SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I4P111

Volume 12 Issue 4, 113-118, April 2025

Review Article

Surface Treatment Methods of Waste Rubber Tyre Aggregates to be Used as Aggregates in Concrete Mix-A Review

Jumnya Basar[1], Yamem Tamut[2], S. Mishra[3]

[1,2,3]*Department of Civil Engineering NERIST, Nirjuli, Arunachal Pradesh, India.*

[1]*Corresponding Author : Erzoom12@gmail.com*

Received: 08 February 2025 Revised: 10 March 2025 Accepted: 11 April 2025 Published: 30 April 2025

Abstract *- The disposal of Waste rubber tyres emerged as a major problem nowadays since drastic growth has been recorded in the usage and demand of rubber tyres; this results in the accumulation of a significant quantity of discarded tyres for disposal. The concrete mix contains cement, sand, coarse aggregate, water, and admixtures. It is largely used worldwide in the construction field to construct structures like road pavements, dams, high-raised buildings, bridges, etc. As concrete is used in such a large volume, the demand for raw materials for its production also increases. Sand and stone aggregates are available naturally to be used as raw materials in the concrete mix, but they are highly used, leading to scarcity of the natural aggregate. As such, the incorporation of waste rubber tyres with some percentage replacement for natural aggregate in concrete has required extensive research and investigation. The ability of waste rubber tyres to elevate certain concrete properties is a sustainable way to dispose of waste rubber generation and hence drew the attention of researchers in this field. This paper contains the techniques of surface treatment applied to increase the bond with the waste rubber tyre aggregate and their effectiveness in a concrete mix.*

Keywords *- Rubberised concrete mix, Surface treatment, Surface bonding, Waste rubber tyre aggregate, Waste disposal, Sustainable material.*

1. Introduction

Disposal of waste rubber tyres has become a global environmental problem; the landfills and the environment face stockpiling of waste rubber tyres, which raises significant risks [16]. The landfills are getting choked with waste rubber tyre disposal, as the waste rubber tyre may take 2000 years to decompose in landfills. When waste rubber tyres are burned for disposal, they emit harmful gases such as Carbon monoxide (CO), Sulfur dioxide (SO2), Nitrogen Oxide (NOx), etc, which are very harmful to the environment.

Since this problem does not have any confined solution, it encourages the researchers to navigate ways of recycling and disposing of them to utilise them for various purposes, including replacing them with naturally available aggregates in the concrete mixing. Waste rubber tyres, when used as an aggregate in the concrete mix by replacing some percentage of natural aggregate, then this concrete mix is often referred to as "rubcrete" or "rubberised concrete". It elevates certain properties of concrete, which are conventional materials, and proves to be a viable solution for waste rubber tyre disposal management [16, 22].

Previous researchers found that when the natural aggregate is replaced with waste rubber tyre aggregate in mixing concrete, it can add to concrete's various properties, such as lower density, higher impact resistivity, and better thermal and sound insulation [16, 22]. However, the lower adhesion of the waste rubber aggregate with concrete mix leads to impaired mechanical properties [24].

Due to this problem, several surface treatment methods were investigated to increase the interfacial bond of the waste rubber tyre aggregate with the cement matrix. The development of treatment methods in the research field of the surface of waste rubber tyre aggregate, and its contribution to the performance of rubberised mix concrete is discussed in this review. These include mechanical intervention, chemical predisposition, thermal and microwave treatment, and hybrid systems of techniques mentioned above to promote the compatibility of waste rubber aggregate particles and cement matrix.

Mixing rubber tyre waste aggregates in concrete is a promising step toward developing a more sustainable construction material. However, one of the main challenges is

the weak bond between the rubber particles and the concrete mix, which adversely affects the material's overall mechanical performance [16, 24]. The issue has been studied by several researchers who have investigated various surface treatment methods to increase the mechanical zone of interfacial bonds with a mix of concrete.

Whenever waste rubber tyre aggregates are incorporated into a mix of concrete, the energy absorption and flexibility parameters partially could solve the problem of premature concrete failure due to impact loadings and fatigue, which is common for conventional concrete [32, 24]. However, the drop in the mechanical aspects of concrete that arose from the untreated waste rubber tyre aggregates mixing must be addressed by proper surface modification [32].

Enhancing the surface of waste tyre aggregates helps improve their bond with the concrete mix, leading to better overall strength and durability of the concrete. Additionally, it increases resistance to freezing and thawing cycles, making it more suitable for cold climate applications.

