The Use of Post-Consumer Tyres in Civil Engineering

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ABSTRACT. The implementation of the Landfill Directive will result in the progressive banning of the disposal of tyres in landfills by 2006. However, recycled tyres are suitable for a wide range of applications in civil engineering. Their low density makes them suitable as lightweight fill in areas of soft ground and as backfill to retaining structures. They can be used in a variety of forms, including tyre bales, whole tyres, shred, chips and granulate, and in a variety of applications including lightweight fill, soil reinforcement, drainage, erosion control, landfill engineering, artificial reefs and use in asphalt and concrete. Many of these applications are common in various parts of the world, and they are being increasingly used in the UK, particularly in the form of tyre bales. Examples of the use of tyre bales in the UK are given and a new project to develop specifications for tyre bales is described.

Keywords: Tyres, Tyre bales, Recycling, Specifications, Road construction, Flood defence embankments

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INTRODUCTION

Post-consumer tyres are those which have been permanently removed from vehicles without the possibility of being remounted for further road use. Approximately 480,000 tonnes of post-consumer tyres arise each year in the UK [1]. Of these, it is estimated that about 60% were recovered, of which 25% were reused or retreaded, 22% were recycled, mostly as granulate, 8% sent for energy recovery and 3% used for landfill engineering. A total of 145,000 tonnes was disposed of to landfill, of which 57,000 tonnes were from shredding of end-of-life vehicles [1].

The Landfill (England & Wales) Regulations 2002 introduce new operating requirements for landfill sites, including a ban on the disposal of both whole and shredded tyres. From July 2003, in accordance with the Landfill Regulations, whole used tyres cannot be deposited at landfills for hazardous waste or at landfills permitted or licensed since July 2001. Because whole or shredded tyres are not inert, they cannot go to inert landfills. Shredded used tyres may be accepted at landfills until 16 July 2006 where the waste management licence or permit provides that they may be accepted. However, as tyres are not considered to be hazardous waste, a landfill for hazardous waste may not accept shredded used tyres after 16 July 2004.

In the light of these developments, there is a need to find alternative uses for post-consumer tyres. One area that is at present little used is in civil engineering. However, this is an area where a number of uses are possible, and examples are available from the UK and many other parts of the world. A guidance document has recently been produced to describe these applications and encourage their use [2]. This paper describes the engineering properties of tyres and gives an overview of their potential applications, with case studies from the UK, and describes a current project to produce specifications for the use of tyre bales. The emphasis is on unbound applications for shred, chips, whole tyres and tyre bales rather than the use of granulate in asphalt, concrete or other products.

MATERIALS

Post-consumer tyres have a number of properties that make them attractive for use in civil engineering. These include being lightweight, durable, inert and having good thermal insulation properties. Tyres can also be used in a number of forms, as whole tyres, tyre bales, or processed into shred, chips or granulate. An industry standard has been developed to provide a European system of reference for materials produced from post-consumer tyres based upon their physical properties [3]. The terminology used for the different size fractions is shown in Table 1.

The engineering properties depend to some extent on the fraction that is being used. Typical values for material from chips to bales are shown in Table 2. The main properties that are of interest for civil engineering are described below:

Lightweight: The compacted dry density of shredded tyres is about one third that of a typical soil [4]. This makes them attractive for use as a lightweight fill for embankment construction where the foundation soils are weak or compressible. Because of their low density, tyre shreds produce lower horizontal stress than normal soils. If used as backfill to retaining walls and abutments this reduces the earth pressure on the back of the structure, enabling the walls to be thinner.

Table 1 Terminology for different size fractions for post-consumer tyres

NAME FOR FRACTION	MINIMUM SIZE (mm)	MAXIMUM SIZE (mm)
Powder	0	1
Granulate	1	10
Buffings	0	40
Chips	10	50
Shreds (small)	40	75
Shreds (large	75	300
Cut	300	Half tyre
Whole tyre	-	-
Tyre bales	-	-

Hydraulic conductivity: Whole and shredded tyres have high hydraulic conductivity. This makes them suitable for drainage applications or where free-draining fill is required.

