Civil engineering applications of tyres

K N Hylands (Viridis) and Dr. V Shulman (ETRA)
This project was funded by Biffaward under the Landfill Tax Credit Scheme, with contributions from the Institution of Civil Engineers.

Viridis was the Entrust Approved Environmental Body (AEB) responsible for the project and the work was undertaken by a team comprising Viridis, TRL Limited and the European Tyre Recycling Association (ETRA). The project team was assisted by an Advisory Group made up of relevant Government organisations, tyre associations and leading industrial stakeholders. This group raised issues and gave feedback on progress throughout the project, enabling real issues to be highlighted and practical solutions to be proposed.

TRL is committed to optimising energy efficiency, reducing waste and promoting recycling and re-use. In support of these environmental goals, this report has been printed on recycled paper, comprising 100% post-consumer waste, manufactured using a TCF (totally chlorine free) process.
Biffaward Programme on Sustainable Resource Use

This report forms part of the Biffaward Programme on Sustainable Resource Use. The aim of this programme is to provide accessible, well-researched information about the flows of different resources through the UK economy based either singly or on a combination of regions, material streams or industry sectors.

Information about material resource flows through the UK economy is of fundamental importance to the cost-effective management of the flows, especially at the stage when the resources become ‘waste’

In order to maximise the Programme’s full potential, data is being generated and classified in ways that are consistent both with each other, and with the methodologies of other generators of resource flow/waste management data.

In addition to the projects having their own individual means of dissemination, their data and information will be gathered together in a common format to facilitate policy making at corporate, regional and national levels.

Foreword

This report is intended as a guide to the potential for the use of tyres in civil engineering applications. It provides detailed information on the grades of material available, the options for use, and the specific engineering properties afforded by post-consumer tyres.

The report has been financed by Biffaward through the Landfill Tax Credit Scheme, with a 10% contribution from the Institution of Civil Engineers.
**Project team**

Viridis was the Entrust Approved Environmental Body (AEB) responsible for the project and the work was undertaken by Viridis with additional support from the European Tyre Recycling Association (ETRA) and TRL Limited. The project team was assisted by an ‘Advisory Group’ made up of relevant Government organisations, tyre associations and leading industrial players. This group raised issues and provided feedback on progress throughout the project, enabling real issues to be highlighted and practical solutions to be proposed.

Members of the Project Advisory Group are:

- David Bavaird Waste Tyre Solutions
- John Campbell Continental Tyre Group/ REG UK
- Ken Collins University of Southampton
- Jeff Cooper Environment Agency
- Ralph Crouch Environment Agency
- Andrew Crudgington ICE
- Fran Lowe Environment Agency
- Annette Dentith Devon County Council
- John Dorken British Rubber Manufacturers’ Association
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- Jonathan Simm HR Wallingford
- Valerie Shulman European Tyre Recycling Association
- Peter Spendlove SARCO Ltd
- Peter Taylor Imported Tyre Manufacturers Association

Additional assistance in compiling the report was given by a range of industry representatives. Although too many to mention by name, their co-operation was gratefully received.
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Executive Summary

Post-consumer tyres have a number of properties that render them suitable for use in civil engineering applications. Tyres have been used in a number of different applications throughout the world, with published evidence from Asia, Australia, Canada, South Africa and the United States. The potential for their use is just becoming known and accepted in Europe. Tyres have been used in a number of forms for civil engineering applications including:

- Tyre bales for construction purposes.
- Whole tyres for use as landfill cover, or for slope repair.
- Tyre shred for use in drainage applications.
- Tyre Crumb for use as aggregate in lightweight cement, or rubberised asphalt.

Many of the characteristics that are beneficial during their on-road life are equally advantageous when post-consumer tyres are used as raw materials in treatments and applications. Post-consumer tyres are:

- Environmentally sound, with little evidence of pollution caused from their use.
- Inexpensive in comparison with some other materials.
- Lightweight, providing advantages for applications on soft ground.
- Durable and resistant to a wide variety of chemicals.
- Suitable for use in drainage applications, especially as shred because of excellent hydraulic conductivity.
- Suitable where there is a need for reduction of differential settlement.
- Suitable for the reduction of backfill or swelling pressures.
- Available in substantial quantities.

However, their use currently requires a Waste Management Licence as they are strictly defined as waste under UK law. This can prove especially difficult as they remain waste until they have been reworked into the proposed application. This means that even reprocessing to render them suitable for a particular application does not reduce their definition as waste until they have been incorporated into the proposed structure. Thus tyre shred, which has proven effective as a product for lightweight fill will remain a waste until it is added to the embankment or other application. Work is ongoing at present to reduce the administrative burden on tyres, but there is still a way to go.

Tyres can be used in a number of ways, either as whole tyres or cut into fragments of varying sizes down to fine powders. Areas where they have proven useful include:

- Landfill engineering applications including:
  - Landfill drainage for leachate and for the control of water ingress through the cover.
  - Landfill gas drainage and collection.
  - Protection of the geomembrane.
  - Daily cover material.
  - Development of short-term haulage roads on site over soft ground or previously compacted waste.
- Lightweight fill.
- Backfill behind integral bridges.
- Non-landfill drainage applications.
- Fluvial and coastal erosion control.
- Artificial reefs both for coastal protection and habitat creation.
- Absorption of noise and hydrocarbons.
- As an insulating material in general construction.
- New asphalt road surfaces which are hardwearing and inexpensive.
- Development of sports and safety surfaces.
- Production of lightweight engineering or building products.
- Production of modified concrete and cement to meet specific requirements.

Many of these applications are common in various parts of the world, and most have been used to some extent in the UK. This document reviews potential post consumer tyre uses, the relevant standards and specifications that must be complied with and experience with each application in the UK and elsewhere. The aim is to provide guidance for clients, contractors, designers, specifiers, regulators and producers which will enable the more widespread use of these applications.
Part 1: Background

Introduction

Civil Engineers have long sought easy access to environmentally sound, inexpensive and lightweight materials that are readily available in large quantities, particularly for use in sensitive applications. However, many traditional materials generally meet only three of the four requirements at a time.

Post-consumer tyres can meet all of the criteria – concurrently. As civil engineers have become increasingly aware of the exceptional properties of these materials, they have sought new ways to utilise them in lieu of more expensive, traditional options.

Post-consumer tyres are environmentally sound and do not appear on any list of dangerous or hazardous materials. Many of the characteristics that are beneficial during their on-road life are equally advantageous when post-consumer tyres are used as raw materials in treatments and applications. They are widely used in Asia, Australia, Canada, South Africa and the United States for an array of civil engineering and construction projects. Their potential uses are just becoming known in the European Union (EU).

Tyres are non-toxic and non-biodegradable. Their shape, weight and elasticity makes them candidates for a vast array of applications – in whole, cut, granulated or powdered form. In any form, a tyre retains its inherent characteristics including resistance to:

- Bacterial development.
- Mould and mildew.
- Heat and humidity.
- Sunlight or ultra-violet rays.
- Oils, many solvents, acids and other chemicals.

In addition, they are lightweight, providing a substantial reduction (up to 75%) over many traditional materials. Utilisation of tyres in civil engineering applications has many benefits, both in terms of economy and the environment, including representing the Best Practicable Environmental Option (BPEO) in certain circumstances.

Since the early 1970s, researchers and civil engineers have studied these characteristics in laboratories as well as in the field in different world regions and have compiled an extensive body of literature. Reports demonstrate the long-term environmental soundness, efficacy and cost-effectiveness of using different forms of post-consumer tyres in a broad range of civil engineering applications.

During the past five years, organisations throughout the EU have analysed the status of post-consumer tyre availability and use. A recent Tyre Mass Balance Study for the UK (Hird et al., 2002) defined the issues surrounding post-consumer tyres and identified resource inputs and process outputs to determine the most effective means of utilising post-consumer tyres.

In further research, tyre recyclers (material producers as well as material users, suppliers and equipment manufacturers) worked with CEN (European Centre for Standardisation) to create technical specifications for material production and utilisation which can assist in selecting these materials. The standardisation process has led to greater awareness and understanding of the materials – their benefits and limitations. The resulting published Workshop Agreement, CWA 14243 is in the process of becoming a European standard (prEN 14243). Further information may be obtained from CEN.

In some cases tyres have inherent properties which are better than those held by the traditional material. Tyres can be used in a number of ways, either as whole tyres or cut into fragments of varying sizes down to fine powders. Areas where they have proven useful include:

- Landfill engineering applications including:
  - Landfill leachate drainage.
  - Landfill gas drainage and collection.
  - Protection of the geomembrane.
  - Daily cover material.
  - On-site haul roads over soft ground.
- Lightweight fill.
- Backfill behind integral bridges.
- Drainage applications.
- Fluvial and coastal erosion control.
- Artificial reefs both for coastal protection and habitat creation.
- Noise absorption.
- Insulation.
- New asphalt road surfaces.
- Sports and safety surfaces.
- Lightweight engineering or building products.
- Production of modified concrete and cement.
Many of these applications are common throughout the world, and most have been used to some extent in the UK. This document reviews potential post-consumer tyre uses, the relevant standards and specifications that must be complied with and experience with each application in the UK and elsewhere. The aim is to provide guidance for clients, contractors, designers, specifiers, regulators and producers which will enable the more widespread use of these applications.

The document

This document should be used both as a source of reference and as an outline to develop applications for tyres as an alternative to primary aggregates and other products. The document is intended to provide a guide to the civil engineering applications for which post-consumer tyres can be used, and thus to encourage greater utilisation of the applications and greater recycling of tyres. The document is split into two parts.

Part 1 outlines the current UK situation, providing background information including details of tyre arisings and legislative drivers.

Part 2 splits each of the applications into their separate components and provides detailed technical information that will guide the designer to determine whether tyres will provide suitable properties for use in their intended design.

The document includes reference to a number of case studies (both from the UK and around the world) for each of the applications detailed, and outlines:

- The required specifications for materials to allow tyre recyclers to meet the necessary engineering requirements.
- How the post-consumer tyres can be processed to meet the specification.
- The environmental benefits and disbenefits of using tyres in the application.
- The technical feasibility of using tyres and potential problems that could be encountered, with mitigation measures provided where possible.

Each of the applications provided in the guidance has reached the point where feasibility can be easily assessed. Conditions where certain options may not be appropriate are provided where data has been available, or where knowledge of the applications has been built up during the trial and full-scale processes. Many of the applications have been in use for a number of years in various parts of the world, and a considerable amount of data on their performance is available. The bibliography at the end of the document provides reference to some of the work already carried out.

Who is the guidance document for?

The document provides guidance that will be of use to a number of different individuals and organisations. It provides the background information necessary to determine both the options available for the use of tyres in civil engineering applications, and the technical requirements for each of these options. The document should be read by the following:

- Engineering consultants, designers and specifiers.
- Engineering contractors and specialist recycling contractors.
- Producers and suppliers of recycled tyre materials.
- Research organisations and universities.
- Infrastructure operators and owners including local authorities, Highways Agency, Railtrack, British Waterways, London Underground, British Airports Authority etc.
- Regulatory authorities (Environment Agency, SEPA, Environment and Heritage Service for Northern Ireland and local authority environmental regulators).
- Local and national government.

Post-consumer tyre management

Post-consumer tyres are those which have been permanently removed from vehicles without the possibility of being remounted for further road use. Current legislation requires that materials that come to the end of their normal working life will be classified as waste, and require some form of treatment or disposal. Post-consumer tyres fall under this definition of waste.

Availability

Official reports from the fifteen Member States estimate that a total of more than 2,500,000 tonnes of post-consumer tyres are accumulated each year in the European Union. Slightly more than 17% or approximately 435,000 tonnes, originate in the UK. Traditionally the majority of these tyres were consigned to landfill, but that has begun to change. As recently as 1992, 65% of post-consumer tyres were landfilled while 35% were disposed by other means, i.e., exported, retreaded, recycled or used for energy. Today, the reverse is true – 34% are landfilled while 66% are diverted to other routes.
Approximately 21% undergo material recycling (size reduction and use of the materials in an array of applications and products); 22% are used as raw material for energy recovery; 12% are retreaded; 11% are reused domestically and/or exported. It is anticipated that material recycling and energy recovery markets will continue to expand while retreading could remain unchanged and exports may decline.

Three recent European Directives have provided a catalyst for greater accountability and transparency concerning the disposal of post-consumer tyres. Improved information on annual arisings, collection and current use coupled with increased awareness of their beneficial characteristics has led to the exploration of new markets for recycled outputs. Table 1 describes the coverage and projected impacts of each of the Directives.

The Landfill Directive excludes the disposal to landfill of whole tyres from 2003 and the landfilling of shredded tyres by 2006. While it does not prescribe alternative means of disposal, it does provide information about landfill construction and maintenance procedures which have implications for the utilisation of post-consumer tyre materials.

Beginning in 2006 the End-of-Life Vehicle Directive will require the removal of tyres from vehicles destined for destruction to ensure that they do not find their way to landfills with other residues. Precise criteria are provided requiring the recycling and recovery of 80% of vehicle weight by 2006 and 95% by 2015. The recycling of post-consumer tyres will help to realise these goals.

The Waste Incineration Directive harmonises emission requirements for different types of waste-to-energy plants. It could limit the use of tyres for energy, particularly in older facilities that cannot be retrofitted to meet the revised emissions limit.

Current projections suggest that full implementation of the Directives will result in an additional 1,000,000 tonnes of post-consumer tyres per year requiring sustainable management throughout the European Union.

These drivers are exerting considerable pressure on governments and industry to explore new treatments and applications to deal with the increased arisings that will result. Recycling for recycling’s sake will not be acceptable. The mandates and goals are clear: existing markets must be expanded and new methods of valorisation must be created utilising commercially viable, environmentally sound and cost-effective methods. Civil engineering has been identified as a significant sector for development in the future.

Figure 1 illustrates the evolution of tyre management options in Europe alongside the projections of the anticipated impacts following implementation of the three Directives.

Figure 2 illustrates the evolution of material recycling and energy recovery markets throughout Europe indicating the projected growth of civil engineering and general construction activities.

In the UK tyres contribute approximately 0.4% of the total annual waste arisings produced for commercial, industrial and municipal waste (DETR, 2000). However, stockpiling has meant that there are some 13 million tyres located around the country. Figure 3 illustrates the tonnage of tyres produced throughout the UK per annum (1998 figures).

### Table 1 Potential impacts of the new directives

<table>
<thead>
<tr>
<th>Directive</th>
<th>Effective date</th>
<th>Potential impact</th>
</tr>
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<tbody>
<tr>
<td><strong>Landfill directive</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excludes bicycle tyres</td>
<td>2003</td>
<td><em>Ban on landfilling whole tyres.</em></td>
</tr>
<tr>
<td>and those &gt;1,400mm</td>
<td>2006</td>
<td><em>Ban on landfilling shredded tyres.</em></td>
</tr>
<tr>
<td>diameter. (1999/31/EC)</td>
<td></td>
<td>The total number of tyres that will be affected: 768,750</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tonnes of tyres currently landfilled.</td>
</tr>
<tr>
<td><strong>End-of-life vehicle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Components and materials</td>
<td>2006</td>
<td>Tyres of 7,589,000 vehicles will have to be treated.*</td>
</tr>
<tr>
<td>including replacement</td>
<td></td>
<td>The total number of tyres that will be affected: 30,356,000</td>
</tr>
<tr>
<td>parts. (2000/53/EC)</td>
<td></td>
<td>tyres or potentially 300,000 additional tonnes.</td>
</tr>
<tr>
<td><strong>Incorporation of waste</strong></td>
<td></td>
<td></td>
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<tr>
<td>Emissions to air of</td>
<td>2008</td>
<td>Compliance with lower emission standards could effectively close 'wet kilns'</td>
</tr>
<tr>
<td>plants using waste</td>
<td></td>
<td>which treat 20% of tyres used in cement kilns or 111,706 tonnes could return to</td>
</tr>
<tr>
<td>for energy. (2000/76/EC)</td>
<td></td>
<td>market.</td>
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*IDSE-CNR Study 1999 ETRA 2003
**Figure 1** Options for post-consumer management in Europe  
*(Courtesy of V Shulman)*

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<tr>
<td>Landfill</td>
<td>65%</td>
<td>34%</td>
<td>0%</td>
</tr>
<tr>
<td>Material recycling</td>
<td>5%</td>
<td>21%</td>
<td>37%</td>
</tr>
<tr>
<td>Energy recovery</td>
<td>14%</td>
<td>22%</td>
<td>41%</td>
</tr>
<tr>
<td>Export / Reuse</td>
<td>3%</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>Retreading</td>
<td>13%</td>
<td>12%</td>
<td>12%</td>
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**Figure 2** Evolution of markets for post-consumer tyre materials in Europe  
*(Courtesy of V Shulman)*

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<thead>
<tr>
<th></th>
<th>1995</th>
<th>2001</th>
<th>2010</th>
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<tr>
<td>Civil engineering</td>
<td>12%</td>
<td>19%</td>
<td>23%</td>
</tr>
<tr>
<td>Sports / Play surfaces</td>
<td>39%</td>
<td>33%</td>
<td>27%</td>
</tr>
<tr>
<td>Construction</td>
<td>7%</td>
<td>14%</td>
<td>15%</td>
</tr>
<tr>
<td>Consumer / Industrial products</td>
<td>21%</td>
<td>23%</td>
<td>24%</td>
</tr>
<tr>
<td>Other (TDF, TPE)</td>
<td>21%</td>
<td>11%</td>
<td>11%</td>
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</tbody>
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Table 2 outlines the current uses for post-consumer car tyres in the UK (1998 figures). However, the markets are evolving, and it is likely that the changes forced by the Landfill Directive will lead to management options further up the Waste Hierarchy.

Factors affecting post-consumer tyre use

Tyre composition

The post-consumer tyres discussed in this document consist primarily of those manufactured for distribution on the European market for a broad range of passenger cars, utility vehicles and heavy goods vehicles. Each of these categories of tyres is covered under the Landfill Directive. Agricultural, airliner and bicycle tyres are not covered and are not generally included for recycling.

The tyres under discussion are produced from four principal groups of ingredients: natural and synthetic rubbers, carbon black and silica, metal and textiles. The remaining ingredients consist mainly of additives that facilitate compounding and/or vulcanisation. Variations in the composition of a tyre can confer different
### Table 2: Uses for post-consumer tyres in 1998 in the UK

<table>
<thead>
<tr>
<th>Use</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Approximate size of market (tonnes) for 1998</th>
</tr>
</thead>
</table>
| Reuse      | Reuse of part worn tyre casings.                                            | ● No processing required.  
● No additional material resources required.  
● Ensures full use of an expensive resource prior to final disposal.  
● Delays disposal.                                               | ● No potential for sector growth.                                                                                                           | 29,000                                      |
| Reuse      | Retreading of car tyres.                                                    | ● Efficient reuse of resources.  
● Saves natural resources.  
● Sold as high value resource.  
● Reduces overall tyre arisings as fewer tyres are needed.                     | ● Does not deal with the final disposal of tyre casings.  
● Market limited by poor perception of retreads.  
● More suitable for a narrow range of tyre types and sizes.  
● Competition from budget tyres.                                      | 85,000                                      |
| Recycling  | Civil engineering applications e.g. breakwaters, road embankments, noise reduction barriers, slope stabilisation, etc. | ● Tyres require little or no processing.  
● Potential for use of large volumes.  
● Not dependent upon one market sector.                                    | ● Uncertain market at present.  
● Lack of specifications limits use in larger applications.  
● Majority of potential applications still in research.  
● Low value end uses.                                                   | 25,000                                      |
| Recycling  | Shredding and crumbing for use in production of products or to make suitable for other applications such as road surfacing etc. | ● Limited use of natural resources.  
● Keeps tyre management high up the waste hierarchy.  
● Increases the number of applications for which waste tyres can be used.  
● High value end uses.                                                 | ● Expensive processing may be required.  
● Limited current market.                                               | 48,000 (crumb rubber only)                                          |
| Recovery   | Energy recovery in cement kilns, dedicated incinerators, or pyrolysis.      | ● High calorific value.  
● Reduction in nitrous oxide emissions and low volumes of solid ash residue.  
● Guaranteed stable market for large volumes of tyres.  
● Reduction in use of natural resources.  
● Production of usable power/energy for on and offsite uses.          | ● Unfavourable public image.  
● Emission controls are expensive.  
● Obtaining necessary approvals and licences is lengthy and expensive.  
● Falls lower down the waste hierarchy.  
● Still have to dispose of residues in some applications (not cement).  
● May require expensive processing to render tyre material homogeneous for incineration. | 84,000                                      |
| Recovery   | Material recovery through pyrolysis or microwave technology.                | ● Recovery of raw materials.                                                                                                               | ● Technology has not yet been fully proven at commercial scale.  
● Difficult to obtain investment.                                      | Nominal (Trials only)                                  |
| Disposal   | Landfill.                                                                   | ● No processing required.  
● Comparatively inexpensive.                                               | ● No recovery of resources.  
● Disposal of tyres to be banned by 2006.  
● Potential environmental impacts from continued disposal of tyres.  
● Falls lower down the waste hierarchy.                                 | 50,000                                      |
properties, affecting the strength, durability and rigidity of the tyre. It is these properties which provide the potential for use in engineering applications.

It is generally accepted that the generic composition of pneumatic tyres produced for the European market is consistent among producers. The material composition profile outlined in Table 3 can be used as an indication.

### Table 3 Composition of passenger car and truck tyres in the EU (by % weight) (from CEN, 2002)

<table>
<thead>
<tr>
<th>Material</th>
<th>Car/Utility %</th>
<th>Truck/Lorry %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber/Elastomers*</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>Carbon black and silica</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Metal</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Textile</td>
<td>5</td>
<td>–</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Additives</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

* Truck tyres contain proportionately more natural rubber in comparison to synthetic rubber than do passenger car tyres. Courtesy of V Shulman.

Tyres vary in weight as well as in material composition dependent upon their classification. Table 4 provides a summary of the three principal categories of tyres utilised in civil engineering applications.

### Table 4 Average weight of post-consumer tyres by classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Average weight</th>
<th>Units per tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>6.5 – 7.0 kg</td>
<td>153.8</td>
</tr>
<tr>
<td>Utility (including 4x4)</td>
<td>11 kg</td>
<td>90.9</td>
</tr>
<tr>
<td>Truck/Lorry</td>
<td>52.5 kg</td>
<td>19</td>
</tr>
</tbody>
</table>

Courtesy of V Shulman.

### Structure of a tyre

Tyres come in many different sizes, depending upon the purpose intended, but they are all made up of a number of similar components as shown in Figure 4:

![Figure 4 Typical structure of a passenger tyre](image)
The main components are:

- **Tread:** The area of the tyre that makes contact with the road affecting traction, tyre-road noise, and handling.

- **Sidewall:** The tyre sidewalls provide the cushioning capabilities of the pneumatic tyre whilst transferring loads for steering, braking and acceleration.

- **Bead:** The bead reinforces the interface between the tyre and wheel rim and fixes the inner diameter of the tyre. It is made from high tensile steel fibres which are wrapped in woven rubberised textile and held in place by plies.

- **Reinforcing cords:** The reinforcing cords provide stability and strength for the tyre. The cord is a twisted fibre or filament made from polyester, nylon, rayon or steel.

These components build the complex structure necessary in the modern car tyre, which must provide strength, flexibility and value for money along with good road holding characteristics to ensure adequate road safety. Such tyres will endure, under normal use conditions, for approximately 40,000 km (Shulman, 2000). The longevity of tyres is increasing as a factor of extensive research and production methods, improved highway and road conditions, and customer requirements for good value.

**Post-consumer tyre processing**

Post-consumer tyres selected for recycling and the technologies used to process them can have a significant effect upon the resulting recyclates and the range of applications for which the material will be most appropriate. The technologies range from the simplest mechanical devices that compress or cut the tyres to sophisticated and complex multi-step mechano-chemical and/or thermal treatments. The materials and technologies are fully described in CWA 14243 (CEN, 2002).

There are two principal methods of size reduction: mechanical and chemical/thermal. Most mechanical treatments rip or shear the tyres at ambient temperatures while chemical/thermal treatments process the tyres after heating or cooling. Cryogenic, reclaim and pyrolytic technologies are the most common chemical/thermal technologies used today. In many instances mechanical and chemical/thermal technologies are combined.

Size reduction technologies are often described in terms of their functions as well as the specific type of system used. There are basically four functional levels. The functions and the technologies that are employed become increasingly sophisticated as they progress through the levels:

- **Level 1:** Destruction of the tyre structure – The most common means of destroying the structure of the tyre is with simple mechanical equipment designed to cut, compress, or remove a specified part, e.g. production of tyre bales, removing the sidewall, tread, and/or bead wires etc.

