

# TIRE DERIVED AGGREGATE (TDA):

## A STUDY ON APPLICATIONS, ENVIRONMENTAL PRODUCT SAFETY.

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*The views expressed in this study are opinions of the author and do not necessarily reflect the views of Tire Stewardship Manitoba.*

## Summary

The extensive generation of end-of-life tires (ELTs), with over one billion discarded globally each year, poses significant environmental and public health challenges. To address this issue, Tire Derived Aggregate (TDA) has emerged as a sustainable and versatile solution, repurposing shredded tires for various civil and environmental engineering applications. This report provides a comprehensive analysis of the properties, applications, advantages, and potential barriers associated with the use of TDA.

TDA is characterized by its lightweight, high permeability, thermal insulation, and shear strength properties, making it suitable for applications such as embankments, drainage systems, retaining walls, road construction, and environmental remediation. Its ability to adsorb contaminants like heavy metals, synthetic organic compounds (SOCs), and per- and poly-fluoroalkyl substances (PFAS) highlights its role in water treatment and pollution control. Additionally, TDA has been successfully implemented in numerous infrastructure projects across Canada and the United States, demonstrating its economic and environmental benefits.

Despite its advantages, the adoption of TDA faces challenges, particularly concerns about potential leaching of chemicals into soil and water. While studies indicate that leached substances typically remain within regulatory limits and pose minimal risks, ongoing research is required to fully understand long-term environmental impacts. The report emphasizes the need for improved design practices, comprehensive guidelines, and long-term assessments to maximize TDA's potential while mitigating environmental concerns.

This report concludes that TDA presents a promising solution to the ELT disposal crisis, offering significant benefits for sustainable engineering. However, broader adoption will require addressing misconceptions, advancing research, and refining regulatory frameworks to ensure its safe and effective use in diverse applications.

## 1. Introduction

In 2021 alone, over 270 million tires were discarded in the United States (Park et al., 2023). Despite a nearly 7% annual increase in the generation of used tires, the recycling market experienced a significant 25% decline between 2013 and 2021 (Park et al., 2023). This trend has promoted the U.S. Tire Manufacturers Association (USTMA) to urge recyclers, industry stakeholders, environmental groups, and academic institutions to collaborate with state and federal regulators to advance a circular economy. Waste tires can be safely and cost-effectively transformed into TDA, which can be used as a sustainable alternative to traditional gravel and lightweight fill for a wide range of applications (Park et al., 2023).

Between 2011 and 2021, only 5-10% of end-of-life tires were used in civil engineering projects (Park et al., 2023). The broader adoption of TDA in public and civil engineering applications has been hindered by the misinterpretations of published laboratory and field data. Additionally, inadequate peer reviews of technical reports and the reliance on test data obtained under extreme conditions, which are unlikely to occur in most TDA applications, have further restricted the widespread use of TDA (Park et al., 2023).

Globally, the use of TDA has grown significantly in recent years as countries strive to reduce landfill waste and promote a circular economy. TDA is utilized in a wide range of infrastructure projects, including road construction, embankment stabilization, drainage layers, and landfill cover systems. In the United States, TDA has become an integral component of civil engineering projects. With approximately 300 million used tires generated annually, recycling initiatives have successfully diverted the majority of these tires from landfills (Park et al., 2023). States such as California, Texas, and Washington have led the way in utilizing TDA for roadway construction, slope stabilization, and retaining wall backfill, supported by legislation and funding programs (Cheng, 2016).

Canada has also embraced TDA as part of its tire recycling strategy. Each year, the country generates around 25 to 30 million end-of-life tires, the majority of which are recycled or repurposed through provincial tire stewardship programs. Provinces like Manitoba, Ontario, and Alberta, TDA is commonly used in road construction, landfill drainage systems, and erosion control projects. For example, Tire Stewardship Manitoba (TSM), has supported several successful road construction projects incorporating TDA, reinforcing the province's commitment to sustainable infrastructure development.

The objective of this study is to accurately analyze published data on the environmental impact of TDA and assess its potential applications in civil and environmental engineering. By gathering and evaluating the most recent scientific data, the report aims to promote the expansion of TDA usage in over 20 potential applications, contributing to sustainable infrastructure development and advancing a circular economy.