This may help in the accommodation of the rapid increase in demand for natural aggregates in construction industries, as aggregate gives strength to the concrete mix; studies showed that surface treatment of waste rubber tyres enhances the properties of concrete mix.

Studies were conducted to modify the waste rubber tyre aggregate using different types of treatment methods such as Chemical, Thermal, Mechanical, and Microwave treatments to elevate the interfacial bond of the waste rubber tyre materials with the concrete matrix. Surface treatment techniques for rubber particles are designed to modify the properties of waste rubber tyre aggregates, improving their interfacial bonding with rubberized concrete and cement.

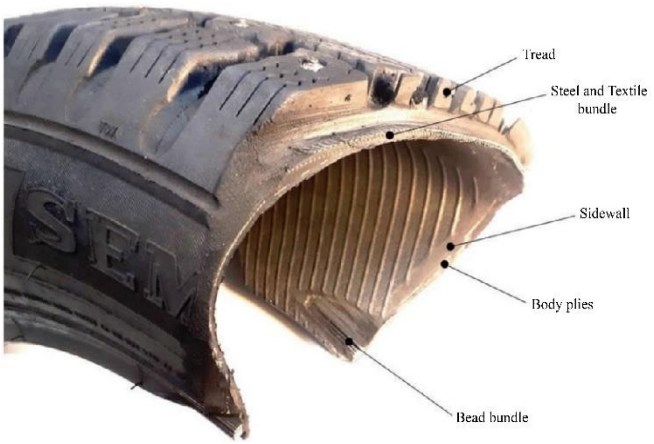

Fig. 1 An illustration of a typical tyre and its components (Lapkovskis et al. 2020)

Source:https://www.researchgate.net/publication/375187888_Recent_advances_on_waste_tires_bibliometric_analysis_processes_and_waste_management_approaches?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ

2. Chemical and Physical Properties of Rubber Tyres

Rubber tyres consist of materials such as rubber, metal, and textiles. Both the physical and chemical characteristics of rubber tyre aggregates play a key role in determining the appropriate treatment agent to enhance the surface of aggregates made from waste rubber tyres.

2.1. Composition of Waste Rubber Tyres

The following table shows the composition of waste rubber tyres [14].

Table 1. Composition of waste rubber tyre [14]

Ingredient	Passenger car	Lorry	Off-road
Rubber/Elastomers	47%	45%	47%
Carbon Black	21.5%	22%	22%
Metal	16.5%	23%	12%
Textile	5.5%	3%	10%
Zinc Oxide	1%	2%	2%
Other	8.5%	5%	7%

Source: https://doi.org/10.1016/j.procir.2016.03.141

2.2. Physical Properties

Physical characteristics of rubber tyre aggregate exhibit the following characteristics [8]:

Table 2. Physical properties of crumb rubber tyre [8]

Properties	Value
Specific Gravity	1.66
Color	Black
Surface	Moderately rough
Fineness Modulus (%)	4.1
Water absorption (%)	1.25

Source: https://ssrn.com/abstract=3610526

2.3. Chemical Properties

The XRF apparatus determines the composition of chemicals in waste rubber tyre aggregate, tabulated below [7].

Table 3. Chemical composition of rubber aggregates [7]

Chemical composition	Percentage (%)
SBR	48.00
Carbon Black	47.00
Extender Oil	1.90
Zinc Oxide	1.10
Stearic Acid	0.50
Sulfur	0.80
Accelerators	0.70

Source: https://doi.org/10.11113/jt.v71.3750

3. Surface Treatment Methods of Waste Rubber Tyre Aggregate

Aggregates made from waste rubber tyres have a weak link with other materials of concrete mix, which could be the reason leading to lower compressive strength of rubber aggregate mixed concrete; the surface treatment may elevate the different properties of rubber tyre aggregate mix concrete to a high extent [13]. as to achieve better quality of rubber aggregate mixed concrete, the surface treatment methods are carried out as below.

3.1. Mechanical Treatment Method

This method is adopted for increment of the surface area so that there will be more area for interfacial bonding between concrete mix and rubber tyre aggregate, which could be achieved by grinding, polishing, or roughening the surface of rubber tyre aggregate. The increased area of the rubber aggregate surface leads to improved interlocking, higher stress transmission and adhesion [5, 9, 31].

