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Performance of Concrete with Plastic Waste as Fine Aggregate

Shaik Munwar[1], Sk. Abdulkareem[2]
[1]PG Scholar, Department of Civil Engineering, Chalapathi Institute of Technology(Autonomous), Abburi Raghavaiah Nagar, CITY College Rd, Mothadaka, Andhra Pradesh, India-522016.
[2]Assistant Professor, Department of Civil Engineering, Chalapathi Institute of Technology(Autonomous), Abburi Raghavaiah Nagar, CITY College Rd, Mothadaka, Andhra Pradesh, India-522016.

Abstract- Pavements form a critical component of the transportation infrastructure, providing a safe, smooth, and durable surface for the movement of vehicles ranging from two-wheelers to heavy-duty trucks. The performance of pavements directly influences transportation efficiency, road safety, vehicle operating costs, and the overall comfort of commuters. A well-constructed and maintained pavement ensures smooth traffic flow, reduces wear and tear on vehicles, and minimizes travel time, thereby supporting economic growth and societal mobility. Conversely, poor pavement conditions lead to discomfort, increased maintenance costs, accidents, and higher energy consumption. The deterioration of pavements is a multifaceted problem resulting from both mechanical and environmental stresses. Mechanically, pavements are subjected to repeated traffic loading, which ranges from light two-wheelers to heavy commercial vehicles such as trucks and buses. The intensity, frequency, and axle configuration of these loads significantly influence pavement performance. Over time, heavy loading can cause surface deformations, cracking, rutting, and fatigue failure, particularly in the surface course and base course, which bear the majority of the applied stresses. The surface course may develop rutting, potholes, and micro-cracks, while the base course can suffer from structural weakening and loss of load-bearing capacity if not properly designed and constructed. Environmental factors also play a critical role in pavement deterioration. Rainfall, flooding, and water infiltration can weaken the subgrade, erode materials, and cause pavement settlement or potholing. Seasonal temperature variations lead to expansion and contraction cycles, contributing to thermal cracking, while extreme events such as earthquakes and heavy storms can induce abrupt structural damage. The combined effect of traffic loading and environmental exposure accelerates pavement distress, reducing its service life and increasing the need for maintenance interventions. The interaction between mechanical loading and environmental effects makes pavement design a complex process. Modern pavement engineering emphasizes the use of high-performance materials, proper layered design, and durability-focused construction practices to mitigate the adverse effects of heavy traffic and environmental exposure. Techniques such as improved mix designs, geosynthetics reinforcement, drainage management, and periodic maintenance are essential to prolong pavement life.

Keywords: Pavement performance, heavy traffic loading, surface course, base course, environmental effects, rainfall, thermal cracking, earthquake damage, durability, sustainable materials, fly ash, GGBS, structural health, rutting, fatigue failure, maintenance, transportation infrastructure, subgrade stability, mix design, non-destructive testing.

I. INTRODUCTION

India has emerged as one of the fastest-growing automobile markets in the world due to rapid urbanization, expanding infrastructure, rising income levels, and increased demand for personal and commercial transportation, which has led to a substantial rise in the production and consumption of vehicle tyres. The Indian tyre industry is highly consolidated, with the top seven manufacturers accounting for nearly 85% of the total tyre production, reflecting large-scale industrial growth and strong market dominance. This expansion is closely associated with the growth of two-wheelers, passenger cars, and heavy commercial vehicles, driven by improved economic conditions, enhanced logistics networks, and greater vehicle ownership.

As tyre demand increases both as original equipment and replacement products, the number of tyres reaching the end of their service life has also risen significantly. Every tyre produced eventually enters the waste stream despite retreading or reuse, making disposal a critical environmental and engineering challenge. The accumulation of end-of-life tyres poses serious concerns due to their non-biodegradable nature, large volume, and resistance to natural decomposition. Improper disposal practices such as open dumping and stockpiling create environmental pollution, fire hazards, and public health risks. Consequently, the rapid growth of the automobile and tyre industries has intensified the need for sustainable waste tyre management, recycling, and innovative engineering applications to address environmental impacts while promoting resource conservation and long-term sustainability.

II. MATERIALS AND METHODOLOGY

SOIL

Soil Classification and Its Principles

Soils are highly variable in their composition, texture, and engineering behavior. To study them effectively, it is necessary to classify them according to well-defined principles into a definite system. A system is essentially an ordered grouping of elements in a discipline based on pre-determined scientific rules. Just as classification is essential in chemistry, zoology, and botany to study elements, species, and plants systematically, soils are classified in Geotechnical Engineering to predict their behavior and suitability for construction purposes.

