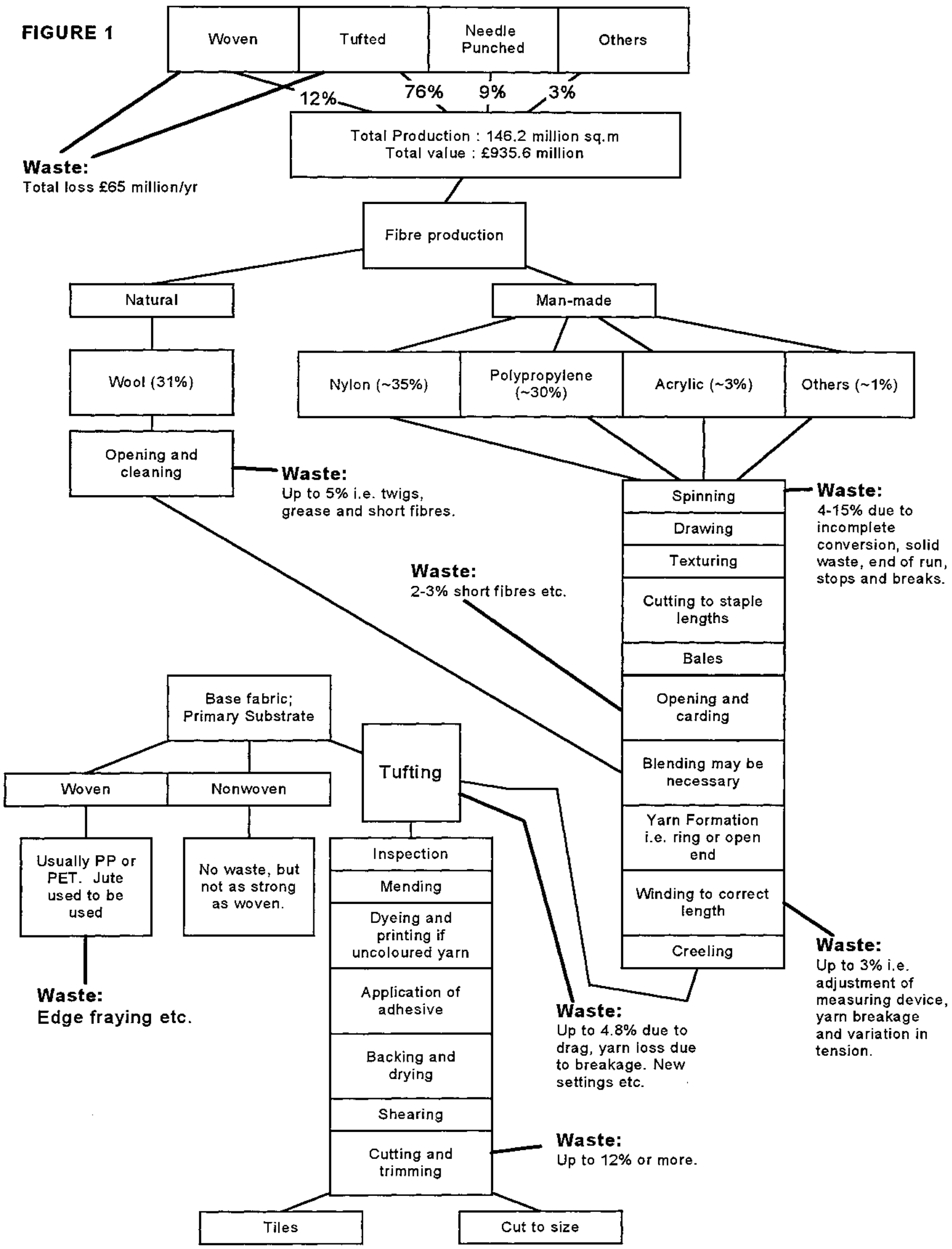
Carpet manufacturing methods

Once fleece has undergone opening, cleaning and the carding processes it can then be spun into pure woollen yarns or blended with other fibres. Similarly, after extrusion, drawing and crimping, man-made fibres are cut to suitable staple lengths and baled. Within the yarn spinning mill, bails are opened and fibres carded and possibly blended before entering the spinning zone. Spinning has traditionally been carried out by either ring or open-end methods. The ring spinning converts roving or finely combed, lightly twisted assemblies of fibres into yarns by drawing and inserting further twist. The open-end method directly converts sliver or loose rope-like continuous fibrous masses into yarns by entering a rotating drum from one end and exiting as yarns from the other.

Spun yarns are wound on appropriately sized packages before going on creels to feed into tufting machines or wound on beams, as warp yarns, to be used for weaving. Tufting is simple in principle and involves a base scrim or primary backing into which loops are inserted by vertical movements of needles. The bases of these loops are then secured by resin and secondary backing, which may include polyvinyl chloride, polyvinyl acetate copolymer (latex) or polyurethane foams as well as fillers. Patterns and colours are introduced by controlling the movements of the needle bars and using coloured yarns. Alternatively pile printing with intricate designs and wide choice of colours could follow. Tufted carpet may subsequently be cut into predetermined shapes as tiles.

In contrast, woven carpet production is much more complicated requiring yarn preparation, beaming, weft insertion and independent control of warp threads especially when jacquard weaving is used.

Figure 1: Schematic representation of the full carpet manufacturing route(s)



In scouring and bleaching it is often necessary to remove hydrogen peroxide before dyeing a fabric with peroxide sensitive dyestuffs. Generally, peroxide removal is achieved after thorough rinsing and possibly the addition of reducing agents. The use of the enzyme catalase allows rapid removal of the peroxide. The dyeing process can therefore, often be carried out in the original treatment bath, which aids water usage, reduces the overall treatment time and is in fact more cost-effective than the conventional reducing agents. The possibility of completing the whole scouring and bleaching process using enzymes (Bioscour) has been examined by a number of workers, utilising pectinases, cellulases, ligninase and lipases with surfactants [2,3]. However, a commercial process is not yet available that gives, a finished cotton of comparable quality to the conventionally scoured material.

Waste associated to processes

Figure 1, shows the full processing route involved in carpet manufacturing and the amount of wastes generated at each stage along the entire path.

Freshly sheered wool fleece contains a large quantity of grease, dirt, twigs as well as unprocessable short fibres, which must be removed. After scouring the total unavoidable waste associated to this early stage is often quoted [4] at around 5%. Some of this waste can be recovered and used as fillers or be included in low-grade products.

