# Sustainable Approaches Towards Renewing Discarded Vehicle Tire Rubbers

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## Abstract

A significant portion of discarded rubber is originated from the automobile and truck industry. It is a major concern as discarded tyres are non-biodegradable and undesirably influence the ecosystem. The available treatment methods, such as landfilling, stockpiling, and burning, are not feasible due to environmental and economic issues. Discarding vehicle tires in landfills generates toxic leachate including lead, cadmium, aluminium, mercury, iron, zinc, barium, calcium, etc.. Discarded tire rubbers are impervious that trap water, and offer breeding environments for mosquitos, rats, and rodents. Additionally, considerable land areas are consumed by discarded tires while stockpiling and landfilling and turning out to be challenging due to the scarcity of unoccupied lands. Unexpected fires in stockpiled discarded tires are tremendously challenging to control because of the existing highly flammable hydrocarbons. Another treatment method, i.e., re-treading of discarded tires, may adjourn the issue as a transient economical resolution. Therefore, it is high time to introduce scientific and sustainable approaches to renewing discarded vehicle tires. End-of-life cycle tires can be renewed by reconstructing and recovering for stemming energy and engineering materials. The discarded tire rubbers are collected at the end of their life period and renewed to produce in severalshapes and sizes. While renewing the discarded tire rubber, the vehicle tire structure is deemed for screening the composing materials to assemble in various classifications. The construction industry has introduced a variety ofchemical and mechanical techniques to obtain optimum utilization of discarded tire rubbers. Specifically, there are two techniques to produce rubber aggregatesfrom discarded tires, such as cryogenic grinding and mechanical grinding. These various grinding practices enable the yielding of diverse sizes of rubber particles, and the most frequently employed size ranges from 2 mm to 4 mm. This study focuses on the available methods to renew discarded vehicle tires for the construction industry.

## Keywords

Sustainability, Automobiles, Vehicle tires, discarded tire rubber and Renewing.

## 1. Introduction

With the continuous growth of the population and social-economic uplifting, there have been substantial demands for vehicles worldwide; consequently, the amounts of discarded or waste vehicle tires are mounting each year alarmingly(Bala and Gupta 2021). The management and disposal of discarded waste tire rubbers are a growing concern in current years. WBCSD (COSO 2018) conducted a study on 51 nations encompassing 90% of vehicles all around the world and reported that approximately 26 million tons of ELTs are produced annually, where only 69% are recycled as tire-derived fuel (TDF) and tire-derived materials (TDM), and a total of about 17 million tons of recovered rubber particles (RPs) are used for civil engineering applications and backfilling every year. The rest f 31% of the discarded tires are sent for landfilling and stockpiling throughout the worlds (COSO 2018). United States of America (U.S.A) is a top manufacturer of tires with a moderate to a higher level of shares in the market, which is approximately 65% of the yearly industrial revenue (Kaczanowska 2012). Based on the recent statement published by the Rubber Manufacturing Association (RMA), the U.S.A alone generated about 249 million waste tires weighing 4200 thousand tons in 2017, and approximately 16% (687 thousand tons) of these total waste tires were shipped for landfilling. It was reported that the land-disposed waste tires in the U.S.A were increased by 43% in 2017 compared to 2015(Islam and Li 2022; Rodríguez *et al.* 2018). Canada also maintains a greater share in the market as the tire manufacturing industry(Islam *et al.* 2022c). Approximately 395 thousand tons of waste tires were produced in Canada, with a yearly recovery of 111% in 2016 (COSO 2018), which indicates that the discarded tires can be a value-added product after their end of the life cycle. In 2017, a total of 50 thousand tons of waste tires were collected from landfills and stockpiles in British Columbia (Onuaguluchi and Banthia 2017). Moreover, Europe produces about 355 million tons of tires annually, which is about 24% of the total tire production of worldwide (Davide 2013).

