Environmental restoration by using waste tires: an example of the Nan-Liao landfill in Taiwan

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Abstract

Waste tires are becoming one of the modt serious solid waste problems because the use of automobiles is increasing. If they are incinerated, some hazardous chemical compounds are emitted. When they are deposited outdoors, they become the habitats of mosquitoes and may cause environmental diseases such as breakbone fever. Much effort is devoted to waste tire treatment, but most of the available methods need pretreatment processes such as the separation of other materials or chipping into small parts. Energy, materials and man resources are always needed in these pretreatment processes. Furthermore, without any pretreatment process, whole waste tires can be used in civil structures. Hence, whole waste tires as a construction material in landfill restoration are investigated in this research.

More than 20,000 waste tires were used in this study. First, waste tires were used to construct retaining walls in order to protect the site. Second, they were used for the pavement together with other materials to avoid soil erosion. Additionally, they were used to build the leachate drainage system. After restoration, the Nan-Liao landfill was planned as a recreation park. In this design, waste tires can be reused for recreational purposes, such as landmarks and other landscape features concerned with environmental protection. A playground for children in the form of a maze was also made out of waste tires in this study.

1 Introduction

130,000 metric tons of waste tires are produced each year in Taiwan. A key challenge facing local governments has been in addressing waste tire disposal and recovery. Unlike most types of solid waste, waste tires cannot be simply land filled without first being processed. This contributes to illegal dumping and the development of tire stockpiles. Discarded tires present a variety of hazards for the environment and public health, including providing a habitat for disease-carrying vectors and creating the potential for fires at both illegal dumps and regulated tire stockpiles. A waste tire is a tire that is no longer mounted on a vehicle and is no longer suitable for use as a vehicle tire due to wear, damage, or deviation from the manufacturer's original specifications. A waste tire includes a repairable tire, scrap tire and altered waste tire, but does not include a tire derived product, crumb rubber, or a used tire that is organized for inspection and resale.

2 Recycling, reuse and disposal of waste tires

Tire recycling, reuse and disposal are discussed first to provide an overview as to the magnitude of the waste disposal problems and the various paths at which the tires enter into the environment. In order to prevent waste rubber and in particular discarded automobile tires from damaging the environment, it is highly desirable to recycle this material. However, the total mass quantity of tires currently recycled in a given year (not including reuse, retreading, or combustion) is less than 7% of the annual tire generation rate in California [1], and Taiwan is in the same situation. Only a small portion of the waste tires are retreaded, and a very small portion is devulcanized by tedious processes. In California, the asphalt highway construction business holds the greatest potential for the demand of scrap and used tires in the form of ground rubber [2].

The reuse options for waste tires are significantly affected by the tire's particle size. Some of the recycling applications for tires based on particle size are shown in Table 1. Some recycling alternatives use whole tires, thus requiring no extensive processing, while other alternatives require that tires be split, punched, or shredded to make new products. Recycling of waste rubber from tires can be carried out by grinding the tire and adding the waste rubber particles to rubber mixtures for manufacturing new products. This process, however, leads to a strong deterioration of the desired physical properties of the rubber. Yet, another method of recycling is to reclaim the waste rubber in which the network formed by vulcanization is thermally degraded. The reclaimed material can be added to rubber mixture for manufacturing new products. This process also leads to a loss of the desired physical properties of the rubber, in comparison with virgin polymers.

Table 1: Alternative applications for waste tires based on particle size [1].

Particle Size	Applications
Whole Tire:	Artificial reefs and breakwaters
	Playground equipment
	Erosion control
	Highway crash barriers
Split or Punched Tire:	Gaskets, seals, washers, shims, and insulators
	Floor mats, belts and shoe soles
	Dock bumpers
	Muffler hangers
Shredded Tire:	Lightweight road construction material
	Playground gravel substitutes
	Sludge composting
Ground Rubber:	Rubber and plastic products (e.g., molded floor mats, mud guards, carpet padding, and plastic adhesives)
	Rubber railroad crossings
	Additives for asphalt pavements

In some recycling applications, removal of the metal bead in the waste tire is not required. For example, processed waste tires (or chipped tires) can be used as a lightweight fill material without requiring the removal of the metal from the rubber chips. Normal construction machinery can successfully operate on top of fill material consisting of tire chips provided that precautions are taken to prevent exposed wires at the edge of the chips from puncturing the tires of the machinery. Other recycling applications require the removal of the steel bead. Splitting of tires requires removal of the steel bead prior to stamping or punching. Manufacturing of crumb rubber and the use of tire chips as a substitute for playground gravel requires the tires to be shredded and magnetic separators be used to remove all steel fragments.