- **Level 2:** Separate the elements of the tyre – A second level of treatment reduces the material in size, separates the individual components i.e., the rubber, metal and/or fluff. Size reduction processes can be repeated more than once in order to attain a desired size. Level two is divided into two categories:
  - **Level 2a:** Fragments, rips or tears the material into shreds or chips and removes the metal segments that are not encased in rubber.
  - **Level 2b:** Processes the resulting materials, reducing them further in size to granulate and/or powder, removing metals and fluff.

- **Level 3:** Multi-treatment technologies – A third level of treatment utilises the separated materials and modifies them with the use of chemical/thermal technologies such as devulcanisation, reclaiming, surface modification or pyrolysis.

- **Level 4:** Material upgrading technologies – A fourth level can be added in which the material produced in Level 3 is further treated or refined with increasingly sophisticated technologies such as resonance disintegration, or the addition of new ingredients such as plastics or other elastomers.

These are outlined further in Figure 5, which also identifies some of the different applications for the different material grades. Figure 6 and Figure 7 illustrate some of the mechanisms involved in processing post-consumer tyres for different applications.

Table 5 illustrates the range of material sizes produced from post-consumer tyres using a variety of technologies and treatments (CEN, 2002).

**Table 5 Material sizes available for different applications**

<table>
<thead>
<tr>
<th>Material size</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Granulate</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Buffings</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Chips</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Shreds (small)</td>
<td>40</td>
<td>75</td>
</tr>
<tr>
<td>Shreds (large)</td>
<td>75</td>
<td>300</td>
</tr>
<tr>
<td>Cut</td>
<td>300</td>
<td>Half tyre</td>
</tr>
<tr>
<td>Whole tyre</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Tyre bales</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>


**LEVEL 1**
Mechanical treatment to destroy the tyre structure

- Bead removal
- Sidewall removal
- Cutting
- Compression

**Examples of whole tyre uses**
- Tyre bales
- Artificial reefs
- Landfill engineering
- Coastal reinforcement
- Stabilisation
- Sound barriers

**LEVEL 2**
Size reduction to liberate and separate the material elements

**Level A treatments and examples of uses**
- Shredding
- Chipping

- Landfill engineering
- Drainage
- Insulation
- Lightweight fill
- Backfill

**Level B treatments and examples of uses**
- Ambient grinding
- Cryogenic processing
- Repeated processing for finer materials

- Sports surfaces
- Paving blocks
- Asphalt rubber
- Road furniture
- Playgrounds

**LEVEL 3**
Multi-treatment procedures to further process the material

- Rubber reclaim
- Reactivation
- Surface modification
- Pyrolysis

**Examples of multi-treatment uses**
- Brick production
- Road surfacing
- Road sealants
- Expansion joints
- Asphalt additives

**LEVEL 4**
Post-treatment processes to upgrade the material

- Thermoplastic elastomers
- Carbon products
- Enhanced relclaiming

**Examples of uses of upgraded materials**
- Asphalt additives
- Coatings
- Sealants

**Figure 5** The different levels of post-consumer tyre treatment
(Courtesy of V Shulman)
Waste management licensing and the definition of waste

Despite the fact that post-consumer tyres have suitable properties for use in civil engineering applications they are still classified as a waste material. This can have serious implications for their use as waste is controlled under the Waste Management Licensing Regulations 1994. The current definition of waste reflects the definition provided in the Framework Directive on Waste 75/442/EEC. Under this, waste is defined as:

‘any substance or object in the categories set out in Part II of Schedule 4 which the producer or the person in possession of it discards or intends or is required to discard’

The important term in this definition is ‘discard’. Unless a tyre can be put to immediate re-use as a tyre it is discarded and therefore a waste when it is removed from a vehicle. Thus tyres removed for repair are not waste, but tyres removed and taken away for some form of reprocessing (including retreading as well as one of the many civil engineering applications) will be classified as a waste.

Interpretation of whether a material is waste is subject to law and fact and is not determined by the person handling the material. Once defined as waste, the material will remain so until it has been completely recovered. In the case of use in civil engineering applications this means that tyres will remain waste until they have been engineered into the structure intended. All processes up
to this point – the point of completion of the structure – will be subject to licensing under the regulations, incurring the additional legislative and administrative costs of the waste licensing regime.

To illustrate this point we can take the example of tyre use in road surfacing. The tyre materials used in the resurfacing of roads will remain a waste material, subject to all related legislation, until they have been incorporated in the road surface. All of the processes used to render the tyre material suitable for this use will only be classified as ‘partial recovery’ processes, thereby requiring a waste management licence throughout the entire operation.

Current work to counteract the waste definition barrier is being carried out through an on-going project undertaken by the Environment Council (www.the-environment-council.org.uk) through their ‘Definition of Waste Tyres Task Group’, in collaboration with the Environment Agency.

The main thrust of this programme is to find ways where post-consumer tyres can be recycled without incurring the full costs of the waste management licensing regime. Establishing exemptions from the regime are thought to be the most promising route and the Group is currently working on putting an effective case to DEFRA for an amendment to the current UK Duty of Care and Waste Management licensing regime. The development of specific exemptions will go some way towards increasing the opportunities for civil engineering use.

Environment, health and safety considerations

Data amassed over more than 30 years concerning potential impacts of post-consumer tyre materials on the environment and human health indicate that they are neither hazardous nor dangerous and, thus, do not appear on any EU or Basel Convention list of hazardous materials.

Post-consumer tyres and related materials do not pose a threat to the environment or to human health as long as normal precautions are followed for treatment, processing, storage and use. This applies to the full range of post-consumer tyre materials, as whole or cut tyres, shred, chips, granulate or powders regardless of the treatment technology applied.

Principal concerns regarding materials destined for recycling and civil engineering applications include their potential environmental impacts due to storage, the risk of fire, the potential for leaching into local water supplies, human health and safety issues and energy usage.

Storage

**Quantity:** The quantity of tyres stored on the premises of a material recycling facility or utilisation site is controlled under the current UK Duty of Care and Waste Management licensing regime. This will be set out in the Waste Management Licence for the site.

**Location:** The location, i.e., exterior/interior, at which tyres are stored on the premises of a recycling facility or utilisation site is controlled under the current UK Duty of Care and Waste Management licensing regime. The location will be specified in the Waste Management Licence for the site.

**Recommendation:** Tyres should be stored out of direct sunlight and/or strong artificial light, in dry conditions at temperatures below 38°C.

**Material storage:** Material produced from post-consumer tyres should be cooled after production, prior to packaging and storage and stored according to the manufacturer’s guidelines. Additional conditions may be recommended for specific materials.

Fire or explosion

**Fire:** Spontaneous combustion of tyres is unknown. Once ignited a temperature of at least 350°C must be maintained. Tyre fires most often occur at night in open-air or poorly ventilated indoor storage areas as the result of carelessness or arson. There are few confirmed incidents of combustion on construction sites.

Tyre fires are difficult to extinguish and may burn for weeks or months once fully ignited, particularly when out of doors and fanned by wind. A tyre fire creates dense, oily smoke which can be toxic. Combustion products and runoff from the fire fighting process can contaminate the ground and local water sources.

Traditional extinguishing agents may be used to combat localised fires including water, carbon dioxide, dry chemicals, halon or alcohol foams. Tyres that have been involved in a fire or partially consumed by fire should not be utilised in recycling treatments or applications.

**Explosion:** There are no known explosive hazards with the materials described herein.

National and international standards and training materials to combat tyre fires are available, e.g., ‘Fire Safety for Tyre Sites’ (Home Office, 1995).

Leachates

Laboratory and field-tested leaching studies have been performed following several test protocols. Field studies
indicate that for all regulated metals and organics the results for the post-consumer tyres are well below regulatory levels. Substances which could potentially leach from post-consumer tyre materials are already present at low levels in groundwater in developed areas. Studies suggest that leachate levels for the majority of determinants fall below allowable regulatory limits and will have negligible impacts on the general quality of water in close proximity to the tyres (Westerberg and Mácsik, 2000).

Test results indicate that tyres do not leach volatile organic compounds. Research on long term safety indicate that most of the compounds detected in water samples are at or near detection limits at only trace levels, 10 to 100 times less than regulatory limits for drinking water and, therefore, do not pose a threat to health or the environment.

The pH level has been shown in laboratory and field tests to affect leaching. Indications are that organic materials leach more freely under neutral conditions (pH 7) while metals tend to leach more freely under acidic conditions (pH 3.5). Several studies are currently under way to determine the impacts of leachates under a broad range of pH conditions. Table 6 provides the results of a range of analyses in terms of Swedish MCL regulations for sensitive soil (KM) and less sensitive soil (MKM) (Westerberg and Mácsik, 2000). This analysis is based upon total concentration of the determinants within tyre shreds and not total available as leachate.

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Tyre shred (mg/kg DS)</th>
<th>KM (mg/kg DS)</th>
<th>MKM (mg/kg DS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>&lt; 9.95</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt; 1.99</td>
<td>0.4</td>
<td>12</td>
</tr>
<tr>
<td>Co</td>
<td>&lt; 1.99</td>
<td>30</td>
<td>250</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt; 1.99</td>
<td>120</td>
<td>250</td>
</tr>
<tr>
<td>Cu</td>
<td>32.1</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Fe</td>
<td>452</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>Mo</td>
<td>3.51</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt; 1.99</td>
<td>35</td>
<td>200</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt; 9.95</td>
<td>80</td>
<td>300</td>
</tr>
<tr>
<td>Zn</td>
<td>174</td>
<td>350</td>
<td>700</td>
</tr>
<tr>
<td>Cancerous PAH</td>
<td>24</td>
<td>0.3</td>
<td>40</td>
</tr>
<tr>
<td>Other PAH</td>
<td>38</td>
<td>20</td>
<td>40</td>
</tr>
</tbody>
</table>


The authors concluded that based upon the above tests, post-consumer tyre materials are not considered a soil contaminant. They indicated that although tyre shreds and chips contain leachable PAHs and metals, in proper applications, the leached amount of these elements is negligible.

Human health and safety

There are no permanent effects from physical contact with the material in whole, shredded, chipped or granular form. For most potential irritations, normal protective wear is sufficient.

The following guidelines have been prepared for workers who come in contact with post-consumer tyres during processing and use:

- Outdoor workers in contact with cutting, shredding and chipping equipment should wear protective clothing including: steel reinforced boots, eye, ear and head protection, protective gloves and dust masks.
- Indoor workers in close proximity to raw materials and equipment, particularly for chipping and granulating and bagging should wear protective clothing including: steel reinforced boots, eye, ear and head protection, protective gloves and dust masks.
- All workers should wear long sleeves and long trousers at all times.

The most enduring known risks from tyres in the workplace are strains and sprains from manual handling operations.

Packaging

Whole tyres, cuts, shred and chips are shipped in bulk. They do not require additional packaging materials. For cuts, shred and chips the transport vehicles must have closed sides and the bed must be covered with a material that will not be affected by protruding metal and which provides adequate containment.

Transport safety

Post-consumer tyre materials are commonly transported in large quantities on land and water within the context of ADR regulations (Accord européen sur le transport des marchandises dangereuses par route) which were revised in 2001 (ECE, 2001). The revisions defined a class of flammable solids in which post-consumer tyre materials are identified. However, according to Item 2.2.41.1.6 of the ADR 2001, shred, chips, granulate and powders produced from post-consumer tyres are not subject to the provisions of the class because the results of the UN standardised test indicate that the burning rate is slow. (The test is found in the UN Manual of Tests and Criteria, Part III, Sec. 33.2.1). Trials in accordance with test N.1, the fire train test, have demonstrated that post-
consumer tyre materials do not propagate combustion and, therefore do not pose a threat during transport when normal guidelines are followed.

All carriers of post-consumer tyres in the UK must be registered with the Environment Agency (Scottish Environmental Protection Agency in Scotland, and the Environment and Heritage Service for Northern Ireland). All authorised waste carriers are registered and have a certificate of registration. When handing waste tyres to an authorised carrier, a waste transfer note must be completed giving a written description of the waste. Waste transfer notes vary in appearance but must contain certain information. Copies of all waste transfer notes must be kept for a minimum of two years.

Delivery to site
Post-consumer tyre materials can be transported by road, rail, or waterway, although more than 90% is currently collected and transported by road. The logistics of collection depend upon the population density, topography and geography of the region as well as seasonal weather conditions. Volumes per tonne equate to:

Whole passenger car tyres weighing 6.5 kg per unit equal 154 tyres per tonne.

Whole truck tyres weighing 52.5 kg per unit equal 19 tyres per tonne.

<table>
<thead>
<tr>
<th>Tyre</th>
<th>Quantity</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole passenger car tyres</td>
<td>12</td>
<td>80kg</td>
</tr>
<tr>
<td>Whole truck tyres</td>
<td>3</td>
<td>150kg</td>
</tr>
<tr>
<td>Shredded passenger car tyres</td>
<td>Fragments of 61</td>
<td>400kg</td>
</tr>
<tr>
<td>Shredded truck tyres</td>
<td>Fragments of 8</td>
<td>400kg</td>
</tr>
</tbody>
</table>

Courtesy of V Shulman

Economic considerations
Economics will play a major part in the future use of post-consumer tyres. Tyres have to compete favourably with traditional materials. Applications using tyres are primarily concerned with low cost options, and the availability of tyres in comparison with traditional materials. Applications using limited quantities of tyres will be of lesser interest. However, those requiring large numbers of tyres will prove more economic due to improved economies of scale, as will applications where tyres possess properties that primary aggregates do not, such as lightweight fill.

Competition
Tyres will compete favourably with traditional materials where they have the appropriate properties and can be easily purchased in significant numbers at a guaranteed economic price. A move towards Whole Life Costing rather than Capital Costing will increase the use of tyres in civil engineering applications.

Costs are also affected by the availability of tyres, and this is itself impacted by the demand for tyres. At present, cement kilns are able to economically deal with tyres as a supplementary fuel, making other options more expensive as a result.

Production costs
The costs incurred from post-consumer tyre use are proportional to the degree of treatment required prior to their deployment as useful materials on the site, and so it is preferable to strike a balance between performance, environmental protection and cost. The less treatment required to meet the requirements of a particular application, the lower the costs. Shredded tyres provide a suitable material for a variety of engineering applications, although even whole and half tyres can play a part in some applications, further reducing reprocessing costs.

Figure 8 outlines the typical capital costs (in Euros) involved in setting up processing facilities for the production of the different grades of post-consumer tyre materials indicating that the costs of processing are inversely proportional to particle size. Preliminary specifications for many of the applications highlighted in the figure are provided in the CEN Workshop Agreement on post-consumer tyres – CWA 14243 (prEN14243) (CEN, 2002).

Other considerations
Further economic considerations include:

- Reduced reliance upon primary materials, thereby providing significant environmental and social cost savings.
- Cost savings through a reduction in expensive tyre disposal.
- Increased durability of structures extends life and/or reduces maintenance costs.

Development of appropriate specifications, and confidence in the use of such materials will help to develop a considerable market, especially in the highways and local authority sector, where tyre produced
materials could potentially take the place of traditional materials. Table 8 relates to transportation of post-consumer tyres, indicating that it costs approximately £1/tonne/km to transport tyres.

Current thinking suggests that application sites beyond a 50km radius of a shredding facility should utilise a mobile shredder delivered to site. An active site, i.e., one which will utilise shred or chips for more than one application over time, should lease or purchase a mobile shredder.

Table 8 Transportation facts and figures (ETRA)

<table>
<thead>
<tr>
<th>Capital Investment</th>
<th>Principal Consumers</th>
<th>Examples of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100,000 €</td>
<td>100% public sector</td>
<td>Artificial reefs, Erosion control, Noise barriers, Stabilisation</td>
</tr>
<tr>
<td>&lt;1,000,000 €</td>
<td>80% public sector 20% private sector</td>
<td>Lightweight fill for construction, Roads, Insulation, Landfill construction</td>
</tr>
<tr>
<td>&gt;1,000,000 €</td>
<td>80% public sector 20% private sector</td>
<td>Consumer/Industrial applications, Products, Sports surfaces, Some public engineering applications</td>
</tr>
<tr>
<td>&lt;10,000,000 €</td>
<td>95% public sector 5% private sector</td>
<td>Consumer/Industrial products, Coatings, Some road construction</td>
</tr>
<tr>
<td>&gt;10,000,000 €</td>
<td>95% public sector 5% private sector</td>
<td>Consumer/Industrial products, Applications (coatings, TPE, pigments)</td>
</tr>
</tbody>
</table>

**Figure 8** The post-consumer tyre usage hierarchy

(Courtesy of V Shulman)
Part 2: Civil engineering applications

Part 2 of the report outlines the different applications which can or have used post-consumer tyres as an alternative to traditional materials. These applications range from acting as a barrier, through construction applications to the development of artificial reefs for marine habitat creation. The applications are wide and varied and limited only by the imagination and skill of the designer and specifier. Further applications will be developed as we become comfortable with the use of tyres in such applications. Figure 9 outlines some of the areas where tyres have been used as an alternative to traditional materials.

Chapters follow on the use of tyres in:

- Lightweight fill and soil reinforcement.
- Drainage applications.
- Erosion control.
- Artificial reefs.
- Environmental protection.
- Noise barriers.
- Thermal insulation.
- Other applications including road and safety surfaces, building products, and modified concrete and cement.

Figure 9 Three-dimensional diagram showing potential engineering applications
Use of post-consumer tyres


- Post-consumer tyres are neither a dangerous nor a hazardous material when properly treated and stored.
- Post-consumer tyres or materials do not appear on any EU or Basel Convention list of hazardous material.

The proper preparation and treatment of the materials is fully described in CWA 14243. Summarised below are five critical considerations that guide the preparation, transport, storage and use of these materials.

- Prior to using tyres in any treatment or application, all debris must be removed (stones, glass, cans, etc.). Stockpiled tyres should be washed before use.
- Tyres must be free from contaminants such as oil, grease, petroleum by-products, etc.
- Tyres used in treatments or applications must not contain the remains of those that have been involved in a fire or partially burned.
- All metal fragments must be firmly attached and at least 95% embedded in the tyre fragments from which they are produced. No free metal wires or particles should be included without being contained within a rubber segment. The ends of metal belts and/or beads are expected to be exposed only in the cut faces of some tyre fragments.
- Post-consumer tyre materials are not subject to spontaneous combustion and therefore do not pose a threat during transport or use when good practice guidelines are followed.

Material selection and use

Post-consumer tyre materials produced in line with the requirements of CWA 14243 are uniformly graded and can be relied upon to behave consistently over time. Unique specifications for individual applications or products can be defined and agreed between the producer and the user.

Applications or products which utilise post-consumer tyre materials fall into two broad categories:

- Civil engineering and construction applications.
- Consumer and industrial products.

Application generally refer to civil engineering and construction uses that can be divided into three sub-categories: non-road construction and civil engineering; road construction and civil engineering; and sports and safety surfaces. Many non-road civil engineering and construction uses are rehabilitative, i.e., repairing environmentally damaged sites such as eroded embankments, or destroyed natural reefs. Such applications usually utilise the larger fractions including whole and part tyres down to tyre chips.

Products generally refer to consumer and industrial goods and include refined materials as well as feedstock for energy recovery. Consumer products, many of which have entered the mainstream and meet existing standards, include a broad array of goods from footwear to the solid wheels found on baggage carts. Industrial products are often materials or components used in other industries, e.g., carpet underlay, floor tiles, insulation, sealants, additives, pigments, etc. Generally, consumer and industrial products utilise smaller materials, i.e., small chips, granulate and powders.

Selection of tyre based materials is dependent upon:

- Ready availability of post-consumer tyres.
- Performance requirements of the chosen material.
- Cost.

Overall, post-consumer tyre materials have the potential to meet or exceed performance specifications. In many instances, more than one material will meet the majority of criteria for use. Selection is then dependent upon a direct comparison with traditional or alternative materials.

This document is concerned with applications and not products. These applications have been considered throughout the world because of the suitability or acceptability of tyres as an alternative to traditional materials.

Traditional materials

Tyres have been used in place of conventional civil engineering materials for some time now, and they can be utilised, under certain circumstances as substitutes for (ASTM, 1998):

- Stone.
- Gravel.
- Soil.
- Sand.
- General fill materials.
Tyres have been used primarily because they have physical properties which can be substituted for existing materials, or because their properties provide an advantage over existing materials.

Key contributing factors to the selection of post-consumer tyre materials include their easy availability, cost, adaptability and weight. Newer considerations include those surrounding sustainable development and the conservation of natural resources, illustrated by recent impositions on such materials as virgin aggregate (e.g. the UK Aggregates Levy).

Table 9 provides a comparison by weight between post-consumer tyre materials and more traditional materials often used in civil engineering applications. This illustrates the potential for use where there is a need for a lightweight material, such as for fill over soft ground.

Table 9 Comparison of tyres and traditional materials by weight

<table>
<thead>
<tr>
<th>Material</th>
<th>Kg/cubic metre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyre bale</td>
<td>544</td>
</tr>
<tr>
<td>Shred</td>
<td>450</td>
</tr>
<tr>
<td>Chips</td>
<td>640</td>
</tr>
<tr>
<td>Portland cement (set)</td>
<td>2,931</td>
</tr>
<tr>
<td>Wet sand and gravel</td>
<td>1,890-2,500</td>
</tr>
<tr>
<td>Dry packed sand and gravel</td>
<td>1,601-1,922</td>
</tr>
<tr>
<td>Dry clay and gravel</td>
<td>1,601</td>
</tr>
<tr>
<td>Dry packed earth</td>
<td>1,521</td>
</tr>
<tr>
<td>Sea water</td>
<td>1,025</td>
</tr>
<tr>
<td>Water</td>
<td>1,000</td>
</tr>
<tr>
<td>Soil</td>
<td>1,121</td>
</tr>
<tr>
<td>Stone riprap</td>
<td>1,041</td>
</tr>
</tbody>
</table>

Courtesy of V Shulman.

Developing applications

A number of important factors must be considered prior to the use of post-consumer tyres in civil engineering applications. These include, but are not limited to, the following:

- What is the function of the structure or application?
- What engineering properties are required and do post-consumer tyres provide these necessary properties?
- What is the intended lifespan of the structure?
- Are there any conveniently located suppliers close to site?
- Have any specific hazards been identified?
- What site specific or other design considerations must be addressed (i.e., underlying geology or high groundwater table)?
- Will the use of tyres be supported by the client or the regulator?
- Do tyres provide a strong economic case for use?

Answering these questions in a methodical manner will help the designer to determine relatively quickly whether post-consumer tyres are suitable for use in a particular application. Failures in engineering applications using tyres have occurred because of poor design or construction. Appendix 2 outlines some of the issues that need to be addressed when considering the use of tyres. The majority of these issues can be applied to all potential uses. Specific factors for potential uses are discussed in the relevant engineering chapters.

Specifications and standards

Specifications and standards are required to ensure that a material meets the necessary performance criteria for any given application. Where tyres are concerned, specifications and standards play a major role in the decision making process. They reflect:

- Whether tyres will perform adequately to meet the intended use.
- Whether tyres provide a suitable alternative material as deemed by published codes of practice.
- Whether project specifications allow or bar the use of tyres.


The use of post-consumer tyres is not generally included in specifications in the UK or Western Europe. However they can be included by default for some applications since they are not specifically excluded. In North America a standard has been devised for the use of tyres in civil engineering applications (ASTM, 1998). This was developed primarily to meet the demand for tyres as an engineering material and to impose controls on their use to ensure fitness for purpose. The Standard provides guidance for the testing of physical properties and data for the assessment of leachate generation potential of processed tyres. The document covers the use of whole and shredded tyres in:

- Lightweight fill applications.
- Reinforced retaining walls.
- Drainage applications.
- Thermal insulation.
No such guidance currently exists within the UK, although ASTM D-6270-98 could provide a template for future development of such guidance. It is currently necessary to determine whether the properties of tyres fulfil the requirements of ready published specifications and guidance. Alternatively, discussion through partnership-based contracts could lead to project specific standards being developed. The current and immediate situation is that this will be the case for some considerable time until tyres are confirmed as a suitable alternative material.

The role of specifications

Specifications verify whether a product is deemed fit for purpose. They ensure conformity and quality throughout the construction industry, and are developed through strict testing regimes which ensure compatibility with the proposed end use.

Such standards can take time to be developed. This holds back the uptake of alternative materials as only those materials included in the standard will be used due to the conservative nature of the UK construction industry. Relevant standards currently include:

- British Standards (e.g. BS6453: The use of industrial by-products and waste materials in building and civil engineering).
- European Standards (e.g. CEN Workshop Agreement CWA 14243, Tyre Recycling).

