CIP Eco-innovation
Pilot and market replication projects
Call 2008

Agreement Number- ECO/08/239011/SI2.535202

RECTYRE

USED TYRES VALORISATION AS LIGHTWEIGHT FILLER FOR EMBANKMENTS

D2.2. Barriers Analysis and Solutions

Due date : 30/04/2010
Actual submission date : 12/05/2010

Start date of the project: 01/06/2009 **Duration: 24 Months**

Lead contractor for this deliverable: SOLINTEL

Revision: FINAL

Project funded by the Executive Agency for Competitiveness and Innovation (2009-2011)		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Deliverable Administration & Summary	**RECTYRED 2.2**			
No & name	**D2.2. Barrier Analysis and Solutions**			
Status	<~~Draft / Working~~ / Released>	**Due**		**Date** 12/05/2010
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Document history

Version	**Date**	**Editor**	**Description**
V0	23/04/2010	J. Antonio Barona B.	Barriers Analysis and Solutions

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EXECUTIVE SUMMARY

This document is the contractual deliverable “D.2.2 – Barrier Analysis and Solutions”.

This project aims to contribute to reduce the impact of tyres wastes treatment using scraped tyres as filler for road embankments. The result is a new lightweight, environmental friendly, filler for road embankments that avoids the demand of foreign soil in the case of the presence of clays or non suitable soil for road construction on work sites.

Nowadays there is clearly defined barrier that makes difficult the implementation of the proposed technology. There is a gap between different key actors, from production transformers or recyclers, through gatherers or final users. This problem is even greater if we are talking about different countries. The way each Member State implements the ELV is different, making it more difficult to establish trans-boundary networks. Also, there are several technical and environmental barriers that prevent the optimal execution of the embankment.

The deliverable “D.2.2 – Barrier Analysis and Solutions” is related to the Task 2.2 Previous results and Barriers detected, which is part of the WP2 Definition of Transferable knowledge performed by Acciona and supported by the rest of the RECTYRE partners. In this WP2, the results of the experience gathered by ACCIONA, through the implementation of a new embankment design based on the use of used tyres as lightweight filler, will be analysed in order to detect the barriers of this technology and propose solutions. The objective of Task 2.2 is to analyse the main problems found during the development of previous experiences, paying special attention to technical and environmental aspects.

1. INTRODUCTION

Tyre shreds have a potential as road construction material (Figure 1). However, there are three major concerns that need to be further investigated before it can be used as a conventional road building material, namely design properties, environmental aspects and accessibility of material.

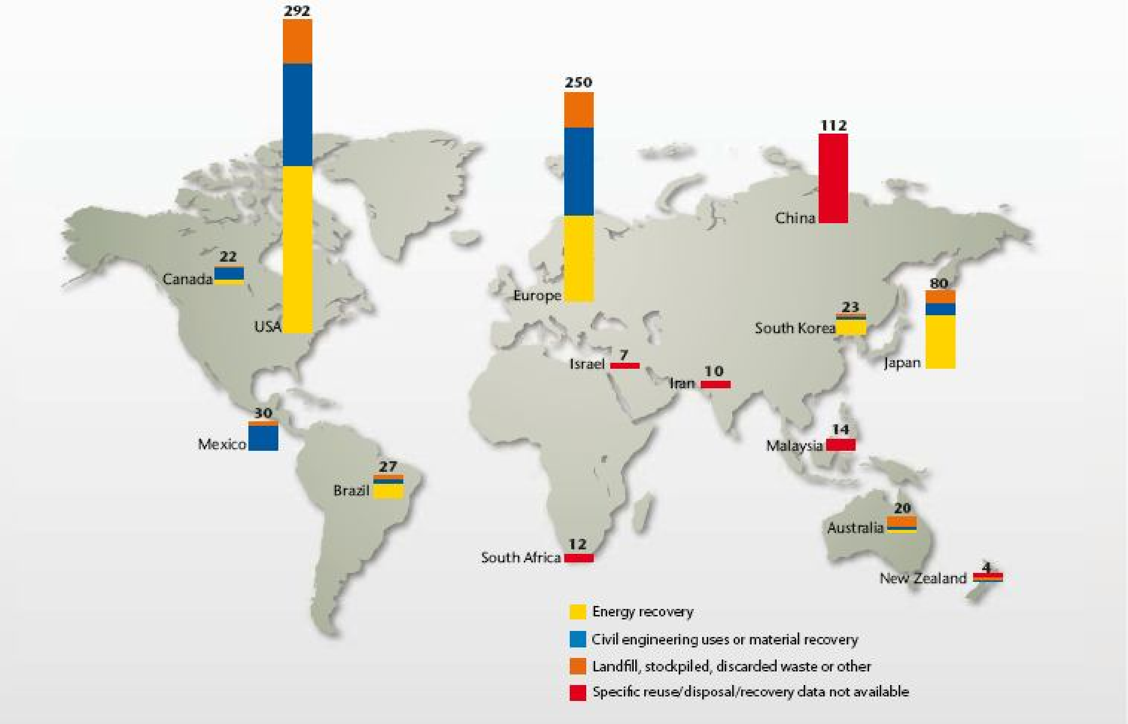

Figure 1 Millions of end-of-life tires generated each year

To be able to make a satisfying design of a road construction there is a need both for methods for accurate determination of material properties and for better theoretical models to predict the behaviour of the construction. Methods used to determine technical properties of tyre shreds origins from geotechnical testing methods. The main problems in using these methods for tyre shreds are the large particle sizes, protruding steel cord and the high elasticity of the material. Reported values of properties like shear strength and elastic modulus ranges by a factor of 1.5 to 2 depending on used method. This indicates that there is a need to develop more specific testing methods, and perhaps new criteria for example for definition of failure. The non-linear elastic (and possibly plastic) behaviour of tyre shreds implies the need for appropriate constitutive models to be used in design. There is also a lack of knowledge about the interaction between tyre shreds and other materials in layered constructions like a road construction.

Because of the content of potential hazardous compounds it is necessary to take precautions when using tyre shreds, even if there has not yet been reported negative environmental effects due to use of tyre shreds in road constructions. In sensitive environments and where aesthetic values are important tyre shreds should not be used due to rust precipitation, unless protruding steel is controlled.

When using tyre shreds in road constructions large amounts of tyres are consumed. Therefore the collecting chain of used tyres is important when planning a construction project. Due to potential supply problems tyre shreds are probably more suitable in minor projects.

Today there exist data describing the technical properties of tyre shreds. However, some of these properties need to be further investigated, e.g. the shear strength. The design methods used today are not directly applicable on the non-linear elastic (and plastic) behaviour that tyre shreds show. Therefore the results from the design conducted in the studies must be considered with caution.