European Tire and Rubber Manufacturers' Association (ETRMA) reported that about 3.8 million tons of waste tires were generated in 31 European countries in 2013, and a total of 1.5 million tons of used tires were dumped in landfills and stockpiled illegally(Islam *et al.* 2016b). Australia alone generates 51 million of discarded tires yearly (Mountjoy *et al.* 2015), which is more likely to ascend proportionally with the current population growth rate. It has been reported that approximately 1200 million waste tires will be disposed of annually throughout the world by the year 2030(Islam *et al.* 2016a).It is alarming as the waste tire rubbers are non-biodegradable, long-lasting, and possessed with adverse issues to the ecosystem. Several studies reported that disposal of waste tires to landfills produces toxic leachate, such as Cadmium, Lead, Aluminium, Iron, Mercury, Zinc, Calcium, and Barium, etc.(Islam *et al.* 2022b). Various techniques have been adopted to cope with the waste tires at the end of their life-cycle, such as recycling and reusing to generate raw materials, landfilling, re-treading, and fueling for the combustion(Islam 2022; Islam 2021). However, disposing of the end of life-cycle waste tires to landfills causes severe environmental issues because toxic and harmful elements are leaching to the neighboring ecosystem (Thomas and Gupta 2015). As waste rubbers are impermeable, the water trapped into the discarded tires offers breeding habitats for rodents and mosquitos. Moreover, large areas are consumed by waste tires during the stockpiling and landfilling strategies, which is turning out to be challenging because of the non-available unoccupied lands (Mohajerani *et al.* 2020; Siddique *et al.* 2021). Fire can catch up to the stockpiled waste tires, which is difficult to control. Therefore, it is crucial to renew the discarded vehicle tire for sustainability. In this paper, the sustainable approachesto renew the discarded vehicle tires for the construction industryare discussed from the previous research.

## 2.Renewing discarded vehicle tires

### 2.1 Physical pre-treatment methods

The elimination of impurities, such as additives, organic materials, and soil from the discarded tire RPs improves the bonding between concrete matrix and rubber surface (Rostami *et al.* 2000; Youssf *et al.* 2018). The method of soaking (for 24 hours), filtering, washing, and air drying of RPs exhibited improved compressive strength of about 15% compared to the unwashed RAs [36]. In the case of self-compacting RuC, the washed RAs increased the compressive strength and splitting tensile strength by approximately 5% and 4%, respectively, compared to the unwashed one [34]. Similarly, pre-coating of the rubber surfaces with cement paste (Najim and Hall 2013), styrene-butadiene copolymer (by 2% mass of rubber) (Najim and Hall 2013), synthetic resin (Liu *et al.* 2016), METHOCEL cellulose ethers solution and cement paste (Li *et al.* 1998), silica fume (Kashani *et al.* 2018), and limestone powder (3 µm) (Onuaguluchi 2015)were also adopted to improve the properties of RuC, as shown inTable 1. The purpose of pre-coating is to form a hard shell on the rubber surface, thereby developing the modulus of elasticity of the RPs, lessening the modulus of elasticity difference between the surrounding concrete matrix and RAs, and further encountering the stress concentration (Guo *et al.* 2017; Islam *et al.* 2021; Kashani *et al.* 2018). This is because the hydrophilic matrix shells replace the hydrophobic rubber surfaces at the ITZ of matrix slurry surfaces (Islam *et al.* 2022a), improving the ITZ bonding between rubber surfaces and concrete matrix. Moreover, the cementitious coating functions as nucleation spots that develop the formation of calcium silicate gel (C-S-H) at the ITZ due to the pozzolanic reactions, consequently increasing the ratio of Ca and Si as well as the density of the concrete matrix.