The general requirements of an ideal soil classification system include:

- **Scientific Basis**

A reliable soil classification system must be firmly grounded in scientific principles, ensuring that the grouping of soils is based on measurable and reproducible properties rather than subjective observations. Scientific parameters include particle size distribution, Atterberg limits (liquid limit, plastic limit, and plasticity index), compaction characteristics, and specific gravity, which can be determined through standardized laboratory tests. These properties directly influence the engineering behavior of soils, including their compressibility, shear strength, permeability, and stability under load. By using scientifically validated parameters, engineers can predict soil performance with a reasonable degree of accuracy, which is essential for design and construction of foundations, embankments, and pavements. Subjective characteristics, such as color or odor, may vary due to external factors and are not consistent indicators of soil behavior, highlighting the importance of a scientific approach. Furthermore, reproducibility of results ensures that different laboratories or engineers can classify the same soil in the same manner, which is critical for standardized engineering practice. A system with a scientific basis also facilitates research, comparison of results, and development of engineered solutions for soil stabilization, compaction, and improvement. In summary, scientific grounding makes the classification objective, reliable, and engineering-relevant, forming the foundation of geotechnical decision-making.

2. Simplicity and Objectivity

An effective soil classification system must be simple to understand and easy to apply, avoiding overly complex procedures that can confuse engineers or technicians. Simplicity ensures that the system can be applied consistently in field surveys, laboratory testing, and design projects, even by engineers with varying levels of experience. Objectivity implies that the classification criteria are quantitative and measurable, minimizing subjective judgment or personal interpretation. For instance, classifying soils based on clearly defined parameters such as grain size limits, plasticity index, and soil behavior under standard compaction provides clear, repeatable outcomes. A complex system with numerous overlapping categories or ambiguous boundaries can lead to inconsistent results and potential engineering errors.

A simple and objective system improves communication among design engineers, contractors, and field personnel, ensuring uniform understanding of soil characteristics. Moreover, such systems can be incorporated into design software and geotechnical databases, allowing for more efficient planning and decision-making. The combination of simplicity and objectivity also ensures faster decision-making in the field, reducing delays during soil surveys and construction activities. Ultimately, a simple and objective classification system enhances practical usability, reliability, and predictability of soil behavior in engineering projects.

3. Limited Number of Groupings

A well-structured soil classification system should use a limited number of groups, avoiding excessive subdivisions that may overcomplicate the categorization process. Too many categories can make the system confusing and reduce its practical utility for engineers in the field or in laboratories. Each group should represent soils with similar engineering behavior, ensuring that the classification is meaningful in predicting performance. The focus should be on critical properties that significantly influence soil behavior, such as compressibility, shear strength, plasticity, or permeability.

For example, grouping soils into major categories such as coarse-grained, fine-grained, and organic soils provides a balance between detail and usability, allowing engineers to quickly assess the soil's suitability for construction. Limiting groupings also simplifies reporting, documentation, and communication of soil characteristics to clients, contractors, and regulatory authorities. A concise system allows efficient planning of laboratory tests, field investigations, and design calculations, saving time and resources. Additionally, maintaining a limited number of groups facilitates uniform interpretation across different projects and regions, ensuring consistency in geotechnical practice. Ultimately, a limited but strategically defined grouping system balances technical accuracy with practical usability, enabling engineers to make reliable decisions without unnecessary complexity.

III. RESULTS AND DISCUSSION

Standard Proctor Compaction Test

The Standard Proctor Compaction Test is a laboratory procedure used to determine the maximum dry density and optimum moisture content (OMC) of a soil. These parameters are crucial for designing road bases, sub-bases, and embankments, ensuring that the soil can support traffic loads without excessive settlement or deformation. The test simulates field compaction conditions and provides guidance on the amount of compactive effort and moisture required to achieve maximum soil density in pavement construction.

Procedure for Standard Proctor Test

1. **Sample Preparation:**

A representative soil sample is collected and air-dried. Any large particles or debris are removed, and the sample is sieved to a specified size to ensure uniformity.

2. **Moisture Addition:**

The soil is mixed with varying amounts of water to create multiple test samples. This allows determination of dry density corresponding to different moisture contents, ultimately identifying the optimum moisture content (OMC).

3. **Compaction in Mold:**

A standard cylindrical mold of known volume is filled with the soil in three or more layers, each compacted using a standard Proctor rammer. The weight of the rammer and the number of blows per layer are controlled to maintain consistency. The compaction ensures that the soil reaches a uniform bulk density in the mold.