Based on the experience of the constructed test road, handling, spreading and compacting tyre shreds is easy with conventional machinery. However, tyre shreds in the field requires special care compared using conventional material since it is necessary to minimise the amount of traffic directly on uncovered tyre shreds, due to risk of punctures. It is also some difficulties in predicting final density after compaction and construction of the upper layers due to the elastic behaviour of tyre shreds. Quality control of the tyre shreds is very important. Depending on used shredders during the cutting process the sizes, shapes and amount of free steel cords varies.

It is important to control the density obtained after extending the tyre shreds, and trying to improve the process by compacting in more high layers. In the ACCIONA experiences, the maximum layer height for compaction was 60 cm, but it is important to know if it is possible to obtain the same density in layers with 100 cm height and the same number of passes.

2. DETECTED BARRIERS (TECHNICAL & ENVIRONMENTAL)

During the execution of the two embankment experiences (Figure 2) with tyre shreds ACCIONA has detected the following technical barriers:

1. Compaction analysis: nowadays there is no in situ technique to measure density during the execution of the embankment.
2. Geotextile installation, with risk of puncture.
3. Supply and transportation of tyre shreds.
4. Obtaining the material with the appropriate requirements.
5. Quality control of tyre shreds in site execution.
6. Stockpile shreds control in site.

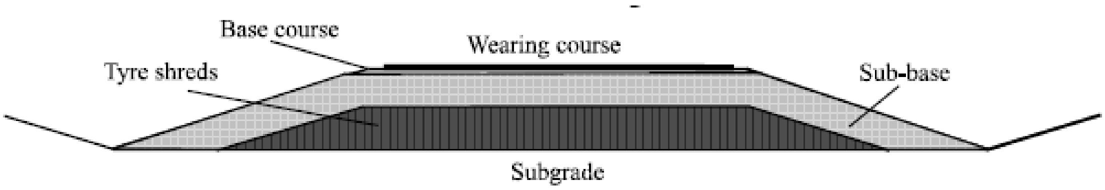

Figure 2 Embankment with tyre shreds

Possible environmental barriers to analyse:

1. CO_2 consumed in transportation
2. LCA of tyre shreds

Table 1 includes main advantages and disadvantages of using tyre shreds as lightweight material:

Advantages	Disadvantages
Low Density	Density depending on confining pressure
Sink when place in water	Dificult to predict density (compaction)
Cheap	Needs stiff superstructure
Replace virgin materials	Environmental limitations

Table 1 Advantages and disadvantages of using tyre shreds as lightweight material

3. BARRIERS ANALYSIS

3.1 Compaction Analysis

Compaction of soils is one of methods of soil stabilization. Principal purposes of compaction of fill materials are:

1) Increasing stiffness, to minimize settlements during and after construction,
2) Increasing strength, to prevent sliding shear failure of embankment, and
3) Making water tight, to obtain required imperviousness of the core zone

Shredded scrap tires are easy to compact and are very lightweight with a density of 384 to 529 kilograms per cubic meter (kcm) in haul trucks. They have a compacted density of around 721 kcm (a little less than half the weight of ordinary compacted soil) before being surcharged with soil, the pavement structure, and traffic. The maximum density of the shredded tire fill after completion of the pavement structure and several months of traffic is approximately 833 kcm. Vibratory compaction equipment does not work well with shredded tires because the material tends to "bounce" rather than compact. One successful compacting technique is to place approximately three feet of loose tire shreds and then compact with three "full coverage" passes of a D-8 or equivalent bulldozer.

A common way to describe compaction work has its origin from Proctor compaction. The method is used for granular materials like soils to find the optimum water content resulting in maximum dry density at given compaction work. Laboratory compaction of tyre materials using the Proctor method has been done by Cecich[1] et al. (1996) and Bosscher[2] et al. (1997) among others. After Proctor compaction the range of dry density varies in the ranges of 594-684 kg/m^3, for the studied references.

In field applications there are different opinions about the impact of using vibrating equipment compared with static. Humphrey and Nickels [3] (1997) evaluated the effect of different compaction equipment in a field study of a

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[1] Cecich, V., Gonzales, L., Hoisaeter, A., Williams, J., and Reddy, K. (1996). “Use of Tires as Lightweight Backfill Material for Retaining Structures.” *Waste Management & Research*, 14, 433-451.

[2] Bosscher, P. J., Edil, T. B., and Kuraoka, S. (1997). “Design of highway embankments using tire chips.” *J. Geotechnical and Geoenvironmental Engineering*, 123(4), 295-304.

[3] Humphrey, D. N., and Nickels, W. L. (1997). “Effect of tire chips as lightweight fill on pavement performance”, Proc. XIV international conference on soil mechanics and foundation engineering, Balkema, Rotterdam.

light-weight application with tyre shreds. Measurements showed that smooth drum or tamping foot vibratory rollers with a static weight of 9 tons and a track mounted bulldozer with a constant pressure of 59 kPa were all equally effective. But a loaded 11 m^3 dual rear axle dump truck proved to be ineffective since its tyre sank deeply into the tyre shreds and fluffed up the tyre shreds rather than compacting them. So, the conclusion is that densification of tyre shreds best is achieved by application by pressure rather than vibrations. Also, the compaction and high overburden pressure might cause large-size tyre shreds to rearrange and form a layered structure.

Compaction of shredded tyres does not follow Proctor´s moisture-density relationship. This behaviour may result from the non-existence of pore water to form the liquid film around the shreds. It makes conventional density controls, such as relative compaction, inapplicable for evaluating tyre shreds in field constructions. This may imply that some other means needs to be used to control the field density of tyre shreds during construction.

In general, the factors affecting compaction of tyre shreds are: compaction methods, tyre chip sizes, lift thickness, chip/soil ratio (if used as a mix) and in laboratory testing the size of compaction mould. There are no investigation found that studies the compaction impact of lift thickness.

Edil and Bosscher [4] (1992) recommend that optimum compaction effort should be determined on test section in field for the actual material under actual conditions. Cosentino[5] et al. (1995) suggests that compacted density in field could be determined by the volume change method. Theoretically, the compacted density is equal to the initial density (bulk unit weight) multiplied by the change ratio of volume induced by compaction.

That is:

$$\rho_c = \rho \times \frac{V_0}{V_c} = \rho \frac{H_0}{H_c} \qquad [\mathrm{t/m^3}]$$

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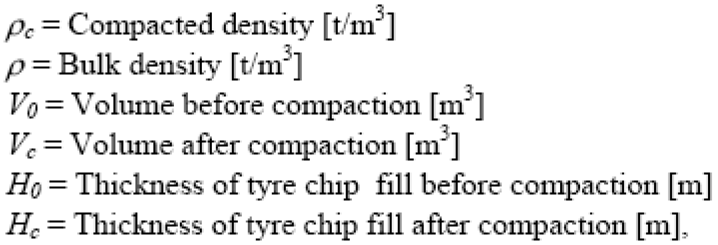
[4] Edil, T. B. and Bosscher, P. J. (1992). Development of Engineering Criteria for Shredded or Whole Tires in Highway Applications. Report No. WI 14-92, Department of Civil and Environmental Engineering, University of Wisconsin, Madison.