### 2.2 Chemical pre-treatment methods

The chemical pre-treatment of rubber particle basically involves soaking or submerging in chemical solutions, such as sodium hydroxide (NaOH) (Islam 2019; Mohammadi et al. 2016), potassium permanganate ($KMnO_4$) (Kashani et al. 2018), nitrogen flow (Chen and Lee 2019), acetone (Rivas-Vázquez et al. 2015), methanol (Rivas-Vázquez et al. 2015), ethanol solution (Rivas-Vázquez et al. 2015), sulphuric acid ($H_2SO_4$) solution (Kashani et al. 2018), silane coupling agent (SCA) (Li et al. 2016), carboxylated styrene-butadiene rubber (CSBR) latex (Li et al. 2016), hydrochloric acid (HCl) solution (Abdulla and Ahmed 2011), carbon disulfide ($CS_2$) (Chou 2011), nitric acid solution ($HNO_3$) (Leung and Grasley 2012), anhydrous ethanol (AE) (Zhang et al. 2014), acrylic acid (ACA) (Zhang et al. 2014), polyethylene glycol (PEG) solvent (Zhang et al. 2014), and alkoxysilane such as tetra ethoxy- silane (Yu et al. 2010) and Ultraviolet radiation (Ossola and Wojcik 2014), as demonstrated inTable 1. NaOH treatment involves washing the waste tire RPs with NaOH solution to remove the surface impurities andthe complete reaction, and afterward, draining and air drying the RPs to reach the pH level 7 (Wang et al. 2017; Youssf et al. 2016; Yung et al. 2013). Chemical pre-treatment is primarily performed to wash dirt, oil, and dust from the waste tire rubber, which improve hydrophilicity and surface abrasion along with counteracting the zinc stearate

Table 1. Different pre-treatment details, rubber sizes and types for rubberized concrete.

| Reference | Pre-treatment methods for RPs | Pre-treatment details | Rubber aggregate sizes | Rubber type | Specific gravity of rubber aggregate | Rubber content (by aggregate volume) | Replacement type | Concrete type |
|---|---|---|---|---|---|---|---|---|
| (Chen *et al.* 2019) | Surface modifier | Silane coupling agent and ethanol | 20 mesh | Natural rubber | 985 kg/m$^3$ | 8% | Fine aggregate | Rubberized concrete (RuC) |
| (Najim and Hall 2013) | Physical method | Cement paste | 2 – 6 mm | Crumb rubber | - | 38% | Coarse and fine aggregate | Self-compacting RuC |
| (Pham *et al.* 2018) | Physical method | Styrene-butadiene copolymer (by 2% mass of rubber) | 4 mm | Crumb rubber | - | 30% | Fine aggregate | Rubberized mortar |
| (Liu *et al.* 2016) | Physical method | Synthetic resin | 2 – 4 mm | Crumb rubber | 1.2 | 5 - 20% | Fine aggregate | Rubberized concrete |
| (Kew *et al.* 2004) | Physical method | Cement paste | <20 mm | Crumb rubber | - | 10 – 50% | Coarse aggregate | Rubberized concrete |
| (Li *et al.* 1998) | Physical method | METHOCEL cellulose ethers solution and cement paste | <2.5 mm | Crumb rubber | - | 33% | Fine aggregate | Rubberized concrete |
| (Zhang and Poon 2018) | Physical method | Cement paste | 1.18 – 5 mm | Crumb rubber | 1564 kg/m$^3$ | 25-100% | Fine aggregate (to replace furnace bottom ash) | Lightweight aggregate concrete |
| (Guo *et al.* 2017) | Physical method | Cement paste | 7 – 13 mesh | Crumb rubber | - | 15% | Fine aggregate | Rubberized concrete |
| (Kashani *et al.* 2018) | Physical method | Silica fume coating | 2.36 - 4.75 mm | Crumb rubber | 1100 kg/m$^3$ | 10% | Fine aggregate | Lightweight concrete |
| (Onuaguluchi 2015) | Physical method | 3 µm limestone powder | 0.85 – 4 mm | Crumb rubber | - | 5 – 15% | Fine aggregate | Rubberized mortar |
| (Onuaguluchi 2015) | Physical method | Limestone powder and Silica fume | 0.85 – 4 mm | Crumb rubber | - | 5 – 15% | Fine aggregate | Rubberized mortar |
| (Kashani *et al.* 2018) | Chemical method | NaOH solution | 2.36 - 4.75 mm | Crumb rubber | 1100 kg/m$^3$ | 10% | Fine aggregate | Lightweight concrete |
| (Chen and Lee 2019) | Chemical method | Nitrogen flow | 300 – 600 µm | Crumb rubber | - | 5% | Cement replacement | Rubcrete |
| (Meddah *et al.* 2014) | Chemical and gluing method | NaOH solution and gluing the sand | 2.5 – 8 mm | Shredded rubber | 1273 kg/m$^3$ | 25% | Coarse aggregate | Roller compacted concrete |