Tires can be used as fuel alternatives. Combustion facilities currently using tires as fuel include: (1) power plants; (2) tire manufacturing plants; (3) cement kilns; (4) pulp and paper plants; and (5) small package steam generators. In addition to fuel alternatives, pyrolysis of tires can be performed to chemically alter the materials of the tire or to derive various products such as carbon black. Burning tires whole obviates the need for expensive shredding operations.

However, the burning of whole tires requires a relatively sophisticated high temperature combustion facility to keep emissions within environmental limits. If the combustion process requires removal of the wire, the cost for combustion is increased. The wire removal from rubber chunks is an expensive process, which requires fine shredding and the use of powerful magnets.

In Oregon State, uses of waste tires which may be eligible for the reimbursement include [3]:

(1) Energy recovery. Energy recovery should include: (a) burning whole or chipped as tire-derived fuel, (b) incineration or pyrolysis of whole or tire chips to process heat or steam.

(2) Other eligible uses. Other eligible uses include: (a) pyrolysis of tires to produce combustible hydrocarbons and other salable products; (b) use of tire chips as road bed base and the like; (c) recycling of waste tire strips, chips, shreds, or crumbs to manufacture a new product; (d) use of whole tires, such as: in artificial fishing reefs in nonocean water, and for the manufacture of new products which have a market value such as buoys.

Many reports discuss the environmental effects associated with waste tire recycling, reuse and disposal options. Potential hazards and environmental effects with combusting, pyrolyzing, and irradiating tires during the recycling and reuse activities have already been identified [1].

3 Civil engineering applications

Waste tires can be used in numerous structural and nonstructural applications, such as alternative daily cover at landfills, lightweight fill, fence construction, and retaining walls. Other civil engineering applications include [4]:

(1) Loose fill. Shredded tires can be used as a fill for low places and trenches. A layer of topsoil would then be placed over. This allows excess water to drain as well as acting as a fill material.

(2) Slope stabilization. Shredded tires are used on inclines to prevent sliding of the soil because of the tire material's lighter weight compared with the surrounding soil. This reduces the risk of mud and landslides.

(3) Levee slurry walls. Tires can be chipped into 1–2 inch pieces and added to a slurry mixture to form a levee cutoff wall. The mixture hardens into a water impermeable levee.

(4) Baled tires. Baled tires have been used in several structural and nonstructural civil engineering applications such as retaining walls, berms, and as fences. Tire bales have been successfully used as fill material in a Gabion-style retaining wall in Humboldt County.

In Colorado State, civil engineering applications which include lightweight aggregate in fill, additive to embankments, sub-grade thermal insulation, backfill behind retaining walls, shredded as fill in landfills and in septic, are eligible [5].

4 Municipal solid waste landfill applications in California

Over 280 million scrap tires are generated annually in the United States with California accounting for an estimated 30 million of this total [6]. In response to this continuing waste problem, the California Integrated Waste Management Board (CIWMB) has initiated a program to define, document, and develop major applications for the use of scrap tires. Numerous civil engineering applications, including those for construction, operations, and closure of municipal solid waste (MSW) landfills, have been identified. The materials at MSW landfill applications identified include the use of tire shreds for: (a) alternative daily cover; (b) final cover foundation layer; (c) landfill gas collection material; (d) leachate drainage material; and (e) operations layer.

4.1 Alternative daily cover (ADC)

Daily cover material is placed on the entire surface of the active face at least at the end of each operating day in order to control vectors, fire, odor, blowing litter and scavenging. The CIWMB has approved the use of shredded tires as an alternative daily cover (ADC) at municipal solid waste landfills. The Board has also determined that it is an approved diversion end use. This represents a potentially large market in California because there are 190 landfills in the state. A large municipal landfill may use up to 3 million tires per year in this application. For example, the Altamont landfill in Alameda County and the Chicago Grade landfill in San Luis Obispo County are using ADC in California.

4.2 Foundation layer of a final cover system

Closed landfills should be provided with not less than two feet of appropriate materials as a foundation layer for the final cover. These materials may be soil, contaminated soil, incinerator ash, or other waste materials, provided that such materials have the appropriate engineering properties for use as a foundation layer. The foundation layer should be compacted to the maximum density obtainable at optimum moisture content using methods that are in accordance with accepted civil engineering practice. The process of using the tire shreds as a foundation layer material and a test pad demonstration program has been completed by GeoSyntec [7, 8]. Tire shreds are considered by the State of Califrornia to be a nonhazardous material [9]. Assessment of the performance criteria has indicated that tire shreds are compatible with waste and, if used appropriately, are generally acceptable for use as foundation layer material.