## **2. Description of TDA**

### **2.1 What is TDA?**

The two primary products obtained from used tires are tire-derived fuel (TDF) and TDA. TDA is produced by shredding discarded tires into small fragments and is widely used in various civil engineering, and infrastructure projects (Pehlken & Müller, 2009). Tire shreds are categorized based on their dimensions and the shredding methods employed. The sizes ranging from 50 to 305 mm are classified as tire shreds, while those ranging from between 12 and 50 mm are referred to as tire chips. Collectively, the sizes are categorized as TDA. Tire particles smaller than 12 mm are commonly referred to as granular or crumb rubber (Wartman et al., 2007).

TDA is typically manufactured from passenger tires, truck tires, or a combination of various tire sizes. The sources of tires used for TDA production include newly discarded tires, stockpiled tires, or tires collected during site cleanup operations. To produce TDA, tires are introduced into a primary shredder equipped with slow-speed rotating knives. This shredder commonly features sets of spaced circular blades mounted on pairs of shafts rotating in opposite directions. Each blade on one shaft is offset by a spacer of the same width on the other shaft, allowing the blades to counter-rotate in an overlapping manner. An alternative primary shredder design utilizes knife rotors with rotor spacers permanently affixed to them. This design includes detachable blade sections bolted onto the knife rotor for easy replacement. Additionally, wear plates or liners are installed on each side of the rotor to protect against wear and tear during operation (Scrap Tire News, n.d.).

### **2.2 Classification of TDA**

The American Society for Testing and Material (ASTM) defines two primary types of TDA for engineering applications. They are Type A and Type B, along with two associate fill classifications: Class I and Class II. Type A and Type B represent size classifications used for distinct engineering applications, while Class I and Class II refer to the lift thicknesses of the fill, as outlined in Section 6.11.1 of ASTM 6270-08 (ASTM, 2008). Class I fills correspond to TDA layers less than 1 meter in height, whereas Class II fills apply to TDA layers between 1 and 3 meters in height.

For Class I fills, ASTM (2008, Section 7.1.2.) stipulates that a maximum of 50 percent (by weight) may pass through a 38-mm sieve and a maximum of 5 percent (by weight) passing through the 4.75-mm (No. 4) sieve. In Class II fills, ASTM (2008, Section 6.10.4) specifies that a maximum allowable is 25 percent (by weight) may pass through the 38-mm sieve and no more than 1 percent (by weight) may pass through a 4.74-mm (No. 4) sieve. Generally, Type A material is utilized in Class I fills, while Type B material is preferred for applications requiring a Class II fill designation.

Type A TDA typically ranges from approximately 3 to 4 inches (75-100 mm) in size with a maximum dimension of 200 mm in any direction. All Type A material need to pass through a 100-mm square mesh sieve, with at least 95% passing through a 75-mm square mesh sieve.

Type B material typically ranges from approximately 6 to 12 inches (150-305 mm) in size. Its maximum dimension should not exceed 450 mm, with 90% of the material being smaller than a 300 mm maximum dimension. Additionally, no more than 25% should pass through a 37.5-mm square mesh sieve, and a maximum of 1% should pass through a 4.57-mm (No. 4) sieve.

## 2.3 Properties of TDA

TDA possesses several unique properties that civil engineers can leverage to address challenging design scenarios. One of the most significant properties is its lightweight nature. Even under compression from overlying fill, the in-place unit weight of tire shreds ranges between 45 and 58 pounds per cubic foot. This is notably lighter compared to soil fill, which typically weighs around 125 pounds per cubic foot.

This makes tire shreds serve an exceptional lightweight fill material. Civil engineers often require lightweight fill to enhance the stability of embankments constructed on weak soils and to aid in stabilizing landslides.

In addition to being light weight, tire shreds exhibit low horizontal stress and compressibility. When fill is utilized behind walls, they exert reduced horizontal pressure on the backside of the wall, enabling the design of thinner and more cost-effective walls. Tire shreds also exhibit excellent drainage characteristics, remaining highly permeable even when compressed. Their permeability typically exceeds 1 cm/sec, making them an effective drainage layer for landfills and road construction. Furthermore, tire shreds have a high insulating capacity, with a thermal conductivity of approximately 0.14 Btu/hr·ft·°F for shreds up to 3 inches in size. This value is approximately seven times lower than the thermal conductivity of soil, which is typically around 1 Btu/hr·ft·°F (Humphrey & Blumenthal, 2010).

Three sets of tests for water adsorption and specific gravity were done for each of the following size ranges: less than 50mm, 50–100mm, 100–200mm, and 200–300mm. The results presented in Table 1, show water adsorption values ranging from 6.70% to 7.10%, with specific gravity values close to 1.10 across all sizes (Moo-Young et al., 2003).