(Table 1continues)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Balaha *et al.* 2007) | Several surface treatments | NaOH solution, Silica fume and PVA | 0.15 – 4 mm | Ground waste time rubber | 0.9 | 5-20% | Fine aggregate | Rubberized concrete |
| (Mohammadi *et al.* 2016) | Chemical method | NaOH solution | 0.075 – 4.75 mm | Crumb rubber | 1.15 | 20% | Fine aggregate | Rubberized concrete pavement |
| (Kashani *et al.* 2018) | Chemical method | Potassium permanganate ($KMnO_4$) solution | 2.36 - 4.75 mm | Crumb rubber | 1100 kg/m$^3$ | 10% | Fine aggregate | Lightweight concrete |
| (Munoz-Sanchez *et al.* 2017) | Chemical method | NaOH solution and Sulphuric acid ($H_2SO_4$), Calcium hydroxide (CaOH) or acetic acid ($CH_3OOH$) aqueous solutions | 0.6 – 2.5 mm | Crumb rubber | - | 10% | Fine aggregate | Rubberized mortar |
| (Rivas-Vázquez *et al.* 2015) | Chemical method | Acetone, Methanol, Ethanol solution | 0.074 - 1.18 mm | Shredding of automobile tires | - | 10% | Fine aggregate | Rubberized concrete |
| (Kashani *et al.* 2018) | Chemical method | Sulphuric acid ($H_2SO_4$) solution | 2.36 - 4.75 mm | Crumb rubber | 1100 kg/m$^3$ | 10% | Fine aggregate | Lightweight concrete |
| (Wang *et al.* 2017) | Chemical method | NaOH solution | 15 mesh (0.6 – 2.36 mm) and 30 mesh (0.3 – 1.18 mm) | Crumb rubber | 536 kg/m$^3$ | 20 – 40% | Fine aggregate | Cementitious composite |
| (Li *et al.* 2016) | Surface modifier | Silane coupling agent (SCA) and carboxylated styrene–butadiene rubber (CSBR) latex | <0.6 mm | Crumb rubber | 1.1 | 5 – 30% | Fine aggregate | Rubberized concrete |
| (Abdulla and Ahmed 2011) | Chemical method | Hydrochloric acid (HCl) solution | 2 – 2.36 mm | Crumb rubber | 1.1 | 30% | Fine aggregate | Rubberized mortar |
| (Chou 2011) | Chemical method | Carbon Disulfide ($CS_2$) | 30 – 50 mesh | Crumb rubber | - | 9% | Fine aggregate | Rubberized mortar |
| (Leung and Grasley 2012) | Chemical method | Nitric acid solution ($HNO_3$) | 40 mesh | Crumb rubber | 0.87 | 12.2% | Cement | Rubberized mortar |
| (Zhang *et al.* 2014) | Chemical method | Anhydrous ethanol (AE), acrylic acid (ACA) and polyethylene glycol (PEG) solvent | 5 mesh and 40 mesh | Rubber particles | - | 5 – 20% | Fine aggregate | Rubberized concrete |
| (Yu *et al.* 2010) | Chemical method | Alkoxysilane such as tetra ethoxy-silane | 80 mesh | Crumb rubber | - | 9% | Cement | Rubberized mortar |