4. **Wet Density Calculation:**

After compaction, the wet (bulk) density of the soil is computed using the formula:

ρ=Weight of Compacted SoilVolume of Mold\rho = \frac{\text{Weight of Compacted Soil}}{\text{Volume of Mold}}ρ=Volume of MoldWeight of Compacted Soil

where:

- ρ\rhoρ = wet or bulk density of the soil (g/cm^3 or kg/m^3)
- Weight of compacted soil = mass of soil after compaction
- Volume of mold = internal volume of the Proctor mold

5. Moisture Content Determination:

A small portion of the compacted soil is weighed and oven-dried to determine its moisture content (m). The moisture content is expressed as a fraction or percentage of the dry weight of the soil.

Dry Density Calculation:

The dry density of the soil is computed using the formula:

ρd=ρ1+m\rho_d = \frac{\rho}{1 + m}ρd=1+mρ

where:

- ρd\rho_dρd = dry density of soil
- ρ\rhoρ = wet density of soil
- mmm = moisture content (decimal form, e.g., 12% = 0.12)

Plotting and Determination of OMC:

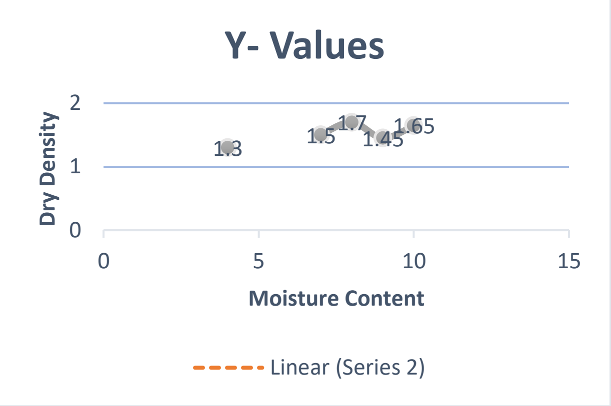
The dry densities for various moisture contents are plotted on a graph, with dry density on the y-axis and moisture content on the x-axis. The peak of the curve represents the maximum dry density of the soil and the corresponding moisture content is the Optimum Moisture Content (OMC).

Significance in Pavement Construction

- The OMC indicates the moisture level at which soil achieves maximum compaction, essential for achieving stability and strength in road bases and subgrades.
- The maximum dry density provides a benchmark for field compaction, ensuring that the soil layer can support vehicular loads without excessive settlement.
- Compaction at OMC reduces voids, minimizes water infiltration, and increases shear strength, contributing to the long-term durability of pavements.
- This test is particularly important when using modified materials, such as waste plastics or MIBA (Municipal Incinerator Bottom Ash), to ensure proper mixing, compaction, and performance of the base course.

Example Outcome

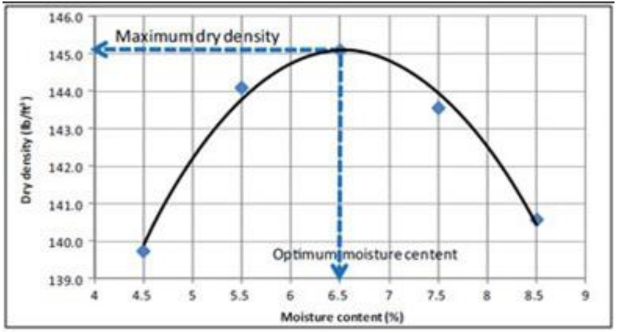
From your notes, the Optimum Moisture Content (OMC) for the soil in question is approximately 95% (likely 9–10% in decimal, depending on context). At this moisture content, the soil achieves maximum dry density, providing the best structural stability for the subsequent placement of coarse aggregates and bituminous layers in road repair.



Graph2 :dry density and moisture content of soil

Table 1:standard proctor test results

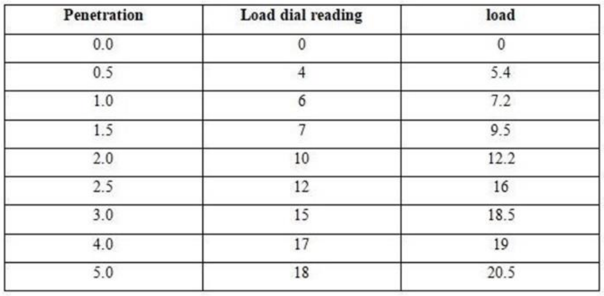
Description	4%	6%	8%	10%	12%
Bulk density(gm/cc)	1.40	1.5	2	1.65	1.9
Water content%	0.112	0.0517	0.157	0.122	0.163
Dry density(gm/cc)	1.27	1.44	1.72	1.42	1.63