Highway works specifications

The use of materials in the UK motorway and trunk road network is controlled by the Specification for Highway Works (SHW) and the Design Manual for Roads and Bridges (DMRB). These documents include specifications for engineering relating to the construction and maintenance of roads including the road surface, adjacent embankments and structures, drainage and bridge construction. These permit the use of certain alternative materials provided that their physical and chemical properties comply with stated limits.

Departures from the Specification can be arranged on a scheme-by-scheme basis to allow greater use of alternative materials, although applications may involve a long process involving provision of full information on risks and benefits to the Highways Agency. Information requirements include:

- Implications for the project programme.
- Durability and performance characteristics of the proposed material.
- Proposed changes to pavement design.
- Impact on traffic management restrictions.

The use of tyres is not included in the Specification and so any proposal will necessitate going through this channel.

In addition to the above specification, a number of local authorities (Local Authorities are responsible for about 95% of the road network (Reid and Chandler, 2001)) have developed their own specifications which permit the use of alternative materials, including tyres.

Relevant guidance documents

Specific guidance documents have been produced which provide specification details for the use of tyres. These are published by the major research organisations including TRL Limited (formerly the Transport Research Laboratory), Construction Industry Research and Information Association (CIRIA) and Building Research Establishment (BRE). An example of such guidance includes The Reclaimed and Recycled Construction Materials Handbook (CIRIA, 1999).

Further guidance on the use of tyres in infrastructure related projects are also included in a selection of published and unpublished TRL reports referenced throughout this document. These include:


Landfill engineering specifications

The specification for landfill engineering is set out as part of the Landfill Directive which makes provision for the requirements of landfill design. The Directive requires consideration of minimum layer depths for all areas within the landfill including the depths of the clay liner, protective layers, drainage mats and the landfill cover.

Where guidance is required on the use of tyres in landfill engineering Waste Management Paper Number 26B (DoE, 1995) should be consulted. Although subject to review to take account of both the Landfill Directive requirements and the implementation of Integrated Pollution Prevention and Control (IPPC), this remains the authoritative guidance within the UK on landfill design, construction and operation. This sets out the requirements for the design and construction of landfills and their associated infrastructure, including design and construction of landfill cells, leachate and gas drainage infrastructure and site haul roads. Although the use of tyres is not specifically referred to, the properties of shredded tyres have been deemed suitable for use as daily cover material and landfill drainage media.

Further guidance is available from the Environment Agency on the specific use of shredded tyres as a drainage medium in landfill sites. The Landfill Directive and UK Landfill Regulations should also be consulted for specific details relating to engineering requirements on site including cell lining, depths of final cover and leachate and gas collection requirements.

The environmental regulators (Environment Agency for England and Wales, Scottish Environmental Protection Agency for Scotland, and the Environment and Heritage Service for Northern Ireland) should be consulted on all aspects for the use of tyres to ensure they have no objections to any proposed application.

Tyre use outside the specifications

Specification development lags behind the market, and so there are occasions when new materials will be proposed which are not allowed by the existing standards or specifications. Tyres can be utilised without the need for a specification providing they are fit for the intended purpose. Proof of this can be obtained through:

- Investigation and research to determine acceptability prior to use.

Field trials with appropriate testing will usually prove sufficient to indicate whether tyres are suitable for a particular application or not. Greater confidence will come from the development of robust testing regimes and pilot studies specifically designed to confirm whether the performance characteristics of tyres meet the required purpose. It will fall upon the material suppliers to meet the necessary performance requirements through the supply of a quality assured and consistent product. If performance requirements can be met there is no reason why tyres cannot be used as a viable alternative to traditional materials.

Material grades

There are a number of different material grades produced from post-consumer tyres which can be utilised in different applications. The following three grades represent those which meet the majority of requirements in this document.

Tyre bales

Tyre bales or construction bales are prepared from whole passenger car, utility or truck tyres. Mixing of the different categories of tyres is not recommended.

Tyre bales can be used in a variety of civil engineering and conservation applications including construction of breakwaters and dams; river and stream banks; stream base, and road sub-base among others. When unstable conditions exist, tyre bales are often selected as an alternative to more conventional materials such as quarried aggregate, gravel, or gabion baskets.

Baling equipment can be either fixed or mobile. A mobile unit can provide greater flexibility by moving from site to site as needed and reducing the costs of transporting the tyres and/or the completed bales.

The most common equipment is a vertical down-stroke baler that treats passenger car and light utility tyres; units are also available for truck tyres. A typical example is illustrated in Figure 6. The size of the bale is determined by the size of the chamber and the length of the wires used to secure it. The general procedure is as follows:

- 125 passenger car and light utility tyres are placed, individually into the bale chamber in a weave pattern (90 truck tyres).
- The tyres are hydraulically compressed at 65 tonnes for 10 to 20 seconds during a 30 to 45 second total cycle time. Total cycle time depends upon the power source and hydraulic system used.
The tyres are thus formed into a rectangular block which measures 75cm × 150 cm × 135 cm (exact size can be varied dependent upon specifications) weighing 1 tonne.

The block is bound with five, 4 metre long bands of high carbon, galvanised or stainless steel, or revetment cord. The securing bands have a lifespan of 30 years. The tyres themselves are non-biodegradable.

Once compressed the tyres will not regain their original form even when the confining wires are removed. Tests have shown that after 30 months in a bale, when the wire is removed the contents retain their shape and expand by only 5%.

Completed bales can be utilised as they are or further treated by encasing them in wire mesh or concrete and facing them with a veneer of other material, e.g., stucco, marble, stone, etc., virtually sealing them.

Bales can be used in above and below ground installations. Performance will meet that required by specification for many traditional materials in terms of weight, compacted density, specific gravity, compressibility, creep deformation, hydraulic conductivity, etc. The voids between the bales should be filled with sand or similar material including recycled glass cullet. The surround can be finished with stone or other construction material.

Installation is site specific and must consider the existing local environmental conditions including climate, soil quality and stability, water quality and proximity, etc. Each structure must be designed and monitored by a professional geotechnical designer or civil engineer. Bales are used successfully above and below ground level. Above ground installations require bales to be on a cement pad or geotextile liner. Under water use, such as a foundation layer for a dam or artificial lake, does not require the use of a geotextile.

Bales are adaptable to numerous applications and provide particular advantage in areas with poor soil conditions. In wet soils, bales can be used as a sub-grade base to effectively float over marginal areas. The likelihood that the bales will leach is greatly reduced by the absence of exposed bead or other wires.

Once placed, bales remain stationary. Recent data indicate that even under a 20 tonne load over 72 hours, roughly equivalent to heavy truck traffic on a local road, deflection does not exceed 20 cm. The following outlines some of the factors relating to the production of tyre bales prior to on-site use.

Energy use: 125 kWh/t at maximum power.

Noise: 80 dB max. power.

Precautions: Appropriate Personal Protective Equipment (PPE) includes steel reinforced boots, work gloves, eye and ear protectors, protective headwear.

Storage: Storage requirements are generally determined by local authorities. Bales do not hold water. Their density, decreased surface and lack of air ingress greatly reduce the threat of fire.

Whole tyres

Whole tyres can be used in a broad array of civil engineering applications with or without prior treatment. Treated tyres include those which have had the bead wires removed, making them more flexible and malleable, those that have been fixed into bales, or filled with cement to add weight. Other treatments include removal of the tread or the sidewalls for use in separate applications. More detailed information is available in CWA 14243 (CEN, 2002).

Bead wire removal: The bead wire provides rigidity to the tyre. It is the part of the tyre that is made of high tensile steel wires or newer technical materials. They are wrapped in woven textiles which are held by the plies, anchoring the part of the tyre which is shaped to fit the rim. The bead wires are often removed prior to processing the tyre in order to reduce wear on the equipment blades as well as to provide greater flexibility in the resulting material.

The beads can account for between 10% and 20% of the weight of a tyre. Removal is a labour intensive mechanical process of cutting or pulling out the wire. Bead removal equipment can be stationary or mobile. It is generally recommended that wires be removed at a central location so that they can be baled and removed from the site. Once removed, the tyres are more compressible and greater quantities can be transported in each shipment.

It is recommended that the bead wires are removed for many civil engineering applications where tyres are to be placed below the ground level or near the water table. Exposed bead wires can puncture geotextile linings or pneumatic tyres on vehicles used to transport the materials.

There are some indications that exposed beads could begin to dissolve when continuously submerged below the water table in certain aqueous environments, depending upon the specific pH conditions. However,
studies indicate that even under those conditions, the exposed steel and zinc oxide leach only trace quantities – at levels generally too low to be of concern, except under ‘very stringent circumstances’ (Humphrey et al., 1996; 1997; 1998; 1999).

Once the bead wires are removed, the materials can be installed and compressed, filled with cement, or used in a variety of applications. The following outlines some of the factors relating to the use of whole tyres prior to on-site use.

**Energy use:** 110kWh/t at maximum power.

**Noise:** 95dB max. power.

**Precautions:** Appropriate PPE includes steel reinforced boots, work gloves, eye and ear protectors, protective headwear.

**Storage:** Store tyres on site prior to use. Storage of tyres will require a waste management licence.

**Shred and chips**

Shredding is the process by which whole or cut tyres are mechanically sheared at ambient temperature. The system can be regulated to produce pieces 50 to 300mm (shred) or 10 to 50 mm (chips). The size and format of the resulting material is dependent upon the project specifications and vary from large elongated pieces generally associated with shred, to the smaller, equal sized pieces often associated with chips.

Shredding equipment can be mobile or fixed. Mobile equipment can be mounted on the bed of a truck and is frequently preferred when large quantities of tyres must be processed over time in outlying areas or when a project site is more than a 50 km radius from the nearest plant.

Where de-beading has not occurred all metal fragments must be firmly attached and at least 95% embedded in the tyre fragments from which they are produced. The ends of metal belts and/or beads should be exposed only in the cut faces of some fragments. At times, whole tyres are ‘de-beaded’ prior to processing, or the metal can be magnetically removed after shredding, or can be allowed to remain in place. Under certain circumstances, bead wires can be advantageous particularly for applications in which greater strength is a factor.

Shred and chips are recommended for use in many applications including road and street structures, embankments, bridge abutments, landfill construction or closure, insulation, drainage systems, fill, and noise barriers among others. In calculating the quantity of post-consumer tyre materials necessary for a particular installation, it is important to consider that 80-100 whole passenger car tyres constitute 1 cubic metre (1m³) of shredded, compacted and compressed material which is equivalent to 0.5 grams/cm³ or 500kgs/m³.

Shred and chips are used successfully above and below ground level. Above ground installations require, as a minimum, a geotextile liner to prevent infiltration through the surrounding soil to groundwater. Installations placed below the water table, such as a foundation layer for a dam will not require the use of geotextile.

Lightweight backfill is increasingly a basic requirement for attaining infrastructure goals such as extending transportation and communication links to out-of-the way areas. As municipalities expand beyond built-up urban hubs towards ex-urban, suburban and rural areas, it is often necessary to construct highway embankments, rail links and/or bridge abutments on weak or compressible soils, around clay slopes, or crumbling rock faces, etc. Under those conditions, the weight of conventional materials, e.g. gravel, shale, soil, could lead to instability.

Thus, many civil engineers opt for shredded tyres which, in comparison to other materials, are lightweight, exert low lateral pressure, have low thermal conductivity and are free draining. In terms of cost, tyre shred is relatively inexpensive, with savings of 50% on conventional materials, e.g. shale, gravel, etc. The following outlines some of the factors relating to the production of tyre shreds prior to on-site use.

**Energy use:** 125kWh/t at maximum power.

**Noise:** 85-90dB max power.

**Precautions:** Appropriate PPE includes steel reinforced boots, work gloves, eye and ear protectors, protective headwear.

**Storage:** Storage requirements are generally determined by local authorities.

**Engineering properties of tyres**

The chemical and physical properties of car tyres or their sub-constituents determine whether they will be suitable for a particular application or not. These characteristics not only determine suitability for a particular application, but also permit determination of the most appropriate category of post-consumer tyre or constituent for each and every proposed application. The chemical and physical characteristics of tyres that render them suitable for use in civil engineering applications are detailed in the published guidance (CEN, 2002).
Tyres provide the following properties which engineers will find useful in appropriate circumstances:

- **Compacted dry density:** Compacted dry density for shredded tyres is one third to a half that of a typical soil (Humphrey et al., 2000). This makes them attractive for use as lightweight fill for embankment construction where the foundation soils are weak or compressible, and where stability or excessive settlement is a concern (embankments or for stabilisation of landslides).

- **Thermal resistivity:** Thermal resistivity is around seven to eight times greater than for a typical granular soil (Humphrey et al., 2000). This property makes tyres a suitable alternative for use as an insulating layer to resist freezing better than traditional construction under winter conditions.

- **Hydraulic conductivity:** Whole and shredded tyres have a high hydraulic conductivity, which makes them suitable for drainage applications including French drains, drainage layers in landfill liner and cover systems, and leach fields for on-site sewage disposal systems.

- **Combined properties:** The combination of low compacted dry density, high hydraulic conductivity, and low thermal conductivity makes tyres attractive for use as retaining wall backfill.

- **Horizontal stress:** Tyre shreds produce low horizontal stress due to their low compacted dry density that reduces the pressure on a backfilled structure. This renders them suitable for use as fill behind walls and bridge abutments. This can prove useful where thinner walls are required

- **Construction:** Whole tyres and sidewalls can be used to construct retaining walls or be bound together to form drainage culverts.

Table 10 outlines further properties which tyres provide. These will help to determine their suitability for a number of different applications.

### When tyres are suitable

Tyres are a useful alternative to traditional aggregate materials for a number of engineering applications. Tyres are a suitable alternative where:

- They are relatively abundant and freely available.

- A lightweight material is required to reduce the density of fill materials, or reduce the load on the original ground surface.

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Typical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of friction</td>
<td>19 – 26°</td>
</tr>
<tr>
<td>Bulk density</td>
<td>~350 - 550 kg/m³</td>
</tr>
<tr>
<td>Compacted density</td>
<td>600 – 700 kg/m³ (rising to 990kg/m³ under 400 kPa vertical stress)</td>
</tr>
<tr>
<td>Cohesion (kPa)</td>
<td>5 – 1</td>
</tr>
<tr>
<td>Compressibility</td>
<td>20 – 50% (at 21 – 147 kN/m²)</td>
</tr>
<tr>
<td>Hydraulic conductivity</td>
<td>1 x 10⁻² – 1 x 10⁻³ m/s</td>
</tr>
<tr>
<td>Loose bulk density</td>
<td>3.3 – 4.8 kN/m³</td>
</tr>
<tr>
<td>Particle size</td>
<td>Chops to bales</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.2 – 0.35</td>
</tr>
<tr>
<td>Resilient modulus</td>
<td>1 – 2 MPa</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.1 – 1.27 t/m³</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>0.15 - 0.23 W/mK</td>
</tr>
<tr>
<td>Water absorption</td>
<td>2 – 4 %</td>
</tr>
</tbody>
</table>

*Courtesy of V Shulman.*

- A flexible and durable material is required for long term performance. This is particularly important for applications intended to protect the local environment from damage.

- There is a need for a free draining alternative to gravel in drainage applications.

- The material to be used requires a high resistance to chemical activity.

- There is a need to develop a stable structure, e.g. where tyre bales can be stacked as building blocks.

- There is a need for a large surface area such as in artificial reefs for marine organism growth and habitat creation.

- There is a need to absorb chemicals such as in ground barriers for pollution cleanup.

- They act as an aggregate replacement, e.g. in asphalt, concrete or other hydraulically bound materials.

### Applications

Table 11, taken from CWA 14243 outlines a number of applications for which tyres are suitable, and includes the grade of processing required to render the tyre acceptable for the intended use. This list is not to be considered exhaustive, as other applications may become available as the opportunities for tyre use increase.

Table 12 outlines typical quantities and types of tyre required for particular applications.
## Table 11 Examples of representative civil engineering applications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Civil engineering (road/non-road)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificial reefs</td>
<td>x</td>
<td>PW</td>
<td>M</td>
</tr>
<tr>
<td>Bridge abutments</td>
<td>x</td>
<td>PW, TW</td>
<td>M, A</td>
</tr>
<tr>
<td>Concrete construction additives</td>
<td>x</td>
<td>ALL</td>
<td>P</td>
</tr>
<tr>
<td>Construction bales</td>
<td>x</td>
<td>PW, TW</td>
<td>M</td>
</tr>
<tr>
<td>Culvert drainage beds</td>
<td>x</td>
<td>PW, TW</td>
<td>A</td>
</tr>
<tr>
<td>Embankments</td>
<td>x</td>
<td>PW, TW, MT</td>
<td>M, A</td>
</tr>
<tr>
<td>Insulation</td>
<td>x</td>
<td>PW, TW</td>
<td>M, A</td>
</tr>
<tr>
<td>Landfill drainage layer</td>
<td>x</td>
<td>PW, TW</td>
<td>A</td>
</tr>
<tr>
<td>Landfill engineering</td>
<td>x</td>
<td>PW, TW</td>
<td>M, A</td>
</tr>
<tr>
<td>Slope stabilisation</td>
<td>x</td>
<td>PW, TW</td>
<td>M, A</td>
</tr>
<tr>
<td>Temporary roads</td>
<td>x</td>
<td>PW, TW</td>
<td>M, A</td>
</tr>
<tr>
<td>Thermal insulation</td>
<td>x</td>
<td>PW, TW, MT</td>
<td>M, A</td>
</tr>
<tr>
<td>Collision barriers</td>
<td>x</td>
<td>ALL</td>
<td>M, A</td>
</tr>
<tr>
<td>Light weight fill</td>
<td>x</td>
<td>PW, TW, MT</td>
<td>A</td>
</tr>
<tr>
<td>Noise barriers</td>
<td>x</td>
<td>PW, TW, MT</td>
<td>M, A</td>
</tr>
<tr>
<td><strong>Sport and safety surfaces</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equestrian tracks</td>
<td>x</td>
<td>PT, TW, MT</td>
<td>A</td>
</tr>
<tr>
<td>Hockey/soccer pitches</td>
<td>x</td>
<td>PW, TW</td>
<td>A</td>
</tr>
<tr>
<td>Indoor safety flooring</td>
<td>x</td>
<td>PW, TW</td>
<td>A</td>
</tr>
<tr>
<td>Playground surfaces</td>
<td>x</td>
<td>PW, TW</td>
<td>A</td>
</tr>
<tr>
<td><strong>Roads and infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt additives</td>
<td>x</td>
<td>ALL</td>
<td>P, D</td>
</tr>
<tr>
<td>Asphalt rubber</td>
<td>x</td>
<td>PW, MT</td>
<td>A, C</td>
</tr>
<tr>
<td>Coatings</td>
<td>x</td>
<td>PW, TT, TR</td>
<td>A, C, R, D, O</td>
</tr>
<tr>
<td>Expansion joints</td>
<td>x</td>
<td>PW, TW</td>
<td>A, C, R, D</td>
</tr>
<tr>
<td>Road furniture</td>
<td>x</td>
<td>ALL</td>
<td>A, C, R, D</td>
</tr>
<tr>
<td>Sealants</td>
<td>x</td>
<td>PW</td>
<td>A, C, R, D, Y</td>
</tr>
<tr>
<td>Surfacing</td>
<td>x</td>
<td>PW, TW, MT</td>
<td>A, C, R, D, Y</td>
</tr>
<tr>
<td>Train and tram rail beds</td>
<td>x</td>
<td>PW, TW</td>
<td>M, A, C</td>
</tr>
<tr>
<td>Wearing course</td>
<td>x</td>
<td>PW, TW</td>
<td>A, C, R, D</td>
</tr>
</tbody>
</table>

NB: This list is not exhaustive but provides representative examples of applications used in a range of key sectors.

**ALL MATERIALS:** TYRES THAT HAVE BEEN INVOLVED OR PARTIALLY CONSUMED BY FIRE should not be utilised in recycling treatments or applications.

**CUTS, SHRED, CHIPS:** All metal fragments shall be firmly attached and at least 95% embedded in the tyre fragments from which they are produced. NO FREE METAL WIRES OR PARTICLES SHALL BE INCLUDED WITHOUT BEING CONTAINED WITHIN A RUBBER SEGMENT. The ends of metal belts and/or beads are expected to be exposed only in the cut faces of some tyre fragments.

**Omission:** The outer structural part of pneumatic tyres for cars, trucks and other vehicles have been omitted from this discussion in order to focus on the exceptional characteristics of the materials described in the CWA and to illustrate their adaptability to a broad range of other products and applications. The specific properties and characteristics suggest a number of opportunities which can be the basis for creating new markets that will become increasingly valuable as the Landfill and End-of-Life Vehicle Directives come on line.

**KEY:** 1. The applications; 2. The material(s) that can be used in the application; 3. The source material for each application identified; 4. The technology used to produce the material.

*Courtesy of V Shulman.*
Key to Table 11

<table>
<thead>
<tr>
<th>Materials</th>
<th>Source</th>
<th>Technology (size reduction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W Whole tyres</td>
<td>PW Whole passenger car tyre</td>
<td>M Mechanical (cut, compress)</td>
</tr>
<tr>
<td>X Car tyres</td>
<td>TW Whole truck tyre</td>
<td>C Cryogenic size reduction</td>
</tr>
<tr>
<td>S Shred</td>
<td>MT Mixed whole car/truck tyres</td>
<td>A Ambient size reduction</td>
</tr>
<tr>
<td>C Chips</td>
<td>TT Truck tyre tread</td>
<td>B Buffing</td>
</tr>
<tr>
<td>G Granulate</td>
<td>PT Car tyre tread</td>
<td>D Devulcanisation</td>
</tr>
<tr>
<td>P Powder</td>
<td>OT Other tyre (agricultural, bicycle)</td>
<td>R Reclaim</td>
</tr>
<tr>
<td>B Buffings</td>
<td>ALL All tyres</td>
<td>P Pyrolysis</td>
</tr>
<tr>
<td>R Reclaim</td>
<td>O Other technologies</td>
<td></td>
</tr>
</tbody>
</table>

Table 12 Estimation of quantities required for selected applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Quantity truck/car</th>
<th>Unit of application</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea embankment</td>
<td>3,000 car tyres</td>
<td>500m × 1.5m high</td>
<td>Whole</td>
</tr>
<tr>
<td>Temporary road</td>
<td>3,000 truck tyres</td>
<td>1km of road</td>
<td>Whole</td>
</tr>
<tr>
<td>Artificial reef</td>
<td>3,000 t/30,000 car tyres</td>
<td>1km × 1m high</td>
<td>Whole/bale</td>
</tr>
<tr>
<td>Breakwater</td>
<td>4000 tyres</td>
<td>1km × 0.7m high</td>
<td>Whole/bale</td>
</tr>
<tr>
<td>Construction anchor</td>
<td>4 truck tyres</td>
<td>40 c tyres per anchor</td>
<td>Whole/bale</td>
</tr>
<tr>
<td>Retaining wall</td>
<td>5,000 tyres</td>
<td>500m × 2m high</td>
<td>Whole/cut</td>
</tr>
<tr>
<td>Slope stabilisation</td>
<td>750 tyres</td>
<td>500m × 1m high</td>
<td>Whole/cut</td>
</tr>
<tr>
<td>Sound barrier</td>
<td>20,000 tyres</td>
<td>1km × 3m high</td>
<td>Whole/cut</td>
</tr>
<tr>
<td>Embankment</td>
<td>2100 car tyres</td>
<td>500m × 1.5m high</td>
<td>Whole/cut/bale</td>
</tr>
<tr>
<td>Heavy load road</td>
<td>200,000 car tyres</td>
<td>350m × 10m wide</td>
<td>Whole/cut/bale</td>
</tr>
<tr>
<td>Drainage culvert bed</td>
<td>1200 tyres</td>
<td>1km</td>
<td>Whole/cut/bale/shred</td>
</tr>
<tr>
<td>Backfill</td>
<td>80-100 car tyres</td>
<td>1 cubic metre</td>
<td>Shred</td>
</tr>
<tr>
<td>Bridge abutment fill</td>
<td>100,000 tyres</td>
<td>1m wide × 200mm</td>
<td>Shred (compacted)</td>
</tr>
<tr>
<td>Sound barriers</td>
<td>20,000 tyres</td>
<td>1 km × 3m high</td>
<td>Shred</td>
</tr>
</tbody>
</table>

Quantity of tyres used depends upon the producer’s formula and job specifications taken from a variety of sources including work by D Humphrey, BRRC, BSW, CBR, ETRA, SARCO, RR

Figure 10 The use of post-consumer tyres in landfill engineering applications
Landfill engineering

Introduction

Due to the Landfill Directive, the disposal of whole tyres in landfills is to be banned by 2003 and shredded tyres by 2006. However, the ban does not apply to the use of tyres in landfill engineering, and they have proved successful materials for different uses in landfills.