(Chou et al. 2007; Kashani et al. 2018; Khorrami et al. 2010; Meddah et al. 2014). This adversely affects the bonding between concrete matrix and rubber surface through the conversion of sodium stearate that is solvable in water and gets eliminated (Jumaat and Bashar 2015; Pacheco-Torgal et al. 2012). Saline coupling agent (SCA) is used to enhance the bondage between concrete matrix and RAs by both physical and chemical means (Iorio et al. 2018; Mohammad Momeen 2015). The methoxy groups from SCA convert to hydrophilic hydroxyl groups during the hydration process, which facilitates chemical bonding with concrete matrix by dehydration and condensation (Yu et al. 2010). RPs can also be washed in two stages, where initially rubber surface is treated with SCA and later washed with NaOH solution (Ghedan and Hamza 2011). Another chemical pre-treatment method, i.e., acid treatment, is conducted by introducing lactones and esters compounds in rubber particle surface to increase surface roughness, hydrophilicity, and abrasion (Colom et al. 2006; Medina et al. 2018; Munoz-Sanchez et al. 2017). This is due to indentations on rubber surfaces, depositing the hydration product of the binder at the setting time (Pham et al. 2017). Correspondingly, $KMnO_4$ solution reduces trapped air and improves hydrophilicity by oxidizing the active impurities in the rubber surfaces (He et al. 2016). For betterperformance, the rubber surface is initially washed with NaOH and oxidized with $KMnO_4$ solution, and then soaked into sodium bi-sulfite solution for sulphonation(Hamdi et al. 2021). Emulsified asphalt is another chemical that is well attuned with both RAs and cement paste (Bing and Ning 2014; Chen et al. 2019), and is considered as an agent to enhance the workability, compressive and flexural strength (Oikonomou and Mavridou 2009). Another organic solvent, i.e., acetone solution, is used to improve the bonding between rubber surface and concrete matrix by changing the structure of RAs. However, acetone solvent is toxic in nature which is not adopted very commonly (Rivas-Vázquez et al. 2015). Furthermore, treating rubber surface with mineral type $Ca(OH)_2$, a key element for cement hydration, enhances compressive strength and flexural strength and provides additional benefits, such as less hazardous, mild alkanity and environment friendly (Munoz-Sanchez et al. 2017). Another unconventional chemical treatment method, i.e., latex treatment, facilitates the formation of hydrophilic film at the ITZ of rubber surface and concrete matrix, enhances the mechanical properties, and improves impact resistance and durability (Bowland et al. 2012; Li et al. 2016; Sgobba et al. 2015; Xu et al. 2016). Similarly, partial oxidation treatment enables the hydrophilic group formation, such as S-O and S=O, enhancing cement hydration and the mechanical properties RuC(Chen and Lee 2019; Chou et al. 2010). Ultraviolet radiation is another pre-treatment method that improves the properties of RuC by shattering chemical bonding in RPs and producing free radical elements. These free radicals cross-link the polymer chains and form groups of hydrophilic function in the rubber surface (Ossola and Wojcik 2014; Shanmugharaj et al. 2006).

## 3. Conclusion

Renewing discarded vehicle tires can be a major step towards sustainable development, which requires more attention in the recycling procedures. Integrating recycling waste tire rubbers and fibers in concrete can contribute to sustainability and circular economy in the construction industry and also imply economic means of energy propagation during concrete production.There are numerous engineering applications of vehicle tire rubber in construction, such as vibration damping, structure retaining, bridge decks, bridge sidewalks, sound barriers, dam and tunnel spillways, high abrasion resistance, acoustic and thermal insulation, roadside barriers, running tracks, parking areas, cold climate areas, railway sub-ballast layer, flowable fill, soil stabilization, and drainage systems. The majority of these applications are non-structural due to significant strength loss of RuC compared to the plain concrete.

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## Biography

**Mohammad Momeen Ul Islam** is a full-time Ph.D. student at RMIT University, Melbourne, Australia. He successfully developed structural lightweight concrete for the first time by utilizing 100% waste tyre rubber particles during his Ph.D research. His Ph.D. research has received significant attention from national and international news outlets, including mainstream media, scientific magazines, and live radio programs in Australia and overseas. He has nine years of research experience and has successfully published a considerable number of journal articles as a sole and first author in top-quality journals with very high impact factors. He also received at least 248 citations for his highly impactful works. He received three full scholarships, including the Australian Government Scholarship RTP, for his higher degrees from renowned Australian universities. He was awarded the 'Deans Commendation Award' by The University of Adelaide, Australia, for his excellent performance in the Master of Philosophy degree. He is a certified peer reviewer in the world's reputed journals. Engineers Australia recognizes his skill as a professional civil engineer. He joined as Lecturer at Southern University Bangladesh. He also worked as a Casual Academic at The University of Adelaide, SA, Australia, and the University of Malaya, Malaysia, tutoring undergraduate engineering courses. He is well experienced in Concrete and Structural Engineering with a demonstrated history of working in the higher education sectors in three countries. He is also registered as a member and has affiliations with world's reputed institutions, such as ACI, ASCE, Engineers Australia, ICE, and Concrete Institute of Australia.