Man-made fibre production, by virtue of its creation method, may be assumed to produce no waste at all. In fact polymerisation of the parent monomer and subsequent extrusion into fibres could give rise to as much as 15% waste [5]. The high level of waste is partly due to incomplete conversion of some raw materials to the final polymer and wastes resulting from one or combination of the following factors;

a) the operator
b) equipment breakdown
c) power failure

Since man-made fibre production is a continuous process, incorrect machine settings by the operator could lead to inferior quality fibres, which would have to be discarded as waste. Partial or full breakdown of the spinning equipment due to wear and tear or such faults as clogging at extruder heads results in stoppages and more fibre wastage before smooth running conditions can be resumed. Power failures may ruin a whole series of the production sequence and create excessive cleaning work as well as fibre wastage. Further waste could result from end of runs, filament breakages and changeovers from one specified condition to another.

After spinning and drawing of filaments, they are then usually crimped and cut into staple lengths before undergoing subsequent opening and carding stages. These mechanical actions cause some fibres to stretch beyond their load bearing ability and eventually break, making them unsuitable for further processes. The waste associated to these kinds of actions is estimated at around 2-3%, but they are usually in reasonable enough quality to be used in furniture and pillow fillings.

During tufting, yarn is usually drawn simultaneously from a series of packages stationed on creel frames. Despite their supposedly identical weight and linear density, variations in actual length of packages occur and could be as high as 3%. A further element of variation in yarn length is introduced by the physical layout of the packages on the creel i.e. those furthest away from the tufting machine run out sooner; the subsequent imbalance in length often leads to more waste when fresh packages are knotted in.

In the actual tufting process, the piles are created on a fine woven or nonwoven flat scrim, which may also include a secondary backing, as well as resin. The processed carpet is eventually cut and trimmed along both edges. The waste, by this stage has considerably increased both in terms of size (i.e. 12%) and value. Whether coloured yarn or pile printing methods are used, such faults as stripes and streaks and similar defects caused by faulty needles or knives are picked up during inspection and subsequently discarded as yet more waste.

By and large, the biggest quantity of waste in newly processed carpet occurs during fitting with an average waste of up to 20% or more. Cutting carpets into tiles largely avoids this otherwise valuable waste, but the market they address limits their applications.

In weaving, waste associated to beaming, breaks, weft insertion and subsequent inspections and fittings results in even greater losses, both in terms of quantity and value.

Current methods of tackling carpet waste

Carpet is claimed [2] to account for approximately 2% of all waste dumped into landfill. In the first instance, this may not appear to be a cause for concern but given the steady rise in consumption and high volume to weight ratio, the trend, if not controlled could grow out of all proportions.

Currently 93% of this waste is associated with used carpet and many fibre manufacturers are already considering various methods of salvaging these wastes. The techniques used will be briefly discussed later in this paper. The remaining 7% are clean and potentially more valuable waste resulting from the processing and installation operations already highlighted.

If landfill dumping and incineration are to be avoided, the alternatives must include one or more of the following routes:

- incineration to recover energy;
- re-use in alternative forms; or
- mechanical and chemical recycling.

Incineration to recover energy

The locked in potential or LIP in carpets can be as high as those attained from normal fuel. Table 1 shows comparative calorific values for a range of fibres and those of more common sources of heat. Polypropylene and polyethylene in particular, produce high amounts of energy matching those of diesel oil and naphtha.

Table 1: Comparative calorific values [6]

Calorific values, MJ/kg			
Fibres		**Other sources of fuel**	
Polypropylene	46	Diesel oil	46
Polyethylene	46	Naphtha	42-46
Polystyrene	41	Carbon	21-33
Polyurethane	24-31	Wood	16-21
Polyester	19-30	Paper	16-19
Polyvinyl chloride	20		

However, burning carpets to generate energy also produces its own waste commonly referred to as ash, which is also hard to dispose of. The ash consists of inorganic metals and halogens that are often included in the binder material to increase bulk. Efforts to replace these with organic substances has already led to some composite backing structures where polypropylene is used as the main binder with reinforcing threads to secure the carpet assembly[7].

Pyrolysis or burning in absence of oxygen is another process by which carpet waste is carbonized at high temperatures to generate synthetic coal. The manufactured coal has quite a high calorific value and can be burned with or instead of regular coal, leaving relatively small quantities of ash[8]. The carbonization process is rather energy intensive and, therefore as yet, not economical.

Re-use in alternative forms

Short and unprocessable fibres resulting from different stages of manufacture already find use in soft furniture fillings, mattresses and pillows. This is likely to continue as a feeder to an already established manufacturing practises. Other utilisation schemes include shredding, granulation and mixing of the waste with binders to produce sheets or panels suitable for thermal and sound insulation materials in the building industry. Outdoor and more demanding applications of these panels would require further stabilisation treatments and thus increase their costs.

Finely fragmented carpet waste is often used as passive fillers to increase bulk in concrete and similar building and plastic materials. Currently, attempts are being made to utilise selected range of carpet wastes in a more positive way where overall load-bearing abilities of such matrices are enhanced[9].

Other novel ideas include use of cutting edges and trimmed materials to produce needle felt structures to replace foams or secondary backings in tufted carpets.

Mechanical and chemical recycling

Carpets are multi-component structures, normally designed to provide optimum performance characteristics as well as versatility in colour and design. The notion of waste and the need for dismantling fully made-up carpets has never been a strong enough issue to influence raw material selection and manufacturing processes. However, recent public pressures, reinforced by legislation have compelled manufactures to clean up their technology and recycle their waste.

DuPont, BASF, Hoechst and Allied Signal among other manufacturers, have taken the lead in this crusade and between them, they have tried a number of recycling processes. Despite different approaches, all manufacturers agree that their biggest challenge is the collection of post-consumer carpets followed by separation and cleaning[9-11].

One approach has been the extension of the shredding and granulation, followed by density separation where nylon and polypropylene, in particular, are effectively sorted. The separated nylon could be used as low grade engineering resin or, alternatively, depolymerised to its parent monomer and subsequently repolymerised to feed into the manufacturing cycle. Success rates of up to 99% purity are reported with these techniques. The entire operation, however, is rather lengthy and, as yet, more expensive than the virgin polymer route. Other alternatives include dissolution of one or two components in solvents which, arguably, generate their own waste and cost more. A more recent approach to separation has been the use of near infrared (NIR) detection system employed by Allied Signal. This method is extremely fast and reportedly very accurate but also very expensive.

Since only a third of a typical carpet consists of fibres it is most important that, whichever separation and thus recycling techniques are used, the final cost of production should not override the virgin route. Practicality and survival of any one recycling system is ultimately dependent on its commercial viability.