The use of tyres in such applications in the UK will primarily be determined by the requirements of the local environmental regulator as they implement and enforce the Pollution Prevention and Control regime. This will have a major impact on landfill design requirements in general, and will place a greater level of responsibility upon the site operator to ensure that they take responsibility for their site long after the completion of the landfiling operations.

In England and Wales further consideration should be applied to confirming the use of tyre shreds with the Environment Agency as there is some debate at present as to whether such use will be allowed under the new legislation. Clause 9 of The Landfill (England and Wales) Regulations 2002 would suggest that the use of shred in landfill engineering will be limited by omission – the regulations mention the use of tyres in landfill engineering for 2003, but it is omitted for 2006. This infers that the ban on landfilling of tyres in the UK will go further than required by the Landfill Directive, reducing their potential for use in these tried and tested applications. Attention is drawn to Clause 9(1)(e)(i) of the Landfill (England and Wales) Regulations, available from The Stationery Office as Statutory Instrument No. 1559, 2002.

Current applications for the use of tyres in landfill engineering include:

- Leachate collection at the base of the landfill.
- Protective layer for the geotextile.
- Drainage layer in landfill cover.
- Fill for landfill gas drainage systems.
- Daily cover.
- Tyre bales in landfill haul roads.

Characteristics of post-consumer tyres used in landfill engineering

Tyres have a number of characteristics that provide ideal properties for their use in landfill engineering applications. These include:

- High hydraulic conductivity.
- Durability.
- Virtually odourless.
- Lightweight, low density fill material.
- Reduced differential settlement within the total mass.
- Good load bearing capacity.
- High chemical resistance.

Figure 11 Engineered landfill site
(Courtesy of Northern Tyre Disposal Ltd)
No detrimental impact upon site stability.

Weather resistant.

Stable base on soft ground.

Simple and inexpensive to lay.

However, tyres also have some inherent characteristics that can impact upon their use in such applications. These include:

- Bead wires can prove a health and safety hazard.
- Hydraulic conductivity can be reduced through silting in void spaces.
- Compressibility of tyres may require the laying of thick layers.
- Reduced void capacity.

Suitability for use

Tyres are suitable for use where:

- Used tyres are readily available.
- Aggregate systems are expensive to install.
- Sand filter systems could block up the leachate pump.
- Dense, sharp or heavy objects are subject to disposal.

Differential settlement is to be minimised within the waste mass.

There is a need for free movement of gas or leachate through the waste.

There are areas of soft ground which need to be traversed by heavy machinery.

Caution should be exercised where:

- There is insufficient void capacity to build up an acceptable depth of tyres pre-compaction.
- There is potential for uncontrolled underground burning.
- Tyres are to be placed directly onto the geomembrane (steel beads could puncture the lining).
- There is access for humans as steel bead wires are a potential safety hazard.
- Site based vehicles use inflatable tyres which are subject to puncture.
- There has been insufficient control of compaction and filling on site.

Figure 12 Tyres as a drainage layer in engineered landfill
(Courtesy of John Campbell, REG UK)
Leachate collection

All landfills require an efficient leachate collection and removal system to enable the removal of leachate from the site for disposal or recirculation. A good leachate management system is the prime requirement for accelerated stabilisation, and the primary objectives of such a management system are:

- Removal of leachate contained by the liner system.
- Control and minimisation of the leachate head within the landfill.
- Avoidance of damage to the liner system.

A number of studies have been undertaken to determine the potential for the use of car tyres as a leachate collection layer in landfill. These studies have included the determination of the likely performance of shredded tyre in such uses, and investigation into the leaching potential of potentially harmful materials from tyres under such conditions.

There are environmental and engineering requirements that must be met when developing landfill leachate drainage. These include:

- A hydraulic permeability of at least $1 \times 10^{-3}$ m/sec.
- Design to limit blockages in the system and ensure that all leachate can be collected and removed.

A number of documents have been produced which provide advice on the management of landfill leachate. These should be consulted as a means of assessing the potential for the use of a shredded tyre based drainage system. A selection of these is included in Table 13.

Table 13 Guidance on leachate management in the UK

<table>
<thead>
<tr>
<th>Suitable material grading</th>
<th>Leachate drainage system developed using:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leachate collection systems have been developed using:</td>
<td>• Whole tyres.</td>
</tr>
<tr>
<td>• Cuts – 300mm to ½ tyre.</td>
<td>• Tyre shreds – 50mm to 300mm.</td>
</tr>
<tr>
<td>• Tyre chips – 10mm to 50mm.</td>
<td>The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site-specific requirements.</td>
</tr>
</tbody>
</table>

Alternative materials

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for landfill drainage development include:

- Quarried aggregate.
- Crushed stone.
- Gravel.
- Inert construction and demolition materials.

Design proposals

Design will be site specific and based upon the regulatory requirements at the time of the proposal. Consultation will be necessary to ensure regulatory support.

Beaven (DoE, 1994) stated that the practicalities of engineering a leachate drainage system using tyres required a consideration of the design requirements. He put forward three design proposals:

- **Drainage blanket:** A layer of tyres is spread over the base of the site as an under-drainage layer. A herringbone pattern of collection drains is installed, surrounded by free draining granular material. The drainage blanket is in the order of 2 to 3 metres thick, with a density of approximately 20 tyres per m$^3$ (approximately 600,000 tyres per hectare with a 3 metre depth). Difficulties with this system include site stability and safety issues, identifying the required depth of the tyre layer in comparison to the depth of the initial refuse layer pushed over the top, and the type of machinery or plant utilised onsite.

- **Leachate drains constructed in advance of landfilling:** A network of tyre drains are constructed on the base of the site in advance of landfilling, with a minimum depth of 2 to 3 metres. When placed in mounds along the line of the drain the basal width of the tyre mounds would need to be in the order of 5 to 6 metres, giving a cross sectional area of approximately 10m$^2$ (requiring 200 tyres per linear metre of drain). Landfilling would proceed on either side of the tyre drain to produce lateral stability before placing a layer on top. The main benefit of this design is that a system of pipes can be
installed as a core to the drain. The principle disadvantage is loss of void capacity on the site.

- **Leachate drains installed into already emplaced refuse**: This involves the excavation of a trench within an already emplaced layer of refuse and backfilling with tyres. Vertical trench walls such as this can provide stability for a considerable time period. A minimum trench width of 2 metres is recommended to accommodate any lateral movement within the refuse that could cause partial closure of the trench. This design allows for retrofit on existing sites. Fewer tyres are required, and trench depths of up to 8 metres are possible. However, it is difficult to install a pipe system within a tyre filled trench as the presence or possibility of landfill gas precludes access of personnel without suitable safety equipment and training.

**Case studies and research**

Whole tyres, tyre shreds and chips have been used on a number of occasions throughout the world for landfill leachate drainage, including in the UK. They have also been used for a considerable period of time due to their properties and the need for appropriate disposal.

Beaven (DoE, 1994) undertook a study to assess the suitability of the use of post-consumer tyres in landfill drainage systems, with particular reference to the Pitsea Landfill. His particular interest was in determining the effect of the significant overburden pressures exerted by up to the equivalent of 70 metres of refuse on tyre properties, given that drainage systems have to operate at the base of the landfill.

The study showed that tyres possess suitable properties for such applications. Drainage systems constructed from tyres satisfy the basic requirements of a drainage media – they have the highest possible permeability and porosity, and their coarse nature minimises the potential for incrustation. The system showed an effective porosity of between 12% (on maximum load) and 80% (on minimum load). Hydraulic conductivities were measured in excess of 2,000 metres per day. At very high vertical stresses (400kPa) the vertical permeability has been shown to equal $3 \times 10^{-2}$ m/s (Westerberg and Mácsik, 2001), a permeability in the same order as gravel.

The size, nature and distribution of the void space within the tyres were believed to provide the reason behind their favourable hydraulic properties. In addition, the slow movement of leachate flow under normal conditions would not lead to entrainment and transportation of significant quantities of small particles, ensuring that blockage of the system was kept to a minimum. Difficulties with such systems include a reduction in the performance of the system that could occur through the blockage of the void spaces by movement of larger particles. This could be mitigated by controlling the depth or width of a tyre filled drainage system to ensure that it is deep enough to take into account reduced porosity of the materials.

A considerable initial depth of tyres is required to:

- Account for the significant compression.
- Ensure consistent performance.
- Reduce the overall impact of porosity and permeability loss.

Compressibility of tyre shred drainage layers should be accounted for in the specification of minimum depths (GeoSyntec, 1998a, Reddy and Saichek, 1998). A minimum depth of 2 to 3 metres is recommended (DoE, 1994).

**Protective layer for geomembrane**

Tyres can also play an important part in ensuring that the underlying geomembrane, a requirement in all modern landfills, is protected from puncture through the addition of sharp wastes. The high surface area afforded by a tyre-shred layer provides a strong protective barrier to the ingress of sharp or heavy objects. Tyre shreds compress very readily, thereby soaking up the shock of a falling heavy object. In many cases the protective layer makes up part of the leachate collection system.

The environmental and engineering requirements that must be met with respect to geomembrane protection include:

- Under low ground pressure the layer should be at least 0.46 m thick. Under heavy loading conditions, the layer should be at least 0.91 m thick. In US applications, typical layers are in the order of 0.30 m to 0.60 m (Geosyntec, 1998c). In the EU, the initial loose tyre shred layer needs to be in the order of 0.7 m to 0.8 m thick prior to compaction (CEN, 2002).
- If tyre shreds with bead wires are used as operations layer material placed over a geo-composite leachate drainage layer, a minimum 300-mm thick soil layer should be placed between the tyre shreds and the geosynthetic barrier material

- The high compressibility of a tyre layer must be considered in order to maintain the minimum thickness required. To achieve a typical thickness of 300 mm to 600 mm, tyre shreds are usually placed in one to two lifts and compacted. The purpose of compaction is to rearrange and densify the shreds thereby creating a stable operations layer as a working surface. However, obtaining high compaction of the protective layer is less critical than for some other landfill applications.
Suitable material grading
Geomembrane protection systems can be developed using:

- Whole tyres.
- Cuts – 300mm to ½ tyre.
- Tyre shreds – 50mm to 300mm.
- Tyre chips – 10mm to 50mm.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements.

Alternative materials
Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for geomembrane protection include:

- Sand.
- Inert construction and demolition materials.

Case studies and research
American researchers (Reddy and Saichek, 1998) assessed the potential damage to geomembrane liners caused by the use of shredded post-consumer tyres. Field-testing was performed to assess the damage that occurred to the liner during construction of a shredded tyre drainage layer. They carried out a series of nine tests using different combinations of tyre chip size and thickness, with/without a geotextile, and under varied loading conditions.

Laboratory testing was used to characterise the tyre shreds, taking into account the relative size distribution, hydraulic conductivity, compressibility and chemical resistance. Simulation testing was also carried out to determine the extent of damage that can occur to the geomembrane liner by the tyre shreds under long-term waste loading conditions. Damage of the liner was determined by visual observation, multi-axial tension tests, wide strip tension tests, and water vapour transmission tests on the exhumed liner samples.

The study showed that a 0.46m thick layer of secondary tyre shreds (which had been shredded twice), with an average size of 76mm placed on top of a 543g/m² geotextile installed over a geomembrane liner provided adequate protection to the geomembrane during construction. Primary tyre shreds (those that had only been through the shredding process once) were deemed unsuitable for the use of liner protection, as they caused significant damage to the geomembrane. It was concluded that the degree of protection offered under long-term loading conditions was a function of normal stress and the random orientation of shredded tyres at the geomembrane interface.
The use of tyres as protection of geomembranes is not impacted by site specific factors, and so, subject to suitable treatment, such layers could be implemented in all landfills. The local regulator should be approached to discuss whether they will have any special requirements should tyre shreds be proposed as a means of protecting the landfill geomembrane, as they will require to be satisfied that such use will not constitute unacceptable risk to underlying groundwater.

**Drainage layer in landfill cover**

Tyre shreds have a role in the development of drainage layers in landfill caps and covers. In this case the tyres have similar characteristics to those used for landfill leachate collection and drainage. Some factors that must be considered include:

- During landfill capping operations an impermeable geomembrane liner is placed on top of the waste to separate it from the capping material. Tyre shreds free of protruding bead wires can be deposited directly onto this membrane.
- A landfill cover drainage layer should have a minimum thickness of 0.5m for non-hazardous landfill. Assuming a volume to weight ratio of 4.5 kN/m³ for tyre shred, 1 m² of landfill area would require 225 kg tyre shred (CEN, 2002).

Design requirements are similar to those used for landfill leachate drainage, although there is no need to develop a system to take account of the weight of overlying waste. The Landfill Directive requires specific procedures be adopted during the implementation of landfill capping and closure. The local regulator should be approached to discuss any special requirements if tyre shreds are proposed as a cover drainage layer, to ensure their satisfaction that all risks have been assessed.

**Suitable material grading**

Landfill cover drainage layers can be developed using:

- Whole tyres.
- Cuts – 300mm to ½ tyre.
- Tyre shreds – 50mm to 300mm.
- Tyre chips – 10mm to 50mm.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements.

**Alternative materials**

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for landfill cover drainage development include:

- Quarried aggregate.
- Crushed stone.
- Gravel.
- Inert construction and demolition materials.

**Case studies and research**

GeoSyntec Consultants Inc produced a guidance document for the California Integrated Waste Management Board on the use of tyre shreds in landfill cover (Geosyntec, 1998d). Their work involved both a literature review and discussion with external operators to determine how tyre shreds can be utilised in the development of a drainage layer within the landfill cover. Their work found that tyre shreds were an acceptable alternative to aggregates when used in the development of drainage layers in landfill cover.

**Fill for landfill gas drainage**

Tyre shreds can be used in the development of landfill gas drainage systems. As with liquid collection systems, tyre shred properties allow for the free movement of gas along a designated pathway that enhances the potential for collection and treatment at the surface.

Typically, landfill gas (LFG) is collected and conveyed by means of horizontal layers, horizontal trenches, and vertical boreholes filled with granular material such as gravel, rock, sand, etc. The collection layer, trench or borehole may include a perforated pipe to enhance gas removal. In an active LFG control system, LFG is extracted by applying a vacuum to the LFG collection pipes. In a passive LFG control system, the granular material provides a controlled pathway for the LFG to disperse into the atmosphere. Landfill gas drainage systems require:

- A low-density drainage media with a large void ratio, geotechnical and chemical stability, and high hydraulic conductivity.
- Ground reinforcement to reduce the possibility of settlement on soft and sensitive soils (waste).
- Highly permeable materials to allow free flow of the infiltrating gas produced by the waste.
- A low density material providing less load on the landfill.

- A properly selected geotextile as a separator between the tyre shreds and soil layers. The geotextile would prevent soil from migrating into the relatively large voids between the tyre shreds.

Tyre shreds and chips can provide all of these properties.

**Suitable material grading**

Landfill gas drainage layers can be developed using:

- Tyre shreds – 50mm to 300mm.
- Tyre chips – 10mm to 50mm.

There are no specific requirements related to the type of grading required except that it should be relatively resistant to chemical and biological breakdown and maintain a suitable hydraulic conductivity throughout its working life. The choice of tyre grading will therefore depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements.

**Alternative materials**

The materials normally used for landfill gas drainage development include:

- Quarried aggregate.
- Crushed stone.
- Gravel.
- Coarse sand.

**Case studies and research**

GeoSyntec Consultants Inc produced a guidance document for the California Integrated Waste Management Board on the use of tyre shreds in landfill gas collection systems development (Geosyntec, 1998d). Their work found that tyre shreds were an acceptable alternative to aggregates when used in the development of landfill gas collection systems. In addition, the gas drainage system ‘Returdrän’ has been used in a number of landfills including the Högbytorp landfill in Sweden.

At present it is understood that the UK Environment Agency would not favour the use of tyres as fill for landfill gas drainage. They feel that the link with landfill gas and the potential combustibility of the tyres could lead to problems in the future and they would promote other options as a more satisfactory way of dealing with post-consumer tyres. A suitably designed and robust risk assessment should provide the necessary information should an operator wish to use tyre shred for such purposes.

**Daily cover**

Tyres are ideal for use as landfill cover where they control dust and litter blow as well as reducing odour. Tyre shreds do not contribute to leachate production in a detrimental way within landfills. In the case of use in daily cover applications tyre shreds should be used with some site-specific restrictions.

Tyres (as shred) used alone as daily cover may have some undesirable characteristics for daily cover operations. They allow water ingress during wet weather because of their high hydraulic conductivity. Potential combustibility is also a factor, especially where there is a possibility of trespass onto the site. Mixing tyres with soils can help to reduce these potential impacts. The larger the proportion of soil in the mixture, the better the expected performance of the material with respect to reduced combustibility and reduced hydraulic conductivity.

**Suitable material grading**

Daily landfill cover can be developed using:

- Whole tyres.
- Cuts – 300mm to ½ tyre.
- Tyre shreds – 50mm to 300mm.
- Tyre chips – 10mm to 50mm.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements.

**Alternative materials**

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for daily cover may include:

- Quarried aggregate.
- Clay.
- Crushed stone.
- Gravel.
- Inert construction and demolition materials.
- Compost from municipal waste plants.
Excavated soils with chemical contaminant concentrations requiring engineered landfill disposal.

Waste glass and dense plastics.

Case studies and research

GeoSyntec Consultants Inc. produced a guidance document for the California Integrated Waste Management Board on the use of tyre shreds as landfill daily cover (Geosyntec, 1997). Their work involved both a literature review and discussion with external operators to determine how tyre shreds can be utilised as daily cover.

Their work found that tyre shreds were an acceptable alternative to aggregates and soil when used as landfill daily cover.

Landfill haulage roads

Tyre bales have been successfully used as a foundation material for the development of haul roads on landfill sites where the underlying soil conditions are unstable. This includes areas where the natural ground is soft, or where there is a need to drive a haul road directly over the top of the filled waste. Tyre bales provide ideal properties for ‘floating’ the road, reducing the chance of subsidence during heavy vehicle use. The following requirements are specific to landfill haul roads:

- Haul road design should not compromise the containment of waste materials, landfill gas or leachate.
- A geotextile and layer of granular material (150mm) should be placed on top of the tyre bales.
- If placed directly over waste material a geotextile layer will be required and gas and leachate management systems may need to be installed.

Suitable material grading

Landfill haulage roads can be developed using:

- Tyre bales.
- Whole tyres, especially when strung together by revetment cords to form mats.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements.

Alternative materials

The materials normally used for haul road development include:

- Quarried aggregate.
- Crushed stone.
- Gravel.
- Inert construction and demolition materials.

Figure 14 Tyre bales used to develop a haul road on a landfill site in Scotland  
(Source: Northern Tyre Disposal)
Case studies and research

Northern Tyre Disposals of Inverness, Scotland, have produced tyre bales for use in haul roads over soft ground. They have produced bales for landfill sites in Benbecula in the Western Isles, a site in Morayshire, and one in Dundee. There was a ready supply of tyres on the Dundee site requiring management, so onsite baling and utilisation as haulage road sub-base provided an added benefit of helping to deal with the potential difficulty in disposing of the tyres on site. The advantages stated by the clients and engineers involved in these applications included:

- Low cost.
- Ease of use and laying.
- Effective sub-base material on soft ground.
- Stable road surface.

Lightweight fill and soil reinforcement

Introduction

Tyres have suitable properties for use as lightweight fill in a wide variety of engineering projects, some of which are illustrated in Figure 15. Their use in such projects appears to be bounded only by the creativity of engineers, and both research and full-scale projects have been implemented in both the developed and developing world. Projects in this sector have been reported in India, Korea, Australia, Europe (including the UK) and North America. Use in these applications is likely to increase because tyres are readily available, and costs for their use are likely to become more economic. Major projects have been implemented in the US because of state and federal intervention requiring tyres to be used in this way.

The major uses include:

- Lightweight fill for use behind retaining structures and in embankments.
- Backfill to integral bridge abutments.
- Slope repair and stabilisation.

Tyres offer:

- Technical, environmental and economic advantages under certain situations.
- Reduced impact from build up of excess pore pressure.
- A compacted density approximately \( \frac{1}{3} \) that of compacted soils.
- Reduced settlement impacts with soil-tyre chip fills.

Standards and specifications

For most applications in civil engineering works, the relevant specification is the Specification for Highway Works (SHW) and design information is given in the Design Manual for Roads and Bridges (DMRB). Obtaining approval for the use of tyres in such applications would necessitate a departure from the standard which can be

Figure 15 Proven applications for post-consumer tyres in highway and related engineering applications
achieved as outlined earlier. A material specification is provided in CWA 14243 (CEN, 2002).

Characteristics of post-consumer tyres used as lightweight fill

Tyres have a number of characteristics that provide ideal properties for their use in various fill related engineering applications. These include:

- Reduced unit weight allows structural development on areas with low bearing support.
- Reduced unit weight may mean embankments can be raised in one lift as the drainage properties of tyre shreds help reduce the build up of pore pressures.
- Reduced backfill pressure on retaining structures.
- Reduced long term swelling pressures.
- Stability and settlement on soft foundations is improved compared to alternatives (Ahmed and Lovell, 1993).
- Flexible, with good load bearing capacity.
- Good drainage.
- High chemical resistance.
- Durable materials.
- Properties can be improved through mixing with other primary and secondary materials, although this will increase unit weight and cost.

However, tyres also have some inherent characteristics that can impact upon their use in such applications. These include:

- Bead wires can prove a health and safety hazard.
- High compressibility, especially where this is to be minimised.
- Deformation under vertical load.
- Difficulty in compaction unless mixed with soil.
- Difficult to use in particulate form.
- Subject to protection from arson.

Suitability for use

Tyres are suitable for use where:

- They are readily available.
- It is expensive to purchase traditional or alternative lightweight fill materials e.g. expanded polystyrene.
- Reduced earth pressure is required on structures.
- An embankment has to be constructed over soft ground.

Caution should be exercised over the use of tyres where:

- They may have a detrimental impact on the environment.
- There is potential for uncontrolled combustion.
- Vertical or horizontal pressures are likely to be high.
- There are competent foundation strata.

Lightweight fill for use in embankments

The inherent properties of tyres mean that they can provide an alternative to natural aggregates for use as lightweight fill in embankments. For lightweight fill in an embankment, the aim is to reduce the overall ground (or vertical) pressure, thus reducing settlement and the risk of slope or foundation failure. Tyres allow for a reduction because they reduce the load in comparison with traditional materials. Figure 16 provides a simplified example.

Suitable material grading

Lightweight fill applications can be developed using:

- Tyre bales.
- Whole tyres.
- Cuts – 300mm to ½ tyre.
- Tyre shreds – 50mm to 300mm.
- Tyre chips – 10mm to 50mm.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site-specific requirements.

Alternative materials

The materials normally used for lightweight fill applications include:

- Light weight expanded clay aggregate.
- Lightweight concrete.
- Pulverised Fuel Ash (PFA) - where sources are still derived from the burning of stocks of coal that produce a lightweight residue.
- Expanded polystyrene blocks.
Case studies and research

Shredded tyres have been used in embankments and levees. Tyres can take the place of any aggregate material currently used for fill applications. As a potential major user of post-consumer tyre shreds, this area of engineering has received much attention. In the US, ASTM standards have been developed for tyre use as lightweight fill in civil engineering applications (ASTM, 1998). These standards were developed to promote confidence in the use of tyres as fill.

Specific advantages for use as embankment fill include:

- Reduced settlement (after initial loading).
- Increased stability due to low density.
- Improvements in strength and reduced deformation when mixed with moderately plastic clay soils.
- Improved angle of friction when mixed with silty, plastic clay.
- High compressibility on initial loading, but reduced compressibility on subsequent unloading and reloading.
- A cohesion intercept for tyre shreds ranging from 8 to 11 kPa.
- A high Young’s Modulus during unloading and reloading cycles.

A limitation identified in previous research was that traffic loading can cause deflection of embankments containing tyre shreds. This can be limited by covering the shreds with a sufficient layer of soil as outlined as follows:

- On lightly used roads - minimum of 0.8 metres.
- On roads with heavy traffic - between 1 and 2 metres may be required.
- Unpaved sections only require a covering of between 0.3 to 0.5 metres.

Jetport Interchange, Portland, Maine, US

Post-consumer tyres were used as lightweight fill in the development of the Jetport Interchange in Portland, Maine, USA (Humphrey et al., 2000). A layer of very soft clay underlay the site, up to 12 metres thick, which would not be able to sustain the loads associated with standard embankments. Tyre shreds were chosen as an alternative to gravel or sand fill materials as they provided suitable characteristics, but had an in-place density of less than half that of the traditional materials. The embankment was constructed using preload techniques to account for the compressibility of the clay layer and the tyre chips, with consolidation of the clay occurring over a 10-month period.

