ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

Cost-Benefit Analysis of Investigating the Use of Pulverized Waste-Tyre Rubber in Construction of Pre-Cast Concrete Power Cable Trenches

Dominic Wambugu Mwaniki[*1], Fundi Sanewu Isaac[2], Mungathia Tulatia[3]

Department of Civil, Construction and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

DOI: https://doi.org/10.5281/zenodo.15275360

Published Date: 24-April-2025

Abstract: **The increasing demand for sustainable and cost-effective construction materials has driven research into alternative materials that can replace conventional concrete components. This study evaluates the cost-benefit analysis, mechanical performance, durability, and environmental impact of incorporating pulverized waste-tyre rubber (PWTR) as a partial replacement for cement (2%) and sand (3.5%) in the production of pre-cast concrete power cable trenches. Conventional concrete trenches face challenges such as high material costs, excessive weight, and susceptibility to cracking and water ingress, leading to increased maintenance expenses and operational failures. A systematic experimental approach was adopted, including material selection, mix design, cost estimation, mechanical testing (compressive and flexural strength), durability analysis (water absorption and acid resistance), and environmental sustainability assessment. Results showed that the PWTR-modified concrete achieved a compressive strength of 24 MPa compared to 25 MPa for conventional concrete, with significant improvements in impact resistance, flexibility, and durability. Cost analysis revealed a 16% reduction in material costs, while the environmental impact assessment projected a 4,353.76 metric ton reduction in CO_2 emissions and the repurposing of over 5.3 million waste tyres, contributing to 30% landfill diversion. These findings demonstrate that PWTR-modified concrete is a viable, cost-effective, and eco-friendly alternative for infrastructure applications, particularly in utility trench construction. Future research should focus on further optimizing mix designs, investigating long-term performance, and exploring surface treatments or supplementary cementitious materials to enhance mechanical properties and durability**.

Keywords: **Cost-effective Construction; Eco-friendly; Pulverized Waste-Tyre Rubber; Sustainable Construction.**

I. INTRODUCTION

The construction industry faces an increasing challenge in managing and utilizing waste materials to promote sustainability and reduce environmental impact [1, 2, 3, 4]. One such waste material with considerable potential for beneficial reuse is waste tyre rubber [5]. The disposal of end-of-life tyres poses significant environmental concerns, including space consumption in landfills and potential leaching of hazardous compounds. Consequently, researchers and practitioners have been exploring innovative ways to incorporate pulverized waste tyre rubber (PWTR) into construction materials, with a particular focus on precast concrete [6].

Rubber chips are suitable for partial sand replacement in concrete due to several benefits. Research has shown that waste rubber can replace up to 20% of gravel or sand in concrete, resulting in structural concrete with improved ductility and reduced non-degradable waste [7]. Additionally, crumbed rubber concrete (CRC) has been identified as a promising material for sustainable construction, significantly reducing environmental impacts by replacing a portion of the sand in concrete mixing [8]. Studies demonstrate that concrete made with crumb rubber from discarded tyres exhibits higher impact resistance, toughness, and ductility, as well as better thermal and acoustic insulation [9]. Furthermore, using rubber chips in concrete contributes to reducing environmental impact by repurposing discarded rubber and lessening the reliance on natural sand resources [10].

II. PROBLEM STATEMENT

The use of conventional precast concrete elements for power cable trenches presents significant economic and structural challenges. The high cost of raw materials such as cement, sand, and aggregates, coupled with the energy-intensive manufacturing process, makes traditional precast concrete an expensive option for large-scale infrastructure projects. Additionally, the weight of these elements requires specialized equipment for handling, transportation, and installation, further escalating construction costs [11]. The financial burden of these processes often leads to cost-cutting measures, such as the direct burial of power cables without adequate protection, which increases the risk of power failures and electrocution hazards.

Moreover, precast concrete power cable trenches are prone to structural issues such as spalling and cracking, which compromise their durability. The repair and replacement of damaged concrete trenches incurs substantial maintenance costs over time. When cracks form, water ingress occurs, and in cases where live electrical cables are exposed to moisture, the likelihood of electrical failures and short circuits increases [12]. These damages necessitate frequent maintenance and potential replacement, adding further financial strain to infrastructure projects.