[5] Cosentino, P.J., Kalajjan, E.H., Shieh, C-S. and Heck, H.H. (1995). Developing Specifications for waste glass, municipal waste, combustor ash and waste tires as highway fill materials. Volume 3 of 3 (Waste tires), Report No. FL/DOT/RMC/06650-7754, Florida Department of Transportation, Tallahassee



ρ_c = Compacted density [t/m^3]
ρ = Bulk density [t/m^3]
V_0 = Volume before compaction [m^3]
V_c = Volume after compaction [m^3]
H_0 = Thickness of tyre chip fill before compaction [m]
H_c = Thickness of tyre chip fill after compaction [m],

Where ϱ_c is the compacted density of concern, ϱ is the initial bulk density and V_0/ V_c is the volume change ratio after compaction. Since the change of layer thickness is induced by compaction, the ratio f initial height and the compacted height, H_0/ H_c, can be used instead of the volume ratio.

The dry densities achieved in compaction tests, i.e. proctor tests, are in most cases not the final density in field applications since the elasticity of the material will decrease the volume resulting in increase in density when tyre shreds compresses under load. Achieving a high dry density by compaction effort decreases the settlements in a tyre shred fill.

3.2 Geotextile Installation

First of all, materials used for geotextile installation must meet the following requirements.

- The fibres of the geotextile and thread used in joining lengths shall consist of long chain synthetic polymers composed of at least 95% by mass of polyolefins or polyesters.
- The geotextile filaments shall be rot-proof, chemically stable and shall have low water absorbency. Filaments shall resist delamination and maintain their relative dimensional stability in the geotextile.
- Non-woven geotextiles shall have filaments bonded by needle punching, heat or chemical bonding processes.
- Woven geotextiles shall have filaments interlaced in two sets, mutually at right angles. One set shall be parallel to the longitudinal direction of the geotextile.
- Geotextiles shall be free of any flaws which may have an adverse effect on the physical and mechanical properties of the geotextile.
- Geotextiles shall be stabilised against ultraviolet radiation such that when tested they shall have retained strength of at least 50% after 672 hours of test exposure. A certificate not more than 1 year old shall be provided by the manufacturer.

In order to have a previous assessment of geotextile durability several concepts must be taken into account. Exposure to sunlight degrades the physical properties of polymers. The rate of degradation is reduced by the addition of carbon black but not eliminated. Hot asphalt can approach the melting point of some polymers. Polymer materials become brittle in very cold temperatures. Chemicals in the groundwater can react with polymers. All polymers gain water with time if water is present. High pH water can be harsh on polyesters while low pH water can be harsh on polyamides. Where a chemically unusual environment exists, laboratory test data on effects of exposure of the geotextile to this environment should be sought.

Experience with geotextiles in place spans only about 30 years. All of these factors should be considered in selecting or specifying acceptable geotextile materials. Where long duration integrity of the material is critical to life safety and where the in-place material cannot easily be periodically inspected or easily replaced if it should become degraded (for example filtration and/or drainage functions within an earth dam), current practice is to use only geologic materials (which are orders of magnitude more resistant to these weathering effects than polyesters).

Another important factor is the placement. Pinning the geotextile with long nail-like pins placed through the geotextile into the soil has been a common method of securing the geotextile until the other components of the drain have been placed; however, in some applications, this method has created problems.

According to the Department of Transport and Main Roads from Queensland Government[6] (USA), the Elongation to differentiate woven from non-woven geotextiles shall be the % CBR (California Bearing ratio) elongation at puncture corresponding to maximum puncture strength determined in accordance with AS 3706.4.

In general, woven geotextiles will puncture at elongations less than 30% and non-woven geotextiles will puncture at elongations equal to or greater than 30%.

The geotextile use in the sites built by ACCIONA had the following characteristics:

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[6] "Main Roads technical Standards (MRTS27)". Geotextiles (Separation and Filtration). Jun 09. Queensland Government (USA)

CHARACTERISTICS	UD	PG3
Geotextile kind		
Deformation energy (e)	kN/m	≥ 6.4
Straint at failure (ε_r)	%	
Tensile strenght (R_T)	kN/m	≥ 16
Dynamic Perforation Resistence	mm	≤ 20
Type		0

3.3 Supply and transportation of tyre shreds.

Tyre shreds are fragmented end-of-life tyres, mainly from passenger cars but also from heavy vehicles. The fragmentation is performed by a shredder. Primarily tyres are shredded for volume reduction before transportation to recovery or disposal processes. The size of the individual shreds is controlled by sieving and re-shredding of coarse shreds. The first pass results in 100-300 mm large tyre shreds, the second pass results in 100-150 mm and finer tyre shreds are re-processed until the material passes the desired sieve size. The result is disc shaped tyre shreds with protruding steel cord. Smaller tyre shreds have relatively more protruding steel cord compared to coarser fractions, figure 3.

Figure 3 Fragmentation of tyre shreds

When using tyre shreds in road constructions large amounts of tyres are consumed. One cubic metre of compacted tyre fill consists of approximately 100 used tyres. To supply a major road building project with tyre shreds some logistic effort needs to be done since the available amount of tyres is limited and the tyres must be properly processed. For example, in Sweden, the available amount of used tyres is about 60.000[7] tons per year. This corresponds to about 75 000-85 000 m^3 in road applications. This is enough to build 16 to 19 km of a road. Therefore the collecting chain of used tyres is important when planning a construction project. Due to potential supply problems tyre shreds are probably more suitable in minor projects.

The economical aspects of the use of recycled materials are more complex than for common construction materials. Instead of only a production cost, a disposal cost must be included into the analysis if the material is not used in construction. The accessibility of material is independent of the potential market of tyre shreds and the volumes are limited to the exchange of the tyres on the car stock. In a developed country the end-of-life tyres arise geographically distributed, reflecting the population density. From an economical point of view smaller projects are thus favorable since the construction material need can be provided with minimum transportation costs.

3.4 Appropriate requirements of materials.

Technical properties, i.e. engineering properties, have mainly been investigated by using geotechnical engineering testing methods. There are some important basic differences between soil material and tyre shreds that must be considered. Individual tyre shreds are in general larger than maximum allowed sizes in standard geotechnical tests, the compressibility of tyre shreds is larger resulting in deformations out of range of standardized test methods and protruding steel cord may cause puncturing of membranes used in e.g. triaxial tests etc.

Compared to soil materials, tyre shreds show low bulk density, high permeability, low thermal conductivity and high friction angle. These properties are useful in construction works to solve problems associated with e.g. settlements of soft soils, frost penetration and heave, and drainage. Tyre shreds may be used as an alternative to other industrial products.