**Table 1: Specific Gravity and Water Adsorption Results (Moo-Young et al., 2003)**

| Tire size (mm) | Specific gravity | Water adsorption % |
|----------------|------------------|--------------------|
| < 50           | 1.10             | 6.70               |
| 50-100         | 1.10             | 6.95               |
| 100 - 200      | 1.06             | 7.10               |
| 200- 300       | 1.10             | 7.00               |

The physical characteristics of TDA include an aspect ratio (length/width) of approximately 2.8 for particles sized between 0-75mm, with an average thickness 8.9 mm. The water content is negligible (0%) and the maximum dry density is about 723 kg/m<sup>3</sup>. These properties are summarized in Table 2 (Iranikhah & El Naggar, 2018).

**Table 2: Characteristics Values of TDA (Iranikhah & El Naggar, 2018 ).**

| Characteristics       | values                |
|-----------------------|-----------------------|
| Optimum water content | 0%                    |
| Maximum dry density   | 723 kg/m <sup>3</sup> |
| Average thickness     | 8.9 mm                |
| Average aspect ratio  | 2.8                   |

3(Kreider et al., 2010).

**Table 3: General Chemical Family of TDA (Kreider et al., 2010)**

| Chemical family       |
|-----------------------|
| Plasticizers and oils |
| Polymers              |
| Carbon blacks         |
| Minerals              |

### 3. TDA Applications

#### 3.1 Applications of TDA

TDA is a cost-effective, versatile, and long-lasting materials used in various civil engineering and environmental applications, including drainage systems, road construction, and noise barriers. Its eco-friendly attributes and minimal ecological footprint render it an attractive alternative to conventional aggregates. TDA has found practical application in the following areas:

- Retaining wall backfills (Humphrey, 2008)
- Embankment fill material (Humphrey, 2008)
- Vibration dampening for railways and seismic activity (Cheng, 2016)
- Road landslide repair, lightweight road fill(Cheng, 2016)
- Slope and bank stabilization (Cheng, 2016)

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- Capillary break/freeze–thaw mitigation barrier fill (Cheng, 2016)
- Thermal insulation fill (Humphrey & Blumenthal, 2010)
- Green-roof Garden backfill material (Wanielista et al., 2008)
- Floating foundation (Cheng, 2016)
- Drainage material for golf courses (Park & Ye, 2016)
- Backfill material in landfill leachate and gas collection systems (Cheng, 2016)
- Pesticides adsorption in golf-course and tee-ground elevation material (Park & Ye, 2016)
- Leaching field distribution-layer backfill material (Wanielista et al., 2008)
- Rain garden backfill material (Maeda & Finney, 2018)
- Stormwater management system backfill material (Maeda & Finney, 2018)
- Filtration media for wastewater treatment and contaminant removal (Wanielista et al., 2008)
- Removal of nutrients such as phosphorus and nitrogen in water (Maeda & Finney, 2018)
- Catalyst for hydrogen sulfide removal in biofilters (Scheels & Park, 1995)
- Free draining fill
- Water storage, retention, and infiltration
- Compressible layers between integral and general abutments
- Backfill for above-ground and buried pipes
- Wastewater treatment filter and support media (United States Scrap Tire Workgroup., 2022)

TDA offers numerous advantages over conventional aggregates, supporting its wide range of applications. These advantages include cost-effectiveness, environmental benefits, superior performance, and health-related aspects, making TDA a valuable material for various civil engineering applications.

TDA possesses several unique characteristics that provide significant benefits for civil engineering projects. These include:

- **Lightweight:** TDA weighs 67% less than conventional aggregates, making transportation more cost-effective while alleviating pressure on soft soils and delicate structures (Humphrey, 2008).
- **Thermal insulation:** TDA provides thermal insulation eight times more efficient compared to gravel, making it ideal for applications requiring temperature regulation, such as freeze–thaw mitigation (United States Scrap Tire Workgroup., 2022).
- **High void space and porosity:** With a porosity rating of 0.5, TDA boasts high void space and porosity, rendering it highly suitable for various drainage and filtration purposes (Mwai et al., 2016).