LEGISLATION WITH RESPECT TO WASTE

With German initiative, a group of European carpet manufacturers in 1990 founded the Association for Environmentally Friendly Carpets or GUT. With current membership of 86 carpet manufacturers [12], representing approximately 70% of the total European market, GUT has become a formidable organisation. In 1995 some GUT members, together with a number of carpet and chemical manufactures initiated a three-year European funded project, known as RECAM. The general aims of this project were to reclaim recyclable materials from carpet wastes and to reuse them in an economically viable manner. To achieve these objectives a closed loop system using all known recovery processes are used. With a budget of 5.5 million ECU and the backing of at least four major European countries, ambitious solutions are predicted for the year 2000 and beyond.

The UK as yet, is not affiliated to these activities and the Department of Trade and Industry, takes the view that as there are no current proposals on end-of-life carpet recycling on the European scene, there is nothing for British exporters to be concerned about [13]. However, in a recent conference[14] held in Aachen, Andreas Bohnhoff from the recycling department of the German national carpet test house or TFI hinted on end-of-life recycling assurances already being demanded by some regional governments in Germany. If this attitude should prevail it will only be a matter of time before some sort of European ruling becomes imminent. The danger for the UK carpet manufactures could then be the inability to export into Europe without firm commitment to recycling.

FUTURISTIC APPROACH TO WASTE MANAGEMENT

The most effective way of preventing waste is to avoid or minimise its creation in the first place. This in itself, however, calls for new and novel technologies as well as processing techniques that will have to come with time. The long-term strategy for eradication of waste however, cannot be left to the manufacturers alone but it needs to grow out of partnership between the manufacturers, consumers and the governments working together towards a common goal. These partnerships may take the following form:

Manufacturers need to concentrate efforts on:

a) creating homogeneous as opposed to heterogeneous carpet structures, which would simplify manufacturing, processes and reduce subsequent separation difficulties and hence recycling costs. Hoechst Celanese have already tried, with some success, making 100% polyester carpets known as Trevira One. They have also been able to extend their programme to carpet packaging materials and labels made from recycled polyester bottles;

b) adopting computer aided systems similar to those widely used in the clothing sector to drastically reduce fitting wastes. Incentive driven tactics by the manufacturers could be used to encourage their regular use by the retailers; and

c) new and novel approaches to carpet making which, for instance, would allow installation of heavy and life-long underlays with relatively cheap and light top layers that would fit on and peel off by some "Velcro-like" action.

The consumer's role could include:

a) adaptation to single fibre carpets and acceptance of perhaps less variety in choice at possibly higher costs;
b) acceptance of carpet tiles rather than full length carpets, whenever possible;
c) use of reconditioned carpets where new designs and colours are applied on old carpets; and
d) responding favourably to voluntary or cash-back incentives for recycling purposes.

Government's co-operation can be reinforced by:

a) legislating and implementing strict roles and regulations with regards to waste and its environmental impacts;
b) subsidising and supporting companies who take initiatives in recycling programmes.
c) increasing tax levies on landfill and nonrecoverable incineration practises; and
d) educating and informing public to the potential dangers of mounting waste and identifying their role in helping the situation.

CONCLUSIONS

In the next century, waste of all types will be one of the biggest challenges facing man. Synthetic carpets will only account for a small but significant portion of this waste. If today's standards of living are to be maintained and even improved, delay tactics and half-hearted measures to tackle waste will only postpone rather than solve the problem. What needs to be done, is collective long-term planning, supported by serious investment commitments that would turn waste into a valuable commodity essential for sustainable development and ultimately preservation of balance in nature.

REFERENCES

1. Environmental Technology Best Practice Programme, Carpet Waste Reduction and Recycling Scoping Study, March Consulting, January 1996.
2. L.Benisek, "environmental issues highlighted at dornbirn", *Textile Month*, 1995 (November), 30-33.
3. K.Gandhi, "Floorcoverings:trends in the 21st. century", *Textile Month*, 1995 (October), 63-67.
4. B.Westwood, "The problem of yarn wastage in the carpet industry, A Management Perspective", *J. Text. Inst.*, 1979 **70** (11) 461-468.
5. S.B. Iyer, "Processing of textile waste and machinery required", *Man-made Textiles in India*, 1991 (March/April), 94-98
6. N. Pasquini, *Fibre Industry and Waste Management*, Himont Belgium N.V., Brussels, ***Date not known***
7. R. Wolff, "Environmentally friendly carpets: A carpet-backing manufacturers view", *International Carpet Yearbook*, 1996. p. 20.
8. 8. P.L. Hauck, "Textile floorcoverings and environmental protection", *Melliand Textilber*, 1994 Page E8.
9. 9. J.Herlihy (Ed.), "Carpet recycling update, carpet and rug industry", 1994. p. 25.
10. 10. P.L. Hauk et al, "DuPont on carpet waste recycling," *International Carpet Yearbook*, 1996. p. 29-32.
11. V. Matthews, "Recycling of polyester containers", Maastricht Conference, May 1996.

12. A.Bohnhoff, *EURECA, An Exemplary Recycling Initiative of the European Carpet Industry*, TFI, Germany 1997.
13. Private communication with British Carpet Manufacturers' Association, 1997.
14. "Economic advantages by ecological optimization". Extracts from textile conference *Economic advantages by ecological optimization*, Aachen, November 1997.

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POLYMER RECYCLING IN TECHNICAL TEXTILES

Philip Davies and Mohsen Miraftab

INTRODUCTION

Synthetic materials originating from coal and oil are perhaps among the greatest discoveries of this century, benefiting almost every consumable discipline. Their range of applications includes anything from fibres to composite implants and computer casings. However, as we approach the close of the 20th century waste from these non-biodegradable materials and their ultimate disposal has become a challenging burden to society at large. The lack of available landfill sites in which most of these wastes have been dumped and the environmental hazards associated to incineration has forced governments to take action in order to reduce waste. Glass, paper and metal recycling are now very well established, however, the focus is now firmly on synthetics or plastics, as they are generally known. Whilst plastic may only account for 7.4% by weight of municipal solid waste, its relatively low density means that by volume there is a much higher quantity of polymer, about 20%. Of this 20% it has been estimated [1] that 60% is polyolefin in nature (polyethylene and polypropylene). In addition to reducing landfill usage increasing recycling will reduce the strain on raw materials either within the process of polymer production or as a fuel for energy production as will be discussed later.