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[7] “LCA of the utilisation of used tyres”. IVL Swedish Environmental Research Institute Ltd

There are some aspects of the tyre material that need to be mastered in order to fully benefit the useful properties. Examples of these are the high compressibility, creep and low stiffness.

The laboratory studies of the effect of compaction energy on compressibility show that, in spite of results in previous studies, high compaction energy is useful to reduce the compressibility at low stress intervals. At higher stresses a limit void ratio is reached independently of initial applied compaction energy.

The experiences of design with tyre shreds in civil engineering constructions show that most concepts used for design of soil materials works satisfactory, e.g. compression prediction. There are, however, some properties that need to be especially considered. The long-term creep could cause deformation problems. Empirical guidelines is recommended to use for bearing capacity in road constructions since the experience of choosing a resilient modulus in the pavement design models is still limited. Empirical stiffness modulus works, but has limited physical meaning and there are uncertainties of the valid stress intervals for these parameters.

There are several examples of successful use of tyre shreds in construction works, e.g. frost insulation in roads, drainage layer in landfills and trotting tracks. In general the same construction methods used for conventional materials such as soil and crushed rock is applicable on tyre shreds which are beneficial in a practical and economical point of view. Additional concern during the construction phase is to avoid flattening of tyre on construction vehicles, preferable solved by using caterpillar treads on the machinery equipment. Logistics have to be considered concerning distributing the material and create drivable surface for wheel tracked construction equipment during the handling phase. This is important for a rational and economic success.

Frozen conditions are known to affect soil materials and results generally in increased stiffness. Considering the nature of the material and field observations during standard field tests the material properties, e.g. compression behaviour and stiffness, is not expected to be affected in an extent that needs to be specially considered. In a conventional road the bearing capacity during the frozen season increases temporarily. This effect is reduced if tyre shreds are used as capping layer. On the other hand, during thaw the bearing capacity of a road with a layer of tyre shreds is possibly not decreased as much as in a conventional road structures. The reason is that tyre shreds function well as drainage material due to its high porosity which improves drainage during thaw.

For all new materials durability is a key question. Used as construction material, tyre shreds are protected against key degradable factors such as UV-radiation and oxidation due to its placement in the construction. Investigations on old rubber show that the material remains intact even after long periods in oxidising environments. Biodegradation has been proven in laboratory environment to be limited and old tyre material shows no signs of biodegradation. If the measured affected layer on 40 year old tyre material from an oxidising environment is used as a measurement and by assuming the degradation rate to be constant, the chemical degradation rate is equivalent to 1.25 µm/yr. This is equivalent to 1 mm degradation of the surface in 4000 years, which would be sufficient even for long term constructions such as drainage systems in landfill constructions.

3.5 Quality control of tyre shreds in site execution.

Based on the experience of the constructed test road, handling, spreading and compacting tyre shreds is easy with conventional machinery. The tyre shreds could be filled up and compacted in several lifts to full height without sidewall support. However, at the construction site tyre shreds requires special consideration compared using conventional material since it is necessary to minimize the amount of traffic directly on uncovered tyre shreds, due to risk of punctures.

It is also some difficulties in predicting final layer thickness after compaction and construction of the upper layers due to the low stiffness of tyre shreds. Unloading tyre shreds on the construction site from vehicles results in minor rust dust release. It is showed in compression tests that tyre shreds increases in stiffness as the vertical stress increases also at lower stresses, e.g. Edeskär and Westerberg 2006[8].

If the superstructure above a tyre shred capping layer contains of lighter materials such as air blast furnace slag there is a need to compensate in thickness for the lost in weight. Initial compression caused by the load of the finished construction and creep deformations is usually of the same magnitude

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[8] Edeskär, T. and Westerberg, B. (2006). “Effect of compaction work on compressibility of tyre shreds.” J. Geotechnical and Geoenvironmental Engineering, ASCE. (Submitted)

in most of previous studies (Tanska[9] et al. 2000; Vallila and Uotinen[10] 2000). Commonly, it is not possible to clearly separate the total initial compression from creep deformations since the construction is performed in several phases with a long period of time in between the construction phases. The tendency after the construction is completed is declining creep deformations in the tyre shred layer.

From the temperature distributions and the registration of the freezing front in most of studies developed until the moment, it is showed that the tyre shreds has a good thermal insulation performance. The high drainage capability of tyre shreds may contribute to increased bearing capacity in thawing periods by draining the superstructure and subgrade surface from excess water.

3.6 Stockpile shreds control in site.

End-of-life tyres have become a voluminous problem. Besides the on-going generation of new end-of-life tyres there are in many countries historical stockpiles that need to be taken care of in order to reduce the risk of fire and environmental concern from leachate in stockpiles. Over the last 15 years recovery rates for ELTs have dramatically increased in Europe, Japan and the US. Japan started recycling programs even earlier. In Figure 4 it is shown the recovered end-of-life tyres, including historical recovery rates[11].

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[9] Tanska, H., Länsivaara, T., Forsman, J. and Talola, M. (2000). ”Large size tyre chips in structures submitted to traffic loads”, Int. conf. on practical applications in environmental geotechnology 2000, VTT, Helsinki, 167-172.

[10] Vallila, E. and Uotinen, V-M. (2000). “Case study of using shredded tires in a road structure (local road 11863 Ilola-Sannainen pilot structure).” Int. conf. on practical applications in environmental geotechnology 2000, VTT, Helsinki, 197-204.

[11] Sources: Estimates based on data from European Tyre & Rubber Manufacturers’ Association, Rubber Manufacturers Association and Japan Automobile Tyre Manufacturers Association Inc.