Durability: Tyres are inert materials. They are non-toxic, non-biodegradable and resistant to a wide variety of chemicals and climatic conditions.

Thermal resistivity: Thermal resistivity is around seven to eight times higher than for a typical granular soil [4]. Tyres are thus a suitable alternative for use as an insulating layer.

Table 2 Typical values of engineering properties of post-consumer tyres

PROPERTY	TYPICAL VALUES
Compacted density	600 - 700 kg/m^3
Angle of friction	19 - 26 degrees
Cohesion	1 - 5 kN/m^2
Compressibility	20 - 50 % (at 21 - 147 kN/m^2)
Hydraulic conductivity	1 x 10^{-2} - 1 x 10^{-3} m/s
Poisson's ratio	0.2 - 0.35
Resilient modulus	1 - 2 N/mm^2
Specific gravity	1.1 - 1.27 kg/m^3
Thermal conductivity	0.15 - 0.23 W/mK

WASTE MANAGEMENT LICENSING REGULATIONS

Although post-consumer tyres are suitable for a wide range of civil engineering applications, they are still regarded as waste under the UK Waste Management Licensing Regulations [5]. This means that a waste management license is required for all operations to transport, process and store tyres until they have been completely recovered. The point at which this occurs is subject to debate, but the view currently taken by the Environment Agency in England and Wales is that this does not occur until the material is incorporated into the final product: for granulate, this might be incorporation in asphalt in a road surface layer; for shred, whole tyres or tyre bales this might be until they are placed in their final position in a road, embankment or other structure.

Regulatory controls apply as long as a tyre is waste and the longer view of waste has wide-ranging implications for many of those currently involved in the treatment of used tyres, as traditionally they have not been subject to such controls. A working group, facilitated by the Environment Council under the Environment Agency's TyreWatch programme, has developed a case for exemptions from waste management regulatory requirements on the basis that regulation should be proportionate to the environmental risk posed by that activity [6].

APPLICATIONS

Tyres can be used in a number of ways in civil engineering including:

- Lightweight fill
- Backfill to structures
- Drainage for roads
- Landfill engineering
- Fluvial and coastal erosion control
- Artificial reefs
- Noise absorption bunds
- Insulating layers
- Absorption layers for hydrocarbons in ground remediation
- As a constituent in asphalt and concrete
- As a constituent in sport and safety surfaces
- As a constituent of building products

Examples and design guidance are given in [2]. Although the use of tyres has been demonstrated in civil engineering applications, such as repairs to slope failures on highways [7], for many years, most of these applications have only been used on a small scale in the UK to date. This may partly be because tyres are not included in most civil engineering specifications, such as the UK Specification for Highway Works [8]. Each application therefore has to be decided on a case-by-case basis, which causes delay and expense and acts as a disincentive. However, in North America a standard has been developed for the use of tyres in civil engineering by ASTM [9]. 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; and thermal insulation. The draft standard prEN 14243 [3] provides a means of standardising and testing tyres for civil engineering applications. A TRL project is currently underway to develop specifications for tyre bales; this project is described in more detail later in the paper.

Although applications are available for all the forms of post-consumer tyre listed in Table 1, tyre bales are a particularly attractive option for a number of reasons. They involve much less processing than the fractions where size reduction is required, such as shred and chips, and are hence much cheaper to produce. The plant used in their production is mobile, which reduces transport costs. Tyre bales are prepared from whole passenger car, utility or truck tyres, with about 125 passenger car/utility tyres compressed mechanically into bales approximately 0.75m x 1.50m x 1.25m. Each bale weighs approximately 1 tonne. The bales are each bound with five bands of galvanised steel. The lack of exposed steel, as in shred or chips, reduces the possibility of leaching of metals. Bales are adaptable to numerous applications, as a type of lightweight gabion, as shown by the following case studies.