The notion of recycling has existed for many years now but has never before been the focus of as much research as it is today. This is almost entirely due to the environmental demands for reducing waste. In particular environmental concerns on the recycling of plastics are increasing and the polymer processors who are looking to introduce an appreciable level of recycled polymer into their products are reflecting this. One of the areas which has received particular attention for the inclusion of recycled polymer is that of technical textiles and at Bolton Institute work has been carried out on the effect of recycled polyolefins in geotextile tapes and filaments. The end-use of a geotextile is as a reinforcing/filtration initiating substructure, mainly for civil engineering structures, in which the textile will not be seen and as such aesthetics need not be a consideration. One major factor, however, is that such a reinforcing structure should, theoretically, last for in excess of 100 years. As a result of this the use of recycled polymer in such a structure has been called into question since contaminants (e.g. degradation products or mixed polymers) present in the recycled polymer may affect the durability of the produced textile. This paper discusses the available methods of polymer recycling, focusing on thermoplastic polymers, and the uses and limitations of recycled polymers in technical textile production. The effect of additional stabilisers and the possibility of recyclate selection methods will also be discussed.

RECYCLING METHODS

Bearing in mind that an item can only be truly considered as recycled once the costs for reprocessing have been recouped, it is generally accepted that there are four possible routes for the recycling of polymers. Mechanical recycling, in which the polymer is directly reprocessed into a reusable form for processing, has the highest economic value. The two possible mechanical recycling routes are termed as primary or secondary recycling in which the polymer can be reintroduced into the processing system from which it as taken (primary recycling) or can be used in a processing system other than that from which it was taken (secondary recycling). In the current environmental climate this could conceivably mean using polymer waste from a lower specification product and putting it into a higher specification product as will be explained later. Mechanical recycling is limited to thermoplastic polymers since a thermal process is usually involved. It is the main route for polymers to be included into technical textiles and will be discussed in depth below. Below mechanical recycling in economic terms is feedstock recycling (tertiary recycling) in which the polymer is broken down into the constituent monomer which can then be re-polymerised or is used in gas synthesis for use in other manufacturing processes. Most feedstock recycling involves heating the polymer in a specific atmosphere depending on the required final outcome. The final method of recycling is that of energy recovery (quaternary recycling). Here the polymer is incinerated as a fuel in power generation. Plastics have a higher calorific value than coal and so the demand on fossil fuels could be greatly reduced, however, the resultant ash must be put into landfill. Whilst this ash has only 10% of the original waste volume it may represent a concentration of metal catalyst and pigment residues. The leaching of these into the watercourse may pose a hazard. There are also perceived emission problems with the combustion of polymeric substances; however, these should be prevented if an efficient combustion system is used.

RECYCLING AND TECHNICAL TEXTILES

Mechanical recycling

As mentioned previously, the mechanical recycling route is limited to thermoplastics since the thermo-mechanical nature of this route will result in the complete degradation of thermosets. For primary recycling only uniform uncontaminated polymers should be used, however, for some polymers, small percentages of other polymers can be tolerated in the final component so long as there is some degree of miscibility between the polymers. As a result of this it is generally post-industrial waste polymers that are used for primary recycling. Within secondary recycling the waste polymer is usually comprised of a mixture of polymer types from municipal solid waste type sources i.e. items that would usually go to municipal solid waste. This type of waste polymer tends to be contaminated by non-plastic materials (e.g. paper labels and aluminium rings from bottle caps) which, along with immiscible polymer components could result in processing problems and subsequently poor mechanical properties. Separation of polymer types and removal of non-polymeric contaminants is therefore essential before any thermoplastic processes take place.

A fully automated separation process can be quite complex in design and so far the most effective method of separation has been by hand, however, semi-automated systems are now available. These make use of physical and chemical differences in the polymers; most typically density differences and differences in chemical structure. The density differences of polymers may be utilised by the use of a number of tanks each containing different solutions having a predetermined density. The basic principle is that in each tank, polymers with a higher density than the liquid will sink and those with a lower density will float [2]. A density separation system for the separation of polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polystyrene (PS) and poly(vinyl chloride) (PVC) is shown schematically in Figure 1.

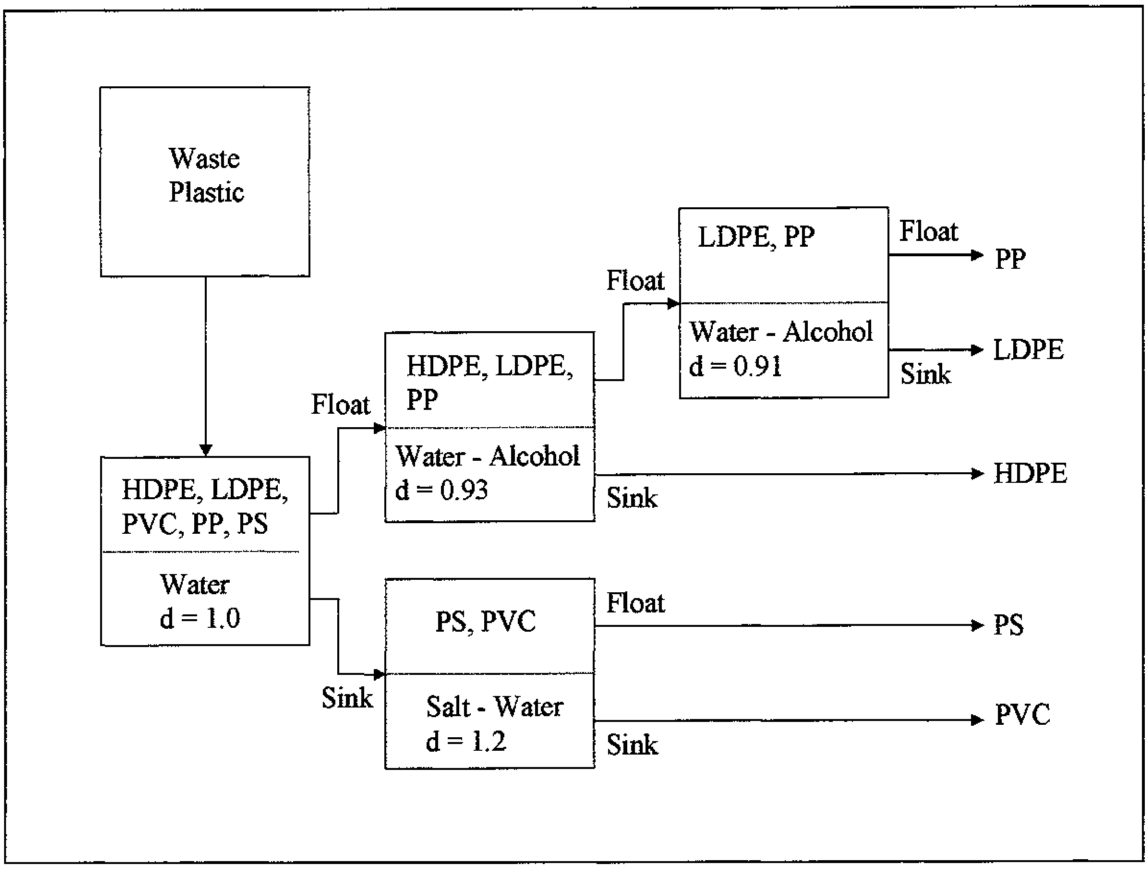

Figure 1: Schematic diagram of density separation.