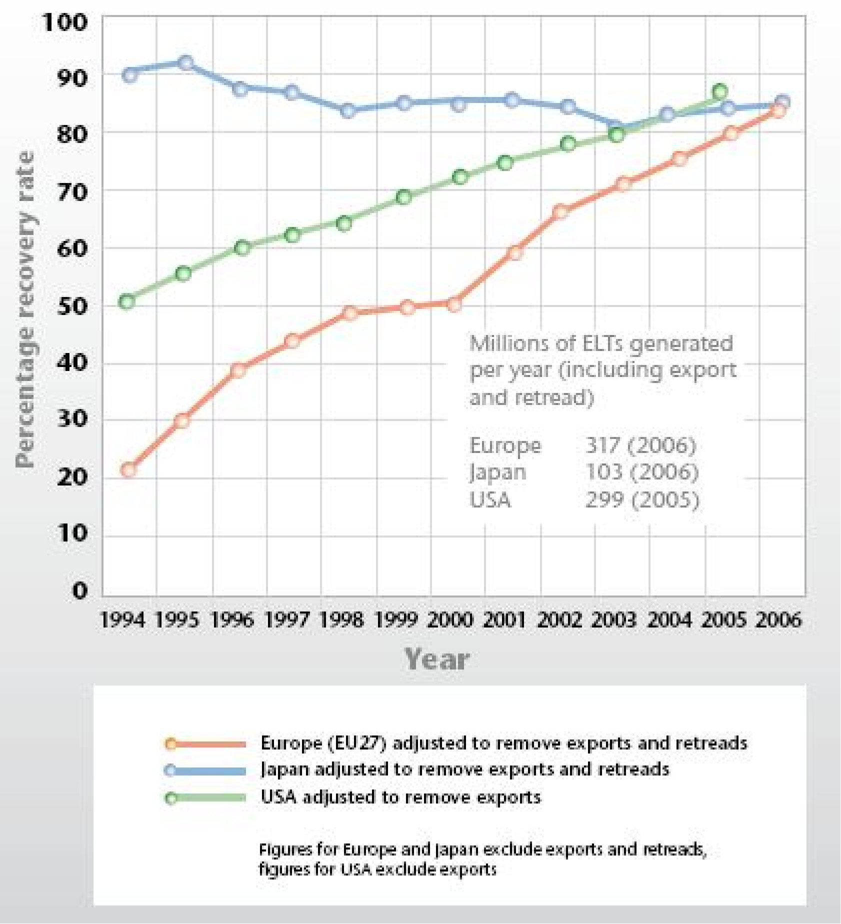

Figure 4 Recovered ELV tyres

Stockpiles of scrap tires are serious fire hazard, public health hazard, and an environmental burden. The construction of road embankments, using tire shreds as a lightweight fill, can consume large quantities of scrap tires and has certain engineering benefits. Waste tires are an ecological and financial burden in many regions of the world. In Canada and the United States, it is assumed that an equivalent of one waste tire per capita is discarded annually. Two of the most pressing environmental and health hazards related to the tire stockpiles are the catastrophic fires and insect breeding. Scrap tires are serious fire hazards, which pollute the air with large quantities of smoke, hydrocarbons, and residue. A discarded tire has 75%[12] void space hence, the tire fires are virtually impossible to extinguish once started.

The tire pile fires are dangerous and highly polluting and the clean up after wards is very expensive. In addition to the fire hazard, pools of water retained by whole or shredded waste tires create an ideal breeding ground for

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[12] “Markets for Scrap Tires” United States Environmental Protection Agency.

mosquitoes, which were shown to spread various dangerous diseases (Engstrom and Lamb[13], 1994)

Also, there have been cases where shreds which had been accepted were contaminated by the relocation or loading operation to the point where they were no longer acceptable. There have also been cases where tire shreds being delivered were contaminated by trash remaining in the truck from a previous hauling operation.

3.7 CO_2 consumed in transportation.

The characteristics of tyre shreds are well documented and do not vary significantly with season or location in terms of material content, contaminant levels, heating value, etc. This is a result of the distributed nature of the shredder businesses as well as the broad spectrum of tyre wastes accepted and the common tyre recovery systems used.

For most of developed studies it was assumed that there are no temporal and geographical differences in tyre shreds composition to consider. Tyre shreds composition differences would likely only result in different relative proportions of products recovered for a given alternative management method. While the net volumes may change with time, the characteristics of separated or processed streams are assumed to consistently meet market requirements.

The fact that the majority of Tyre shreds are generated near large population centers will lead to transportation impacts for the shipment to recovery plants which are often located in rural areas. It is assumed that recovered secondary materials and products will compete in local markets.

A landfill site operator from the USA, Credential Environmental Ltd, has developed a study about the economic and environmental appraisal of Used Tyre Derived Aggregate Replacements[14] (UTDAR) for use in landfill engineering. In this study, at the reference site primary aggregate would have been sourced from a minimum of 88.5 km from the site, whereas the UTDAR could be delivered from a distance of only 48.3km. The result is that associated vehicle movements are reduced by up to one half when UTDAR is used as a

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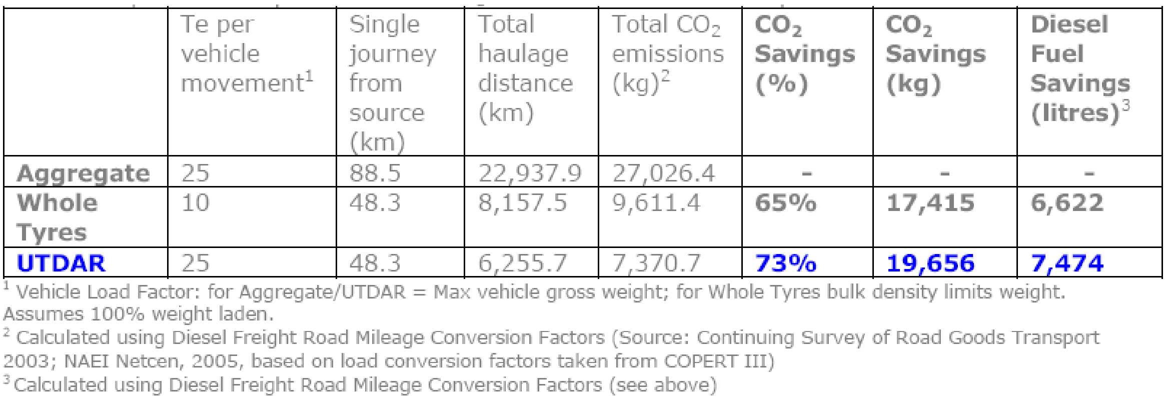
[13] Engstrom, G.M., Lamb, R. (1994). Using shredded Waste Tires as a Lightweight Fill Material for Road Subgrades. Minnesota Department of Transportation, Report MN/RD - 94/10, Maplewood.

[14] “An Economic and Environmental Appraisal of Used Tyre Derived Aggregate Replacements for use in landfill engineering”. Credential Environmental Ltd.

substitute material. Table 2 summarizes the economic and environmental implications of this reduced haulage. Since the transportation of whole tyres is affected by the bulk density, use of UTDAR produces the most significant savings in CO_2 and fuel, although both produce savings when compared with primary aggregate.



	Te per vehicle movement[1]	Single journey from source (km)	Total haulage distance (km)	Total CO_2 emissions (kg)[2]	**CO_2 Savings (%)**	**CO_2 Savings (kg)**	**Diesel Fuel Savings (litres)[3]**
Aggregate	25	88.5	22,937.9	27,026.4	-	-	-
Whole Tyres	10	48.3	8,157.5	9,611.4	**65%**	**17,415**	**6,622**
UTDAR	25	48.3	6,255.7	7,370.7	**73%**	**19,656**	**7,474**

[1] Vehicle Load Factor: for Aggregate/UTDAR = Max vehicle gross weight; for Whole Tyres bulk density limits weight. Assumes 100% weight laden.