Pevensey Beach Recharge

Pevensey Beach is a 9 km shingle embankment that protects 50 km^2 of the low-lying Pevensey Levels, 35 km^2 of which is a Site of Special Scientific Interest (SSSI). Major beach replenishment took place during the summer of 2002. However, littoral drift through Pevensey bay results in a net loss to the frontage of 20,000 m^3 per year. This amount has to be added annually by way of maintenance recharge to preserve the improved defences. This would normally require the import of large amounts of natural shingle to build up the beach to the required level. If some of the shingle could be replaced by other materials this would preserve scarce resources of this valuable natural material. If materials that would otherwise be waste, such as used tyres, can be used to replace the shingle this gives additional environmental benefits.

A trial was carried out in which 350 tyre bales were buried in the landward side of the beach in November 2002, generating shingle that could be used elsewhere on the beach. The performance of the tyres bales has been monitored over a year since construction. The trial was carried out as an awareness raising exercise of the potential uses of tyre bales in construction. It is partly funded by the Partners in Innovation programme run by the Department of Trade and Industry.

Tyres are generally inert and durable materials. However there are concerns that they could release contaminants adhering to them as a result of use on roads, and metals from the reinforcing cords within the tyres. To assess leaching, five groundwater sampling wells have been placed in and around the tyres bales. Zinc is used as the main indicator of tyre leaching. Monitoring will be continued for a year after construction and the results will be given in the final project report, due in 2005.

Unsurfaced Road, East Sussex

A 180 metre long section of an unsurfaced road through an area of soft ground in woodland near the Sussex Downs had developed deep ruts as a result of use by four-wheel drive vehicles and motorcycles. Normally this would have been repaired by excavating the rutted area and replacing the soil with free draining granular aggregate. As an alternative, the excavated soil was replaced by tyre bales, with a 150 mm layer of crushed natural stone to form the road surface. This resulted in savings of about 75% in the cost of materials and a significant reduction in the overall cost of the repair as well as avoiding the use of natural aggregate.

The use of tyre bales avoided the use of natural aggregates and required less construction traffic, as the equivalent volume of stone would have weighed a great deal more and required more lorries to bring it to site. The site is in an Area of Outstanding Natural Beauty (AONB) and limiting the amount of construction traffic was an important consideration in the choice of repair method. The lightweight nature of the tyre bales is a considerable advantage for placing in soft ground, as it imposes much less load on the underlying soil than natural aggregate would. The density of the tyre bales is approximately 0.7 tonnes/m^3, about one third that of natural aggregate.

Landfill Site Haul Road, Fochabers

The Nether Dallachy landfill site at Fochabers is located at a former sand and gravel quarry near the Moray Firth. The site is subject to flooding in the winter due to seasonal variation in the ground water level. An extension to the existing haul road was required to service a new landfill cell.

The majority of the new road utilises cobbles from the sand and gravel quarry for general fill and unbound sub-base. The project aimed to investigate how other materials could be utilised for these applications. The replacement material had to provide a robust alternative. Tyre bales were chosen as a test material due to the ban of whole tyres from landfill and availability from a local source. The use tyre bales also had the advantage of giving an overall cost saving to the project.

The total length of the road construction was 200 m. Two trial sections 16 and 18 m in length were constructed using tyre blocks. The rest of the road was constructed using cobbles. The road is used by 30 to 40 vehicles/day, with gross weights ranging from 10 to 40 tonnes. The access road will be in use for 1.5 years, the trial areas will then be deconstructed to allow construction of the next landfill phase.

The tyre blocks have proved fit for use in this situation as they are free draining and can therefore cope with the frequent flooding that the landfill site experiences. The road has now been in place for over one year and has been monitored for signs of potholing, cracking and settlement. No evidence of failure has been observed and the areas of road constructed with tyre bales are performing equally with those constructed using cobbles.

The road has been constructed so that the edges of the tyre blocks project from the shoulder to allow observation of the blocks as vehicles pass, and a shallow bund has been constructed to collect water running off from the tyres. This area is being observed for visual signs of pollution. If any are seen the water can be sampled for pollution. To date no visual signs of pollution have been observed.