3.2. Chemical Treatment Method

These methods have been studied by using different coupling agents, etching and oxidation to enhance the chemistry of the surface of the waste rubber tyre aggregate [31]. The improvement in compressive strength up to 25% and 5% in flexural strength after treating waste rubber tyre aggregate with sodium hydroxide (NaOH) was recorded [32]. An increment of 10% for the compressive strength more than untreated rubber tyre aggregate has been seen [3].

3.3. Combined Treatment

Several studies have explored the combined utilization of mechanical and chemical treatment to enhance concrete performance by incorporating waste rubber tyre aggregates. This method enhances the adhesion between rubber aggregate particles and the mortar paste, plays a significant role in determining the material's overall performance, and enhances the concrete's strength and durability [3, 9].

3.4. Thermal-Microwave Treatment

Studies have indicated that subjecting waste rubber tyre aggregate particles to elevated temperatures can modify their surface characteristics, which may enhance bonding. This treatment triggers both chemical and physical transformations, refining the aggregates's surface properties and increasing the interface area for better adhesion within the concrete mix.

4. Impact of Surface Treatment on Rubberised Concrete Properties

4.1. Mechanical Properties

Several surface treatment techniques have been identified as effective in enhancing material properties to greatly influence the characteristics of rubber aggregate mixed concrete. Studies suggest that treating rubber tyre aggregates can enhance their performance in concrete applications. Treating waste rubber tyre aggregate with sodium hydroxide (NaOH) improves the compressive strength of the concrete in which it is incorporated, with slight improvements in flexural strength. However, it was also observed that not all treatment methods resulted in superior adhesion, possibly due to the rough texture of the modified rubber aggregate [6].

Research has shown that the primary function of sodium hydroxide treatment is to eliminate additives from waste rubber tyre aggregates. However, it was found that the treatment has minimal effect on the hydrophobic nature of the rubber aggregate's surface [23].

4.2. Durability Properties

The durability of concrete containing waste rubber tyre aggregates showed notable improvement. When various surface treatment methods were examined to assess their effect on water permeability in rubberized concrete, their findings revealed that treating the rubber aggregate with a hypochlorite solution significantly reduced permeability while also enhancing sulfate resistance [9].

4.3. Tensile and Flexural Strength

When waste rubber tyre aggregate replaces natural aggregates in concrete, a significant decrease in tensile and flexural strength can be observed. However, surface treatment plays a crucial role in helping to retain these properties in rubberized concrete [32]. Another study found that treating the rubber aggregate with sodium led to a notable enhancement in the tensile and flexural strength of concrete containing rubber aggregates [14].

4.4. Workability

Treating waste rubber tyre aggregate can greatly enhance the ease of handling and placing rubberized concrete mixture [31]. Using Sodium hydroxide solution for the treatment modifies the surface properties of rubber aggregates, leading to improved performance in the concrete [32].

4.5. Dimensional Stability

Rubberized concrete can experience dimensional instability due to the porosity in its interfacial zone. However, applying surface treatment methods to waste rubber tyre aggregates enhances the dimensional stability of the concrete. Treating rubber aggregates with sodium hydroxide solution has been found to reduce shrinkage in rubberized concrete [32]. Similarly, research has shown that using rubber aggregates treated with calcium hypochlorite solution helps minimize shrinkage and thermal expansion in concrete, ultimately enhancing stability and lowering the risk of cracking [33].

4.6. Density

Surface treatment improves the characteristics of waste rubber tyre aggregate concrete can be improved; however, the issue of low density in rubberized concrete remains

unresolved, making conventional concrete naturally denser. Nonetheless, this is attributed to the lower specific gravity of waste rubber tyre aggregates in comparison to natural aggregates. Treating the rubber aggregates can help slow down the reduction in density, resulting in a more balanced rubberised concrete mix [23].

4.7. Sustainability

Incorporating waste rubber tyre aggregate in construction offers significant environmental sustainability while addressing disposal challenges. Surface treatment of waste rubber tyre aggregates improves their interfacial bonding with cement paste, enhancing overall performance.

Additionally, using rubber tyre aggregates in concrete provides a sustainable solution to the global issue of tyre waste while also helping to preserve natural aggregates [31].

5. Factor Influencing Surface-Treated Waste Rubber Tyre Aggregate Concrete Mix Properties

Several factors affect the characteristics of surface-treated waste rubber tyre aggregate, such as the concentration of the treatment, the duration of the treatment process, and the proportion of rubber aggregate replacing natural aggregates:

5.1. Type and Concentration of Treatment Solution

The nature and strength of the treatment solution are essential factors in the performance of rubberized concrete. Research indicates that a 5% calcium hypochlorite solution enhances compressive strength and reduces permeability in comparison to a 20% sodium hydroxide solution or water [9].