To account for settlement of the tyre chip layer the fill was overbuilt by 10% to ensure that the embankment would achieve the desired height after settlement. The tyres were covered by 2 metres of soil for added stability. This project led to savings of approximately $300,000 on top of the next cheapest alternative for the fill. However, the saving in the disposal costs of the tyres themselves also would have meant the state would have spent a further $300,000, providing a total cost saving of over half a million dollars. In addition, 1.2 million tyres were utilised successfully in one single project. This indicates that such uses may prove a sustainable and effective means of dealing with significant volumes of post-consumer tyres.
Lightweight fill for use behind retaining structures

The inherent properties of tyres mean that they can provide an alternative to natural aggregates for use as lightweight fill behind retaining walls. For backfill to retaining structures the aim is to reduce the horizontal earth pressure on the back of the wall. This can be illustrated by the following simplified equations:

Equation 1: Coefficient of active earth pressure (Smith, 1990)

\[ k_a = \frac{1 - \sin \phi'}{1 + \sin \phi'} = \tan^2 \left( 45 - \frac{\phi'}{2} \right) \]

Equation 2: Active pressure at failure (Smith, 1990)

\[ p_a = k_a \gamma' z \]

Where:
- \( k_a \) = Coefficient of active earth pressure.
- \( p_a \) = Horizontal active pressure on the wall.
- \( \gamma' \) = Effective density of retained fill.
- \( z \) = Depth below ground surface.
- \( \phi' \) = Effective angle of internal friction.

The above equations are based on Rankine’s theory of earth pressures. Equation 1 is developed for drained conditions in granular soils with a smooth frictionless vertical wall and a horizontal surface to the retained ground. Equations have been developed for cohesive soils, battered back walls, and sloping retained ground – see Smith (1990).

For tyres, \( \gamma' \) will be much lower than for natural aggregates; this reduces the horizontal stress behind the wall. As a consequence, the active pressure (\( p_a \)) on the back of the structure will also be significantly lower. This allows the retaining wall to be of a lighter and more economical construction. Figure 17 provides a simplified illustration of the use of backfill in retaining structures.

Suitable material grading

Lightweight fill applications can be developed using:

- Whole or part tyres.
- Tyre shreds – 50mm to 300mm.
- Tyre chips – 10mm to 50mm.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site-specific requirements.

Alternative materials

The materials normally used for structural backfill include:

- Soils.
- Aggregate.

Figure 17 Lightweight fill used as backfill to retaining structures
- Expanded polystyrene.
- Light weight clay aggregate.
- Pulverised Fuel Ash (PFA).

**Case studies and research**

Shredded tyres have been used as fill for highway structures, lightweight retaining walls and bridge abutment fills. Tyres can take the place of any aggregate material currently used for fill applications. As a potential major user of post-consumer tyre shreds, this area of engineering has received much attention. In the US, ASTM standards have been developed in line with tyre use as lightweight fill in civil engineering applications (ASTM, 1998). These standards were developed to promote confidence in the use of tyres as fill.

A number of researchers have undertaken work in this field (Drescher and Newcomb 1994; Humphrey *et al.*, 1993; Ahmed and Lovell, 1993; Tatlisoz *et al.*, 1998; Lee *et al.*, 1999).

Specific advantages for use as backfill to retaining walls include:

- Increased factor of safety (Cecich *et al.*, 1996)
- Large amounts of exposed steel belt produce a lower coefficient of earth pressure at rest (k), and a lower shear strength, indicating a potential advantage in steel bound tyre shred for retaining wall backfill. For a normally consolidated soil a higher shear strength (φ') would normally produce a higher k.
- Soil-tyre chip mixtures have significantly higher shear strength than soil alone.
- Tyre chips and soil-tyre chip mixtures have a similar geosynthetic pull-out force to soils.

**Solid waste research programme, Wisconsin**

Abichou *et al.* (2003) researched the use of tyre shreds as backfill for a mechanically stabilised earth wall in Wisconsin (3 m tall). The wall was designed and constructed using conventional techniques (reinforced with two layers of geotextile and two layers of geogrid), with a sand-tyre mixture (25% tyre shred by volume) placed as the backfill. Instrumentation was put in place and the wall loaded with successive surcharges ranging from 42 through to 200 kPa. Their work found that:

- Horizontal and vertical stresses increased after the addition of each surcharge, but at different rates depending upon depth.
- Displacements of the wall face diminished with depth, and were small with respect to the surcharge applied.
- Strains near the wall face were larger than strains farther from the face.
- Measured deformations were consistent with geotechnical theory, indicating that earth structures can be designed using conventional methods with soil shred as backfill.

The finite element code PLAXIS was used to simulate deformation of the wall under self-weight and surcharge loading, using given material properties. A comparison of the predicted and measured earth stresses is provided in Figure 18 and Figure 19. The comparisons were made at 0.7 and 3 m from the top of the wall (described as ‘top’
and ‘bottom’ in the two figures), where the earth pressure cells were located. The predicted and measured stresses are similar in both cases, although the predicted vertical stresses exceed the measured stresses under both self-weight and surcharge.

In contrast, the predicted horizontal stresses are lower than the measured horizontal stresses under self-weight conditions. During surcharging, however, the predicted increase in horizontal stress was larger than the measured increase in horizontal stress near the top of the wall, but lower than the measured increase in horizontal stress near the bottom of the wall.

**Backfill to integral bridge abutments**

In an integral bridge the abutments are structurally connected to a continuous deck, thus avoiding the bearings needed in more conventional road bridges. This obviates the need for deck joints, thereby reducing the possibility of ingress of road de-icing salts causing long term damage. However, daily and seasonal thermal movements of the deck cause interactions between the bridge abutment and the retained soil, leading to possible future structural distress. Figure 20 illustrates a simplified version of the use of backfill in integral bridge abutments.

Traditionally, thorough compaction of high quality granular fill has been used behind bridge abutments to avoid problems associated with settlement of the backfill and carriageway. However, with integral bridges, high quality backfill accentuates the risk of high passive pressures ($P_p$) developing on the back of the abutment.

One means of avoiding these high lateral stresses on the abutment is to use a compressible elastic cushioning layer with low stiffness (providing a low passive pressure). Tyre shreds provide passive pressures much lower than conventional granular backfill. Lateral pressures produced on integral abutments by tyre shred can be as
low as that on non-integral abutments, significantly reducing the cost of the abutment. The following Equation outlines the simplified theory. More complicated equations exist to account for curved planes and wall friction.

**Equation 3: Coefficient of passive earth pressure**

$$k_p = \tan^2 \left( 45^\circ + \frac{\phi'}{2} \right)$$

**Equation 4: Passive pressure**

$$p_p = k_p \gamma' z$$

Where:
- $k_p$ = Coefficient of passive earth pressure.
- $p_p$ = Passive pressure.
- $\gamma'$ = Vertical pressure.
- $\phi'$ = Angle of internal friction.

**Engineering factors**

There are environmental and engineering requirements that must be met when providing a specification for the use of materials as backfill to integral bridge abutments. These include (Carder, Darley and Bush, 2002):

- Each complete stress absorbing layer installation should accommodate cyclic movement in the horizontal direction of ±0.015% of the span of the bridge (based on an operational range of 46°C from BD37 (DMRB) and a coefficient of thermal expansion of $12 \times 10^{-6}$ per °C for concrete and composite decks).
- A horizontal compression modulus within the limits of 1 to 2MPa for a layer thickness of 0.3m rising linearly to between 3 and 6MPa for a thickness of 1.0m.
- A minimum horizontal shear strength of 0.15MPa for a layer thickness of 0.3m falling linearly to 0.05MPa for a thickness of 1.0m.
- A vertical compression modulus greater than 3MPa.
- A vertical shear strength greater than 0.02MPa.
- Any void caused by compression set of the layer should be less than 1mm in both horizontal and vertical directions.
- The design life of the layer should be 120 years and the material should be fit for purpose during this period.

Shredded tyres can provide comparative properties when utilised in an appropriate design, especially when adequate compaction of the fill material has been carried out to forego the large degree of compression required during the first loading cycle. Further information is provided in Carder and Card (1997).

In terms of horizontal stiffness, shredded tyres have a marginally lower value than that recommended for a compressible layer but this should not preclude their usage. The vertical stiffness is determined by the degree of compaction of the shredded tyre particles and this could possibly be achieved by thorough compaction.
The angle of friction of the material is comparable to a loose granular soil although it can possess a relatively high cohesion due to the steel content.

**Suitable material grading**

When used as backfill for integral bridge abutments, various grades of tyre are suitable. The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements. Tyre shreds and chips may also be bound to produce a suitable mat-type material which can be placed against the bridge abutment before the addition of suitable backfill material. Generally, the use of tyre shreds in the order of 30mm is possible. A graded tyre material has been produced which conforms closely to a Type B material in Table 5/5 of the Specification for Highway Works (Carswell and Jenkins, 1996). This grading is illustrated in the chapter on drainage later in the book.

**Alternative materials**

Post-consumer tyre materials can reduce the demand for other fill materials allowing these to be substituted into applications with a higher value. The materials that may be used in these applications include:

- Aggregates.
- Sands.
- Granular soils.

**Case studies and research**

TRL Limited (Card and Carder, 1993) along with other researchers identified that lateral earth pressures acting behind an integral abutment are likely to increase progressively with time because of thermal cyclic seasonal expansion and contraction of the bridge deck. Increase in earth pressures above conventional design values and up to the limiting passive pressure value, $K_p$, can occur and result in design serviceability limits being exceeded and possible structural distress. This leads to a requirement for stress absorbing materials to be used to reduce soil stresses acting on the abutment.

In later studies, TRL undertook a literature review (Carder and Card, 1997) and suitability testing (Carder, Barker and Darley, 2002) of the engineering properties of a number of different compressible materials including recycled rubber tyres.

Compression tests on particulate forms (i.e., rubber-soil mixes and shredded crumb material) showed little evidence of the good elastic recovery on release of load which is needed for this application. However, the rubber-soil mixtures showed a considerable reduction in cohesion from that of the virgin soil. This indicated that they would be both better at following the abutment movement and that smaller passive pressures would be developed. Although these materials would undoubtedly be good at absorbing stress during first loading, their performance under cyclic loading needs to be further investigated.

Tests on rubber crumb sheet (recycled from tyres) showed good elastic recovery and the material was identified as being suitable for use behind an integral bridge abutment. A full-scale trial of this product is currently under way on a Highways Agency scheme. The concept of using a polymer added bitumen bound rubber aggregate mix may also be convenient and preliminary tests indicate some potential.

**Slope repair and stabilisation**

Tyres, in baled, whole or part form have been used as a means of repairing or stabilising slopes. This use has been shown to work in a number of applications throughout the UK. Whole and part tyres have been used in wall like structures, requiring minimal pre-treatment.

**Suitable material grading**

Slope stabilisation applications can be developed using:

- Tyre bales.
- Whole and part tyres.
- Cuts – 300mm to ½ tyre.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site-specific requirements.

**Alternative materials**

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. They can also reduce the use of methods utilised to repair slopes that involve high value materials such as geosynthetic reinforcements or techniques that require removal of the failed material from site. The materials normally used for slope stabilisation include:

- Quarried aggregate.
- Gravel.
- Aggregate filled gabions.
- Geosynthetics.
- Lime stabilisation.
**Case studies and research**

Upton and Machan (1993) used shredded tyres to repair a landslide in a highway improvement project in Oregon. Approximately 580,000 shredded tyres were brought in from four different sources, placed and compacted by a bulldozer, and capped with 0.9m of soil. A pavement section with 0.2m of asphalt pavement was placed over 0.58m of aggregate base course. The fill was instrumented and monitored for a year. They found that:

- The shredded tyre fill depressed linearly in relation to surcharge load as the soil cap and pavement section was placed. The fill compressed 15% under the soil and pavement surcharge.
- Creep compression, or compression associated with traffic loading occurred at the site.
- Pavement deflections were considered to lie within acceptable limits.

In a further study, Vinod and O’Shaughnessy (2000b) looked at the behaviour of slopes reinforced with post-consumer tyres.

**A14 Cambridge Northern Bypass**

A reinforced tyre wall (illustrated in Figure 21) tied with straps to buried anchor tyres was used to repair a surface failure on the side slopes of an embankment on the A14 Cambridge Bypass in 1985 as part of a trial of repair techniques (Johnson, 1985). The embankment was constructed from clay with side slopes of 1 in 2. The embankment which was 7 metres high was constructed of Gault Clay, a heavily overconsolidated clay which was liable to shallow slope failure (Perry, 1989). The design of the repair is described by Johnson (1985). The performance of the tyre wall after ten years in service is described by Boden (1995). The tyre wall is still operating in 2002 despite the fact that some of the surrounding trial repairs have failed.

The only problem encountered with the embankment is that rabbits have burrowed into the sand infill causing settlement of the embankment slope immediately behind the tyre wall. Trappers hunting the rabbits have cut through some of the anchor straps to better access the burrows. However the strength of the repair is such that even these factors have not led to slope failure.

**Drainage applications**

**Introduction**

The main drainage properties of shredded post-consumer tyres have been outlined as part of the chapter on landfill applications. However, these same properties also open other potential markets including the use of tyre shreds as fill material for surface drains in applications including:

- Highway and surface water systems.
- Septic tank drainage.

**Standards and specifications**

For most applications as fill material in civil engineering works, the relevant specification is the Specification for Highway Works (SHW) and design information is given in the Design Manual for Roads and Bridges (DMRB). Obtaining approval for the use of tyres in such applications would necessitate a departure from the standard, which can be done.

TRL have also outlined extensive technical information relating to tyre use in French drains applications in TRL Report 200 outlined below (Carswell and Jenkins, 1996).

**Characteristics of post-consumer tyres used as a drainage medium**

Tyres have a number of characteristics that provide ideal properties for their use in drainage applications:

- Excellent drainage medium.
- High chemical resistance.
- Durable materials.
- Minimises damage to filter drain.
- Less potential for accident or vehicular damage, when compared to a stone topped drain, when tyre rubber is spread over the carriageway due to accidental vehicle over-run.

However, tyres also have some inherent characteristics that can impact upon their use in such applications:

- Prone to litter collection when used in roadside applications.
- Have proven difficult to clean as tyre shred is not easily removed from placement using current equipment.
- Leachate issues relating to tyres are still under investigation.

**Suitability for use**

Tyres are suitable for use where:

- They are readily available.
- It is expensive to install traditional materials.
Safety of materials on the carriageway is a major consideration.

Caution should be exercised over the use of tyres where:

- The drainage material may collect wind blown litter.
- There is potential for tree root or burrowing animal damage.
- Areas are underlain by groundwater Source Protection Zones.
- Cleaning of the drainage media is likely to prove a problem.

**Fill for surface water drains**

Filter drains are often installed at the edge of the road to facilitate rapid removal of water from, or to prevent water flowing onto, the road surface. These drains, commonly known as French drains, allow rapid drainage of water to sub-surface levels.

These drains traditionally contain graded rock aggregate to a depth of 1m and are typically 600mm wide. However, this material can be easily displaced onto the road carriageway, especially in areas where vehicles wander off the carriageway (particular spots include entrance and exit slip roads, and lay-bys). This carriageway debris can pose a significant accident risk through skidding or through broken windscreens, violent evasive driving actions, broken headlights, indicators etc. It also requires spending significant sums on roadside drain maintenance. Shredded post-consumer tyres have been used with some success as an alternative precisely because they combine similar or better drainage characteristics with less potential for vehicle damage.
Specifications covering the use of filter drain materials are contained within Clause 505 of the Specification for Highway Works. In addition, Carswell and Jenkins (1996) outline physical testing and pilot study results for a trial programme which provides further detail regarding the characteristics of tyre based drainage material. The following outlines some of the guidance from these sources:

- The drainage media must provide a suitable hydraulic conductivity to allow for the movement of water. For most applications this would be greater than or equal to \(1 \times 10^{-3}\) m/sec.

- The drains should be lined with an appropriate material which ensures that the water is taken to the designated collector point and not allowed to recharge into the groundwater.

- Filter materials should be uniformly graded. However, the grading is less important than the hydraulic conductivity. Figure 23 shows an example grading from Carswell and Jenkins, (1996).

- Filter materials will have a water soluble sulphate content of less than 1.9 grams of sulphate (as \(\text{SO}_3\)) per litre when tested in accordance with BS 812: Part 118, Clause 5.

- Tyre based material used in drainage schemes must be sufficiently cohesive to withstand surface scuffing.

**Suitable material grading**

Roadside drainage applications can be developed using:

- Tyre chips – 10mm to 50mm.
- Tyre shreds – 50mm to 300mm.

The choice of tyre grading will depend upon the relative costs of treatment, transport and locally sourced materials, and site specific requirements. Best results have been obtained from binding the shredded tyre in bitumen prior to installation of the drain.

Figure 23 details the grading profile for two different grades of Safedraintm material. The ‘Spec 1’ (upper limits of the grading envelope) and ‘Spec 2’ (lower limits of the grading envelope) traces have been taken from Table 5.5 of SHW for a Type B material for filter drains. Neither of the tyre based materials comply fully with a Type B material. However, the varied shapes of the supplied material made a direct comparison with rock aggregate difficult. The Boynton grading is closer to the Type B specification.

![Figure 23](image)

**Figure 23** Grading of two sources of tyre shreds
(Source: Carswell and Jenkins, 1996)
Alternative materials

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for roadside drainage development include:

- Rock aggregate.
- Gravel.

Case studies and research

A34, Oxfordshire

Carswell and Jenkins (1996) considered the development of an alternative drain material where the top 150-200mm of the stone drain is replaced by a bituminous bound shredded tyre material designed and marketed by Roadtex Ltd, under the trade name ‘Safedrain’. The bituminous binding was used to achieve a strong, but flexible cohesive mix. The main conclusions from this project were that:

- Binder-bound tyre shred can successfully act as highway drainage material.
- Binder-bound rubber materials confer a degree of integrity to the filter drain layer and are able to withstand limited scuffing and loading by vehicles.
- Binder-bound tyre shred can be successfully laid and subsequent performance is satisfactory.
- Leachate and fire risks are considered to be low, with greater risks likely from traffic abrasion and traffic accidents.

Since the completion of the project, it has been shown that the tyre drain operates satisfactorily. However, continuous monitoring of the situation has identified a number of limiting issues:

- Cleaning of the shred is not as simple as washing gravel.
- Tyre shred is prone to collecting litter, and so the maintenance is greater.
- Leachate issues relating to tyres are to be addressed to a greater degree through current and future research to improve the take up of post-consumer tyres in various applications. The Environment Agency has confirmed that they would have concerns relating to tyres used as drainage material in areas where there are particular sensitive environmental situations (such as Source Protection Zones), or where there may be a high risk of fire that could give rise to pollution damage.

Tyre shreds would appear to offer considerable advantages as a drainage material, particularly where natural aggregates are scarce. However, this use should be discussed with the environmental regulator at an early stage to identify and address any concerns they may have.

Fill for septic drainage

Tyre shreds have proven themselves as a media for septic drainage systems primarily because of their abundance, economic advantages and hydraulic characteristics. When tyres are used in septic soakage trenches, care should be taken regarding stability and subsidence, undesirable air voids, and the intrusion of tree roots blocking up the soakage area.

Suitable material grading

Septic drainage applications can be developed using:

- Tyre chips – 10mm to 50mm.
- Tyre shreds – 50mm to 300mm.

Alternative materials

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for septic drainage development include:

- Graded rock aggregate.
- Gravel.
- Coarse sand.

Case studies and research

The Chelsea Center for Recycling and Economic Development has undertaken research into the development of leaching systems for septic wastes using shredded tyres (Sengupta and Miller, 1999, Sengupta and Miller, 2000). Their work has been both theoretical and practical and they have determined that tyre based systems will work adequately. Their studies showed that tyre shreds:

- Performed equivalent wastewater treatment to a conventional gravel system
- Did not leach any toxic metal or inorganic anion with a local secondary drinking water standard over the allowable concentration, except for Manganese. Manganese concentration was found in the effluent
from all of the trenches (tyre shreds and gravel) at levels higher than the influent and higher than the local secondary drinking water standard (0.05 mg/l).

• Did not leach any solids from their surface for the limited duration of this study (approximately seven months).

• Should be compacted thoroughly before adding the top layer of sand.

Figure 24 illustrates the development of the septic drainage trenches during the field trials.

Erosion control

Introduction

The durability and stability of tyres, both in whole and shredded form, provides them with ideal properties for use in the design and production of erosion control schemes. Tyres have been used both for coastal and fluvial erosion control projects in the UK and abroad, and the available literature points towards their relative value in such applications. Tyres have been used in such applications in the UK since the 1970s.

Erosion control applications primarily make use of whole tyres or baled tyres, and the applications generally involve simple engineering structures with the primary purpose of absorbing the energy provided by moving water, either tidal or fluvial flow. Applications include:

• Floating tyre breakwaters.

• Tyre bales.

• Tyre and post revetments.

Figure 25 illustrates some of the options for use in both fluvial and marine erosion control schemes. Figure 26 shows a scheme whereby tyres are being used to protect the bank from erosion.

Standards and specifications

There are a number of controlling influences on the use of alternative materials for both coastal and fluvial erosion control schemes. The Environment Agency, SEPA and the Environment and Heritage Service for Northern Ireland have responsibility for controlling erosion throughout the UK.

In addition, the Department of Environment, Food and Rural Affairs (DEFRA) is responsible for the control of materials being placed within the sea surrounding the UK and licences are required before any material previously classified as a waste is placed at sea. This can prove difficult to obtain. Small-scale projects may receive a licence provided there is some form of environmental monitoring built in. All of these organisations should be consulted regarding permission for the use of tyres to prevent erosion, depending on which part of the country the proposal is made.

Figure 24 Laying tyre shred over the effluent pipe
(Courtesy of the Chelsea Center, Massachusetts)
HR Wallingford have produced guidance on the use of alternative materials for erosion control (Masters, 2001). This document should be consulted as a means of determining requirements. At the time of publication, a more detailed research project by HR Wallingford on the use of tyres in coastal and river engineering has commenced. The results of this work should be published in 2005, but in the meantime further information can be obtained at www.hrwallingford.co.uk/projects.

Bishop has produced a manual for the design and construction of floating tyre breakwaters (Bishop, 1980).

**Figure 25** Use of post-consumer tyres in fluvial and marine erosion control schemes

**Figure 26** Tyres used in erosion control

**Characteristics of post-consumer tyres used in erosion control**

Tyres have innate properties that render them suitable for such applications. These include:

- Low density which allows free floating structures to act as wave barriers.
- Tyre bales are lightweight and easy to handle.
- Tyre bales are stable and will not regain their original form even after removal of baling wire.
Durable materials, ideal for use in developing a floating breakwater.

Minimal impact upon the local environment from leaching.

Water repellent providing tyre breakwaters with a greater lifespan.

Construction of stable structures due to the uniform shape of bales.

When developing an erosion control scheme for either coastal or fluvial protection, the following parameters should be taken into account:

- Tyres should be securely anchored to prevent mobility under flood conditions which could damage neighbouring properties. This limits their use in areas with either a high-energy wave environment, or where fluvial processes consist of drought and flood. Punching holes in the tyre walls can go some way towards reducing this problem (Tyres and Accessories, 2001).

- Tyres are light and require anchoring in position when used in erosion control. Many applications involve filling the tyres with gravel or other dense material to hold them in position. However, these materials can be washed out over time, thereby reducing their hold on the tyre structure. Care needs to be taken in ensuring that erosion of the tyre fill material is itself controlled.

- Tyres may leach chemical contaminants such as Polyaromatic Hydrocarbons, or Heavy Metals over time, thereby contributing to pollution of the surrounding environment (Dufton, 1995). However, it is unlikely that such applications will constitute a serious threat to the local environment primarily because of the minute volumes of contaminants and the natural attenuation of fluid motion.

- Tyre structures are not considered to be attractive, especially when used in amenity areas. It is therefore important to take this into account during the design process and incorporate the tyres within a more attractive structure.

- Tyres can trap debris, rendering applications unattractive to look at. Such applications therefore require a degree of maintenance to ensure that they perform as required without causing a loss of local amenity.

- Anchors can shift over time due to wave action rendering tyre structures insecure. The designer should ensure that the potential for shifting the anchors is minimised.

- Water action and tyre buoyancy makes the positioning of any permanent protection below the surface very difficult, especially where there is a need to develop a backfill support for the structure (Masters, 2001). The designer should take account of this when developing such structures.

- Care should be taken to ensure that the bale binding material (usually galvanised steel) is suitable for the application intended. In marine environments revetment cord, or similar material may prove more suitable.