Road Embankment over Peat, Sutherland

The B871 road in Central Sutherland between Kinbrace on the A897 and Syre at the junction with the B873 is typical of the types of lightly trafficked road found in much of the Highlands. Despite its low traffic levels it provides a vital link for isolated communities and is constructed across an area of soft peat. In 2002 settlement had become evident along its length. At Loch Rosail the pavement surface had settled to the extent that it was located below the ground water table and was frequently covered with water to a depth of 0.2 m.

The Forestry Commission planted two large conifer forests near the B871 in the 1950s, due to mature in the late 1990s. However, given the condition of the B871 road it was deemed unlikely that it would be economic to get the timber to market. However strenuous efforts by the Highland Council and the Forestry Commission led to an agreement that the timber would be transported along the B871 to Kinbrace.

Detailed studies of the B871 also identified that the Loch Rosail road required urgent treatment before being exposed to the substantial increase in heavy traffic due to timber extraction vehicles. A 100 m section was selected for reconstruction with the central 55 m section being constructed using tyre bales.

Construction of the tyre bale embankment took place during a two week period in December 2002. The construction sequence was important to the successful installation of the tyre bales and involved excavation to 1500 mm below existing road level, then placing the geosynthetic and the first layer of bales. At this stage the gaps between the bales and the accessible voids in the bales were filled with lightweight fill. The second layer of bales and lightweight fill was then placed before the geosynthetic was wrapped around the entire assembly and a 250 mm layer of fine rockfill was placed to create a working platform. A nominal layer of welded reinforcing mesh (8 mm bars at 200 mm centre-to-centre spacings) was included in this layer to provide additional stiffness, following common practice in Finland. These operations were carried out in 5 m long bays, such that each complete bay created a secure working platform from which the next could be constructed.

A 100 mm layer of primary Type 1 sub-base was compacted on top of the fine rockfill layer to provide a running surface to the road that was then opened to traffic. After three months some loosening of the Type 1 sub-base surface was observed and a 50 mm layer of fine sand and gravel was added using a paving machine to provide better interlock at the surface. This enabled the timber extraction traffic to commence in that month. To further bind and waterproof the surface, two layers of surface dressing were applied in July 2003, comprising 10 mm chippings and 2 litres/m^2 of bitumen spray on each layer.

Monitoring indicated that maximum settlements were 200 mm and 450 mm either side of the road during the first ten months of opening. However, most (in excess of 75%) of this settlement occurred in the first four months after opening to traffic. The rates of settlement are now such that cumulative settlements over the next year are anticipated to be a maximum of 150 mm. In reality these are likely to be considerably less due to further decreases in the rate of settlement. Of the gross settlements between 0 and 10 mm is attributed to compression of the lower tyre bale layer.

SPECIFICATIONS FOR TYRE BALES

The baling of tyres to form blocks for use in construction represents not so much a means of disposal as a means of creating a valuable commodity. However, at present tyre bales are generally being used in informal civil engineering applications (e.g., small erosion protection projects) and also in landfill construction where innovation is less constrained than in other sectors of the construction industry. The project on the B871 and described above is something of an exception to this rule.

Applications in other sectors of the civil engineering industry require a greater degree of design and specification, and a greater consideration of the design life of the completed construction. Experience strongly suggests that without formal design procedures and specifications, consultants and other designers will not use tyre bales in more critical, higher value applications.

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Thus, further information in a simple and easily usable format is required to allow the application of tyre bales to higher value applications. A project is currently underway to develop specifications and design methods for tyre bale applications in civil engineering. The work is funded by Onyx Environmental Trust, Inverness & Nairn Enterprise and the Scottish Executive.

CONCLUSIONS

The case studies illustrate some of the uses to which tyre bales can be put. As shown by their properties and the range of fractions in which post-consumer tyres are available, there is a wide range of options for their use in construction. Developing specifications for these uses and resolving the waste/product issue will be important in unlocking this potential. Recent guidance documents and standards are helpful steps in this direction and should encourage greater use of tyres in civil engineering.

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