5.2. Duration of the Treatment Process

The length of the surface treatment process also affects the effectiveness of rubberized concrete, as evidence by various studies have shown that extending the treatment duration from 2 hours to 72 hours further enhances characteristics like compressive strength, water permeability, and splitting tensile strength in concrete incorporating waste rubber tyre aggregate [9].

5.3. Quantity of Waste Rubber Tyre Aggregate as a Replacement of Natural Aggregates in the Concrete Mix

The quantity of waste rubber tyres incorporated by replacing natural sand also influences the properties of the concrete mix. A higher replacement level tends to reduce compressive strength, while optimal strength is typically achieved at a replacement rate of up to 25% [33]. Research has shown that using 8% treated rubber aggregate with different solutions leads to satisfactory mechanical and durability properties. These replacement levels have been suggested as a viable option for practical applications [9].

Table 4. Effects of treatment on waste rubber tyre aggregates

Sl.No	Mechanical Treatment	Chemical Treatment	Combined Treatment	Thermal and Microwave Treatment
1	H Su et al., 2015 reported that mechanical treatment enhances the interaction with rubber aggregate and cement paste [26].	Khern et al.,2020 observed that treating waste tyre aggregates with 5% calcium Hypochlorite (CaClO2) led to a 22% increased compressive strength and a 15% improvement in tensile strength [9].	Li et al. (2016) found that using silane coupling agents and carboxylate styrene-butadiene improved compressive strength by 4% and flexural strength by 13% [12].	A Swilam et al., 2022 discovered that crumb rubber heat-treated at 200º C for 2 hours resulted in compressive strength recoveries of up to 14.9% [25].
2	Khern et al.,2020 found that mechanically treated rubber tyre aggregate reduces air voids in concrete and Improves impact resistivity [9].	A. Diwakar et al., 2021, reported that Sodium Hydroxide (NaOH) treated rubber tyre aggregate showed a 10% hike in compressive strength and a 368% enhancement in splitting tensile strength [2].	Khern et al., 2020 demonstrated that an acid treatment combination for rubber aggregate resulted in a 13% rise in compressive strength [9].	Y Kong et al., 2016 revealed that thermally treated rubber tyre aggregate concrete achieved compressive strength recovery rates of 40%, 60%, and 80% compressive strength at rubber content levels of 14.9%, 10.4% and 9.7%, respectively [9].
3	H Su et al., 2016 Showed improved workability, especially when soaked in water for 72 hours [26].	Kumar et al., 2022 found that Sulfuric acid treated rubber tyre aggregates resulted in a 15% enhancement in compressive strength and a 12% improvement in impact resistivity compared [10].	A Swilam et al., 2022 combined silica fume and sodium hydroxide treatment resulted in 18% higher compressive strength [25].	Kong et al., 2016 found that when microwave-treated mortar is cured, it develops 1.5 times higher compressive strength than steam-cured mortar [9].

Source: [2, 9, 10, 12, 25, 26]

5.4. Concrete Mix Design and Curing Condition

The characteristics of rubberised concrete are largely affected by the mix composition, including the ratios of cement, aggregates, water, and admixtures, as well as the curing conditions [17].

5.5. Surface Treatment Method

The adhesion between waste rubber tyres and the relationship between aggregate and cement paste is influenced by the surface treatment method applied; using solutions like sodium hydroxide or calcium hypochlorite enhances the overall performance of the concrete mix [9].

6. Discussion and Recommendation

Treating the surface of waste rubber tyre aggregate can facilitate the broader adoption of rubberized concrete in construction by improving its properties, including compressive strength, durability, porosity, and permeability. Additionally, it supports the conservation of natural aggregates, as the rapid expansion of the challenges of waste rubber tyre disposal makes rubber aggregates a greener and more sustainable choice for construction. Numerous studies have demonstrated the benefits of treating waste rubber tyre aggregate to enhance its performance in concrete. However, further research is needed on:

- Separation and recycling of reinforcement materials for effectiveness of surface treatment methods.
- Development of improved and easy collection of waste rubber tyres.
- Policy and regulations for the treatment of waste rubber tyres.
- In-depth study of life cycle assessments of different treatment methods.
- The potential health and environmental effects of incorporating surface-treated waste rubber tyre aggregates in concrete.