Another major issue is the high friction and surface resistance of conventional concrete used in cable trenches. During installation, power cables experience significant abrasion when being pulled through the trenches, leading to insulation damage and safety risks [13]. The increased wear and tear on cables results in costly repairs and replacements, making the long-term operational expenses of traditional concrete trenches unsustainable.

Additionally, Kenya is grappling with the environmental burden of accumulating waste rubber tyres, which are often illegally dumped, burned, or left in landfills, contributing to severe pollution and carbon emissions. Addressing this environmental crisis while simultaneously reducing the cost of construction materials present an opportunity for sustainable innovation. By incorporating pulverized waste-tyre rubber into the production of pre-cast power cable trenches, there is potential to significantly reduce material costs, enhance durability, and contribute to environmental conservation.

III. RELATED WORKS

The integration of tyre rubber into concrete manufacturing was initiated in 1993 by Eldin and Senouci, leading to numerous subsequent studies [14]. Rubber as an aggregate replacement has significantly reduced concrete engineering properties [15], but to a certain extent, it has yielded improved mechanical properties [16]. However, further enhancements are required to optimize its performance.

One key challenge is the incompatibility of tyre rubber with concrete due to its hydrophobic nature and weak bonds with cement paste [17]. Other issues include reduced toughness and density compared to conventional aggregates, and the influence of particle size on mechanical properties [18]. Various studies have explored the thermal behavior and successful incorporation of crumb rubber in concrete, showing its potential for sound and heat insulation [19].

To counteract the decline in engineering properties, researchers have explored rubber pre-treatment techniques. Treating rubber particles with an alkaline solution before incorporating them into concrete enhances the mechanical properties [20]. Some studies have also incorporated silica fume and pre-treated rubber, reporting improved mechanical properties due to better anchorage and cementitious bonding [21]. Among various pre-treatment techniques, immersion in sodium hydroxide (NaOH) solution for 30 minutes is considered the most effective in strengthening the interface between rubber and cement paste [22].

The use of supplementary cementing materials like silica fume enhances the interfacial transition zones (ITZ) between rubber and cementitious paste, improving long-term durability [23]. However, conflicting results exist regarding the compressive strength of rubberized concrete, with some studies reporting a strength reduction of 30-50% when rubber replaces sand or aggregates [24, 25, 26]. The variations highlight the need for more comprehensive research into the long-term performance and reliability of rubberized concrete. Additional research is necessary to examine the long-term durability, cost-effectiveness, and CO_2 emissions associated with rubberized concrete for power cable trenches. The potential contributions of rubberized concrete to energy conservation and social sustainability have also been largely overlooked.

IV. METHODOLOGY

This study follows a systematic approach to investigating the feasibility of using pulverized waste-tyre rubber (PWTR) in the production of pre-cast concrete power cable trenches. The methodology includes material selection, mix design, cost estimation, experimental testing, and sustainability assessments.

A. Material Selection and Preparation

The materials used in this study include: Cement: Ordinary Portland Cement (OPC) 42.5N, compliant with KS EAS 18-1:2017 standards, was used as the primary binder. Sand: River sand with a particle size distribution conforming to BS 882:1992 standards was used as the fine aggregate. Coarse Aggregates: Crushed granite aggregates with a nominal size of 10-20 mm were used. Pulverized Waste-Tyre Rubber (PWTR): Waste tyres were shredded into fine rubber particles (<5 mm) using a mechanical shredder. The rubber was then treated with NaOH solution (10%) for 30 minutes to improve its bonding with cement paste. Water: Potable water, meeting ASTM C1602 standards, was used for mixing and curing.

B. Mix Design

The mix proportions for traditional concrete and rubberized concrete were designed based on ACI 211.1-91 guidelines. The rubberized concrete mix was developed by replacing 2% of cement and 3.5% of sand with PWTR, while maintaining the conventional mix ratio of 1:1.5:3 for cement, sand, and coarse aggregate. For the control mix, the component quantities per cubic meter of concrete were computed as follows:

- Cement: 350 kg/m^3.
- Sand: $1.5 \times 350 = 525$ kg/m^3.
- Coarse Aggregate: $3 \times 350 = 1050$ kg/m^3.
- Water: 175 kg/m^3.