- **High shear strength:** TDA exhibits high shear strength due to its high friction coefficient. This characteristic enhances structural stability, minimizes deformation, increases durability, raises safety margins, and offers greater design flexibility (Xiao et al., 2015).
- **Reduced lateral load:** By exerting only 50% of the earth pressure, TDA diminishes lateral load, thereby lessening structural demands, bolstering structural stability, improving safety, enhancing durability, and affording greater design flexibility (United States Scrap Tire Workgroup., 2022).
- **Interlocking properties:** TDA's interlocking properties contribute to heightened stability, even load distribution, decreased maintenance needs, accelerated construction timelines, reduced risk of cracking, and simplified installation processes, thus expediting construction projects (Balunaini et al., 2014).
- **Freeze-thaw mitigation:** TDA forms a non-capillary and hydrophobic layer, effectively blocking moisture infiltration into foundations. This property enhances durability by mitigating structural damage, particularly in cold climates (Balunaini et al., 2014).
- **High permeability and drainage:** TDA boasts high permeability and drainage capabilities, facilitating water drainage ten times faster than gravel. This feature mitigates water damage, enhances safety, promotes durability, reduces standing water, improves water management, and lowers maintenance requirements (United States Scrap Tire Workgroup., 2022).
- **Vibration seismic force mitigation:** TDA surpasses earth backfill materials in vibration absorption, resulting in reduced noise levels, heightened comfort, enhanced safety, improved durability, decreased maintenance needs, and an extended lifespan (United States Scrap Tire Workgroup., 2022).
- **Chemical adsorption and filtration capability:** TDA consists of nonpolar compounds, carbon, and steel, which renders it effective for adsorbing nonpolar substances, precipitating metals, and eliminating halogenated hydrocarbons. This is facilitated by the presence of iron and zinc in end-of-life tires, which act as reducing agents in these processes (Park & Ye, 2016).
- **Lower cost:** TDA is 1.4 to 29.5 times more cost-effective compared to traditional materials, largely due to reduced transportation costs and enhanced safety measures. These measures mitigate the chances of road, vehicle, and machinery damage (Cheng, 2016).
- **Sustainable construction material:** TDA, composed of non-toxic recycled rubber, is durable, requires less maintenance, and can withstand harsh weather, making it an excellent choice for sustainable construction, even in freezing winter conditions (Tehrani et al., 2019).

TDA's unique adsorption capabilities enable it to act as an effective sorbent for environmental cleanup. For example:

- **Removal of Contaminants:** Tire chips have demonstrated effectiveness in removing a wide array of contaminants from landfill leachate, encompassing substances like mercury, sulfur, arsenic, selenium, oil, grease, cobalt, lead, nickel, BTEX (benzene, toluene, ethylbenzene, and xylene), and toluene. This capability makes TDA a valuable tool for mitigating environmental pollution and improving ecosystem health (Park et al., 2023).

- **Dual Functionality:** The rubber content in TDA can eliminate pesticides, while the steel wire component can effectively precipitate phosphorus. This dual functionality enhances the environmental remediation potential of TDA, offering a comprehensive solution for addressing diverse pollutants in various contexts (Park et al., 2023)

- **PFAS Removal:** Per- and poly-fluoroalkyl substances (PFAS) represent a class of synthetic organofluorine compounds widely distributed in the environment. These compounds, known for their high mobility and persistence, resist natural degradation processes and tend to accumulate in both human and wildlife populations. Several studies have shown that TDA could effectively adsorb and degrade per- and polyfluoroalkyl substances (PFAS), persistent environmental pollutants. According to the U.S. Centers for Disease Control and Prevention, elevated PFAS levels may lead to adverse health effects, including specific types of cancer and reduced vaccine efficacy in children. Several methods have been explored for removing PFAS from water. Johnson et al. (2007) found that iron-rich sand surfaces could adsorb between 74% to 99% of PFAS at concentrations in the range of parts per million (ppm) Blotvogel et al. (2018) estimated that using zero-valent zinc could reduce the half-life of perfluorooctanoic acid (PFOA) by eight years. Hence, PFAS compounds have the potential to undergo defluorination using iron and zinc present in steel wires and TDA rubber as reducing agents. This process operates similarly to the mechanism observed with zero-valent iron, which has been established to remediate halogenated hydrocarbons via reductive dehalogenation (Vasek, & Bizova, 2004). In summary, by employing a combination of mechanisms including zero-valent metal reductive dehalogenation, biological degradation facilitated by autotrophic and other PFAS-consuming anaerobic bacteria adhering to the TDA surface, and the sorption of PFAS-related compounds onto TDA rubber, it is expected that TDA-baled blocks can effectively remove over 50% of perfluorooctanoic acid (PFOA) and other PFAS chemicals from sources such as landfill leachate, runoff from composting facilities, and stormwater collection and infiltration systems (Kreider et al., 2010).