7. Conclusion

Using waste rubber tyre aggregate in construction is an innovative and sustainable approach that helps address the shortage of natural aggregates while providing an effective solution for waste tyre disposal. While rubberized concrete generally exhibits lower compressive strength, surface treatment methods have been proven to enhance its overall performance significantly. Treatments involving silane, coupling agents, and sodium hydroxide enhance the properties of rubberized concrete, while various methods such as mechanical, chemical, combined, and thermal-microwave treatments positively impact the surface characteristics of rubber tyre aggregates. These treatment methods not only enhance the quality of rubberized concrete but also promote its wider application by modifying the aggregate's surface for better bonding with cement paste and improving its chemical properties for increased resistance to surface deterioration. Research indicates that surface-treated rubber aggregates consistently perform better in concrete than untreated ones. Additionally, surface treatments effectively counteract the strength loss typically associated with using rubber aggregates in the concrete mixture. Further research and experimentation are needed to explore different chemicals, surface modification techniques, and treatment processes to further enhance the properties of rubberized concrete.

Acknowledgements

The authors would like to acknowledge and sincerely thank the organizing committee of the International Conference on Computer-Aided Modelling for the Sustainable Development of Smart Cities (CAMSSC), sponsored by the Anusandhan National Research Foundation (ANRF), held at the Department of Civil Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, Arunachal Pradesh, India, during November 27-30, 2024, for allowing us to present the paper and sponsoring the paper for publication.

References

[1] Farhad Aslani et al., "Development of High-Performance Self-Compacting Concrete Using Waste Recycled Concrete Aggregates and Rubber Granules," *Journal of Cleaner Production*, vol. 182, pp. 553-566, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] Arjun Diwakar, Anand Kumar, and Vinay Singh, "Mechanical Properties Evaluation of Concrete with Crumb Rubber Particles Used as Fine Aggregate," *Usak University Journal of Engineering Sciences*, vol. 4, no. 1, pp. 28-41, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Qiao Dong, Baoshan Huang, and Xiang Shu, "Rubber Modified Concrete Improved by Chemically Active Coating and Silane Coupling Agent," *Construction and Building Materials*, vol. 48, pp. 116-123, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[4] Alessandra Fiore et al., "On the Fresh/Hardened Properties of Cement Composites Incorporating Rubber Particles from Recycled Tires," *Advances in Civil Engineering*, vol. 2014, no. 1, pp. 1-12, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[5] Tahir Gonen, "Freezing-Thawing and Impact Resistance of Concretes Containing Waste Crumb Rubbers," *Construction and Building Materials*, vol. 177, pp. 436-442, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[6] Liang He et al., "Surface Modification of Crumb Rubber and its Influence on the Mechanical Properties of Rubber-Cement Concrete," *Construction and Building Materials*, vol. 120, pp. 403-407, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[7] Euniza Jusli et al., "Effect of Using Waste Tyre Rubber on the Properties of Double Layer Rubberized Concrete Paving Blocks," *Journal of Technology*, vol. 71, no. 3, pp. 1-5, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[8] Raja Bilal Nasar Khan, and Anwar Khitab, "Enhancing Physical, Mechanical and Thermal Properties of Rubberized Concrete," *Engineering and Technology Quarterly Reviews*, vol. 3, no. 1, pp. 33-45, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Yih Chen Khern et al., "Impact of Chemically Treated Waste Rubber Tire Aggregates on Mechanical, Durability and Thermal Properties of Concrete," *Frontiers in Materials*, vol. 7, pp. 1-11, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[10] Rahul Kumar, and Nirendra Dev, "Mechanical and Microstructural Properties of Rubberized Concrete after Surface Modification of Waste Tire Rubber Crumb," *Arabian Journal for Science and Engineering*, vol. 47, pp. 4571-4587, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[11] G. Nagesh Kumar, V. Sandeep, and Ch. Sudharani, "Using Tyres Wastes as Aggregates in Concrete to Form Rubcrete–Mix for Engineering Applications," *International Journal of Research in Engineering and Technology*, vol. 3, no. 11, pp. 500-509, 2014. [Google Scholar] [Publisher Link]