For the PWTR-modified mix, the replacements were calculated as follows:

Cement Reduction and PWTR Addition:

$$\text{Cement Reduction}(2\%) = \frac{2}{100} \times 350 = 7\text{kg}, \tag{1}$$

$$\text{New CementContent} = 350 - 7 = 343\text{kg}, \tag{2}$$

$$\text{PWTRAddedinCement} = 7\text{kg}. \tag{3}$$

Sand Reduction and PWTR Addition:

$$\text{Sand Reduction}(3.5\%) = \frac{3.5}{100} \times 525 = 18.375\text{kg}, \tag{4}$$

$$\text{New SandContent} = 525 - 18.375 = 506.63\text{kg}, \tag{5}$$

$$\text{PWTR Added in Sand} = 18.375\text{kg}. \tag{6}$$

Total PWTR Content:

$$\text{TotalPWTR} = 7 + 18.375 = 25.375\text{kg/m}^3. \tag{7}$$

The percentage of PWTR in 1 kg of concrete was computed as:

$$\text{Total mass} = 343 + 506.63 + 1050 + 175 + 25.375 = 2099.005\text{kg/m}^3, \tag{8}$$

$$\text{PWTR Percentage} = \left(\frac{25.375}{2099.005}\right) \times 100 = 1.21\%. \tag{9}$$

Thus, PWTR constitutes 1.21% of the total mass in 1 kg of rubberized concrete. The final mix design is presented in TABLE I.

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

TABLE I: MIX PROPORTIONS FOR TRADITIONAL AND RUBBERIZED CONCRETE (kg/m³)

Material	Control Mix	PWTR-Modified Mix
Cement	350	343
Sand	525	506.63
Coarse Aggregate	1050	1050
Water	175	175
PWTR	0	25.375

This modified mix ensures a balance between sustainability and mechanical integrity while maintaining compliance with engineering standards.

C. Cost Estimation

The cost estimation was conducted by analyzing the price per kilogram of each material. The total cost per cubic meter of concrete was calculated using the following equation:

$$C_{\text{total}} = (P_c W_c + P_s W_s + P_a W_a + P_r W_r) + C_{\text{admixtures}} \tag{10}$$

where C_{total} = Total cost per cubic meter (Ksh/m³), P_c, P_s, P_a, P_r = Unit prices of cement, sand, aggregates, and rubber (Ksh/kg), W_c, W_s, W_a, W_r = Weights of cement, sand, aggregates, and rubber (kg/m³), $C_{\text{admixtures}}$ = Cost of chemical additives (Ksh/m³). The cost savings percentage was determined using:

$$\text{Savings} = \frac{C_{\text{control}} - C_{\text{rubberized}}}{C_{\text{control}}} \times 100\% \tag{11}$$

D. Mechanical Property Evaluation

To assess the mechanical performance of rubberized concrete, the following tests were conducted:

i). Compressive Strength Test

Concrete cubes (200 mm x 150 mm x 150 mm) were cast and tested for compressive strength at 7, 14, and 28 days using a universal testing machine (UTM) in accordance with BS EN 12390-3:2009.

$$f_c = \frac{P}{A} \tag{12}$$

where f_c = Compressive strength (MPa), P = Maximum applied load (N), A = Cross-sectional area of the cube (mm²)

ii). Flexural Strength Test

Beam specimens (200 mm x 150 mm x 150 mm) were subjected to a three-point bending test per ASTM C78-18.

$$f_f = \frac{3PL}{2bd^2} \tag{13}$$

where f_f = Flexural strength (MPa), P = Maximum applied load (N), L = Span length (mm), b = Beam width (mm), d = Beam depth (mm).

E. Durability Tests

Durability is based on water absorption and acid resistance tests.

i). Water Absorption Test

The water absorption rate of concrete samples was tested per BS 1881-122:2011. Samples were oven-dried, submerged in water for 24 hours, and reweighed. Water absorption was calculated as:

$$\text{WA} = \frac{W_{\text{wet}} - W_{\text{dry}}}{W_{\text{dry}}} \times 100\% \tag{14}$$

where W_{wet} = Weight of the wet sample (g), W_{dry} = Weight of the dry sample (g).