[2] Calculated using Diesel Freight Road Mileage Conversion Factors (Source: Continuing Survey of Road Goods Transport 2003; NAEI Netcen, 2005, based on load conversion factors taken from COPERT III)

[3] Calculated using Diesel Freight Road Mileage Conversion Factors (see above)

Table 2 Economical and Environmental implications of the reduced haulage.

3.8 LCA of tyre shreds.

A life cycle analysis consists of a large number of environmental parameters, e.g. natural resources such as crude oil, natural gas, uranium, limestone, iron ore etc., and the emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitric oxides (NO_x), methane, hydrocarbons, heavy metals, etc. These parameters are evaluated with regard to the environmental impact, greenhouse effect, acidification, eutrophication and the forming of photochemical oxidants. A number of water discharges are also studied as a result of leaching in the different applications. The parameters included lead, nickel, chromium, cadmium, copper, zinc, iron, quicksilver and polynuclear aromatic hydrocarbon (PAH).

In a life cycle perspective the environmental impact quantified and different disposal, recycling or utilization of tyre shreds scenarios are compared. Environmental costs in disposal options for end-of-life tyres are included in the analysis. Environmental production costs for the production and transportation of conventional construction materials are also included in the analysis. The results from a LCA analysis are dependent on stated boundaries in the analysis and the weighing of environmental aspects. The overall conclusion in a life cycle assessment performed by the Swedish Environmental Research Institute

(IVL), Hallberg[15] et al. (2006), is that utilization of tyre shreds are beneficial compared to use conventional materials from an environmental point-of-view. Emissions of lead, nickel, chromium and cadmium to the environment are less by the use of tyre shreds in construction works (lightweight fill and drainage layer in landfill closures) compared to conventional materials. The total emissions of copper, zinc, iron, mercury and PAH were equal to conventional alternatives.

On the other hand, the density and durability improve with extra load. The permeability and heat insulation qualities of tyre shreds are hardly affected. Tyre shreds sink when placed in water, so rising is not a problem for constructions using shreds.

The technological service life of tyre shreds is very long, approximately a couple of thousand years when the material is used correctly. Old tyre material examined is both chemically and technologically intact. Biological breakdown has not yet been observed and is difficult to achieve, even in a laboratory environment.

A study conducted by the joint recycling company Svensk Däckåtervinning AB [16] in 2007 evaluated six recycling alternatives:

- Combustion in a cement furnace
- Filling material for a football pitch
- Final covering of landfills
- Combustion in a district heating plant
- Mixed in asphalt
- Filling material for noise barriers

The six scenarios were compared in the form of diagrams relating to the use of fossil resources, CO_2 and NO_x emissions (Figure 5, 6 and 7). The discharge of lead, nickel, chromium and cadmium showed a similar result to the use of fossil resources. The "recycling in football pitch" scenario was clearly inferior to the others with regard to copper, zinc, iron, quicksilver and PAH discharges. The leaching discharges is much greater from a football pitch than a landfill and noise barrier due to the water flow per tonne of tyre material being much

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[15] Hallberg, L., Strömberg, K., Rydberg, T., and Eriksson, E. (2006). Comparative life cycle assesment of the utilisation of tyres. Report on behalf of Svensk Däckåtervinning, IVL, Stockholm.

[16] "LCA of the utilisation of used tyres" IVL Swedish Environmental Research Institute Ltd.

higher for a football pitch. With regard to the discharge of these substances, the other scenarios are generally just as “good”.

Most of the scenarios gave a negative net result. In other words, it is better for the environment to use used car tyres than”virgin” material.

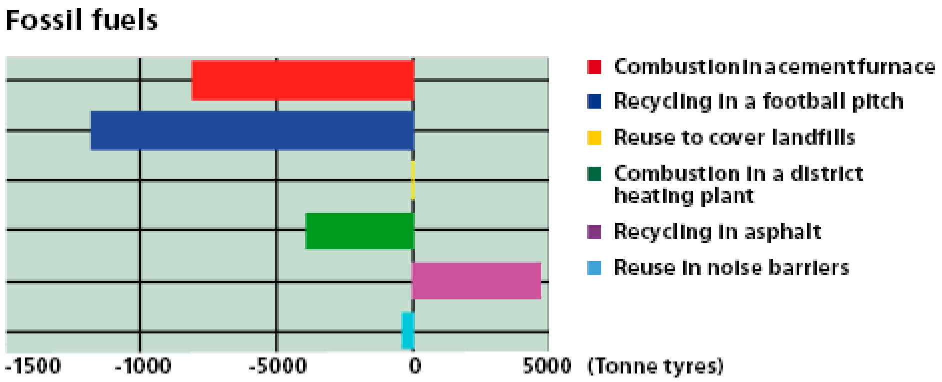

Figure 5 Fossil Energy Use

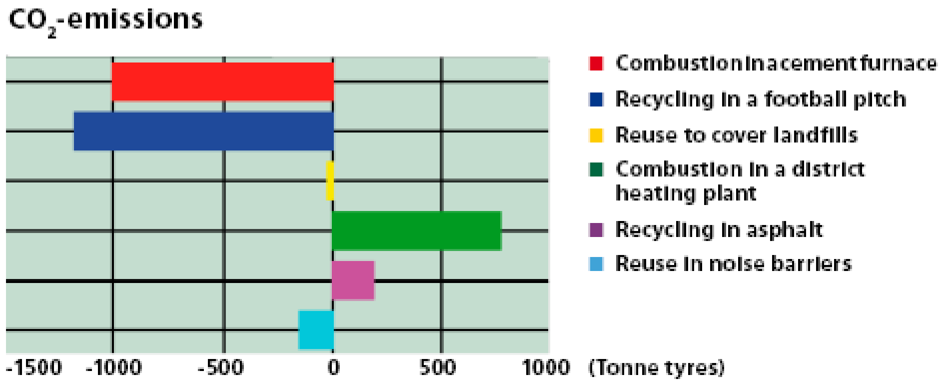

Figure 6 CO$_2$ Emissions

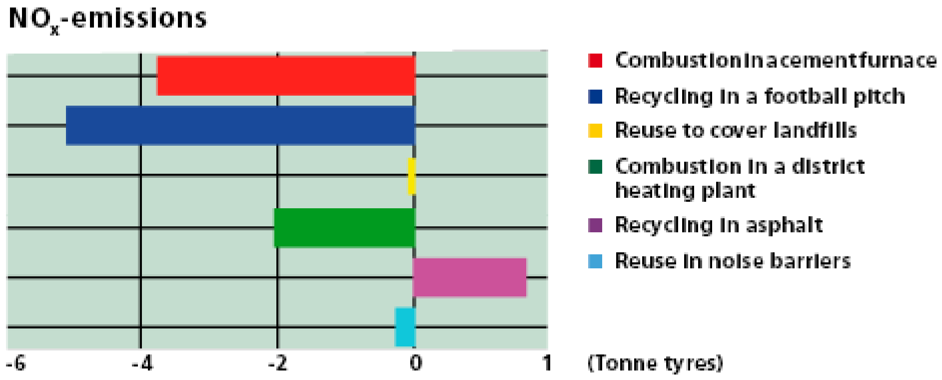

Figure 7 NOx Emissions

4. PROPOSED SOLUTIONS

4.1 Compaction Analysis

In order to solve the abovementioned barriers, the following *in situ* techniques to measure density during the execution of the embankment will be proposed:

SASW test, which is non-intrusive and rapid in the field application, is used to evaluate the layer density in the roller compaction without performing the complicated inversion process. The concept of normalized shear wave velocity is introduced to minimize the effect of confinement in the density evaluation. SASW test is performed to determine the shear wave velocity of the layer, and a free-free resonant column (FF-RC) test is adopted to determine the correlation between the normalized shear wave velocity and density of the site, which is almost unique independent of confinement. So an evaluation procedure of the field density should be proposed by effectively combining in-situ shear wave velocity determined by the SASW test with the correlation between the normalized shear wave velocity and the density determined by the FF-RC test. Finally, the feasibility of the proposed method should be verified by performing a field case study at the road construction site.

4.2 Geotextile installation

The first issue that must be addressed is the geotextile material. So, it is necessary to find an innovative geotextile with excellent resistance to installation damage that is to say with high puncture resistance. The proposed material is a nonwoven geotextile using the drylaid needlepunch technology. In this technology, virgin polypropylene fibres are extruded, carded and finally needlepunched. These geotextiles are unique due to a combination of intensive needling and various bonding processes. After being laid out horizontally the intensive needling ensures that the fibres are fixed vertically. The result is a strong and flexible 3-dimensional product which is advantageous in all parameters related to geotextiles. The excellent static puncture resistance of these geotextiles makes them ideal for protecting waterproof membranes and other sealing materials from puncture when fill material and/or loads are applied. When placed between sealing material and other layers, the geotextile withstands and distributes any local pressure from the layer above, ensuring that the protected material is not stressed to failure.

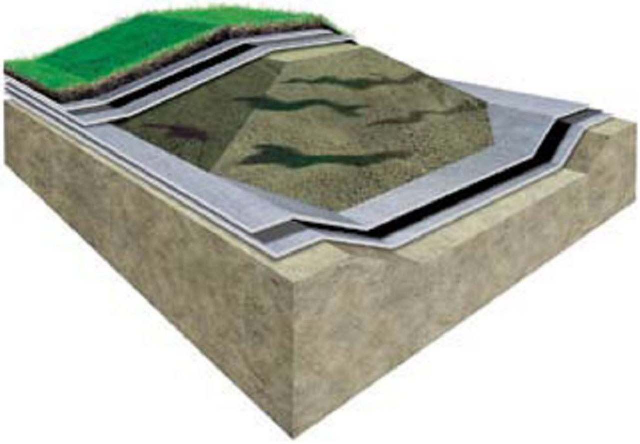

Figure 8 Geotextile material

In order to avoid the puncture problem related to geotextile installation it will be important to take into account some factors during the execution of the work. Placement of aggregate on the pinned geotextile normally puts the geotextile into tension which increases potential for puncture and reduces contact of the geotextile with soil, particularly when placing the geotextile against vertical and/or irregular soil surfaces. It is much better to keep the geotextile loose but relatively unwrinkled during aggregate placement. This can be done by using small amounts of aggregate to hold the geotextile in place or using loose pinning and re-pinning as necessary to keep the geotextile loose. This method of placement will typically require 10 to 15 percent more geotextile than predicted by measurement of the drain's planer surfaces.

Also, variations of the basic trench drain are the most common geotextile drain application. Typically, the geotextile lines the trench allowing use of a very permeable backfill which quickly removes water entering the drain. Trench drains intercept surface infiltration in pavements and seepage in slopes and embankments as well as lowering ground-water levels beneath pavements and other structures. Then, if high compactive efforts are required, the puncture strength requirements should be doubled.

4.3 Supply and transportation of tyre shreds.

The collection of used vehicle tyres should be made through a nationwide network of tyre distributors, vehicle dealer networks, contracted vehicle maintenance companies, end-of-life vehicle processors, and vehicle servicing and repair outlets. Under the End-of-Life Vehicle (ELV) Directive, car manufacturers are obliged to set up networks of authorized treatment facilities to take in used cars at no cost to the consumer. In addition, there are independent facilities which are not contracted to vehicle manufacturers.

For example, it has been estimated that at present there are around 100[17] specialist waste collectors of used tyres in the UK recycled tyre market. Collectors of used tyres are paid to take the tyres away. They in turn are charged a lower gate fee by recyclers. Collected used tyres are generally taken to a centralised facility (often located within the main zones for used tyre production in the UK, e.g. the West Midlands). Such facilities may slice the tyre into several pieces making its onward transportation more efficient by increasing the volume: mass ratio. These tyre slices (in the category >300mm) may be used directly for landfill engineering or processed further (potentially in a separate facility) for finer grade materials. So, a similar methodology should be applied from the Spanish Government in order to solve the problems related to supply and transportation of tyre shreds.

In UK, the major tyre collection companies and recyclers appear to influence the market significantly as their networks and relationships with recovery outlets pre-dispose the used tyres they handle to a certain route. So, in order to overcome this barrier, a map of involved actors in the process must be plotted in every country of the EU.

The trend towards over supply of used car tyres up to 2010, arising out of the Landfill Regulations and the ELV Directive, has put upward pressure on gate fees throughout the supply chain as businesses experienced increasing difficulty in disposing of stocks of used tyres or tyre shred. Whilst there may be some regional upward movements in disposal charges at the retail level, this effect will probably be contained by the industry overall, assuming that there are no further disruptions. In the event of a significant adverse disruption in the market the increased gate fees are likely to be passed on to the consumer by means of an increased recovery charge from the new tyre retailer.

If the retailer is forced to increase the disposal charge to the consumer, this will raise additional funds at the front end of the supply chain. Some of this will be absorbed by the industry in increased transport costs (since tyres are likely to have to travel longer distances to recovery locations) and in the cost of stockpiling. However, a portion of the additional fees will work through to the processor and end user.

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[17] "Partial Financial Impact Assessment of a Quality Protocol for the production and use of tyre-derived rubber" WRAP Environment Agency

This scenario of rising gate fees applies in principle to other sectors of the market. Such an improvement in margins within the industry will encourage accelerated uptake in investment in applications for used tyres which, in time, will increase demand and drive the market back to near 100% recovery.

Clearly in the event of a favorable market scenario, which increases the demand for used tyres, the converse will apply, with lower gate fees and returns having the effect of slowing demand in other areas. This scenario will also encourage further used tyre imports from countries with a less developed recovery infrastructure.