6PPD is a member of the p-phenylenediamine chemical family and serves as an antiozonant, which is a protective agent used to guard rubber compounds in tires against the damaging effects of ozone. By incorporating 6PPD, tire manufacturers aim to improve the durability and lifespan of tires by mitigating ozone-induced degradation. It has recently been discovered that 6PPD-quinone, a chemical derivative of 6PPD, is present in harmful concentrations for coho salmon in runoff originating from roadways and in the surface water that receives this runoff following stormwater discharge (Tian et al., 2020).

- **Pollution Control Mechanism:** 6PPD undergoes relatively rapid transformation into other transformation products. Both 6PPD and 6PPD-quinone can be effectively removed by organic carbon present in the soil, tire rubber, and activated carbon. In combination with a layer of sand-TDA mixture surrounded by soil rich in organic matter, TDA can effectively mitigate 6PPD-related chemical pollution leading from road runoff (Crouthamel, 1995).

- **Removal Efficiency:** Park et al. through empirical research indicates that a 15 cm layer of TDA or TDA-baled block material can absorb 99% of 6PPD from runoff on roads over a period of 50 years (Park & Ye, 2016; Park et al., 1996). The levels of tire components released from end-of-life tires into groundwater or runoff can be influenced by factors such as pH, temperature, the size of tire particles (Selbes, 2015), and the duration of contact (Kim et al., 1997).

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Compared to ground and granular tires, TDA has a minimal environmental impact in civil engineering applications due to its reduced surface area, which limits the leaching of tire components. Key considerations include:

- **Crumb Rubber vs. TDA:** Crumb rubber is more susceptible to ultraviolet (UV) light and rainwater exposure, increasing leaching potential.

In contrast, TDA is typically buried underground, covered with layers such as geotextiles, gravel, and asphalt, further reducing its environmental impact (Park et al., 2023).

**Leaching Control:** TDA releases fewer tire components into groundwater or runoff than whole or open-dumped tires, ensuring a safer environmental footprint (Park et al., 2023).

### 3.2 Advances of TDA

A coupled TDA Geocell stress bridging system has been developed through three additional full-scale tests and detailed 3D modeling. This system utilizes a geocell-reinforced granular backfill layer placed over a TDA layer to create a stress arching effect. This effect effectively reduces the stresses imposed on underlying pipes and assists control surface settlement (Mahgoub, 2020).

A Recent study suggested that Portland cement concrete (PCC) mixes containing rubber (TDA) can be used in concrete structural elements, offering sufficient strength and a suitable service life. Additionally, these mixes have the advantage of absorbing a significant amount of plastic energy under various loading conditions (Pham et al., 2019). Moreover, research indicates that combining TDA with Recycled Concrete Aggregate in pavement subbase systems can create a more robust structure. This combination reduces rigidity and cracking, leading to an extended pavement service life (Arulrajah et al., 2019). Recently TDA serves effectively as a filter medium because of its unique physical characteristics. Its porous structure offers a large surface area for water interaction, aiding in the removal of suspended solids, organic matter, heavy metals, and certain pathogens. Additionally, TDA's adsorptive properties help retain dissolved contaminants, making it a highly effective solution for water treatment (Scrap Tire News., 2023, July 6).

Despite these potentially advantageous qualities of TDA, its integration as a common material in civil engineering projects has progressed slowly. This reluctance might be attributed in part to lingering environmental apprehensions, despite evidence suggesting that when TDA meets accepted standards, adverse environmental effects are improbable. Additionally, engineers tend to favor established products with well-defined procedures rather than needing to ascertain the precise specifications of TDA for each project's requirements (Scrap Tire News., 2020).

### 3.3 Notable Projects

has been successfully applied in various civil engineering projects worldwide, demonstrating its versatility and effectiveness in diverse applications. Below are examples from Canada and the United States, highlighting TDA's utility in infrastructure and environmental projects.