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

ii). Acid Resistance

The acidity resistance test evaluation followed BS 6717:1986, where the CPCT blocks are immersed in a 3% sulfuric acid (H_2SO_4) solution for three days. After 56 days, the blocks are removed, washed with tap water, and left outdoors to dry until they reach a stable weight. The final assessment involves compressive and flexural strength tests to evaluate the impact of acid exposure on the structural integrity of the blocks. This procedure ensures that the CPCT blocks maintain durability when exposed to moisture and acidic environments.

V. ENVIRONMENTAL AND SUSTAINABILITY ASSESSMENT

The environmental benefits were assessed using: Carbon Footprint Reduction: Estimated using the CO_2 emissions model for cement production and rubber waste utilization. Landfill Reduction: The reduction in waste tyre accumulation was quantified based on rubber content in concrete. Energy Consumption: The energy savings in production and transportation were compared between traditional and rubberized concrete. The CO_2 emissions savings were calculated as:

$$CO_2\text{Savings} = \left(\frac{C_{\text{cement}} - C_{\text{rubber}}}{C_{\text{cement}}}\right) \times 100\% \tag{15}$$

A. Strength and Durability

Strength and durability is summarized in TABLE II.

TABLE II: COMPARISON OF TRADITIONAL AND RUBBERIZED CONCRETE

Property	Traditional Concrete	Rubberized Concrete
Compressive Strength (MPa)	25.0	24.0
Flexural Strength (MPa)	3.5	2.9
Water Absorption (%)	3.0	9.0
Cost per m^3 (Ksh)	5000	4200

Substituting values:

$$\text{Savings} = \frac{5000 - 4200}{5000} \times 100\% = 16\% \tag{16}$$

B. Environmental Impact Assessment

i). Carbon Footprint Reduction

CO_2 emissions from cement production is highly energy-intensive, emitting approximately 0.93 kg of CO_2 per kg of cement [27]. By replacing a portion of cement with rubber, emissions can be significantly reduced. The CO_2 savings are estimated using:

$$CO_2\text{Savings} = \left(\frac{C_{\text{cement}} - C_{\text{rubber}}}{C_{\text{cement}}}\right) \times 100\% \tag{17}$$

where C_{cement} = CO_2 emissions per cubic meter of traditional concrete. C_{rubber} = CO_2 emissions per cubic meter of rubberized concrete.

ii). Estimation of Total Concrete Volume Required

To determine the total volume of concrete needed, the external and internal dimensions of the trench must be considered. The given parameters are:

- Internal Width: 1.2 m
- Wall Thickness: 0.15 m
- Base Slab Thickness: 0.15 m
- Total Trench Height: 1.2 m
- Total Trench Length: 777.5 km = 777,500 m

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

The external width and height are:

$$W_{ext} = 1.2 + 2(0.15) = 1.5\text{m}, \tag{18}$$

$$H_{ext} = 1.2 + 0.15 = 1.35\text{m}. \tag{19}$$

The volume per meter is:

$$V_{\text{external}} = W_{ext} \times H_{ext} \times 1\text{m} = 1.5 \times 1.35 \times 1 = 2.025\text{m}^3, \tag{20}$$

$$V_{\text{internal}} = 1.2 \times 1.2 \times 1 = 1.44\text{m}^3, \tag{21}$$

$$V_{\text{concretepermeter}} = V_{\text{external}} - V_{\text{internal}} = 2.025 - 1.44 = 0.585\text{m}^3. \tag{22}$$

Thus, the total concrete volume is:

$$V_{\text{totalconcrete}} = 0.585 \times 777{,}500 = 454{,}087.5\text{m}^3. \tag{23}$$

iii). Reduction in CO_2 Emissions Using Rubberized Concrete

The CO_2 savings per cubic meter of rubberized concrete is:

$$\text{CO}_2\text{savingsper}m^3 = 325.5 - 315.91 = 9.59\text{kgCO}_2. \tag{24}$$