4.3 Landfill gas collection system

A landfill gas (LFG) collection system at a MSW landfill, serves to collect landfill gases and to convey them to an outside location. Typically, 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. The actual placement and spreading of tire shreds, in the LFG collection layer or trench, are similar to that of aggregate material. Experience has indicated that 375-mm shreds are spread most easily on slopes 3H:1V or flatter using small equipment rather than large. Generally, tire shreds alone have predominantly been used as LFG collection material at MSW landfills.

4.4 Tire shreds as leachate drainage material

Leachate collection and removal systems (LCRSs) are required for landfills and surface impoundments. The actual placement and spreading of tire shreds are similar to that of aggregate material. To spread tire shreds for leachate drainage material at a MSW landfill, a track-mounted dozer, track-mounted loader, or steel-wheeled compactor with a blade should be used. Experience has indicated that 75-mm shreds are spread most easily on slopes 3H:1V or flatter using small equipment rather than large. The Yolo County landfill uses this method to drain their local landfill [10].

4.5 Tire shreds as operations (protective) layer

The operations layer separates waste from the underlying landfill containment system. The main purpose of this layer is to protect the underlying components of the containment system, particularly the liner (e.g., geosynthetic membrane, geosynthetic clay liner, compacted clay liner). The operations layer is typically placed over the leachate drainage layer. Geosynthetic materials, such as geocomposite typically used on side-slopes, or granular materials, such as gravel and sand, can be used for the leachate drainage layer. Generally, tire shreds alone have been used as operations layer material at MSW landfills [11].

5 Environmental restoration with waste tires in the Nan-Liao landfill

The Nan-Liao landfill began to dispose of municipal solid waste in 1973. The total area of this MSWL was about 30 ha in 1994 when this landfill was closed, and the following environmental restoration program was planned. 5.5 ha of this landfill was planned as a recreation park and whole and shredded waste tires were used in this demonstration program funded by Taiwan's EPA. More than 20,000 waste tires were used in this study. First, waste tires were used to construct retaining walls in order to protect the site. Second, they were used for pavements together with other materials to avoiding soil erosion. Additionally, they were used to build the leachate drainage system. Whole waste tires were reused for recreation purposes in this demonstration program, such as landmarks and other landscape features concerned with environmental protection. A playground for children in the form of a maze was also constructed with whole waste tires in this demonstration program.

5.1 Retaining walls

Scrap tires are a readily available, lightweight and inexpensive alternate building material. When properly engineered, scrap tires can be successfully used for erosion control, terracing, retaining walls, steps, bridge supports, dams, and levees. The advantages of using tires in construction and repair projects include: low cost, ready availability, and durability.

(1) Low height retaining structures: Considerable use has been made of whole used and scrap tires as low retaining walls, to add and reinforce road widths in steep slope areas, to provide shoulder support on paved roads, and to repair wash outs.

(2) Gravity retaining structures: Gravity retaining structures are horizontal layers of tires designed to stay in place as a result of their weight. Individual tires are arranged in a single layer and clipped together with rebar fasteners.

(3) Geotextile-reinforced tire wall: This design was constructed by the U.S. National Park Service using 250 scrap tires reinforced with layers of geotextilematerial and anchored into the soil that was compacted behind the tire face of the wall. The voids in the tires were filled with hand-compacted local material as each layer was placed. This left exposed space on the face of the wall between the tires for vegetation, further stabilizing the wall and improving the appearance of the project.

For example, the California Department of Transportation (Caltrans) and the North Carolina Department of Transportation (NCDOT) have utilized some truck tires to stabilize slopes in emergency situations. The high cost of new construction materials, used to provide temporary protection for erosion can delay construction on projects. The availability of these discarded tires makes it extremely attractive as an alternative material for erosion control. Caltrans' first project was a shoulder stabilization project using recycled tires and was located on Route 32 in Tehma County. The project used whole truck tires to mechanically stabilize the shoulders [12]. Caltrans made several observations, conclusions and recommendations. First, construction of shoulder reinforcement and slope protection by maintenance personnel are simple and economical projects, mainly because of the availability of discarded tires. These projects also provide designers with immediate solutions. The availability, combined with the low cost of acquiring and installing discarded tires, makes them the ideal solution for many emergency problems which occur on highways.

Whole tires have been used successfully in the Nan-Liao landfill, in areas such as low height retaining structures, gravity retaining structures, and geotextile-reinforced tire walls, and it really saves many dollars of public work in this study.

5.2 Leachate drainage system

The following criteria should be evaluated on a site-specific basis to evaluate the suitability of whole tires or tire shreds as a leachate drainage system: protection of public health; protection of the environment; durability; operational impact; product characteristics; cost impact; and engineering performance. Generally, tire shreds, when used as leachate drainage material, will provide protection of the environment by not contributing to leachate generation and not contributing significant organics or inorganics to leachate or surface run-off [13]. Whole waste tires were used to construct the leachate drainage system in the Nan-Liao landfill. According to the results of field tests, the leachate drainage system can work well and reach the criteria.