[12] Yaning Kong et al., "Hydration and Microstructure of Cement-Based Materials under Microwave Curing," *Construction and Building Materials*, vol. 114, pp. 831-838, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[13] Gengying Li et al., "Properties of Rubberized Concrete Modified by Using Silane Coupling Agent and Carboxylated SBR," *Journal of Cleaner Production*, vol. 112, no. 1, pp. 797-807, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[14] Daniele Landi, Samuele Vitali, and Michele Germani, "Environmental Analysis of Different End of Life Scenarios of Tires Textile Fibers," *Procedia CIRP*, vol. 48, pp. 508-513, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[15] Yang Li et al., "Potential Use of Waste Tire Rubber as Aggregate in Cement Concrete – A Comprehensive Review," *Construction and Building Materials*, vol. 225, pp. 1183-1201, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Kudzai Mushunje, Mike Otieno, and Yunus Ballim, "A Review of Waste Tyre Rubber as an Alternative Concrete Constituent Material," *MATEC Web of Conferences*, vol. 199, pp. 1-8, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] M. Nuzaimah et al., "Recycling of Waste Rubber as Fillers: A Review," *IOP Conference Series: Materials Science and Engineering, The Wood and Biofiber International Conference*, Selangor, Malaysia, vol. 368, pp. 1-10, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[18] Yeonho Park et al., "Structural Performance of Dry-Cast Rubberized Concrete Pipes with Steel and Synthetic Fibers," *Construction and Building Materials*, vol. 77, pp. 218-226, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[19] Suvash Chandra Paul et al., "Treated Waste Tire Using Cement Coating as Coarse Aggregate in the Production of Sustainable Green Concrete," *Eng*, vol. 4, no. 2, pp. 1432-1445, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[20] Shaker M.A. Qaidi et al., "Engineering Properties of Sustainable Green Concrete Incorporating Eco-Friendly Aggregate of Crumb Rubber: A Review," *Journal of Cleaner Production*, vol. 324, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[21] Fengming Ren et al., "Crumb Rubber as Partial Replacement for Fine Aggregate in Concrete: An Overview," *Construction and Building Materials*, vol. 343, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Samar Raffoul et al., "Optimisation of Rubberised Concrete with High Rubber Content: An Experimental Investigation," *Construction and Building Materials*, vol. 124, pp. 391-404, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[23] Rajeev Roychand et al., "Practical Rubber Pre-Treatment Approach for Concrete Use—An Experimental Study," *Journal of Composites Science*, vol. 5, no. 6, pp. 1-17, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[24] Nadia Segre, Paulo J.M. Monteiro, and Garrison Sposito, "Surface Characterization of Recycled Tire Rubber to be Used in Cement Paste Matrix," *Journal of Colloid and Interface Science*, vol. 248, no. 2, pp. 521-523, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[25] Weiguo Shen et al., "Investigation on Polymer–Rubber Aggregate Modified Porous Concrete," *Construction and Building Materials*, vol. 38, pp. 667-674, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[26] Abdelrahman Swilam, Ahmed M. Tahwia, and Osama Youssf, "Effect of Rubber Heat Treatment on Rubberized-Concrete Mechanical Performance," *Journal of Composites Science*, vol. 6, no. 10, pp. 1-13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[27] Blessen Skariah Thomas et al., "Strength, Abrasion and Permeation Characteristics of Cement Concrete Containing Discarded Rubber Fine Aggregates," *Construction and Building Materials*, vol. 59, pp. 204-212, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[28] Shengtian Zhai et al., "Effect of Modified Rubber Powder on the Mechanical Properties of Cement-Based Materials," *Journal of Materials Research and Technology*, vol. 19, pp. 4141-4153, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] Ge Zhang, Yingzi Yang, and Huaming Li, "Calcium-Silicate-Hydrate Seeds as an Accelerator for Saving Energy in Cold Weather Concreting," *Construction and Building Materials*, vol. 264, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[30] Mahmoud Eissa et al., "Recent Efforts on Investigating the Effects of Recycled Rubber Content on the Mechanical Properties of Structural Concrete," *Discover Civil Engineering*, vol. 1, pp. 1-28, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[31] Iman Mohammadi, Hadi Khabbaz, and Kirk Vessalas, "Enhancing Mechanical Performance of Rubberised Concrete Pavements with Sodium Hydroxide Treatment," *Materials and Structures*, vol. 49, pp. 813-827, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[32] Jing Lv et al., "Shrinkage Properties of Self-Compacting Rubber Lightweight Aggregate Concrete: Experimental and Analytical Studies," *Materials*, vol. 12, no. 24, pp. 1-14, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[33] Sulagno Banerjee, and Jessy Rooby, "Strength Properties of Tyre Rubber Concrete," *International Journal of Recent Technology and Engineering*, vol. 8, no. 4, pp. 12345-12350, 2019. [CrossRef] [Google Scholar] [Publisher Link]