#### Canada

##### *Use of TDA in Highway Embankments*

In regions with extensive industrial and mining activities, like Alberta, Canada, discarded Off-The-Road (OTR) tires have become a notable source of TDA. The tire recycling industry's ability to process various waste tires into TDA, along with the increasing accumulation of discarded OTR tires, prompted Alberta Recycling and Alberta Transportation to explore the use of TDA as embankment fill material for highway projects (Meles et al., 2016). TDA is produced by processors registered and approved by Alberta Recycling Management Authority (ARMA). Since the program's inception, municipalities throughout Alberta have utilized approximately 600,000 tonnes of TDA as drainage material in leachate collection systems. Used in nearly 200 landfill cells since 2006, this material repurposes over two million Alberta scrap tires annually, helping to lower municipal costs (Alberta Recycling Management Authority. (n.d.)). In New Brunswick in 2007, TDA was employed as a lightweight fill during the initial stage construction of the Route 1 highway embankment. This decision was made after the collapse of the embankment during construction, attributed to the presence of soft marine clay underneath. TDA was utilized to enhance the holding capacity of the foundation soil (Hoppe & Oman, 2013).

### *Road Construction Projects*

Canada has made substantial progress in managing end of life tires, with most provinces having established tire stewardship programs. These programs are designed to recycle or properly dispose of ELTs through partnerships between governments, industries, and consumers. For example, in Manitoba, several road projects utilizing TDA have been successfully completed with the support of Tire Stewardship Manitoba (TSM). Some of the most recent projects include:

- Rural Municipality of Lac du Bonnet: Red Deer Road (2017)
- Rural Municipality of St. Laurent: Ludovic Road (2019)
- Rural Municipality of West Interlake: Picnic Ridge Road (2023) and Silver Bay Road
- Rural Municipality of Gimli: Anson Road (2023)

These projects highlight the continued efforts to incorporate sustainable materials like TDA in infrastructure development across Manitoba.

### *Cost-Effective Municipal Solutions*

In Halifax, Nova Scotia, in 2016, TDA was employed as a cost-effective solution in constructing a high-traffic off-ramp for the Ragged Lake Bus Depot, resulting in savings of up to \$140,000 for the municipality, according to Moore in 2016. TDA was chosen due to its effectiveness in road construction, particularly in areas with a high groundwater table and poor soil conditions (Moore, 2016).

In Halifax, Nova Scotia, in 2016, TDA was utilized as a drainage system for the Shubenacadie Ball Field, enabling overnight drainage. The decision to use TDA was based on its superior compressibility compared to conventional soil (Moore, 2016).

### *Thermal Insulation Applications*

In Winnipeg, Manitoba, in 2000, TDA was employed to construct a 305-meter-long embankment above soft ground. This embankment served as a subgrade thermal insulator, aiming to restrict frost penetration and prevent road damage (Hoppe & Oman, 2013)..

### **The United States**

Since 1990, numerous projects in the United States have successfully utilized TDA as lightweight fill. In contrast, TDA use has been less common in Canada, but its application in highway infrastructure projects is now being increasingly considered.

Every year, millions of tires are shredded into pieces six to twelve inches long and reused as lightweight fill to address civil engineering challenges.

### *Stormwater and Drainage Solutions*

In Woodbury, Minnesota TDA was utilized as a stormwater treatment solution in their public works and parks facility expansion project. They constructed basins beneath two parking lots using 210,000 tires, equivalent to three years' worth of tires from Woodbury residents. These basins were paved over with porous pavement, allowing water to slowly infiltrate and recharge clean groundwater. According to the Woodbury Green Times in July 2019, the city saved money by using TDA, which cost about \$3 per yard compared to traditional fill materials that range from \$25 to \$35 per yard.

### *Lightweight Fill for Landslide and Settlement Prevention*

In Sonoma County, California, in 2008, TDA was utilized as the subgrade layer for Geysers Road. It served as a lightweight fill to address the landslide failure triggered by the saturation of soil backfill during periods of heavy rainfall (Cheng, 2016). In Indiana, in 2008, a combination of TDA and soil was employed as lightweight backfill during the widening of SR-110 road in Marshall County and SR-19 road in Elkhart County. This approach was necessary as the road grade needed to be elevated over peat to reduce soil settlement (Hoppe & Oman, 2013).

### *Widespread Infrastructure Usage*

Eden Prairie, Minnesota: TDA has been used to mitigate differential settlement at the Southwest Light Rail Transit station. Over the past 30 years, First State Tire Recycling and TDA Manufacturing has supplied TDA for more than 350 projects, including roads, driveways, embankments, and stormwater management systems. Niemi, the company's owner, highlighted the growing popularity of TDA among municipalities, corporations, and homeowners (Scrap Tire News., 2020).