5.3 Recreation applications

Examples of recreational facilities and areas constructed with recycled waste tires or materials derived from waste tires include: athletic track surfaces; cushioned safety material for recreational equipment; picnic table; play equipment; parking blocks; and basketball court, pavilion, and walking path surfaces. To help educate the public about the importance of reusing and recycling waste tires, The Department of Environmental Protection of Pennsylvania, supported a number of demonstration projects through the Waste Tire Recreational Grants. Recreational Grants are for projects that utilize waste tires in the design, renovation or installation of public recreational areas. It provided grants for the design and development or renovation of public recreational areas or facilities utilizing waste tires during Fiscal Years 1997–1998, 1998–1999, and 1999–2000 [14]. Eighteen projects, selected competitively from the proposals submitted, were awarded a total of $966,979. An estimated 957 tons of waste tire derived materials were used in the projects. For example, in Manheim Borough, construction of a public park with walkways created from recycled tire pavers. Also, material was utilized as safe fall areas under playground equipment. The project used approximately 17.2 tons of waste tires. In the Nan-Liao landfill, waste tires can be reused for recreation purpose, such as landmarks and other landscape concerning about environmental protection. A playground for children such as maze was also made of waste tires in this study (figure 1).

6 Conclusions

Tires have historically represented a significant solid waste management and disposal problem, as evidenced by large stockpiles that have become public health hazards and liabilities. Tires that are not recycled or reused are usually shredded and disposed of in landfills, or stockpiled whole in Taiwan. Stockpiling whole tires creates two significant hazards: mosquitoes and fires. Due to their shape and impermeability, tires managed in stockpiles tend to hold water for long periods of time. This stagnant water provides an ideal breeding ground for

mosquitoes and sites for mosquito larvae development. These mosquito species are often more difficult to control and spread more disease in Taiwan.

Taiwan's EPA efforts to recover tires create an opportunity for local public works. Innovative uses for old tires are providing creative ways to reduce waste, cut costs, and improve the quality and safety of public works projects. Waste tires can become an important part of local public works projects in three key areas: (a) use of rubberized asphalt in local road projects; (b) use of tire shreds and rubber products in other civil engineering applications; (c) use of crumb rubber products in playground renovations. The environmental restoration with waste tires in the Nan-Liao landfill is the first demonstration program in Taiwan. More than 20 thousands are used and most of them are in whole type without any pretreatment processes. After restoration, the landfill has become a very popular recreation park. Some wildlife returns back this area, eggs of a bird were also found in the retaining wall (figure 2). Hence, the whole waste tires are not only important in civil engineering applications but also become useful materials in recreational area or playground renovations.

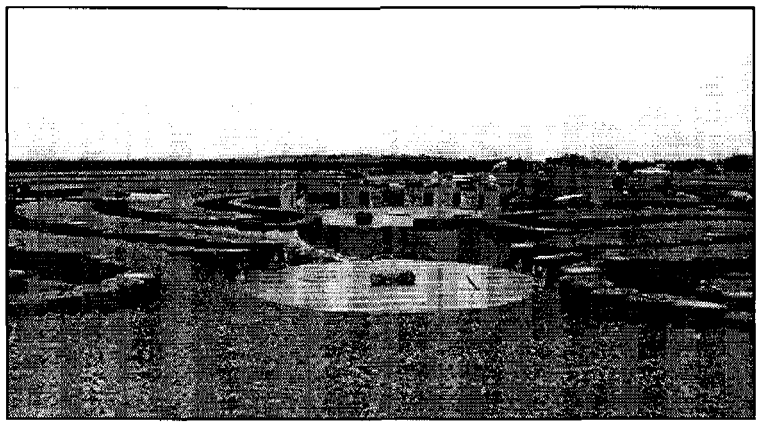

Figure 1: A waste tires maze.

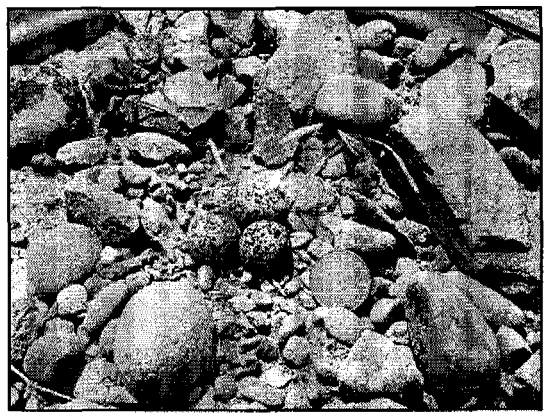

Figure 2: Eggs of a bird in the retaining wall.

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