Optimization of Pavement Design Using Tire-Derived Aggregate (TDA)

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***Abstract*— This study explores the potential of Tire-Derived Aggregate (TDA), a recycled material from scrap tires, as a sustainable alternative in pavement construction. TDA's unique properties, such as high resilience, lightweight design, and excellent drainage capabilities, offer promising solutions to common pavement issues like cracking, rutting, and water damage. The research compares TDA's performance against traditional aggregates in sub-base and base layers, focusing on key metrics like load-bearing capacity, durability, and environmental impact. To better understand its benefits, the study develops a modified pavement design framework using advanced modeling techniques like finite element analysis, alongside empirical-mechanistic methods. Field tests further assess TDA's performance under real-world conditions, with data collection over time providing insights into its long-term effectiveness. This research not only highlights the environmental benefits of using TDA, such as reducing waste tire stockpiles and lowering greenhouse gas emissions, but also explores its economic potential, with cost savings derived from reduced reliance on virgin materials and longer pavement lifespans. Ultimately, the findings position TDA as a transformative material for road construction, offering a sustainable, cost-effective, and resilient solution for modern infrastructure needs, and demonstrating how recycling can play a critical role in creating a greener, more sustainable future.**

***Index Terms*—Tire-Derived Aggregate (TDA), Rigid Pavement, Aggregate Replacement, mix design, PQC, Concrete Testing.**

I. INTRODUCTION

Pavement design is a crucial element in civil engineering, as it directly influences the performance, durability, and sustainability of road infrastructure. Traditionally, materials like natural aggregates and bitumen have been the go-to components for constructing pavements. However, with growing concerns about the depletion of natural resources, rising construction costs, and the increasing volume of waste materials, there's an urgent need for alternatives. One promising solution is Tire Derived Aggregate (TDA), made from shredded, discarded tires. This innovative material not only helps reduce tire waste, which contributes significantly to landfills, but also decreases the demand for natural aggregates. TDA's lightweight and flexible properties make it an attractive choice, allowing for thinner pavement layers and lower overall weight, improving the efficiency of road structures. It also offers mechanical advantages, such as better drainage, reduced cracking, and enhanced thermal performance. Moreover, TDA's ability to reduce thermal expansion and noise makes it an environmentally friendly option that boosts the durability and sustainability of roads. Despite these advantages, optimizing TDA for widespread use requires understanding its behavior under various environmental and load conditions.

This study seeks to explore the potential of TDA in pavement design by evaluating its mechanical, thermal, and environmental properties, comparing its performance to traditional materials, and assessing its cost-effectiveness. The aim is to determine whether TDA can improve pavement integrity, load-bearing capacity, water drainage, and longevity, while also providing economic savings in both construction and long-term maintenance. By examining TDA's role in creating more sustainable, durable, and cost-efficient road infrastructure, this research aligns with the global push for greener construction practices and addresses both the growing challenge of tire waste and the need for optimized road materials.

II. RESEARCH GAP

1. The previous work done with TDA is the replacement of 5-10% with M30 concrete
2. Lack of studies on the durability and long-term behaviour of TDA in pavements under various environmental conditions and traffic loads.
3. Need for research on the ideal proportion of TDA with other materials for different pavement types

to achieve optimal strength, flexibility, and durability.
4. Insufficient research on the potential environmental risks (e.g., leaching of contaminants) and sustainability of TDA in pavement applications

III. OBJECTIVES

1.Prepare a mix design with 10-30% TDA replacement enhances crack resistance, fatigue performance, and moisture resistance.
2.To determine the influence of TDA on the mechanical properties (strengths, durability) of pavements.
3.Providing insights into optimal replacement percentages for maintaining pavement integrity in various climates.
4.Examine the environmental benefits of using TDA. Assess the potential of TDA replacement to reduce the environmental footprint of pavements while maintaining performance.

IV. METHODOLOGY

The methodology for optimizing pavement design with Tire-Derived Aggregate (TDA) is a step-by-step approach that focuses on understanding how TDA affects the performance of pavements. First, TDA and traditional aggregates are collected and tested for key characteristics like density, strength, and permeability.

Mix designs are calculated by replacing traditional aggregates with varying amounts of TDA—10%, 20%, and 30%. The materials used in the concrete mix, including Ordinary Portland Cement (OPC) grade 53, fine aggregates (crushed sand), and coarse aggregates (crushed granite), are all tested to ensure they meet the necessary standards.