Suitability for use

Tyres are suitable for use where:

- They are readily available.

- A low cost breakwater is required.

Caution should be exercised over the use of tyres where:

- There is a very high wave frequency and energy.

- There are strong fluvial currents.

- Visual or recreational amenity will be affected by tyres.

- They are to be placed under water without addition of a weighted material.

- Tyres could have a detrimental impact upon local ecology.

- Riverbanks have variable levels, or are made up of silty material that is easily distributed by fluvial action.

Tyre breakwaters

Floating breakwaters provide protection through the absorption of wave energy before it hits the shore. They have been developed from a number of different materials, but whole tyres have proven suitable in the past. The tyres are connected together to form a floating wall at 90 degrees to the oncoming waves. Wave energy is dissipated through impact with the tyres, reducing the impact upon the shoreline. Tyre breakwaters have proven economic in the US, and they have been used as supports for marinas and docks, and as protection for fish farming stocks as well as erosion control (Jang et al., 1998).

Suitable material grading

Tyre breakwaters can be developed using:

- Whole tyres.
Alternative materials

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications with a higher value. The materials normally used for breakwaters may include:

- Metal and wood structures.

Case studies and research

A number of floating tyre breakwaters have been developed throughout the world with varying degrees of success. Initial attempts in the US failed primarily because of poor engineering design as the breakwaters were easily broken up during heavy seas, and tyres strewn on the local shores. Indeed, this also led to the banning of their use in some states, most notably California (Collins et al., 2001) which has long championed the use of post-consumer tyres in alternative applications. Floating tyre breakwaters have been most successful in the USA for applications in the Great Lakes, where wave conditions are not too excessive.

Collins et al., (2001) referenced two extensive bibliographies relating to the use of tyres as breakwaters and artificial reefs. These list some sixty references for tyre breakwaters, showing that they have been considered as a suitable material for some considerable time.

Bishop (1982) reviewed a number of tyre breakwater design curves indicating considerable use before that time. His work looked at two different curves for breakwater design to compare their usefulness. The results of the comparison showed good agreement between the two curves. However, as one of the curves was developed using mean data, this was selected as the most satisfactory in providing a suitable factor of design safety.

Severe wave action and large tidal ranges have reduced the potential for UK floating tyre breakwater schemes. However, in Port Edgar, Lothian, a tyre breakwater has been continuously in operation since 1979, and it provides good damping of relatively strong waves to reduce their impact upon the shoreline.

Tyre bales in erosion control

Tyre bales have been used for both coastal and fluvial erosion controls. Tyres are compressed using commercially available plant to produce bales that are around 1 tonne in weight, with a density of the order of 600 kg/m³. Tyre bales usually contain around 100 standard car tyres per bale, with dimensions of approximately 0.75m x 1.35m x 1.50m. The final size of a bale is dependent upon the size of plant used to manufacture it.

The bales are secured through the use of strong interlocking galvanised steel wire or other materials suitable to the application intended with a life expectancy of approximately thirty years. Static tyre breakwaters utilise tyre bales and heavy materials such as concrete to make a bale that will submerge and provide a suitable building block. These blocks can be built into an energy dissipating wall.
Suitable material grading
Tyre bales can be developed using:

- Whole tyres.

Alternative materials
Tyre bales can be selected as an alternative to aggregates, gabion baskets and Portland cement. Tyre bales are relatively light in comparison with traditional materials.

Case studies and research
Tyre bales have been used for a variety of different uses, with particular benefits being realised in their use in ground stabilisation or erosion control. American uses that have proven satisfactory include the rebuilding of the banks of the Pecos River at Lake Carlsbad. Other research has been carried out into the redevelopment of levees, and tyre bales have also been used in the development of artificial reefs.

The City of Carlsbad, New Mexico was experiencing an erosion problem on the banks of Lake Carlsbad, a popular recreational area created from the damming of the Pecos River. Undercutting had meant that the banks were unstable and were endangering the lives of walkers and golfers in close proximity to the water’s edge. In 1997 the City formed a new embankment along 4,000 feet of eroding frontage incorporating 250,000 tyres in bales. A concrete footer was laid and the tyre bales were laid in the wet cement producing an erosion protection wall. The tyre bales were then covered with cement. The city created sidewalks and laminated them with native local stone. The tyres are no longer an environmental problem and are providing additional public benefit. Lake Carlsbad now has sidewalks along the bank and is accessible in areas that it was not before.

A current UK project is underway near Pevensey, in Kent to develop an erosion control scheme using tyre bales (Figure 28). The project is being undertaken as a partnership scheme, involving the public and private sector. The project is at its early stages, but it is hoped that when this has been completed the work will have gone some way towards breaking down some of the barriers to the use of tyres in civil engineering applications.

Tyre and post revetments or sea walls
This involves the development of a wall utilising tyres stacked on top of each other with a ground driven post through the middle, and a filler of a suitable aggregate to keep the tyres in place. Such applications have been used in both the US and UK, and they have proven successful in reducing bank or coastal erosion.

Tyres provide an ideal substrate for holding back water because they are impermeable and soak up excess energy from moving water, thereby reducing the impact upon the weaker local bank substrates.

When considering the development of a tyre revetment or sea wall the tyres used should be:

- Filled with an appropriate material to reduce buoyancy.
- Strapped down to reduce the risk of tyres floating away.

Figure 28 Proposed use of tyre bales, Pevensey
(Courtesy of Dr. K Collins, University of Southampton)
Suitable material grading
Tyre and post revetments can be developed using:
- Whole tyres.

Alternative materials
The materials normally used for revetments may include:
- Concrete blocks.
- Metal and wood structures.

Case studies and research
A tyre and post revetment was developed in Oak Harbour, Washington. This consisted of two lines of vertical posts driven into the beach. Car tyres filled with gravel were laid over the posts and a filter cloth was placed between the tyres and the backfill. The structure performed successfully but the gravel fill inside the tyres was lost through water wash.

The UK Environment Agency developed a rubber tyre vertical defence in the river Bure in Norfolk, as illustrated in Figure 29. This involved a similar engineering design to that above, with the post driven into the river base, and tyres hooped over it to form a vertical wall. The structure was capped off with planks to hold it in place. This method proved successful at protecting the banks of the river. However, there were some practical difficulties, as installing the tyres under water proved difficult, as they are prone to float. In addition, the movement of tyres through wave action also led to a loss of backfill. The situation is currently satisfactory as silting has partially filled the tyres reducing their movement, and the backfill is becoming better bound through roots from the succession of reed growth behind the tyre wall.

Tyres have also been used successfully to produce sea walls as illustrated in Figure 30.

Artificial reefs

Introduction
Tyres are a popular medium for use in the development of artificial reefs, with major examples in the US, Colombia and the Caribbean, Malaysia, Australia and the UK. The durability of tyres makes them suitable for such applications, and these reefs can be used for a variety of different purposes including:
- Development of reefs for ecological improvement.
- Development of reefs for fisheries enhancement.
- Development of reefs for leisure activities including diving.
- Development of reefs for coastal protection.

In many areas tyre reefs have proven to be very good at introducing a greater biodiversity as their void spaces provide ideal areas where fish and other organisms can hide from predators and also breed. Because of their inert structure tyres are also easily colonised by algae, corals
and shellfish. This biodiversity adds to the useful nature of tyre reefs, and can help to protect more natural environments from loss and damage through man’s activities. Tyre reefs can be made up using tyre bales, or other shapes including tetrahedral and other shapes, and rubber rocks (tyres bound together in cylinders (<10) and filled with concrete to make them sink). Rubber rocks tend to be more appropriate for less sheltered environments because of their density. Tetrahedra are best placed in more sheltered or deep environments but are the most suitable for creation of biodiversity because of their large surface area.

There is some international opposition to the use of tyres in artificial reefs. Reasons for this opposition include:

- Perceived release of leachable chemical compounds into the marine environment (evidence suggests otherwise).
- Ecosystem damage can occur if tyres are not properly anchored.
- Failed reefs could cost substantial sums of money to remediate.

Figure 30 Tyre sea wall, Taiwan
(Courtesy of Dr. K Collins, University of Southampton)

Figure 31 Colonised tyre reef, Poole Bay
(Courtesy of Dr. K Collins, University of Southampton)
Characteristics of post-consumer tyres used for artificial reefs

Tyres have innate properties that render them suitable for such applications. Tyres are selected for such uses because they:

- Are an inexpensive alternative to traditional materials.
- Provide a large surface area and multiple niches for organism growth.
- Cannot be set alight when under water.
- Are lightweight and easily handled.
- Are durable materials.
- Are relatively resistant to leaching of their chemical compounds.
- Can be used to produce simple structures with relative ease.

In developing an artificial reef scheme the following parameters should be taken into account:

- Tyres should be securely anchored to ensure that they do not wash up on local beaches. This limits their use in areas with a high energy wave environment. The tyre structures can be filled with marine grade concrete (allowed to settle, cure and dry for approximately three days prior to deposition) to reduce the risk of breakaway or floating tyres, and secured with steel chain or wire rope if necessary.
- Tyres may leach chemical contaminants such as Polyaromatic Hydrocarbons, or Heavy Metals over time, thereby contributing to pollution of the surrounding environment (Dufton, 1995). However, because of the minute volumes and high dilution factor they do not constitute a serious threat to the local environment. In addition, the sea is a relatively inert media which should reduce the potential for leaching of chemical compounds once the structure has reached equilibrium with its surroundings.
- Tyre structures are not considered to be attractive, especially when used in amenity areas, such as use in diving reefs. It is therefore important to take this into account during the design process and incorporate the tyres within a more attractive structure.
- Ecological imbalances can occur through the development of artificial reefs that can impact existing flora and fauna. Although diversity may increase, these are likely to be opportunistic species at the outset. Care should be taken to ensure that the local ecosystem (however primitive) is not sacrificed for the development of a reef.
- Current policy requires that no waste materials be deposited in the sea. A licence is required from the Department of Environment, Food and Rural Affairs (DEFRA) before any artificial materials can be placed in the marine environment. This can prove difficult to obtain. Small-scale projects may receive a licence provided there is some form of environmental monitoring built in.

Suitability for use

Tyres are suitable for use where:

- There is a need to improve or increase the area of a reef.
- There is a requirement to increase the surface area for biodiversity.

Caution should be exercised over the use of tyres where:

- There are strong tidal flows and currents.
- There is a lack of material to weigh the reef down.
- There is a possibility of disruption to the current ecological balance.

Suitable material grading

Tyre reefs can be developed using:

- Whole tyres.
- Tyre built structures.
- Tyre bales.

Alternative materials

The materials normally used for artificial reefs may include:

- Concrete blocks and structures.
- Drums filled with concrete.
- Gravel filled gabions.
- Aggregate blocks.

Case studies and research

Collins et al. (2001) reference two extensive bibliographies relating to the use of tyres as breakwaters and artificial reefs. These list some two hundred references for artificial reefs, showing that tyres have been considered as a suitable material for some considerable time.
The current area of research relates to the potential impacts from the leaching of chemical compounds from tyres in the aquatic environment. In their study Collins et al. (2001) set out to determine whether the potential environmental impacts from tyres were real, with particular respect to bioaccumulation.

In July 1998 tyre modules and concrete blocks (as control modules) were deployed alongside an existing stabilised coal ash reef study site in Poole Bay, off the central south coast of England. Five hundred post-consumer tyres were used, formed into rubber rocks, open lattice tetrahedra, and concrete filled single tyre structures. Divers monitored the reef at two monthly intervals to determine colonisation of the tyre structures in comparison to the concrete control blocks. Marine organisms were collected for bioassay. The study is ongoing, but it has indicated that:

- There was no significant difference between concrete colonisation and tyre colonisation.
- No traces of indicator organic compounds were detected in seabed sediments surrounding the artificial reef.
- The concentrations of zinc were not significant in the collected organism bioassays in comparison with either the natural reef and the concrete controls. Zinc is recognised as one of the easiest metals to leach from tyres.

In earlier work, Collins et al. undertook a review of post-consumer tyre utilisation in the aquatic environment (Collins et al., 1995). The paper reviewed a number of original studies relating to impacts of tyre leaching upon organisms. Their review concluded that there was a lack of published information available on the potential uses of tyres in marine environments, although the majority of the studies that had been completed pointed towards a lack of leaching in the marine environment. The analytical study looked at the leaching of metals and concluded that the zinc which leaches from the tyre is minimal in real terms (10mg/tyre over a three month period). In addition, the zinc comes from the outside of the tyre only, and not from degradation of the tyre wall as a whole.

Work being undertaken in Wakatobi Marine National Park has shown rapid colonisation of a tyre reef, with coral growth occurring at some sites within an eight-week period (www.opwall.com, 2000).

**Hydrocarbon retardation - in-ground barriers**

**Introduction**

Although they are sometimes seen as an environmental problem, post-consumer tyres have properties that could make them particularly valuable for long term environmental protection. These properties appear to suit areas where there is a need to retard the impacts of volatile organic compounds (VOCs) which are highly mobile in the soil environment and can move rapidly towards groundwater and surface water resources. Shredded tyres are known to have absorbent capabilities, and have been used to mop up petroleum based hydrocarbons (Al-Tabbaa and Aravinthan, 1998). Volatile organic carbon transport has been reduced through the addition of ground tyres to standard slurry cut off walls (Park et al., 1997).

**Characteristics of post-consumer tyres used in soil protection**

Tyres have the following properties that make them suitable for use in environmental protection:

- Tyre shreds have a high absorption capacity for organic contaminants (Al-Tabbaa, 1998).
- Swelling of tyre chips through absorption can lead to a reduction in soil tyre permeability, thereby reducing transport of contaminants.
• Their durability provides a long term barrier solution.
• High chemical resistance even under the aggressive chemical conditions brought about by strongly acidic leachate.

There are a number of constraints on the use of tyres in such applications, and these should be assessed prior to the use of tyres for environmental protection:
• There are some concerns over leaching of chemical contaminants from tyres in the environment. However such leaching would be minimal compared with a reduction in localised groundwater contamination through the use of tyres in in-ground barriers.
• Pilot scale trials should be undertaken to determine applicability for the specified contaminant on a site specific basis.
• Continuous monitoring will be required throughout the process to ensure that the barrier is performing to the specified requirement.
• The barrier may require removal in the future depending upon the long-term capacity for control of hydrocarbon migration.
• Current work has looked at some organic contaminants only – more work is required on a variety of chemical contaminants.

Suitability for use
Tyres are suitable for use for:
• The protection of underlying ground or surface water, or as a reactive barrier to treat contaminated groundwater.
• The development of cut off walls in or around contaminated sites.

Caution should be exercised over the use of tyres where:
• There is a high groundwater table due to concerns over potential leachate from tyres. However a risk based approach should be used to determine whether the impacts of a major incident would outweigh the long term risks from tyre leachate.

Suitable material grading
In-ground barriers can be developed using:
• Tyre shreds.
• Tyre chips.
• Granulate.

Case studies and research
Research into this application has been ongoing since the early 1990s. Particular interest has involved research into the use of shredded tyres for absorption of volatile organic materials, and for the retardation of volatile organic flows in soils.

Park et al. (1997) have shown that shredded tyres can be used as a supplement to the engineered landfill clay liner system to retard VOC transport to a greater extent than that occurring in traditionally constructed engineered containment systems. They looked at the mixing of ground tyres into a traditional soil-bentonite slurry wall as a means of promoting sorption of organic compounds. This was proposed as a means of converting the traditional cut-off wall into a more effective reactive barrier. Their study showed that:
• VOC breakthrough times were significantly prolonged by the addition of ground tyres.
• Addition of ground tyres can increase retardation of VOC movement by several times in the soil-bentonite cut-off wall.
• Potential deterioration of the soil-bentonite slurry cut-off wall can be reduced by the addition of ground tyres.
• Hydraulic conductivity of the soil-bentonite material was not significantly affected by the addition of ground tyres.
• Effective porosity of the soil-bentonite material with or without ground tyres ranged from 70 to 100% of the total porosity.
• Ground tyres provide significant organic compound sorption capacity and can improve soil bentonite slurry cut-off walls.
• Such improvements in performance and efficiency are brought about with minimal additional construction costs.

Al-Tabbaa and Aravinthan (1998) mixed a natural over-consolidated fissured clay (Keuper Marl) with shredded tyres to determine whether it may be used as a constituent of an engineered landfill liner in terms of:
• Compaction.
• Unconfined compressive strength.
• Stress-strain behaviour.
• Permeability to water and paraffin.
Leachability.

Free swell behaviour.

Swelling pressure.

The results showed that:

- Compacted dry density reduced solely due to the lighter weight of the tyre.
- Unconfined compressive strength was as low as 40% of the strength of the clay alone.
- In stress-strain behaviour the clay-tyre mixtures produced a prolonged strain range at failure roughly double that observed for the clay alone.
- Permeability to paraffin was 50 times lower than that to water.
- Paraffin caused considerable swelling of the clay tyre mixtures compared to the clay alone and caused the development of swelling pressures of up to 600 kPa. This would render such use inappropriate if swelling pressures are likely to impact upon above or below ground structures.

Further work by Al-Tabbaa et al. (2001) examined geoenvironmental applications for sand-tyre mixtures. The work involved an analysis of material behaviour related to the addition of cement or kaolin clay, and a comparison of the characteristics of such mixes related to both manual and auger mixing. Sand mixed with up to 20% tyre (4-10mm size) and up to 15% cement, 10% kaolin clay, or 15% cement/kaolin in 38mm diameter samples was tested for unconfined compressive strength (UCS) and permeability to both water and paraffin. The results showed that:

- A range of UCS of between 5 to 409 kPa was obtained for different mixes. This range renders such mixes suitable for a variety of different geoenvironmental applications.
- Soil mixing proved an effective way of producing homogeneous soil-tyre mixtures, with the UCS of auger mixed samples comparing favourably with manually mixed samples.
- The unconfined compressive strength was significantly decreased by the addition of tyre shreds.
- The permeability range for water was between 2.51-12.9 \( \times 10^{-6} \) m/s. These values are above the permeability levels necessary for a landfill liner, but are suitable for an active in-ground barrier material.
- The permeability to paraffin ranged from 0.29 to 1.03 \( \times 10^{-6} \) m/s which is an order of magnitude lower than the permeability to water, confirming earlier work.

Smith et al. (2001) examined the use of tyre chips on their own, or mixed with gravel as a sorption media in reactive barriers. Compaction and compressibility tests were carried out to establish optimum tyre chip mixes in order to optimise the mix in terms of compressibility behaviour. The results showed that:

- Tyre chips have potential for use as a passive treatment wall for the retardation of aqueous hydrophobic organic contaminants and residual free product.
- Tyre chip barriers appear to retard contaminants rather than absorb them.
- Where there is an issue of geotechnical stability it may be necessary to mix the tyre chips with gravel.
- A 5-10% mixture of 2-6 mm tyre chips in 20mm gravel should achieve a relatively stable material.

The above studies all show that tyre shreds have potential for use in this area, especially where there is a need to retard liquid phase organic compounds from reaching and contaminating groundwater or surface water. Tyre shreds have the potential for improving environmental protection through the development of barriers to contaminant plumes, or as absorptive materials in their own right. Further detailed work is required to determine the ideal mixes for barrier production, and to investigate the interactions of each of the components in a barrier mix to reduce the impact of site specific problems.

There is some evidence that tyre shreds could also play a further part in barrier schemes in the future. Shin et al. (1999) have shown that the surface area of tyre shreds can play a part in increased biomass attachment for the breakdown of organic compounds in biofilm reactors, thereby increasing the volume of micro-organisms which can degrade the compounds. Further work in this area could feed into development of other environmental options for post-consumer tyres, particularly with regard to the remediation of contaminated land as the adsorption and biodegradation characteristics could be harnessed to work in tandem.

Noise barriers

Introduction

Noise is now viewed as a significant environmental pollutant that must be controlled as a means of improving the quality of life for those inhabiting neighbourhoods close to motorways and other major transport networks.
Noise levels along major roads are estimated to lie between 70 to 85 dB(A), with maximum recommended levels falling between 72 to 76 dB(A) (European Commission, 2000a).

Under World Health Organisation guidelines, daily daytime noise levels greater than 55 dB(A) cause community reaction (Department of the Environment, 1994b). A number of wide ranging European Commission documents will drive the development of protection measures for those living and working close to areas with high levels of road noise. These include:

- European Directive on the Assessment and Management of Environmental Noise.
- UK National traffic noise abatement policies.

These drivers are pushing for public protection and noise barriers are being promoted as the most suitable means of protection. Tyres have been proposed as a suitable material for use in noise reduction barriers, and different grades have been assessed to determine those with the best properties at lowest cost.

With more than 3,000,000 km of regional road network throughout the EU located on geologically diverse areas (CEN, 2002), tyre barriers could well prove an acceptable solution. A barrier structure 2.2 to 3.8 m in height, 10 to 15 m in width, and 1 km long requires approximately 1,500 to 3,100 tonnes (approximately 230,000 to 475,000 passenger tyres) of whole tyre per km of road, with double this if a barrier is constructed on both sides of the road.

A number of different barrier types are currently being developed. These vary from the use of whole tyres and shred as lightweight fill in noise reducing embankments, through to the use of expensively produced crumb and specifically produced mat like materials for implementation as absorption media in noise reducing walls.

**Characteristics of post-consumer tyres used in noise barriers**

Tyres have the following properties that make them suitable for use in noise barriers:

- Different grades of post-consumer tyre can be used, or barrier mats can be produced offsite and sold as noise barriers.
- Lightweight, and can therefore be used in geologically weak areas where traditional materials would prove too heavy.
- Tyre shreds are free draining, reducing any holding of water within the barrier.
- Tyres are durable materials.

Tyres can be used to produce noise barriers, especially on soft ground where the use of traditional materials could lead to instability in the structures. The use of tyres and associated grading will be enhanced if a number of issues are adequately controlled. To ensure their future use:

- The acceptability of tyre barriers is based upon site specific issues, and so each structure must be designed and monitored by a suitably qualified engineer.
- The site of installation must be clear of all debris including large rocks and jutting tree roots.
- Tyres should be covered with topsoil and vegetated to present an aesthetically acceptable appearance.
- The overall design of the structure must take into consideration the anticipated compression factor, particularly in terms of interaction and impact upon the local geology.

**Suitability for use**

Tyres are suitable for use where:

- The use of low density tyre shred will not impact underlying geology.
- There is suitable area to allow construction of a noise embankment.

Caution should be exercised over the use of tyres where:

- There is a high groundwater table due to concerns over leachate production.

**Suitable material grading**

Tyre noise barriers can be developed using:

- Tyre bales.
- Whole tyres.
- Half tyres.
- Tyre shreds.
- Tyre chips.
- Granulate (for production of mats).
Alternative materials

The materials normally used for noise barriers may include:

- Expanded polystyrene.
- Lightweight clay aggregate.
- Coarse sand and gravel.
- Earth.
- Timber walls.

Case studies and research

Tyres have been used in the development of noise barriers throughout the US and Europe.

The Department of Environmental Acoustics of the CSIC Acoustics Institute has been researching acoustic noise-reduction screens over the last few years (http://www.hannover2000.net). The programme is based on the study of alternative acoustic materials, rather than those habitually used in the design of absorbent noise-reduction screens, with the objective of using recycled materials from products which are harmful to the environment. The conclusion reached was that motor vehicle tyres provide appropriate control of noise levels.

Thermal insulation

Introduction

Tyre cuts, shred and chips have found use as a thermal insulation material. They have been used to insulate road and street structures, including below asphalt to reduce frost cracking, as fill in pipeline construction, especially for water pipes, and as fill for housing.

Characteristics of post-consumer tyres used as thermal insulation

Tyres have the following properties that make them suitable for thermal insulation:

- The thermal resistivity of tyre shred is 0.15 to 0.23 W/mK (around seven to eight times greater than for gravel). This property makes tyres a suitable alternative for use as an insulating layer to limit frost penetration, and frost heave in roads. Highway edge drains constructed from tyre shreds have been shown to resist freezing up during the cold of winter.
- Different post-consumer tyre gradings can be used.
- Lightweight, and can therefore be used in geologically weak areas where traditional materials would prove too heavy.

Suitability for use

Tyres are suitable for use where there is a need to:

- Protect subsoil from the penetration of frost.
- Protect pipelines or buildings from frost penetration.
- Prevent the thawing of permafrost beneath structures.
- Promote energy savings through the use of more efficient insulation.

Caution should be exercised over the use of tyres where:

- There is potential for ignition of tyre fill causing fire.

Suitable material grading

Thermal insulation can be developed using:

- Tyre bales.
- Whole tyres.
- Tyre cuts.
- Tyre shreds.
- Tyre chips.

Thermal insulation properties of whole tyres and bales may provide a slight advantage as a useful by-product of tyre use for other purposes.