Generally the density separation systems are used after the polymer has been washed, granulated down and is free from all non-polymeric contaminants. On the other hand the systems, which separate polymers by differences in the chemical structure, are usually used on the bulk items. These systems utilise differences in the infrared absorption spectra of the polymers either in the near infrared (NIR) range [3] or in the mid infrared (MIR) range [4]. The NIR detection system utilises the tendency of each polymer to absorb specific wavelengths of NIR radiation depending on the chemical structure of the polymer. Different polymers have different absorption bands which effectively 'fingerprint' the polymer and with the use of filters removing all but the required wavelength bands the system can simply check for the absence or presence of a given band and hence identify the polymer. The identification system is shown schematically in Figure 2. Here the polymer sample is brought into contact wit the probe and the resulting spectra are passed through the five filters. The filters only allow a specific range of wavelengths of infrared radiation through, these being specific to the important fingerprint regions, and the detectors will give a value of absorbed radiation which indicates the presence or absence of specific chemical groups. This then allows identification of the polymer. With current technology these NIR systems can work at very high speeds with very accurate polymer sorting so making the system cost-efficient. It must be noted that the NIR system only differentiates between the polymers, it cannot identify any fillers or additives nor can it physically separate the polymers. The MIR detection system works on a similar principle to that of the NIR systems with the exception that the whole spectra produced in the mid-infrared range is studied. The latest systems [5] can, with use of a library of spectra, identify blends of polymers and also the presence of some fillers and additives. It is possible in principle to couple these infrared detection systems to a series of air jets or other separation systems which will separate the plastic items into the correct collection bin from which the single polymer type can be reprocessed.

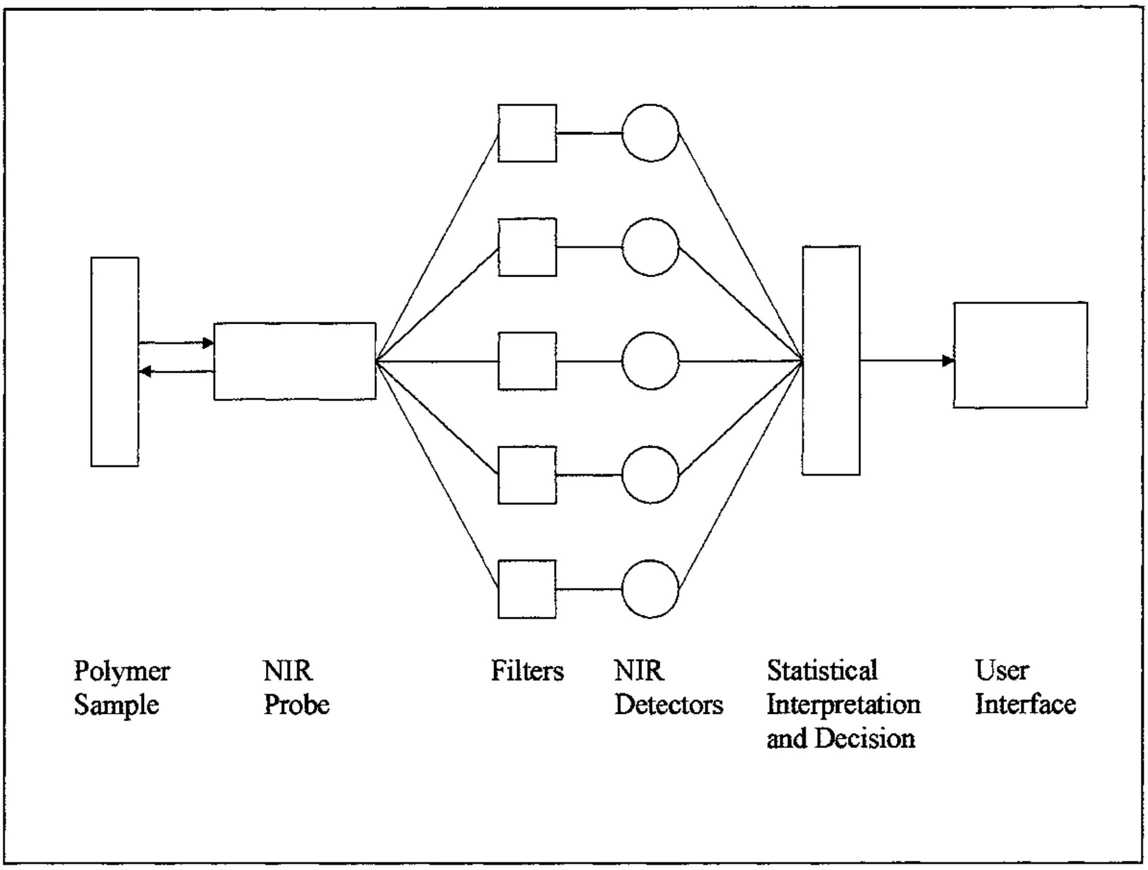

Figure 2: Schematic diagram of near infrared detection system.

For some polymers, the prevention of colour contamination is required since a batch of recycled polymer, which is colourless, will have a higher economic value [6]. To this end PET bottles are colour-separated to prevent discolouration. It is essential that there is no PVC present in a batch of PET since as little as 1ppm in PET will also have the effect of discolouring the polymer [6]. Fully automated separation systems are available[7], which will efficiently differentiate and separate PVC, PET and HDPE by both types and colours.

Once separated into polymer types the waste polymer is washed to remove any residues of the contents or dirt. The washing system will also remove any paper labels and the glue adhering labels to the polymer. The polymer can then be granulated down and any metal contaminant may be removed by the use of an electro-statically charged drum which will attract the polymer but not the metal or be using metal detector coils and air jets to blow the metal away from the polymer.