## **4. Challenges and Risks Associated with TDA**

### **4.1 Environmental Risks of TDA Use**

Adding TDA to soil can introduce elements that may potentially pollute water sources. For example, contaminated drinking water with chromium and iron may cause health problems such as anemia, stomach cancer, and hemochromatosis. There is limited research on how rubber tire waste in soil behaves in terms of leaching. Some studies suggest that water contamination from

rubber tire waste in soil generally stays within the acceptable limits established by various regulatory agencies for drinking water quality. On the other hand, another study showed that the concentration of leached iron in the soil-tire mixture exceeded the maximum allowable level. Researchers observed that mixtures of soil and rubber tire waste may require chemical stabilization to meet these standards (Yadav & Tiwari, 2019). Therefore, more research is needed to understand how chemicals might leach from soil mixed with rubber tire waste, such as TDA and crumb rubber, along with chemical stabilizers. (Yadav & Tiwari, 2019).

In general, end-of-life tires contain various additives, including filler materials like calcium carbonate, carbon black, clays, and silicas; stabilizing agents such as antioxidants, antiozonants, and waxes; cross-linking substances like sulfur, accelerators, and activators; and other components like pigments, oils, resins, and short fibers (Halsband et al., 2020). These tires may also contain impurities from exposure to various chemicals during their lifecycle. Car tires encompass a diverse chemical category such as dithiocarbamates, guanidines, phenolics, phenylenediamines, phthalates, polyaromatic hydrocarbons (PAHs), sulfur donors, sulfonamides, thiazoles, thiurams, and heavy metals (Ruffino et al., 2013). Importantly, the quantities of chemicals leached from tires are minimal. When evaluated against regulatory thresholds and water-quality-based standards, the leached chemicals do not pose significant risk to ecosystem or human health (Halsband et al., 2020; Ruffino et al., 2013; Cheng et al., 2014; Canepari et al., 2017).

Unlike concerns regarding tire-related chemicals, the hydrophobic nature of tires can make end-of-life tires efficient adsorbents. This characteristic restricts the movement of contaminants into the surrounding environment, thereby reducing the risk of environmental harm (Park et al., 2023).

The levels of tire components leached into groundwater or runoff from end-of-life tires are influenced by factors like pH, temperature, tire particle size, and the length of exposure (Selbes, 2015). Using TDA in civil engineering projects reduces its environmental impact as it has a smaller surface area for tire component leaching. Additionally, it is usually installed underground and protected by layers of geotextile, gravel, and asphalt, which minimizes exposure to UV light and rainwater that could cause leaching (Park et al., 2023). The following sections provide more detailed insights into leaching behavior from TDA.

#### **4.2 Leaching Behavior in Waterbodies**

In aquatic environments, tire components tend to have higher concentrations due to prolonged contact with water, unlike in unsaturated conditions. The release of tire components is influenced by factors such as particle size, pH levels, and the solid-to-liquid (S/L) ratio (Rhodes et al., 2012). In the case of TDA, the release of inorganic elements like aluminum, arsenic, calcium, cadmium, chromium, copper, iron, potassium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, sulfur, and selenium has been found to be minimal. This indicates that TDA is a safe and reliable material for civil engineering applications, as it does not release substantial quantities of potentially harmful substances into the environment (Park et al., 2023).

#### **4.3 Transport of Tire Components in Soil and Water**

Tire components leaching into the soil can attach to organic matter, undergo biodegradation, precipitate, or be transported downstream. Heavy metals released from tires interact with the soil matrix, resulting in low mobility. Due to the hydrophobic nature of synthetic organic components in tires, they typically bind to existing organic matter in soils through adsorption. On the other hand, polar compounds are easily biodegradable, so even if they are leached, they do not significantly impact the environment. Some previous leaching studies have been conducted under extreme conditions, such as highly acidic or alkaline environments. However, for civil engineering applications, these scenarios are unlikely. For more accurate and relevant assessments, tests should simulate conditions similar to rainwater or groundwater to ensure relevance (Edil, 2008).

#### **4.4 Metals Leached from TDA**

Most metals such as aluminum, iron, manganese, copper, tin, antimony, chromium, nickel, cadmium, zinc, and lead, are found at higher concentrations in background soils compared to tires, with the exception of zinc. As a result, the leaching of heavy metals from tires generally does not pose a significant environmental concern (McLean & Bledsoe, 1992).