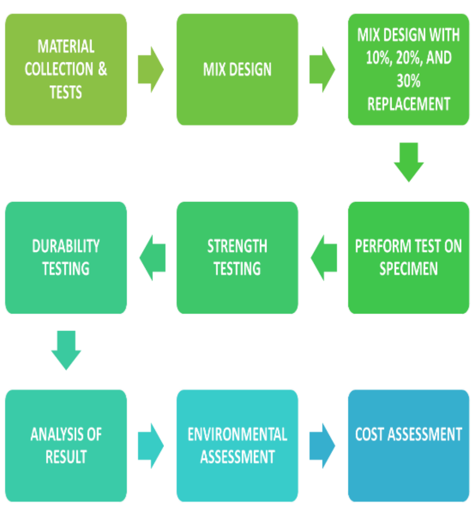

CHART NO.1

4.1. MATERIAL COLLECTION AND TESTING

- CEMENT

Type: Ordinary Portland Cement (OPC)
Grade: 53 Grade

- COARSE AGGREGATE

Size: 20 mm nominal size
Shape: Angular and crushed (Crushed Granite)
Specific gravity: 2.64

- TDA

Size Range: 10–30 mm
Specific gravity: 1.15 (by Pycnometer)
The Flaky Index is 10.46%. < 15 %
Elongation Index is 2.15%

Fig. no :1 TDA

4.2. MIX DESIGN

Final Approximate Mix Proportions M45 (for 1 m³ of concrete):

- Cement: 392 kg
- Water: 149 kg
- Coarse Aggregate: 1223 kg (SSD - Saturated Surface Dry)
- Fine Aggregate: 729 kg (SSD)
- Admixture (Superplasticizer): 3.1 kg (if used)
- Water-Cement Ratio: 149 / 392 = 0.38
  1: 1.85: 3.11: 0.38

(Mix design by is code method, IS code referred for mix design are IRC:44, IRC:58, IRC:15, IS:10262)

4.3. MIX DESIGN WITH 10% TDA REPLACEMENT

(Assumptions for TDA:

Specific Gravity of TDA: We'll assume a specific gravity of 1.15 for the tire-derived aggregate. This can vary, so it's crucial to obtain the actual value for your TDA source.

Water Absorption of TDA: TDA typically has low water absorption. We'll assume 0% for simplicity in this initial calculation. However, it's good practice to check this for your specific TDA.

Size of TDA: We'll assume the TDA is within a similar size range as the coarse aggregate it's replacing (e.g., a portion of the 20mm fraction).)

Mix Proportions (for 1 m³ of concrete with 10% TDA replacement by volume):

- Cement: 392 kg
- Water: 149 kg
- Natural Coarse Aggregate (SSD): 1096 kg (rounded)
- Tire-Derived Aggregate (SSD): 51 kg (rounded)
- Fine Aggregate (SSD): 729 kg
- Admixture (Superplasticizer): 3.1 kg (if used)
- Water-Cement Ratio: 0.38

4.5.MIX DESIGN WITH 20% TDA REPLACEMENT

Mix Proportions (for 1 m³ of concrete with 20% TDA replacement by volume):

- Cement: 392 kg
- Water: 149 kg
- Natural Coarse Aggregate (SSD): 975 kg
- Tire-Derived Aggregate (SSD): 102 kg
- Fine Aggregate (SSD): 729 kg
- Admixture: 3.1 kg
- Water-Cement Ratio: 0.38

4.6. MIX DESIGN WITH 25% REPLACEMENT

Mix Proportions (for 1 m³ of concrete with 25% TDA replacement by volume):

- Cement: 392 kg
- Water: 149 kg
- Natural Coarse Aggregate (SSD): 911 kg
- Tire-Derived Aggregate (SSD): 127.5 kg
- Fine Aggregate (SSD): 729 kg
- Admixture: 3.1 kg
- Water-Cement Ratio: 0.38

4.6 MIX DESIGN WITH 30% REPLACEMENT

Mix Proportions (for 1 m³ of concrete with 30% TDA replacement by volume):

- Cement: 392 kg
- Water: 149 kg
- Natural Coarse Aggregate (SSD): 848 kg
- Tire-Derived Aggregate (SSD): 153 kg
- Fine Aggregate (SSD): 729 kg
- Admixture: 3.1 kg
- Water-Cement Ratio: 0.38

V. TESTS

5.1. Strength Testing

These tests assess the load-bearing capacity of the blocks.

- **Compressive Strength Test**
  Evaluate the block's ability to resist crushing loads. (IS 516:1959)

Fig. no :2 Compressive Strength Test

- **Flexural Strength Test**
  Measure the block's ability to resist bending or tensile stress. (IS 516:1959)

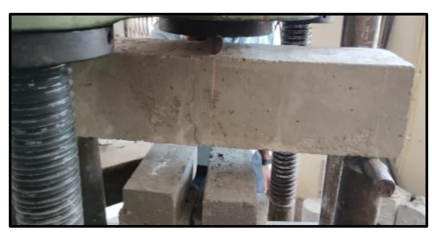

Fig. no :3 Flexural Strength Test

- **Splitting Tensile Strength Test**
  Assess the block's resistance to tensile stress indirectly. (IS 5816:1999)

Fig. no :4 Splitting Tensile Strength Test

2. Durability Testing

These tests ensure the blocks can withstand environmental and operational stresses.