4.4 Appropriate requirements of materials.

The density of tyre shreds is low compared to soil and rock material. This property makes the material suitable for lightweight fill applications. Since the compact density of tyre shreds is slightly above the density of water the tyre shreds does not float and therefore do not need buoyancy prevention if put into water. However, the density difference is low and there is likely that tyre shreds could be mobile in rough water conditions.

Tyre shreds have high porosity and thus have high permeability. Despite the compressible nature of tyre shreds permeability tests shows that tyre shreds still have high porosity even at high pressures. The low water content, even after long periods submerged in water may mainly be explained by the hydrophobic nature of rubber, the main component of tyre shreds. Studies of capillarity of tyre shreds have not been found. However, it is reasonable to assume that the capillarity is low and can be assumed to be negligible considering the high porosity and the low maximum water content.

Compacting tyre shreds is easy because no water needs to be added, maximum density is achieved with low amount of compaction energy and static compaction equipment is preferable. There is a lack of knowledge about maximum height in lifts to achieve acceptable compaction. Therefore it is recommended either to use small lifts or to test the compaction result at the construction site. The strains are smaller if the initial state of tyre shreds is compacted compared to loose fills.

The stress-strain behaviour of tyre shreds is non-linear. Tyre shreds become stiffer as the stress increases. In applications where the overlaying stress will change, in for example road embankments, the strain caused by the additional stress must be considered. It is not only the load distribution that needs to be considered for overlaying materials, but also the overlaying load.

4.5 Quality control of tyre shreds in site execution.

The dust release could easily be prevented by wettening the tyre shreds or use fresh tyre shreds, i.e. not stored, before the protruding steel cord begins to corrode. Quality control of the tyre shreds is important, because depending on used shredders during the cutting process the sizes, shapes and amount of free steel cords varies.

Also, the performance of most test sites indicates that the superstructure probably could be thinner than the used. However this possible thickness reduction is difficult to validate analytically in linear elastic pavement design models. Empirical tests are still needed to find the most economical, i.e. thinnest acceptable superstructure, design. It is recommended a minimum thickness of the soil cover above the tyre shreds in order to compensate for the high compressibility of tyre shreds for protection of the pavement against cracking.

It has still to be investigated if the use of a heavier sub-base material would result in a thinner minimum soil cover recommendation. Since the sub-base also distribute load due to its thickness this may not be the case. Road construction guidelines should be revised to state two criteria for the soil cover above the tyre shred layer; a minimum thickness and a minimum surcharge of this soil cover.

Regarding the initial compression caused by the load of the finished construction and creep deformations issues, both of them may thus cause problems like cracking of pavement of the road. Therefore it is recommended to not pave road until the major parts of the deformations have taken place.

Finally, the back calculated thermal conductivity is ranging from 0.15 to 0.19 W/(m•K) in most of studies. For design purposes are 0.20 W/(m•K) recommended.

4.6 Stockpile shreds control in site.

Regarding the stockpile size and configuration, as a general recommendation, pile size shall not exceed the following dimensions: 15 m wide by 60 m long by 6 m high. Note that shredding processors may be limited to smaller pile sizes.

Also, regarding location requirements for stockpiles, it is important to take into account the following recommendations:

- Piles shall be located so that the material can be easily accessed from all sides.
- Piles shall be at least 30 m from any building that is occupied or in use, and at least 15 m from any unoccupied or unused building.
- Piles shall be located far enough from streams and bodies of water so that shreds that may tumble down the sloping sides of the stockpile will not fall into the water.

All piles shall be placed on a pad of concrete or a paved surface, or a 0.3 m thick pad of crushed stone or under-drain filter material to prevent contamination of the shreds. The minimum distance between piles shall be sufficient to keep adjacent piles from “overlapping”, and shall also provide sufficient maneuvering room for loaders and other construction equipment, or 15 m, whichever is greater.

It is the intent to construct the piles without causing contamination of the tire shreds, which may have already been sampled and tested. To accomplish this, it will be necessary to provide and use equipment that can move shreds without picking up the underlying soil. Tire shred processors have used grapples successfully, although the process is slow. Any machine used to push or scoop shreds should be used cautiously, as it is possible that the machine will scrape up the underlying soil and mix it into the shreds. Grapples, or other machinery which will not pick up any underlying material, should be used to load shreds onto trucks.

All stockpiles shall be identified with at least one weather-resistant sign, placed on the pile where it is not likely to not be disturbed and can be easily viewed from the ground. The information on the sign must be legibly written using weather-resistant paint or marker, and be easily readable from ground level. Minimum dimensions of the sign shall be 760 mm by 760 mm. Any signs that are damaged or misplaced must be replaced immediately. The sign(s) must remain in place until the stockpile is depleted. The sign shall also show the quantity of approved material in the stockpile, in short tons.

It is very difficult to obtain representative samples from existing piles. For that reason, the person in charge of inspection has to be alert for signs that the pile may not meet specification requirements. Use judgment to try to ascertain the overall condition of the pile. Existing piles can hide problems such as debris and other contamination. It is impossible to determine if this is the case simply by inspecting the outside of the pile. For that reason, an Inspector shall be present when the pile is moved.

4.7 CO_2 consumed in transportation.

Tyres are typically disposed illegally in remote locations, meaning they can be expensive to remove as a result of the high transport costs involved. Removal costs can also increase if the tyres are covered with dirt, or buried underground. Inappropriate disposal of tyres costs the community and local Councils, who typically incur the removal costs. Illegal dumping of tyres not only takes up limited landfill space, but also has the potential to cause environmental harm.

Then, the proximity principle should be applied: the principle that waste should generally be disposed of as near to its place of production as possible (recognizing that the transportation of wastes can have a significant environmental impact)

4.8 LCA of tyre shreds.

In order to develop an adequate LCA of tyre shreds several issues must be taken into account. For each recovery method, the environmental impact is calculated for the same service rendered: recovering one tonne of ELT from a given collection point. LCA is based on calculations per tonne, which:

- Guarantees that the results can be compared method by method,
- Makes possible future weighting in relation to the tonnages recovered

In order to provide the analysis with a framework, a choice should be made to define the limits of the study:

1. Collection of tyres.
2. Sorting of tyres.
3. Transportation of tyres to shredder unit.
4. Shredding of tyres.
5. Transportation of tyres shreds to site.
6. Recovery of tyre through the construction of an embankment.

The Life Cycle Assessment should be based on eight fundamental indicators:

- Total primary energy consumption
- Contribution to the greenhouse effect

- Consumption of non renewable resources
- Acidifying gas emissions
- Water consumption
- Tropospheric ozone formation
- Contribution to eutrophication
- Production of non dangerous waste.

Then, environmental assessment would be calculated stage by stage for the criterion. The overall impact for the criterion is:
- On the one hand, the sum of the results for each stage,
- On the other, the comparison of this overall result with the impacts generated and avoided.