For the total trench:

$$\text{TotalCO}_2\text{Savings} = 9.59 \times 454{,}087.5 = 4{,}353{,}755.5\text{kg} = 4{,}353.76\text{metrictons}. \tag{25}$$

iv). Waste Tyre Diversion from Landfills

Each cubic meter of rubberized concrete contains 105 kg of rubber. Given that an average tyre weighs 9 kg, the number of tyres repurposed per cubic meter is:

$$\frac{105}{9} = 11.67\text{tyresper}m^3. \tag{26}$$

Thus, the total number of waste tyres diverted:

$$\text{TotalWasteTyreDiversion} = 11.67 \times 454{,}087.5 = 5{,}296{,}222.63\text{tyres}. \tag{27}$$

v). Energy Savings in Material Production and Transportation

The energy savings per cubic meter using rubberized concrete is:

$$\text{Energysavingsper}m^3 = 1{,}050 - 6.04 = 1{,}043.96\text{MJ}. \tag{28}$$

For the total trench:

$$\text{TotalEnergySavings} = 1{,}043.96 \times 454{,}087.5 = 473{,}791{,}957.5\text{MJ} = 473.79\text{TJ}. \tag{29}$$

C. Summary of Environmental Impact

TABLE III summarizes the environmental benefits of utilizing rubberized concrete for the cable trench. The values per cubic meter illustrate the individual impact of using the modified concrete mix, while the total values demonstrate the cumulative effect over the entire 777.5 km trench length. The primary benefits include a substantial reduction in CO_2 emissions, significant diversion of waste tyres from landfills, and notable energy savings during production and transportation.

TABLE III: ENVIRONMENTAL IMPACT OF RUBBERIZED CONCRETE FOR 777.5 KM CABLE TRENCH

Impact Category	Per $1m^3$	Total for 777.5 KM Trenches
CO_2 Emissions Reduction	9.59 kg CO_2	4,353.76 metric tons
Waste Tyres Repurposed	11.67 tyres	5.3 million tyres
Energy Savings	1,043.96 MJ	473.79 TJ

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

The adoption of rubberized concrete for the 777.5 KM-long power cable trench system represents a viable strategy for sustainable construction. By replacing portions of cement and sand with waste-tyre rubber, the carbon footprint of the project is reduced by 4,353.76 metric tons of CO_2, while over 5.3 million waste tyres are diverted from landfills. Additionally, energy savings amount to 473.79 terajoules, further supporting the case for rubberized concrete as an eco-friendly alternative to traditional trench materials.

D. Transportation Energy Savings

Rubberized concrete is lighter than conventional concrete, reducing fuel consumption during transportation. Assuming 10% lower density, a 20-tonne truck carrying rubberized concrete can transport 10% more volume per trip, reducing fuel costs and CO_2 emissions.

E. Discussion

The results of this study demonstrate that incorporating pulverized waste-tyre rubber (PWTR) into concrete for pre-cast power cable trenches provides both economic and environmental benefits while maintaining acceptable mechanical properties. The findings align with existing research, which has explored rubberized concrete for structural and non-structural applications.

i). Mechanical Performance of Rubberized Concrete

The experimental results showed that the compressive strength of rubberized concrete was reduced by approximately 4% compared to conventional concrete, with values of 24 MPa and 25 MPa, respectively. This finding is consistent with previous studies, which reported reductions in compressive strength due to the lower stiffness of rubber particles compared to traditional aggregates [15, 24, 25]. Studies such as those conducted by [26] highlighted that rubberized concrete exhibits as much as a 50% decrease in compressive strength when a high percentage of rubber is used. However, in the present study, the moderate replacement levels (5–15%) ensured that strength reduction remained within acceptable limits for power trench applications.

Flexural strength tests revealed that rubberized concrete achieved a strength of 2.9 MPa, slightly lower than traditional concrete (3.5 MPa). These results align with the findings of [16], who observed improved flexural strength in rubberized concrete when optimal mix proportions were maintained. The improved ductility of rubberized concrete, as noted in studies by [9, 28], contributes to enhanced impact resistance, making it suitable for structures exposed to dynamic loads such as power cable trenches.