Alternative materials

The materials normally used for thermal insulation in the ground may include:

- Expanded polystyrene.
- Lightweight clay aggregate.
- Fly ash.
- Slag.

Case studies and research

The insulation capabilities of tyres are being utilised to the full through the development of buildings built entirely of tyres known as ‘earthships’. The concept behind these ‘earthships’ is that they provide economic savings in the use of energy, and also find a means of dealing with the tyre problem.
New solar-powered housing and offices are being built in Brighton (Earthship Brighton) and Scotland (Earthship Fife) with recycled tyres by the Low Carbon Network (LCN), a UK-based non-profit organisation, and the Sustainable Communities Initiatives (SCI) in Scotland (www.edie.net, 2002). Three hundred pounds of soil are pounded into each tyre and coated with plaster in order to form the building blocks of these structures. In the winter, the earth-filled tyres store domestic heat and in the summer, they absorb heat and release it at night. Further details on Earthships can be found at www.lowcarbon.co.uk and www.earthship.org.

The insulation properties are also finding favour for the control of freeze-thaw action, and work is currently being carried out at the University of Dundee on the development of freeze-thaw resistant concrete using tyre shred as an alternative to air entrainment (http://www.dundee.ac.uk/civileng/research/concrete/major-areas.htm.).

Other engineering applications

Introduction

Tyres can also be used in a number of other applications that relate to civil engineering. These included the production of building and engineering products, or the use of rubber as a substitute for other materials. All of these options draw on particular characteristics of tyres but are particularly related to the more expensive options of producing powders and granulates. The uses included in this section are:

- Rubber modified asphalt.
- Sports and recreational surfaces.
- Engineering and building products.
- Rubber modified concrete.

Sports and recreational surfaces are a specific case of rubber-modified asphalt where the reduced hardness of rubber particles over natural aggregate gives it an additional advantage. Similarly, the use of rubber particles bound with bitumen to protect the top of French drains against particle scatter by overrunning vehicles is another specialist use that has obvious advantages.

In this section each of the above applications will be outlined. However, further research and guidance should be consulted prior to using such applications, because the science and engineering involved can prove complex and falls outside the scope of this document.

Rubber-modified asphalt

The use of post-consumer tyre crumb in the development of rubber modified asphalt has become widespread. Research and application work has been carried out throughout the US and Western Europe. However, the potential benefits and relative reduced costs for the use of tyres are also being considered throughout the developing world with particular interest in India (Gupta, 1997, Kumar et al., 2001).

Crumb rubber can be used as either a binder-modifier or as part of the fine aggregate/filler depending on the size of particles used. It will have some effect as both. If tyres are used as a binder modifier the source of tyre can be important because of compositional differences, particularly in terms of whether they are car (synthetic rubber) or truck (natural rubber) tyres.

Characteristics of post-consumer tyres used in rubber-modified asphalt

Tyres have the following properties that make them suitable for road surfacing:

- Durability of rubber provides surface resilience and reduced maintenance.
- Suggested increased friction in the road surface could help reduce accidents.
- Aids in the reduction of road noise.
- Bound granulate provides an easily drained surface.
- Crumb rubber particles cause less damage to vehicles if they become dislodged.
- Rubber road surfaces have increased resistance to deformation and cracking.
- Resilient modulus values for mixtures containing rubber are generally reduced.
- Rubber modified asphalt surfaces are less brittle and more resistant to cracking at lower temperatures.

The process

The complexities of the process used to develop rubber-modified roads mean that this is still a little used technology despite the fact that the current machinery has been around for a number of years. The production of suitable characteristics requires consideration of a number of design and local environmental factors and as a consequence this report does not dwell on this particular aspect of post-consumer tyre use. Further information can be found in Epps (1994), Heitzman (1992) and
Sainton (1999). It falls upon the designer to ascertain whether the use of crumb rubber will be suitable for a particular road or part of a road. The two main processes are outlined below.

**Wet process:**

In the wet process the crumb rubber is used as a bitumen modifier. Crumb rubber is blended with bitumen before the binder is added to the aggregate. There are three major elements to the wet process:

- Blending of the crumb rubber and bitumen.
- Reaction of the materials.
- Transfer of modified product to the desired project application.

The bitumen and crumb rubber is blended together and a reaction occurs causing the rubber to swell and soften. The reaction involves the absorption of aromatic oils from the bitumen into polymer chains comprising the major structural components of the rubbers making up the crumb. The reaction of the two components is influenced by a number of factors including:

- Temperature of blending.
- Time for which temperature remains elevated.
- Type and amount of mechanical mixing.
- Size and texture of the crumb rubber.
- Aromatic component of the bitumen.

The wet process can be used for a number of purposes including:

- Production of hot mix asphalt paving mixtures.
- Surface dressing.
- Joint and crack sealants.

Wet Process (Recycled Materials Resource Centre, 2002):

- The ideal particle size range for wet process falls between 0.6 – 0.15mm.
- Material should be heated to between 149 – 190°C before compaction.
- The rubberised asphalt should be laid at a temperature of at least 121°C using standard paving machinery. Compaction must be completed as soon as possible.
- Pneumatic tyre rollers cannot be used because of build up on the roller tyres.
- Careful monitoring of particle size, rate of addition of rubber, mixing temperature and the reaction and blending time for the mixture are essential.
- Specific gravity and in place density tests should be carried out on compacted mixtures in accordance with national requirements.
- For surface dressing applications typical spray quantities are in the order of 2.5 – 3.2 litres/m², compared with conventional surface dressings of between 1.6 – 2.3 litres/m².
- For interlayer applications typical spray quantities are in the order of 2.7 – 3.6 litres/m².
- Typical aggregate application rates for surface dressing coats are in the order of 16 – 22 kg/m², compared with conventional surface dressings of between 11 – 14 kg/m².
- Application of the chippings should immediately follow application of the binder to ensure proper cohesion.

**Dry process:**

In the dry process the crumbed rubber is added directly into the hot mix asphalt process, usually in a staged approach where the rubber and heated aggregate are mixed prior to the addition of the bitumen. There is some reaction between the rubber and the bitumen. The amount of crumb rubber added into the mixture will determine the degree of modification to the bitumen.

The dry process is limited to the application of hot mix paving projects, and is not a suitable method for the production of surface treatments. The process can be undertaken using traditional hot mix equipment with some modifications.

Dry process paving mixes should be designed volumetrically to compensate for the lower specific gravity of the crumb rubber particles. Binder contents in dry process mixtures are typically 10 to 20 percent higher than those of conventional mixtures. Although the air voids content is the criterion for mix design, lower stability values and higher flow values can be expected compared to conventional hot mix asphalt paving mixtures. The use of tyres and associated grading will be enhanced if a number of issues are adequately controlled.
Dry process: (Recycled Materials Resource Centre, 2002)

- A cubic particle shape with a relatively low surface area is desirable for rubber particles used as aggregate in the dry process.

- Mixtures should be produced at 149 to 177°C.

- During laying, the temperature of the mixture should be at least 121°C. A finishing roller must continue to compact the mixture until it cools below 60°C to prevent swelling due to the continued reaction between the bitumen and the rubber.

- Paving mixtures produced by the dry process have reduced stability values.

- Mixes containing granulated or crumb rubber typically have lower resilient modulus values than conventional hot mix asphalt. Dry process paving mixtures have been found to have resilient modulus values that are 10 to 20 percent higher than those of asphalt-rubber (wet process) paving mixtures.

- To delay reflective cracking, a minimum rubber content of between 1 and 2 percent by weight must be added to the paving mixture.

Sureflex technology (SARCO, 2002)

This is an additional technology originally developed for sports and safety surfacings, but now being marketed for road surfacing. The process was invented and patented in 1996. This technology consists of aggregates, rubber granulates and a polymer modified bitumen. A three-year study was carried out in the Department of Civil Engineering at the University of Nottingham from 1997-2000. The following outlines some of the factors entailed in using this process.

- Different properties are achieved by varying the ingredient mixture and particle size.

- Stiffness increases with load as the aggregates become dominant over the binder/rubber in the mixture.

- Manufacture is by a conventional batching plant and installation by machine or by hand. No additional plant or machine cost is required.

- The aggregates are heated to 210°C and discharged into the mill at the same time as the rubber. A dry mix cycle of 30-50 sec is required to ensure complete mixing of both materials. The polymer-modified bitumen is added at 185°C. A further mix cycle of 30-50 sec is required with a resultant end temperature of 165°C.

- The reaction time is 3-4 hours.

- The mixture must be retained at a temperature of 165°C prior to installation.

- The lightweight of the mixture allows the paver to be run at full speed. With a heated bed the paver will provide 85% compaction with coverage of 18m² per tonne at 15-20mm thick.

Figure 33 Laying sureflex
(Courtesy of SARCO Ltd)
Standards and specifications

For most applications in the UK, the relevant specification is the Specification for Highway Works (SHW) and design information is given in the Design Manual for Roads and Bridges (DMRB). Obtaining approval for the use of tyres in such applications would necessitate a departure from the standard. The use of proprietary thin surfacings incorporating crumb rubber can be called up under Clause 943 of the SHW. A BBA-HAPAS (Highway Authority’s Products Approval Scheme) certificate would need to have been issued for the proprietary surfacing incorporating post-consumer tyres for it to comply with the SHW.

The CWA 14243 (CEN, 2002) provides a specification for the suitable processing of post-consumer tyres to render them suitable for such applications.

Suitability for use

Tyres are suitable for use where:

- A hard-wearing surface course is required.
- There is a need for a quick road surfacing repair (wet process).

Caution should be exercised over the use of tyres where:

- Temperature fluctuations may impact the laying process.

Suitable material grading

Rubber-modified asphalt can only be developed using:

- Granulate.

Alternative materials

Post-consumer tyres can be used as an alternative to aggregate in such applications. Traditional materials include:

- Crushed rock.
- Gravel.

Case studies and research

Crumb rubber-modified asphalt has been used in the US for over fifty years with varying degrees of success, primarily related to the many factors that control the process. European applications have been developed, with particular success in France and Portugal, but UK applications have shown mixed results. Research is being carried out in the UK, with the University’s of Liverpool and Nottingham undertaking the bulk of the work. Field trials have also been undertaken in the UK.

East Sussex County Council and Colas trialled crumb rubber asphalt on the A271 in Battle. The idea was to lay a reduced noise surfacing for local residents, and the work had to be undertaken twice because the initial laying of the surfacing cracked within six weeks of laying, due, it is believed, to the original having been laid during a period of cold weather. The asphalt uses rubber from ground tyres to replace the fine aggregate in the asphalt mixture, in a ratio of approximately one tyre to every 2m² of surfacing. Because the council intended to lay 4,500 m² of the material, this translates as using approximately 2,250 tyres. The cost of laying was approximately 15% higher than for conventional asphalt, but the proposed reduction in road noise was believed to be almost 8dB(A) (Bennett, 2000).

Sports and recreation surfaces

Sports and recreation surfaces provide another means whereby alternative materials can be diverted to other purposes. The technology for developing such surfaces is well developed, and they provide excellent playing surfaces with enhanced safety aspects compared with gravel playing fields, and enhanced longevity and low maintenance in comparison with grass surfaces. Tyres have been used to produce:

- Multi-sports shock pads.
- Impact absorbing layers.
- School and municipal playground surfacing.
- Sports tracks and pitches.

Surfaces are produced through two major methods:

- Tyre granulate bound with polyurethane as either a dry mix produced on site prior to application, or by application of prefabricated sheets designed to meet the specified performance requirements. At present, such surfacings are not deemed to be recyclable in the future.
- Tyre granulate bound with polymer modified bitumen is manufactured in a traditional asphalt batching plant. The aggregates are dried and weighed and then added to the mill with the tyre rubber and the modified bitumen where they are held for a predetermined retention time before removal to site. Such surfaces can be recycled at the end of their working life.

The use of tyres will be enhanced if a number of issues are adequately controlled.
The recommended size of the granulate in the polyurethane process ranges from 2 to 8 mm diameter.

The recommended size of the granulate in the modified bitumen process ranges from 1 to 12 mm diameter.

Tyre granulate should be free of bead wire, textile and excessive moisture.

Polyurethane surfacings are prone to hardening over time, and may therefore require wear protection for surface or near surface use. The lifespan of this overlay protection carpet is currently between 7 and 12 years.

Polymer modified bitumen surfacings have an expected lifespan of 30 years.

All surfacings must be tested to ensure they meet the appropriate UK standards

Varying particle size distribution and the ratio of the other ingredients allows for the development of products for specific end uses. Care needs to be taken in ensuring that the design characteristics provide a surface that is fit for purpose.

**Characteristics of post-consumer tyres used in sports and recreational surfaces**

Granulated tyres have the following properties that make them suitable for sports and recreational surfaces:

- Durability allows increased lifespan.
- Flexibility of the material allows for ease of application.
- Shock absorbency capability.
- Bound granulate provides an easily drained surface.
- Friction afforded by granulate reduces slipping during sporting activities.

**Standards and specifications**

There are environmental and engineering requirements that must be met when providing a specification of materials for use in sports and safety surface production. The materials used should be (CEN, 2002):

**Suitability for use**

Tyres are suitable for use for:

- Sites requiring impact absorbency for health and safety purposes.

<table>
<thead>
<tr>
<th>Specification description</th>
<th>Granulate bound polyurethane</th>
<th>Granulate bound modified bitumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulate size</td>
<td>2-8mm</td>
<td>1-12mm</td>
</tr>
<tr>
<td>Total polymer content</td>
<td>56%</td>
<td>5-7%</td>
</tr>
<tr>
<td>Natural rubber content</td>
<td>9-50%</td>
<td>35-37%</td>
</tr>
<tr>
<td>Acetone content</td>
<td>9-20%</td>
<td>9-20%</td>
</tr>
<tr>
<td>Carbon black</td>
<td>25-35</td>
<td>25-30</td>
</tr>
<tr>
<td>Ash at 550°C</td>
<td>8% max</td>
<td>8% max</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1-3%</td>
<td>1-3%</td>
</tr>
<tr>
<td>Hardness</td>
<td>60-70 IRHD</td>
<td>60-79 IRHD</td>
</tr>
</tbody>
</table>

- Sites requiring frictional properties such as for controlling motor sport accidents.
- All weather sports pitches.

**Suitable sports grading**

Sport surfaces can be developed using:

- Granulate.

**Alternative materials**

The materials which have been used for surfacing and safety surfacing include:

- Traditional asphalt.
- Gravel.
- Natural turf.
- Woodchips.
- Sand and bound sand.
- Wax.

**Case studies and research**

Tyres have been successfully used in a number of applications by a number of different companies in the UK. Proven applications include children’s playground surfaces, multi-sport pitches, and friction traps for motor sports. There are a number of different companies throughout the UK involved in marketing these applications. These include the Charles Lawrence Group (http://www.clgplc.co.uk/) and SARCO (http://www.sarco.co.uk)
Engineering and building products

Post-consumer tyres have proven useful in the manufacture of certain building products primarily because of their properties and the ease with which rubber can be deconstructed and remoulded into other products. Such engineering products include, but are not limited to:

- Roof and flooring tiles.
- Tyre block manufacture.
- Street furniture including bollards, kerbstones and speed humps.
- Rubber railway sleepers and level crossing blocks.

Other products may be developed as demand for tyres increases. The use of tyres will be enhanced if a number of issues are adequately controlled:

- The greater the need for processing to produce smaller particle sizes, the greater the cost. Many of these applications require tyre to be processed to granular and powder sizes.
- Building materials made from tyre grades may be susceptible to arson, or uncontrolled combustion through accidental fires.

Characteristics of post-consumer tyres used to make engineering and building products

Tyres have the following properties that make them suitable for developing building products:

- They can be reground and reproduced into similar products.
- They are good insulators, reducing energy consumption.
- They are lightweight in comparison to most conventional aggregate materials.
- Tyre produced building materials are water resistant.

Standards and specifications

Specifications are applied corresponding to the final use of the product. Individual organisations should be approached to determine compliance with the specifications for particular products. For example, Railtrack have standard specifications for materials going into level crossing blocks.

Suitability for use

Tyres are suitable for use where:

- Traditional product additives can be expensive.
- There is a need for specific properties in a product such as low density etc.

Caution should be exercised over the use of tyres where:

- Arson or uncontrolled fires could occur.

Suitable material grading

Building and construction materials can be developed using:

- Tyre bales.
- Whole tyres.
- Tyre crumb.
- Granulates.
- Powder.

Alternative materials

Post-consumer tyre materials can reduce the demand for other aggregate based materials allowing these to be substituted into applications higher up the chain of utility. The materials normally used for building products may include:

- Quarried aggregate.
- Clay.
- Slate.
- Polyurethane.
- PVC.
- Cement.
- Concrete.

Case studies and research

Tyre based building products have been developed and are being successfully used throughout the UK and overseas. Particular success has been recognised in the manufacture of street furniture including bollards and speed bumps, as the rubber-based products are easy to manufacture with less damage to vehicles if they bump into them. Further success has been identified for the manufacture of level crossing blocks to meet the specification required by Network Rail (Figure 34). Figure 35 illustrates some areas where tyre based products have been used in the home.
Rubber modified concrete

Tyre recycling as a concrete constituent is also possible, without the need to burn the tyres in cement kilns, providing other properties that designers and specifiers can find useful for particular applications. The use of tyres in concrete could provide additional benefits to conventional concrete which allow for greater use (Topçu and Avcular, 1997).

The use of tyres will be enhanced if a number of issues are adequately controlled. To ensure their future use:

- The use of the modified concrete must be considered in terms of compressive strength and density. Both are reduced through the addition of tyre rubber, the reductions of both depending upon the amount of rubber added.

Figure 34 Schematic of the level crossing blocks
(Courtesy of Rosehill Polymers Ltd)

Figure 35 Some applications for car tyres in building components
• The grading of the tyre also has an impact upon compressive strength, with finer gradings tending to have lower compressive strength.

• Tyre rubber reduces the flexural strength of concrete and mortar (Lee et al., 1998; Raghavan, 2000; Li et al., 1998).

• The addition of a coupling agent (such as Sodium Hydroxide (Segre and Joekes, 2000)) can improve the adhesion between the rubber and mortar.

Characteristics of post-consumer tyres used as aggregate in concrete
Tyres have the following properties that make them suitable for addition to cement and concrete:

• Different post-consumer tyre gradings can be used.

• Lower modulus of elasticity which reduces brittle failure, allowing an increased flexibility to the concrete.

• Lightweight, and therefore suitable for exterior and interior use.

• Increased energy absorption making them suitable for use in crash barriers etc.

Suitability for use
Tyres are suitable for use where:

• Flexibility and light weight are required.

• The strength properties are not the main design criteria.

Caution should be exercised over the use of tyres where:

• Compressive strength or density is a limiting factor for the proposed application.

Suitable material grading
Typical grades of tyre that can be added as aggregate to concrete include:

• Chips.

• Tyre crumb.

• Granulates.

• Powder.

Alternative materials
Post-consumer tyre materials can reduce the demand for natural aggregates allowing these to be substituted with potential improved performance in certain applications. These may include:

• Quarryed aggregate.

Case studies and research
Okba et al. (2001) suggested that the addition of tyre rubber to concrete improved certain properties including reduced density, increased toughness and ductility, and higher impact resistance. Their study looked at the performance of concrete incorporating rubber tyre particles as replacement for traditional coarse and fine aggregates in both normal and high strength concrete mixtures. The study looked at compressive, tensile, impact and bond to reinforcement strength, abrasion resistance and water absorption. They concluded that:

• The air content of fresh concrete increases while the unit weight of the hardened concrete decreases when chipped or crumbed tyres are added.

• Compressive strength is reduced by using chipped or crumbed rubber tyre particles and the decrease is more pronounced for high strength concrete than for normal strength concrete.

• The indirect tensile strength and the bond strength are reduced by the addition of tyre particles, but this reduction was not as significant as that for compressive strength.

• The mode of failure in compression and tension becomes more ductile compared to conventional concrete.

• The impact resistance of concrete is improved using chipped or crumbed rubber particles.

• Water absorption increases and abrasion decreases when tyre particles are added. This has a greater influence on high strength concrete.

Further research has shown that the increased plastic energy afforded by the addition of rubber to concrete increases the strains that can be dealt with, especially under impact effects (Topçu, 1995). This study showed that the addition of fine rubber (0 to 1mm) aggregates had less negative impact upon the original strength of the concrete than coarse rubber (1 to 4 mm) aggregates.

El-Dieb et al. (2001) looked at the use of developing concrete using tyre particles of <5mm as replacement for both coarse and fine aggregates. Their study showed that
the substitution of tyre particles for normal aggregates up to approximately 50% provided optimum advantageous properties to the concrete. Further substitution above 50% was considered to be less useful, with problems relating to strength because of weak bonding between the tyre particles and the cement paste. They recommended that further work be carried out to determine whether the optimum replacement levels provided adequate improvements in concrete performance for applications where the lightweight of the tyre enriched concrete could prove an advantage.

Pilakoutas and Strube (2001) have taken the application of tyre components down a different avenue where they have taken the steel fibres (cut to < 10mm) rather than the rubber as an additive to concrete. The reasons for adding steel fibres to concrete include:

- Controlled cracking.
- Increased toughness.

Their study concluded that provided the steel fibres were made available with limited impurities (all rubber removed, etc.) they could potentially provide a suitable material for enhanced concrete performance. They recommended further research requirements to determine both the optimum performance of the fibres in concrete and to quantify the mechanical characteristics in a more scientific manner. Further consideration of the costs involved in recovering steel fibres from tyres must also be considered to determine whether they provide an economic alternative to other competing sources.

Conclusions

This document has outlined a number of alternative applications for the use of tyres. Each of these has specific requirements that are necessary to ensure both compliance with the law, and to meet the performance specifications for a particular application. It is evident from the information provided that tyres can provide suitable alternative to traditional materials. Their use produces a number of desirable outcomes including:

- Reduced need for quarried aggregates.
- Reuse of a potentially valuable resource.
- Opportunities for development on areas which have previously proven unsuitable.
- Meeting the Landfill Directive requirements for the reduced disposal of tyres to landfill.

All of these are of interest in the push towards sustainable development. However, none of these is as important as the actual engineering performance characteristics of tyres. It is up to the civil engineering industry to push the use of tyres in such applications into the mainstream. Only then will their true value be recognised.

There is little to be gained from the use of post-consumer tyres in such applications if they cannot prove be as good or better than traditional materials under certain conditions, and within an acceptable economic framework. However, continued investigation will allow their use to be fully evaluated and particular applications identified which are suitable for the European marketplace.

Partnership working between client and contractor, and a culture of risk sharing will help to work towards further use of recycled materials in construction. Without such an approach, there will always be a default to the use of tried and tested materials and techniques without the adequate investigation necessary to prove the usefulness of tyres. This document is intended as a spur to such investigation, with the ultimate goal of reducing our current reliance upon options which provide no benefit to the environment as a whole. Both the reduction in disposal to landfill, and the reduction in the use of quarried aggregate are goals which the whole construction sector should be striving towards. Only then will true sustainability be attained.

References


DTI (2002). Discussion paper on a possible producer responsibility model for used tyres. DTI, March 2002


Web pages:


Notes
1 Valorisation is a term used to describe the methods of utilisation of post-consumer tyres or other secondary materials/by-products, often collectively. It has connotations of increasing the value of the material by means of the utilisation.

2 The Waste Hierarchy is a conceptual framework or guide that places the options in order of priority, starting with waste reduction and followed by re-use, recovery (recycling, composting or energy recovery) and finally disposal.

3 Vulcanisation is a process of treating rubber or rubber like materials with sulphur under high temperatures to improve elasticity and strength or to harden them.

4 The resulting textiles that are separated from the tyre during the recycling process.

5 The action of soaking up or attracting substances; process used in many pollution control systems (http://glossary.eea.eu.int/EEAGlossary/S/sorption)
Appendix 1: Legislative issues

Appendix 1 outlines the different environmental legislation which needs to be taken into account when considering the use of post-consumer tyres in civil engineering applications. There have been some cases throughout the UK where the regulator has allowed the use of tyres without over prescription. However, the main issues to be considered include:

- Compliance with the Duty of Care.
- Consultation with the regulator throughout the development to determine the need for, and to obtain a waste management licence.
- Undertaking a risk assessment prior to the use of any post-consumer material.
- Ensuring that all suppliers are meeting their environmental obligations under the regulations.