At this point the chips are in a manageable form but a final process of re-extrusion and pelletisation can be incorporated which results in a recycled polymer being processed in a manner identical to that of the virgin polymer. Care must be taken when re-extruding since the process will result in some degree of thermal degradation and hence degradation of the mechanical properties. The granulated chips are stored in a hopper which feeds them into a conventional screw-extruder which melts the polymer and them pumps it through a die containing a number of holes which will produce 'laces' of polymer 3 - 5mm in diameter. The laces of polymer are extruded into a water bath, which cools and solidifies them. They are then fed into a pelletiser to produce pellets for future processing.

Recyclate inclusion into technical fibre production

Most polymer processors, including technical textile manufacturers producing their own fibre, use in-house recycling (which is essentially primary recycling) and can achieve an almost zero polymer waste output in the polymer processing. This rarely occurs during textile conversion stages because waste from off-cuts, etc., may be more difficult to handle. In the field of filament or tape extrusion the tensile properties are very important and losses in properties should be avoided. The use of waste from within the processing system is deemed acceptable since the high demands of a uniform uncontaminated polymer can be met by a full knowledge of the recycled polymer. However, increasing environmental pressures are such that processors are starting to look at increasing the level of recycled polymer in their products. If a zero waste output is already being achieved, the processors must look to other sources for recycled polymer. Furthermore, since the polymers used for filament and tape extrusion are usually the highest available grade (with the exception of polyester), this implies that they will need to look at secondary recyclate as a source, which brings along with it a number of problems as discussed below.

Polymer immiscibility.

Some polymers, when processed together, tend to separate into their own phases and will not mix together. The result of this is that the polymer mix tends to be very difficult to extrude and the physical properties of the blend tend to be very poor. To prevent this, when selecting a recycled polymer, the polymer type should match that of the virgin polymer. Work is being carried out at Bolton Institute [8] studying the effect of mixing polyolefin types (which are known to be partially immiscible) and methods of achieving blends with acceptable physical and long-term properties.

Polymer rheology

It is accepted that whilst polymer processors would like to increase the level of recycled polymer in their products, it will still remain the minor component of a virgin / recycled polymer mix. However, even as the minor component of the mix, the recycled polymer can severely affect the melt rheology of the mix, which is very important and especially so when extruding fine textile filaments. A basic method of characterising the melt rheology of a polymer, and one, which is widely used, is that of melt flow rate. This is basically a measure of the viscosity of the polymer when molten. When selecting a recycled polymer it is preferable that the melt flow index of the recycled polymer is similar to that of the virgin polymer.

Extrusion parameters and stabilisation

Generally when extruding a virgin / recyclate blend the extrusion parameters may be set as if virgin polymer was being extruded, however, care should be taken to minimise further thermal degradation of the recyclate which will occur during the extrusion process. If possible, the simplest method of control is to slightly lower the temperature profile of the extruder thus reducing degradation, however, in practice this is not always easy since high temperatures are used in order to reduce the viscosity of the polymer to ease extrusion. The preferred method of reducing process degradation is to add additional stabiliser during extrusion. Stabiliser packages are available [9], which are specifically designed for recycled polymers. These usually contain a high level of process stabiliser and some long-term thermal stabiliser. The high level of process stabiliser is needed to deactivate any free radicals, which may be present during the extrusion. Free radicals are produced during extrusion or can be present from the previous processing cycle and lifetime. Since the production of free radicals is generally the initiation step in polymer degradation, reduction in the number present will enhance the stability of the polymer and will increase its lifetime. The long-term stabiliser loading is similar to that in a virgin polymer and performs the same job of stabilising during the polymers lifetime.

Care should be taken when adding stabilisers to the extrusion process since there may be a level of residual stabiliser within the recycled polymer or there may have been stabiliser added during the extrusion of the recycled polymer for the formation of pellets. Whilst the stabiliser is advantageous in the sense that degradation will be minimised it can be considered as a contaminant in the polymer matrix and at ambient temperatures can be relatively insoluble in the polymer. Thus if there is too much stabiliser present then this could result in a drop in the physical properties of the polymer since the stabiliser will interfere with the polymer morphology.

Effect of recyclate inclusion

Whilst legislation is driving an increase in the level of recycled polymer inclusion in processing there are still concerns as to the effect this will have on the initial and long-term properties of the polymer. For the processors of lower grade products where physical properties and durability are not a great concern, then recyclate inclusion is not a problem. However, for producers of technical textiles, where filament and tape production requires a polymer with a high level of purity, introduction of legislation requiring increase of recycled polymer inclusion could mean them being forced to take recycled polymer from a lower grade production route than their own and using it in their production route. To increase confidence in recycled polymer use in technical textile areas, work has been carried out [10,11], and is continuing [8], at Bolton Institute to demonstrate that it is possible to included recycled polymer from secondary sources whilst maintaining acceptable physical properties and durabilities.

Tensile properties of polypropylene filaments containing recycled polymer

The effect on the tensile properties of polymer filaments may be split into two areas, un-aged properties and aged properties. The former will, in general, define the initial performance of a produced textile whereas the latter is important when the lifetime or durability of the textile is being considered.

Both filaments and tapes have been extruded at Bolton Institute containing varying concentrations of commercially available and laboratory produced recycled polymers. The Laboratory produced polymers were used as a control, which would help in the interpretation of results.

In terms of the un-aged properties it has been seen that recyclate levels of up to 20% by weight in filaments [10] and 25% by weight in tapes [11] may be included, without any additional stabiliser, without an unacceptable drop in the tensile properties of the derived filaments and tapes. In both filaments and tapes it was seen that the addition of a stabiliser allowed an increase in the level of recyclate whilst maintaining properties.

The filaments containing recycled polymers were also oven-aged to give an idea of the effect of the recycled polymers on their relative durabilities. Here it was interesting to note that the first filaments to fail were those without any recycled polymer present and that the presence of recycled polymer appeared to have a stabilising effect. This did correlate with the measured thermal characteristics of the polymers used [10], which has been seen in polyolefins previously [12] and hence could be used as part of a selection procedure for recycled polymers. The addition of stabiliser produced a significant enhancement in the durability of all the filaments [10].

CONCLUSIONS

It is the intention of this paper to demonstrate that the use of recycled polymer should not be a problem even in the processing of high tenacity filaments or tapes for technical textiles. With this in mind, the following point should be noted:

- The use of recycled polymer will benefit polymer processors in two ways; firstly it will improve their environmental standing and help them meet any legislative changes and secondly there is a cost advantage if recycled polymer can be used, as it is generally cheaper than virgin material.
- The selection of any recycled polymer to be used should be based on polymer type and melt viscosity, both of which should be matched to that of the virgin polymer being used. A simple measure of the thermal characteristics of the recycled polymer could also help in the selection process since this will give an indication of the effect the recycled polymer may have on the durability of the final textiles.
- It is best that as much history of the polymer is known, however, its original use, recycling conditions and level of stabiliser addition during recycling are probably the most detail one could expect to reliably get. The better the history detail, the easier it will be to make a selection decision and set up processing conditions.
- The benefit of additional stabiliser has been seen, however, it has also been seen that additional stabiliser may not be necessary. Careful assessment of the stabiliser requirements is needed.