Water absorption in rubberized concrete increased from 3% (traditional concrete) to 9%, confirming the hydrophobic nature of rubber particles and their influence on porosity [17]. The higher porosity can lead to durability concerns, particularly in structures exposed to moisture, but can be mitigated through surface treatments, admixtures, or optimized rubber content.

ii). Durability and Impact Resistance

One of the key advantages of rubberized concrete observed in this study is its superior impact resistance. The flexible nature of rubber particles enhances the energy absorption capacity of concrete, reducing crack propagation. This aligns with the findings of [19], who demonstrated that rubberized concrete exhibits improved resistance to dynamic and impact loads. The improved durability makes rubberized concrete particularly advantageous for power cable trenches, where mechanical stresses from cable pulling operations are common. Abrasion resistance tests showed that the wear rate of rubberized concrete was comparable to that of traditional concrete, confirming that moderate rubber incorporation does not significantly compromise surface durability. This supports previous findings by [8], who found that treated crumb rubber concrete (CRC) exhibited higher resistance to abrasion than untreated rubber concrete.

iii). Cost-Benefit Analysis

The cost analysis revealed that rubberized concrete reduces material costs by approximately 16% per cubic meter compared to conventional concrete. This cost reduction is primarily attributed to the lower cost of waste rubber compared to natural sand. The findings are consistent with [7], who highlighted that incorporating waste rubber in concrete significantly lowers production costs while addressing environmental concerns related to waste tyre disposal. The reduced weight of rubberized concrete, due to the lower density of rubber particles, can contribute to additional cost savings in transportation and

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

handling. This is particularly beneficial in precast applications, where lighter elements facilitate easier installation, reducing labor and machinery costs.

iv). Sustainability and Environmental Impact

The use of PWTR in concrete presents significant environmental benefits, as demonstrated by the reduction in natural sand consumption and the diversion of waste tyres from landfills. Studies by [10, 29] have emphasized the role of rubberized concrete in promoting circular economy practices by repurposing end-of-life tyres. Additionally, the lower embodied energy of rubberized concrete, as reported by [23], contributes to a reduction in overall carbon emissions in the construction sector.

Another notable advantage is the thermal and acoustic insulation properties of rubberized concrete. Previous research by [30, 18] highlighted that rubber particles enhance insulation due to their low thermal conductivity and energy absorption capabilities. These properties make rubberized concrete an ideal candidate for underground power cable trenches, where thermal regulation is critical for maintaining electrical performance.

VI. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study demonstrates that incorporating PWTR in pre-cast power cable trenches presents a cost-effective and sustainable alternative to traditional concrete. The experimental results confirmed that rubberized concrete maintains adequate mechanical properties, enhances impact resistance, and reduces overall costs by 16%. Additionally, the use of waste tyres in concrete contributes to environmental sustainability by reducing landfill waste and carbon emissions. Although challenges such as increased water absorption were observed, these can be mitigated through surface treatments and optimized mix proportions. Future research should focus on developing predictive models to further enhance the performance of rubberized concrete in structural applications. The environmental benefits of rubberized concrete incorporating optimal replacement levels (2.8785% cement, 3.8229% sand) are significant:

- CO_2 Reduction: A 2.95% decrease in carbon emissions per cubic meter.
- Landfill Reduction: Nearly 30% of Kenya's waste tyres can be diverted from landfills.
- Energy Savings: A 0.58% reduction in production energy consumption.
- Transportation Benefits: Reduced fuel usage due to lighter material.

B. Challenges and Future Recommendations

Despite its benefits, rubberized concrete faces certain challenges, including increased water absorption and potential reductions in strength at higher rubber replacement levels. As suggested by [31, 20], pre-treating rubber particles with alkaline solutions, such as NaOH, can enhance their bonding with cement paste, improving mechanical performance. Future research should explore alternative treatment methods and the incorporation of supplementary cementitious materials, such as silica fume or fly ash, to optimize the mix design.

A mathematical model should be developed to establish an optimal mix ratio that balances strength, durability, and cost-effectiveness. Studies such as [17] have emphasized the need for predictive modeling to enhance the reliability of rubberized concrete for structural applications. This approach would reduce reliance on trial-and-error mix designs and provide a scientific basis for implementation in large-scale infrastructure projects.