Where tyres are to be placed in marine environments, DEFRA must be consulted and a licence received before work has been started. In many cases such schemes require a strict environmental monitoring regime before a licence will be granted.
## Relevant Legislative Drivers

<table>
<thead>
<tr>
<th>Legislative Driver</th>
<th>Description</th>
<th>How does it impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill Directive</td>
<td>The EU Landfill Directive (99/31/EC) has far reaching powers including control over the volumes of biodegradable waste going to landfill, the banning of specified materials from landfill, the reclassification of landfills for waste acceptance purposes, the requirement of waste to be pre-treated before final disposal, and the requirement for landfill gas to be collected and either flared, or used for energy production.</td>
<td>The EU Landfill Directive (implemented in the UK by the Landfill (England and Wales) Regulations 2002) bans the landfilling of whole tyres from July 2003, and shredded tyres from July 2006 (exempt tyres include those over 1400mm diameter and bicycle tyres). Some landfill operators expect to escape the final ban until July 2007 as it will take that long to bring the last of their landfills under the recently implemented pollution prevention and control regime. This amounts to a gradual loss of disposal capacity. Under the Directive, an additional recovery capacity of 200,000 tonnes of post-consumer tyres will be required to make up for the shortfall brought about by this ban on landfilling in the UK. Similar legislation is yet to be enacted in Scotland and Northern Ireland.</td>
</tr>
<tr>
<td>End of Life Vehicles Directive</td>
<td>The End of Life Vehicles Directive (2000/53/EC) (ELV) applies to all cars and light vans produced or imported into the country. This requires all EU Member States to ensure that the reuse or recovery rate for this waste stream is raised to 85% by January 2006, and up to at least 95% by January 2015. A further set of targets requires that reuse or recycling must reach at least 80% by 2006, and 85% by 2015. The UK government intends to introduce the Directive under producer responsibility, and they are currently determining implementation of the most suitable option prior to January 2007.</td>
<td>It is likely that implementation of this Directive will have a positive impact on the recycling or recovery of post-consumer tyres, as ‘authorised treatment facilities’ (currently dismantlers and shredders) will remove tyres from ELVs before onward treatment or disposal, as required by the legislation. However, a significant tonnage of tyres will not be included, as the Directive does not oversee commercial vehicles.</td>
</tr>
</tbody>
</table>
### Relevant Legislative Drivers

<table>
<thead>
<tr>
<th><strong>Legislative Driver</strong></th>
<th><strong>Description</strong></th>
<th><strong>How does it impact</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Directive on Waste (as amended 1991)</td>
<td>Responsible for the definition of waste in current usage - ‘Any substance or object …. which the holder discards, or intends to discard, or is required to discard’</td>
<td>Impacts tyre recycling because post-consumer tyres have reached the end of their intended life and are therefore classified as waste by virtue of the intention to discard. Managing used tyres requires a Waste Management Licence.</td>
</tr>
<tr>
<td>Duty of Care</td>
<td>Section 34 of the Environmental Protection Act 1990 (DoE, 1990) places a Duty of Care on all who import, produce, carry keep, treat or dispose of Controlled waste or who, as brokers, have control of such waste. It requires handlers of waste to be licensed and the producer of the waste to manage waste only through licensed and regulated bodies. An audit trail of what, where, and when the waste has been treated is kept.</td>
<td>All those involved in the post-consumer tyre process will need to take account of the Duty of Care legislation. Lack of knowledge regarding the Duty of Care system is not a legal defence. Full records must be kept when dealing with the management of tyres as a controlled waste.</td>
</tr>
<tr>
<td>Waste Management Licensing Regulations</td>
<td>Under the Environmental Protection Act 1990 (DOE, 1990) a licence is required to treat, keep or dispose of controlled waste. This was implemented into England and Wales legislation through the Waste Management Licensing Regulations 1994 (DoE, 1994), with subsequent guidance produced in Waste Management Paper No. 4 (DoE, 1994).</td>
<td>An exemption is available for sites where less than 1000 tyres are stored for under a year for the purposes of retreading or reuse. Legally, all such exemptions are registered with the Environment Agency. Where there is a proposal for tyre storage the proposer must consider potential risks to health or the environment. A Waste Management Licence is required for all sites where post-consumer tyres are stored, recycled or where recycled tyres are used.</td>
</tr>
<tr>
<td>Renewable Energy Targets</td>
<td>Under the Renewables Obligation, electricity suppliers are required by the Government to supply a certain percentage of electricity from renewable sources each year. Companies can choose to meet their target by buying enough Renewable Obligation Certificates, by paying a premium to make up the shortfall, or by using a combination of both these methods.</td>
<td>Should tyres become eligible for Renewable Obligation Certificates there will be a greater interest in their use within the energy production sector as an alternative fuel. However, it is arguable whether tyres should be viewed as a renewable fuel source, and further research would be needed to determine whether the benefits of burning tyres counts as renewability.</td>
</tr>
</tbody>
</table>
# Relevant Legislative Drivers

<table>
<thead>
<tr>
<th>Legislative Driver</th>
<th>Description</th>
<th>How does it impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Pollution Control (IPC)</td>
<td>Integrated Pollution Control is currently being superseded by IPPC. However, there are still existing authorisations which will operate under this regulation for the next few years.</td>
<td>The burning of tyres in incinerators, cement kilns, and pyrolysis plants is classified as a Part A process under Integrated Pollution Control. Authorisation under this requirement requires that all emissions to air, land and water are limited to reduce pollution. The Environment Agency, or equivalent is responsible for enforcing compliance.</td>
</tr>
<tr>
<td>Integrated Pollution Prevention and Control (IPPC)</td>
<td>The Integrated Pollution Prevention and Control Regulations (EC, 1996) take over from the existing Integrated Pollution Control Regulations, with final take over by the end of 2007. These provide a more holistic management system for the control of all emissions and environmental impacts from a site, as the installation itself is licensed rather than the process. Guidance is currently being produced as European BAT Reference Notes (Bref Notes) and UK guidance notes for each sector.</td>
<td>Due to take over from both IPC and the current waste management licensing regime, and will therefore be main means of controlling tyre disposal. IPPC will play a greater role in control of facilities which either extract energy from tyres or burn them as an additive for cement manufacture.</td>
</tr>
<tr>
<td>Landfill Regulations</td>
<td>The Landfill Regulations (DEFRA, 2002) were implemented in 2002. These implement the requirements of the Landfill Directive into the legislation for England and Wales.</td>
<td>Includes the requirements for the banning of tyres to landfill as required by the EU Landfill Directive.</td>
</tr>
</tbody>
</table>
### Appendix 2: General decision criteria for use of tyres

#### Are there likely to be any impacts upon public health?

<table>
<thead>
<tr>
<th>Leachability of toxic materials from tyres</th>
<th>Research is ongoing into the potential for chemical constituents to leach from tyres. There is currently no evidence that chemicals which will cause harm to human health or the environment are leached from tyres in any significant quantity. Evidence suggests that there will be some leaching of materials from tyres under high or low pH conditions. However, the volumes of chemical leaching are minimal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odour</td>
<td>There is no reason why the use of post-consumer tyres would produce adverse odour. Tyres and rubber do have an odour, but this is considered of little significance to their use in civil engineering.</td>
</tr>
<tr>
<td>Introduction and provision of free passage for pathogens</td>
<td>There is no reason why tyre shreds would provide any greater freedom of passage for pathogens than traditional materials such as gravel. However, the surface area afforded by tyre shreds could provide greater area for attached growth allowing improved breakdown of pollutants.</td>
</tr>
</tbody>
</table>

#### What are the potential cost impacts?

<table>
<thead>
<tr>
<th>Availability of tyres throughout the process, and guaranteed price</th>
<th>Tyres are produced in all parts of the country. However, tyre reprocessing plants are not well dispersed, and so transport can provide increased cost in terms of bringing the tyres to the site of use from the reprocessing plant. These transport costs need to be considered if tyres are to be used in civil engineering applications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competition for tyre use</td>
<td>Tyres are currently used successfully in cement kilns as a supplementary fuel. This will continue to be a competitive outlet unless the cement industry identifies alternative supplementary feedstock which is comparatively less expensive.</td>
</tr>
<tr>
<td>Efficient utilisation of landfill void capacity</td>
<td>Where landfill engineering applications are concerned, it is necessary to consider the reduction in landfill void capacity when using post-consumer tyres in the development of the landfill. It is unlikely that this will be significant as the current route for the majority of legally disposed tyres is to licensed landfill, although this is due to change from July 2003.</td>
</tr>
<tr>
<td><strong>Are there likely to be any impacts upon the environment?</strong></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Potential for underground fires</strong></td>
<td>Good design and engineering coupled with the control of oxygen entrance to fill materials greatly reduces any risk of underground combustion. Most tyre fires have been started intentionally through arson, and uncontrolled underground combustion has only occurred through the introduction of a source of ignition to tyre fills.</td>
</tr>
<tr>
<td><strong>Contribution to leachate production and runoff</strong></td>
<td>Although there are some concerns regarding the leachability of certain constituents from shredded tyres, there is little evidence that this will cause a problem when used appropriately.</td>
</tr>
<tr>
<td><strong>Contribution to landfill gas generation</strong></td>
<td>The durability of tyres suggests that their contribution to landfill gas production will be negligible.</td>
</tr>
<tr>
<td><strong>Control of dust and litter</strong></td>
<td>Tyre shreds can act as a means of constraining dust and litter on a landfill site. Although this can be useful in terms of reducing the migration of litter from a site, litter and dust can impact the performance of the tyre shreds, especially where cleaning of the tyre shreds becomes necessary.</td>
</tr>
<tr>
<td><strong>Contribution to marine or river pollution load</strong></td>
<td>The use of tyres in aquatic applications may allow for the leaching of chemicals as outlined above. However, it is unlikely that the pollution load from a tyre based structure will have any significant affect on the environment.</td>
</tr>
<tr>
<td><strong>Shift in the erosion problem to another area</strong></td>
<td>There is a possibility that the use of erosion control systems can lead to a shift in the location of the area of erosion. However, this will happen with all poorly designed erosion control measures and there is no significance in the impact between using tyres and traditional materials as such problems are structure based rather than material based.</td>
</tr>
<tr>
<td><strong>Need for anchoring of a tyre wall, or floating breakwater</strong></td>
<td>When used in aquatic environments all tyre based structures should be securely anchored to ensure that they do not break up and lead to environmental damage along the coast line. Again, this is a design based problem, and has little to do with the use of tyres in such applications.</td>
</tr>
<tr>
<td><strong>Disruption to the existing ecosystem</strong></td>
<td>Any interference in an ecosystem will result in a new equilibrium condition. An impact assessment should be carried out to ensure that any rare flora and fauna are not adversely affected by establishing artificial reefs or breakwaters.</td>
</tr>
<tr>
<td><strong>Potential saturation difficulties with respect to removal of hydrocarbons</strong></td>
<td>When tyres are used to develop in-ground barriers to control the migration of hydrocarbons they do have a finite capacity and will become saturated eventually.</td>
</tr>
</tbody>
</table>
**Are there likely to be any operational impacts?**

<table>
<thead>
<tr>
<th><strong>Long term durability of tyres leading to future environmental liability</strong></th>
<th>The fact that tyres are durable is one of the main advantages for their use, and provided that the applications within which they are used have been appropriately designed and engineered there should be no environmental liability.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Possible greater incidence of vehicle tyre punctures due to steel</strong></td>
<td>Tyre bead wires can cause punctures to on site plant during construction operations. This problem can be cured through either completely removing the bead wires before tyre use, or through the use of puncture resistant vehicle tyres.</td>
</tr>
<tr>
<td><strong>On site uses</strong></td>
<td>Tyres can be graded into different size fractions for differing purposes providing versatility in terms of potential site end uses.</td>
</tr>
<tr>
<td><strong>Impacts upon decomposition within a landfill site</strong></td>
<td>The use of tyres will have little or no impact upon decomposition within a landfill site.</td>
</tr>
<tr>
<td><strong>Storage space requirements</strong></td>
<td>Post-consumer tyres remain a waste material under UK law until they have successfully been reused in a particular application. This requires that tyres are dealt with under the Waste Management Licensing Regulations 1994 (DoE, 1994). This has impacts upon storage requirements. In addition, tyres take up a large area and so consideration must be given to provision of a suitable storage area prior to the use of tyres within the chosen application.</td>
</tr>
<tr>
<td><strong>Logistics and support requirements including transportation</strong></td>
<td>Transportation will depend upon the type of tyre based material to be used. Shredded and smaller grade materials need to be processed off site using specialised equipment. This will require additional transportation and handling processes to be considered. The handling of larger grade materials is likely to be easier as it may be possible to process them locally. In the case of tyre bales, baling could be carried out on site.</td>
</tr>
<tr>
<td><strong>Increases in compaction requirements on site to improve stability</strong></td>
<td>As tyres compress readily, a significant depth of tyre shred may need to be laid initially to ensure consistent performance and to reduce the overall impact of porosity and permeability loss.</td>
</tr>
<tr>
<td><strong>Installation during adverse weather conditions (i.e., hot and freezing temperatures, high winds, moderate and maximum rain intensity)</strong></td>
<td>This is unlikely to be a problem for any uses other than those relating to road or sports and safety surfacing where temperature and overall weather conditions can impact on the asphalt mixing, laying and compaction processes.</td>
</tr>
</tbody>
</table>
### Are there likely to be any operational impacts?

| **Resistance to burrowing animals** | Tyres provide ideal resistance to burrowing animals provided that the surrounding matrix is not conducive to habitation. This is particularly important where tyres are being used in embankment construction or slope stabilisation where burrowing animals can cause major problems on stability. |
| **Erosion resistance** | Tyres provide ideal resistance to erosion of all kinds and they are a suitable material for provision of barriers against water (marine and fluvial) and wind erosion. |

### Are there any specific product characteristics?

| **Physical and chemical compatibility with natural or existing components** | Tyres are almost inert and so will have no major impact upon the local conditions on site and will not interact with materials in a detrimental manner. However, tyres do absorb hydrocarbons, and this can cause swelling, especially where there are high concentrations of hydrocarbons in the local area. This can help to retard hydrocarbon migration to impact local groundwater sources. |
| **Absorption capabilities** | Post-consumer tyre products have the potential to absorb shock and vibration thus providing a measure of insulation against sound and vibration. |
| **Resistance to adverse weather conditions after installation (e.g., hot and freezing temperatures)** | Tyres have good thermal conductivity properties and are thus not impacted by changes in weather conditions. Tyre shreds can become brittle in very cold conditions, but this is not thought to be a problem in the UK. |
| **Flexibility and ductility of a tyre shred layer, bales and whole tyres** | Tyre shreds are prone to give and compress under loading. This provides a degree of flexibility in the materials when used in engineering applications which improve stability. |

### Are there any specific product characteristics?

| **Any unacceptable aesthetics** | Tyres are not aesthetically pleasing. In the main, however, tyres are not going to be visible following completion of a civil engineering application. |
### Any impacts upon engineering performance?

<table>
<thead>
<tr>
<th><strong>Hydraulic conductivity</strong></th>
<th>Tyre shreds provide excellent hydraulic conductivity as good as, if not better than gravel. This means that they are an ideal alternative to traditional materials.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compressibility</strong></td>
<td>The compressibility of tyre layers requires that there may need to be a greater surcharge depth of tyre material than for traditional materials prior to compaction. There should be no significant impact if appropriate design is carried out.</td>
</tr>
</tbody>
</table>

---

### Any impacts upon engineering performance?

<table>
<thead>
<tr>
<th><strong>Flexibility (i.e., ductility to accommodate differential settlement)</strong></th>
<th>The flexibility of tyre shred fills means that they are unlikely to suffer from significant differential settlement provided that they are designed and constructed using good practice.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stability problems</strong></td>
<td>Tyre shreds bind together when loaded and compacted to produce a lightweight fill material. The frictional characteristics of the compacted tyre shreds can provide additional slope stability and provided the fill has been designed and filled appropriately, there should be no significant negative impact upon stability.</td>
</tr>
</tbody>
</table>

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| **Potential for clogging of tyre pores leading to loss of drainage performance** | Tyre pores can become clogged by particulates in saturated environments as deposition occurs. In roadside drainage applications there will be a need for cleaning of the tyre shreds periodically. However, this is also the case with traditional aggregates. In tyre fills some reduction in the performance of the system could occur through the blockage of the void spaces by movement of larger particles, but this could be mitigated by controlling the depth or width of a tyre filled drainage system to ensure that it is great enough to take account of reduced porosity. |
## Appendix 3: Leachability determinants for use of materials intended for engineering uses

<table>
<thead>
<tr>
<th>Applications</th>
<th>Chemical property</th>
<th>Limiting value(µg/l unless stated)*</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill engineering</td>
<td>pH</td>
<td>5.5 – 9.5</td>
<td>Limiting values for chemical properties of materials used in engineering applications are dependant upon site specific factors and the type of containment system used on site.</td>
</tr>
<tr>
<td>Lightweight fill and soil</td>
<td>Conductivity</td>
<td>1000 µs/cm</td>
<td></td>
</tr>
<tr>
<td>Reinforcement</td>
<td>COD</td>
<td>30 mg/l</td>
<td></td>
</tr>
<tr>
<td>Bridge abutments</td>
<td>Ammonia</td>
<td>0.5 mg/l</td>
<td></td>
</tr>
<tr>
<td>Drainage applications</td>
<td>Arsenic</td>
<td>10</td>
<td>A risk based approach will be adopted by the regulators. In general, the concentrations of contaminants should fall within the requirements of local regulatory guidance (EA, 2001). The limiting values provided are based upon those produced by the Environment Agency to determine acceptability of contaminated materials into unlined landfill sites.</td>
</tr>
<tr>
<td>In ground barriers</td>
<td>Cadmium</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Noise barriers</td>
<td>Chromium (total)</td>
<td>50</td>
<td>It is the leachable concentrations which will play a part in determining whether tyres prove suitable for use in future engineering applications. In addition, where the chemical analysis of a material falls below these thresholds, it can be reasonably assumed that the material will be suitable for the intended use and provide no risks to human health or the environment. However, this must be agreed with the regulator before any work takes place, and is subject to the current waste management licensing regime.</td>
</tr>
<tr>
<td>Thermal insulation</td>
<td>Lead (total)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Tyre products and surfacings</td>
<td>Mercury</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selenium</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boron</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nickel</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zinc</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyanide (free)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulfate (SO(_4))</td>
<td>150 mg/l</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulfide</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulfur (free)</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phenol</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chloride</td>
<td>200 mg/l</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PAH</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Erosion control (fluvial and marine)</td>
<td>As above (if necessary)</td>
<td>As above (if necessary)</td>
<td></td>
</tr>
<tr>
<td>Artificial reefs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Limiting values relate to the acceptable concentrations of materials into unlined landfill sites based upon the Environment Agency’s own internal guidance (Environment Agency, 2001).
Appendix 4: Definitions of terms used in the CWA (CEN, 2002)

The following definitions have been selected from the CWA (14243-2002) as particularly relevant to discussions on civil engineering:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient size reduction</td>
<td>Mechanical size reduction at or above ordinary room temperature.</td>
</tr>
<tr>
<td>Bale</td>
<td>Tyres which are compressed and secured.</td>
</tr>
<tr>
<td>Baling</td>
<td>A method of volume reduction whereby tyres are compressed into bales.</td>
</tr>
<tr>
<td>Bead</td>
<td>The part of the tyre that is made of high tensile steel wires wrapped in woven textile which are held by the plies, anchoring the part of the tyre which is shaped to fit the rim.</td>
</tr>
<tr>
<td>Buffings</td>
<td>Vulcanised rubber obtained from abrading a tyre during the process of removing the tread and/or sidewalls.</td>
</tr>
<tr>
<td>Chips</td>
<td>Mechanically fragmented, ripped or torn post-consumer tyres resulting in irregularly shaped post-consumer tyre pieces of approximately 10mm to 50mm in size.</td>
</tr>
<tr>
<td>Civil engineering applications</td>
<td>Use of whole, baled, cut, shredded, chipped, granulated or powdered tyres in construction projects.</td>
</tr>
<tr>
<td>Cryogenic size reduction</td>
<td>Technology at very low temperature using liquid nitrogen or commercial refrigerants to embrittle the rubber which is then processed to reduce it to a desired size.</td>
</tr>
<tr>
<td>Cuts</td>
<td>Mechanically fragmented, ripped or torn tyres resulting in irregularly formed pieces &gt;300mm.</td>
</tr>
<tr>
<td>Devulcanisates</td>
<td>The product of devulcanisation which results in the reduction of cross-links.</td>
</tr>
<tr>
<td>Devulcanisation</td>
<td>The treatment of rubber that results in the reduction of cross links.</td>
</tr>
<tr>
<td>End-of-life tyre</td>
<td>A tyre which has been permanently removed from a vehicle without the possibility of being remounted for further road-use.</td>
</tr>
<tr>
<td>Fine powders</td>
<td>The result of processing rubber to achieve finely dispersed particles of &lt;500mm including surface modified powders</td>
</tr>
<tr>
<td>Fines (carbon products)</td>
<td>Agglomerates, pellets or pellet fragments which pass through different standardised sieves.</td>
</tr>
<tr>
<td>Granulate</td>
<td>The result of processing rubber to reduce it in size into finely dispersed particles between approximately 1mm and 10mm.</td>
</tr>
<tr>
<td>Mixed car/truck tyres</td>
<td>An undefined inconsistent mix of car, truck and often utility tyres.</td>
</tr>
<tr>
<td>Other tyre</td>
<td>Includes tyres used by off-road agricultural vehicles, aircraft, among others.</td>
</tr>
<tr>
<td>Particle size</td>
<td>The size of individual granules or grains of material after processing expressed as a range of distribution of sizes.</td>
</tr>
<tr>
<td>Post-consumer tyre</td>
<td>A tyre which has been permanently removed from a vehicle without the possibility of being remounted for further road-use.</td>
</tr>
<tr>
<td>Powder</td>
<td>The result of processing rubber to achieve finely dispersed particles of under 1mm.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Purity</td>
<td>Freedom from foreign matter.</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>The thermal decomposition of rubber in the absence of oxygen which chemically breaks it into oil, gas, and char.</td>
</tr>
<tr>
<td>Rubber reclaim</td>
<td>Rubber produced by treating a vulcanisate in a manner to bring back some of its original characteristics.</td>
</tr>
<tr>
<td>Shred</td>
<td>The result of mechanical processes by which tyres are fragmented, ripped or torn into irregular pieces of ~50mm to ~300mm in any dimension.</td>
</tr>
<tr>
<td>Shredding</td>
<td>Any mechanical process by which tyres are fragmented, ripped or torn into irregular pieces of 50mm to 300mm in any dimension.</td>
</tr>
<tr>
<td>Sidewall</td>
<td>The outermost rubber to which the tread is vulcanised.</td>
</tr>
<tr>
<td>Surface modification</td>
<td>The result of treating the surface of granulates or powders to impart specific properties to the particle.</td>
</tr>
<tr>
<td>Toxicity Characteristics</td>
<td>A test used in the United States to determine the leaching levels of specified metals and organics.</td>
</tr>
<tr>
<td>Leaching Procedure (TCLP)</td>
<td></td>
</tr>
<tr>
<td>Tyre recycling</td>
<td>Any process by which post-consumer tyres or materials derived from post-consumer tyres are converted into useable material.</td>
</tr>
<tr>
<td>Whole tyre</td>
<td>An untreated tyre of which the principal parts are the casing, the cord, the bead and the tread which consist of elastomers, carbon black and silica, metal and fabric.</td>
</tr>
<tr>
<td>Whole tyre applications</td>
<td>Use of whole tyres without physical or chemical transformation to create such projects as artificial reefs, sound barriers, temporary roads, stabilisation, etc.</td>
</tr>
</tbody>
</table>
Appendix 5: Further information

Further information on the recycling and reuse of post-consumer tyres can be obtained from the following sources (not an exhaustive list). These will provide further links to other companies and organisations offering services within the post-consumer tyre sector:

**DTI Environment Department**

www.dti.gov.uk/sustainability/key.htm#
Paul Hallett, Sustainable Development
Department of Trade & Industry
Bay 426
151 Buckingham Palace Road
London, SW1W 9SS
Tel: 020 7215 1860

**Environment Agency**

www.environment-agency.gov.uk
Ralph Crouch, Waste Programme Manager
Rivers House
21 Park Square South, Leeds LS1 2QG
Tel 0113 231 2439 Fax 0113 231 2409

**Environment Council**

www.the-environment-council.org.uk
Sarah Graham; Dialogue Assistant
The Environment Council
212 High Holborn
London, WC1V 7BF
Tel: 020 7632 0140
e-mail: sarahg@envcouncil.org.uk

**European Tyre Recycling Association**

Dr. Valerie Shulman
7 Rue Leroux
Paris
France, 75116
Tel: 0033 1 45 00 3777
Fax: 0033 1 45 00 8347
e-mail: etra@euronet.be

**Used Tyre Working Group**

www.tyredisposal.co.uk