Graph3: maximum dry density and moisture content

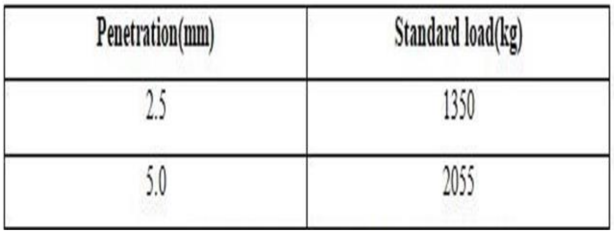
California bearing ratio test results

Table: 2 observations of cbr test on normal value

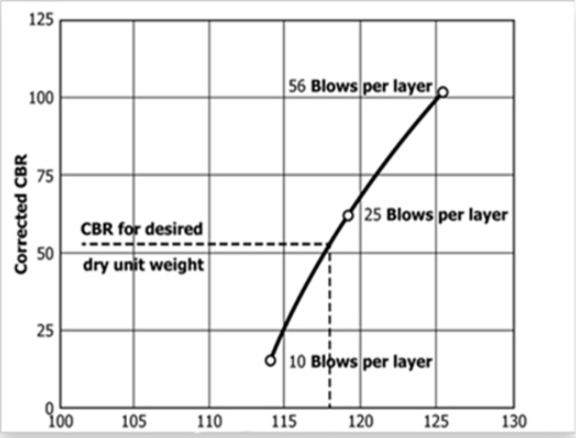


Penetration	Load dial reading	load
0.0	0	0
0.5	4	5.4
1.0	6	7.2
1.5	7	9.5
2.0	10	12.2
2.5	12	16
3.0	15	18.5
4.0	17	19
5.0	18	20.5

Table3 : standard load values of cbr test



Penetration(mm)	Standard load(kg)
2.5	1350
5.0	2055



Graph 4:density value with blows

IV. CONCLUSION

Tyre rubber has emerged as a promising material for sustainable pavement construction, offering both environmental and structural benefits. It can be incorporated into asphalt mixtures either as a bitumen modifier or as a replacement for fine or coarse aggregate, depending on the design requirements. There are two primary methods for using rubber in asphalt: the wet process and the dry process. In the wet process, crumb rubber is blended directly with hot bitumen to form rubber-modified binder, which is then mixed with aggregates. In the dry process, shredded or crumb rubber is directly added to the aggregate before mixing with bitumen. Both methods have been successfully applied in road construction globally, with documented improvements in pavement performance and durability.

Pavements constructed with rubberised asphalt demonstrate enhanced skid resistance due to the elastic nature of rubber, which improves the microtexture of the surface and increases friction between vehicle tires and pavement. They also show higher resistance to rutting, particularly in high-temperature regions or under heavy traffic loads, as the elastic behavior of rubber helps the pavement recover from permanent deformations caused by repeated loading. Moreover, fatigue cracking resistance is improved because the rubber particles allow the asphalt to absorb energy and deform without fracturing, extending the service life of the pavement compared to conventional asphalt sections.

Beyond mechanical advantages, tyre rubber utilization contributes to environmental sustainability by providing a productive use for waste tyres, which are otherwise difficult to dispose of. Incorporating rubber into pavements reduces landfill waste, air pollution from burning tyres, and the demand for virgin materials, aligning with circular economy principles. Additionally, roads constructed with rubber-modified asphalt often exhibit flexibility, which allows them to adapt to minor subgrade movements or thermal expansion, reducing the occurrence of cracks and surface defects.

However, careful consideration must be given to the geotechnical properties of the underlying soil before adopting rubber-modified pavements. Tyres, when used as aggregates or as part of the sub-base layer, are permeable and lightweight, which can lead to water retention or percolation issues if the soil does not drain properly. Therefore, soil permeability, bearing capacity, and moisture content must be assessed to prevent water logging and maintain structural integrity. Roads built in regions with welldrained soils are ideal candidates for tyre rubber incorporation, whereas poorly drained soils may require additional subsurface drainage measures.

From a civil engineering perspective, the application of tyre rubber in pavement construction is versatile. It can be used in wearing courses, base courses, and even embankments, depending on the required performance criteria. The use of tyres not only improves mechanical performance but also makes pavements more resilient to extreme temperatures, traffic loads, and environmental degradation. The successful implementation of rubberized roads depends largely on the ability of engineers, designers, and project authorities to recognize the long-term benefits and adopt innovative design standards.

In conclusion, tyre rubber-modified pavements offer a combination of structural efficiency, flexibility, and environmental sustainability. When designed and constructed properly, these pavements can withstand heavy traffic, resist cracking and rutting, and contribute to pollution reduction by recycling waste tyres. The incorporation of tyres in road construction is a practical and forward-looking approach that balances performance, durability, and ecological benefits, making it a viable option for modern road infrastructure development.

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