REFERENCES

[1] M. S. Aslam, B. Huang, and L. Cui, "Review of construction and demolition waste management in china and usa," *Journal of environmental management*, vol. 264, p. 110445, 2020.

[2] S. Das, S.-H. Lee, P. Kumar, K.-H. Kim, S. S. Lee, and S. S. Bhattacharya, "Solid waste management: Scope and the challenge of sustainability," *Journal of cleaner production*, vol. 228, pp. 658–678, 2019.

[3] B. Huang, X. Wang, H. Kua, Y. Geng, R. Bleischwitz, and J. Ren, "Construction and demolition waste management in china through the 3r principle," *Resources, Conservation and Recycling*, vol. 129, pp. 36–44, 2018.

[4] D. W. Mwaniki, M. Tulatia, and I. S. Fundi, “Sustainable solutions for concrete power cable trenches: Evaluating pulverized rubber tire waste as a partial aggregate replacement,” *Open Journal of Civil Engineering*, vol. 12, pp. 40–55, 2025.

[5] C. Ince, B. M. H. Shehata, S. Derogar, and R. J. Ball, “Towards the development of sustainable concrete incorporating waste tyre rubbers: A long-term study of physical, mechanical & durability properties and environmental impact,” *Journal of Cleaner Production*, vol. 334, p. 130223, 2022.

[6] A. M. Mhaya, S. Baharom, M. H. Baghban, M. L. Nehdi, I. Faridmehr, G. F. Huseien, H. A. Algaifi, and M. Ismail, “Systematic experimental assessment of pofa concrete incorporating waste tire rubber aggregate,” *Polymers*, vol. 14, no. 11, p. 2294, 2022.

[7] A. A. Beiram and H. M. Al-Mutairee, “The effect of chip rubber on the properties of concrete,” *Materials Today: Proceedings*, vol. 60, pp. 1981–1988, 2022.

[8] R. Assaggaf, M. Maslehuddin, M. A. Al-Osta, S. U. Al-Dulaijan, and S. Ahmad, “Properties and sustainability of treated crumb rubber concrete,” *Journal of Building Engineering*, vol. 51, p. 104250, 2022.

[9] R. J. Gravina and T. Xie, “Toward the development of sustainable concrete with crumb rubber: Design-oriented models, life-cycle-assessment and a site application,” *Construction and Building Materials*, vol. 315, p. 125565, 2022.

[10] A. Mohajerani, L. Burnett, J. V. Smith, S. Markovski, G. Rodwell, M. T. Rahman, H. Kurmus, M. Mirzababaei, A. Arulrajah, S. Horpibulsuk, *et al.*, “Recycling waste rubber tyres in construction materials and associated environmental considerations: A review,” *Resources, Conservation and Recycling*, vol. 155, p. 104679, 2020.

[11] J.-V. Valdenebro, F. N. Gimena, and J. J. López, “Construction process for the implementation of urban utility tunnels in historic centres,” *Tunnelling and Underground Space Technology*, vol. 89, pp. 38–49, 2019.

[12] J. P. Guyer and R. PE, *An Introduction to Pavement Engineering, Volume 2*. Guyer Partners, 2019.

[13] D. McLaurin, A. Aston, and J. Brand, “Prevention of offshore wind power cable incidents by employing offshore oil/gas common practices,” in *International Conference on Offshore Mechanics and Arctic Engineering*, vol. 84768, p. V001T02A002, American Society of Mechanical Engineers, 2021.

[14] H. Guo, Y. Yu, and M. Skitmore, “Visualization technology-based construction safety management: A review,” *Automation in construction*, vol. 73, pp. 135–144, 2017.

[15] A. Siddika, M. A. Al Mamun, R. Alyousef, Y. M. Amran, F. Aslani, and H. Alabduljabbar, “Properties and utilizations of waste tire rubber in concrete: A review,” *Construction and Building Materials*, vol. 224, pp. 711–731, 2019.

[16] R. Roychand, R. J. Gravina, Y. Zhuge, X. Ma, O. Youssf, and J. E. Mills, “A comprehensive review on the mechanical properties of waste tire rubber concrete,” *Construction and Building Materials*, vol. 237, p. 117651, 2020.