- **Compressive Strength Test**
  Evaluate the block's ability to resist crushing loads. (IS 516:1959)

Fig. no :5 Compressive Strength Test

- **Water Absorption Test**
  Evaluate porosity and potential degradation from water ingress. (IS456:2000)

- **Pull Out Test**
  The force required to pull out the insert is correlated with the compressive strength of concrete.

VI. RESULTS

6.1 COMPRESSIVE STRENGTH TEST

	3 Days	**7 Days**	**28 Days**
Conventional	24.58	41.26	51.88
10% TDA	22.44	32.94	53.55
20% TDA	20.56	31.12	40.10
25%TDA	16.09	26.33	39.74
30%TDA	11.56	18.79	28.91

Table no:1 Average results of compressive strength test

6.2 FLEXURAL STRENGTH TEST

	3 Days	**7 Days**	**28 Days**
Conventional	3.8	4.99	5.22
10% TDA	3.6	4.82	5.06
20%TDA	3.19	4.88	4.41
25% TDA	2.15	3.026	4.00
30%TDA	1.80	2.66	3.38

Table no:2 Average results of flexural strength test

6.3 SPLIT TENSILE STRENGTH TEST

Replacement	3 days (MPa)	7 days (MPa)	28 days (MPa)
Conventional	2.96	3.6	4.1
10% TDA	2.73	3.2	3.7
20% TDA	2.53	3.1	3.53
25% TDA	2.11	3.04	3.76
30% TDA	1.8	2.66	3.38

Table no:3 Average results of split tensile strength test

6.4. DURABILITY TESTING

6.4.1.COMPRESSIVE STRENGTH TEST

25% TDA	45 Days	60 Days	90 Days
Sample1(Mpa)	41.76	43.76	50.04
Sample2(Mpa)	40.08	42.15	43.82
Sample3(Mpa)	39.4	41.76	44.06

Table no:4 Average results of compressive strength test

6.4.2. PULL OUT TEST

	3 Days	7 Days	28 Days
10% TDA	1.82	2.95	3.18
20% TDA	1.91	2.04	3.26
25% TDA	1.71	2.04	3.16
30% TDA	1.69	2.99	3.72

Table no:5 Average results of pull-out test

VII. ENVIRONMENTAL ASSESSMENT

1. **Waste Tire Recycling & Landfill Reduction**

266700 kg (266.7 tons) of TDA is used instead of virgin aggregates.
Every ton of TDA diverts about **1 ton of waste tires** from landfills.
Benefit: Reduces landfill use and prevents long-term pollution caused by buried tires (e.g., leachate, fires, pests).

2. **Reduced Carbon Footprint**
3. **Embodied Carbon Savings:**

Mining and transporting 1 ton of natural aggregate emits roughly **5–20 kg CO_2**.
Saving **266.7 tons** × average **12.5 kg CO_2/ton = ~971 kg CO_2 saved**.
Tire recycling processes do have emissions, but **TDA typically has lower overall CO_2 impact** compared to producing virgin stone aggregate.

4. **Energy Savings**

Virgin aggregate production is energy intensive.
Recycling tires into TDA uses about **one-third** of the energy compared to producing new aggregates.
Benefit: Less fossil fuel usage, supporting climate action goals.

5. **Potential Challenges (Managed)**

Leaching Risk: Minimal if properly processed TDA is used (washed, clean).
Durability & Performance: TDA is lighter and more elastic — great for drainage layers but needs engineering checks for high-load pavements.

VIII. CONCLUSION

1.Strength Performance:
From the strength tests carried out the results shows that the compressive strength of 25 % replaced concrete is optimistic replacement of aggregate for rigid pavement.

2.Mechanical Properties and Durability:
Although there was a gradual decrease in **compressive, flexural, and tensile strengths** with increasing TDA content, mixes with up to **10–30% TDA** retained sufficient mechanical strength for pavement applications.

3.Optimal Replacement and Climate Consideration:
The performance across varying TDA levels suggests that **10–20% TDA** is suitable in most climates, especially where **flexibility, thermal stress resistance, and sustainability** are priorities.

4.Environmental Benefits: The reuse of scrap tires in concrete has **significant environmental advantages**, including:

- Diverting waste from landfills,
- Reducing the demand for virgin aggregates,
- Lowering the carbon footprint of concrete production.

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