REFERENCES

1 G. Camino, 'Polymer Recycling', postdoctoral course *Degradation and Stabilisation of Polymeric Materials*, Clermont-Ferrand, France, 1994.

2 J.L. Holman, J.B. Stephenson and J.W. Jensen, 'Processing the Plastics Waste from Urban Refuse, TRP50, Rolla Metallurgy Research Centre, Bureau of Mines, Rolla, MO., 1972.

3 Anon, 'Buhler NIR, Factorfilter-Spectrometer, System Niriks', Buhler Ltd.

4 P.E.R. Mucci, 'Rapid Identification of Plastics Using External Beam Mid-Infrared Spectroscopy', *Chemical Aspects of Plastics Recycling*, Cambridge, Royal Society of Chemistry, 1997.

5 G. Zachmann and P. Turner, 'Rapid Characterisation of Black Polymeric Material by Mid-Infrared Reflectance Spectroscopy', *Chemical Aspects of Plastics Recycling*, Cambridge, Royal Society of Chemistry, 1997.

6 J. Milgrom, *Plastics Recycling - Products and Processes*, R.J.Ehrig, Ed., Hanser, 1992.

7 G.R. Kenny and R.S. Bruner, Experience and Advances in Automated Separation of Plastics for Recycling', J. Vinyl Technol., 1994, 16(3), 181-6.

8 Engineering and Physical Sciences Research Counsil Project Reference 97300641

9 Anon, 'Recyclostab – New Life for Plastics', Ciba Speciality Chemicals Ltd., Publication No. 28886/1/e, 1994.

10 P.J. Davies, 'The Durability of Polypropylene Filaments Containing Recycled Polyolefin', Ph.D. Thesis, Bolton Institute, Bolton, England, 1996.

11 A.R. Horrocks, A.F. Richards and S. Ghosh, Influence of Waste Polymer Inclusion on the Performance of Orientated Polypropylene Geotextile Tape. Part 1: Effect on Tensile Properties, Textile Res. J., 1995, 65(10), 601-6.

12 A.R. Horrocks, J. Mwila and M. Liu, 'The Use of Thermal Analysis to Assess Oxidative Degradation in Polyolefins', *Oxidative Behaviour of Materials by Thermal Analytical Techniques*, ASTM STP 1326, A.T. Riga and G.H. Patterson, Eds., American Society for Testing and Materials, 1997.

USE OF ENZYMES IN TEXTILE PROCESSING - INDIGO BACKSTAINING DURING CELLULASE WASHING

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INTRODUCTION

The increasing use of enzymes during the last 20 years in textile wet processing has enabled previously environmentally-damaging processe to be more effectively carried out in terms of reduced energy and chemical consumption. More recently, the use of cellulose-degrading enzymes or cellulases has enabled processes to be developed which are both novel and environmentally acceptable. Since enzymes are catalysts and therefore, in principle, not consumed in the chemical process, improved environmental performance would follow from the development of enzymes which could be recycled and reused. This paper presents work carried out to increase our understanding of how cellulases interact with substrates during specific textile processes with a view to arriving at means of recycling them.

The production of the aged look of Denim garments with cellulases is the most successful enzyme process achieved in the textile area during the last decade [2]. The aged look is obtained by the non-homogeneous removal of the indigo dye trapped inside the fibres by the combined action of the enzymes and mechanical factors such as beating and friction. The removed indigo has a strong tendency to backstain on the reverse side of the denim fabric (over white filler yarn) resulting in a lower white/blue contrast. Controlling Indigo backstaining has thus become a major issue in the enzymatic stone washing.

The first explanation for backstaining was the pH of the enzyme bath, a more acidic pH will cause more backstaining, no matter what kind of enzyme used, because it was observed that the use "neutral cellulases" (from fungi *Humicola insolens* with a pH optimum of 6-8) yielded lower dye reposition than "acid cellulases" (from fungi *Trichoderma reesei* with a pH optimum of 4.5-5.5) [12]. The logic of this explanation was not particularly scientific and in this paper we intend to make a close analysis of the Indigo Backstaining problem.

Cellulase Ageing Process

Cellulase enzymes will cleave cellulase chains producing a reducing end and a non-reducing end for each broken 1-4 ß-D glycosidic bond [9]. The cleavages are done, in a synergistic fashion, by three class of enzymes: Endoglucanases (EGs) that hydrolyse randomly cellulose chains; Cellobiohydrolases (CBHs) that split cellobiose from the chain ends and by Cellobiase that splits cellobiose to glucose. The combined effect of mechanical agitation with cellulase activities (specially with EG activity) will produce soluble (chains of less than 6 residues are soluble) and insoluble sugars [2-4] along with the Indigo dye trapped inside the fibre [8]. The enzymatic hydrolysis of insoluble cellulose is preceded by strong adsorption by the substrate in such way that cellulase is partitioned between cellulose and the solvent, water [1, 10]. Therefore in the liquor it is expected to have reducing soluble and insoluble sugars, non-adsorbed cellulase proteins, insoluble Indigo dye and some other additives like buffers, wetting agents and dispersants. Also from what it is mentioned above, the cotton fibre surface during the ageing process could be in one of the three forms: i) intact cellulose surface, untouched by the enzyme;

ii) cellulose surface, with reducing ends produce by enzymatic hydrolysis and after enzyme desorption; iii) cellulose surface where the enzyme is adsorbed.

EFFECT OF SPECIES AT COTTON FIBRE SURFACE ON BACKSTAINING

Because backstaining is likely to depend on what is present at the fibre surface, we have simulated the above-mentioned cellulose surfaces. An original bleached cotton fabric was used to represent an intact cellulose surface. A cellulose surface with a high concentration of reducing end groups was prepared by treating the original fabric with HCl . The cellulose surface adsorbed with the enzyme was simulated by adsorbing a catalytically inactive mutant of *C. fimi* Endoglucanase A. The staining of those fabrics were measured after incubation with Indigo dye in distilled water.

The presence of a higher amount of reducing ends on the acid treated sample did not increase the indigo staining levels significantly, as it might have been expected, since these ends can reduce the Indigo dye (even at pH as low as 5). These results seem to be due to the lower affinity already reported [8] of the non-ionic leuco or reduced form of indigo for cellulose essentially present at neutral and acidic pHs. At pH 9, the level of deposition on the acid treated sample increased 1.5 fold relative to the untreated control.