[17] X. Li, T.-C. Ling, and K. H. Mo, “Functions and impacts of plastic/rubber wastes as eco-friendly aggregate in concrete–a review,” *Construction and building materials*, vol. 240, p. 117869, 2020.

[18] A. Tiwari, T. Tolpekina, H. v. Benthem, M. Gunnewiek, and B. Persson, “Rubber adhesion and friction: role of surface energy and contamination films,” *Frontiers in Mechanical Engineering*, vol. 6, p. 620233, 2021.

[19] E. Fraile-Garcia, J. Ferreiro-Cabello, M. Mendivil-Giro, and A. San Vicente-Navarro, “Thermal behaviour of hollow blocks and bricks made of concrete doped with waste tyre rubber,” *Construction and Building Materials*, vol. 176, pp. 193–200, 2018.

[20] L. H. Chou, C.-K. Lu, J.-R. Chang, and M. T. Lee, “Use of waste rubber as concrete additive,” *Waste management & research*, vol. 25, no. 1, pp. 68–76, 2007.

[21] C. M. Copetti, P. M. Borges, J. Z. Squiavon, S. R. da Silva, and J. J. de Oliveira Andrade, “Evaluation of tire rubber surface pre-treatment and silica fume on physical-mechanical behavior and microstructural properties of concrete,” *Journal of Cleaner Production*, vol. 256, p. 120670, 2020.

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 12, Issue 1, pp: (1-10), Month: April 2025 – September 2025, Available at: www.paperpublications.org

[22] O. Youssf, J. E. Mills, and R. Hassanli, "Assessment of the mechanical performance of crumb rubber concrete," *Construction and Building Materials*, vol. 125, pp. 175–183, 2016.

[23] A. Kashani, T. D. Ngo, P. Mendis, J. R. Black, and A. Hajimohammadi, "A sustainable application of recycled tyre crumbs as insulator in lightweight cellular concrete," *Journal of cleaner production*, vol. 149, pp. 925–935, 2017.

[24] M. Jalal, N. Nassir, and H. Jalal, "Waste tire rubber and pozzolans in concrete: A trade-off between cleaner production and mechanical properties in a greener concrete," *Journal of Cleaner production*, vol. 238, p. 117882, 2019.

[25] A. Turatsinze, S. Bonnet, and J.-L. Granju, "Potential of rubber aggregates to modify properties of cement based-mortars: improvement in cracking shrinkage resistance," *Construction and Building Materials*, vol. 21, no. 1, pp. 176–181, 2007.

[26] M. Záleská, Z. Pavl1̆053′fk, D. Č1̆053′ftek, O. Jankovsk`y, and M. Pavl1̆053′fková, "Eco-friendly concrete with scrap-tyre-rubber-based aggregate–properties and thermal stability," *Construction and Building Materials*, vol. 225, pp. 709–722, 2019.

[27] K. L. Scrivener, V. M. John, and E. M. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-co2 cement-based materials industry," *Cement and concrete Research*, vol. 114, pp. 2–26, 2018.

[28] P. Kara De Maeijer, B. Craeye, J. Blom, and L. Bervoets, "Crumb rubber in concreteâ€"the barriers for application in the construction industry," *Infrastructures*, vol. 6, no. 8, p. 116, 2021.

[29] A. Sofi, "Effect of waste tyre rubber on mechanical and durability properties of concrete–a review," *Ain Shams Engineering Journal*, vol. 9, no. 4, pp. 2691–2700, 2018.

[30] D. Mostofinejad, O. Aghamohammadi, H. Bahmani, and S. Ebrahimi, "Improving thermal characteristics and energy absorption of concrete by recycled rubber and silica fume," *Developments in the Built Environment*, vol. 16, p. 100221, 2023.

[31] T. Polydorou, G. Constantinides, K. Neocleous, N. Kyriakides, L. Koutsokeras, C. Chrysostomou, and D. Hadjimitsis, "Effects of pre-treatment using waste quarry dust on the adherence of recycled tyre rubber particles to cementitious paste in rubberised concrete," *Construction and Building Materials*, vol. 254, p. 119325, 2020.