Elements such as arsenic (As), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), lead (Pb), selenium (Se), and zinc (Zn) leached from TDA or tire chips were found to be either below the detection limit or did not exceed the Maximum Contaminant Levels (MCLs) set by federal and state regulations under field conditions with a pH of 6.5 to 8.5 (Park et al., 2023).

The primary metals leached from TDA were iron and zinc. Once released, these metals become immobilized within the soil matrix at depths of 0.3 to 3 meters, where they remain for over 10 to 20 years, indicating very limited mobility. Furthermore, leached iron and zinc can react with waterborne contaminants, leading to their precipitation or adsorption onto the soil matrix, which contributes to environmental cleanup. Additionally, this metal may interact with soil minerals to form insoluble precipitates or adsorbed complexes with limited mobility, thereby reducing the risk of groundwater contamination (Park et al., 2023).

#### **4.5 Leaching of Synthetic Organic Compounds (SOCs) from TDA**

The release of synthetic organic compounds (SOCs) from TDA into water samples can vary depending on factors such as exposure duration, the presence of headspace, organic carbon levels in water, sample collection techniques, and other variables. Although the risk of exposure to leached chemicals from TDA in aquatic environments is generally low, regulatory measures have been established to control the release of these substances into the environment.

Under simulated field conditions, SOCs leached from TDA remained below the regulatory limits set by federal and state authorities. TDA functions as a reducing agent, effectively removing SOCs through processes such as adsorption and microbial degradation on its surface. Microbial breakdown of SOCs on TDA enhances its adsorption capacity over time. Therefore, TDA should be considered a beneficial medium rather than a concern in civil engineering projects, due to its effectiveness in cleaning both organic and inorganic contaminants (Park et al., 2023).

#### 4.6 Effects of TDA on Ecological and Human Health

While compounds leached from tire-wear particles and the particles themselves have been shown to harm certain aquatic species, there is currently no conclusive evidence demonstrating that TDA has a detrimental impact on aquatic organisms. The low concentration of substances leached from TDA, combined with the dilution effect, suggests that its use in civil engineering projects is unlikely to pose significant toxicity to aquatic species, including coho salmon, and even humans (Park et al., 2023).

The potential routes for human exposure to leached chemicals from TDA in civil engineering applications include (1) skin contact, (2) inhalation of volatilized compounds, and (3) ingestion of contaminated drinking water. However, previous research indicates that the levels of leached chemicals typically remain below regulatory thresholds, resulting in a low likelihood of exposure through skin contact and inhalation of volatilized compounds. Therefore, it can be confidently concluded that the potential health risks associated with exposure to leached chemicals from TDA in civil engineering projects are minimal (Park et al., 2023).

The risk associated with using TDA in civil engineering projects is relatively low when compared to other everyday risks. For example, rubber gaskets, which have a similar chemical composition to tires, have been used in drinking water distribution pipes for over a century, despite the potential for leaching "toxic" rubber components. Should the discovery of such leaching necessitate the removal of all such gaskets from our water distribution infrastructure? This highlights the importance of evaluating the use of TDA on a case-by-case basis, considering the specific application and balancing the potential risks against the benefits (Park et al., 2023).

#### 5. Conclusion

TDA represents an innovative and sustainable approach to managing the global challenge of end-of-life tires. Its unique properties, including lightweight, thermal insulation, and high permeability, position it as a valuable material for various civil engineering applications. Moreover, TDA's ability to mitigate environmental pollutants and support water treatment underscores its dual role as both an engineering material and an environmental remediation tool.

While concerns about leaching and environmental risks have hindered its widespread adoption, extensive research indicates that these risks are minimal under standard conditions. The integration of TDA into projects such as road embankments, landfill drainage systems, and stormwater management systems has demonstrated its economic and environmental benefits. By diverting millions of tires from landfills, TDA contributes to circular economy goals and reduces environmental hazards associated with tire waste.

To fully realize the potential of TDA, further research is needed to refine its applications, address specific environmental concerns, and expand its use in emerging fields such as filtration and contaminant removal. Comprehensive guidelines, including regulatory compliance and design standards, will play a critical role in fostering confidence among stakeholders and encouraging its broader adoption.

In conclusion, TDA offers a cost-effective, environmentally friendly solution to the tire disposal challenge. By balancing its benefits against potential risks and advancing its implementation

through research and regulation, TDA can play a pivotal role in sustainable infrastructure development and environmental protection.

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