The presence of the enzyme protein adsorbed on the fabric yields Indigo staining three times higher than for other samples and, therefore, the fact that cellulases will adsorbed seems to be the most important factor that causes backstaining.

A linear relationship between the level of Indigo staining and the amount of bound protein (same inactive CenA) was also verified. The exception to this linearity was the fabric with no bound protein (control fabric). In this control the K/S value is much lower than the extrapolated zero value of the linear relation K/S versus bound protein. This suggests that the dispersed Indigo dye binds only to the protein by the numerous ionic group present and possibly that the Indigo dye is repulsed from unbound cellulose surfaces.

H.insolens Celulases Versus *T. reesei* Cellulases

Similar relationships are seen to exist between Indigo backstaining and pH and between "Bound Protein" and pH, confirming that the ability of enzymes to bind on the cotton substrate plays a major role in indigo backstaining. The binding behaviour of the acid cellulase (from *Trichoderma reesei*) is maximum at pH 5, the pH for maximum cellulase activity, while for the neutral cellulase (from *Humicola insolens*) the lower binding behaviour at pH 7, is the pH of maximum cellulase activity. This unusual behaviour of Humicola cellulases, might be due to different pH maxima shown by their CBHs enzymes relative to the all crude mixture [14]. However, the pH binding behaviour on cotton of the individual components needs to be further studied.

The neutral cellulase gives always lower staining levels when compared with the acid one. This is has been also verified before [11]. Those results also indicated that the Indigo staining also depends on the nature of the enzyme protein, i.e, the Indigo dye affinity will depend on the external ionic residues of the globular enzyme protein which seem to be different for *Humicola* and *Trichoderma* cellulases. We further investigated the interaction between Indigo and the cellulases from both fungi, and we verified that *T.reesei* cellulases have adsorption constants 35 times higher than *H.insolens* celulases and *T.reesei* cellulases have Indigo saturation levels up to 6 times more than *H.insolens* cellulases.

FINAL REMARKS

The dye binding to the bound protein seems to be the main reason for backstaining during enzymatic washing. This has been also suggested previously when the use of proteases for reducing the backstaining was proposed earlier [5]. The binding ability of an enzyme to a substrate is due to the presence of a substrate binding domain and it was further suggested that elimination of this binding domain would give lower indigo staining levels. In our view this seems counter-productive because the elimination of the binding domain will greatly reduce the activity of the enzymes towards a high crystalline substrate like cotton [10]; possibly no backstaining is seen because no ageing effects are obtained.

The fact that Indigo backstaining is reduced by several surfactants and that desorption of cellulase from the cellulosic fibers is enhanced by a wide range of different surfactants[13], suggests also that Indigo comes into the liquor bound to enzyme proteins.

The previous way to look for new cellulase systems was to search for enzymes active at higher pHs which prevent backstaining while still active enough to yield a good colour contrast. It seems now to us, that backstaining is not pH-dependent and a good cellulase for stone-washing should have also low affinity to the Indigo dye.

It is probable, therefore, that such cellulases would be easier to recycle and reuse and work is continuing with this in mind.

REFERENCES

1. Beldman, G., Voragen, A., Rombouts, F., Searle-van Leeuwen, M. and Pilnik, W. , "Adsorption and Kinetic Behavior of Purified Endoglucanses and Exoglucanases from *Trichoderma viride*", *Biotechnol. Bioeng.*, **30** 251-257, (1987)
2. Cavaco-Paulo, A., Almeida, L. and Bishop, D., "Cellulase Activities and Finishing Effects", *Textile Chemist and Colorist*, **28(6)** 28-32 (1996).
3. Cavaco-Paulo, A., Almeida, L. and Bishop, D., "Effects of Agitation and Endoglucanase Pretreatment on the Hydrolysis of Cotton Fabrics by a Total Cellulase", *Textile Research Journal*, **66** 287-294 (1996).
4. Cavaco-Paulo, A., Almeida, L. and Bishop, D., "Hydrolysis of Cotton Cellulose by Engineered Cellulases from*Trichoderma reesei* ", *Textile Research Journal*, in press
5. Clarkson, K., Lad, P., Mullins, M., Simpsom, C., Weiss, G. and Jacobs, L., "Enzymatic Compositions and Methods for Producing StoneWashed Look on Indigo-Dyed Denim Fabric", PCT WO1994-29426
6. Damude, H., Withers, S., Kilburn, D., Miller, R. and Warren, A., "Site-directed Mutation of the Putative Catalytic Residues of Endoglucanase A from *Cellulomonas fimi*", *Biochemistry*, **34** 2220-2224 (1995)
7. EGU- Endoglucanase Activity by CMC-Vibration Viscosimetry Analytical Method AF 275/1-GB, Novo Nordisk, (1988)
8. Etters, J. N., "Advances in Indigo Dyeing: Implications for the Dyer, Apparel Manufacturer and Enviroment, *Textile Chemist and Colorist*, **27(2)** 17-22 (1995).
9. Ghose, T., "Measurement of Cellulase Activities", *Pure & Applied Chemistry*, **58(2)** 257-268, (1987)
10. Kilburn D., Assouline, Z., Din, N., Gilkes, N., Ong, E., Tomme, P. and Warren, A., "Cellulose Binding Domains: Properties and Aplications", in *Trichoderma reesei Cellulases And Other Hydrolases*, P. Suominen and T. Reinikainen, ed. Foundation for Biotechnical and Industrial Fermentation Research - Finland, **8** 281-290, (1993)

11. Klahorst, S., Kumar, A. and Mullins, M., "Optimizing the Use of Cellulase Enzymes", *Textile Chemist and Colorist*, **26(2)** 13-18 (1994).
12. Kochavi, D., Videback, T. and Cedroni, D., "Optimizing Processing Conditions in Enzymatic StoneWashing",*Am. Dyestuff Rep.*, Sept., 24-28, (1990)
13. Otter, D., Munro, P., Scott, G. and Geddes, R., "Desorption of *Trichoderma reesei* Cellulases from Cellulose by a Range of Desorbents", *Biotec. Bioeng.*, **34** 291-298, (1989)
14. Schulein, M., Tikhomirov, D. and Schou, C., "*Humicola insolens* Alkaline Cellulases", in *Trichoderma reesei Cellulases And Other Hydrolases*, P. Suominen and T. Reinikainen, ed. Foundation for Biotechnical and Industrial Fermentation Research - Finland, **8** 109-116, (1993)